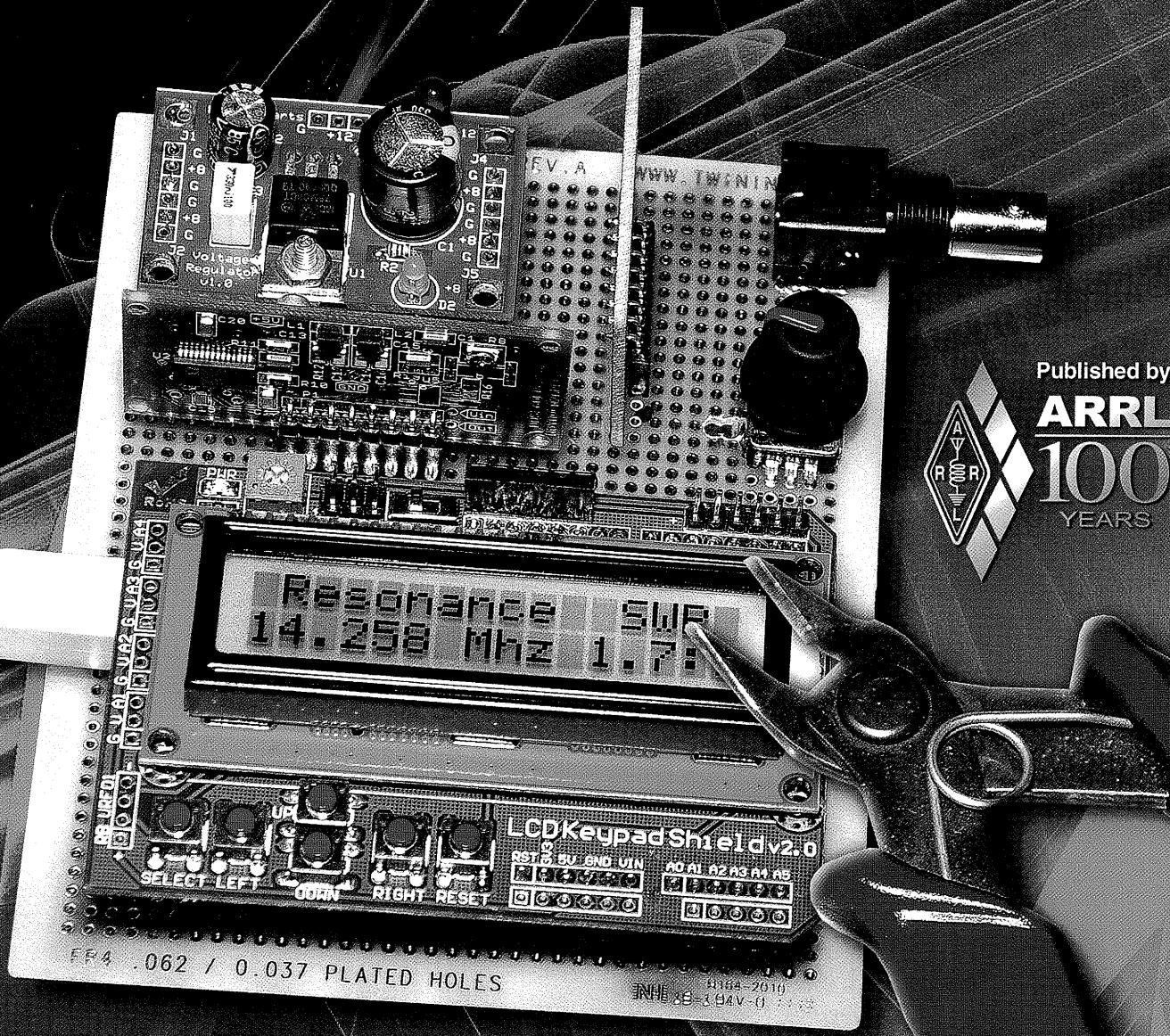


Ham Radio for Arduino and PICAXE

*Easy to build microcontroller weekend projects—for use
in the shack, in the field, and on the air!*

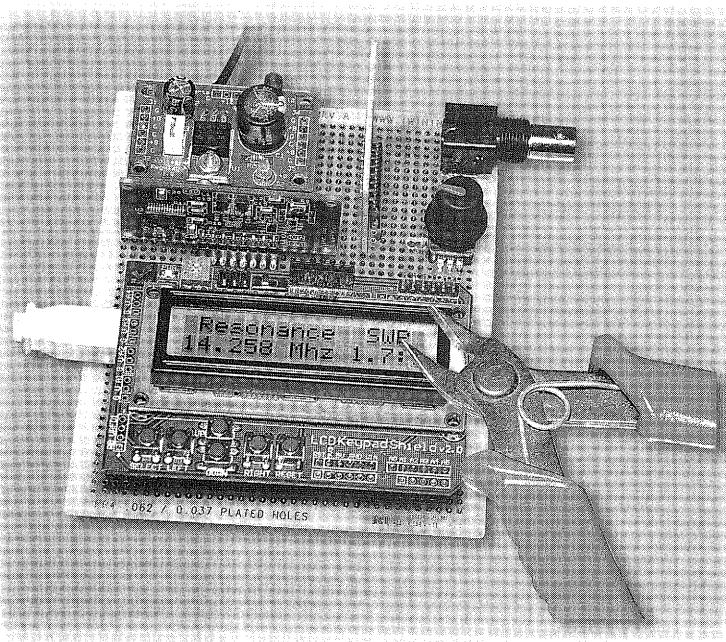
Edited by Leigh L. Klotz, Jr. WA5ZNU



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Science of Radio
—Since 1914

On the Cover

The Sweeper project by Alan Biocca, W6AKB, uses the Arduino Uno and PC boards to make an SWR scanner. The Sweeper measures SWR over a range of frequencies and displays center frequency, 2:1 SWR bandwidth in kHz and minimum SWR. [Alan Biocca, W6AKB, photo]

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Foreword

Experimenting. Homebrewing. Modifying. Most Amateur Radio operators enjoy *doing* things, whether it's building a simple radio from a kit or handful of parts, integrating a new station accessory, or making a new antenna from a length of wire or aluminum tubing. Tune the ham bands, surf the web or pick up the latest issue of *QST*, and you'll discover hams fiddling with a new piece of hardware or software and using it to improve station or operating capabilities — and then sharing their experiences with others.

In this book, Editor Leigh L. Klotz, Jr, WA5ZNU, leads a team of contributors who show us new ways to experiment — this time with the Arduino Uno microcontroller board or PICAXE and ATtiny microprocessor chips. These low-cost microcontrollers can be used in a variety of interesting and creative ham radio applications.

Most of the projects described here use a microcontroller combined with a few additional components or accessory boards — all of which are inexpensive and readily available. Software is open source and may be downloaded from this book's website or from manufacturers' websites. The examples and explanations in this book, along with online tutorials and support groups, put these projects within reach even if you are not an experienced programmer. Or perhaps you already have some experience, and one of these articles will provide ideas or building blocks for your own project — which you can then share with fellow hams.

Leigh and his fellow authors have close ties to the thriving worldwide community of Maker/DIY (Do It Yourself) experimenters who are using these tools for countless homemade applications and sharing information about them. See "Makers and Hams" by Dale Dougherty, founder of *MAKE Magazine* and The Maker Faire, and Leigh's Preface in the following pages for an overview of how ham radio fits in with the broader DIY community. We hope you'll join in and give it a try too.

David Sumner, K1ZZ
Chief Executive Officer
Newington, Connecticut
February 2013

About This Book

Dear Imaginary Reader,

You have a ham license, and you already have some electronics skills: you can read schematic diagrams, solder, and use a solderless prototyping board. You know your way around a computer and can find a web page or two to get help on installing software. Your ARRL membership is current, and you just bought this book.

Oh, you're a *real* reader? How embarrassing! I'd better start over.

This book is a collection of weekend projects for hams to spark creativity and give you the tools you need to get your own projects done around the shack and in the field.

If you already have the skills and interests the imaginary reader does, you're ready to start. If you are a real person and don't have all these superpowers, this book is still for you, but there are some other books you might want to have handy at the same time.

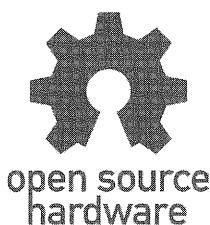
If you don't have an Amateur Radio license at all, a great book to start with is *Ham Radio for Dummies* by H. Ward Silver (whose FCC-issued amateur call sign is NØAX). You probably already know where to buy books, but if not, look for it by ISBN: 978-0-7645-5987-7. As the dust jacket puts it, Ward goes to "extreme wireless."

Let's say you have a ham license, and you know which end of a soldering iron to hold (hint: not the hot one), but beyond that you need a little help. This time, try another Ward Silver book called *Do-It-Yourself Circuitbuilding for Dummies*, ISBN: 978-0-470-17342-8.

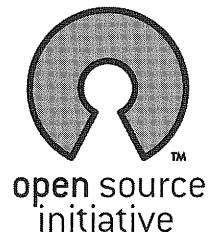
OK, so you know about circuits, but it's the whole analog thing that causes you trouble. Ward again comes to the rescue with *ARRL's Hands-On Radio Experiments*, 978-0-87259-125-7 and *ARRL's Hands-On Radio Experiments, Volume 2*, ISBN: 978-0-87259-341-7.

If you feel comfortable with RF and analog electronics, but need a less steep slope to ramp up on programming, try *Getting Started with Arduino*, 2nd Edition, by Massimo Banzi, ISBN 978-1-4493-0987-9. (By the way, Massimo had a ham license as a kid, and credits that with putting him on track to design the Arduino.)

By buying this book, you are supporting the ARRL and the authors in their efforts to promote Amateur Radio. The software and hardware in the projects that the authors have developed for this book are all released under licenses compatible with the goals of the Open Source Initiative and the Open Source Hardware Association, and are available for free download at the companion website. The chapters in this book, however,



open source
hardware



open source
initiative™

are a separate work, and are only available in the book.

But books aren't the only answer. Ham radio is all about community, and we have clubs and organizations around the country ready to welcome you. Visit www.arrl.org/find-a-club and get involved with a local club whose members are eager to learn what you have to contribute, and are glad to *Elmer* (mentor) you back.

So there you have it: this book will help you join the fantastic Arduino microcontroller community, or roll with the PICAXE controller, or go your own way with the bare-minimum 8-pin ATtiny micro.

73,

Leigh L. Klotz, Jr, WA5ZNU

Makers and Hams

When I started writing computer programming books with Tim O'Reilly over 25 years ago, one of the things that struck me then — and which I still find exciting — is that I truly enjoyed seeing what other people do with the information I helped bring to them. That's one reason I started *MAKE Magazine*, to expand that bounty of interest in doing things with computers to include making things happen in the real, physical world.

The urge and ability to tinker was a part of American know-how until at least the 1960s: if you wanted to fix your car, you read *Popular Mechanics*, and you knew how to do it. Yet in the decades since, the complexities of modern life and modern technology have weakened this spirit.

In founding *MAKE Magazine*, I helped this culture re-emerge. I did it by building on the enthusiasm found in Silicon Valley's Home Brew Computer Club in the 1970s and 1980s. And I learned from the first computer hackers (the good ones) at MIT in the 1960s and 1970s, and took what they knew and loved and applied it to help people create their own successes.

And with *MAKE*, we succeeded hugely, and branched out to start the Maker Faire, where hundreds of thousands of people attend gatherings each year. They gather because they want to share their passion, their ideas, and their interest with others to help make things by combining art, electronics, software, and rediscovered traditional skills such as working with wood, metal and glass.

I am proud of having had a hand in starting this movement, but I also acknowledge another debt to history: Ham radio operators may be the originals in this mold. Since the early 1900s, they have been tinkering, inventing, and bending ideas in electronics, radio technology, mathematics and space exploration to solve a problem or achieve something new.

Hams have a fantastic and growing community, with over 700,000 in the US and well over a million in Japan, and more in every country in the world. Hams are still active in cutting-edge areas such as satellites, digital signal processing, electronics design and ionospheric research. And even though ham radio is a dynamic, passionate community, in some ways it remains an isolated ecosystem with its rich, specialized knowledge, a universe parallel to the growing DIY and Make movement I helped create.

When the ARRL proposed this book, the goal was to bring the ham community and the Maker community closer. The projects here use common, off-the-shelf physical computing parts such as the Arduino, and leverage techniques and expertise from the ham community and the Maker community to make something that both groups can appreciate, use and extend.

I hope you enjoy reading this book and building the projects. Ham radio has been an inspiration to the people who have made the makers, bringing the vitality and excitement of building your own stuff to the world. This year marks the intersection, igniting interest in contemporary *making* in hams and a fascination for radio in Makers. The line should blur. Makers will want to become hams; hams will want to become modern tinkerers. Only then will the universe be right.

Dale Dougherty

Founder, *MAKE Magazine* and The Maker Faire

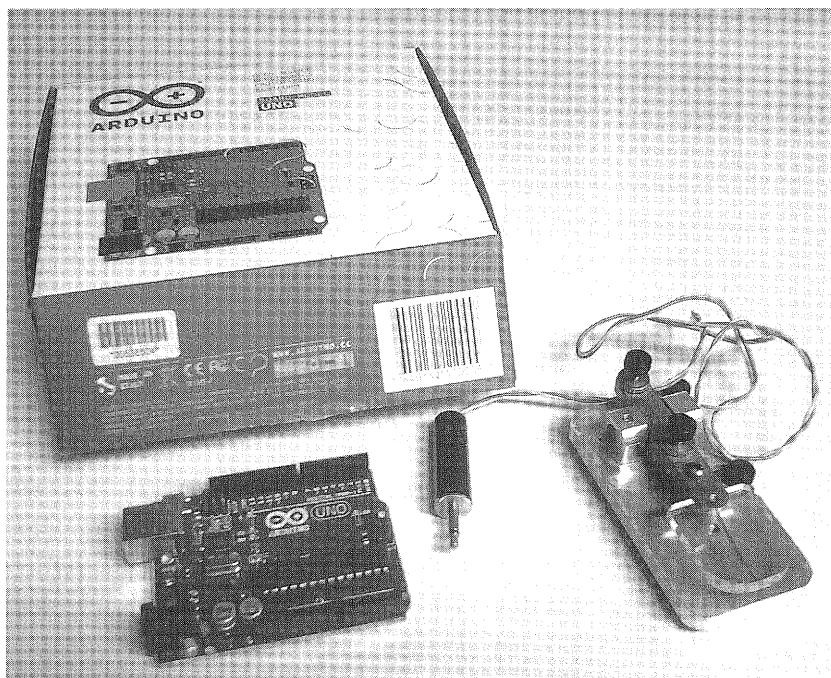
Preface

The Arduino is a point on a curve, an arc of development reaching back in human history to the same events that spurred the development of ham radio. As a small, inexpensive, easily programmed and easily interfaced microcontroller board with an extensive support community of practitioners and a rich ecology of software libraries, hardware add-on shield boards, and well-written project explorations, it serves as a platform on which to build and enhance ideas and inventions, and share them with other enthusiasts. In this regard, the Arduino community resembles some of the best parts of ham radio.

Hams have been coming up with circuit ideas, inventing new types of modulation, and experimenting with the aether since the early 1900s. We have a long tradition of do-it-yourself projects, and also a great history of building on each other's ideas. This belief runs so deep that among the Q-signals, the three-letter abbreviations used originally in Morse code, there is one that stands for it: QST means "Information to share with all stations." The ARRL embodies this spirit, and has expressed it by publishing a magazine called *QST* since 1915.

At its basis, ham radio involves communicating over radio waves, but it is also rests on a foundation of experimentation and sharing. In the US, the FCC codifies this goal in its regulations, where the purpose of Amateur Radio includes "continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art," and "advancing skills in both the communications and technical phases of the art."

Based on physical phenomena whose discovery dates back to James



New technology meets old technology: The Arduino Uno and a key for sending Morse code by hand.

Clerk Maxwell and Heinrich Hertz, communicating information by radio is highly interoperable. A college student in India who learns about ham radio in the aftermath of a natural disaster can discover techniques in books such as *Experimental Methods in RF Design*, and go on to design and build his own low-powered radio, and then use it to talk to a ham operating a lovingly-restored Collins KWM-2 SSB transceiver, the dream station of 1959. The robustness of radio phenomena, and the simplicity of modulation techniques such as AM, SSB and CW, make these achievements possible.

But ham radio moves on, and new techniques and new types of modulation, particularly those involving digital modes, have been appearing regularly, and the home computer is now an integral part of many a ham shack. Again, the ham's can-do spirit of sharing and building on one another's ideas shows up here: When Peter Martinez, G3PLX, developed a new phase modulation technique to make a low-power, narrowband, fast version of radioteletype (RTTY) for keyboard-to-keyboard digital communication, he chose to announce it and share full technical details in *QST*. Originally implemented using specialized hardware, the new mode PSK31 rapidly made the jump to PC software using the sound card as an ADC (analog-to-digital converter). Moe Wheatley, AE4JY, made a reusable software library for PSK31, and released it under a software license that allowed wide reuse in ham software, but required that any improvements be channeled back into public view. This development spawned a series of open ham radio software programs for digital modes, and one such program today, *Fldigi* by David Freese, W1HKJ (and to which I am a minor contributor) runs on *Windows*, *Mac OS*, and *Linux* computers as well as more exotic operating systems. And *Fldigi* itself has been the source of the modem software used in the popular *Windows*-only *Digital Master 780* by Simon Brown, HB9DRV. The *Fldigi* program also originally incorporated elements from *gMFSK*, by Tomi Manninen, OH2BNS, benefitting from other programs available and explicitly shared for improvement and reuse.

The realm between home computer software and RF circuit design, however, has been a chaotic area. In the early days, inexpensive embedded computers and microcontrollers were dogged by proprietary and expensive development systems, and so ham software for onboard CPUs was difficult to share easily. The skills necessary to program the most popular microcontrollers were often hard to acquire, and the results were difficult to build on. Thus these early microcontrollers lacked the platform aspect that enabled easy sharing of home computer software, and so never reached the universality within ham radio that non-computer analog and digital electronics has long enjoyed due to the simple transparency of schematics and block diagrams for RF and electronics circuits.

Quite a few projects involving microcontrollers have graced the pages of the ARRL's more technical journal, *QEX*, but the projects there require an advanced level of skill across many different domains — mathematics, software, RF engineering, electronics and mechanical construction — and it is the rare ham who has such an abundance that he or she can share with others.

Makers and Hackers

In the mid 2000s, a parallel, non-ham universe of electronics and mechanical engineering hackers began to emerge. Like the oldest meaning of “hacker” from the MIT culture that brought us video games and electronics games, these tinkerers were interested in exploring technology for its own sake, and in the glory of sharing their achievements, not in destructive operations. Since the hacker name had been co-opted, these folks began to be known as *Makers*, a term coined by Dale Dougherty, who started *MAKE Magazine* and the Maker Faire, a gathering not unlike a hamfest in which Makers show off their accomplishments.

An important part of the DIY/Maker movement began in 2005 with the development of the Arduino in Italy, by the parent company of Olivetti. The Arduino is a platform on which to build applications from hardware and software, and was itself a serendipitous loose collaboration of ideas among Massimo Banzi of Interaction Design Institute Ivrea in Italy and his student Hernando Barragan, along with others including John Maeda at the MIT Media Lab and his students Casey Reas and Ben Fry.

The students in John Maeda’s lab who developed the programming language Processing did so in the MIT Media Lab environment, which itself created out of fundamental work at MIT in Architecture by Nicholas Negroponte and in Computer Science by Seymour Papert, whose development of the programming language Logo was a major influence on a generation of educators and psychologists.

Originally developed in the 1970s for children (and with an eye toward “naïve users” of computers), Logo helped us re-think what people can do once computers are designed to be used rather than programmed. The theory of *bricolage* that Papert developed was derived from the tinkering and hacker culture at MIT, and Papert and others noticed that this cognitive style often lead to breakthroughs, especially when used in a cultural setting that valued open-ended collaborative effort. A *bricoleur* may start with a set of tools and skills, but only a vague idea of a goal or direction. The computer then becomes a medium for expression that merges the artistic and the scientific, with engineering taking a supporting role.

My own personal involvement with this area began with the transition of Logo from a laboratory project to a full-blown national education experiment: I worked as research staff for Professors Papert, Harold Abelson, and Andrea diSessa, and helped bring Logo to the Apple II computer for use in schools. Through the work of the MIT Artificial Intelligence Laboratory and the Logo Laboratory, and the various companies that took Logo out into the world, we and our colleagues provided the first exposure to computers as malleable tools to over one-fourth of all elementary schools in the US. Logo and the culture it begat delivered Lego-Logo and later Lego Robotics, a project started by Papert and Abelson’s student Mitchel Resnick, now at the MIT Media Lab. So, the MIT Media Processing project and its combination with Olivetti’s work in bringing hardware experimentation to naïve users had its roots in the culture of bricolage at MIT.

Free and Open

Another idea from this time has grown to shape the Arduino, and has arguably had a greater influence on society. Richard Stallman was a part of the MIT Artificial Intelligence laboratory as well, and he took on the task of bringing forth the collaborative elements of the culture, under the kind sponsorship of my professors Harold Abelson and Gerald Sussman, WA1NSE. Richard Stallman is the famous MacArthur prize winner who started the Free Software Foundation, and produced the now well-known General Public License (GPL), and the Limited GPL, the licenses under which Moe Wheatley's PSK31 development began.

GPL ensures sharing of innovation, and yet does not prevent its commercialization. GPL is used for *Fldigi* and *DM780*, the Arduino software itself, and of course, most famously, Linus Torvald's *Linux* kernel. Additionally, Harold Abelson was a founding member of the Creative Commons, the organization under whose aegis the Open Hardware License was created. Open Hardware brings hardware sharing into the open realm, and allows authors a framework to publish reference designs for schematics and circuit boards. Open Hardware provides for the spectrum of same publication rights and reuse that we see in software, and spurred the development and adoption of the Arduino beyond the single source of the Olivetti spin off.

Throughout this book you will see projects with software and hardware designs shared under licenses such as the GPL, the MIT license and through the Creative Commons. These legal documents are to help you share your ideas, yet still get credit for them. Others will be able to build on your work, but will share their improvements with the community. If you are doing a project for a hobby, publishing your work with these protections ensures that both you and those who build your project will be able to enjoy it, and you will be able to help each other. Without some form of license, you may still find that others have copied your ideas and work, but give you no credit, or hide the results away inside some potted circuit that benefits few. If you share your work appropriately, we will all share in the benefits.

Parallel Revolution: The PICAXE

In the years before Olivetti solidified its vision of the Arduino as an experimental tool for artists and other non-programmers, the British Oil and Gas industry was also searching for a way to make the power of embedded computers available to non-specialists. In mid-2002, their funded company Revolution Education (now Rev-Ed) released the PICAXE 08, an expensive 8-pin DIP computer programmed in BASIC and needing only a few resistors and a free desktop software package to program. Although it was based on a Microchip PIC microcontroller, the free software and built-in BASIC interpreter opened up the world of embedded microcontrollers to a new generation of hobbyists and experimenters. While the speed and capability of the PICAXE is greatly reduced compared to that of the native PIC controllers, the simplicity of programming in PICAXE BASIC compared to Microchip PIC assembly language assured success for the projects of countless experimenters who otherwise would not have even been able to begin their projects. While other

BASIC chips had been available before (notably the BASIC Stamp from Parallax, Inc.), the cost reduction — a PICAXE chip is only a few dollars — made it possible to scatter PICAXE chips in-circuit, much as hams and experimenters in the past used the 555 timer-oscillator IC.

Like the Arduino, the PICAXE has its own no-cost download of software IDE (integrated development environment) in which you write software. Unlike the Arduino, however, the PICAXE chip firmware and the IDE are proprietary, and available only from Rev-Ed. Fortunately for experimenters, Rev-Ed is committed to making their software and chips available at an affordable price, and does not restrict commercial use, so there is no bar to offering your PICAXE projects for sale.

PICAXE experimenters are also indebted to Peter H. Anderson, who sadly passed away in 2012. Through his website he shared a wide variety of application notes and kits using the PICAXE and other embedded microcontroller chips.

Although the PICAXE series includes a wide range of microcontroller chips, in this book we focus on the PICAXE 08M2, an 8-pin DIP chip including built-in routines for a number of operations you might encounter in building ham projects. In cases where the 08M2 doesn't offer enough power, you might prefer to step over to the Arduino, or in the case of embedded designs, to the Arduino's kid cousin, the 8-pin DIP ATtiny85 chip.

We hope you find an Arduino project that catches your eye, or perhaps a PICAXE project may feel more comfortable to you because the programming language is a little more basic. Once you begin with either of these systems and have some tools under your belt, you won't have much trouble moving over to the other.

Crossing the Streams

The DIY culture of ham radio and the DIY culture of Maker Faire began to merge in 2007 when Dale Dougherty gave a talk at Xerox's PARC research facility, entitled "You are What you Make." I asked Dale about the parallels, and how we could bring the communities closer together. Of course, hams have been involved in individually in the Maker Faire sphere since the inception, but I wanted to see something more structured. Dale replied that he had already spoken with the ARRL, but no SF Bay Area ham radio clubs had stepped up to the challenge.

In 2008, Philip Stripling KG6ILU, and his friends were demonstrating ham radio and emergency communications at the Maker Faire, and active Maker Michael Pechner (now NE6RD) first encountered ham radio at the Faire. By 2009 he was ready to lead the Foothills Amateur Radio Society (FARS), and members from Palo Alto Amateur Radio Society (PAARA) to produce an ARRL-sponsored booth, where I also joined and showed my *Marauders* project (an APRS-like system using 433.92 MHz remote-control transmitters).

Each year since 2009, Bob Inderbitzen, NQ1R, of the ARRL has provided extensive support and Michael Pechner has picked a theme, and we have relied on the community of hams to deliver projects and presentations around that theme.

As the 2012 Maker Faire was just getting under way, Dale Dougherty and Travis Good, N6RSU, held their ground breaking Open Hardware Innovation Workshop in the same Xerox PARC auditorium where I first spoke to Dale about ham radio in 2007. The Open Source Hardware, Arduino and Maker movements have grown, and so has ham radio, now topping 700,000 licensees in the US alone. And I learned that many of the dynamic, creative people there were hams as kids, including founders Massimo Banzi of Arduino and Limor Fried of Adafruit. This year marks the beginning of a new wave of excitement, where we bring hams and Makers together to create something big.

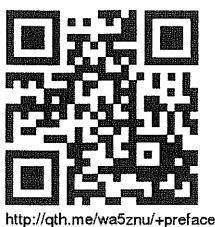
Acknowledgments

This book is the result of a collaborative effort among the hams who built the trail from ham radio to larger DIY worlds, and it brings together sentinel projects from recent years with work done specifically for the Faire and this collection. Making this book was possible because of the collaboration of everyone mentioned so far, and all of the authors you are about to meet. In addition to the kind professors and mentors who established the field of educational computing and brought me into their framework of tinkering, bricolage, and creative sharing, I also thank Deborah Tatar, Aubrey Jerome Ford, and Patrick Sobalvarro. I cannot list all my helpful and supportive professional colleagues, but I particularly want to thank want to thank Ranjit Padmanabhan, who helped me to simultaneously finish this book and start a new job, and a few with whom I have worked for decades: David Smith, Walter Johnson, Roger Chan, Richard Hyde, KD6WYK, Julia Craig, Diane Fraser, Gary Kenney, Tom Carter and Mike Mahoney.

It would not have been possible for me to make this book without the support from my family: My father Leigh L. Klotz, Sr. N5LK, answered my five-year-old question, “How does a radio work?” with “Let’s find out together,” leading to his license WN5UBQ that year, and my call WN5ZNU the summer after first grade, issued the day Neill Armstrong walked on the moon. My sister Leah Kolt (ex-WN5UOE) provided helpful editing advice, though any mistakes in style are mine, not hers. I also thank my wife Becky Burwell, K6BEC, tolerant and supportive as always, and our children Yuki, K6YUU, and Hunter, KI6IMM, both General class licensees.

The authors, the ARRL, and I hope that you enjoy this book and use it in good spirit.

Leigh L. Klotz, Jr., WA5ZNU



<http://qth.me/wa5znu/+preface>

References

The two-dimensional barcode shown here is a Quick Response code representing the URL shown below it. If you have a mobile phone or camera with a barcode reading application, you can use it to follow the link to online page at the companion website for this book, where you can read updated versions of the references, download example code, and find links to other information about the projects in this book. There is a similar QR code and list of references at the end of each project.

- Online resources
<http://qth.me/wa5znu/+preface>
- Amateur Radio FCC regulations
<http://www.arrl.org/part-97-amateur-radio>
- Arduino
<http://www.arduino.cc>
<http://en.wikipedia.org/wiki/Arduino>
- BITX-20 homemade transceiver
<http://www.phonestack.com/farhan/bitx.html>
- *Experimental Methods in RF Design* (EMRFD)
<http://www.arrl.org/shop/Experimental-Methods-in-RF-Design>
- Moe Wheatley and PSK31
<http://www.moetronix.com/ae4jy/pskcoredll.htm>
- Open Hardware
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- The Making of Arduino
<http://spectrum.ieee.org/geek-life/hands-on/the-making-of-arduino/0>
- Open Hardware, Andrew (bunnie) Huang
<http://www.bunniestudios.com/blog/?p=1863>
- Maker Media
<http://makermedia.com>

About the ARRL

The seed for Amateur Radio was planted in the 1890s, when Guglielmo Marconi began his experiments in wireless telegraphy. Soon he was joined by dozens, then hundreds, of others who were enthusiastic about sending and receiving messages through the air — some with a commercial interest, but others solely out of a love for this new communications medium. The United States government began licensing Amateur Radio operators in 1912.

By 1914, there were thousands of Amateur Radio operators — hams — in the United States. Hiram Percy Maxim, a leading Hartford, Connecticut inventor and industrialist, saw the need for an organization to band together this fledgling group of radio experimenters. In May 1914 he founded the American Radio Relay League (ARRL) to meet that need.

Today ARRL, with approximately 155,000 members, is the largest organization of radio amateurs in the United States. The ARRL is a not-for-profit organization that:

- promotes interest in Amateur Radio communications and experimentation
- represents US radio amateurs in legislative matters, and
- maintains fraternalism and a high standard of conduct among Amateur Radio operators.

At ARRL headquarters in the Hartford suburb of Newington, the staff helps serve the needs of members. ARRL is also International Secretariat for the International Amateur Radio Union, which is made up of similar societies in 150 countries around the world.

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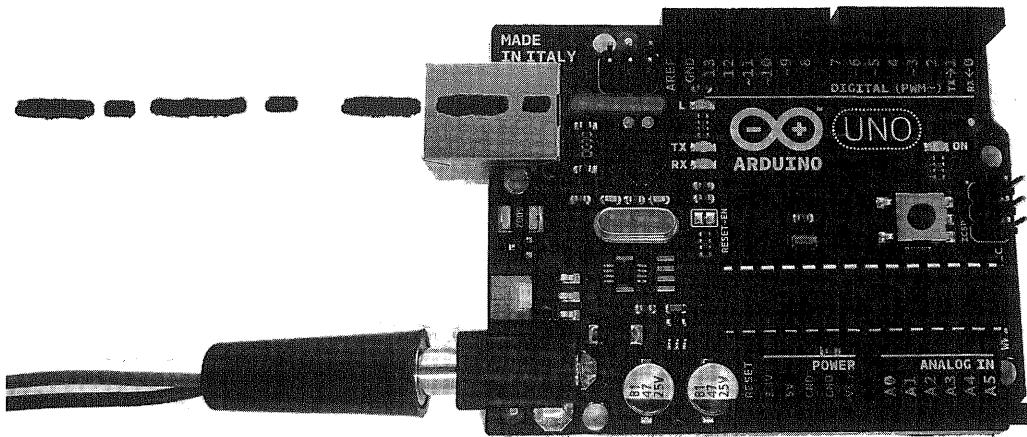
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CQ DX — A Ham's "Hello, World!"

Leigh L. Klotz, Jr, WA5ZNU



The Arduino is a self-contained single-board computer with an easy-to-use development system, helpful libraries and a wealth of peripheral and prototyping boards. [Leigh Klotz, WA5ZNU, photo]

Computer programming of any type, whether it's dabbling in JavaScript to make a web page, writing a BASIC or C program, or getting started with the Arduino, is both an easy task and a hard one. Programming is a deeply abstract task and at the same time an incredibly concrete one. It's important to have a rational thought process and yet keep a creative mindset. Programming is a deeply abstract task and at the same time an incredibly concrete one. It's important to have a rational thought process and yet keep a creative mindset.

Adding hardware and electronics design to the mix can make getting started seem overwhelming, yet once a project gets underway, it will seem to move you along with it, like a great mystery novel that has you turning pages late into the 80 meter DX hours. Then you may hit a seemingly insurmountable obstacle and not know how to proceed, until inspiration strikes — or, more likely, you reach out to a community for help and find others who have been there before you and are ready to help you get back on track.

Sometimes projects suggest themselves and surprise you with how easy they are; other times they take you on long detours, from which you may or may not make your way back to the original idea.

It's reassuring to start with a project you know will allow you to succeed, but also represents jumping-off points where you can leave the map behind and explore on your own.

The traditional introductory program for any new or unfamiliar language is the "hello world program," which does just that: it prints "Hello, World!" Hams have been saying "hello, world" for so long that we have shorthand for it: "CQ DX." So let's start with the many ways we can call CQ, and use those ways to start learning about the Italian Arduino. Later chapters will cover its cousin the Atmel ATtiny85 from California, and their distant British relative, the PICAXE.

The Arduino

The Arduino is a small computer with an amount of memory and I/O (input/output) capability that is limited, when compared to your desktop computer. However, for what's called an *embedded* computer, it boasts a comprehensive set of options and a luxurious memory allocation. The elements of the Arduino should be familiar to any modern ham: a printed circuit board with voltage regulators, decoupling capacitors, and current-limiting resistors set the stage for the main entrant, which is the Atmel Corporation ATmega328 microcontroller.

The microcontroller is the CPU of the Arduino, just as an AMD or Intel x86-compatible CPU is for your desktop, or an ARM-compatible chip is for your mobile phone or tablet computer. Unlike a desktop computer, all the temporary RAM memory and all of the permanent flash memory on an Arduino is inside the chip. And although you'll find a USB port on most Arduinos (and an associated chip for running it), for most Arduino projects, the expansion peripherals are plugged into the 0.1-inch centered pin headers found along the edge of the Arduino board.

The Arduino has a U-shaped arrangement of these headers, and through an accident of design, they are not spaced an even multiple of the 0.1-inch centers of perfboards. This accident has worked out to be a happy one, as it means that there's an incentive to design custom boards to fit atop the Arduino, if only to assure easy assembly. These boards are called *shields* in Arduino parlance, and might be called "cards" or "daughter boards" in other embedded systems. So, when you read about an "Arduino shield," the author is talking about a peripheral board made to provide some hardware extension to the Arduino.

Of course, hams already know that you don't need a PC board to experiment. For the Arduino, you can get along quite well with a package of wire jumpers and possibly a solderless breadboard or protoboard.

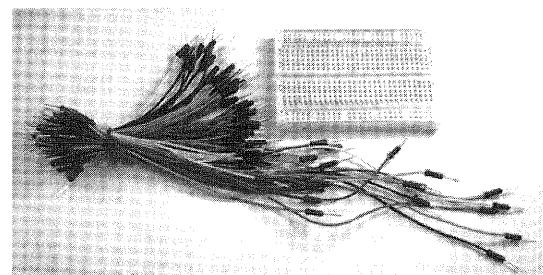
The Arduino designers have thought ahead for those who bought just an Arduino, and have included a test LED directly on the PC board. Remember the headers arranged along the board edges? With the USB and power connectors at the left side, look near the top left and you'll see a pin labeled 13. This pin is hooked to digital pin D13 of the ATmega328 CPU. There's also a surface-mount LED on the board, with its own current-limiting resistor in series. To the right of the LED are a number of other output pins with numbers going down to 0; some may have other labels indicating functions they can perform, such as DIGITAL or PWM. At the bottom of the board, another pair of headers brings

Arduino Suppliers

You can find the Arduino at retailers such as RadioShack or at online, large-scale electronics retailers such as Jameco. In addition to the Arduino board, you will need parts already in your ham junkbox, such as LEDs, resistors and capacitors, and some other parts more easily found at websites specializing in the *accoutrements* for Arduino hacking. This illustration of a small protoboard and jumper wires is typical of the inexpensive and convenient fare you'll find at retail sites such as Adafruit, which provided this image. Throughout this book you'll see references to parts and boards available from these and other suppliers such as SparkFun and SEEEDStudio, DFRobot, and others. The accessories and hardware available for the Arduino changes, and with it also changes the landscape of retailers and manufacturers, so be sure to visit the companion website for this book for any updates. I recommend buying from a vendor or designer who gives back to the open hardware community, for example one who contributes or otherwise supports new designs, tutorials or libraries.

You can save money by buying commodity items such as wire and perfboard or prototyping boards in quantity from inexpensive direct online importers, but use caution when buying more complex or creative boards and kits. While you may also find vendors who have cheaper prices on clones of the same Arduino shields or breakout boards (in many cases they may be, strictly speaking, legally copied), if the vendor has done nothing other than copy a design and undercut the price of the designer, you might think twice about whether saving a dollar or two is worth the price to the community.

Below is an alphabetized list of some of suppliers I have used while writing this book. There are many vendors not listed, because I simply haven't been able to list all the possible choices of great suppliers. During the writing of this book I found that these vendors are the ones I returned to again and again. You may already have favorite suppliers for your ham radio parts, and if they carry the parts you need for



Solderless breadboards and pre-cut jumpers with molded cables offer a fast route to interfacing your own circuits to the Arduino. [Photo courtesy Adafruit.com]

projects in this book, by all means please do order from them.

See also the Appendix *Arduino Hardware Choices*, and the References sections of the individual projects in this book for more ideas.

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out supply voltages and control lines (+5, +3.3, GND, RESET), and finally a set of analog input lines rounds out the bottom right corner. Other headers may have male pins on them, and they're used for lower-level tasks such as upgrading the baseline software already programmed in the Arduino, and you can safely ignore them for now.

Software Guide

If you need help getting the Arduino software installed, see <http://arduino.cc/en/Guide/> for a step-by-step guide. All the links and references for this book are available online at the book's companion site; see the references.

Warming Up

Let's get started controlling this built-in LED from the Arduino. After you download and install the Arduino IDE (development environment) from <http://arduino.cc>, plug the Arduino into your computer's USB port and note that a few LEDs will flash.

Start the Arduino IDE program and you'll be greeted with a blank sheet that's ready for you to type your first program, or as Arduino aficionados call it, your first *sketch*.

Every Arduino program has two parts: a *setup* and a *loop*. The setup is run once, when the Arduino starts, and the loop is run repeatedly. You don't have to use both, but it's convenient. When you turn your Arduino off, the program is retained in the flash memory, so it starts up again from the setup when you turn it back on, or when you press the reset button.

Note that your sketch has a name; the Arduino IDE does this for you so you can get started on your ideas right away. You can change the name later, using the familiar **SAVE AS** option in the **FILE** menu. For now, just type this in to define your setup routine. It uses a *function* called `pinMode` to tell your Arduino that pin 13 (the one with the LED) should be used for digital output; that is, it should be driven by the ATmega 328 microcontroller chip to either a logic low 0 V level or a high 5 V level:

```
#include <Arduino.h>

void setup() {
    pinMode(13, OUTPUT);
}
```

If you need more details on `pinMode` — or on any built-in Arduino function — visit the online reference guide at <http://arduino.cc>. Although websites have a tendency to be reorganized occasionally, we'll go ahead and assume that Arduino.cc will keep their reference documentation at the same page, so you can try right now, by taking a look at <http://arduino.cc/en/Reference/pinMode> to find out about the `pinMode` command. (If that doesn't work for you, check the online References at the end of this chapter.)

Now we'll add a simple loop, just to blink the LED. Since we're hams, we'll use Morse code for blinking. Don't worry if you don't know Morse code — some hams find it fun, but if you don't, just go back to thinking of it as blinking.

We won't start with "CQ DX," but something simpler: "HI," the universal ham sign for laughter. It's also what the first ham satellite, OSCAR 1, sent. So join the space race and type this in:

```
void loop() {
    dit(); dit(); dit(); dit();
    space(); space();
    dit(); dit();
    space(); space();
}
```

Note that there are several `dit()` calls on the same line, each terminated with a semicolon; omitting the line break is allowed and doesn't make any difference to the Arduino. You may want to do this when you have several short commands repeated, just to make things clear. If it doesn't make things clearer for you, feel free to press the `ENTER` key after each semicolon.

Unlike `pinMode`, `dit` isn't built in, so the Arduino doesn't know what you mean. You'll build that up writing your own definition of `dit`, itself built out of other Arduino functions you can find in the References section.

There's an old story, retold by the famous physicist Stephen Hawking in his book *A Brief History of Time*, which recounts a venerable scientist of the past attempting to explain what holds up the Earth to a listener firmly convinced of her own notions. Hawking writes of the apocryphal exchange:

"What you have told us is rubbish. The world is really a flat plate supported on the back of a giant tortoise." The scientist gave a superior smile before replying, "What is the tortoise standing on?" "You're very clever, young man, very clever," said the old lady. "But it's turtles all the way down!"

You may wonder the same about the Arduino, when we have just defined something in terms of something we haven't yet written! But you won't have to believe it — just try it, and in a few minutes, it will all work out.

```
void dit() {
    digitalWrite(13, HIGH);
    delay(100);           // milliseconds
    digitalWrite(13, LOW);
    delay(100);
}

void space() {
    delay(100);
}
```

If you've never encountered a programming language that looks like this before, you're probably convinced that it's something from space! Fortunately, there's not a lot more of this funny-character syntax to understand, and once you get past this point, picking up the remainder will be second nature. So, before we push the big button to program the Arduino, let's take a moment to look at and understand this last bit we typed in. If you're already a whiz at C or JavaScript and are tapping your foot impatiently, skip right ahead, but if you're nodding your head with me, pull up a chair.

There's a bit of Morse code coming up, but it's all in good fun. Even if you don't use it yourself, the ideas and analysis used here are the same ones used in generating digital modes such as PSK31, only a little simpler. So it's a good tool to think with.

This thing we just typed in, and the ones before, are called, variously, *procedures* or *functions*. You might remember functions from high school algebra. Functions such as `sqrt(x)` or `sin(degrees)` take in a number and output a number, as in `2 is sqrt(4)`. The functions we have typed in above don't output (or in Arduino parlance, *return*) anything, and if that distinction is important

to you, you can call it a procedure. The word `void` at the beginning just means that this particular function doesn't return anything: it just *does* something. Similarly, typing `dit` is how you say the name of the function you want to define, and the empty () parentheses say that `dit` doesn't need any inputs.

The call to `digitalWrite` will set pin 13 either `HIGH` or `LOW`, and `delay(100)` is going to delay for 100 milliseconds. A dit length of 100 ms works out to be just under 13 words per minute (WPM) of CW sending speed.

The `// milliseconds` part is what's called a *comment*. It's a part of the program that's there for humans only, and it doesn't have any effect on what the Arduino does.

As with `pinMode`, to find out that `delay` takes its input in milliseconds, you have to look at the Arduino reference page for <http://arduino.cc/en/Reference/delay>. There you will find additional information, such as conditions in advanced programs that might have an effect on the delay time. Throughout the projects, you might want to look the Arduino primitive functions at the Arduino.cc website, since the online reference pages are kept up to date with the latest Arduino software.

Try It Out!

Try this out now with your Arduino. It ought to work. If you have trouble getting started, visit the Arduino environment page at <http://arduino.cc/en/Guide/Environment>, and if you know what to do but it's not working, try the troubleshooting guide at <http://arduino.cc/en/Guide/Troubleshooting>.

Note that when you press the UPLOAD button, the Arduino editor prints out the size of the program in bytes. Take note of this number. The Arduino Uno has up to 32,768 bytes of program storage. All the program commands you type take up space, and while the length of the procedure and variable names doesn't matter, the number of procedures and variables you use does. Sometimes surprising things take up space, such as libraries of procedures you use for Arduino shields, or math subroutines. Don't be overly concerned with program size at this point. There's plenty of space for you to use now, and it starts over from scratch every time you upload a new program into your Arduino, so you're in no danger of running out. By the time you're ready to write or edit bigger, more sophisticated programs, you'll have enough experience under your belt to know what takes up space and what doesn't.

Now let's take a look at extending this program and see what happens.

On to Dah

Now might be a good time for you to write the `dah` procedure on your own. Remember that the `dah` code element is usually three times as long as a `dit`, and it's followed by the same space as a `dit`. You can check yours after.

Ready? Here's one way to write the `dah` procedure:

```
void dah() {
    digitalWrite(13, HIGH);
    delay(100*3);
    digitalWrite(13, LOW);
    delay(100);
}
```

Note that `dah` uses the expression `100*3` instead of the literal `300`. That way, it's easy for you to read, and easy to write, and since the result of the expression is a constant number (`300`), it won't slow your program down at all, as it's computed at *compile time*, which is the time in the Arduino development cycle when you press the VERIFY or UPLOAD buttons on the Arduino editor. You saw this before in the definition of the `space` procedure, and now you understand what it means!

Try uploading your program with the new `dah` procedure in it. Surprisingly, it takes up the same amount of memory! That's because the Arduino compiler has noticed that `dah` isn't used in sending "HI," and so it didn't include it.

Let's edit the `loop` procedure and add a `K` at the end, which means "any station transmit." It's polite, and it gives us a reason to use `dah`.

```
void loop() {
    dit(); dit(); dit(); dit();
    space(); space();
    dit(); dit();
    space(); space();
    dah(); dit(); dah();
    space(); space();
}
```

Try using UPLOAD to test this with your Arduino, and note that the program is longer now. Not only did our `loop` get longer, but the Arduino compiler has also automatically included the procedure definition for `dah`.

Making Letters

If it seems repetitive to you to keep typing "dit dit dit" all the time, you're in good company. Fortunately, as with the metaphorical turtles mentioned earlier, it's okay to use procedures that call other procedures for quite a long way, if not quite forever.

If you didn't do the `dah` exercise, you might want to pause and do this one: Write one new procedure for each letter we've sent so far. Although you're free to give your procedures any name you want, as long as the name isn't already taken for something else, it's probably a good idea to name them in a descriptive way that helps you and others understand what's happening later. In this way, procedure names are a little like the comments we encountered above with the `//` characters, only they actually are read and used by the Arduino environment. You could name the procedure that sends an "H" just "H", but a more descriptive name (and one that's less likely to be confused with something else in the future) would something like `send_h()`.

If you haven't already gotten these done, here's a skeleton version you can get started with:

```
// Send "H"
void send_h() {
    dit(); dit(); dit(); dit();
    space(); space();
}

// Send "I"
void send_i() {
    dit(); dit();
    space(); space();
}

// Send "K"
void send_k() {
    dah(); dit(); dah();
    space(); space();
}

void word_space() {
    space(); space(); space();
}
```

Here's how to rewrite the `loop` procedure: and just for fun (or for turtles), let's take everything out of `loop` and put it in its own procedure, called `send_hi_k`:

```
void loop() {
    send_hi_k();
}

void send_hi_k() {
    send_h();
    send_i();
    word_space();
    send_k();
    word_space();
}
```

What's Next

If you have been reading along without getting your hands on your Arduino yet, now is a great time to go back to the top, type in the program and try it out.

If you have already done that, here are two options, which you can do in either order:

- The title of this chapter is "CQ DX," but so far we've sent "HI K." Write the procedures and add a new function that sends "CQ DX."
- Move on to the next step, which replaces the blinking LED with a speaker.

Help! I'm Stuck!

If you're seriously stuck, here are some resources you can turn to for help:

- The Arduino Tutorial and the Lady Ada sites both have similar examples for blinking LEDs, but not ham-oriented. Maybe taking a look at the problem from a different perspective will help. See <http://arduino.cc/en/Tutorial> or www.ladyada.net/learn/arduino.

- Use your favorite search engine to find your problem. Think of how you might describe your problem to a friendly listener, and chances are someone else has already done that, and you can find their plaintive cry for help and hopefully some

great answers. If that fails, read on...

- There is an Arduino Online Forum at <http://arduino.cc/forum> where you can post questions. It's best to post specific questions and show what you've done so far, so others can help you. It's not a paid support forum, and those who answer questions do so out of a desire to help, so please be as kind and thoughtful as they are!

- The companion website for this book also has a help section, and you'll find information and forums there about the later projects in the book, but if you're really stuck, check it out and see if you can find your answer there.

Now with Sound

Flashing an LED is fun and all, but hams copy CW not with light, but with sound. The Arduino has no speaker, but you can quickly attach one using the jumpers and a few clip leads.

Use a small resistor (100 Ω or so) in series with a small speaker from your junk box, and connect one terminal of the speaker to digital pin 8 through the resistor, and the other directly to the upper-row GND pin. See **Figure 1.1**, which I made with the free program Fritzing.

The easiest way to generate sound is to use the Arduino `tone` and `noTone` procedures built into the Arduino environment. The `tone` procedure takes two inputs: the pin, the frequency in Hz. Similarly, `noTone` just takes the pin number.

If you want to read more about `tone`, you can follow the Arduino Tone tutorial at <http://arduino.cc/en/Tutorial/Tone>.

The great thing about the tower of power we've built with all our procedures is something called *abstraction*: we can just change our dit and dah proce-

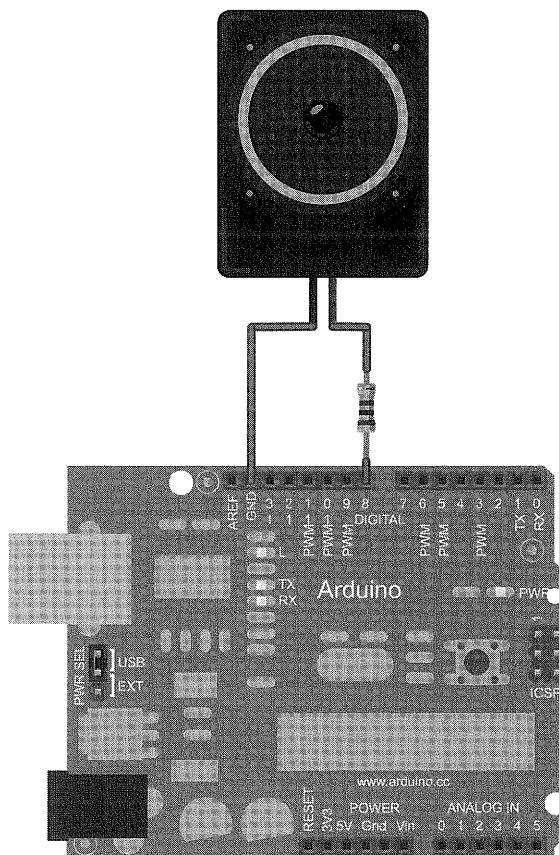


Figure 1.1 — Block diagram showing connection of speaker to Arduino, with current-limiting resistor. [Leigh Klotz, WA5ZNU]

dures to use `tone` instead of `digitalWrite` and that changes modes from blinking LED to making a tone in a speaker. Edit your sketch and change the `dit` and `dah` procedures:

```
void setup() {
    pinMode(8, OUTPUT);
}

void dit() {
    tone(8, 700);
    delay(100); // milliseconds
    noTone();
    delay(100);
}

void dah() {
    tone(8, 700);
    delay(100*3);
    noTone();
    delay(100);
}
```

Variable Speed Control

You might find the speed of the HI call a bit slow or a bit fast, and want to adjust it. If you want it to send faster, just reduce all the delay times.

Since you wrote the program, you already know how to modify it to suit your needs. But it's inconvenient to keep all the different places that control the spacing: `dit`, `dah`, and `space`. There's something in common there, and since we want to vary the speed control, let's use what the Arduino calls a *variable*.

```
byte element_wait=100;
```

Now we have a variable called `element_wait` whose value is 100. This variable can take on any value represented in a single `byte`, which is 0-255. For now, it's a constant because we haven't changed it. But we could! Anywhere in the program where we had 100 before, we can use `element_wait` instead:

```
byte element_wait=100;

void dit() {
    tone(8, 700);
    delay(element_wait); // milliseconds
    noTone();
    delay(element_wait);
}
```

```
void dah() {
    tone(8, 700);
    delay(element_wait*3);
    noTone(8);
    delay(element_wait);
}

void letter_space() {
    delay(element_wait*2);
}

void word_space() {
    delay(element_wait*6);
}
```

You're probably wondering at this point why `letter_space` only waits for two element periods, when the proper CW weighting would call for three. The answer is there if you take a look at `dit` and `dah`: each already ends with one `delay(element_wait)`, so together, that makes three.

Now in order to change the speed, we have to edit only one place and upload the program to the Arduino. For many projects in this book, there will be configurations or settings that you can alter yourself just by typing in the program and recompiling it. If there's not much need to change the setting during use — for example, if the setting is your call sign — then this level of user-friendliness is appropriate. In some cases, though, there will be settings or parameters that you'll want to change more frequently, even while you're using the project you've made with your Arduino. For these cases, some bit of user interface programming is necessary.

At the level of the Arduino, user interface has two primary components: *input* and *output*. Input can be as simple as a button, and output can be as simple as an LED. A fancier project might use a character LCD display such as you find on some ham rigs and handhelds. And the fanciest have full-color LCD display screens of the type you find on today's mobile phones and portable music players.

But for this project, let's just use a couple of buttons for input to control the speed, and leave the advanced craft for a later project.

The Need for Speed

Let's start off writing a pair of new procedures to make the code speed faster and slower.

```
void faster() {
    element_wait = element_wait - 10;
}
void slower() {
    element_wait = element_wait + 10;
}
```

We might be fairly confident that these functions will work, but let's test them out in isolation first. That way if something doesn't work, we'll know what part we have to debug.

To test, add these two routines to your Arduino sketch and then change the setup procedure to call `faster()` five times. That ought to produce a speed of 50, which should be twice as fast as the original 100:

```
void setup() {
    pinMode(8, OUTPUT);
    faster(); faster(); faster(); faster(); faster();
}
```

Try this sketch out and see if it does indeed come out twice as fast. If it doesn't, see if you can figure out why before moving on. You'll save yourself a lot of trouble by debugging programs step by step in this way.

Button, Button, Who's Got the Button?

To add a couple of buttons to our project, it's convenient to use a protoboard and a few jumper wires. Since the Arduino Uno has more than enough digital input lines for this project, we'll use one input per switch just to make things easy, even though there are ways to share one input pin with multiple switches.

Notice that the "DIGITAL" pins on the top row have pins 0 and 1 specially labeled TX and RX; those pins are the serial I/O for the Arduino, and are present at TTL (0 V and 5 V) levels on those pins, as well as being tied to the USB serial conversion chip that goes to your desktop computer, so let's leave those pins alone. Place a pair of buttons on your breadboard and wire them up with from pins 2 and 3 to ground, as shown in **Figure 1.2**.

Remember the `digitalWrite` procedure we used before to turn the LED on and off? There's an inverse function called `digitalRead` that takes the pin number as input and returns HIGH or LOW. We can enable internal 20 k Ω pullup resistors inside the Arduino ATmega328 CPU, so that the normal state of these pins will be HIGH, and then wire a switch to ground. When the button is in its normally open state, the `digitalRead` result will be HIGH, but as long as the button is pressed, the result will be LOW.

Just as with `digitalWrite`, there's a `pinMode` procedure we need to call to set pins 2 and 3 up for digital input with 20 k Ω pullup resistors. We'll use a few more variables to make things easier to read, write and change, just as we did before.

```
#include <Arduino.h>

byte speaker_pin = 8;
byte slower_pin = 2;
byte faster_pin = 3;

byte element_wait = 100;
```

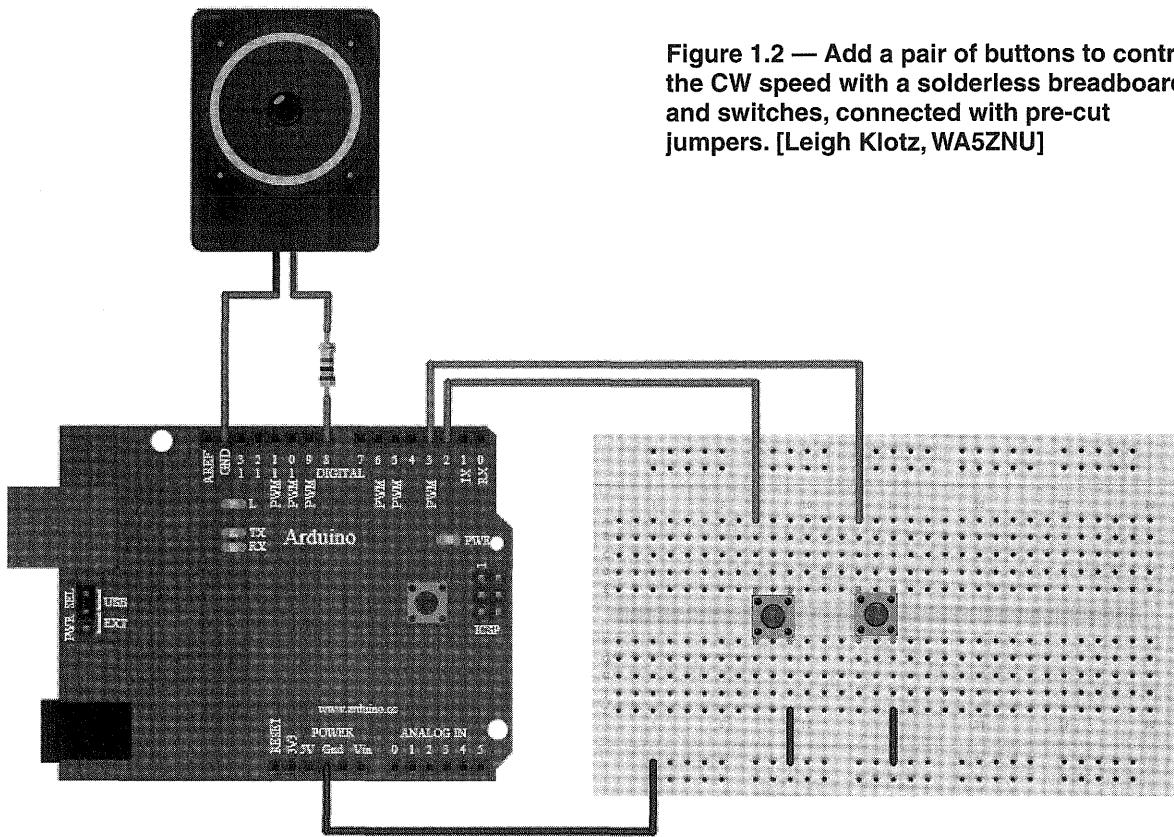


Figure 1.2 — Add a pair of buttons to control the CW speed with a solderless breadboard and switches, connected with pre-cut jumpers. [Leigh Klotz, WA5ZNU]

Made with Fritzing.org

We've also switched the numbers 8, 2 and 3 to variables, in this case byte variables. Byte variables are small and good to use with small numbers. There are more efficient ways of defining constants, but this will do for now.

```
void setup() {
    pinMode(speaker_pin, OUTPUT);
    pinMode(slower_pin, INPUT_PULLUP); // Turn on 20K pullup resistors
    pinMode(faster_pin, INPUT_PULLUP); // on these two pins
}
```

Notice we've taken the explicit calls to `faster()` out of `setup`; leaving in your debugging code is a major cause of failure!

As hams, we know that components such as resistors are seldom ideal, and switches are no exception. What seems to be a simple proposition — is the switch off or on, high or low — turns out to have a real-world answer that is slightly more complicated. There's a transition period during which the switch *bounces* between off and on, and at the speeds the Arduino runs, if we wrote a program to loop and read the switch as quickly as possible, our program would see a tremendous number of button presses where the finger on the button just pushed once. To counteract this problem, there are a number of *debounce* methods. Hams are most likely to jump to an RC low pass filter as an immedi-

ate answer. In an analog or discrete-digital circuit, that's an elegant and effective solution, but it has a parts and assembly cost and it takes time even to prototype.

There's a software solution often used involving the `delay` procedure: Each time you want to read a digital pin, double check: Note whether it's high or now, then delay a very short time and read it again; if still the same, believe the result, but if not, ignore it and try again later. Sometimes it's easiest to do this with your own procedure, but calling that repeatedly for each button would introduce a series of delays and could slow down the operation of your whole Arduino program, because even little delays add up when you call them thousands of times per second! So, often microcontroller programmers will use other techniques to interleave the delay with other fruitful operations, so that there's no perceptible slowdown.

Fortunately in our case, we already have delays built into our program, and can simply take advantage of them. We'll read both switches at the start of each code element, and if the switch is LOW, we'll assume the button is pressed. We won't read it again until there's been another code element output, so any switch bounce happens "off camera" when we're not looking.

In order to make something happen *if* the faster button is pressed, and something else happen *if* the slower button is pressed, we need to use a new language command called (are you ready?) `if`. There are two really annoying things to remember about `if` and if you forget either of them, you may start writing bugs instead of programs.

- when testing to see if two numbers are equal, use `==`, not `=`
 - always use braces `{ ... }` around the commands following the `if`
- Here's an example fragment, but don't type this in right now:

```
if (digitalRead(faster_pin) == LOW) {  
    ... do something ...  
}
```

Can you figure out what we do here to check the speed? Right — it's more turtles.

```
void check_speed() {  
    if (digitalRead(faster_pin) == LOW) {  
        faster();  
    }  
    if (digitalRead(slower_pin) == LOW) {  
        slower();  
    }  
}
```

Add `check_speed` and the latest `setup` and the three byte variable definitions to your sketch, and just put in a call to `check_speed` at the beginning of `dit()` and `dah()` and we're ready to test.

But be forewarned — there is a bug in this code, and we're going to find it in the next section. But go ahead and try it out, and see if you can figure out what works and what doesn't.

```
#include <Arduino.h>

byte speaker_pin = 8;
byte slower_pin = 2;
byte faster_pin = 3;

byte element_wait = 100;

void setup() {
    pinMode(speaker_pin, OUTPUT);
    pinMode(slower_pin, INPUT_PULLUP); // Turn on 20K pullup resistors
    pinMode(faster_pin, INPUT_PULLUP); // on these two pins
}

void loop() {
    send_hi_k();
}

void send_hi_k() {
    send_h();
    send_i();
    word_space();
    send_k();
    word_space();
}

void send_h() {
    dit(); dit(); dit(); dit();
    letter_space();
}

void send_i() {
    dit(); dit();
    letter_space();
}

void send_k() {
    dah(); dit(); dah();
    letter_space();
}

void dit() {
    check_speed();
    tone(speaker_pin, 700);
    delay(element_wait); // milliseconds
    noTone(8);
    delay(element_wait);
}
```

```

void dah() {
    check_speed();
    tone(speaker_pin, 700);
    delay(element_wait*3);
    noTone(8);
    delay(element_wait);
}

void letter_space() {
    delay(element_wait*2);
}

void word_space() {
    delay(element_wait*6);
}

void check_speed() {
    if (digitalRead(faster_pin) == LOW) {
        faster();
    }
    if (digitalRead(slower_pin) == LOW) {
        slower();
    }
}

void faster() {
    element_wait = element_wait - 10;
}
void slower() {
    element_wait = element_wait + 10;
}

```

CQ Test

Whew! That's quite some program and quite an accomplishment. You may be thinking that it's a lot of work to send "HI," but remember that it's built on several layers of other accomplishments, and each of those will be useful when you expand this program to do other things.

So for now, let's pause and try it out. Does pressing the "faster" button make the code speed go up after each element, and does holding down the "slower" button make it go down?

Here are some problems you might encounter:

- If you hold the "faster" button down for a long time, the speed gets faster, then slower again, then faster.
- When it's really fast, it's hard to adjust because it changes after every element, which is too hard to adjust.

So it seems the bug is with `check_speed`. Faster and slower work, but eventually things get all wonky.

If you need to inspect variables and control flow in your Arduino sketch,

the most direct route is to use the RS232 connection you already have to your computer to print information. Add this line somewhere in `setup()`:

```
void setup() {  
  ...  
  Serial.begin(9600)  
  ...  
}
```

And now add some lines to the buggy faster and slower routines:

```
void faster() {  
  element_wait = element_wait - 10;  
  Serial.print("faster: element_wait = ");  
  Serial.println(element_wait);  
}  
void slower() {  
  element_wait = element_wait + 10;  
  Serial.print("slower: element_wait = ");  
  Serial.println(element_wait);  
}
```

Upload this new sketch to your Arduino and press the SERIAL MONITOR button (see **Figure 1.3**) on the Arduino IDE.

Set the baud rate to 9600 and try out the buttons.

Notice that the numbers go all wonky when they are faster, and also when they get slower!

The reason for the problem is the `byte` variable. It's limited to the range 0–255, so in crazy computer byte math, $255+1=0$, and $255+10=9$. What happens when it goes the other way? It just wraps around the other end, so $0-10$ is 246. We need something more sophisticated for our `codespeed` variable.

We could use a bigger variable than a `byte` and take up more Arduino memory. There's a two-byte variable type called `int` and it can represent positive and negative numbers from $-32,768$ to $32,767$. But that's not a lot of help, since even with the `byte` range of 0–255, we have more range than we need for code speed: A delay of 0 ms is really useless, and even a delay of 30 ms works out to be over 40 WPM, a range at the upper end of even the most dedicated hams. And 255 is dead slow — dits of a quarter second reminiscent of the old 5 WPM Novice test requirement. Nowadays we know that slow sending is what produced the 10 WPM “hump” that Novices used go to through, and we train using the “Farnsworth Method,” where the element speed is kept within a narrow range around 13 to 20 WPM and only the letter spacing is adjusted.

Since the data type is not the problem, to fix the sketch we need to change

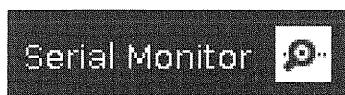


Figure 1.3 — Press the SERIAL MONITOR button of the Arduino IDE tool on your desktop computer to open a window showing data sent by the Arduino over its serial USB connection. The `Serial.println()` command helps debugging.

some code. So we will use another comparison test in our `if` statement. Let's say that we want to limit the speed to a useful range of 10 to 20 WPM. We know that 13 WPM is about 100 ms (technically, using the code for PARIS as the standard, it's 92.3 ms, but that's unwarranted precision here). So if we limit our `element_wait` to the range 50–200 that will give us about half of 13 WPM to about twice 13 WPM, or 7.5 to 26 WPM, which is close enough without having to do any calculations.

Remember the “Use == not =” rule with `if`? Fortunately, to compare less than and greater than, there's no complicated rule: Just use `<` and `>`, or `<=` and `>=` if we want the less-than-or-equals or greater-than-or-equals versions.

So, if we want `faster()` to make the code faster until it reaches a zippy 50 ms, we just use an `if` that tests that:

```
void faster() {
    if (element_wait > 50) {
        element_wait = element_wait - 10;
    }
}

void slower() {
    if (element_wait < 200) {
        element_wait = element_wait + 10;
    }
}
```

CQ DX Sketch

You can download the sketch above from the book resources site, but it still does not send CQ DX; it only sends HI K. This example code is in the public domain.

Your task is to update the sketch so that it sends CQ DX.

Suggestions for Further Work

- To change the speed, you have to hold the button until the element is over, not just press it at any time. Can you make it sample the button more frequently? A good introduction to one Arduino debounce method you might want to use is here: <http://arduino.cc/en/Tutorial/Debounce>
- Use `analogRead()` and a variable resistor to adjust the speed.
- There is no LED feedback in the user interface. Can you think of some useful information to blink with an LED?
- Writing one procedure for each letter is a lot of work. If you know C or JavaScript, can you use a lookup table to make it easier? If you don't know about lookup tables, would you like to learn?

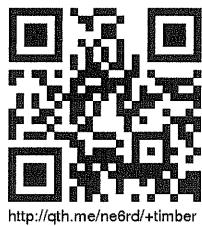
Suggestions for Things Not to Do

You might notice that we used variables where we could have used constants, or that we could have put the `faster()` and `slower()` routines inside `check_speed()`, or any other number of changes you could do to save flash program memory or variable RAM. The process of having that realization,

and then acting on it is called *optimization*. In this case, it saves us almost exactly nothing, since this program uses less than 10% of the Arduino's resources. And what's worse, it makes the code harder to read.

Of course, you will come to a point in one of your projects where you have a need for speed, or run out of memory, and will enter territory where you experiment with various equivalent techniques of expressing the same idea and taking advantage of savings that are "obvious" once you stare at them long enough. The Arduino's rich set of primitive operations and libraries is designed to save you from that drudgery long enough that you can get your project done and have something useful to show for it.

Prof. Donald Knuth of Stanford University, author of many fundamental tomes on computing said, "Premature optimization is the root of all evil." So for the Arduino, we'll take Dr. Knuth's sage advice and stay with something that's easy to write, easy to read, and easy to modify.



References

- Online version of this References list
<http://qth.me/wa5znu/+cqdx>
- Source code for this project
This sketch sends HI K. Your task is to make it send CQ DX.
<http://qth.me/wa5znu/+cqdx/code>

Books

- Banzi, Massimo (2011). *Getting Started with Arduino* 2nd Edition. O'Reilly Media/Make. ISBN 978-1-449-309879.
- Hawking, Stephen (1988). *A Brief History of Time*. Bantam Books. ISBN 978-0-553-053401.

Tutorials

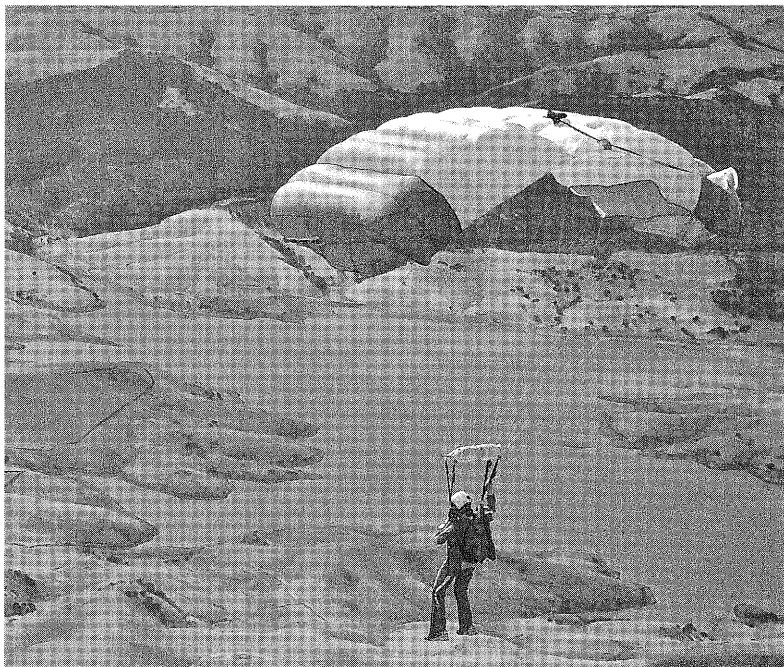
- Getting Started Guide
<http://arduino.cc/en/Guide/>
- Arduino IDE
<http://arduino.cc/en/Guide/Environment>
- Arduino Tutorial
<http://arduino.cc/en/Tutorial/>
- Troubleshooting
<http://arduino.cc/en/Guide/Troubleshooting>
- Lady Ada's *Learn Arduino*
<http://www.ladyada.net/learn/arduino>
- Hello World!
http://en.wikipedia.org/wiki/Hello_world_program
- Debounce
<http://arduino.cc/en/Tutorial/Debounce>
- "A Guide to Debouncing" by Jack G. Ganssle, N3ALO
<http://www.ganssle.com/debouncing.htm>
- Fritzing, a free breadboard layout program
<http://fritzing.org>

Arduino Reference and Troubleshooting

- `delay()`
<http://arduino.cc/en/Reference/delay>
- `pinMode()`
<http://arduino.cc/en/Reference/pinMode>
- Digital Pins
<http://arduino.cc/en/Tutorial/DigitalPins>
- `tone()`
<http://arduino.cc/en/Tutorial/Tone>
- Arduino Forum
<http://arduino.cc/forum>

Timber: An APRS Data Logger

Michael D. Pechner, NE6RD



Mark Meltzer, AF6IM, flying Parachute Mobile. [Jim Wilson, photo]

When the call came from Mark Meltzer, AF6IM, asking me to help collect APRS data for the Parachute Mobile Project (which involves operating Amateur Radio gear while skydiving), I was excited, but a little nervous as well. Even though there was no way I was going to jump out of an airplane, I still felt a bit of vertigo over the responsibility he was asking me to undertake.

I had known about Parachute Mobile for a while. Mark and Michael Gregg, KF6WRW, had coordinated their first combination parachuting and Amateur Radio mission in September 2009, and the news was rapidly circulating in the seven ARRL sections of the Pacific Division, and with good reason too: from 13,000-foot altitude, the VHF horizon is over 150 miles!

For the first few jumps before I could participate, Mark and Michael used their own APRS transmitters on 144.390 MHz. They relied on the Northern California network of APRS received signals and iGates that capture the data packets and route them onto the Internet.

This plan turned out to be unsatisfactory for several reasons, some of which will be apparent to APRS users. The 144.390 MHz frequency is heavily used, and

Parachute Mobile

Mark Meltzer, AF6IM

The Parachute Mobile concept started so simply. Michael Gregg, KF6WRW, and I met on the N6NFI repeater in 2008 and learned that we shared interests in ham radio and skydiving. We originally envisioned jumping with handhelds and just calling out on repeaters, but when we talked about it among other hams, there was a keen interest in expanding our concept, and so the Parachute Mobile Project was born.

Today we have over a dozen dedicated hams on our team, as ground crew, public information officer, safety officer and data collector. The project has grown to include voice communications, navigation, physiological radio telemetry, HF PSK 31 beaconing, live 2.4 GHz amateur television from aloft, and much more.

Our team especially enjoys Parachute Mobile missions that are coordinated with nearby hamfests. Pacificon, the largest ARRL event on the US West

Coast, is put on by the Mount Diablo Amateur Radio Club and draws over a thousand hams to a San Francisco Bay Area location. The 2011 Pacificon event was scheduled for the weekend of October 15 at a hotel in Santa Clara, California. Although the jumpers would like to jump into the actual hamfest sites, their dense urban locations raise too many safety and FAA issues. We opted for jumping at a nearby drop zone (DZ) in Byron, California, and having an interactive booth at the convention site with operators, video and telemetry data displays, and voice communications. We also set up a "parachute control" station on a mountain peak (Mount Diablo), bridging the DZ with the convention site located on the other side of a mountain range.

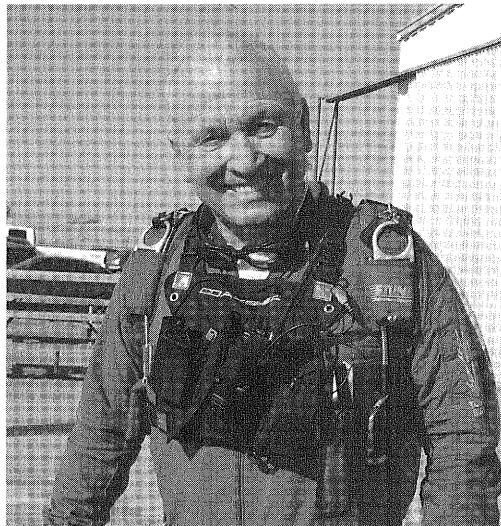
We performed several practice missions at the DZ to be sure we had all the bugs worked out for the Pacificon jumps. There are many things that can go wrong with airborne jumper-carried video, telemetry and voice communications gear, ranging from power connections, to antenna mounts and leads, to conflicts with the parachute gear.

Amazingly enough, we got it all worked out. Our "Data Dude," Mikey, NE6RD, even got a homebrew wireless weather station set up on the DZ to give us second-by-second wind and other weather data using an enhanced Bluetooth radio link to the command center at the DZ.

When the morning of October 15th rolled around, various team members deployed to Pacificon, Mount Diablo and the DZ at Byron. The weather was perfect, with clear skies and light winds. Michael Gregg, KF6WRW, and Royal Canadian Air Force Captain Jim Wilson, our camera flyer, made the first jump from 13,500 feet. We were all literally holding our breath to see if the live video from Michael's 2.4 GHz setup would work. There were a lot of whoops and high fives at the DZ command center when

clear video was received and Michael called the DZ to say that his safety checks were complete and he was ready for Pacificon QSOs. Michael Wright, K6MFW, who is a very experienced skydiver and ATV enthusiast, had all sorts of video gear set up and was displaying and recording the video from the ground and from the jumper. Team Coordinator Rob Fenn, KC6TYD, at the DZ command center handed off KF6WRW to Darryl Presley, KI6LDM, at parachute control on Mount Diablo, who cleared the jumper for QSOs and the fun began.

At 13,000 feet, the radio coverage area is huge and what might sound like a clear channel to a ham on the ground sounds like a big pileup to the jumper as hams from a 100-mile radius compete for a QSO. KF6WRW sorted it out and made a number of Pacificon QSOs as well as contacts with hams in other communities as far away as Sacramento. The Pacificon attendees were thrilled to see live video from Michael's camera sent to the DZ on 2.4 GHz and relayed to the convention site over Justin TV, an Internet streaming link. Jim Wilson was flying a unique pink-colored high aspect ratio canopy known



Mark Meltzer, AF6IM, all geared up for a jump. [Michael Pechner, NE6RD, photo]

as Pink Floyd. Pink Floyd has an incredible glide ratio and speed range which allowed Jim to literally fly circles around Michael to get good still camera photos. At one point Jim dragged his feet across the top of Michael's canopy to get a close shot as he came off the other side.

On the next jump, Michael Gregg and I jumped together. As my chute opened I started making my safety checks, especially looking for damage to the canopy or the suspension lines that might necessitate a cutaway. Everything was shipshape, but I delayed my "safety checks complete" call to allow a brief frequency excursion to the N6NFI repeater to accommodate a request from a ham in the UK to make a Parachute Mobile contact. I had to take my handheld out of its harness pocket and select a different frequency from the Pacificon channel. I prayed that I wouldn't drop the radio while changing channels.

Pink Foster, KG6ILA, Jon Gefaell, K6OJ (a Parachute Mobile co-founder), and Andy Korsak, KR6DD, all helped make the UK QSO happen. EchoLink would allow the UK ham to use N6NFI for a contact with me through K6OJ's node in Hayward, California, which was being controlled by Pink in Tucson, Arizona. It was a dazzling mishmash of radio and Internet technology and it all worked... well, almost. Pink answered immediately when I made my initial call on N6NFI from about 13,000 feet and had been recently in contact with Ian, the UK ham. Unfortunately Ian had dropped off EchoLink when I came up on N6NFI, but I did get to talk with Pink and a number of other hams in my very brief time on that frequency.

Next I called the DZ and announced "safety checks complete." The handoff was made to parachute control on Mount Diablo, staffed by Darryl, KI6LDM, and his wife Rodna, KJ6GVQ. Parachute control gave me the go-ahead for QSOs and I made my first call. I was mobbed with replies and tried to sort them all out. It was a madhouse, but I made it easier by only repeating call suffixes and saying a brief but unorthodox "next" to invite further calls after making a contact, instead of the standard "Q R Zed" call which eats up a bit more time. Rodna, KJ6GVQ, rarely talks on ham radio, but at my request she made an exception and had a QSO with me as I descended. I had an onboard digital audio recorder that could help me complete logs and QSL cards later. The purists wouldn't like my breach of protocol, but I did what I had to do to get the maximum number of QSOs. It wasn't a

contest with rules, just a fun ham radio parachute jump.

KF6WRW had me in sight and called me, "Jumper 1 from Jumper 2. Hey Mark, turn right." I did and saw him flying nearby shooting video. We chatted a bit but kept a safe distance between us while we worked our way back to the DZ, flying over gorgeous fall scenery. We could see San Francisco Bay, the Delta, and a huge panoramic slice of northern California. We could see quite a few airplanes too, above and below us, fortunately none too close.

Passing through 3000 feet, I terminated ham QSOs and asked for a wind update from the DZ. Team member Bernhard Hailer, AE6YN, responded on our 440 MHz band tactical frequency. I didn't hear him and made the request again. My astute team members figured out instantly that my 440 MHz receiver wasn't working and repeated the wind info on our Pacificon working frequency without missing a beat. I love working with the "heads up" hams on my team, especially when communications are so critical to the safety of our mission. The winds were low and steady and I adjusted my approach trajectory accordingly. Michael and I both made smooth standup landings right in the middle of the landing area. With help from our DZ ground crew, we shut off power to various pieces of radio gear, gathered up our collapsed chutes and headed back to the command center to shed the rest of our gear, debrief, repack, and prepare for another jump.

The next day we went to Pacificon and met a lot of hams who had heard us, talked to us, and saw our jumps on ATV. Leo Laporte, "The Tech Guy" (and also a new ham, W6TYT), was doing a live commercial radio broadcast from the convention floor. He snagged me for a brief interview as I walked past his broadcast table heading to our Parachute Mobile presentation room. The interview started with Leo introducing me, pausing, and then asking, "Are you crazy?"

Yeah, we are crazy, the whole Parachute Mobile team. Combining skydiving with ham radio is a crazy idea, but we love doing it. We had a great time doing the Pacificon 2011 mission and we look forward to another hamfest jump mission in conjunction with Radiofest 2012 in Monterey, California. In the meantime we will perfect new gear, plan new jump profiles, and continue preparing for eventual high-altitude ham radio jumps with oxygen gear.

Until then, look up. We are Parachute Mobile: on the air, in the air, taking ham radio to new heights.

with the huge VHF horizon, digipeaters and iGates throughout Northern California should have been able to receive the signal, but they also receive local signals as well, so interference was a big issue. Local traffic covered up APRS signals at some of the iGates, reducing coverage. And far too many digipeaters received the APRS signals from the parachutists and relayed them, causing congestion. Thankfully, the airtime of the jumps was fairly short, only 10 to 20 minutes, so they didn't cause too much QRM on the APRS network. But the rewards were slim, only 10 to 30 data points per jump.

The first jump for which I was to participate on site was at the ARRL event Monterey RadioFest 2010. Mark, Michael, and I met well in advance and planned out what types of data we wanted to collect. Seeing a plot of the whole ascent and descent on an APRS map was a given. But Mark and I both had ideas for a few new capabilities. Adding the third dimension via a service such as Google Earth would be a blast. And since Mark had moved up from 13,000-foot jumps to the ethereal 18,000-foot range where the air is too thin to breathe for long, being able to watch his blood oxygen level as he descended was a must.

I worked out a plan with Mark to capture APRS data, not only of the usual latitude, longitude, altitude, speed and temperature, but adding blood oxygen sensing. Not only would pulse oximeter data help in tracking the jumper's oxygen level through the flight, it could also alert our safety and ground crew to a possible dangerous situation in which a hypoxic jumper might become incapacitated or suffer impaired cognition and performance. In such a case, we could prepare for an offsite or poorly controlled landing or other contingency during the descent.

Next, I needed to come up with a suit-worn APRS transmitting system that could operate in the cold high-altitude environment, within a foot of other jumper-borne transmitters on the 2 meter and 70 cm bands. The most critical requirement, and one that made sense to all of us, was that the equipment should not have any bulky or sharp edges that might catch on a parachute cord and create hazards.

I realized that I would have to assemble my own receiving station, needing at minimum a laptop, a TNC, a handheld transceiver, and an external antenna. With our own dedicated Earth station, we could have Mark and Michael switch to 144.330 MHz, the alternate 2 meter frequency for APRS in our Northern California band plan. Since we expected no Internet access at the ground control site, rather than routing the data to the Internet as an iGate does, I decided to make my receiving station into a data logger. A data logger does just that: it accepts a stream of data from a source, and stores it for later retrieval and processing.

The first ground station I built was a laptop, a Kantronics K3 TNC, and a Yaesu handheld with an external antenna. It was a success, and we captured over 100 packets per jump. However, the setup time and testing for the ground station was considerable, and each time, I was concerned that I would forget something important in my "jump" kit. So I decided I needed to build a self-contained device to do the same job.

I focused on the design of the digital and software parts of the project, and got the system mostly working (at least in my tests) just before I had to take time off from the project to organize the ARRL presence at the San Francisco Bay Area Maker Faire in May 2011.

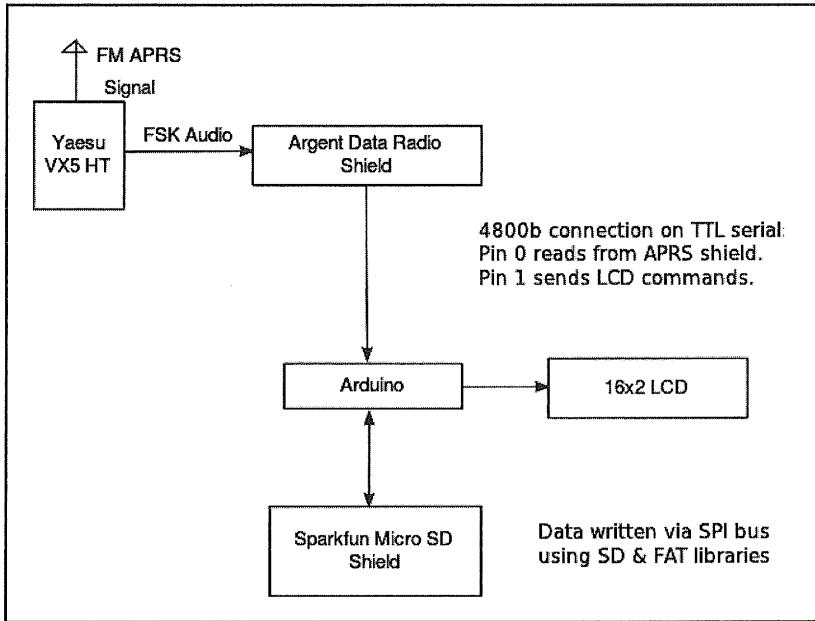


Figure 2.1 — Block diagram of the data logger system.

Unfortunately, our team met with disappointing results due to a bad choice of receive antenna. But by summer 2011, I had a working, reliable ground station that passed my ultimate test: I handed it to someone with minimal instructions and it worked perfectly.

System: Hardware and Software

The Arduino platform is rich with building blocks to leverage for this task, and they literally plug together like building blocks, both in hardware shields and software libraries. Plug together an Arduino, an SD card shield, an Argent Data Systems Radio Shield, a handheld transceiver, and an antenna to make an APRS data logger.

The block diagram in **Figure 2.1** shows the overall organization of the system.

The Arduino platform offers an abundance of examples. Most shields and libraries have tutorials or example code, either on a website, or sometimes embedded in the library and available under the FILE/EXAMPLES menu.

For the SparkFun microSD Shield, you can see the examples in the Arduino IDE by opening FILE/EXAMPLES/SD/DATALOGGER. For the Argent Radio Shield, the example code is the Radio Shield Wiki (see references), and in the Argent Radio Shield library written for this project. I started with the Radio Shield example, and the first sketch I got working was the example that receives and displays packets, from the Argent Data wiki. I then worked on the SD card writing separately, using a different sketch based on the SD card writer example. The SD card interfaces uses a bus standard called TWI or I2C, and which is supported in the Arduino with the Wire library. Learning how to set up the SD card shield pin numbers was the main challenge of getting the SD card to work, but luckily it is a simple piece of code that is easily copied and re-used. The SPI bus is multi-device, though, and each device needs its own dedicated “select” line.

Once I understood how the individual parts worked, I combined them into a

new single sketch. So, the first working sketch of the APRS Logger was a mash-up of the SD card example and the Argent Data shield example. This is the beauty of Arduino: shield developers write reusable libraries and starter code, which the Arduino IDE invites you to edit, so you rarely have to start from scratch. And if you have a good attitude and questions that show you've thought through your problems, there are plenty of people online willing to help.

The Radio Shield decodes the packets and sends the decoded packet over the serial pins (D0 and D1) to the Arduino. The Arduino sketch validates the packet and displays the data on an LCD and then writes it to the SD shield.

Radio Shield Packets

The current firmware of the Radio Shield uses TNC2 format rather than KISS format, as it is more convenient and does not require parsing control characters. However, the Radio Shield format also excludes the APRS path, which is not an issue in this project, but is something to be aware of.

Below is an example incoming packet received from the Radio Shield, shown here split over multiple lines for convenience.

Packet Example:

AF6IM>APOT21:/213231h3750.14N/12137.79W^053/042/A=012814HR
165 Sp02 87 http://ParachuteMobile.org

Arduino Sketch

Here is the sketch to receive packets, decode them, write them to the SD card, and display on an LCD attached to the Radio Shield parallel connection. See the next chapter for more options on LCD, SD cards and real-time clock.

```
#include <SD.h>
```

Define the pin numbers.

```
#define CS 8
#define MOSI 11
#define MISO 12
#define SCK 13
#define CHPSELECT 10
```

Input buffer.

```
#define BUFFERSIZE 256
```

```
char inbyte = 0;           // Received byte
char buff[BUFFERSIZE];    // Incoming data buffer
char callsign[16];        //callsign plus ssid
char printline[18];        //line to print

int buflen = 0;           // Length of buffered data
```

Set up the pins for the microSD shield. Initialize the LCD and the serial port.

```
void setup() {
    pinMode(CS, OUTPUT);
    pinMode(MOSI, OUTPUT);
    pinMode(MISO, INPUT);
    pinMode(SCK, OUTPUT);
    pinMode(CHPSELECT, OUTPUT);
    Serial.begin(4800);           // RadioShield runs at 4800 baud
    // see if the card is present and can be initialized
    if (!SD.begin(CHPSELECT)) {
        Serial.println("Card failed, or not present");
        // don't do anything more:
        return;
    }

    // Set display contrast
    Serial.println("B1023");
    // Clear screen
    Serial.println("C");
    // Can take a bit to clear the LCD, so wait
    delay(10);
    // 'Waiting' message stays until we receive something
    Serial.println("WNE6RD - Waiting");
}
```

The loop gets characters from the Radio Shield, displays them on the LCD, and stores the packet data to the SD card. It also pulls out the call sign, so you can adjust the code to filter on call sign.

```
void loop() {
    // Check for an incoming byte on the serial port
    while (Serial.available() > 0) {
        // Get the byte
        inbyte = Serial.read();
        // until we get a EOL, store just store it
        if ((inbyte > 31 || ch == 0x1c || ch == 0x1d || ch == 0x27)
            && (buflen < BUFFERSIZE)) {
            // Only record printable characters but pass MIC-E
            buff[buflen++] = inbyte;
            buff[buflen] = 0;
        } else if (inbyte == '\n') {    // Check for end of line
            // Write the record to the SD card
            // Open file_handle file that's just been initialized
            File file_handle = SD.open("APRS.txt", FILE_WRITE | O_APPEND);
            if (file_handle == 0) {
                Serial.println("WOPENFAILED");
            } else {
```

```

        file_handle.write((const uint8_t*)buff, buflen);
        file_handle.print("\n");
        file_handle.close();
    }
    // Parse the line to display in the 2x16 LCD
    // See the example packet in the book text above.
    // Zero the buffers
    memset(callsign, 0, 16);
    memset(printline, 0, 17);

    // Clear screen
    Serial.println("C");
    // Can take a bit to clear the LCD, so wait
    delay(10);
    // Start writing to the LCD
    Serial.print("W");

    int callsignLen =0;
    // Find the ">" to get the substring that contains the callsign
    callsignLen = strcspn(buff, ">");
    if ( callsignLen == 0 || callsignLen > 16) {
        //either nothing or too long: bad aprs packet
        continue;
    }
    strncpy(callsign, buff, callsignLen);
    strncpy(printline, buff, callsignLen);

    // skip past header data
    int pastheader = strcspn(buff+callsignLen, ":") + callsignLen;

    // Each line is 16 characters. Callsign is N characters, then
    // marker is how many additional characters
    // can be displayed on the first line
    int marker=17-callsignLen;
    //see if line less than 16 characters
    if ((buflen - pastheader) < (16-callsignLen))
        marker=buflen - pastheader;
    // fill printline with data and print it to the LCD
    strncpy(printline+callsignLen, buff+pastheader,marker);
    Serial.println(printline);
    delay(10);
    // If no more data, we are done
    if ((buflen - pastheader + callsignLen) <= 16) {
        continue;
    }

    // Marker is now at the first character past what was written.
    marker= marker + pastheader;

```

```

Serial.println("G1,0"); // set LCD to second line.
delay(10);
memset(printline, 17, 0); // zero printline
printline[0]='W'; // "W" tells Radio Shield to write
// ex buflen = 25; marker = 18
int line_len = buflen - marker;
if (line_len > 16) {
    line_len = 16;
}
// Copy from marker to the end of the line
strncpy(printline+1, buff+marker, line_len);
// write to the LCD
Serial.println(printline);

buflen = 0;
memset(buff, BUFFERSIZE, '\0');
} else if (buflen >= BUFFERSIZE) {
    // Assume some problem if we read 256 characters
    // and did not receive an EOL
    buflen = 0;
    memset(buff, BUFFERSIZE, '\0');
}
}
}

```

Hardware Design

There are three challenges to assembling the Radio Shield kit: kit assembly, LCD connection, and handheld radio connection.

For kit assembly, remember to use the stacking headers so that the shields can be attached one to another. Pay careful attention to the 2N7000 during assembly. Like all FET parts, it is very static sensitive, so use a static-safe wrist strap.

Another option is to use a connector. For the radio connection, one possibility is the DE9 connector with the Kantronics pinout, but it's difficult to attach physically to the Radio Shield board. Another option is a right-angle header, with either male or female pins on 0.1 inch centers. If you use a female right-angle header, you can make your own mating connector by soldering to a male header and protecting the connection with a small coating of RTV adhesive surrounded by shrink-fit tubing. If you use a male header, you can re-purpose a common CD-ROM four-pin connector. Some of the CD-ROM connectors come with shielded cable, and you need to swap the pin headers for the shield and the next pin so that the shield is connected to pin 1. Of course, you can also make your own cable from scratch.

Jumper JP2 connects Arduino pins D0 and D1 to the USB serial interface or to the Radio Shield. Switch to the PROGRAM position to upload a new sketch to the Arduino, and the RUN position to use the Radio Shield with the Arduino.

For my Yaesu handheld, I needed to install R6 ($2.2\text{ k}\Omega$) to control PTT. Check your radio manual for keying instructions. Notice how I added strain relief to the speaker mic cable.

The SparkFun SD card shield works with microSD cards, and handles the important 5 V to 3.3 V level shifting.

Shield Stack

The shield stack (Figure 2.2) uses the Arduino, SparkFun microSD Shield, Argent Radio Shield, and the LCD connected via parallel cable. The handheld radio cable is directly soldered to the Radio Shield, using a strain relief.

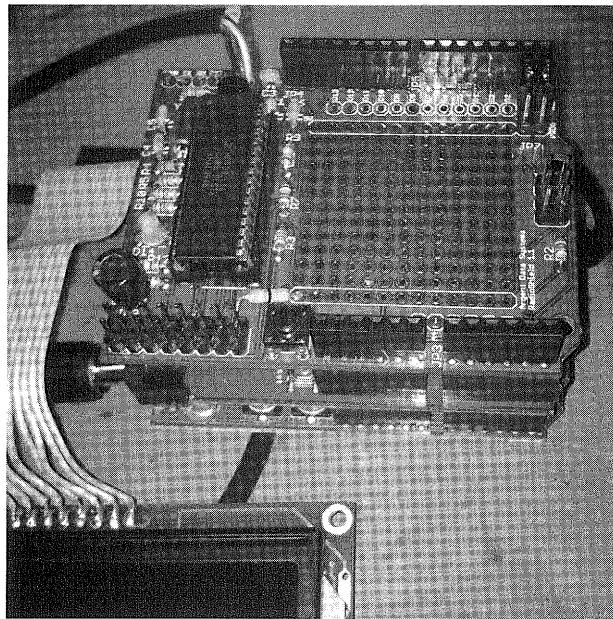


Figure 2.2 — Shield Stack: Radio Shield, SD Card Shield, and Arduino. The LCD parallel connection is the ribbon cable. [Michael Pechner, NE6RD, photo]

Assembling the LCD Ribbon Cable

If you use the parallel LCD feature of the Argent Radio Shield, you will need a cable to connect the two together. The easiest solution is to buy a ribbon cable with 2 x 8 IDC connectors spaced 0.1 inch, cut it to about 8 inches long, and solder the other end directly to the LCD (see Figure 2.3). See the References at the end of the chapter for more information on cables.



Figure 2.3 — Shield and Radio: The data logger in operation, showing a captured APRS packet on the LCD. [Michael Pechner, NE6RD, photo]

Setup and Operation

Using your favorite adapter, connect the microSD to your computer, and delete the old file if you like.

Connect the speaker/mic jack from the radio shield to the radio. Turn on the radio.

Radio settings may need adjustment. For Yaesu radios, I set the squelch so it just barely cuts off noise. For the volume level, I set it so the volume knob is about half between low and high. This works with both the VX5 and the FT-60. For any other radio, you will have to play.

Using the USB or the 2.1 mm jack, connect the power. I usually run it on 12 V, but 9 V will work and generates less heat in the Arduino voltage regulator. Because the data is flushed to the SD card each time, you can disconnect the power at any time. It's good idea to power down before inserting or removing the SD card.

Creating the Google Earth View

Back on the laptop, read the collected data from the SD card using a Python script to produce a KML format file, for display with Google Earth. The `radioshield2kml.py` utility is available in the references downloads, and requires Python 2.5 or later, but would have to be adapted for Python 3. (See the sidebar, “Python,” later in this chapter.)

A sample invocation:

```
python radioshield2kml.py --aprs=APRS.txt --kml=here.kml
--startdate=07072011 --callsign=af6im --fly-alt=1000
--fly-tilt 60 --fly-heading 1 --fly-range 8000
python radioshield2kml.py --aprs aprsdata.txt --kml
output.kml --startdate 07252011 --callsign NE6RD
--min-altitude=0
```

If you want to tweak this script, look at the variable `dataRE` is the regular expression, that parses the APRS line, function `tactical_data()`, that returns the string to be displayed in the bubble when you click on a data point, and function `processFly()` that controls the location to start the point of view. You may also need to change altitude or distance.

For the `--fly-`? options, see the Google KML documentation. These options feed the altitude, heading, tilt and range elements of the `lookat` for the `FlyTo` element setting the initial point of view.

Options:

<code>-h, --help</code>	show this help message and exit
<code>--aprs=FILE</code>	Aprs File to Read
<code>--kml=FILE</code>	KML File to Write
<code>--startdate=STARTTIME</code>	startdate mmddyyyy
<code>--callsign=CALLSIGN</code>	Callsign to extract.
<code>--min-altitude=MIN_ALTITUDE</code>	The minimum altitude we care about. Event below this are ignored. Default is 100
<code>--fly-alt=FLY_ALT</code>	The Altitude used for the initial position

```
--fly-tilt=FLY_TILT    The Tilt used for the initial position  
--fly-heading=FLY_HEADING  
                      The heading used for the initial position  
--fly-range=FLY_RANGE  
                      The initial distance from the point
```

Viewing in Google Earth

To display the file, first install Google Earth. On a Mac, I just double click the file and Google Earth will open the file and display the overlay (**Figure 2.4**). You can also use the FILE menu in Google Earth to open the file.



Figure 2.4 — Google Earth plot of data from the APRS data logger, converted to KML for display with the *radioshield2km* Python program. [Michael Pechner, NE6RD and Imagery © 2011 DigitalGlobe, USDA Farm Service Agency, GeoEye, © 2010 Google]

Python

Python is a programming language available on a wide range of computer systems and operating systems. Although it runs on some of the larger embedded platforms, it doesn't run on the Arduino. Even so, it is a power language, useful for performing analysis operations on data you have collected with your Arduino.

If you know your way around the Arduino, Python will not have a steep learning curve. Python is an *interpreted* language, and that means that it

has no compilation step, and you can type Python commands to experiment with and examine a program while it is still running. One thing to watch out for: spaces matter to Python, and indentation is used for grouping statements together, instead of the brace "{" and "}" characters you see in Arduino programming.

For more information about Python, see the Python Beginners Guides listed in the References at the end of this chapter.

Customization

The APRS radios for Parachute Mobile make use of some custom gear: for example, we have a SPO₂ (pulse oximeter) finger sensor that the jumpers wear. It measures heart rate and blood oxygen level that we display with each packet in addition to position and altitude. You can customize the `tactical_data()` method of the python `radioshield2kml.py` utility.

This utility assumes certain settings. It does not support APRS MICe encoding or other compression. The date format is Hour Minute Second. The packets are those from the Radio Shield. If you grab data from your Kantronics or raw packets from <http://aprs.fi>, it will fail. At a minimum the regular expression “dataRE” will have to be modified. It uses imperial units, not metric.

If you are not logging parachutists jumping from 13,000 feet, set the `--min_altitude` option to 0.

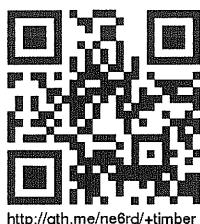
Further Suggestions

- *Change to using SoftwareSerial instead of hardware Serial.* Instead of shorting connectors on the Argent Radio Shield, connect the middle pins directly to a pair of Arduino digital IO pins other than D0 and D1, and modify the sketch to use those pins for SoftwareSerial.
- *Put in a call sign filter.* If you don’t use a different frequency as we do with Parachute Mobile, you will receive packets from many stations. Put in a call sign filter to decide which packets to log. Since you can compile your own code, you can set the call signs there and don’t need to put in an onboard UI for setting the call sign, though designing a UI to do that in the field using the buttons on the common LCD shields would be a good challenge.
- *Timestamps, LCD Shields, and libraries.* For an example of how customize a project to your needs, see the next chapter.
- *Put it in a case.* See the appendix *Laser Cut Case* for ideas.

Acknowledgments

Thanks to Scott Miller, N1VG, of Argent Data who developed the Radio Shield, and who has been very helpful with Parachute Mobile, answering questions and helping with projects and gear.

Thanks to Bay Area Sky Diving. These guys are very nice, even when we all show up and take over an area of the patio.



References

- Online version of this References list
<http://qth.me/ne6rd/+timber>
- Source code for this project
<http://qth.me/ne6rd/+timber/code>
- Bay Area Skydiving
<http://www.bayareaskydiving.com>
- Arduino Wire library for I2C/TWI devices such as the SD Card Shield
<http://arduino.cc/en/Reference/Wire>

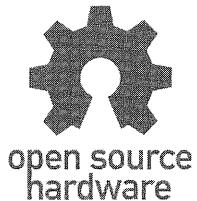
- Argent Data Radio Shield
http://wiki.argentdata.com/index.php?title=Radio_Shield
- SparkFun microSD Card Shield
<http://www.sparkfun.com/products/9802>
- Jameco Electronics
<http://www.jameco.com>
- General APRS information
<http://aprs.org>
<http://aprs.org/doc/APRS101.PDF>
- Google Earth
<http://www.google.com/earth/>
- Google Earth KML reference
<https://developers.google.com/kml/documentation/>
- Google KML lookat
<http://code.google.com/apis/kml/documentation/kmlreference.html#lookat>
- Python programming language for *Windows*, *Linux*, and *Mac OS*
<http://python.org>
- Python Beginners Guide
<http://wiki.python.org/moin/BEGINNERSGUIDE>
- Python for Non-Programmers
<http://wiki.python.org/moin/BEGINNERSGUIDE/NonProgrammers>
- Parachute Mobile Talk, SF Bay Area Maker Faire 2010
http://fora.tv/2010/05/22/Parachute_Mobile_Taking_Ham_Radio_to_New_Heights
- Pacificon
<http://www.pacificon.org>

Component List

- Arduino
Arduino Uno, Duemilanove or any other standard-sized Arduino with an ATmega 328
- Argent Data Systems Radio Shield
http://www.argentdata.com/catalog/product_info.php?products_id=136
- Argent Data Yaesu cable
http://www.argentdata.com/catalog/product_info.php?products_id=68
- Arduino Stackable Header Kit (buy one set for each shield used)
<http://www.sparkfun.com/products/10007>
<http://www.adafruit.com/products/85>
- SparkFun microSD Shield
<http://www.sparkfun.com/products/9802>
- A 16x2, 5 V LCD
You can use a parallel LCD attached via a ribbon cable to the Argent RadioShield
<http://www.sparkfun.com/products/255>
<http://www.pololu.com/catalog/product/773>

- 16 conductor ribbon cable with 8×2, 0.1 inch on one end
<http://www.pololu.com/catalog/product/973>

License



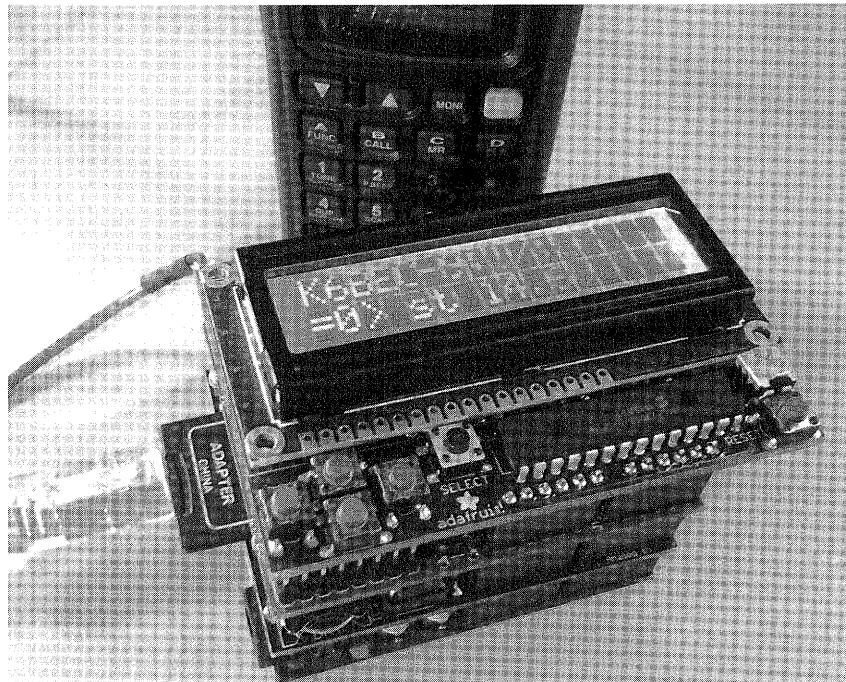
- The main sketch is distributed under the terms of the MIT License
<http://www.opensource.org/licenses/mit-license>
- The hardware design is licensed under CC-BY-SA 3.0
<http://creativecommons.org/licenses/by-sa/3.0/>

About the Author

Michael Pechner, NE6RD, holds an Extra class license and has organized ham radio participation in the San Francisco Bay Area Maker Faire since 2009.

Customizing the Data Logger

Leigh L. Klotz, Jr., WA5ZNU



A handheld transceiver provides audio to the Argent Data Radio Shield, for display on an Adafruit RGB LCD shield and storage to an SD card, all under control of an Arduino sketch. [Leigh Klotz, WA5ZNU, photo]

This chapter describes the WA5ZNU build of the APRS data logger project by Michael Pechner, NE6RD, that was featured in the previous chapter. I made a few changes to the shield stack and wrote some libraries to make it easier to mix and match hardware.

Shield Stack

This build uses the Argent Data Systems Radio Shield and Arduino from Michael's project, but replaces the SparkFun microSD shield with an Adafruit Data Logging shield that includes an SD card interface and real time clock (RTC). This build also uses an LCD shield instead of a parallel LCD on a cable. Figure 3.1 shows the stack of boards.

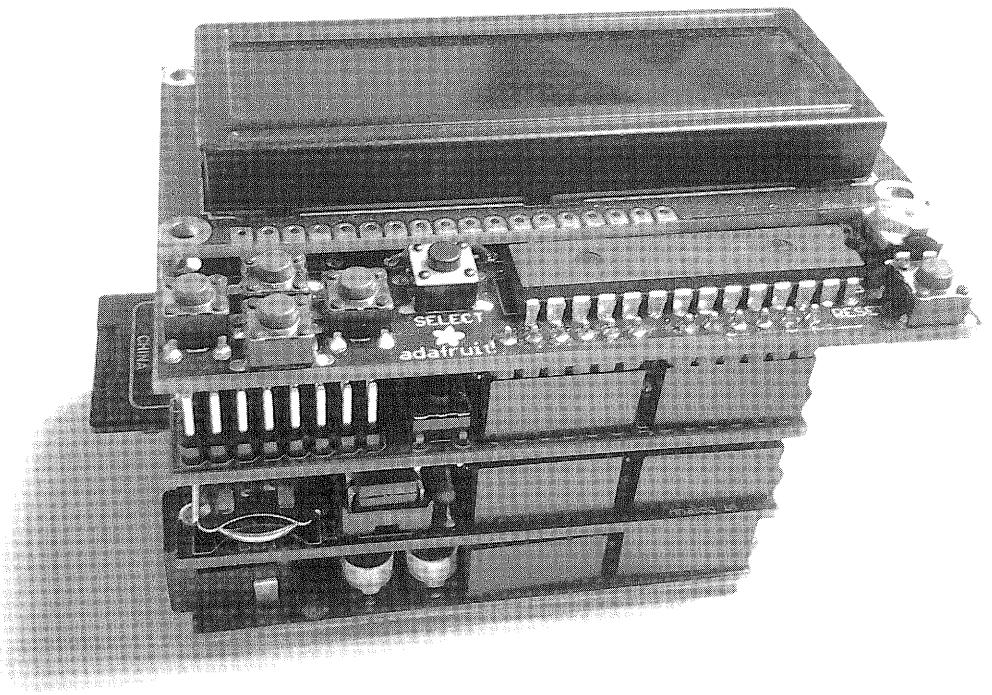


Figure 3.1 — The simplicity and functionality of the Arduino system allows easy composition of hardware and software. Shown here is a side view of the stack of shields. From top to bottom: Adafruit RGB LCD shield, Argent Data Radio Shield, Adafruit Data Logging shield, Arduino Uno. [Leigh Klotz, WA5ZNU, photo]

Instead of a soldered cable with a strain relief, the handheld radio connection is a right-angle 0.1 inch header on the Radio Shield, mating to a repurposed 4 pin computer sound plug, with ground pin repositioned as pin 1. See **Figure 3.2**.

LCD

Without modifying the main sketch, you can use this project with two different LCD shields or you can write your own additions to use a different display. Included are sketch files for the DFRobot LCD Keypad shield and the Adafruit RGB LCD shield. For more information, see the *LCD Shields* appendix.

SD Card Shield

The Adafruit Data Logging shield has a full sized SD card connection and includes and a real time clock. Just as Michael did, I started with the example code included in the libraries, and then I merged in the changes with the main sketch once I understood how everything worked. The RTC is a bonus addition, useful to timestamp your APRS data. If you use the output file of this project with the Python code in Michael's project, you'll need to modify the Python program to accept and make use of the date and time.

Although a version of the SD library is included with the Arduino IDE, an enhanced SD library must be downloaded from the Adafruit website for use with the Logger shield.

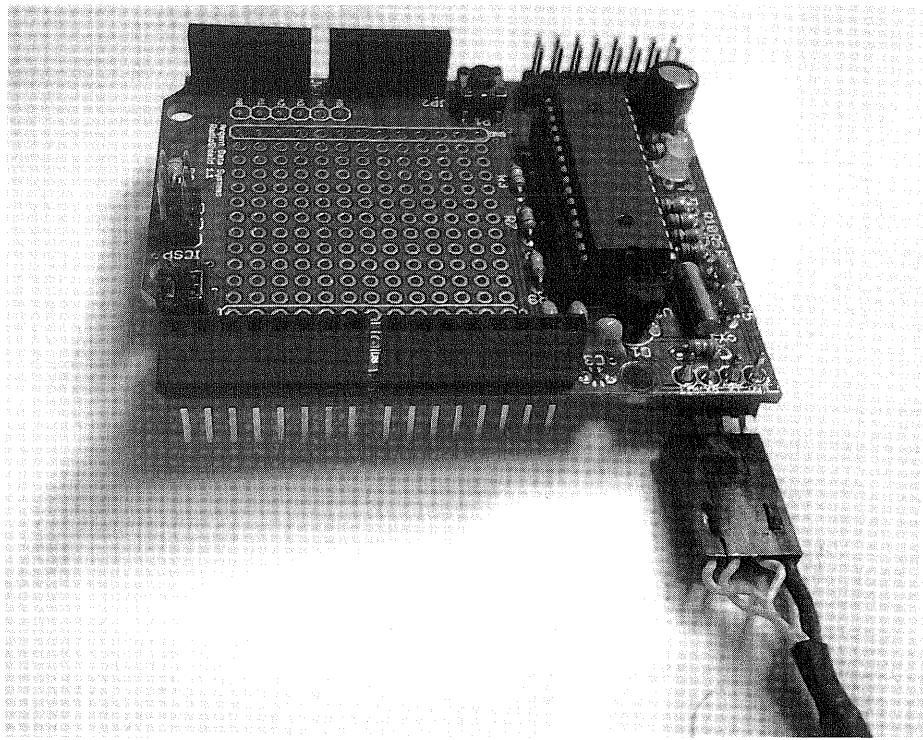


Figure 3.2 — Instead of a soldered cable with a strain relief, the handheld radio connection is a right-angle 0.1 inch header on the Radio Shield, mating to a repurposed 4 pin computer sound plug, with ground pin repositioned as pin 1. [Leigh Klotz, WA5ZNU, photo]

Radio Shield

Instead of using the Radio Shield directly, I wrote a new `ArgentRadioShield` library. It includes enhancements such as functions for setting APRS parameters, and it has the ability to work with the `SoftwareSerial` module if you need to keep pins D0 and D1 assigned to serial communications. See the *Argent Radio Shield Library* appendix.

The Sketch

Michael's sketch is a single file, although it uses a few system files such as the SD card library. This sketch is no longer a single file, and it has different functional areas in different files, some of which can be replaced without changing others. Code written in this top down style may be easier to read, but it is easier to write only the second time around.

To use this sketch, you need to download the `ArgentRadioShield` library from this book's website and the SD card library from Adafruit. If you use the DFRobot LCD Keypad shield, this book's website includes a version of the library with extended button and backlight functionality.

Main Sketch

Below is the main sketch, `TimberRTC.ino`. It is available for download; see the References section at the end of this chapter.

```
/*
 * APRS Recorder
 * Michael Pechner NE6RD
 * RTC and Libraries Leigh L. Klotz, Jr WA5ZNU
 */

#include <Arduino.h>
#include "LCD.h"
#include <ArgentRadioShield.h>
#include <Wire.h>
#include <RTCLib.h>
#include <SD.h>

#define HELLO_MESSAGE "APRS Logger"

// SD Card Shield pin numbers
#define CS      8
#define MOSI    11
#define MISO    12
#define SCK     13
#define CHPSELECT 10

#define BUFFERSIZE 255

char buff[BUFFERSIZE];      // Incoming data buffer
int buflen = 0;             // Length of buffered data
```

This sketch uses the `ArgentRadioShield` library (see the appendix), which offers the option to use `Hardware Serial` or `SoftwareSerial`. Here, it uses the built-in `Serial`.

```
ArgentRadioShield argentRadioShield = ArgentRadioShield(&Serial);
```

This value is for the real time clock on board the Adafruit SD card/RTC shield.

```
RTC_DS1307 RTC;
```

This setup is similar to the previous chapter.

```
void setup() {
    Wire.begin();
    // For RTC
    RTC.begin();
    //Set up the SD Card pins
    pinMode(CS, OUTPUT);
    pinMode(MOSI, OUTPUT);
    pinMode(MISO, INPUT);
    pinMode(SCK, OUTPUT);
    pinMode(CHPSELECT, OUTPUT);

    // Argent RadioShield runs at 4800 baud
    Serial.begin(4800);

    // Setup LCD Screen
    lcdbegin();

    // See if the card is present and can be initialized
    if (!SD.begin(CHPSELECT)) {
        lcdprint("SD Card failed");
    } else {
        // 'Waiting' message stays until we receive something
        lcdprint(HELLO_MESSAGE);
    }
}
```

The loop function checks for an incoming byte on the ArgentRadioShield, and until it gets a newline, adds characters to buffer. On newline, it writes to SD card and LCD, and starts over. It also handles badly formed packets.

```
void loop() {
    while (argentRadioShield.available() > 0) {
        // Get the byte
        char inbyte = argentRadioShield.read();
        if (inbyte == '\n') {
            lcdclear();
            // If end of line, write the packet to the file on the SD card
            appendPacket();
            // And display it on the LCD screen
            displayPacket();
            buflen = 0;
        } else if (ch < 31 && ch != 0x1c && ch != 0x1d && ch != 0x27) {
            // ignore badly-decoded characters but pass MIC-E
    }
}
```

```

    } else if (buflen != BUFFERSIZE) {
        // If we haven't reached end of buffer space, write it.
        buff[buflen++] = inbyte;
    } else {
        lcdprint("Data Too Long");
        // If we read 256 characters and did not receive a EOL,
        // there is a problem
        // so reset buffer and start over.
        buflen = 0;
    }
}
}

```

The `appendPacket` function writes the packet to the SD card and closes the file.

```

void appendPacket() {
    // Open file_handle file that's just been initialized
    File file_handle = SD.open("APRS.txt", FILE_WRITE | O_APPEND);
    if (file_handle == 0) {
        lcdprint("Cannot open File");
    } else {
        printdate(&file_handle);
        file_handle.print(" ");
        file_handle.write((const uint8_t*)buff, buflen);
        file_handle.print("\n");
        file_handle.close();
    }
}

```

The `displayPacket` function displays the call sign and text of the packet on the LCD.

```

void displayPacket() {
    lcdclear();

    // Terminate the string buffer with a '\0'
    buff[buflen] = '\0';

    // Find the ">" to that ends the callsign
    char *callsignEnd = strchr(buff, '>');
    if (callsignEnd == NULL || callsignEnd-buff > 16) {
        // either no call or too call long
        lcdprint("BAD PACKET");
        return;
    }

    // If there's no ":" then packet is malformed.

```

```

char *rest = strchr(callsignEnd, ':');
if (rest == NULL) {
    lcdprint("BAD PACKET");
    return;
}

// Print callsign, then
// skip APRS destination (after ":")
// Leave the ':' as a separator.
lcdprint(buff, callsignEnd - buff);
lcdprint(rest, strlen(rest));
}

```

LCD Sketch Files

The sketch files described in this section are also available for download; see the References section. Note that the Arduino IDE concatenates all *.ino files in your sketch together into one file, so you choose which LCD sketch code you want to use by saving just one of the three available LCD files.

Adafruit RGB LCD Shield

If you decide to use the Adafruit RGB LCD shield, save this file as RGBLCD.cpp:

```

#include <Arduino.h>
#include <Wire.h>
#include <Adafruit_MCP23017.h>
#include <Adafruit_RGBLCDShield.h>

// The shield uses the I2C SCL and SDA pins. On classic Arduinos
// this is Analog 4 and 5 so you can't use those for analogRead() anymore
// However, you can connect other I2C sensors to the I2C bus and share
// the I2C bus.
Adafruit_RGBLCDShield lcd = Adafruit_RGBLCDShield();

// These definition make it easy to set the backlight color
#define RED 0x1
#define YELLOW 0x3
#define GREEN 0x2
#define TEAL 0x6
#define BLUE 0x4
#define VIOLET 0x5
#define WHITE 0x7

void lcdbegin() {
    lcd.begin(16, 2);

```

```
lcd.setBacklight(GREEN);  
lcdclear();  
}  
  
#include "LineWrap.h"
```

DFRobot LCD Keypad

If you decide to use the DFRobot LCD Keypad, save this file as DFRobotLCD.ino:

```
#include <LiquidCrystal.h>  
#include <LCDKeypad.h>  
  
LCDKeypad lcd;  
  
void lcdbegin() {  
    lcd.begin(16, 2);  
    lcd.backlight(64);  
    lcdclear();  
}  
  
#include "LineWrap.h"
```

Argent Data Radio Shield Parallel LCD

If you decide to use the Argent Data Radio Shield parallel LCD, save this file as ArgentLCD.ino:

```
#define lcd argentRadioShield  
  
void lcdbegin() {  
    lcd.begin();  
    lcd.setcontrast(1023);  
    lcdclear();  
}  
  
#include "LineWrap.h"
```

Save this file as LCD.h

```
extern void lcdbegin();  
extern byte lcdRow;  
extern byte lcdCol;  
extern void lcdprint(char *s);  
extern void lcdprint(char *s, byte n);  
extern void lcdclear();  
extern void setCursor(byte col, byte row);
```

Common Header Files for LCD

Save this file as LineWrap.h

```
-----  
// LineWrap.h  
// LCD line-wrapping code  
// In your sketch, define 'lcd' variable and use #include "LineWrap.h".  
// This file is written as an include file, because the type of lcd used  
// varies, so we cannot declare it as an 'extern' variable or parameter.  
-----  
  
#define LCD_COLS (16)  
#define LCD_ROWS (2)  
  
#define ALLOW_LCD_SCREEN_WRAP false  
  
byte lcdRow;  
byte lcdCol;  
  
void lcdprint(char *s) {  
    lcdprint(s, strlen(s));  
}  
  
// Print specified number of characters, and wrap lines.  
// If ALLOW_LCD_SCREEN_WRAP is true, wrap multiple lines  
// to the next screenful; otherwise just truncate.  
void lcdprint(char *s, byte n) {  
    char spaceleft = LCD_COLS - lcdCol;  
    if (n <= spaceleft) {  
        char buf[17];  
        buf[LCD_COLS] = '\0';  
        strncpy(buf, s, n);  
        buf[n] = '\0';  
        lcd.print(buf);  
        lcdCol += n;  
    } else {  
        lcdprint(s, spaceleft);  
        setCursor(0, lcdRow + 1);  
        if (lcdRow == 0) {  
            if (ALLOW_LCD_SCREEN_WRAP) {  
                delay(500);  
                lcdclear();  
            } else {  
                return;  
            }  
        }  
        lcdprint(s+spaceleft, n - spaceleft);  
    }  
}
```

```

void lcdclear() {
    lcd.clear();
    lcdRow = 0;
    lcdCol = 0;
}

void setCursor(byte col, byte row) {
    lcdCol = col;
    lcdRow = row % LCD_ROWS;
    lcd.setCursor(lcdCol, lcdRow);
}

```

Date Formatting

Save this file as PrintDate.ino:

```

// This file provides printdate(File), to format the date and time
// as a file.
// It depends on the RTC shield.

// The date format is YYYY-MM-DD HH:MM:SS
// You can change it here.
void printdate (File *out) {
    if (RTC.isrunning()) {
        DateTime now = RTC.now();
        // Date: YYYY-MM-DD
        out->print(now.year(), DEC);
        out->print('/');
        zero_pad(out, now.month());
        out->print(now.month(), DEC);
        out->print('/');
        out->print(now.day(), DEC);
        // space
        out->print(' ');
        // Time: HH:MM_SS
        zero_pad(out, now.hour());
        out->print(now.hour(), DEC);
        out->print(':');
        zero_pad(out, now.minute());
        out->print(now.minute(), DEC);
        out->print(':');
        zero_pad(out, now.second());
        out->print(now.second(), DEC);
    }
}

// Zero pad numbers < 10 into two digits with a leading zero.
void zero_pad(File *out, byte x) {
    if (x < 10) out->print("0");
}

```



References

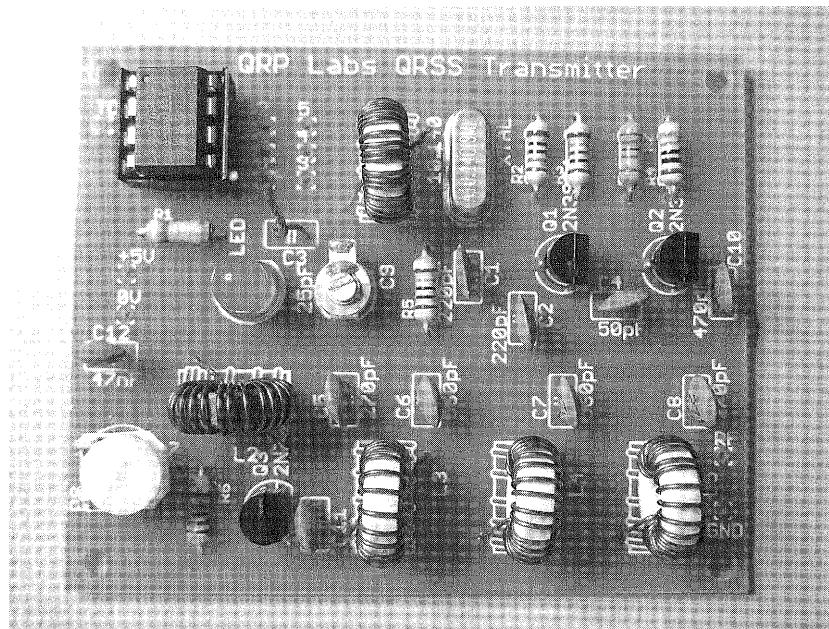
- Online References
<http://qth.me/wa5znu/+timber-rtc>
- Source code for this version of the Timber project
<http://qth.me/wa5znu/+timber-rtc/code>
- Argent Radio Shield Library
<http://qth.me/wa5znu/libraries/ArgentRadioShield.zip>
- Adafruit Logging Shield with SD and Real Time Clock and Library
<http://www.adafruit.com/products/243>
<http://www.ladyada.net/make/logshield>
- Adafruit RGB LCD Shield and Library
<http://www.adafruit.com/products/716>
- DFRobot LCD Keypad Shield
http://www.dfrobot.com/index.php?route=product/product&product_id=51
- DFRobot LCD Keypad Library
<http://qth.me/wa5znu/libraries/LCDKeypad.zip>

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QRSS: Very Slow Sending

Hans Summers, G0UPL



QRP Labs QRSS transmitter kit, with onboard ATtiny MCU. You can reprogram the ATtiny using the Arduino IDE. [Dave Claussen, W2VV, photo]

QRPers like to brag about how far they can get with just 5 W, and often with simple, homebrew transmitters. *QRP* operation restricts the output even further, to less than 1 W. But how low can you go? Surely at some point the fun stops and mere frustration sets in...or does it? Would you believe that David Isele, VK6DI (now VK2DDI), successfully received Larry Putman, WB3ANQ, using $500 \mu\text{W}$ (0.5 mW) on 30 meters over 18,600 km (11,500 miles)? And over a path of 240 miles, David received John Young, VK6JY, on 40 meters using just 80 nanowatts (0.00008 mW). How did they achieve these feats? The answer is something called *QRSS*.

QRSS Basics

QRSS is a weak-signal mode used for propagation experiments with extremely low power. QRSS can be used on all bands, but it is particularly suited to exploring propagation at HF, MF and below. A QRSS signal is transmitted very slowly, often taking five to ten minutes to send just a call sign! Needless to say, reception is not done by ear, nor is transmission done by hand. The signals are instead displayed visually, as in a waterfall display, but usually

Table 4.1
Bandwidth of Various Modes

Mode/CW Speed	Bandwidth	SNR Improvement	Equivalent Power
12 WPM CW	10 Hz	0 dB	5 W
8 WPM	6.67 Hz	+1.8 dB	3.3 W
4 WPM	3.33 Hz	+4.8 dB	1.7 W
QRSS 1 s/dit	1 Hz	+10 dB	500 mW
QRSS 3 s/dit	0.33 Hz	+14.8 dB	133 mW
QRSS 6 s/dit	0.1 Hz	+20 dB	50 mW
SSB	2.4 kHz	-24 dB	1200 W

progressing left-to-right so that the result can be read like text.

The term QRSS is based on the Q signal QRS, which means “Please send slowly.” By extension, QRSS means “very slow sending.” The slower we send information, the smaller the occupied bandwidth, and so the effective signal-to-noise ratio (SNR) is greatly enhanced. Imagine a target signal arriving at your receiver along with unwanted noise. By narrowing the filter bandwidth, more of the noise can be shut out, keeping more of your desired signal.

For a given power level and propagation conditions, CW goes further than SSB. By slowing down CW further to dit lengths of 6, 10 or even 30 seconds, the SNR improvement makes worldwide communication possible on HF with mere microwatts. **Table 4.1** illustrates the theoretical improvements in signal-to-noise ratio, relative to 12 WPM (words per minute) CW, marked as a level reference of 0 dB. The final column shows the equivalent power required for the same communication effectiveness, relative to a full QRP gallon of 5 W CW at 12 WPM. And on QRSS, 1 W would be considered shouting.

The low power requirements of QRSS make it ideal for home construction of simple transmitters. Certain aspects become more critical, such as frequency stability — your crystal drift with temperature is easily visible on QRSS.

QRSS Frequencies

Although QRSS is used for two-way QSOs on LF bands such as 136 kHz where poor antenna efficiencies make the signal-to-noise advantages of QRSS particularly useful, most QRSS enthusiasts concentrate on propagation experiments using a beacon-like operation known as *MEPT* (Manned Experimental Propagation Transmitter). MEPT operators typically announce their station call sign, signal mode and frequency on a forum such as QRSS Knights Mailing List (see the References section at the end of this chapter). Receiving stations capture 10 minutes of slow waterfall display and mail them to the forum or directly to the sender. Some operators have set up Internet-based *grabbers* that post waterfall displays so you can view the received signals directly on a website.

The 30 meter band is the most popular band for HF QRSS activity as worldwide reception is easily possible. Standard operation is in the 100 Hz subband 10,140,000 Hz to 10,140,100 Hz. QRSS is popular on other bands too,

particularly 80 and 40 meters, with operation typically 800 to 900 Hz above the lower band edge (for example, 3,500,850 Hz on 80 meters).

Software

QRSS reception uses a desktop computer running spectrum analysis software, similar to digital mode software such as *fldigi* or *DigiPan*. Although several no-cost software packages are available, *Argo* is one of the more popular, and is very easy to set up. With its slow waterfall speed and large FFT (Fast-Fourier Transform) bin size, *Argo* makes signals visible on the screen that are well below the noise floor in ordinary receiver bandwidths. These signals are impossible to hear by ear.

The typical *Argo* screen shows several minutes of reception over a 100 Hz wide slice of spectrum. As with other waterfall displays, *Argo* shows signal strength by the pixel brightness. For ease of use, frequency is plotted against the vertical axis and time flows left to right across the horizontal axis.

Classic QRSS is just slow on-off keying (OOK) CW. However the most common QRSS signal in use today is frequency shift keyed CW (FSK/CW) in which the transmitter is continuously on, but during key down (*mark*), the frequency is shifted up a few Hz, commonly about 5 Hz. This mode is easy to decode in poor conditions with weak signals.

Figure 4.1 shows a screenshot from *Argo*, with the 100 mW FSK/CW signal of GØUPL while on holiday on the island nation of Grenada in the Caribbean, as received by Jan Verduyn, GØBBL, in the UK. To clarify the decoding, dots and dashes have been drawn in above the signal, with the CW decoding “P” and “L” of the “GØUPL” call sign.

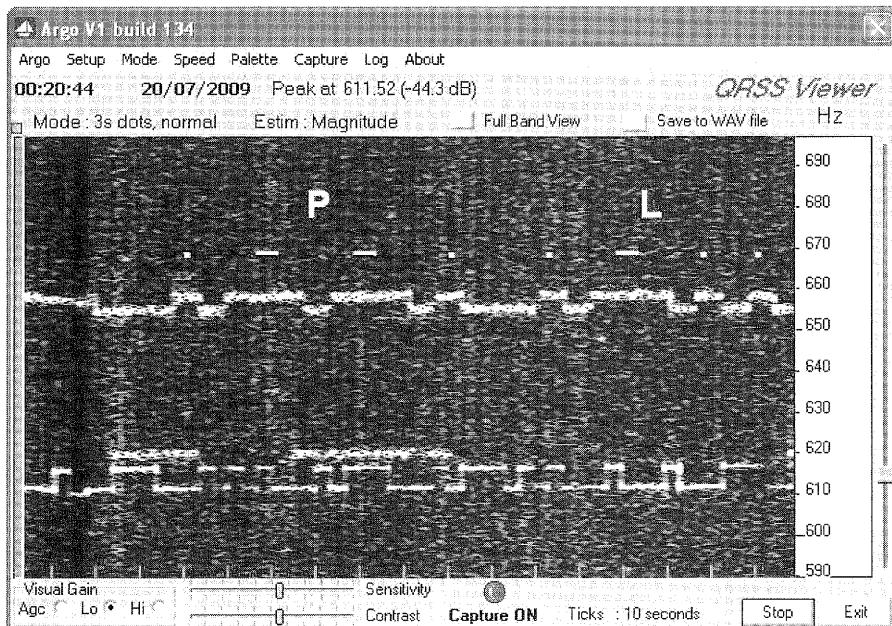


Figure 4.1 — Argo screenshot showing reception of 10.140 MHz QRSS signals from a kit transmitter. The signals were transmitted by J6/GØUPL on the island of Grenada and received by GØBBL in the UK.

QRSS/Beacon Keyer

I developed a QRSS MEPT kit, and have sold it through my website to many QRSS operators. The transmitter uses an Atmel ATtiny13 microcontroller, a varactor-tuned crystal oscillator, and a two-stage power amplifier with a seven-pole low pass filter. You can build this yourself at home, or order the kit. (See the sidebar for further information on the kit design, or see the next chapter to build a MEPT transmitter with more features in Arduino shield format.)

Although I used the ATtiny13 in my kit, for this project we will need to step up to the pin-compatible ATtiny45, because the additional memory makes it easier to use with the Arduino software. The sketch described here turns an ATtiny45 AVR into a QRSS keyer with equivalent functionality to the one used in my kit. You could also just use the sketch and ATtiny45 full-speed beacon keyer with your own transmitter design, perhaps for a Fox Hunt, repeatedly sending a message that is configurable via the msg string constant at the top of the sketch.

Timing Generation

Timing makes use of the Arduino `millis()` function that returns the number of milliseconds since the Arduino was switched on. The standard Arduino `loop()` function monitors the number of elapsed milliseconds, and calls the `beacon()` function when 100 ms have elapsed. That means the `beacon()` function is called 10 times per second, at 0.1 second intervals. This is the correct timing for the dits in 12 WPM CW. Note that if higher CW speeds were required, the 100 in the `loop()` function could be reduced accordingly. For example, for 25 WPM CW you would use an increment of $100 * 12 / 25$, or 48. This will cause the `beacon()` function to be called every 48 ms, which is the correct timing for a 25 WPM dit.

The keyer supports eight different speeds, which are selected by the state of the ATtiny45 pins 0, 1 and 2 (pin numbers 5, 6, 7 respectively). These pins are read by the Arduino `digitalRead()` function once at the end of every message transmission. The eight different speeds are specified by the `speeds[]` array at the top of the sketch, and could be modified for different dit lengths if required.

The connections at digital input 0, 1 and 2 (pins 5, 6 and 7 respectively) correspond to the speeds as shown in **Table 4.2**.

Note that the first transmission of the call sign is at 12 WPM, before reading the inputs and setting the speed accordingly. This provides a convenient way for the operator to verify correct message transmission at switch-on.

Table 4.2
Speed Settings

<i>Pin</i>	12 WPM	6 WPM	1 s	3 s	6 s	10 s	20 s	30 s
Input 2 (pin 7)	0	0	0	0	1	1	1	1
Input 1 (pin 6)	0	0	1	1	0	0	1	1
Input 0 (pin 5)	0	1	0	1	0	1	0	1

QRSS Transmitter Kit

The QRSS transmitter described here and shown in the accompanying schematic may be built from scratch or from a kit available from the author's website (see the References section at the end of this chapter). Note that in the kit, U1 is supplied as an ATtiny13, which is replaced by an ATtiny45 for this project for reasons discussed in the main text.

Q1 operates as a Colpitts crystal oscillator. The FSK is applied using D1, a reverse-connected 5 mm red LED that behaves as a varactor diode (it does not light). The LED is coupled to the crystal circuit via C3, a 1 pF capacitor formed by twisting together half an

inch or so of insulated wire. The amount of frequency shift is adjusted by cutting this "capacitor" shorter, or by slightly twisting/untwisting the wire.

Q2 is a buffer transistor, feeding the power amplifier transistor Q3. R8 adjusts the power level, and should be initially set with the wiper at the ground end to avoid burning out the 2N7000. Then increase it slowly until around 100-150 mW of RF power appears at the output. The standard 7-element low pass filter removes the transmitter harmonics.

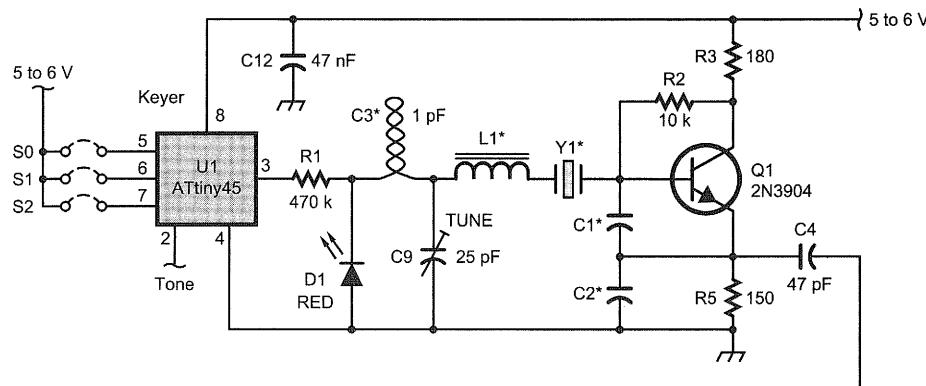
The transmitter may be built for 80, 40 or 30 meters. See **Table 4.A** for the component values.

Table 4.A

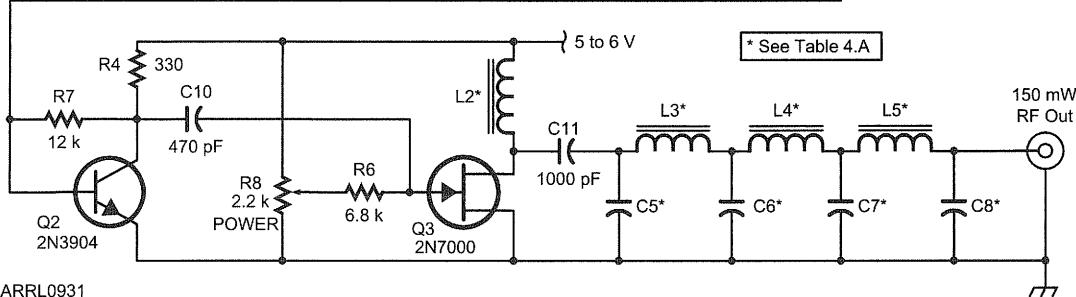
QRSS Transmitter Component Values for 30, 40 and 80 Meters

Part	80 meter version	40 meter version	30 meter version
C1, C2	680 pF	470 pF	220 pF
C3	1 pF twisted wire (see text)	1 pF twisted wire (see text)	1 pF twisted wire (see text)
C4	47 pF	47 pF	47 pF
C5, C8	470 pF	270 pF	270 pF
C6, C7	1200 pF	680 pF	560 pF
C9	25 pF trimmer	25 pF trimmer	25 pF trimmer
C10	470 pF	470 pF	470 pF
C11	1000 pF (1 nF)	1000 pF (1 nF)	1000 pF (1 nF)
C12	0.047 µF (47 nF)	0.047 µF (47 nF)	0.047 µF (47 nF)
L1	27 turns, T-37-6 (yellow)	27 turns, T-37-6 (yellow)	27 turns, T-37-6 (yellow)
L2	25 turns, FT-37-43 (black)	25 turns, FT-37-43 (black)	25 turns, FT-37-43 (black)
L3	25 turns, T-37-2 (red)	19 turns, T-37-6 (yellow)	19 turns, T-37-6 (yellow)
L4	27 turns, T-37-2 (red)	21 turns, T-37-6 (yellow)	20 turns, T-37-6 (yellow)
L5	25 turns, T-37-2 (red)	19 turns, T-37-6 (yellow)	19 turns, T-37-6 (yellow)
Y1	3.5 MHz quartz crystal	7 MHz quartz crystal	10.140 MHz quartz crystal

ARRL0931



Schematic of the QRSS transmitter kit by Hans Summers, GØUPL, showing the oscillator, modulation, power amplifier and output low-pass filter. The power supply is not shown. See **Table 4.A** for component values for 80, 40 and 30 meters.



ARRL0931

* See Table 4.A

CW Character Generator

The `charCode ()` function accepts a character parameter and returns a single byte that represents the CW symbols to be transmitted. The function contains a switch statement to return the correct symbols byte for the input character.

To understand the way in which the sequence of dits and dahs is generated, consider for example the character F.

```
case 'F': return B11100010; // F .-. .
```

The keyer code scans the byte from left to right. The leading 1s are simply ignored, in the search for a 0 to signify that the actual sequence of dits and dahs follows at the next bit position. The dits and dahs are then encoded by 0s and 1s respectively. **Figure 4.2** illustrates the meaning of each of the 8 bits in the encoding byte.

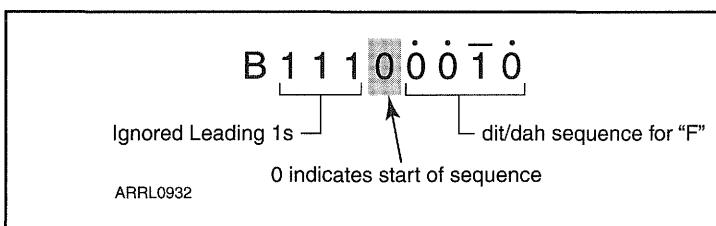


Figure 4.2 — The Morse code representation of a letter, digit, or symbol is encoded in a single byte.

In this way, the code can accommodate the full range of CW characters from 1 to 6 symbols. The code shows just the alphanumeric characters and slant bar (/) that are commonly used in call signs, but other punctuation characters could easily be included.

The `beacon ()` function reads the msg string constant from left to right and sends the characters as CW one by one. Note that the message should contain a space character after the call sign, to obtain a proper spacing between repeated transmissions of the call sign message.

The Sketch

The entire project sketch is available for download from the book resources website, so you do not have to type it in.

The sketch is coded in an efficient manner, to make best use of the memory of the ATtiny45. Below is a discussion highlighting interesting sections.

Change the msg line below to have your call sign, followed by a space:

```
// QRSS Beacon Keyer
// Copyright 2012, Hans Summers G0UPL.

const char msg[] = "G0UPL ";           // Message

// Speeds for: 12wpm, 6wpm, QRSS1, QRSS3, QRSS6, QRSS10, QRSS20, QRSS30
const unsigned int speeds[] = {1, 2, 10, 30, 60, 100, 200, 300};

#define KEY 4
```

The charcode() function below converts a character code to CW the symbol encoding described above:

```
byte charcode(char c) {
    switch (c) {
        case 'a': return b11111001;          // a  ..
        case 'b': return b11101000;          // b  -...
        case 'c': return b11101010;          // c  -.-.
        case 'd': return b11110100;          // d  -..
        case 'e': return b11111100;          // e  .
        case 'f': return b11100010;          // f  ..-.
        case 'g': return b11110110;          // g  --.
        case 'h': return b11100000;          // h  ....
        case 'i': return b11111000;          // i  ..
        case 'j': return b11100111;          // j  ----
        case 'k': return b11110101;          // k  -.-.
        case 'l': return b11100100;          // l  .-..
        case 'm': return b11111011;          // m  --
        case 'n': return b11111010;          // n  -.
        case 'o': return b11110111;          // o  ---
        case 'p': return b11100110;          // p  .---.
        case 'q': return b11101101;          // q  ---.-.
        case 'r': return b11110010;          // r  .-.
        case 's': return b11110000;          // s  ...
        case 't': return b11111101;          // t  -
        case 'u': return b11110001;          // u  ..-
        case 'v': return b11100001;          // v  ...-
        case 'w': return b11110011;          // w  ---.
        case 'x': return b11101001;          // x  ...-
        case 'y': return b11101011;          // y  -.--
        case 'z': return b11101100;          // z  --..-
        case '0': return b11011111;          // 0  -----
        case '1': return b11001111;          // 1  -----
        case '2': return b11000111;          // 2  .---.
        case '3': return b11000011;          // 3  ...--.
        case '4': return b11000001;          // 4  .....-
        case '5': return b11000000;          // 5  .....
        case '6': return b11010000;          // 6  -....
```

```

        case '7': return b11011000;           // 7 --...
        case '8': return b11011100;           // 8 ---..
        case '9': return b11011110;           // 9 ----.
        case ' ': return b00000000;           // space
        case '/': return b11010010;           // / -...
        default: return charcode(' ');
    }
}

```

The `setup()` function is simple, as the sketch uses only a few pins and no libraries:

```

void setup() {
    pinMode(KEY, OUTPUT);                  // Define output pin
    pinMode(0, INPUT);                    // Define pins for input of keying speed
    pinMode(1, INPUT);
    pinMode(2, INPUT);
}

```

The loop uses a `static` variable, which is like a global variable declared outside the function. However, a `static` variable is available only inside the function where it is declared, yet its value persists after the function returns. In such a short program it does not matter much, but in a larger sketch it helps isolate the names of variables from each other.

The ATtiny45 library supports the Arduino `millis()` function, which returns the number of milliseconds since power on. Here, we use the `unsigned long` type because the QRSS keyer could run for a long time, so we need big numbers.

The loop retrieves the time and compares it to a limit time that is set to be 100 ms in the future. Once that time is reached, it calls the `beacon()` function, and resets the `milliNow` time to the next `beacon()` call.

```

void loop() {
    static unsigned long milliLimit;
    unsigned long milliNow;

    milliNow = millis();

    if (milliNow >= milliLimit) {
        milliLimit = milliNow + 100;
        beacon();
    }
}

```

These variables are the state associated with the beacon. The counter is incremented once every 0.1 second, when the `beacon()` function is called, and is used as the clock for dit and dah elements.

```
void beacon() {
    // Counter to generate the bit length, in multiples of 0.1 seconds
    static unsigned int counter;
    // Generates inter-character pause and space
    static byte pause;
    // Index to the message string
    static byte msgIndex = 255;
    // Current character CW symbol code
    static byte character;
    // key down counter - set to 3 for dah, 1 for dit
    static byte key;
    // Indexes the current bit within the character CW symbol code
    static byte symbol;
    // Index (0-7) into the ditspeed array
    static byte ditspeed;
```

The `ditspeed` controls which speed is selected, and it starts off at zero. The value `speeds[ditspeed]` is the number (in 100 ms units) of the length of the basic Morse element, the dit. It initially selects the slowest speed (that is, `speeds[0]`), which is 12 WPM, giving a quick check of the programmed call sign when powered on. On the next round, the `ditspeed` is read from digital input pins 2, 1 and 0, and a QRSS speed is chosen.

The first part of `beacon()` increments the dit length counter, and compares it to the speed setting. Unless the `counter` has reached the currently selected speed for dits, that's all `beacon()` has to do. The transmitter may be key up or key down at this point, but whatever it is, it will remain so for the next 100 ms.

```
    counter++;
    if (counter == speeds[ditspeed]) {
```

If the magic value has been reached, the function continues execution below. Everything in the rest of the sketch is inside this `if`.

First, it resets the dit length counter to zero. If it's currently in an inter-character pause, just decrement the `pause` counter. (The test `!pause` is the same as `pause != 0`.) On a later loop, the `pause` counter will reach 0 and the pause will be over.

If it's not in a pause, then it must be in a key down, so we do the same logic on key down — also with an end-termination test when `key` value reaches 0, so we can insert a pause of 3 elements (countdown 2-1-0 is 3 counts).

If it's currently in key down (not paused), decrement the key down counter. When the key counter and symbol index are zero, generate an inter-character pause:

```
counter = 0;

if (!pause) {
    key--;
    if ((!key) && (!symbol)) pause = 2;
} else {
    pause--;
}
```

When the current symbol is over, the key counter becomes 255, because that is what happens to byte values when they reach -1:

```
if (key == 255) {
```

This section processes the next symbol (dit or dah) within a character. If the symbol counter becomes zero, must now get the next character.

```
if (!symbol) {
    // Increment the message index
    msgIndex++;

    // If the string terminator (zero) is found,
    if (!msg[msgIndex]) {
        // Set the message index back to zero
        // (the beginning of the string)
        msgIndex = 0;
        // and read the dit speed setting from the pins 0-2
        ditspeed = 4 * digitalRead(2) +
                    2 * digitalRead(1) +
                    digitalRead(0);
    }
    // Get the character symbol code for the current
    // message string character
    character = charCode(msg[msgIndex]);
    // Set the symbol counter to the leftmost bit of the symbol
    // code
    symbol = 7;
    // Look for 0 signifying start of coding bits
    while (character & (1<<symbol))
        symbol--;
}
```

Next, just move to the next symbol, either in the same character or in the new one found above.

```
// Decrement symbol index, which moves right
// one bit in the symbol code
symbol--;
```

```
// The space character is a special case,  
// because no key downs occur  
if (character == charCode(' ')) {  
    key = 0;  
} else {  
    // Check the bit pointed to by the symbol index variable  
    if (character & (1<<symbol)) {  
        // a 1 indicates a dah, and a keydown period of 3 dit-lengths  
        key = 3;  
    } else {  
        // a 0 indicates a dit, and a keydown period of 1 dit-lengths  
        key = 1;  
    }  
}  
}  
}
```

Finally, we decide to set the KEY digital pin HIGH or LOW based on whether or not key is 0.

```
// Set the output pin  
if (key)  
    digitalWrite(KEY, HIGH);  
else  
    digitalWrite(KEY, LOW);  
}  
}
```

On the Air

Although you can build this project without holding an Amateur Radio license in the US and many other countries, before putting it on the air you must obtain an appropriate license. In the US, a Technician license from the FCC is sufficient for use on some frequencies, but a General or Amateur Extra license is required for others. Please check the regulations of your country before building and transmitting with this project.

Suggestions

The main techniques in this project — Arduino programming, working with the ATtiny, and interfacing with RF electronics — are great starting points for your own projects. The next chapter, *Multimode Transmitter Shield*, shows one direction: building the transmitter into an Arduino shield and adding more features in the analog and RF domain. You could also take another direction and use the ATtiny to build your own small, inexpensive projects to automate tasks around the shack and in the field. If you are interested in taking the ATtiny further, see the *Time Out* project by Keith Amidon, KJ6PUO, and Peter Amidon, KJ6PUN.

Programming the ATtiny45

Leigh Klotz Jr, WA5ZNU

You could build this project with an Arduino — and in fact a great way to do that would be to build the Multimode Transmitter Shield in the next chapter — but this project is about using the ATtiny series of 8-pin DIP microcontrollers, and so there is a little extra work needed.

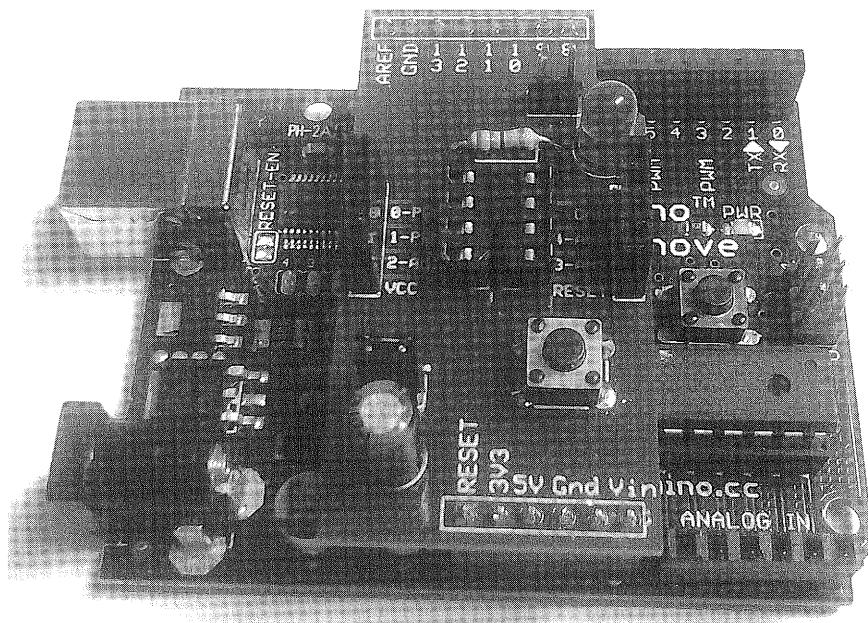
The Arduino IDE supports the concept of “cores,” which are new plug-ins that support different CPU configurations. The ATtiny45 used in this project, and its cousin the ATtiny85 (with double the memory) are supported by at least two different downloadable “cores.” You can then use a dedicated programmer to program your ATtiny, or you can use a technique from the MIT Hi-Lo Tech Lab to program by attaching it to your existing Arduino. *Note: When using an Arduino to program another Atmel microcontroller, installation and setup techniques vary depending on exactly which version of the Arduino IDE you are using. Consult the online resources to find the latest installation instructions.*

You can use the ATtiny cores from the MIT Hi-Lo Tech Lab, or the ones from the Arduino Tiny project. The Arduino Tiny core stands out because it supports the `tone()` library function, which you will find useful in the *Time Out* project later in this

book. You will likely want to read the documentation at the MIT site anyway, as it's so far the clearest on rationale and setup.

Once you've installed a core for the ATtiny in your Arduino IDE, you still need a way to make the Arduino IDE talk to the ATtiny chip to program it. The cheapest way is to use another Arduino, a protoboard and a few wires. For this method, either upgrade to Arduino 1.0.1 or later, or use an older Arduino such as a Duemilanove, because there are some issues with the Uno and the Arduino 1.0 software. You can also buy programming shields to make the task easier. The easiest to use with the ATtiny series was developed by the staff at Instructables.com (see the accompanying photo), but the ones from Adafruit and Evil Mad Science also work, with a few modifications for the smaller chips.

A good starting point is the “Arduino ISP” tutorial page at <http://arduino.cc/en/Tutorial/ArduinoISP>. To prepare, hook up your Arduino to USB and program it with the “ArduinoISP” sketch you can find under the FILE|EXAMPLES menu in the Arduino IDE. Next, insert the ATtiny45 into either a protoboard or the ATtiny programming shield. If you



This ATtiny programming shield from Instructables.com fits atop an Arduino and allows it to program your sketch into an ATtiny MCU.
[Instructables.com, photo]

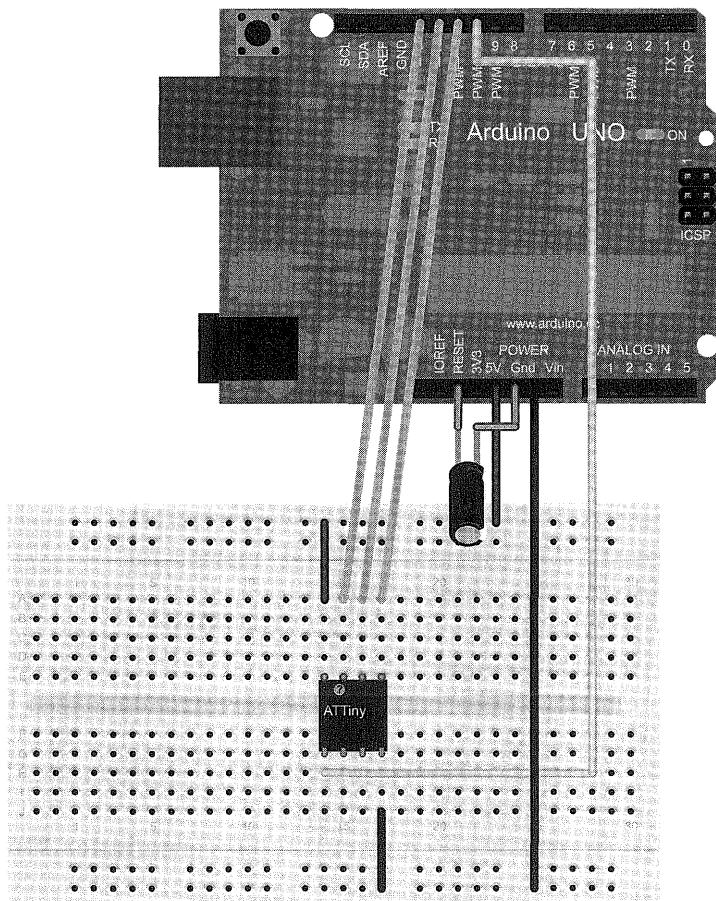
are using one of the programming shields, just plug it in to the Arduino.

If you are using the protoboard as shown in the accompanying illustration, follow the instructions available from <http://hit.media.mit.edu/?p=1706> to wire up your Arduino and ATtiny.

This project is designed for a 1 MHz CPU clock speed, for which the ATtiny45 chip will likely already be set. Change the BOARD menu in the Arduino IDE to the "ATtiny45 1MHz" entry (or a similar one from the core you have installed) and select "Arduino as ISP" from the PROGRAMMER menu. Leave the SERIAL PORT setting as it was for the Arduino when you uploaded the Arduino ISP sketch. You are now ready to upload the QRSS sketch to your ATtiny45. Even though a boot-loader is not used for the ATtiny cores, you can select "Burn Bootloader." After setting up the programmer and core, you want to set the ATtiny

fuses (internal software switches) to switch between using the 1 MHz and 8 MHz internal clocks.

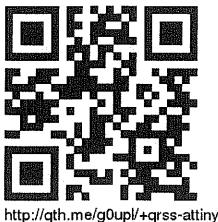
The 1 MHz clock speed is derived from an oscillator internal to the chip, and the exact frequency varies. Although it is possible to use an external crystal with the ATtiny series, that would use up half of the available I/O pins. Instead, Atmel offers an OSCCAL data setting that lets you calibrate the timing for each individual ATtiny. The Arduino Tiny project offers a free program to calculate OSCCAL for you, or you can use a long delay and a stopwatch or WWV and adjust the value by hand, or use the `tone()` function and an accurate frequency counter. For this project, I found that `OSCCAL=0x99` and `OSCCAL=0x98` gave the best results on chip I tested. But of course, you need to test your own chips individually. See the References section at the end of this chapter for the TinyTuner program download link.



ARRL0950

Made with  Fritzing.org

ATtiny wiring graphic from the MIT HLT lab. [courtesy MIT Hi-Lo Tech Lab]



References and Further Reading

- Online references
 - http://qth.me/g0upl/+qrss-attiny
- Project source code
 - http://qth.me/g0upl/+qrss-attiny/code
- Using an Arduino to program another chip
 - http://arduino.cc/en/Tutorial/ArduinoISP
- Arduino Tiny core
 - http://code.google.com/p/arduino-tiny/
- Tiny Tuner clock calibrator
 - http://code.google.com/p/arduino-tiny/downloads/list
- MIT Hi-Lo Tech Lab ATtiny Core
 - http://hlt.media.mit.edu/?p=1695
- Instructables ATtiny programming shield
 - http://www.instructables.com/id/8-Pin-Programming-Shield/
- Adafruit Arduino ISP shield
 - http://www.adafruit.com/products/462
 - But you will need to adapt it for the small size of the 8-pin PDIP:
http://www.instructables.com/id/Hacking-an-Arduino-ISP-Shield-for-AtTiny45-AtTin/
- SparkFun AVR-ISP shield
 - http://www.sparkfun.com/products/11168

QRSS

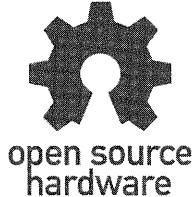
- Author's website, containing considerable QRSS-related content:
 - http://www.hanssummers.com/
- QRSS transmitter kit:
 - http://www.hanssummers.com/qrsskit.html
- Talks by the author
 - http://www.hanssummers.com/talks.html
- WB3ANQ/VK6DI (now VK2DDI) microwatts
 - http://www.wb3anq.com/
 - http://www.users.on.net/~davroz/vk6di/
- QRSS Knights mailing list
 - (announce operation to ensure receiving stations are looking for your transmission):
 - http://mail.cnts.be/mailman/listinfo/knightsqrss_cnts.be
- *Argo* software (receive decoding):
 - http://www.sdradio.eu/weaksignals/argo/index.html
- *Spectran* software (receive decoding):
 - http://www.sdradio.eu/weaksignals/spectran.html
- *Spectrogram* software (receive decoding):
 - http://www.brothersoft.com/spectrogram-267027.html

- *Spectrum Lab* software (receive decoding):
<http://www.qsl.net/dl4yhf/spectra1.html>
- QRSS grabbers:
<http://digilander.libero.it/i2ndt/grabber/grabber-compendium.htm>

RF and Electronics Design

- LEDs as varactor diodes:
<http://www.hanssummers.com/varicap.html>

License



- The Arduino sketch in this project is distributed under the terms of the MIT License
<http://www.opensource.org/licenses/mit-license>
- The schematics in this project are licensed under the CC-BY-SA 3.0 license:
<http://creativecommons.org/licenses/by-sa/3.0/>

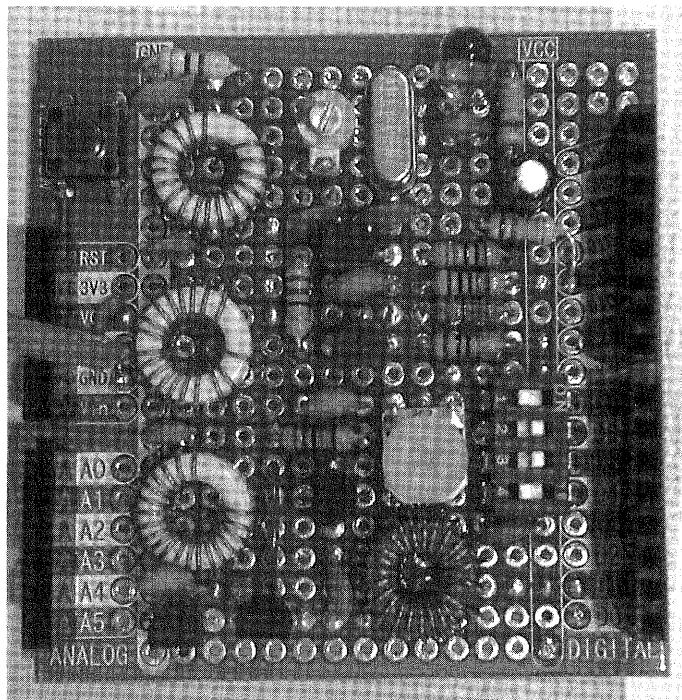
About the Author

Hans Summers, GØUPL, is enthusiastic about his love and enjoyment of radio, electronics, and computing and hopes to inspire you to build something too.



Multimode Transmitter Shield

Hans Summers, GØUPL



This 10.140 MHz multimode transmitter shield, built on an Arduino protoboard, is capable of generating QRPP signals in a variety of weak signal modes. [Hans Summers, GØUPL, photo]

The very slow, computer-decoded, weak-signal, low-bandwidth modes are collectively known as the “QRSS modes.” There are several different modes within this collection, each having different merits. The previous chapter gave the general principles of QRSS and showed how to transmit, receive and decode the most common mode. The project in this chapter describes a complete transmitter shield with support for more types of modulation. The shield delivers up to 100 mW RF output from the Arduino. A new sketch supports QRSS, FSK/CW and DFCW modes as explained in the following sections of this chapter.

The layout is not critical, so the circuit can be built on a full-grid protoshield (prototyping shield), but shields with central bus rails or DIP pad connections are not suitable. A kit containing a PC board and all components is available from the author. See the References section at the end of this chapter.

Simple Patterns

The simplest slow-signal mode is undoubtedly just some form of frequency modulation to produce a repetitive pattern such as the one shown in **Figure 5.1**.

Such a pattern can be produced with no microcontroller at all, and hence lends itself well to home construction of very simple beacon transmitters using just a handful of junkbox components. It has the disadvantage of not providing any identification, but if the station operation is announced on a QRSS forum and the signal shape is unique, this can be adequate — especially for ISM band use.

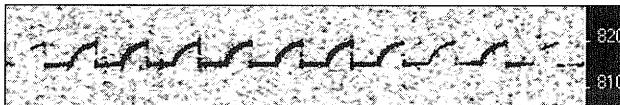


Figure 5.1 — The simplest slow-signal mode is undoubtedly just some form of frequency modulation to produce a repetitive pattern. [Hans Summers, G0UPL]

Plain QRSS

The original QRSS mode is just on/off keyed Morse code, but sent very slowly — typically with dit lengths from 3 seconds to 120 seconds in extreme cases. The longer lengths are used at LF where antenna efficiency is low.

As shown in **Figure 5.2**, the message is quite simple to decode by eye, since it intuitively matches what we are used to hearing. It also has the advantage of being the narrowest bandwidth of all the modes: the actual bandwidth is well below 1 Hz, depending on the speed of sending. Therefore, many stations can coexist happily in a small slice of spectrum.

A disadvantage of this mode is that usually, interfering carriers also appear as a continuous frequency line on the display. If these carriers are weak and at considerable distance, then fading can cause them to look like on/off keyed QRSS. Even real QRSS messages can fade in and out, which can make a Morse dah look like two dits, for example. So the mode can suffer under weak signal, interference, or DX conditions. In practice, it can also be difficult to eliminate “chirp” (oscillator frequency pulling) when the transmitter is on/off keyed.

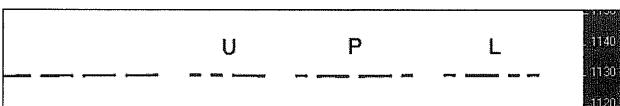


Figure 5.2 — The last few letters of a call sign, in plain QRSS modulation. [Hans Summers, G0UPL]

Dual-Frequency CW (DFCW)

Dual-frequency CW (DFCW) represents Morse dits and dahs by equal length periods of RF transmission (key down). Dahs are shifted in frequency to be a few Hz higher than dits. A gap $\frac{1}{3}$ the length of a dit character inserted between each symbol has been found to give optimum readability. The resulting signal is shown in **Figure 5.3**.

DFCW occupies more bandwidth than QRSS because of the two separated frequencies, but it retains the signal-to-noise ratio of QRSS at each of the two frequencies. A distinct advantage of this encoding method over conventional Morse is that the transmission time is reduced considerably: a dah takes no more time to send than a dit. Unfortunately DFCW is somewhat less intuitive to read. In weak signal conditions it can be harder for the human eye to pick out and decode the DFCW symbols.

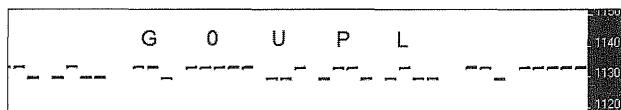


Figure 5.3 — Dual-frequency CW (DFCW) represents Morse dits and dahs by equal length periods of RF transmission (key down). Dahs are shifted in frequency to be a few Hz higher than dits. A $\frac{1}{3}$ dit-length gap inserted between each symbol has been found to give optimum readability.
[Hans Summers, G0UPL]

Frequency Shift Keyed CW (FSK/CW)

As described in the previous chapter, frequency shift keyed CW (FSK/CW) employs dits and dahs with their traditional duration as in normal slow Morse, but they are both shifted upward by a few Hz. The transmitter is continuously on. The key down (*mark*) state is therefore shifted a few Hz upward, whereas the key up (*space*) state is a baseline transmission. See **Figure 5.4** for an example.

Several advantages make FSK/CW the most popular of the simple QRSS modes in use today. Because the transmitter is continuously on, it avoids problems of chirp (frequency pulling) in the oscillator. Provision of the reference baseline, as well as the up-shifted key down dits and dahs, helps to clearly identify the signal in weak-signal or DX conditions. Readability is usually very good, and decoding the signal is as easy and as intuitive as plain QRSS.

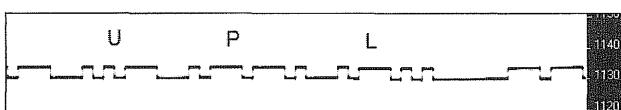


Figure 5.4 — Frequency shift keyed CW (FSK/CW) employs dits and dahs with their traditional duration as in normal slow Morse, but they are both shifted upward by a few Hz. The transmitter is continuously on. The mark state is a few Hz upward shift, and the space state is a baseline transmission.
[Hans Summers, G0UPL]

Slow-Hellschreiber

Hellschreiber (literally, “light writing”) is a fax-like mode developed in Germany around the time of World War II, also using an on/off keyed carrier. The Slow-Hellschreiber variant is a frequency-shifted mode, that produces an actual text image on the receiving station’s spectrum display as shown in **Figure 5.5**.

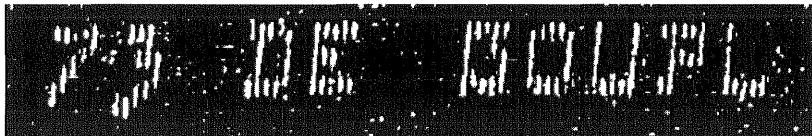


Figure 5.5 — Hellschreiber is a fax-like mode developed in Germany around the time of World War II. Slow-Hellschreiber is a frequency-shifted mode, producing an actual text image on the receiving station’s spectrum display. [Hans Summers, G0UPL]

The transmitter is on/off keyed *and* the frequency shifted slightly to generate the correct pattern at the receiving station. The pixels of each character are scanned in vertical columns, sent as shifted frequencies. A typical pixel time of the order of 1 second may be used in QRSS Slow-Hellschreiber, and with perhaps 0.5 to 1 Hz frequency shift per pixel so that the “height” of the message is somewhere in the range 5 to 10 Hz. Although Hellschreiber is not supported by the sketch in this chapter, it could be implemented easily for this shield.

Digital Modes

A variety of digital slow-speed modes are in use, but none are (yet) supported by this shield. Weak Signal Propagation Reporter (WSPR) has become extremely popular in recent years. The transmission is encoded with an advanced error-correcting algorithm and contains a standard message consisting of call sign, locator and transmitter power. Reception is by means of free PC software, and the software automatically uploads reports to a central reporting database.

Shield Hardware

The entire transmitter is built on an Arduino prototype shield. The circuit (**Figure 5.6**) is changed slightly from the previous chapter, but still incorporates the same output filter section. The circuit diagram shows a 30 meter version, but component values can be scaled for other bands as shown in the QRSS project in the preceding chapter.

Q1 operates as a Colpitts crystal oscillator, whose frequency is set by the crystal (Y1) and can be adjusted precisely by trimmer capacitor C9. The FSK is applied using a reverse-connected 5 mm red LED that behaves as a varactor diode (it does not light). The LED varactor diode is coupled to the crystal circuit via a 3 pF capacitor. The oscillator signal is buffered by Q2.

The voltage across the reverse-biased LED changes its capacitance, causing the crystal frequency to be shifted slightly (see references). FSK shift is thus

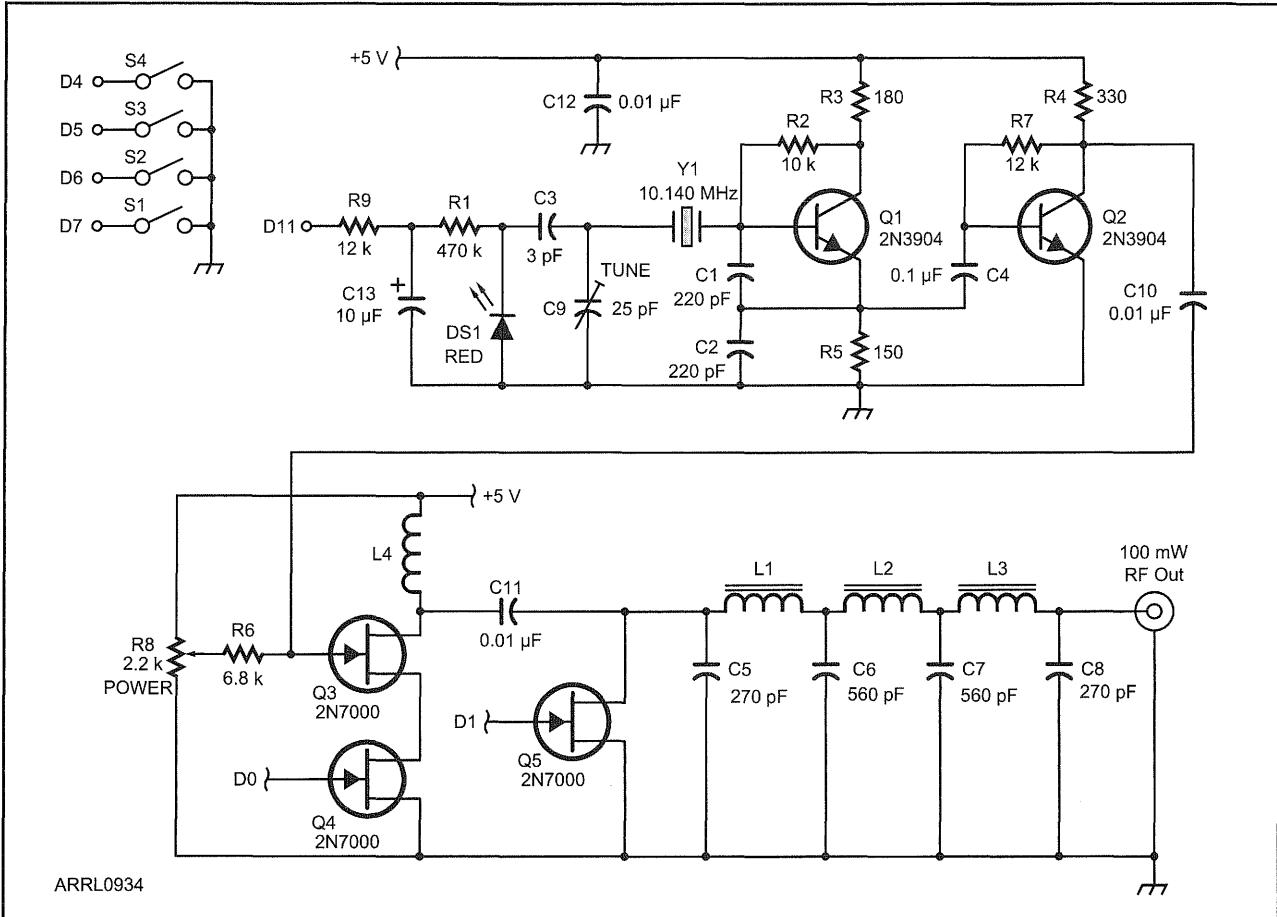


Figure 5.6 — Multimode transmitter shield schematic showing the oscillator, modulation, power amplifier and output low-pass filter. Component values for 30 meters are shown, but the design may be scaled for 80 and 40 meters as in the project described in the previous chapter. The Arduino and power supply are not shown. D0, D1, D4-D7 and D11 refer to Arduino pin numbers for interconnections (see text).

L1, L3 — 19 turns, T-37-6 (yellow)

L2 — 20 turns, T-37-6 (yellow)

L4 — 25 turns, FT-37-43 (black)

controlled by the software. In the previous project, the voltage was a digital hi/low signal, but in this project, the voltage is variable across the 0-5 V range, and is generated by a PWM (pulse-width modulation) output on pin D11 of the Arduino, using the `analogWrite()` function with R9 and C13 as an integrator.

Q3 is a power amplifier FET. R8 adjusts the power level, and should be initially set with the wiper at the ground end, to avoid burning out the 2N7000 — then increased slowly until around 100 mW power output is generated.

The standard 7-element low pass filter removes the transmitter harmonics. The circuit diagram shows a 30 meter version, but component values can be scaled for other bands.

To enable true on/off keying, a provision is made to switch the power amplifier transistor using another 2N7000 FET, Q4. This transistor is keyed by the D0 pin of the Arduino. Unfortunately, even when switched off, some power

still leaks through to the output. Therefore yet another 2N7000 FET, Q5, shorts any residual RF to ground. This then provides excellent total on/off keying.

The Arduino sketch reads the four-way DIP switch (D1 to D4) to select the mode and keying speed.

Multimode Sketch

The code pattern generation in this sketch is based on the same keyer code principles introduced in the preceding chapter. Certain enhancements are added to provide the selection of modes. Supported modes are FSK/CW, QRSS and DFCW.

In this multimode sketch, on-off keying is also required, and is provided by the `setRF()` function which takes a Boolean parameter specifying whether or not RF is to be switched on. The ATT (attenuator) signal, which controls the attenuator FET Q5, is always the opposite of the KEY (key down) signal that controls Q4.

The full sketch is available for download in the book resources site, so you don't have to type it in. See the References section.

The Sketch

Put your call sign here, in capital letters. *Remember to put a space at the end!*

```
const char msg[] = "CALLSIGN ";
```

The sketch supports the selection of four speeds, defined in the `const speeds[]` array. The speeds are referenced to 12 WPM Morse (value 1); for QRSS dit-lengths, multiply the desired dit length (in seconds) by 10. For example, 3 second dits use a value of 30.

The speeds values are for 12 WPM, QRSS3, QRSS6 and QRSS10.

```
const unsigned int speeds[] = {1, 30, 60, 100};
```

Keying is on pin 0, and the attenuator is on pin 1 using inverted keying. The Arduino LED output is on pin 13. FSK is generated by the PWM (analog) output on pin 11:

```
// Pins
#define KEY 0
#define ATT 1
#define LED 13
#define FSK 11
```

The four DIP switches (S1-S4, connected to pins 4-7) are read once per millisecond. S1 and S2 produce a value from 0 to 3 which specifies the mode to use. S3 and S4 select one of the four speeds as determined by the contents of the `speeds[]` array in the sketch.

```
// Switch pins
#define SWITCH1 7
#define SWITCH2 6
#define SWITCH3 5
#define SWITCH4 4
```

Mode NONE means the power amplifier is disabled. QRSS mode is ordinary CW at the specified speed.

```
#define MODE_NONE 0
#define MODE_QRSS 1
#define MODE_FSKCW 2
#define MODE_DFCW 3
```

The FSK_LOW and FSK_HIGH specify the FSK values between 0 and 255 for the low and high (shifted) frequency. Choose values to provide about 4 Hz of shift. If the shift is too wide, space the values closer together to narrow it, or increase the difference between the FSK_LOW and FSK_HIGH values to create a wider FSK shift.

```
#define FSK_HIGH 160
#define FSK_LOW 100
```

The setup() function enables the internal pull ups on the switch input pins (4-7), since the inputs are switched to low (logic 0) when closed.

```
void setup()
{
    // Define Keying, attenuator, LED and FSK pins as outputs
    pinMode(KEY, OUTPUT);
    pinMode(ATT, OUTPUT);
    pinMode(LED, OUTPUT);
    pinMode(FSK, OUTPUT);

    // Define Switch pins as inputs
    pinMode(SWITCH1, INPUT);
    pinMode(SWITCH2, INPUT);
    pinMode(SWITCH3, INPUT);
    pinMode(SWITCH4, INPUT);

    // Enable internal pull-ups on switch inputs
    digitalWrite(SWITCH1, true);
    digitalWrite(SWITCH2, true);
    digitalWrite(SWITCH3, true);
    digitalWrite(SWITCH4, true);
}
```

Function `loop()` calls the `beacon()` function every time the `millis()` value (number of milliseconds the system has been running) changes — 1000 times per second, 100 times faster than in the previous chapter sketch.

```
void loop()
{
    // Static variable stores previous millisecond count
    static unsigned long milliPrev;
    unsigned long milliNow;

    // Get millisecond counter value
    milliNow = millis();

    // If one millisecond has elapsed, call the beacon() function
    if (milliNow != milliPrev) {
        milliPrev = milliNow;
        beacon();
    }
}
```

Character encoding patterns are returned by the `charCode()`, which is unmodified from the QRSS sketch.

```
// function returns the encoded CW pattern for the character passed in
byte charCode(char c) {
    // unmodified from the QRSS sketch ...
}
```

The `setFSK()` function takes a Boolean parameter specifying whether or not shift is to be applied, and outputs the value of `FSK_LOW` or `FSK_HIGH` accordingly as an analog output on pin 11.

```
// Sets the FSK value (shift of the RF carrier)
void setFSK(boolean high) {
    if (high)
        analogWrite(FSK, FSK_HIGH);
    else
        analogWrite(FSK, FSK_LOW);
}
```

```
// Enables the Power Amplifier and disables the attenuator
void setRF(boolean on) {
    digitalWrite(KEY, on);
    digitalWrite(ATT, !on);
}
```

The `beacon()` function is somewhat modified compared to the last chapter. The basic code generation is the same, but enhancements are required

in order to support the new QRSS and DFCW modes as well as the original FSK/CW mode.

The first change concerns the generation of DFCW. In DFCW, the dits and dahs are the same length; however a $\frac{1}{3}$ dit-length pause is inserted in between dit/dah key downs. In order to generate this timing properly, each DFCW symbol is made 3 dit-lengths long, and the pause between symbols always 1 dit-length. So that the symbol length is the same as specified by the keyer speed setting, while maintaining the desired 3:1 ratio, the divisor is changed from 100 to 33, to speed up by a factor of 3. When generating a space between words (space character), the pause variable is set to 3 rather than 2, to generate a pause of 4 dit lengths.

The rest of the code pattern generation is as in the previous chapter, until near the end of the function, where the behavior must be adapted to the keying mode in use. The differences are in how the `setRF()` and `setFSK()` functions are called, to generate the correct mode (QRSS, FSK/CW or DFCW). Note that when switches 1 and 2 are both closed, the RF output of the transmitter is switched off (a NONE mode).

```
// This function is called 1000 times per second
void beacon() {
    // Counter to get to divide by 100 to get 10Hz
    static byte timerCounter;
    // Counter to time the length of each dit
    static int ditCounter;
    // Generates the pause between characters
    static byte pause;
    // Index into the message
    static byte msgIndex = 255;
    // Bit pattern for the character being sent
    static byte character;
    // State of the key
    static byte key;
    // Which bit of the bit pattern is being sent
    static byte charBit;
    // Index into the speeds array - controls the dit speed
    static byte ditSpeed;
    // What mode is being sent (None, QRSS, FSK/CW or DFCW)
    static byte mode;
    // True when a dah is being sent
    static boolean dah;
    // Divide 1kHz by 100 normally, but by 33 when sending DFCW)
    byte divisor;

    // Read the switches, to set the mode and speed
    mode = digitalRead(SWITCH1) + 2 * digitalRead(SWITCH2);
    ditSpeed = digitalRead(SWITCH3) + 2 * digitalRead(SWITCH4);

    // Divisor is 33 for DFCW, to get the correct timing
```

```

if (mode == MODE_DFCW) {
    // (inter-symbol gap is 1/3 of a dit)
    divisor = 33;
} else {
    divisor = 100;
}

// 1000Hz at this point
timerCounter++;

// Divides by 100 (or 33 for DFCW)
if (timerCounter == divisor) {
    // 10 Hz here (30Hz for DFCW)
    timerCounter = 0;

// Generates the correct dit-length
ditCounter++;
if (ditCounter >= speeds[ditSpeed]) {
    ditCounter = 0;

    if (!pause) {
        // Pause is set to 2 after the last symbol
        // of the character has been sent, generating the correct
        // pause between characters (3 dits)
        key--;
        if ((!key) && (!charBit)) {
            if (mode == MODE_DFCW) {
                // DFCW needs an extra delay to make it 4/3 dit-length
                pause = 3;
            } else {
                pause = 2;
            }
        }
    } else {
        pause--;
    }
}

// Key becomes 255 when the current symbol (dit/dah) has been sent
if (key == 255) {
    // If the last symbol of the character has been sent,
    // get the next character
    if (!charBit) {
        // Increment the message character index
        msgIndex++;
        // Reset to the start of the message when end reached
        if (!msg[msgIndex]) msgIndex = 0;
        // Get the encoded bit pattern for the Morse character
        character = charCode(msg[msgIndex]);
    }
}

```

```

// Start at the 7th (leftmost) bit of the bit pattern
charBit = 7;
// Look for 0 signifying start of coding bits
while (character & (1<<charBit)) {
    charBit--;
}
}

// Move to the next rightmost bit of the pattern
charBit--;

// Special case for the space character
if (character == charCode(' ')) {
    key = 0;
    dah = false;
} else {
    // Get the state of the current bit in the pattern
    key = character & (1<<charBit);

    if (key) {
        // If it's a 1, set this to a dah
        key = 3;
        dah = true;
    } else {
        // otherwise it's a dit
        // Special case for DFCW - dit's and dah's are both
        if (mode == MODE_DFCW) {
            // the same length.
            key = 3;
        } else {
            key = 1;
        }
        dah = false;
    }
}
}

if (!key) {
    dah = false;
}

if (mode == MODE_FSKCW) {
    // in FSK/CW mode, the RF output is always ON
    setRF(true);
    // and the FSK depends on the key state
    setFSK(key);
}

```

```

    } else if (mode == MODE_QRSS) {
        // in QRSS mode, the RF output is keyed
        setRF(key);
        // and the FSK is always off
        setFSK(false);
    } else if (mode == MODE_DFCW) {
        // in DFCW mode, the RF output is keyed ON during dit or dah
        setRF(key);
        // and the FSK depends on the key state
        setFSK(dah);
    } else {
        setRF(false);
    }

    // Show keying on the Arduino LED
    digitalWrite(LED, key);
}
}
}

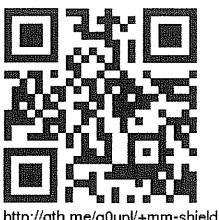
```

On the Air

Although you can build this project without holding an Amateur Radio license in the US and many other countries, before putting it on the air you must obtain an appropriate license. In the US, a Technician license from the FCC is sufficient for use on some frequencies, but a General or Amateur Extra license is required for others. Please check the regulations of your country before building and transmitting with this project.

Further Experimentation

This chapter describes a multimode transmitter shield and accompanying sketch to produce QRSS, DFCW or FSK/CW modes. However it doesn't need to stop there. Since the transmitter can be keyed on or off, or shifted quite accurately at will, this project is capable of producing patterns such as sine waves or other wave shapes at the receiving station. It could be used with Slow-Hellschreiber or WSPR (Weak Signal Propagation Network) signals.



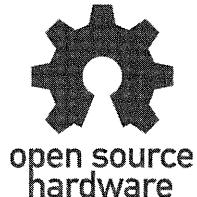
<http://qth.me/g0upl/+mm-shield>

References and Further Reading

- Online references
<http://qth.me/g0upl/+mm-shield>
- Source code for this project
<http://qth.me/g0upl/+mm-shield/code>
- Using LEDs as varactor diodes
<http://www.hanssummers.com/varicap.html>
- Author's website, containing considerable QRSS-related content
<http://www.hanssummers.com>

- Slow-Hellschreiber information
<http://www.hanssummers.com/qrss/qrssqrv2.html>
- WSPR
<http://wsprnet.org/drupal/>
- Kit of PCB and components for this project
<http://www.hanssummers.com/qrssarduino>
- Prototyping Shield
 For this project, a shield with plain matrix of holes is better one with a DIP prototyping area.
<http://www.freetronics.com/products/protoshield-basic>
<http://www.sparkfun.com/products/7914>

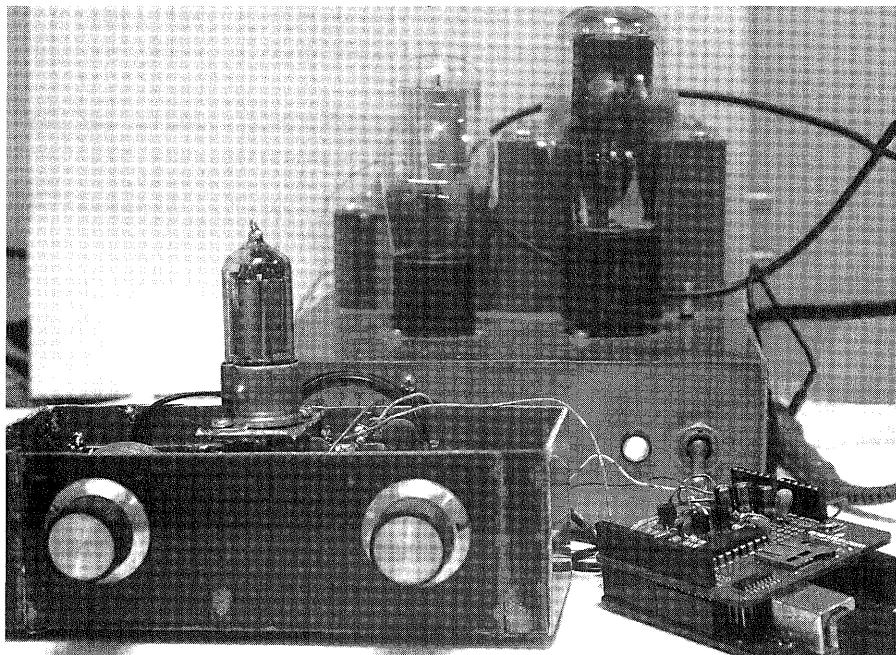
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Thermic: A High Voltage, High Frequency, and High Temperature Data Logger

Hans Summers, G0UPL



Here's an interesting mix of old and new technologies. The Arduino and some simple circuitry built on a SparkFun microSD card prototyping shield are used to automate measurement and logging of the operating characteristics of a vacuum tube oscillator over time. [Hans Summers, G0UPL, photo]

The *Timber* APRS Data Logger described in Chapter 2 by Michael Pechner, NE6RD, shows how to use the SparkFun SD card shield to log digital data from the Argent Data Radio Shield. In Chapter 3, Leigh Klotz, WA5ZNU, adapted the Timber project to use the Adafruit Logger Shield, which sports an onboard real time clock chip. If you go this route, using the Arduino as a digital and analog sensor data logger is not difficult. However, I had a need to log frequency as well, and frequency counting using the Arduino presents several challenges. This project shows methods to overcome these problems, and the techniques are also useful if you want to build a general purpose frequency counter.

The Arduino sketch language is really just a subset of C/C++ with some library utility functions included, packaged up in a convenient and easy-to-use way. It is ideal for first-time programmers, and powerful enough for experienced veterans. It is important, however, to realize that the Arduino environment lets you use *all* the facilities of the C/C++ languages, as well as giving you access to all the registers, timers and peripherals in the Atmel ATmega CPU. This project makes direct use of timers in the ATmega328 processor on the Arduino Uno board, using interrupt service routines. Interested readers may discover the full power of the processor by reading the relevant Atmel datasheets.

Part 1 of this project describes the frequency counter and the logging sketch, because there is a significant amount of interaction between the hardware and the Arduino sketch for the frequency counter. Part 2 adds the temperature and voltage measurement, and Part 3 shows how I used this shield and sketch combination to help solve a design problem I had in homebrewing a stable tube-type high frequency VFO (variable frequency oscillator).

Part 1: Measuring Frequency with the Arduino

The first problem to face the aspiring Arduino frequency counter builder is the accuracy of the Arduino system clock. On several models, including the popular Uno, the system clock is a 16 MHz ceramic resonator, not a quartz crystal. While this is fine for most purposes, ceramic resonators are less accurately specified and have inferior temperature characteristics: their frequency drifts more with temperature change than does a crystal. For frequency counting applications, the lower accuracy specification of the ceramic resonator would limit the measurement accuracy.

One way around this problem is to install a 16 MHz crystal and the associated pair of capacitors, and some Arduino boards seem to provide space for this on the board. However, on the assumption that many readers would prefer to not mutilate their Arduino board, the following solution was developed for this project.

A single-transistor oscillator is used with a commonly available (and cheap) 32.768 kHz watch crystal. This crystal oscillator output signal is fed to the Arduino digital pin 4, which can also be used as the input to the 8-bit Timer0 of the ATmega processor. The timer counts from 0 to 255 then repeats, therefore having the effect of dividing the incoming 32.768 kHz oscillator by 256. An interrupt service routine is triggered by this timer, which is called 128 times per second. This function contains a counter that is used to gate the input frequency, allowing frequency counting for a period of precisely 1 second.

Maximum Frequency Limitation

An unfortunate design fact of the Atmel AVR processor family is that the timer input pins are synchronous — that means they are gated internally by the system clock. The maximum frequency that may be counted by the AVR timers is limited to 50% of the system clock — in a perfect world. In practice, the usual limit is considered to be 40% of the system clock. In the case of the Arduino and its 16 MHz system clock, this would limit the maximum

frequency of the counter to 6.4 MHz. The AVR's main competitor, the Microchip PIC family, does not suffer from this drawback and is therefore more easily made into a frequency counter. Both families have their advantages and disadvantages.

To deal with this issue, an external counter IC is added ahead of the Arduino processor. The 74HC4040 is a 12-stage binary counter, with a maximum input frequency of around 90 MHz. The 74AC4040 is a higher performance version that is suitable for even higher frequencies.

The 10th stage output of the 74HC4040 is used, providing a division ratio of 1024, and feeding into the Arduino's D5 pin, which is also the AVR's Timer1 input. Timer1 is a 16-bit timer, with a maximum value of 65,535. This means that the maximum frequency this project is able to measure is just over 67 MHz. Above this, Timer1 will overflow, a situation that the sketch provided here does not handle. If higher frequencies are required, this could be accommodated either by handling the overflow in the sketch, or by using the 11th or 12th output of the 74HC4040 (divide by 2048 or 4096) and modifying the sketch accordingly.

Ordinarily one might imagine that addition of an external divide-by-1024 prescaler would limit the resolution of the counted frequency to 1024 Hz. However a method is provided here to read the value of the external counter, thereby obtaining the entire frequency count to a resolution of 1 Hz. It is not necessary to read all the stage outputs of the 74HC4040 to accomplish this. Instead, the Arduino need only supply synthetic clock pulses, counting how many it needs to insert in order to cause the 10th stage output to change state. This provides the missing data to determine the accurate frequency count.

A whole measurement cycle takes 2 seconds and consists of the stages illustrated in **Figure 6.1**. First, for 1 second, the count gate is opened, allowing the 74HC4040 and the AVR's Timer1 to count the incoming signal frequency. At the end of 1 second, the gate is closed, halting the count. A function is then triggered, which reads the count in the 74HC4040 by clocking it until its divide-by-1024 output changes state. This is then added to the Timer1 count, to produce the final frequency value. Next, the six analog inputs are read in, just like in the SD library example sketch. When this is complete, the timestamped record is written to the SD card file. These three phases (74HC4040 read, analog read, write to SD card) are not drawn to scale in the diagram — they in

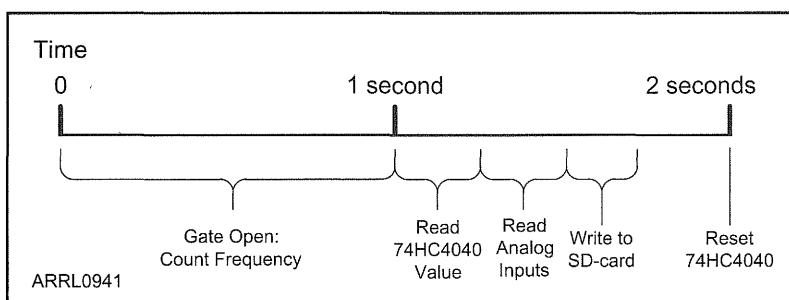


Figure 6.1 — A complete frequency measurement cycle takes two seconds.

fact occur very quickly. The final step is to reset the 74HC4040 counter, ready for the next cycle.

Output File

The sketch creates a CSV (comma separated value) on the SD card, with one measurement record every 2 seconds. The file name is DATA`nnnn`.TXT where `nnnn` is a number starting from 0000. When the Arduino reset occurs (at switch-on or subsequently), the program first checks to find the next sequentially available file number, and then creates that file for writing into. The following example shows a fragment of an output file:

```
00:00:00,6332240,156,155,0,298,0,155
00:00:02,6332313,155,155,0,298,0,155
00:00:04,6332323,155,154,0,298,0,154
00:00:06,6332338,156,155,0,299,0,155
00:00:08,6332490,155,156,0,299,0,155
00:00:10,6332562,156,155,0,298,0,155
00:00:12,6332628,156,155,0,299,0,155
```

The file may be easily imported into Microsoft *Excel*, OpenOffice.org *Calc*, or *GnuPlot*, for charting or other analysis.

Frequency Counter and SD Logger Shield

SD card shields are available from several producers, including SparkFun. These usually include an SD socket and level-shifting circuitry (SD cards operate at 3.3 V), as well as a prototyping area. The latter may be used for constructing the frequency counter circuit consisting of the 74HC4040, input buffer and the 32.768 kHz timebase oscillator as discussed in this section.

Additionally there will be space for components to scale the analog voltage inputs if necessary in the intended application. **Figure 6.2** shows the author's

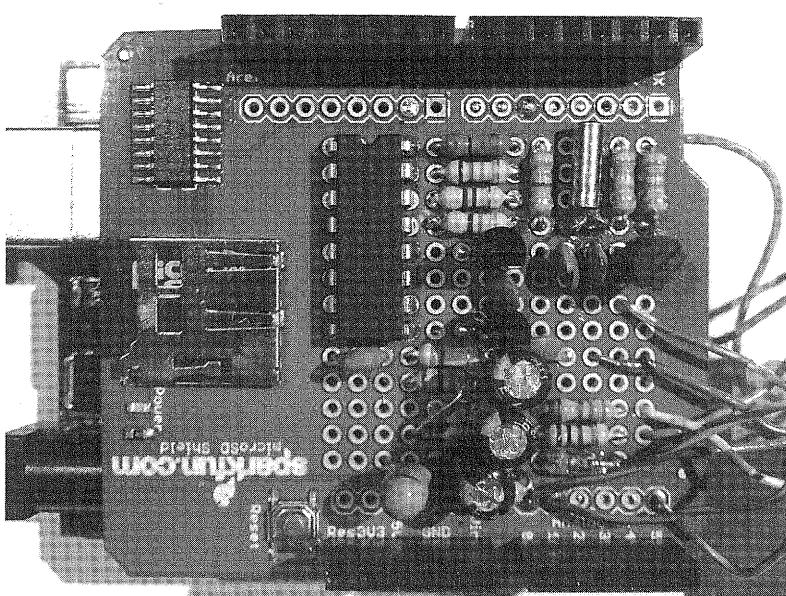


Figure 6.2 —
The author's
prototype
frequency,
voltage and
temperature
data logger, built
on a SparkFun
SD card shield.
[Hans Summers,
G0UPL, photo]

prototype, built on a SparkFun microSD card shield. Note that the lower part of the board is used for scaling analog inputs, since it was used for measuring high voltages.

The circuit diagram for the shield is shown in **Figure 6.3**. The 32.768 kHz clock crystal oscillator is a common design and provides a suitable signal for driving the Arduino's D4 input.

Another challenging part of any homebrew frequency counter project is always the input buffer. Some means must be provided to buffer a low-amplitude sine wave input and convert it to a 5 V TTL level square wave for counting. The two-transistor circuit shown (Q2, Q3) has been found to work well at low-mid HF frequencies, but for higher frequencies may need better transistors or other modifications.

Gating of the incoming signal waveform is accomplished by the Arduino pin D3 connection to the final transistor buffer amplifier stage. When the D3 signal is high (5 V), the buffer stage transfers the signal; when D3 is low (0 V), the signal is stopped.

The Arduino pin D7 is connected directly to the 74HC4040 counter input. During the frequency count phase, this pin is defined as an input and has no effect. When reading the 74HC4040 count value, pulses are supplied to pin D7 which increment the 74HC4040 counter value until the Q9 pin changes state. This pin is the divide-by-1024 output and clocks the processor's Timer1 input via Arduino pin 5.

The power consumption of the circuit is very low and easily supplied by the Arduino board itself.

Serial Monitor

A really nice feature of the Arduino environment is that a SERIAL MONITOR window is provided which may be used by your sketch as an activity or debug log. This is an invaluable debugging tool! The tool may be started by choosing

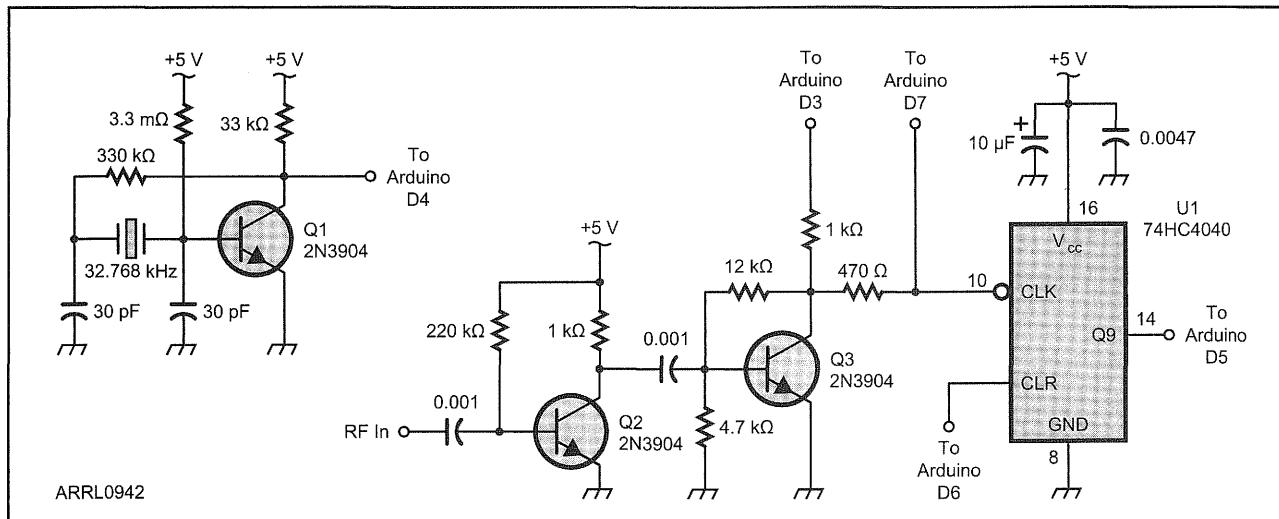


Figure 6.3 — Schematic diagram of the frequency counter. D3 to D7 are connections to the Arduino's digital pins. See text for discussion of circuit operation.

the SERIAL MONITOR menu item under the TOOLS menu. When the SERIAL MONITOR window is opened, the Arduino board is reset (the program restarts). The sketch may write to the SERIAL MONITOR window using the Serial.print() or Serial.println() functions.

In this project, every record written to the SD card is also echoed to the SERIAL MONITOR window. The SERIAL MONITOR window therefore contains the exact same contents as the file written to the SD card, as it is written. This provides a very useful indication that all is well with the measured frequency and analog values, in real time as the measurements are made. The SERIAL MONITOR does not have to be used, but it is available if required.

The Sketch

The measurement interval is 2 seconds but may be altered to a higher number, which must be a multiple of 2 seconds, by amending the #define INTERVAL:

```
// Frequency counting data logger
// Copyright 2012, Hans Summers G0UPL

#include <stdio.h>
#include <SD.h>

// Measurement interval, must be a multiple of 2 seconds
#define INTERVAL 2
```

Remember to #define the CHIP_SELECT pin number to the value appropriate to the SD card shield being used. The SparkFun shield uses pin 8 for the SD card chip select, but some other shields use pin 10:

```
// Pin that connects to the buffer amp to disable (gate) it
#define COUNTER_GATE 3
// Pin to the 74HC4040 counter clock
#define COUNTER_CLOCK 7
// Pin to reset the 74HC4040 counter
#define COUNTER_CLEAR 6
// Pin from the 74HC4040 Q9 output (divide-by-1024)
#define COUNTER_Q9 5

// SD-card Chip Select Pin (8 for the Sparkfun shield)
#define CHIP_SELECT 8
```

The strange choice of starting time 23:59:58 in the initialization of the hours, minutes, seconds variable is chosen merely to ensure that the first record written into the file is given a timestamp of 00:00:00:

```
volatile boolean readCounter;
char filename[13];

volatile byte hours = 23;
volatile byte minutes = 59;
volatile byte seconds = 58;
```

The `setup()` function provides for various initializations such as the Serial port and pin modes:

```
// Sets up the SD-card, and finds the next available file name.
// File names are always DATAnnnn.txt where nnnn is a 4-digit
// number starting from 0000.
void setup() {
    int counter = 0;

    // Initialise serial log interface
    Serial.begin(9600);

    // make sure that the default chip select pin is set to
    // output, even if you don't use it - the SD library needs this
    pinMode(10, OUTPUT);

    // Set the counter gate pin as output
    pinMode(COUNTER_GATE, OUTPUT);
    // Set counter gate to HIGH (counting is allowed)
    digitalWrite(COUNTER_GATE, HIGH);

    // Set counter clear pin to OUTPUT
    pinMode(COUNTER_CLEAR, OUTPUT);
    // and set it to LOW
    digitalWrite(COUNTER_CLEAR, LOW);
```

The while loop after initialization of the SD library is used to search for the next available filename of the form DATAnnnn.TXT, where nnnn starts from 0000 and increments each time the Arduino is powered up or reset:

```
// see if the card is present and can be initialized:
if (SD.begin(CHIP_SELECT)) {
    sprintf(filename, "data%4d.txt", counter);
    // Continue looping until the filename does not exist
    // Each time increase the counter, to try the next filename
    while (SD.exists(filename)) {
        counter++;
        sprintf(filename, "data%4d.txt", counter);
    }
}
```

The final part of the initialization is to set up the AVR processor's Timer registers. Timer0 (8 bit) is used to divide the 32.768 kHz timebase by 256.

Timer1 (16 bit) counts the incoming frequency pulses from the 74HC4040 external counter prescaler:

```
// Setup Timer0 as 32.768kHz-clocked timebase
TCCR0A = 0;
// Timer 0 is clocked by external signal on T0, falling edge
TCCR0B = (1<<CS02) | (1<<CS01);
// Enable compare match A interrupt
TIMSK0 = (1<<OCIE0A);
// Compare match register set to 2
OCR0A = 2;

TCCR1A = 0;
// Timer 1 is clocked by external signal on T1, falling edge
TCCR1B = (1<<CS12) | (1<<CS11);
TCCR1C = 0;
}
}
```

Note that Timer0 is normally used internally by the Arduino for PWM (pulse width modulation) purposes and to control the millisecond timing facilities, using the Timer0 Overflow interrupt service routine. However in this project, the Timer0 Overflow interrupt service routine is disabled, since the Arduino timing functions are not required. Note that the Overflow interrupt cannot be used again in a sketch, because it has been used already by the Arduino infrastructure. So instead, the Compare Match A interrupt service routine is called every time the Timer0 counter value equals 2. It does not really matter what value is used for the match. Any value will result in the interrupt handler being called 128 times per second, which is all that matters.

The `loop()` function watches the state of the `readCounter` flag. This variable is used by the Timer0 interrupt service routine to trigger the phases for the 74HC4040 read, analog inputs read and SD card record write described above:

```
// calls the logData() function if the readCounter flag is True
void loop() {
    if (readCounter) logData();
}
```

The `clockTick()` function maintains a real time clock, incrementing the hours, minutes and seconds variables as required. This function is called once per second by the Timer0 interrupt service routine. Note that there is no provision for days, months or years. This logger project is designed to log data for a maximum of 24 hours. Naturally there are many applications where the user may wish to record data for more than 24 hours. In this case it would be easy to add a day count to the timestamp. This would simply require an additional `int` variable, incremented each time the hours are reset to 0. In the `logData()` function where the measurement record is written to the SD card,

the days would need to prefix the hours, minutes and seconds in the timestamp. These modifications are reasonably simple.

```
// increments the realtime clock by 1 second
void clockTick() {
    seconds++;

    if (seconds == 60) {
        seconds = 0;
        minutes++;

        if (minutes == 60) {
            minutes = 0;
            hours++;

            if (hours == 24) {
                // If a day count is required, this should be incremented here
                hours = 0;
            }
        }
    }
}
```

A function called `pulsePin()` simply applies a HIGH to the specified pin, followed by a LOW. It is used by the `logData()` function to pulse the 74HC4040's clock input and reset pins:

```
// Pulses a pin high then low
void pulsePin(byte pin) {
    digitalWrite(pin, HIGH);
    digitalWrite(pin, LOW);
}
```

The `ISR(TIMER0_COMPA_vect)` function is the interrupt service routine for the Timer0 Compare Match A. There is no mystery to the use of interrupt service routines; their operation is simple, particularly in this project. The function is simply called each time Timer0 has the value 2, which occurs 128 times per second (32.768 kHz / 256).

```
// Interrupt routine is called 128 times per second
// i.e. 32.768kHz / 256
ISR(TIMER0_COMPA_vect) {
    static byte count = 129;
    static int elapsed;
    byte gate;

    // increment count of 1/128ths of a second
    count++;
```

The function handles the gating of the input buffer and 74HC4040 and calls `clockTick()` to update the real time clock once per second:

```
// value of gate is 1 whenever the count value is >= 128
gate = (count & 0x80) >> 7;

if (gate)
// Gates the incoming signal.
// When gate is 0, it closes the gate, stops counting.
    digitalWrite(COUNTER_GATE, LOW);
else
// When gate is 1, opens the gate, starts counting.
    digitalWrite(COUNTER_GATE, HIGH);

// Increment clock tick
if (!(count % 128)) clockTick();
```

It triggers the subsequent phases of the 2 second cycle, namely reading the counter, reading the analog inputs, and writing the measurement record to the SD card:

```
// when count reaches 128, the gate closes, counting stops.
// Set readCounter to true, to read the external counter value
if (count == 128) {
    if (!elapsed) readCounter = true;

    elapsed += 2;
    if (elapsed >= INTERVAL) elapsed = 0;
}
```

Finally at count 255, the function issues a reset pulse to the 74HC4040 to prepare it for the subsequent cycle:

```
if (count == 255) {
    // Reset counter
    pulsePin(COUNTER_CLEAR);
    TCNT1 = 0;
}
```

The `logData()` function is the most important and complex in the sketch. This function first defines the `COUNTER_CLOCK` pin as an output, so that the Arduino can clock the 74HC4040 counter:

```
void logData() {
    unsigned long frequency;
    String dataString = "";
    int analogPin;
    int sensor;
```

```
// Set COUNTER_CLOCK pin as an output  
pinMode(COUNTER_CLOCK, OUTPUT);  
  
// Reset the readCounter trigger  
readCounter = false;
```

The frequency is set to 1024 times the Timer1 value (to account for the division by 1024 by the 74HC4040). The program must now take a different action depending on whether the 74HC4040's 10th stage output (Q9) is 1 or 0. The basic principle is the same — the counter is clocked by the Arduino until Q9 changes state. This allows the Arduino to calculate the value in the 74HC4040, which is 512 minus the number of pulses delivered for example. In the case where Q9 is 1, a further 512 must be added to the frequency count to account for the 512 pulses that must have flowed through the 74HC4040 in order to make Q9 a 1.

```
// The frequency is 1024 * the value of Timer1  
frequency = TCNT1;  
frequency *= 1024;  
  
// Slightly different action depending on the state of Q9:  
if (digitalRead(COUNTER_Q9)) {  
    frequency += 1024;  
  
    // This while loop has the effect of adding 512 + (512 - number of pulses_)  
    // to the frequency. This effectively reads the value in the 74HC4040.  
    // Strategy is: first add the 1024, then subtract 1 for every pulse  
    // sent to the counter  
    while (digitalRead(COUNTER_Q9)) {  
        frequency--;  
        // Clock the counter with a pulse  
        pulsePin(COUNTER_CLOCK);  
    }  
} else {  
    // If Q9 is zero, the number of pulses required to make it 1  
    // indicates the // value of the counter, i.e. 512 - number of pulses  
    // and this is added to the frequency count:  
    frequency += 512;  
  
    while (!digitalRead(COUNTER_Q9)) {  
        frequency--;  
        // Clock the counter with a pulse  
        pulsePin(COUNTER_CLOCK);  
    }  
}
```

Following the determination of the frequency, the `logData()` function creates a string containing the timestamp (using the `sprintf` function), reads

the six analog inputs, and adds them to the measurement string. To save the data, it opens the data file, appends the string to the file, closes it. It also echoes this measurement record to the SERIAL MONITOR window on the PC, if open:

```
char buf[25];
sprintf(buf, "% .2d:% .2d:% .2d", hours, minutes, seconds);
dataString = String(buf) + "," + String(frequency);

// read six analog inputs and append their value to the string:
for (analogPin = 0; analogPin < 6; analogPin++) {
    sensor = analogRead(analogPin);
    dataString += "," + String(sensor);
}

// Open the output data file for writing
File dataFile = SD.open(filename, FILE_WRITE);

if (dataFile) {
    // Write the measurement record to the data file
    dataFile.println(dataString);
    // Close the data file
    dataFile.close();
}

// Also echo the measurement record to the Serial Monitor
Serial.println(dataString);
```

Finally, the COUNTER_CLOCK pin is set back to an input, preparing the circuit for the whole cycle to repeat again:

```
pinMode(COUNTER_CLOCK, INPUT);           // Set counter clock pin to input again
}
```

Part 2: Voltage and Temperature Measurement

The logged value for each of the six Arduino analog input pins is a value between 0 and 1023. This represents the voltage at the input pin, and must be within the range 0 to just under 5 V. The pins should not be connected to any voltage higher than 5 V, otherwise irreversible damage to the Arduino may result. For this reason, a voltage divider network should be used when the voltages to be measured are higher than 5 V.

The calculations to turn the measured value in the range 0-1023 into the voltage are simple. They could be included in the Arduino sketch itself. However, the approach taken in this project has been to simply log the raw digital value and leave it to the subsequent spreadsheet analysis to process this data.

Measurement of High Voltages

Measurement of a high voltage simply requires a voltage divider (**Figure 6.4**) at the analog input. The $10\ \mu\text{F}$ capacitor is useful for noise reduction and improves the measurement accuracy. The voltage at the analog input pin is given by the formula:

$$\text{Arduino Voltage} = \text{Input Voltage} \times R_2 / (R_1 + R_2).$$

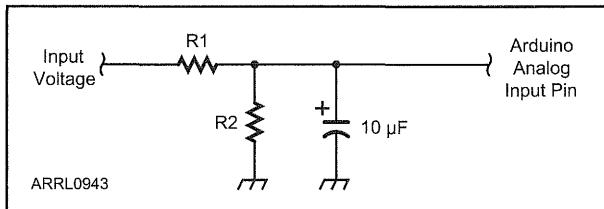


Figure 6.4 — Measurement of a high dc voltage requires a voltage divider at the Arduino's analog input.

high resistor values should be chosen in order to minimize current flow and thus power dissipation.

As an example, consider the need to measure a tube circuit B+ (high voltage) of around 250 V. One may choose $R_1 = 2.2\ \text{M}\Omega$ and $R_2 = 27\ \text{k}\Omega$. R_2 is less than $50\ \text{k}\Omega$, which is consistent with the recommendation relating to the processor input pin. $R_1 + R_2 = 2.227\ \text{M}\Omega$, which at a voltage of 250 V will draw (from Ohm's Law $I = V / R$) a current of 0.11 mA. The power dissipation in the resistors will be 28 mW, which is quite acceptable for common $\frac{1}{4}\ \text{W}$ resistors.

The conversion of the raw digital measurement from the analog-to-digital converter (in the range 0-1023) back to the voltage at the pin is done by multiplying the digital value by $5.0 / 1024$.

Combining the two formulas to convert the recorded digital value back to the input (B+) voltage:

$$\text{Input Voltage} = (\text{Digital Value} \times 5.0 / 1024) \times (R_1 + R_2) / R_2$$

In this example ($R_1 = 2.2\ \text{M}\Omega$, $R_2 = 27\ \text{k}\Omega$), $B+ = \text{Digital Value} \times 0.403$. As an example, if a digital value of 618 is written to the file, this equates to an input voltage of $618 \times 0.403 = 249\ \text{V}$. With these component values, the input voltage could be as high as just over 400 V without overloading the Arduino input. It is always best to have some safety margin available in case the unexpected should occur.

Measurement of AC Voltages

The previous section assumes the voltage to be measured is direct current (dc). If it is an alternating current (ac) voltage, then an additional step is required to rectify the ac voltage, as shown in **Figure 6.5**.

If the voltage to be measured is sufficiently low, then R_1 and R_2 may be

The choice of resistor values, however, is not arbitrarily limited to choosing the desired resistance ratio. The Arduino input pin itself has a non-infinite input resistance, and the Atmel datasheet recommends keeping the value of R_2 below $50\ \text{k}\Omega$. Another consideration is power dissipation — where high voltages are concerned,

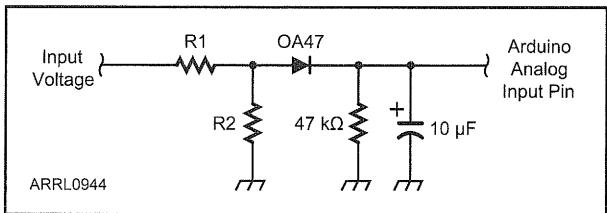


Figure 6.5 — This circuit adds a rectifier diode to the voltage divider for measuring ac voltages. The OA47 is a germanium diode, preferred for this application because it has about half the voltage drop of a silicon diode.

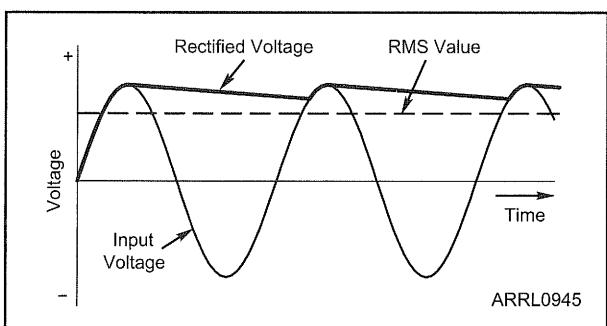


Figure 6.6 — The effect of the rectifier diode on the waveform.

measured value must be doubled. If a root mean square (RMS) value of a sine wave is required, then the measured value must be multiplied by $0.707 (1/\sqrt{2})$.

As an example, consider the filament of a DF96 vacuum tube which is rated at 1.4 V at 0.25 mA dc. One may power this heater filament with ac too, in which case the RMS value should be 1.4 V. With the circuit in Figure 6.5, and without R1 and R2, the measured digital value is 420. The peak value is found by multiplying by $5.0 / 1024$, or 2.05 V. The RMS value is $2.05 \text{ V} \times 0.707 = 1.45 \text{ V}$. The tube filament requirement is satisfied.

Note that there will also be some voltage drop across the diode, causing some inaccuracy. This could be compensated for in the calculation with suitable calibration or reference to the diode datasheet. In any event, it is best to use a germanium diode such as the OA47, because the voltage drop across germanium diodes is less than half that of silicon diodes.

Measurement of Temperatures

The TMP36 temperature sensor is an 8-pin chip manufactured by Analog Devices. It operates from a 2.7 to 5.5 V supply and consumes very low power. The voltage output is linearly proportional to temperature. It has a temperature range of -40°C to $+125^{\circ}\text{C}$ and a typical accuracy of $\pm 1^{\circ}\text{C}$ at 25°C , with a linearity of 0.5°C . The voltage output at 25°C is 0.75 V and changes by 0.01 V per degree centigrade. The TMP36 is a perfect and easy to use device for this logger, but many similar devices are available. **Figure 6.7** shows

left out. If using R1 and R2, the conversion ratios of the voltage divider in the previous section apply. For simplicity, the following example will assume that R1 and R2 are not required for a low voltage application.

Figure 6.6 shows the operation of the rectifier on a sine wave waveform. The diode only passes the positive sine wave peaks, and the capacitor stores the peak value. The load resistor across the capacitor ensures that the capacitor voltage can follow a varying ac waveform. The slope in the rectified voltage in the diagram is exaggerated for clarity.

In its basic form, the measured voltage at the Arduino is the peak voltage of the waveform. If a peak-to-peak value is required, this

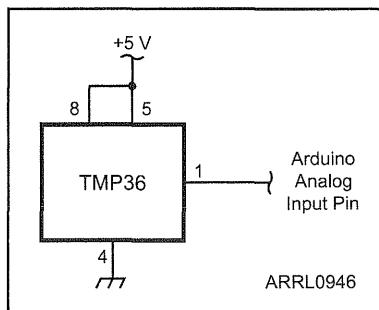


Figure 6.7 — A TMP36 temperature sensor is used to measure temperature changes over time at various points in the circuit.

Improving ADC Accuracy

Leigh L. Klotz, Jr., WA5ZNU

On power up, the Arduino uses the 5 V power supply as a reference voltage (AREF), though you can use the `analogReference` command to change the voltage reference source to the 3.3 V supply or an internal 1.1 V reference obtained from an on-chip band-gap voltage. The Arduino library does not switch the AREF immediately; instead it does so just before reading the ADC. The first call to `analogRead` after switching references will be inaccurate and should be discarded. Don't change `analogReference` to `DEFAULT` or `INTERNAL` with any voltage source connected to the AREF pin, or you will risk damaging your ATmega328.

For this application, Hans chose the 5 V default reference. If the Arduino is powered from a desktop computer USB connection, the 5 V value might be off by as much as 0.25 V and still be within the USB specifications. Even if you power the Arduino from the dc barrel connector and use the onboard regulator to obtain a more accurate 5 V reference, other devices using the 5 V V_{cc} line may cause the voltage to sag. Other devices may also introduce noise in the reference line. You can reduce noise by tack soldering a 100 nF capacitor to the bottom of the Arduino between the AREF pin and ground. Some Arduino variants (such as the Arduino Mega and the Seeeduino) include this capacitor already, so check your schematic first. If your project does not use the 3.3 V rail, and your voltage sensing needs fit in the 0-3.3 V range, you can select 3.3 V using the `analogReference` command and obtain a fairly quiet 3.3 V AREF.

The ATmega328 includes a single ADC and a *MUX* (switch) to connect it to different pins. The `analogRead()` function selects the pin just before reading, so if you use multiple ADC pins with high-impedance sensors, there may not be enough current to charge the capacitor in the ADC immediately after the switch. In this case, you will

find that the first reading after calling `analogRead` with a new pin number is wrong. If you cannot buffer the sensor output, the easiest approach is discard one call to `analogRead` after switching to a different pin. This restriction may complicate your logic and you will likely need to define your own function using an internal static variable to keep track of the last pin.

The math in this section divides the `analogRead()` value by 1024, but you will see projects that use a divisor of 1023. The difference is minor, but since the ADC cannot output 1024, it cannot represent a voltage equal to AREF, and the so the maximum readable voltage is $1023/1024 \times AREF$, or 4.995 V in the case of a 5 V reference. This sketch itself does no conversion and logs the value directly, leaving conversion to voltages up to the graphing program. For best accuracy, instead of using $5.0/1023$ as the conversion factor, calibrate the `analogRead()` values with a known voltage source.

The Arduino `analogRead` function is not the only way to use the ADC. There are many parameters available for tuning, and ways to have the ADC generate and use interrupts, quiet the processor during readings, and so on. These are best left for more advanced projects where timing and accuracy concerns are paramount.

References

- Atmel Application Notes AVR126 and AVR127:
<http://www.atmel.com/Images/doc8444.pdf>
<http://www.atmel.com/Images/doc8456.pdf>
- Arduino AREF
<http://arduino.cc/en/Reference/AnalogReference>
- Arduino analogRead noise discussion
<http://www.arduino.cc/cgi-bin/yabb2/YaBB.pl?num=1295736263>
- OpenMusicLabs discussion of Atmel ADC
<http://www.openmusiclabs.com/learning/digital/atmega-adc/>

the connections — it really can't get much simpler than this.

To convert the logged digital value (in the range 0-1023) to temperature, we derive a formula based on the 25 °C, 0.75 V datasheet point and the 0.01 V/°C slope of the TMP36 output.

The Arduino input pin voltage is

$$V = \text{Digital Value} \times 5.0 / 1024$$

The temperature is simply

$$T = 25 + 100 \times [(\text{Digital Value} \times 5.0 / 1024) - 0.75]$$

As an example, if the logged digital value is 158, the temperature is

$$T = 25 + 100 \times [(158 \times 5.0 / 1024) - 0.75] = 27.1 \text{ }^{\circ}\text{C}$$

Part 3: Using the Arduino to Build a Stable Tube VFO

I designed the Arduino data logger to solve a problem I had in the shack, as part of the work I was doing to homebrew a vacuum tube VFO (in the UK we call a vacuum tube a “valve”). Using the Arduino to automate the task helped me collect and analyze more data than I could manually, and it led me to a more successful and rewarding project in a shorter time.

Building a stable VFO has always been a challenge for radio amateurs, even with a modest target drift of 50 to 100 Hz per hour. The primary cause of drift is temperature change. As the temperature changes, so do the component values, and because many of the components contribute to the determination of the oscillation frequency, the oscillator drifts. The principles here also apply to solid state VFOs, but tubes present particular challenges due to the higher temperatures involved.

Common Causes of Oscillator Drift

Power Supply Voltage

A well regulated and smoothed power supply voltage is important because circuit voltage affects operating characteristics of the circuit and changes the oscillator frequency. A 78xx series three-terminal regulator works for solid state designs, but for tubes, a good choice is a gas-filled tube regulator such as the VR150/30 (150 V). A good voltage regulator can virtually eliminate drift caused by changes in supply voltage.

Shielding

If the oscillator is not adequately shielded, the presence and movement of nearby objects will have the effect of slightly adding stray capacitance, which will change the oscillation frequency. The frequency of an unshielded oscillator may be *pulled* by the operator's hand on the tuning knob. Shielding an oscillator is a requirement for good stability, but an enclosed tube oscillator contains the heat and has an even higher temperature rise.

Mechanical Construction

Without rigid mechanical construction of the oscillator, the frequency can be subject to *microphonics*. Vibrations to the chassis will cause frequency variation as the physical relationship between the components in the circuit is changed.

Component Temperature Coefficients

When it comes to temperature coefficients, the black art of taming a drift oscillator really starts to bite. Almost every component in the oscillator circuit will have some effect on the oscillation frequency, and rising temperatures cause most materials to expand or contract. An air-core inductor, which expands as the temperature increases, will show an increasing inductance value as the temperature increases, decreasing the oscillation frequency. The problem is exacerbated when an inductor with a powdered iron or ferrite core is used, since the permeability of such cores also has a temperature dependence.

Trimmer capacitors and fixed capacitors exhibit temperature variation. Even expensive capacitors with NP0 or C0G temperature coefficient ratings have a non-zero temperature coefficient. For those components, the temperature coefficient is just an order of magnitude less than that for a common cheap capacitor — but it is still present to some degree. Higher quality polyester, polystyrene and silver mica capacitors also exhibit smaller temperature coefficients.

The temperature coefficient of a variable capacitor can be reduced by using a high-quality air-dielectric variable capacitor with widely spaced plates. With wider spacing, the expansion of the metal plates with temperature increase has a smaller effect on capacitance values.

Active Device Temperature Coefficients

The most difficult aspect of temperature compensation is the active device itself. Solid state components such as bipolar transistors and FETs have characteristics that change nonlinearly with temperature. Tube characteristics such as grid capacitance also depend on temperature. While the dependence is more linear, here the problem is that they usually operate at high temperatures, so the temperature variation is extreme.

A Low Power, Stable Tube VFO

Unfortunately, tubes that dissipate a large amount of power operate at extreme temperatures. Even a “miniature” tube with 7-pin B7G base may have a 6.3 V, 300 mA filament rating. That’s almost 2 W of heat dissipation just for the filament, raising the temperature of the whole oscillator circuit. That’s why tube VFOs are thought to be less stable than modern solid state versions.

Andy Smith, G4OEP, reasoned that if the temperature extremes could be reduced, a tube circuit might be easier to tame than a transistor one. He designed a project to see if tube VFO stability could be improved by drastically reducing heat production to control temperature variation. Tube temperature dependency is more linear than that for a transistor, so the resulting oscillator should have a very high stability. He used a subminiature tube, the XFY43, designed for hearing aids. It has a 1.4 V, 10 mA filament, with just 14 mW of dissipation — 135 times less than a common tube filament. In practice, Andy’s oscillator tube

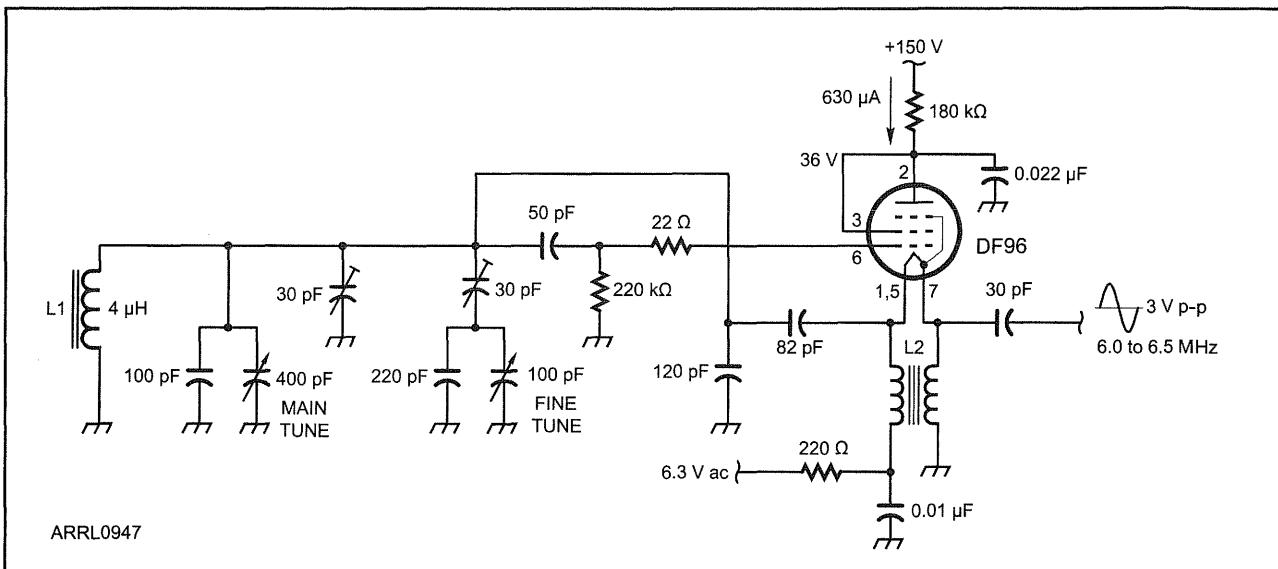


Figure 6.8 — Schematic diagram of the tube type VFO using a DF96 pentode. L1 is 31 turns on a T-37-2 toroid. L2 is 15 turns bifilar wound on an FT-37-43 toroid.

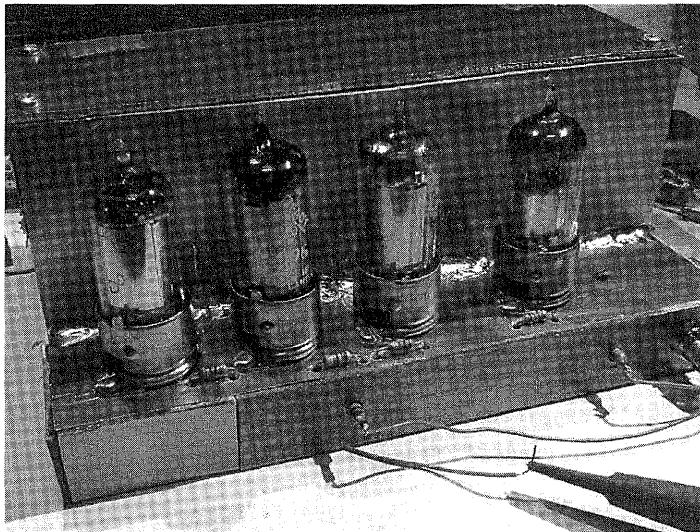


Figure 6.9 — Here's the DF96 VFO circuit included in a larger project. [Hans Summers, GØUPL, photo]

is the largest contributor to drift — it was difficult to interpret the results. I built the Arduino frequency counting data logger to automate measurement, so I could plot frequency drift versus temperature changes.

As part of a larger VFO project, I built a 6.0 to 6.5 MHz variable oscillator circuit as shown in Figures 6.8 and 6.9. Designed for battery powered receivers, the DF96 pentode has a 1.4 V, 25 mA filament (35 mW). The values of the tank inductors and capacitors were chosen empirically, to provide desired frequency coverage using the main tuning capacitor, and plus or minus a few kHz using the fine tuning capacitor.

The circuit was powered by an all-tube power supply, with a VR150/30

circuit dissipates only 20 mW, comparable with a solid state circuit. The resulting stability is spectacular.

Looking through my junk box, I began to replicate G4OEP's results. At first I logged the frequency by hand over a one hour period. It was fun and tremendously educational, but laborious. Since I did not measure temperature — and temperature variation

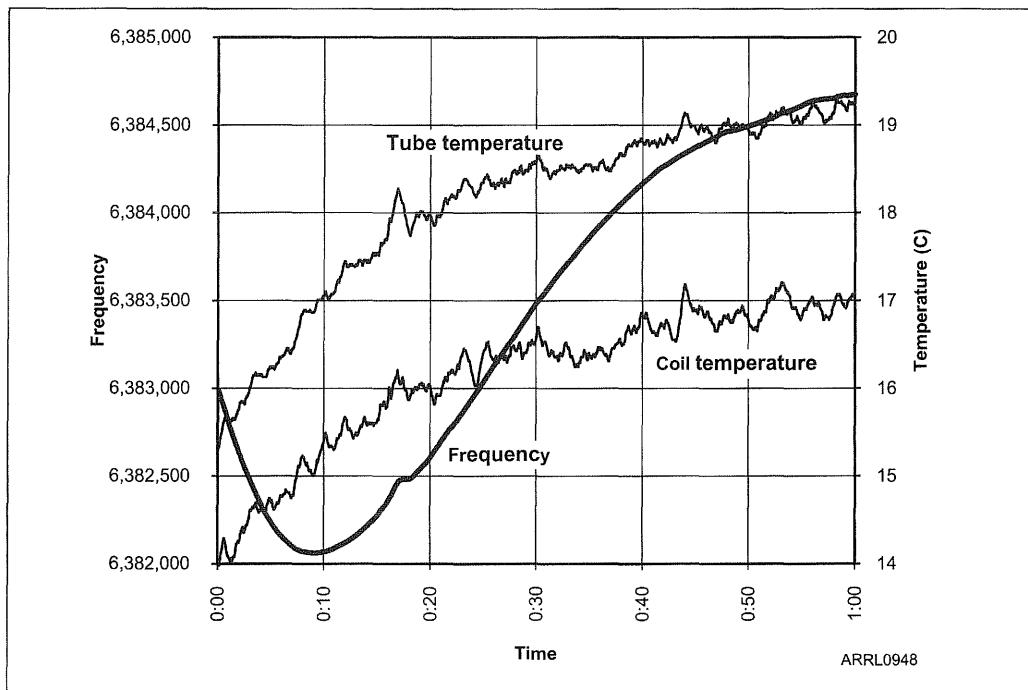


Figure 6.10 — The data from the Arduino logger is loaded into an Excel spreadsheet to show how various parameters of the DF96 VFO change over time.

voltage regulator tube. (Recall the discussion above, concerning the importance of regulated voltage supplies in a stable oscillator.) As the Arduino logger has six analog channels as well as the frequency counter, I was able to measure the rectified filament voltage, the B+ voltage (250 V), and the regulated 150 V voltage. I used three TMP36 temperature sensors: one taped to the DF96 tube, one on the power supply rectifier tube, and one near the LC tank inductor.

The resulting Microsoft *Excel* chart (**Figure 6.10**) shows data recorded during one hour from switch on. The initial downward drift of 1 kHz during the first 10 minutes is probably caused by the expansion of the internal mechanical structure of the tube as it warms up. The remaining upward drift correlates well with the measured temperature. Cancellation of this drift will be a matter

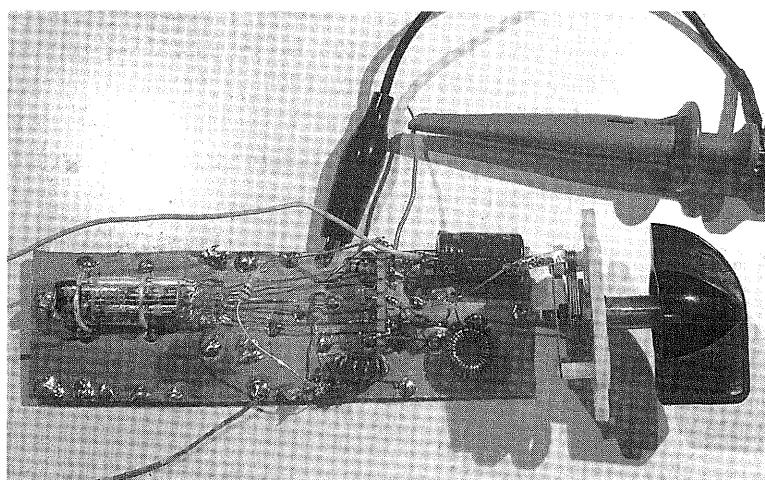


Figure 6.11 — The 6088 pencil tube has very low filament dissipation, making it a good candidate for a stable VFO. [Hans Summers, G0UPL, photo]

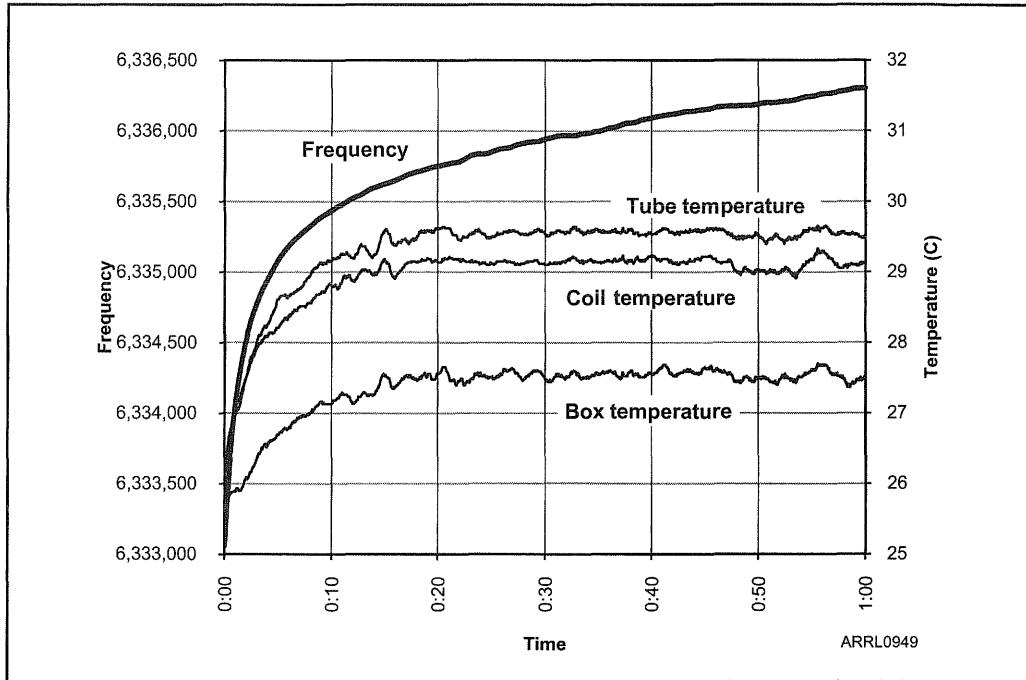


Figure 6.12 — Data from the Arduino logger shows how stable the 6088 VFO is over an hour's time.

of experimenting with inductors and capacitors in the LC tank circuit, so that positive and negative temperature coefficients are balanced.

The temperature rise of the DF96 tube was around 4 °C in an hour, and the inductor around 3 °C. These temperatures are much less than the temperature changes seen in conventional higher power tubes. One circuit constructed using the common dual-triode 12AT7 tube drifted more than 70 kHz in an hour, and the temperature of its rectifier tube rose to more than 80 °C!

The closest I could find to G4OEP's XFY43 tube was a subminiature 6088 "pencil" tube. The 6088 pentode has a 1.25 V, 20 mA filament with 25 mW filament dissipation. See **Figure 6.11**.

With no effort to balance temperature coefficients of components, and using only inexpensive ceramic capacitors in the LC tank circuit, my 6088 circuit oscillated at a supply voltages of 34 to 55 V and had drift of only 3 kHz in the first hour after switch on (**Figure 6.12**). There was no observable initial frequency dip caused by the heating of the tube internals, and the temperature rise of the tube envelope was around 3 °C. This oscillator therefore shows considerable promise and warrants further experimentation to balance the temperature coefficients.

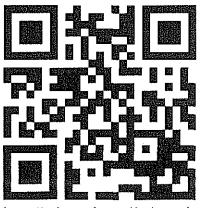
Conclusions and Recommendations

Once the tools are at hand to accurately measure the performance parameters of a VFO, the experiments to improve them become fun, highly educational and even addictive. With care, there is probably no reason why a stable vacuum tube VFO cannot be built with performance as good as, or better than, a solid state version.

Here are some recommendations for building stable tube-type VFOs:

- The choice of tube is important. A high gain, low power tube is best, with a low power filament. Low power dissipation means the temperature changes in the oscillator are much lower, so any imbalance in temperature coefficients of the components is less damaging to the oscillator frequency stability.
- Air-dielectric variable capacitors for tuning the oscillator seem to have a negative temperature coefficient. As the temperature rises, their capacitance decreases, causing the frequency to rise.
- Avoid the inexpensive ceramic capacitors found in the junk box. While these ceramic capacitors are available in a variety of temperature coefficients, both positive and negative, most are likely to show a strong negative temperature coefficient. They are not useful for high stability VFOs.
- Polystyrene capacitors have a very low, slightly negative, temperature coefficient. These are very useful for balancing the temperature coefficients in a VFO.
- The popular Micrometals toroids having a Type 6 material (for example, T-37-6, T-50-6 and so on) are specified at +35 ppm temperature coefficient. The Type 2 material is specified at +95 ppm. An air-core inductor was found to have a temperature coefficient somewhere between these two values.

References and Further Reading

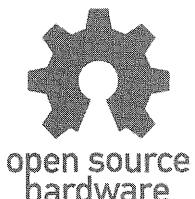


<http://qth.me/g0upl/+thermic>

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<http://qth.me/g0upl/+thermic>
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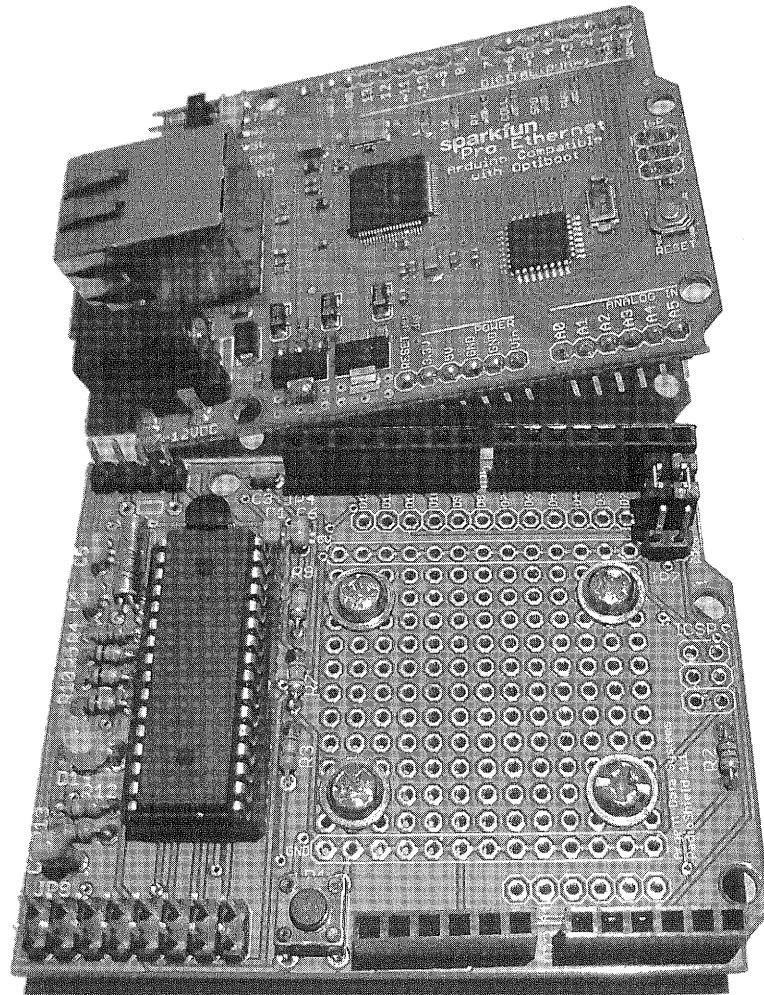
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Airgate: A Receive-Only, Low-Power APRS iGate

Markus Heller, DL8RDS



Airgate Shield Stack: The SparkFun Arduino Ethernet Pro fits atop the Argent Data Radio Shield and Radiometrix NRX1 receiver. (The Arduino Ethernet Pro board is no longer available; use the Arduino Uno Ethernet as discussed in the article.) [Markus Heller, DL8RDS]

APRS is a fast-growing Amateur Radio activity, with hams driving, biking, flying or even parachuting around while sending and receiving positions, messages and telemetry. This popularity has a shortcoming: in most areas there is only one frequency in use (in Europe, 144.800 MHz, and in the US, 144.390 MHz). In densely settled areas this frequency may become quite congested. Many hams who purchase APRS-enabled handheld transceivers such as the Yaesu VX-8 find that the signal is often too weak to make it to the nearest gateway, which may be miles away. In the canyon-like avenues of major cities, very few frames will be decoded — especially when transmitted with low power. Fill-in *digipeaters* can relay received frames, but they retransmit each packet over RF and make channel congestion even worse.

I wanted to find a way to enhance the APRS network to capture and process weak packets from local stations without adding to congestion on the single APRS channel, and to do so without the cost or power consumption of a high powered PC.

In most parts of the world, the amateur packet radio network that was built up in the 1980s no longer exists. In Germany, we are fortunate that it is currently being replaced by *HAMNET*, a high speed network using IEEE 802.11 equipment on the 2.4 GHz and 5 GHz Amateur Radio bands. My idea was to augment the HAMNET sites with local, low-cost APRS iGates. The links in these microwave bands require an unobstructed line of sight path, so the nodes are usually on elevated positions such as high buildings or mountains. Very often, electricity is a rare resource there, so solar panels and lead-acid batteries are used. All the components must be optimized for the lowest power consumption possible.

I settled on the Arduino and the Argent Data Radio Shield as the major components of a design satisfying these goals and faced the next challenge: writing the software.

The APRS Network

APRS is an application built on the well-known AX.25 protocol. A station generates a frame consisting of a header and a data section. A packet radio digipeater receives the frames and forwards (retransmits) them according to the settings of the path included in the frame. Stations within RF range of the original station or digipeater can monitor the messages directly, but eventually the frame will arrive at an Internet-connected *iGate* node.

The iGate node takes the frame and sends it over the Internet to one of the backbone machines of the APRS system. The backbone system APRS2.NET is a set of databases and application machines that collect and aggregate all the packets and provide them to clients in form of streams. Client services such as aprs.fi can again render the data on Google maps or other maps and provide a tactical overview of position information, where the payload data may not just be GPS positions but weather and other sorts of data.

Although the APRS network is actually a bidirectional system, the majority of network traffic — and hence congestion — is due to position and telemetry data, and not messages. Accordingly, if a number of receive-only iGates are deployed in an area, the resulting offloading of wide-area traffic from the 2 meter band will help all APRS users.

Gating to HAMNET

In Germany, HAMNET is still in the early phases of deployment. Even though many regions are not yet interconnected with HF links for topography reasons, there are wire links to a central hub at Nürnberg Polytechnic University (DBØFHN). So it is nevertheless possible to reach all the other German and some other European nodes with a fairly good bandwidth. Since we can assume that the HAMNET users are all licensed hams, there is no need for authentication in APRS proxy gateways, and in fact there are two proxy servers in Koblenz and Karlsruhe at ham-allocated IP addresses (44.225.68.2 and 44.225.73.2) that accept APRS frames without authentication.

Bandwidth, however, remains at a premium, and so we have chosen the UDP Internet Protocol for an APRS proxy server. UDP packets are the Internet Protocol equivalent of the AX.25 *unproto* packets on which APRS is based. Because they are connectionless, UDP packets are not guaranteed to be delivered, but they are suitable for lightweight data forwarding tasks such as APRS iGate. The more familiar TCP, on which Internet protocols such as HTTP are based, requires at least seven packets sent and received to open a connection, send an APRS packet, and close the connection. The amount of TCP network traffic would be large compared to the roughly 256 bytes of a typical APRS message. By contrast, a UDP packet encapsulating APRS is a single packet, and UDP itself adds just 8 bytes of overhead.

Gating to APRS-IS via UDP

If you are outside of Germany, you still have access to the international APRS-IS network. Some APRS-IS servers support UDP, via something called “Send-Only Ports,” though not many are configured to do so. Those that require authentication, so to gate an APRS packet, you send the login information and APRS packet encapsulated in an IP UDP packet to a nearby APRS-IS server port 8080 with UDP.

The data roughly looks like this:

```
user W1AW-1 pass 99999 vers TestSoftware 1.0
TEST-1>APRS,TCPIP*:>This is a test packet
```

The first line is the login line, and together with the passcode, authenticates the call sign. (If you need help finding your passcode, see the companion website for this book.) The second line is the AX.25 frame line, decoded and described in TNC2 format.

Gating to APRS-IS via TCP

In the US, most APRS-IS backbone servers are not enabled for UDP. There are many options for using TCP from the Arduino, but they require a little more care than the simple UDP version. You will find that discussion in the next section. Even if you plan to use TCP, please follow along in this section. The differences are all in the software, and the sketch here is used as a basis for subsequent work.

System Overview

The block diagram in **Figure 7.1** covers both UDP and TCP connection methods, and includes both HAMNET and direct connections, plus other optional components. You can refer to it during the following discussion.

The hardware for the iGate has these components:

- Arduino
- Ethernet shield, which provides IP connectivity
- Argent Data Radio Shield
- Radio

Shields

Even though a stacked Arduino and an Ethernet shield will do, you will probably prefer (as I do) the more integrated Arduino Uno Ethernet with SD card. This version offers full Arduino functionality, and with the Ethernet chip already on board, handling the Ethernet and even the TCP/IP and UDP protocols is a breeze. The Arduino Ethernet library described in the references is an easy-to-use interface, and it is very easy to start from the included examples. (Note that I used the SparkFun Arduino Ethernet Pro, which is similar to the Arduino Uno Ethernet, but that board is no longer available.)

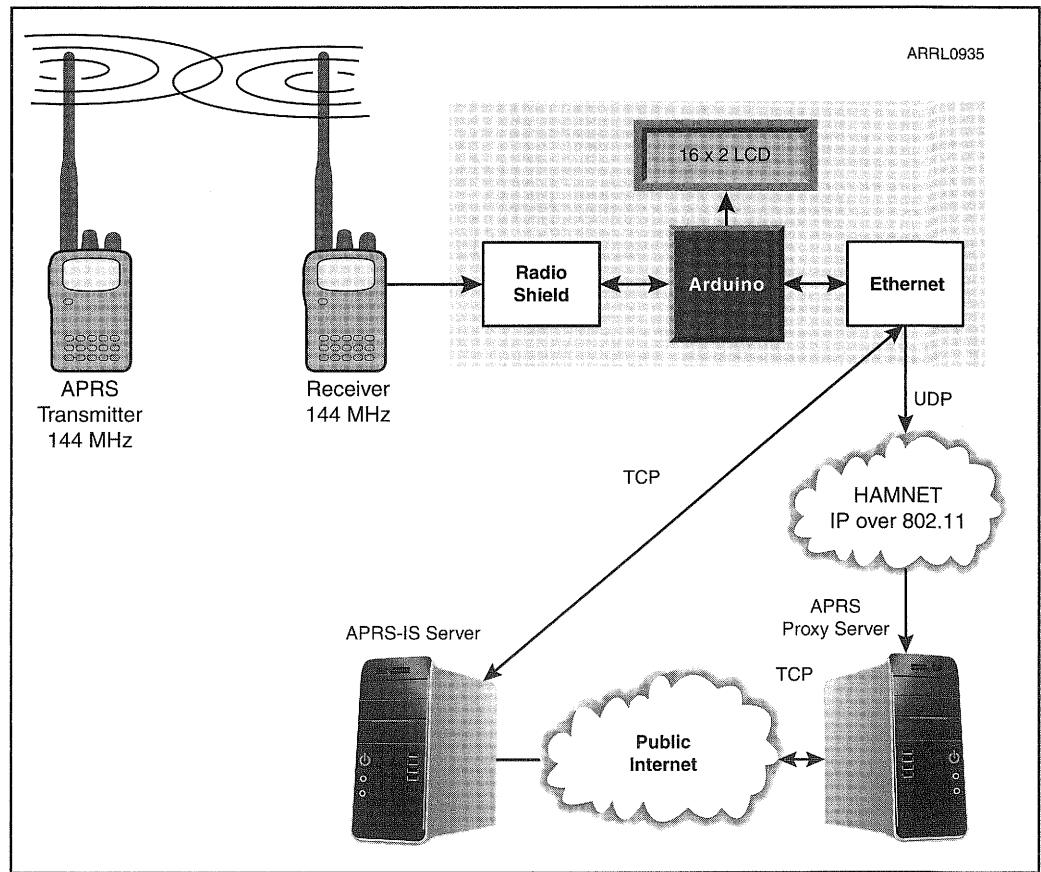


Figure 7.1 — Airgate block diagram, showing the main components of the Airgate system. The project described in this chapter is outlined in grey.

The Radio Shield is custom-designed for ham use by Argent Data. You can order it in their online store or through a reseller in your country, and it will come as a kit that you can solder yourself. The magic is that it contains another microcontroller that can decode and encode audio to AX.25 frames. This means that we can connect it to an arbitrary audio source that produces APRS traffic and it will convert all frames into data packets over the Arduino's serial port.

To get started with a project that uses all these parts, it is best to start from something that can be made to work easily, and then add components and complexity. For testing purposes, you can start with the Argent Data MP3 test file for decoding. Just play it with your favorite media player and connect the soundcard of your computer to the input pins of the Radio Shield, and follow along in the Radio Shield examples to see how to read the data from the Arduino serial port.

Take a close look at the pin headers of your Arduino board. At the right end of the data pin row there are two pins marked TX and RX. These pins carry the TTL serial signal that comes in from the serial connection between the Arduino and your computer. Now keep in mind that it is fairly easy for an Arduino program to capture serial input and write back serial data to the terminal of your computer. If the Radio Shield speaks to the Arduino just through the same channel, the Arduino will only need to capture serial input. You can also submit test data to the Arduino and emulate a Radio Shield submission. In transmit mode, the Arduino will send data to the TX line, which means that it will end up at the Radio Shield and at your terminal at the same time.

The only remaining parameter left for now is the data speed. At 4800 bits/s, it is rather slow. But it is fast enough to deliver all the APRS frames, which come in at 1200 bit/s.

For radio, I have been using a Yaesu VX-8E handheld radio and a Kenwood TM-V7E mobile radio for my experiments which both worked fine. For a receive-only systems, an inexpensive tiny handheld radio from China would work as well.

For the many iGates we expect to deploy in the HAMNET project, power consumption, size and cost are paramount, and so we have chosen the Radiometrix NRX1-144.800-10 (or NRX1-144.390-10 for the US). This single-channel VHF data receiver module consumes just 10 mA, so it is probably the most efficient receiver you can get. For the home builder, it has a disadvantage in that it does not have a squelch and needs an additional active audio filter. I have used the NRX1, and if you choose to use that instead of a handheld for the advantages it offers, see the resources on the companion website for the book to get more information about our progress in building an NRX1 shield for the Arduino.

Hardware Cautions

Stacking the Radio Shield on top of the SparkFun Arduino Ethernet Pro or Arduino Uno Ethernet is a difficult task mechanically, because both boards feature a full-sized RJ45 connector that extends well above the board. As shown in the title page photo, I installed the headers on the Arduino Ethernet Pro *upside down*. In other words, I installed male headers pointing downward instead of female headers pointing upward. That makes the Arduino the top

board in the shield stack, which is inconvenient if you want to put an LCD shield on top. A remote installation such as our HAMNET nodes would not need an LCD.

If you plan to use an LCD atop your stack, or if you choose the Arduino Uno Ethernet, which comes already assembled with standard female headers atop the board, you can use a set of stacking headers to make “stilts” and fit the Radio Shield above the Arduino Uno Ethernet board as shown in **Figure 7.2**. Putting a piece of electrical tape over the RJ45 jack is also a good precaution against unintended shorting of components on the bottom of shields.

To program the Ethernet-integrated Arduino, you will need an adapter cable or a breakout board and a mini-USB cable. There are a number to choose from, and they come in 3.3 V logic and 5 V logic varieties. Since the 3.3 V ones almost always work with the 5 V boards, and they look identical, be on the safe side and buy either a switchable one or a 3.3 V logic version.

You won’t be able to power a big shield stack with the USB connection only, so plan ahead also for an external power supply in the 9 V range. The popular 5 V supplies don’t provide enough headroom for onboard regulators at the current load of a large shield stack, and a 12 V supply will waste both energy and heat.

Since the Radio Shield shares the serial port with the Arduino, it has a pair of shorting jumpers that act as a switch. In the PROG position, the Arduino USB connector (or FTDI connector on the integrated Ethernet versions) can be used to upload a new sketch to the Arduino. In the RUN position, the Radio Shield is connected to the Arduino serial port for read/write operation of APRS packets. In some circumstances, attempting to program the Arduino with the jumpers in the RUN position can scramble the configuration or firmware of the

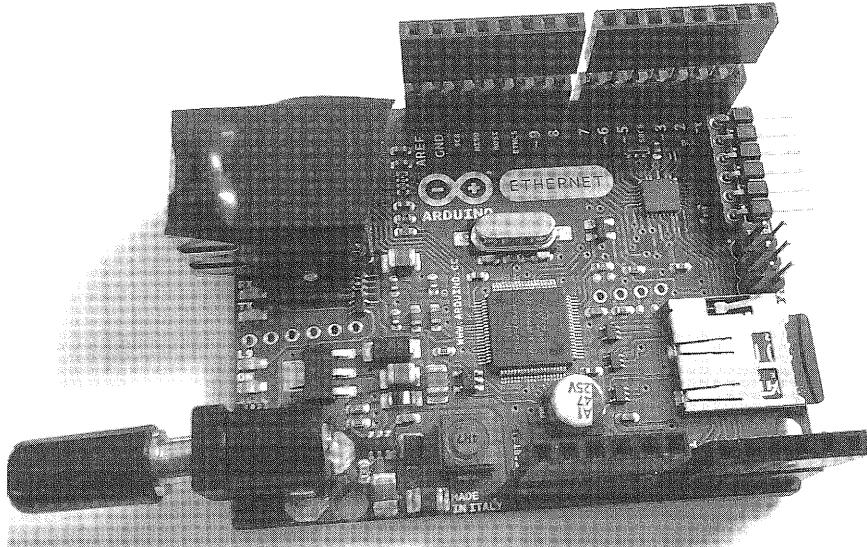


Figure 7.2 —If you use the Ethernet-integrated Arduino, use stackable headers to provide room for the shields to fit on top. A piece of black electrical tape insulates the RJ45 jack from possible component-side shorts. [Leigh L. Klotz, Jr, WA5ZNU, photo]

Freescale CPU onboard the Radio Shield, necessitating a reload of the Radio Shield firmware. If your Radio Shield LED is solid or blinking red, you'll need to reload its firmware following the instructions on the Argent Data website. If you have another shield on top of the Radio Shield, you may find it easiest to remove the Radio Shield from the Arduino when programming a new sketch.

Another reason to update the Argent Data firmware on the Radio Shield is to gain access to new features, such as the ability to receive full APRS path information, critical information for the APRS-IS if your area has digipeaters. Without APRS path information, it looks to the APRS-IS as if your iGate received digipeated stations directly, perhaps from hundreds of kilometers away! Check with the Argent Data Radio Shield support site for firmware updates.

If your Arduino program sends commands to the Radio Shield, it's possible to accidentally trigger packet transmission, or to cause the Radio Shield to enter an unusual mode such as preparing to write to the parallel LCD connector, which is not used in this project. To avoid any problems in this area, take care when using `Serial.print` debugging on the Arduino and start each line with a space character.

Software Serial

Alternatively, you may wish to use the Arduino 1.0 `SoftwareSerial` library. The library allows you to treat any pair of pins as a serial port, and leaves the D0 and D1 pins free, making it possible to use the `Serial` port for Arduino programming and `println` debugging without issue. To find out how to use `SoftwareSerial`, see the appendix on the topic later in this book.

Sketches

The three sketches below all are available for download (see the Resources section at the end of this chapter) and are described in detail here. The first sketch, `AirgateUDP`, is the shortest and easiest to understand, but it requires the Arduino to be part of a network infrastructure that includes proxy servers accepting the UDP protocol and forwarding them on to the APRS-IS. The second sketch, `AirgateTCP`, is a standalone version. It uses TCP networking and displays packets and status information on an attached LCD. A third version adds SD card data logging, with just a few lines of code.

Airgate UDP Sketch

This simple sketch reads the decoded APRS packets from the Radio Shield in TNC2 format. TNC2 format is simpler than the more familiar KISS TNC interface. It consists entirely of readable (ASCII) characters, and the only control character used is the newline to terminate a packet. The Radio Shield itself handles the audio demodulation and the signal decoding, and it sends the packet data to the serial port.

The sketch code for `AirgateUDP` is available for download from the book website. Below is the sketch, explained in parts.

```
// Airgate UDP -- Receive-only iGate
// Relays APRS packets from RadioShield to a UDP APRS-IS server
// Copyright 2012 Markus Heller, DL8RDS

#include <Arduino.h>

#include <SPI.h>
#include <Ethernet.h>
#include <EthernetUdp.h>

EthernetUDP Udp;
```

The section above declares all the resources necessary to send UDP packets over the Ethernet.

```
// Enter a MAC address and IP address for your controller below.
byte mac[] = { 0x90, 0xA2, 0xDA, 0x00, 0x75, 0xCA };
```

These lines may be familiar to you if you have configured a computer for your home network manually. The *MAC* (Media Access Control) address is the Ethernet address of your device. You will find it on a sticker on the box that your Arduino Ethernet came in, or perhaps on the Arduino Ethernet itself. Every Ethernet device on your local network must have its own unique MAC address. If you build multiple Arduino Airgate systems, you will need to set the MAC address of each separately. The “MAC address” has no connection to the popular Apple computers by the same name.

```
// The IP address will be dependent on your local network:
IPAddress ip(192,168,1,145);
byte gateway[] = {192,168,1,1}; // gateway IP
byte subnet[] = { 255, 255, 255, 0 }; // netmask
```

The *IP* (Internet Protocol) address is the next level up, and is shared by both UDP and TCP. Your task is to allocate and manage IP addresses on your home network. In HAMNET, we will likely do this manually in order to save network traffic and increase reliability, but in your own home network you will likely have a *DHCP* (Dynamic Host Control Protocol) server in your Internet gateway that hands out IP addresses for you automatically. If you have an IP address you would like to use, feel free to set it here. Otherwise, you can just leave this section out and make a small change in the next section, and your home network will allocate an IP address for you automatically.

```
// APRS gateway IP; here: a local computer
byte aprsgate[] = { 192,168,1,20 };
// APRS gateway port
int aprsport = 8080;
// local originating port
unsigned int localPort = 8888;
```

This section of code describes the APRS-IS server or proxy server that you wish to send packets to. The `aprsport` is the port service identifier for the server, and the `aprsgate` is the IP address of the server. Here I use a local computer address. If you plan to test your UDP packet iGate, you will need to know the IP address of the server running APRS-IS proxy software. (In the later direct TCP connection version of the sketch, you would use the IP address of a nearby APRS-IS server instead.)

```
char inbyte = 0;
char buf[260];
int buflen = 0;
```

The character buffer of 260 bytes is most important: It will hold the decoded AX.25 frame.

```
void setup() {
    // start the Ethernet and UDP:
    // Ethernet.begin(mac);
    Ethernet.begin(mac, ip);
    Udp.begin(localPort);
    Serial.begin(4800);
}
```

The `setup()` function starts the Ethernet and UDP. Remove the comment characters before the shorter `Ethernet.begin(mac)` line if you have decided to use DHCP, and comment out the longer line.

```
void loop() {
    // as long as there are bytes in the serial queue,
    // read them and send them out the socket if it's open:
    while (Serial.available() > 0) {
        inbyte = Serial.read();
        // Get the byte
```

In each iteration of the runtime `loop()`, we check the UART input of the Arduino for a new character. We retrieve the single character and examine it.

```
if (inbyte == '\n') {
    // Check for end of line
    buf[buflen++] = inbyte;
    buf[buflen] = 0;
    Udp.beginPacket(aprsgate, aprsport);
    Udp.write(buf);
    Udp.endPacket();
    Serial.print(" ");
    Serial.println(buf);
    buflen = 0;
    buf[buflen] = 0;
```

If the newly acquired character is a newline, it means the frame is complete, and we send the buffer contents off via UDP to the proxy server. The character counter is also reset so that the buffer can be filled from the beginning when the next frame comes in.

For better debug monitoring, the frame will also be sent to the serial interface so that you can follow on your console. Note that the serial port output is shared with the Radio Shield input, and the first character of each line is a command to the Radio Shield. To avoid accidentally sending commands to the Radio Shield attached to the same serial port, start each line with a space. (Also, see the later section on how to use an LCD shield for display of packets.)

```
    } else if (inbyte > 31 && buflen < 260) {
        // Only record printable characters
        buf[buflen++] = inbyte;
        buf[buflen] = 0;
    }
}
```

If the character is not the “end of line” character, check if it is a readable character (ASCII value > 31) and if the buffer is not already filled, append the character to the buffer and finish the loop. Also, if we’ve received too many characters, then we discard the data until the end of line. (Unfortunately, this will concatenate bad and good data, so a later improvement will discard the too-long packet and the next one.)

Airgate UDP Sketch Operation

Remove the Radio Shield from the Arduino Ethernet board and connect the FTDI programming cable to upload the compiled sketch from the Arduino IDE. You should see a program size of about 8.5 kB. Replace the Radio Shield and check to make sure jumpers are connected to the RUN position. With a handheld and connected antenna, you should soon see text appearing in the Arduino IDE serial monitor, even if the UDP packets are not reaching their destination.

Back on your desktop or laptop computer, download the `udp-aprs-is-gateway.py` program and edit it to have your call sign, APRS-IS passcode, and latitude/longitude. Once you run it you should see packets being forwarded from the AirgateUDP sketch.

Now that you have an understanding of how the Airgate UDP version works, you can move on to the direct-connect TCP version below.

Airgate TCP with RGB LCD

While the UDP version has low power consumption, it relies on some type of forwarding or proxy server, such as we have with HAMNET. Enhancing Airgate to connect directly to the APRS-IS with TCP makes it a standalone system. For hams without access to a high-speed ham wireless network such as HAMNET, this option is likely to be the best option.

The Arduino Ethernet library makes it easy to switch from UDP to TCP, with only a few lines of change in code. The memory usage on the Arduino

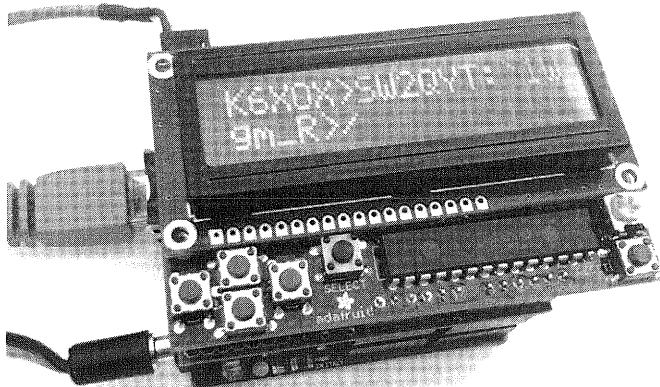


Figure 7.3 — Add the Adafruit RGB LCD shield for a convenient display, shown here atop the Arduino Ethernet MCU board. [Leigh L. Klotz, Jr, WA5ZNU, photo]

will increase to about 12 kB. That is about one third the flash memory that the Arduino has, so the increased code size has not yet become a problem.

Since the TCP version is standalone, we can no longer assume status output will be easily read from the Arduino serial port, so we will also add an LCD display. This sketch uses an Adafruit RGB LCD shield, but you can choose a different one by picking different files from the *LCD Shields* appendix.

Add the RGB LCD shield atop the shield stack (**Figure 7.3**) and, make a new sketch directory called AirgateTCPRGB. Copy the files colors.h, LCD.h, LineWrap.h, and RGBLCD.ino from the *LCD Shields* appendix into the new sketch, and save the file in Airgate_TCP_RGB.ino from the book resources site.

Here is a walk-through of the new sketch:

```
// Airgate TCP / RGB
// Copyright 2012 Markus Heller, DL8RDS
// LCD and libraries by Leigh L. Klotz, Jr. WA5ZNU

#include <Arduino.h>
#include <SPI.h>
#include <Ethernet.h>

#include <Wire.h>
#include "LCD.h"
#include "colors.h"
```

A few new include files make it easy to use the LCD.

```
// Change callsign, network, and all other configuration in config.h
#include "config.h"
```

Configuration information such as call sign and network is now in the config.h file in the sketch directory.

```
#define BUFFERSIZE 260
char buf[BUFFERSIZE+1];
int buflen = 0;
boolean bad_packet = false;

EthernetClient client;

void setup() {
    Serial.begin(4800);
    lcdbegin();
    display("AIRGATE - DL8RDS");

#ifndef USE_DHCP
    Ethernet.begin(mac);
#else
    Ethernet.begin(mac, ip, gateway, subnet);
    delay(1000);
#endif
}
```

Instead of EthernetUDP, the sketch now uses EthernetClient, which provides the TCP interface. lcdbegin() and display() offer an easy route to printing text on the attached LCD.

```
void loop() {
    // connect or reconnect to the APRS gateway
    boolean connected = check_connection();
```

The loop() function starts with a call to check_connection(). Unlike UDP, TCP has *state* and if the TCP connection is not present, there is no way to send data. So each iteration of the loop establishes or re-establishes the TCP connection.

```
// As long as there are bytes in the serial queue, read and send out
while (Serial.available() > 0) {
    char inbyte = Serial.read();
    if (inbyte == '\n') {
        // End of line:
        // send packet to APRS-IS
        buf[buflen] = 0;
        if (!bad_packet && buflen != 0) {
            if (connected)
                send_packet();
            // print packet to LCD
            display_packet();
        }
    }
}
```

```

// reset packet buffer
buflen = 0;
bad_packet = false;
} else if (inbyte < 32) {
    // ignore badly-decoded characters
} else if (buflen != BUFFERSIZE) {
    // If we haven't reached end of buffer space, write it.
    buf[buflen++] = inbyte;
} else {
    display("Data Too Long");
    // If buffer got full of characters and did not receive a EOL,
    // there is a problem,
    // so mark this packet bad and wait for the next.
    bad_packet = true;
}
}

// If connected to APRS-IS, read any response from APRS-IS and display.
// Buffer 80 characters at a time in case printing is slow.
if (connected) {
    receive_data();
}
}

```

The rest of the loop is similar to the UDP `loop()`, but we move the handling of packet data out into new functions `send_packet()` and `display_packet()`. The UDP version never reads back any data from the proxy server, but the APRS-IS server itself does print back data, such as login confirmation or error. The new function `receive_data()` handles displaying APRS-IS server responses.

```

// See http://www.aprs-is.net/Connecting.aspx
boolean check_connection() {
    if (!client.connected()) {
        lcdcolor(RED);
        display("Connecting...");
        if (client.connect(aprsgate, aprsport)) {
            client.println("user " CALLSIGN " pass " PASSCODE " vers " VERSION);
            client.println(CALLSIGN ">" DESTINATION ":" LATITUDE "I"
                           LONGITUDE "&" PHG "/" INFO);
            lcdcolor(BLUE);
            display("Connected");
        } else {
            display("Failed");
            // if still not connected, delay to prevent constant attempts.
            delay(1000);
        }
    }
}

```

```
    return client.connected();
}
```

The new `check_connection()` function sends the login and initial position packets and displays the status on the LCD. The RGB LCD includes a multicolor backlight, so the sketch uses RED for disconnected, and BLUE for connected. (In a cost-reduced implementation, you could substitute a three-color RGB LED for the entire display, just to obtain easy status information when visiting a remote site.)

```
void receive_data() {
    if (client.available()) {
        lcdclear();
        lcdcolor(YELLOW);
        while (client.available()) {
            char c = client.read();
            if (c > 31)
                display(c);
        }
    }
}
```

The `receive_data()` function displays the characters one at a time on the LCD. Besides avoiding the use of an extra memory buffer for what is only debugging information, it is a compromise between printing a screen full at a time with a delay, and printing it all at once. If you truly need to delay, see the screen paging options in sketch file `LineWrap.h`.

```
void send_packet() {
    client.println(buf);
    client.println();
    client.println();
}

void display_packet() {
    lcdclear();
    lcdcolor(GREEN);
    display(buf);
}

void display(char *msg) {
    lcdclear();
    lcdprint(msg);
}
```

```
void display(char c) {
    char rbuf[2];
    rbuf[0] = c;
    rbuf[1] = 0;
    lcdprint(rbuf);
}
```

This set of packet sending and display functions rounds out the sketch.

Airgate TCP Sketch Configuration

Save this file in config.h and edit it for your station:

```
// Configure your AirGate in this file.

// Set your callsign-SID:
#define CALLSIGN "DB0ZM-5"

// Set your APRS passcode code:
// Contact local APRS hams to find out your passcode,
// or ask on the book forum site.
#define PASSCODE "99999"

// Define the latitude and longitude of your AirGate:
#define LATITUDE "4912.65N"
#define LONGITUDE "1203.20E"

// PHG gives information about the station capabilities.
// PHG01000 describes an RX-only beacon 20ft AGL
//           with a 0db gain "discone" antenna.
// PHG01600 is the same with a 6dB gain (J-Pole) antenna
// PHG02600 is the J-Pole up 30ft.
// Calculate yours at http://www.aprsfsl.net/phgr.php
#define PHG "PHG01000"

// IP address of the APRS-IS backbone gateway in your country:
IPAddress aprsgate(93, 221, 125, 165); // Koblenz, Germany

// Enter the MAC address Arduino Ethernet:
// Find it on the board or the box it came in.
byte mac[] = { 0xDE, 0xAD, 0xBE, 0xEF, 0xFE, 0xED };
```

The above configuration options are all personal for your Airgate, and you must set them properly before using your sketch. The next set, configuring your Internet address, has two options:

```
// Specify your IP address, gateway, and subnet with DHCP or manually:
IPAddress ip(192, 168, 178, 177);
byte gateway[] = { 192, 168, 178, 1 };
byte subnet[] = { 255, 255, 255, 0 };
```

If you specify your network address manually, edit the section above. Otherwise, use the section below.

```
// If use you DHCP, use this line and remove the manual settings.  
#define USE_DHCP 1
```

Obtaining the local network IP address and other information from a DHCP server works well in a home network, but it adds over 2 kB of code to the sketch, and may be undesirable in a remote location where the network is configured statically.

```
// TCP port of APRS-IS service:  
int aprsport = 14580;  
  
// Software version information, for login and position packet.  
#define VERSION "Arduino_AirGate (dl8rds,2012-05-30)"  
#define INFO "Arduino AirGate IGATE"  
  
// APRS destination, which indicates the APRS device being used:  
// This one identifies Argent Data products.  
#define DESTINATION "APOTW1"
```

These parts of the configuration are rarely edited.

Adding an SD Card

The Arduino Uno Ethernet has a built-in SD card socket, and so adding in a local data logging feature is a simple addition of a few lines of code. Bringing in the SD card library, however, adds a considerable amount of memory usage on the Arduino. While the TCP version with LCD and DHCP support is about 12 kB, adding in SD card support more than doubles the size to 27 kB, nearing the 32 kB limit for program memory.

Download the AIRGATE_TCP_RGB_LCD_SD sketch, or copy AirgateTCP_RGB_LCD.ino sketch to Airgate_TCP_RGB_LCD_SD.ino and make the following additions:

In the headers section, add this line:

```
#include <SD.h>  
#define SD_CARD_CS 4
```

In the setup() function, add the following at the end:

```
// see if the card is present and can be initialized:  
if (!SD.begin(SD_CARD_CS)) {  
    lcdprint("SD Card Failed");  
    return;  
}
```

In the loop function, right after the call to display_packet(), add these lines:

```
// save packet to SD Card
save_packet();
```

At the end of the sketch file, add this new function definition:

```
void save_packet() {
    File file = SD.open("datalog.txt", FILE_WRITE);

    // if the file is available, write to it:
    if (file) {
        file.println(buf);
        file.close();
    } else {
        lcdcolor(RED);
        lcdprint("SD Card Failed");
    }
}
```

UDP to TCP Relay

If you want use the UDP sketch, but do not have access to an APRS-IS system or a UDP to APRS-IS proxy such as those offered by HAMNET, you can use the a desktop or laptop computer to run a Python program to relay the UDP packets from the Arduino to an APRS-IS. The Python program that implements the UDP to APRS-IS TCP gateway is available as an online resource, and is called `udp-aprs-is-gateway.py`. For more information on Python, see the sidebar in Chapter 4.

Amateur Radio Licensing

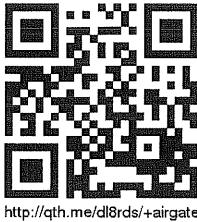
Although you do not need a license to operate a ham radio receiver in the US and most other countries, to take full advantage of the *Airgate* project you need an Amateur Radio license in order to authenticate with the global APRS-IS network.

Further Ideas

Here are some ideas for how you can adapt this project to meet your needs:

- Implement two-way APRS messaging by issuing an APRS FILTER command to the APRS-IS over TCP, process incoming messages for stations in your area, and send them out over the RF link.
- Read the *APRS iGate Properties* document in the references, and implement more iGate features.
- Implement a TCP server and provide your own mini APRS-IS service. At a minimum, accept incoming connections and send the same data stream to them that you send to the upstream APRS-IS. Add in authentication and message transmit features.
- Combine the message TX and TCP server facilities to make a gateway that can relay Internet messages to and from APRS stations in your local area.

- Add a GPRS cell mobile shield make an SMS to APRS gateway for your local area.
- If you are building a large number of Airgate systems, store the MAC address in Arduino EEPROM so that you can use the same sketch on different devices.



<http://qth.me/dl8rds/+airgate>

References and Further Reading

- Online references
<http://qth.me/dl8rds/+airgate>
- Project source code
<http://qth.me/dl8rds/+airgate/code>
- Inspiration
I was inspired by <http://www.botanicalls.com> where an Arduino sends Twitter messages about the thirstiness of flowers.
- YouTube video
I describe the Argent Data Radio Shield, in German:
<http://www.youtube.com/watch?v=SuR8mAFTHw8>
- Argent Data Radio Shield
http://wiki.argentdata.com/index.php?title=Radio_Shield
- APRS information
<http://aprs.org>
<http://aprs.org/doc/APRS101.PDF>
- APRS Tier2 Network
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- APRS protocols
<http://www.aprs.net/vm/DOS/PROTOCOL.HTM>
- Connecting to APRS-IS
<http://www.aprs-is.net/Connecting.aspx>
- APRS iGate properties
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- Python programming language for *Windows*, *Linux*, and Mac
<http://python.org>
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- PHG calculator
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- Python Beginners Guide
<http://wiki.python.org/moin/BeginnersGuide>
- Python for non-programmers
<http://wiki.python.org/moin/BeginnersGuide/NonProgrammers>
- Arduino Ethernet Library
<http://arduino.cc/en/Reference/Ethernet>
- SparkFun Arduino Ethernet Pro (no longer available)
<http://www.sparkfun.com/products/10536>

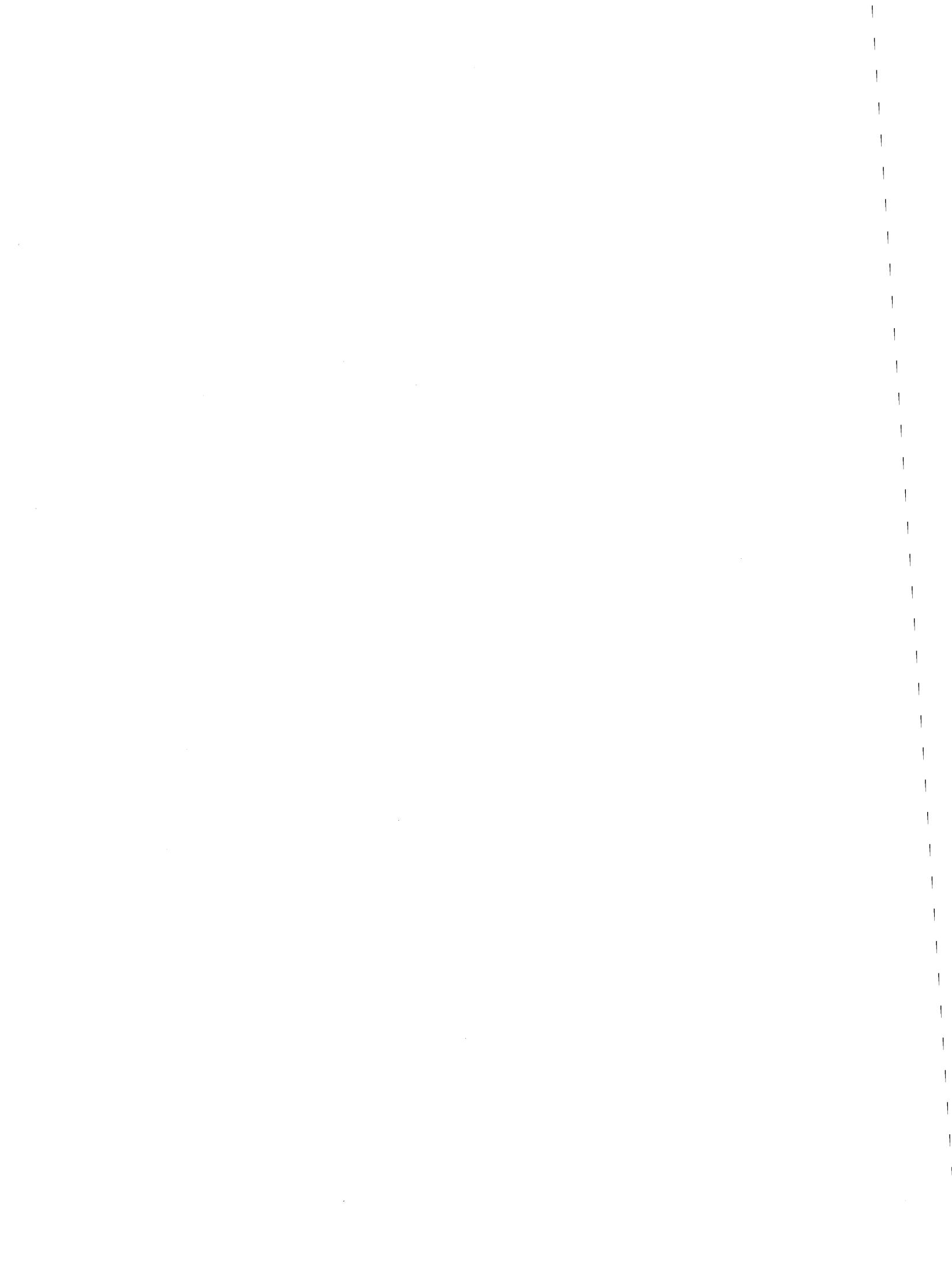
- Arduino Uno Ethernet
<https://www.adafruit.com/products/418>
- NRGX1 FM receiver module (order 144.39 MHz for US)
http://www.lemosint.com/radiometrix/radiometrix_details.php?itemID=212
- APRS-IS send-only ports
<http://www.aprs-is.net/SendOnlyPorts.aspx>
- Internet Protocol UDP
http://en.wikipedia.org/wiki/User_Datagram_Protocol
- Internet Protocol TCP
http://en.wikipedia.org/wiki/Transmission_Control_Protocol
- Stacking headers
 These are a popular item and you can add them to your order from just about any popular Arduino supplier:
 Evil Mad Science: <http://evilmadscience.com/productsmenu/partsmenu/251>
 SparkFun: <http://www.sparkfun.com/products/10007>
 Jameco: <http://www.jameco.com>
 Adafruit: <http://www.adafruit.com/products/85>
- FTDI cable or breakout board for programming the integrated Ethernet Arduino
<http://www.sparkfun.com/products/9717>
<http://www.adafruit.com/products/70>
<http://www.jameco.com>
<http://jeelabs.com/products/usb-bub>

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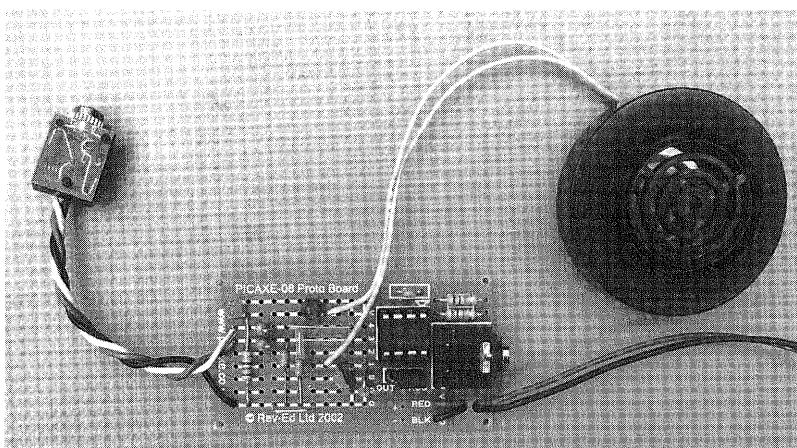
About the Author

Markus Heller, DL8RDS, is a computer scientist by profession and has his HF rig in the Bavarian town of Burglengenfeld, but lives in Munich. Since he cannot set up big HF antennas there, he loves to tinker with small things such as Arduinos and other embedded devices whenever he cannot travel to Burglengenfeld. He has been a ham since 1989. Visit his website at http://www.dl8rds.de/index.php/About_me for more information.



Axekey: A Simple PICAXE Keyer

Rich Heineck, AC7MA



The completed PICAXE keyer, showing the AXE021 prototype board, keyer jack and a small speaker. Battery power is three AA batteries. [Rich Heineck, AC7MA, photo]

Amateur Radio experimenters often end up building a simple single band transmitter or transceiver. These radios are used for sending CW (Morse code) and typically have an input connection for a hand key. A useful addition to these rigs is a circuit called a keyer, which, when used with a set of paddles, will greatly ease the sending of well-timed Morse code. The paddles are a single or dual set of levers that have two contacts — one for sending a dot, and the other a dash.

This project will show how simple a basic, no-frills keyer can be, and is based on the 8-pin PICAXE-08M2. We built ours on the low cost PICAXE-08 Proto Board, but the keyer could easily be built into a new or existing project using less space. Another possible use for the keyer is to use the keying output line to activate an audio oscillator, making it into a code practice oscillator. Our project has a small piezoelectric buzzer in series with an LED.

Hardware

Before we look at the software for the project, let's take a quick peek at the hardware. In order to write any code that directly interacts with a circuit, we first have to figure out what that circuit needs do. For a keyer, we have paddle inputs (two signals) and a keying line output. The convention for paddles is to have contacts that close to ground when pressed. To get two logic voltage levels

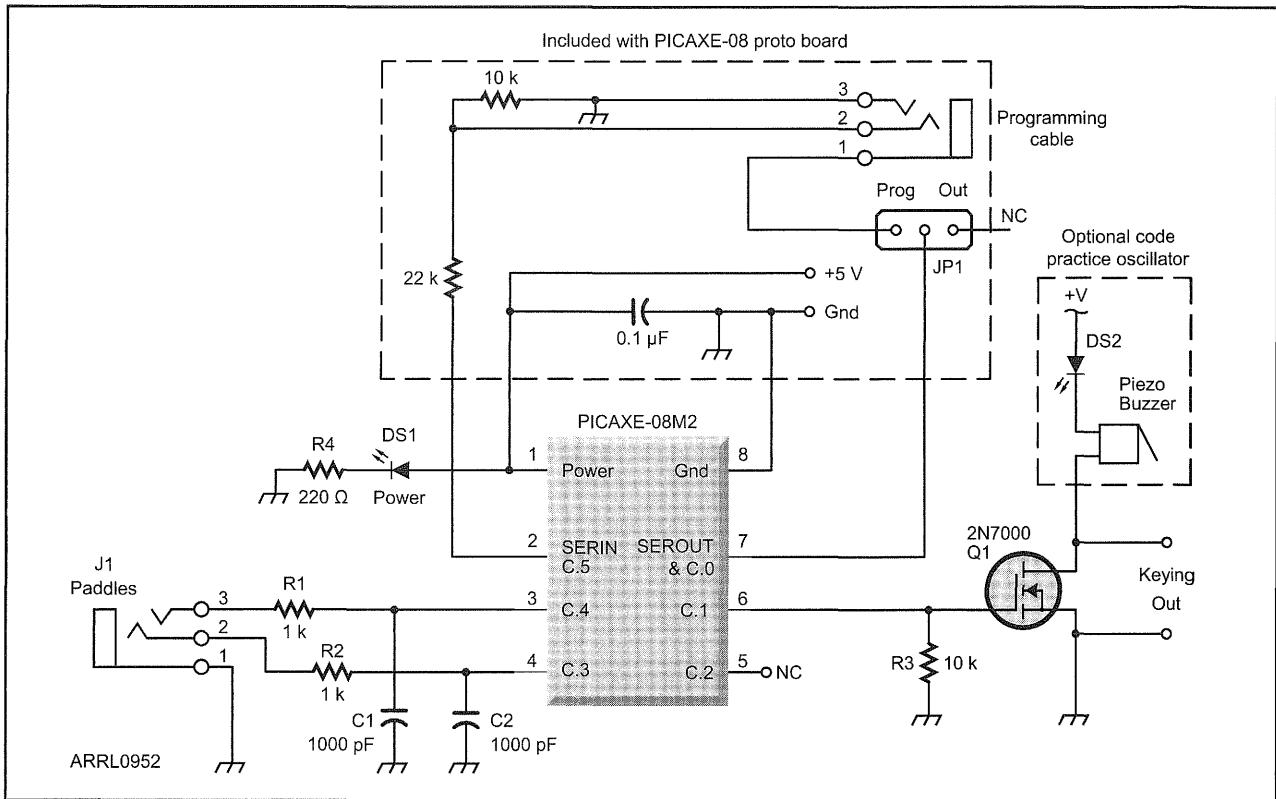


Figure 8.1 — Schematic of PICAXE keyer. The PICAXE-08 proto board (part number AXE021) includes a jack and components for the programming cable interface. A jumper on the board (JP1) switches pin 7 between SEROUT in programming mode and the C.0 output during operation. (C.0 is not used in this project.)

from this, we would use pull-up resistors connected between each input and +V. A nice feature of the PICAXE chip is that it has these resistors built in so we don't need to put them in our circuit. We'll see how to "connect" them when we look at the software.

You may notice from the schematic in **Figure 8.1** that each paddle input goes through a series resistor (R1, R2) and capacitor to ground (C1, C2) before it gets to the PICAXE. These parts aren't required to make a working keyer, but they are good engineering practice because they serve three purposes. The first one is that they provide ESD (electrostatic discharge) protection to the PICAXE CMOS inputs. This type of input conditioning is a common practice in the electronics industry to protect devices from getting zapped on connections that go to the outside world. The second function the RC network serves is to debounce the paddle contacts. For the keyer shown here, the R and C values are probably inadequate for effective debouncing, but we really don't need that feature since the software takes care of it for us. (See the sidebar, "Debouncing," for a full discussion.) And finally, an important consideration for ham projects is bypassing to prevent ingress of RF energy from nearby transmitters.

Moving on to the keyer output, a transmitter's keying input is expected to be pulled to ground to transmit. The PICAXE output is limited to its power supply voltage range, and it can source or sink a maximum of 25 mA. Many transmitter

Debouncing

Although they look like ideal devices in a schematic, mechanical switches do not close instantaneously. Instead, they make and break many times during the initial contact period. We don't perceive this oscillation when we use a switch to control an LED, because our eyes cannot see changes that happen that quickly, but you can see it with a digital storage oscilloscope. Our PICAXE and Arduino microcontrollers will see it as well: A program that reads the state of an input pin and takes quick action in a loop may erroneously take action multiple times in the fraction of a second during which the switch is still doing its make and break.

Two common means of debouncing are an RC low pass filter or integrator on the switch output, and a delay loop in the microcontroller code to wait for a small number of milliseconds after detecting a button push. Software debounce reduces the component count, but analog filtering is necessary when the input is driving a microcontroller interrupt, as software debounce is often not possible.

The PICAXE includes a BUTTON command that provides a software debounce using an internal delay loop, but it is not appropriate for this program because the delay would add to the interval between keying elements, making the program more complicated. However, it is appropriate for PICAXE programs where event timing is not critical.

In the PICAXE keyer, the RC input filter on pins c.3 and c.4 uses the delay in the capacitor charging to build up to the TTL ON voltage and discharging back down to the OFF voltage. With an RC time constant of $1/(2\pi RC) = 2\pi \times 1 \text{ k}\Omega \times 1 \text{ nF}$ or about $6 \mu\text{s}$, the RC low pass filter is not a significant contributor to the debounce, and so in this program, it is the software logic that does the majority of the work for the debounce.

Since the program reads the input pins only at the start of each element, and the minimum delay between elements at 30 WPM is $1200/30 = 40 \text{ ms}$, the switch has ample time to settle down before the next read. The loop delay is present, but spread throughout the program.

circuits have voltages or currents at the keying input that would damage or destroy the PICAXE chip, so we use a 2N7000 MOSFET (Q1) in an open drain configuration. Until the keyer program is running, the C.1 output pin will be floating. This is why we put R3 in the circuit, so we won't inadvertently key an attached transmitter when powering up or programming the part. By default, PICAXE I/O pins are inputs until specifically set up as outputs, so this is a good practice for output pins that need to get held at a certain level when not deliberately driven.

We've now defined the inputs/outputs (I/O), so let's take a look at how the software will view this. For the paddles inputs, when a key is pressed we'll see a voltage close to ground, or a logic low. We need to know this so we can have the program tell the difference between "pressed" or "not pressed." A logic high on the keying output will cause our transmitter to transmit, so we need to know which way to drive that line at the appropriate time.

And one last thing: before we can write a keyer program to generate Morse code, we need to know the exact details of what it is we're supposed to do, so let's summarize it. Morse code is a timed sequence of dots, dashes and spaces. Timing revolves around a *unit time*, which is the duration of one dot or one inter-element space. A dash is three times as long as a dot, and the space between letters is also three unit time periods. The keyer performs the timing

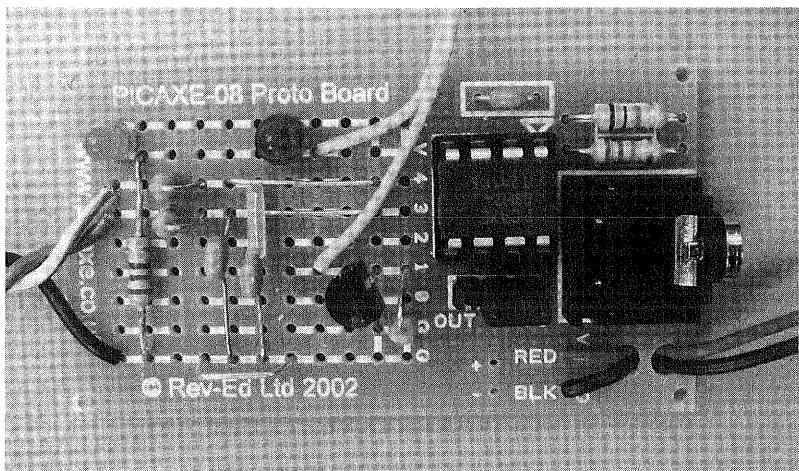


Figure 8.2 — A close-up of the completed keyer on the AXE021 prototype board. [Rich Heineck, AC7MA, photo]

to generate perfect dots, inter-element spaces and dashes. It's up to the sender to add the extra space between letters, and also between words (seven unit time periods).

But what constitutes *keyer speed*, or how many words per minute our keyer sends? A quick look at Wikipedia confirms that the standard for code speed is based on the PARIS standard of 50 dot durations per average word. This simplifies to the formula

$$T = 1200 / W$$

where T is the unit time in milliseconds and W is the number of WPM. Our program will need this formula to translate WPM to our fundamental time unit.

There's one last bit of detail dealing with how paddle presses need to be translated into dots or dashes: If the dot paddle is pressed, generate a series of dots, and if the dash paddle is pressed, generate a series of dashes. But our keyer allows a dual lever paddle with separate levers and contacts for dots and dashes, and that means that both switches can be engaged at the same time. Hams have had different ideas about how to take advantage of this possibility, but the most popular is something called *iambic keying*, and there are two modes, creatively named A and B. The Wikipedia page on iambic keying gives a good explanation of how this is done for the two iambic modes. For iambic A, if both are held simultaneously, the keyer output alternates between dots and dashes. Iambic B builds on this and has to do with the timing of paddle releases. Other timing subtleties can come into play that affect the "feel" of the keyer, but our purpose here is to keep it simple.

Software

Okay, the hardware interface has been defined, and we know exactly what Morse code is, so it's time to move on to software! We'll start out with a program that implements a fixed-speed iambic mode A keyer. From there we'll show how it can be modified to become iambic mode B, and then we'll look at a way to add variable speed. Anything beyond that is up to you, so now is a good time to start building as you follow along.

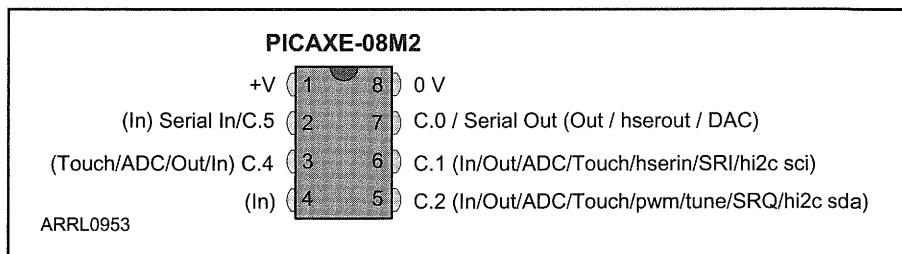
Symbols

Why all those extra lines making up names for things?

We put some extra lines in our program to define names for I/O pins and numbers. These are not necessary to make the program work, and they could have been left out and the values used directly throughout the program instead. However, doing it this way will help reduce programming errors and make the program easier to understand and modify later on.

As you can see in the accompanying pinout diagram from the PICAXE manual, each pin has multiple uses, and using symbolic names helps keep track of exactly what role the pin plays in the circuit.

Let's use `KeyOut` as an example. Right now it translates to I/O pin 1 in the 08M2 (C.1, not physical pin 6), but let's say sometime in the future we need to change the program so it uses I/O pin C.2 as the output keying line instead. With the defined symbol, all we need to do is change that one line then reprogram the PICAXE part. This is much easier and far less likely to result in a mistake when compared to hunting through the entire program for every hard coded 1 where that pin is referenced. Maybe not a big deal with this simple program, but when a program gets a lot more complicated, it becomes a much more difficult task to get every occurrence. Not to mention the debugging time to find the one that got missed — and then only after the bug was discovered! A similar thing for `SPEED_WPM`. If we want to later change this speed, it becomes a simple edit in one (and only one) obvious spot.



PICAXE 08M2 pinout, showing the names and functions of each pin.
[Courtesy Picaxe.com]

The iambic mode A keyer program is in the source file `Keyer_A.bas`, which we'll go through section by section. It may be useful to also refer to the Rev-Ed documentation for a detailed explanation of the PICAXE BASIC commands and keywords. We'll assume at this point that you're somewhat familiar with the PICAXE and its development tools. Now is also a good time to have the PICAXE manuals handy as a reference if you're new to PICAXE programming.

Our `Keyer_A.bas` program starts out with the line:

```
#picaxe 08M2
```

This is a Directive statement to the PICAXE compiler, but is also useful to us in that it defines which PICAXE chip this program is meant to work with.

The program then contains a number of definitions for numerical constants, variables, and I/O pins used.

```

; Constants
symbol SPEED_WPM = 15      ; Keyer speed, words per minute

; I/O Pins
symbol KeyOut = 1      ; Keying output pin (C.1): Set hi to TX
symbol DotPin = pin4      ; Dot paddle input (C.4): Low = pressed
symbol DashPin = pin3      ; Dash paddle input (C.3)
symbol PULLUP_MASK = $18      ; Set bits for Dot and Dash paddle input pins

; Variables
symbol dot_ms = w0      ; DOT time in milliseconds

```

You might be asking why we go to this trouble when we could just plug these numbers into the program where they're needed. See the sidebar, "Symbols," for an explanation and example. The variable `dot_ms` is our keyer unit time described above. For the program, it's the number of milliseconds this fundamental time period needs to be to generate code at a given words-per-minute rate. More on that later.

Next we'll skip to the end of the program where subroutines are defined. A subroutine is a useful way to put a chunk of code that does one thing in one spot, where it can be called (using `gosub`) from multiple spots in the program, saving program space and making a program easier to write and maintain. Even if it only gets called once, it's a convenient way to break the program up into small, easier to understand pieces.

```

; Generate a dot or dash, followed by the inter-symbol space.

gen_dash:
    high KeyOut
    pause dot_ms      ; A dash is 3 dot lengths
    pause dot_ms
    ; Fall through to gen_dot

gen_dot:
    high KeyOut
    pause dot_ms
    low KeyOut
    pause dot_ms      ; Inter-symbol space is one dot length
    return

```

These are the sections of code that generate the dots and dashes. In a programming language such as C, we would have structured this to be two independent subroutines (or functions), but here we chose to use two entry points and one exit. Since a dash is effectively an elongated dot, this approach allows us to share common code and conserve memory.

The first thing we want to do when making a dot or dash is to set the keying output pin high to start the element. We then delay the needed number of `dot_ms` periods using the `pause` command, then set the output low, and finally end it by waiting one unit time for the inter-element space (again using `pause`), before returning. In the case of a dash, we delay two of the three

unit time periods after setting the output high before dropping into the dot generating code to finish it up. You may notice that by dropping into gen_dot from gen_dash we hit the line that sets KeyOut high, but the pin is already at that state. Although redundant, this extra line won't hurt anything, and it is necessary if entering at gen_dot. From here the timing for finishing the dash is just like generating a dot: One more unit time delay, set the output low, wait for the inter-element space, and then exit.

Now that we have the fundamental building blocks under our belt, we'll skip back to the place where the PICAXE actually starts executing code when the program starts running.

Startup:

```
pullup PULLUP_MASK ; Enable internal weak pull-up on paddle inputs
let dot_ms = 1200 / SPEED_WPM ; Set dot time based on word speed

; Main keyer loop
; Check for a pressed switch or paddle and generate a dot or dash
; as needed. By alternating the scanning, Iambic mode A is implemented
; The time generating a dot or dash also does contact debouncing.
```

main:

```
if DotPin = 0 then gosub gen_dot
if DashPin = 0 then gosub gen_dash
goto main
```

The first thing that happens when the program starts up is to initialize stuff that needs to be set up before the main part of the program gets going. These are often things that get done once and never change. The pullup command connects those internal resistors we talked about earlier between the paddle input pins and +5 V. After that we calculate the number of milliseconds a unit time needs to be to run the keyer at the code speed we defined at the beginning of the program.

From there we enter the main part of the program, which we label as `main`. Believe it or not, the three lines of code that follow are what pull everything else together to create an iambic mode A keyer! All it does is alternately check each paddle line to see if the contact is closed, and generate a dot or dash as needed. Pretty simple, huh?

Iambic Mode B

In iambic mode A, we only had to do one thing at once: Check the dot paddle. If closed, generate a dot. Then look at the dash paddle. If closed, generate a dash. Repeat forever. Iambic mode B gets a bit more complicated because while we're generating a dot or dash, we have to watch for the opposite paddle to get closed and then remember it so we can immediately send its element after the current one finishes. Ideally, we would be checking the other paddle contact every nanosecond to pick up even the briefest of closures, but not only is this impractical, it really isn't necessary.

Looking back at the `Keyer_A.bas` program, we see that our timing is

done by the pause command. It's a very convenient way to delay a precise amount of time, but it also doesn't let us do anything else while we're waiting, such as looking at the opposite paddle input, for example. One fairly obvious way to solve this problem is to break our pause periods into really tiny chunks, interleaved with checks of the other paddle input. This would work, but how small do we need to make those chunks? Now here's where we can be a little lazy and do a job partially, and get away with it quite nicely. As long as the keyer feels okay, then we've succeeded, right?

We already have a convenient unit time in `dot_ms`, and remember that a dot is followed by a matching inter-element space, and that a dash is 3 dot lengths and is also followed by an inter-element space. If we add code to check the opposite paddle input every time we do a pause `dot_ms`, it gets one check in at the middle of the dot (plus space), and a couple extra in during a dash. Most of us won't know the difference between doing it this way and doing it the "ideal" way since we're just not that fast or fussy. Not elegant, but good enough!

The relevant section from `Keyer_B.bas` is shown below.

```
; Generate a dot or dash, followed by the inter-symbol space.
gen_dash:
    high KeyOut
    pause dot_ms      ; A dash is 3 dot lengths
    if DotPin = 0 then gosub queue_dot
    pause dot_ms
    if DotPin = 0 then gosub queue_dot
    pause dot_ms
    if DotPin = 0 then gosub queue_dot
    low KeyOut
    pause dot_ms      ; Inter-symbol space is one dot length
    let do_dash = 0
    return

gen_dot:
    high KeyOut
    pause dot_ms
    if DashPin = 0 then gosub queue_dash
    low KeyOut
    pause dot_ms      ; Inter-symbol space is one dot length
    let do_dot = 0
    return

; Set dot or dash flag for remembering double paddle press
queue_dot:
    let do_dot = 1
    return

queue_dash:
    let do_dash = 1
    return
```

Notice that we've split `gen_dash` and `gen_dot` into separate subroutines. This is because each needs to check the opposite paddle while it's running. If we kept a shared section, we wouldn't know which paddle to check. Here's how it works: If a dot paddle closure is detected while in the middle of `gen_dash`, we have to remember that and finish generating the dash before making the dot. Same thing the other way around. We do this by calling `queue_dot` (or `queue_dash`), which sets a flag called `do_dot` (or `do_dash`). We can then test this flag inside the main program loop to see if the opposite paddle was hit while we were generating an element. One last thing we need to do is clear the flag each time we're through with it or we'll get a continuous string of dots/dashes long after we've let go of the paddles.

Here's how the main program loop gets changed to add the checks for the flags:

```
main:
  if DotPin = 0 or do_dot = 1 then gosub gen_dot
  if DashPin = 0 or do_dash = 1 then gosub gen_dash
  goto main
```

It's still only three lines long!

Variable Speed

Changing the speed in either of the two preceding programs is a simple single line edit, but that's still pretty inconvenient when we want to make the adjustment on the fly. Here we'll show a way to set the speed when the keyer is powered up. It even remembers the last setting when power is removed, so the next time it's started, it will be at that same speed.

We start in the symbol definitions area by defining some new constants:

```
; Constants
symbol NV_Speed = 0 ; EEPROM address used to store keyer WPM
symbol MAX_WPM = 30
symbol MIN_WPM = 8
```

Since speed definition takes place at startup, it needs to get executed before we drop into our main program loop. The reason for this is because we use the two paddles to do the setting, and once we drop into the main loop, the paddles are used for sending Morse code. A button could have been added to one of the spare PICAXE pins, and when pressed would change the function of the paddles over to speed setting. This would be an easy way to put the speed setting into the main loop so it could be done at any time the keyer is running without having to cycle power off then on. Maybe it's something to add later?

```
read NV_Speed, tmp_Speed      ; Retrieve stored value
let old_Speed = tmp_Speed    ; Keep copy of stored speed

set_speed:
  if DotPin = 0 then
```

```

; DOT pressed - increment speed
tmp_Speed = tmp_Speed + 1
if tmp_Speed > MAX_WPM then ; Don't go above maximum WPM
    let tmp_Speed = MAX_WPM
endif
gosub update_speed
goto set_speed

else if DashPin = 0 then
    ; DASH pressed - decrement speed
tmp_Speed = tmp_Speed - 1
if tmp_Speed < MIN_WPM then ; Don't go below minimum WPM
    let tmp_Speed = MIN_WPM
endif
gosub update_speed
goto set_speed

else if old_Speed != tmp_Speed then ; Store new value if changed
    write NV_Speed, tmp_Speed
endif

; Signal exit from speed setting by sending "dit dit"
gosub gen_dot
gosub gen_dot

let dot_ms = 1200 / tmp_Speed ; Set dot time based on word speed

```

The first thing we do is fetch our last saved speed from nonvolatile memory and make a copy of it. The copy allows us to see if the speed got changed so it can get saved for next time. It's not necessary to make the copy and test for a change before saving, but it saves needless wear and tear on the EEPROM.

We then drop into the main part of the speed setting loop. As long as one of the paddles is held down, the speed will either be increased or decreased, and the program will keep looping back to `set_speed`. This is where the constants `MAX_WPM` and `MIN_WPM` come into play. We obviously don't want to decrease or increase the speed beyond reasonable limits, so these two values put caps on how low or how high the speed actually goes.

We've also added a new subroutine:

```

update_speed:
    let dot_ms = 1200 / tmp_Speed ; Set dot time based on word speed
    gosub gen_dot
    pause 300
    return

```

This block of code plays two important roles. One is to calculate the new value for our unit time and output a dot so we can hear the new speed, but the second is to put a fixed throttle on how fast we update by using the `pause`

300 statement. This way if we get up to high speeds we'll still have good control without blasting away like a machine gun! Try commenting that line out and see what happens!

The Completed Project

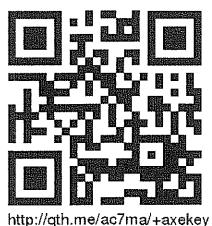
You can build the keyer as I did on the PICAXE 08M2 Proto Board, part AXE021. It includes a connection for the inexpensive PICAXE programming cable and a prototyping area with room for the project parts. You can also breadboard the design, or incorporate the PICAXE 8-pin DIP and its associated parts into your own PCB design.

Where to Go from Here

The PICAXE is an affordable and easy to use platform for these one-of-a-kind projects that don't require sophisticated features or difficult programming. One advantage of building — and programming — your own keyer is that you get to change it as you see fit. The examples shown are by no means the only way to accomplish these goals, nor necessarily the best, but are meant to be a way to get started. With a few spare pins left and a lot of unexplored PICAXE commands available, there are a number of enhancements that could be done or new features added.

Many keyers have memory, but it's easy to forget how to operate the memory given the limited user interface of a keyer. Since you've programmed your own, you can reprogram it at any time and add or change memories. Add a switch to the C.2 pin to send CQ or your call sign. Or use a resistor ladder and two buttons (or a potentiometer) to use the READADC command to add multiple memories.

A bigger challenge is to modify the program to implement an Ultimatic mode keyer. While iambic keying is the most broadly supported keyer style from transceiver manufacturers, Ultimatic dates from 1953 (!) and has been getting attention the last few years. Where the two iambic modes alternate between dots and dashes when both paddles are held, Ultimatic starts with the element for the first paddle pressed then follows with a continuous string of elements for the last paddle pressed. A *QST* article search for "Ultimatic" will find a wealth of information on this mode. Give it a try and you might find you like it better than iambic!



<http://qth.me/ac7ma/+axekey>

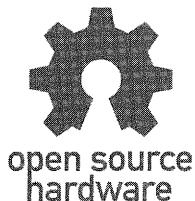
References and Further Reading

For more information on topics covered in this project, see the following references:

- Online references
<http://qth.me/ac7ma/+axekey>
- Source code
<http://qth.me/ac7ma/+axekey/code>
- Getting started with the PICAXE:
<http://www.picaxe.com/Getting-Started/PICAXE-Manuals/>
<http://www.picaxe.com/docs/picaxem2.pdf>

- Keyers and keying interfaces
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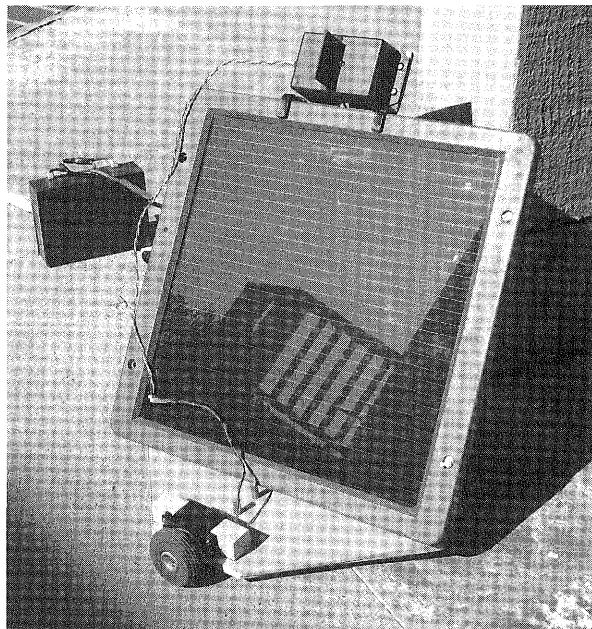


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About the Author

Rich Heineck, AC7MA, lives near Seattle, Washington. He has a Bachelors degree in Electrical and Computer Engineering, and had worked for more than 25 years in the medical device industry. Following a very brief retirement, he recently has been involved with product development at Elecraft. Rich holds an Amateur Extra class license and enjoys homebrewing and QRP operation, particularly when combined with hiking and camping. He also enjoys mountain biking and exploring the mountains and wild areas of the western US.

Sunflower Solar Tracker

Bill Prats, K6ACJ

The Sunflower solar tracker is a simple device that keeps a 5 W solar panel oriented toward the sun. Elevation is fixed, and the Sunflower adjusts the azimuth to follow the sun throughout the day.
[Bill Prats, K6ACJ, photo]

Living in Southern California near the beach, I am torn between staying in the ham shack for the high-band radio propagation that the solar UV generates, and going outside and enjoying the sun and surf directly. On warm summer days, I often load up my VW van with portable HFPack style ham gear and head to a beachfront park where I rag chew with hams nearby in California and Nevada on 40 meters NVIS (Near Vertical Incident Skywave propagation). I enjoy working DX on 20 meters when I can park within a few wavelengths of the Pacific Ocean and enjoy the benefits of the saltwater “amplifier.”

When winter rolls around again and the low bands go long at night, my 40 meter friends and I plan a trip to somewhere warm again, and this January our destination was Quartzsite, Arizona. There we joined hundreds of other hams who drove across the west to share 10 days of ham radio activities in the desert at Quartzfest, an ARRL event for ham RV enthusiasts. There are no facilities: just dirt, rocks and little crawly things. To enjoy the camaraderie of your fellow hams, you need to bring your own supplies, including food,

water and power. We enjoyed hourly forums, public service communications training, antenna shootouts, geocaching, ARDF fox hunts, license exams, and brainstorming with fellow hams.

Experiments in radio and antennas are everywhere. Ground mounted and RV roof mounted antennas abound, some tilted and raised by hydraulic or direct drive mechanisms, and a few suspended from kites or balloons. There is almost everything from simple antenna configurations to complicated Sterba curtain arrays. Off-grid power is the rule, and sources vary from solar to wind to conventional gasoline powered generators.

In this remote location, solar power can quietly maintain batteries to extend operating hours and enjoyment. A portable solar panel set against a tree or tire and carefully aimed at the sun provides power for a while, but as the QSOs pile up, the sun moves across the sky and the output current drops. I have found at 43 degrees latitude that repositioning the solar panel is necessary at least four times per day.

For the last few years I have used a large homebrew solar tracker that faces a 43 W Kyocera KC-40T photovoltaic (PV) panel both horizontally and vertically into the sun as it arcs across the sky. When I operate with a 100 W SSB rig, it maintains battery voltage near 13 V, resulting in full power output from the rig and longer hours of operation.

Sunflower Solar Tracker

At Quartzfest, where the Arizona desert visibility extends to the far horizons, two-dimensional (2D) tracking gives as much as 50% more energy per day than a fixed position panel. Using the NOAA online solar calculator (see the References section at the end of this chapter), I found that daylight hours during Quartzfest extend from 6:38 AM to 5:01 PM local time, and I used the graphic shown in

Figure 9.1 to decide how many degrees of tracking I would need. The right line shows sunrise in the east, and the left line points to the setting sun in the west. Other information at the NOAA site gives the elevation angles of the sun during the day.

If you don't have a full view of the horizon, a fixed elevation angle is good enough for many hours of operating, and the necessary mechanism weighs and costs less than a 2D tracker. For Quartzfest this year, I decided to showcase a simpler, lightweight one-axis solar tracker that would work well at Quartzsite, at my beach front park, and in the Northern California county parks where I sometimes hike with other HFPack hams.

The Sunflower solar tracker supports a 5 W automotive dashboard solar panel to charge NiCd and NiMH AA-size battery packs. The electronics package contains the battery power, microprocessor, light sensors and motor driver H-bridge.

The key innovation in this project is a pivot and wheel drive that is easy to assemble and works

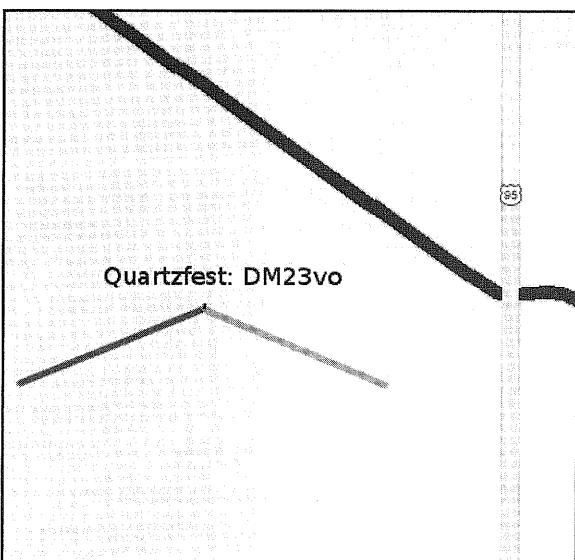


Figure 9.1 — The direction of the sun at sunrise (right trace) and sunset (left trace) can be found using the solar calculator on the NOAA website (see the References section at the end of this chapter).

well in the field. The pivot supports the back end, and a large rubber wheel moves the front end to follow the sun and to maintain maximum output current. Because the sun moves slowly, Sunflower needs a motor drive system that can make small, precise movements of the wheel.

I modified a standard-sized remote control (RC) airplane servo motor to drive the solar platform left and right. Servo motors for RC projects are inexpensive and use low-voltage dc motors with gear reduction to generate high torque. They are absolute angle rotary drives, where rotation angle is limited in range and position is directly set by a pulse-width modulated (PWM) digital signal.

In this project I repurposed a servo and removed the both internal electronics and the motion stop so I could use just the motor assembly as a precise, low-voltage, high-torque motor. The HiTec HS-425BB servo has mechanical features that are ideal for maneuvering the solar panel and support: high gear reduction for precise, low speed operation; 57 ounce-inches of torque; and a dual ball-bearing output shaft, so it can support the weight of the panel and support perpendicular to the shaft.

In Sunflower, I use a PICAXE 08M2 microcontroller, also featured in the *PICAXE Keyer* described in the previous chapter by Rich Heineck, AC7MA, and in my *Pharos* beacon project in the next chapter. The 08M2 outputs logic HI and LOW values to a SN754410 H-bridge motor driver IC to control forward or reverse current (up to 1 A) to the motor.

To track the sun, I used a pair of sensors to detect light and shadow. For inexpensive light sensors, I used green LEDs. (Earlier in this book, you also saw another unusual use of a red LED, as a voltage variable capacitor, in the *QRSS ATtiny* project by Hans Sommers, GØUPL.) The PICAXE READADC command reads the voltage from the LEDs and the software compares the voltage levels and turns the motor and wheel until the two LED voltages are the same, so the panel faces the sun. Delays in the control software serve as a low-pass filter to prevent unwanted movement from waving hands and birds.

Sensor Board Construction

Two green 5 mm LEDs make up the light sensor board. In full sunlight each LED should output approximately 1.6 V on a high-impedance digital voltmeter (DVM).

Try several LEDs with your DVM and select a pair LED that both output the same voltage in the same sunlight — do not use a flashlight.

A 1 inch square perfboard (**Figure 9.2**) supports the LEDs, and an opaque plastic 1 inch light shield separates them (**Figure 9.3**). I spaced them 13 mm center to center. The shield casts a shadow on

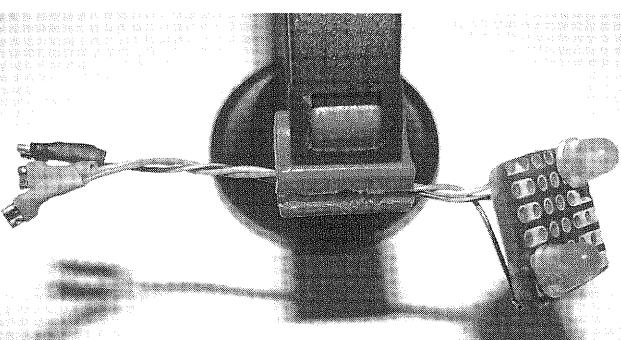


Figure 9.2 — To keep things simple, the design uses a pair of green LEDs as inexpensive light sensors.
[Bill Prats, K6ACJ, photo]

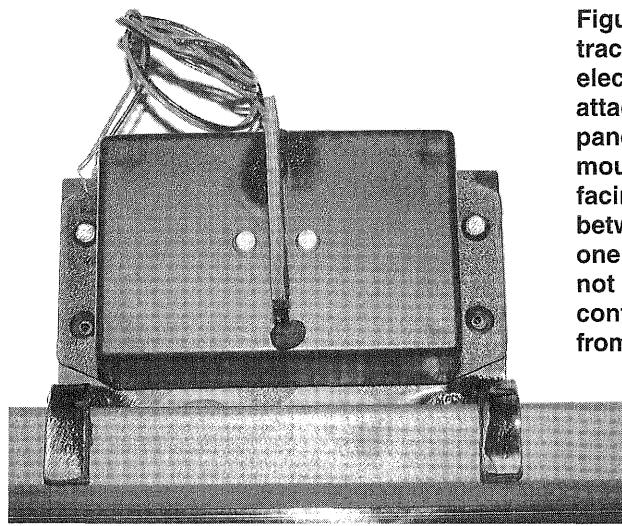


Figure 9.3 — The Sunflower solar tracker sensor and controller electronics fit in a small enclosure attached to the top of the solar panel. The LEDs from Figure 9.2, mount to the front of the case, facing the sun. The plastic shield between them casts a shadow on one of the LEDs when the sensor is not pointed directly at the sun. The controller compares the voltages from the LEDs and drives the servo motor left or right until they are equal (and thus moving the tracking platform until the solar panel is pointing directly at the sun). [Bill Prats, K6ACJ, photo]

one LED when the sensor is not pointed directly at the sun. A three-conductor cable connects the sensor board to the control board.

Control Board

A PICAXE 08M2 microcontroller, low dropout 5 V regulator such as the 78L005, 1N5818 Schottky diode, and SN754410 motor driver chip complete the electronics circuit as shown in **Figure 9.4** and **Table 9.1**. LEDs at pins 5 and 6

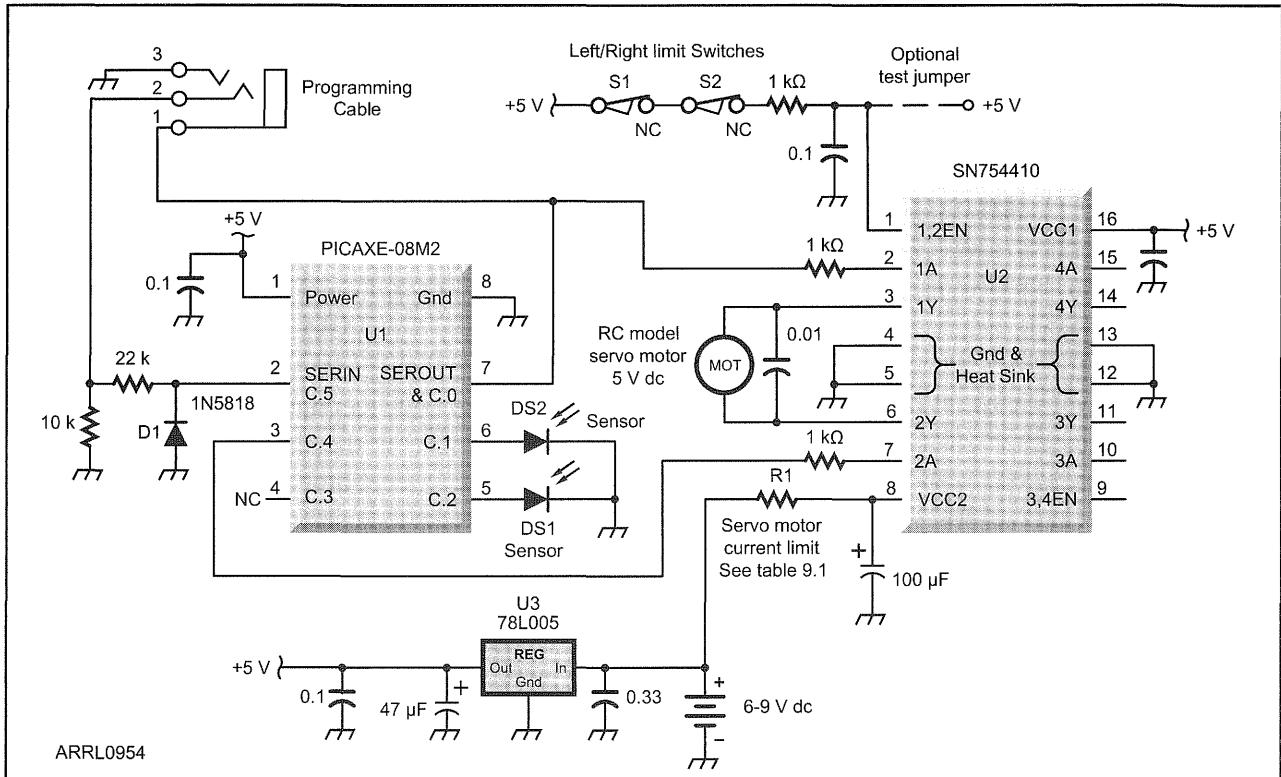


Figure 9.4 — Schematic of the Sunflower solar tracker. See Table 9.1 for a parts list.

Table 9.1
Control Board and Sensor Parts

- Proto board options:
 - PICAXE 08 8-Pin Proto Kit SparkFun DEV-08321
 - Wire proto board
 - Kiwi Patch Kit from KEI in New Zealand
 - PICAXE 08M2 microcontroller (U1)
 - SN754410 H-Bridge Motor Driver 1 amp (U2)
 - SparkFun COM-00315 (the L293NE may be substituted)
 - 78L005 low dropout 5 V regulator, TO92 package (U3)
 - 1N5818 Schottky diode with 0.2 V drop (D1)
 - Green 5 mm LEDs (qty 2), tested for matched output (DS1, DS2; see text)
 - Capacitors:
 - 0.01 μ F (mounts on servo motor power lead)
 - 0.1 μ F (qty 4)
 - 0.33 μ F
 - 47 μ F, 25 V electrolytic
 - 100 μ F, 25 V electrolytic
 - Resistors:
 - 1 k Ω , $\frac{1}{8}$ W (qty 3)
 - 10 k Ω , $\frac{1}{8}$ W
 - 22 k Ω , $\frac{1}{8}$ W
 - R1: Motor current limit, varies with motor supply voltage.
 - Choose value for 4.5 to 6 V at 180 mA.
 - Left/right limit switches (S1, S2): SPST momentary contact pushbutton, normally closed.
 - HiTec HS-425BB servo, modified (see sidebar)
 - RC model rubber wheel, 2 inch diameter, $\frac{1}{8}$ inch wide
 - #28 - #40 stranded wire (such as wire from old USB, video or RS-232 cables)
 - dc power source: 6 AA alkaline batteries and battery holder
-

are the solar sensors and must be wired correctly, with the cathodes to common ground. The SN754410 is a Quad Half-H Motor Driver designed to drive two dc motors forward or reverse up to 1 A. The SN754410 chip enable (pin 1) must be high at 5 V for chip select. Switches S1 and S2 open the driver Enable line to stop motion at the far right or far left of the platform movement. They are not necessary and the optional test jumper can be left in place to hold 5 V on the SN754410 Enable pin. PICAXE port C . 0 drives SN754410 pin 2 port 1A and PICAXE port C . 4 pin 3 drives SN754410 pin 7 port 2A for direction control. The dc motor is at pins 3 and 6. Refer to the SN754410 application notes for the H-bridge circuit and the function table for direction logic. *Only one direction input port can be active high at a time.*

Control Board Construction

The circuit can be assembled on a protoboard, perfboard or custom circuit board. PICAXE boards with prototyping area are available from SparkFun. Place 8 and 16 pin socket and pin headers using point to point wiring to complete construction. My version is shown in **Figure 9.5**. Another alternative is the Kiwi Patch Kit from KEI in New Zealand (see references).

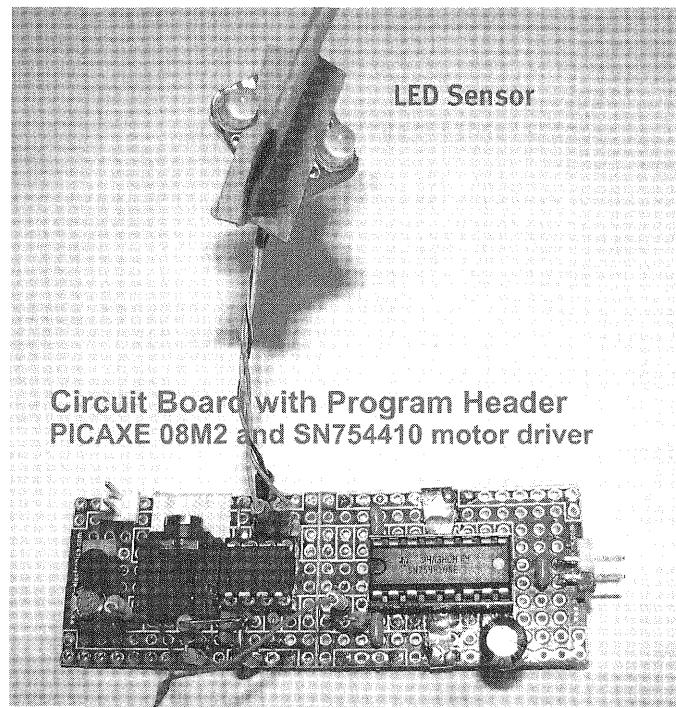


Figure 9.5 — The circuit of Figure 9.4 is built on a prototyping board. The PICAXE 08M2 is on the left and the motor controller chip is on the right. [Bill Prats, K6ACJ, photo]

Rotation limit switches (S1 and S2) are shown in Figure 9.4, wired to hold the SN754410 chip enable pin at 5 V. If limit switches are not used, a jumper must be connected from the enable pin to +5 V, or else the motor driver will not operate.

The ADC input is referenced to the 5.0 V regulated supply voltage. The 0.2 V drop across the 1N5818 Schottky diode stabilizes a condition that causes the ADC reference to change when the PC programming cable is attached and removed.

SN754410 pins 4-5-12-13 are ground and heat sink connections. Solder all four to a common ground pad as a heat sink. Keep all leads short and use plenty of capacitors to bypass noise from the dc bus to ground. The leads between the control board and the LED sensors are less than 4 inches long, and the leads from the microcontroller circuit board to the motor are 18 inches long. A small 0.01 μ F capacitor across the motor wire terminals limits noise back to the driver chip.

Good circuit operation depends on a regulated and stable voltage source, so at minimum a 1 A source is needed. I used six AA batteries in series for a 9 V supply, but you could also power the regulator circuit (U3) and servo motor (U2 V_{CC2} input, pin 8) from the 12 V the battery you are charging, but R1 will need adjusting so the motor dc is 5-6 V.

As the sun is slow to travel across the horizon, low-pass filtering of the sensor signal keeps shadows from people and birds from causing unnecessary “servoing.” The filtering is done with simple delays in the code, so the motor and platform move into position at 10 second intervals.

Platform Construction

A key feature of this project is the simple motorized platform shown in Figures 9.6 and 9.7 and Table 9.2. You can build it from common and easy

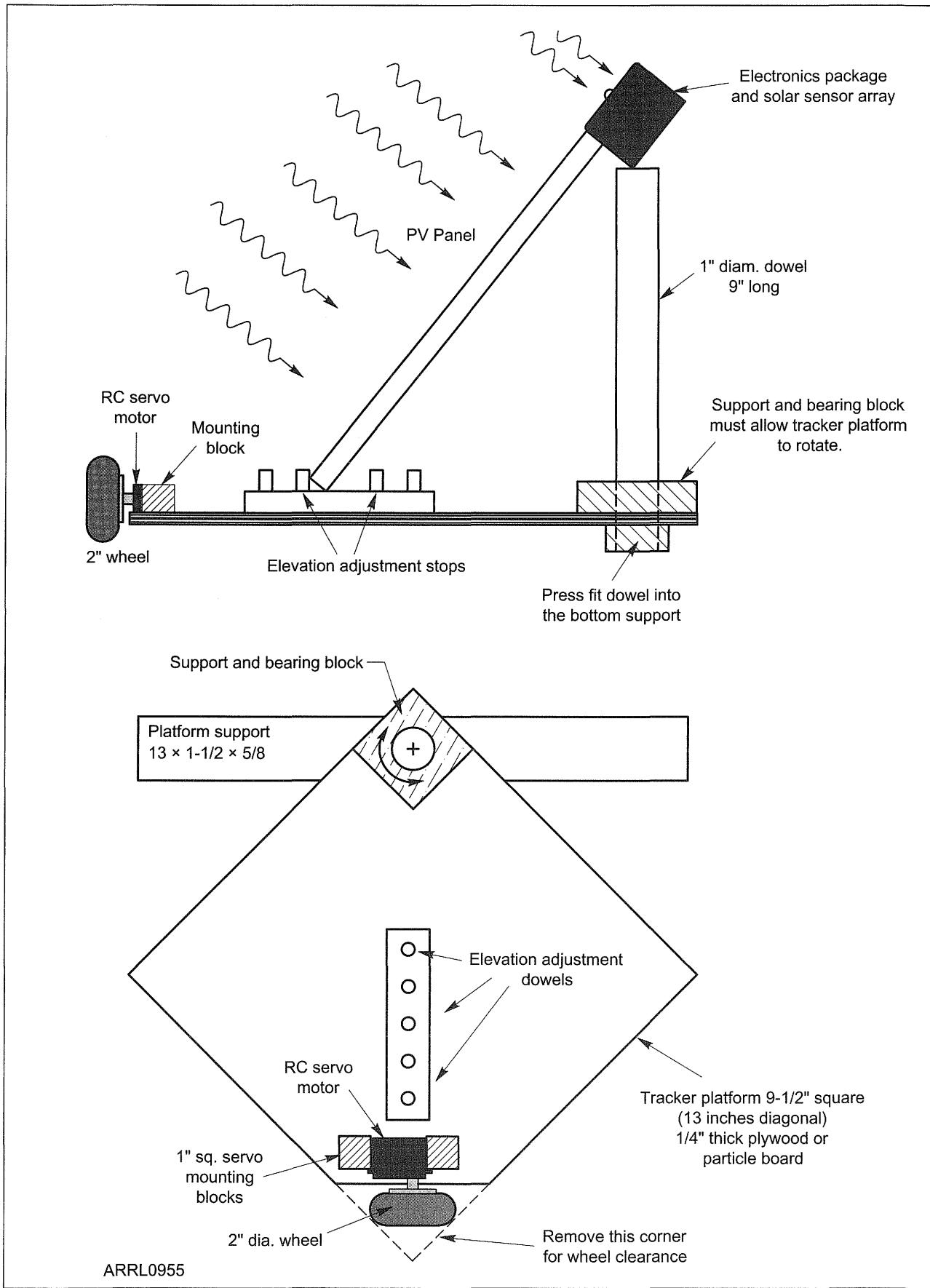


Figure 9.6 — Details of the solar tracker platform construction. See Table 9.2 for a materials list.

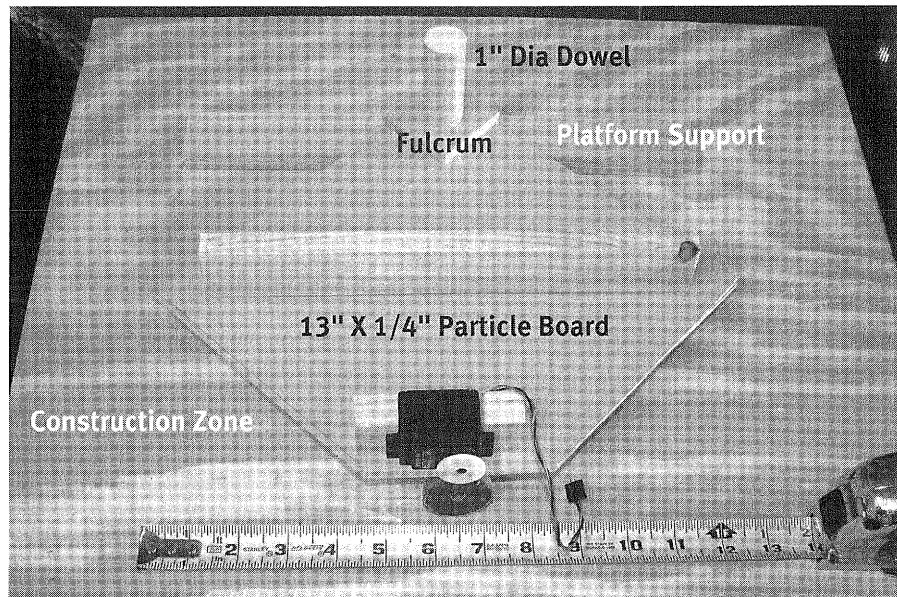


Figure 9.7 — A partially assembled platform. [Bill Prats, K6ACJ, photo]

Table 9.2

Tracker Platform Materials

Particle board, plywood or laminated construction board for the solar panel support platform. I used $\frac{1}{4}$ inch thick hobby plywood from Midwest Craft Plywood. The platform is $9\frac{1}{2}$ inches square (13 inches diagonal).

Wood dowel, 1 inch diameter by 9 inches long

Saw, 1 inch hole cutter and Gorilla Glue or similar adhesive

$13 \times 1\frac{1}{2} \times \frac{5}{8}$ inch pine board for the horizontal support and a $1\frac{1}{2}$ inch square piece for the bearing block.

1 inch square wood blocks for motor mount

$\frac{1}{2}$ inch dowels and strip of $\frac{1}{4}$ inch plywood for elevation adjustment stops

to obtain materials to rotate the solar panel without expensive gear reduction motors, pinion gears, roller thrust bearings, drive gears or chains. This project was designed for a 5 W automotive dashboard solar panel measuring 13×14 inches and weighing about 1.5 pounds. Operation is simple with only one active moving part, and the roller wheel is robust enough to use in an outdoor setting over grass or hard desert. The platform support could be improved by adding 2 inch to 3 inch diameter wheels at each end.

I built the platform out of hand-cut $\frac{1}{4}$ -inch-thick particle board using power tools in my wood shop. You might choose to use another fabrication technology and material, such as laser-cut board or acrylic sheet.

The solar panel support platform is $9\frac{1}{2}$ inches square. At the fulcrum a 1 inch dowel is press fit into the horizontal platform support, and the solar panel support platform rotates around the dowel. A bearing block on the upper side of the support platform provides additional strength. Be sure the holes are large enough that the platform rotates cleanly around the dowel. I used a new 1 inch wood boring tool and drill press to cut clean holes into the wood.

The drawing and title page photo show a thin strip of wood with four $\frac{1}{2}$ inch dowels just above the servo motor assembly. This keeps the bottom of the solar panel from sliding and allows for setting several different fixed elevations.

The motor mount is attached next. See the next section and the sidebar, "Servo Motor Modification," for details. The electronics package mounts to the top of the solar panel as shown in Figure 9.3. Limit switches wired into the SN754410 chip select pin stop the motor drive at the extreme ends of the arc.

Motor Mount

Remove the hot glue covering the motor terminals and solder a $0.01 \mu\text{F}$ capacitor and two long #18 flexible wires to the motor terminals using a small solder pen (15 W or so).

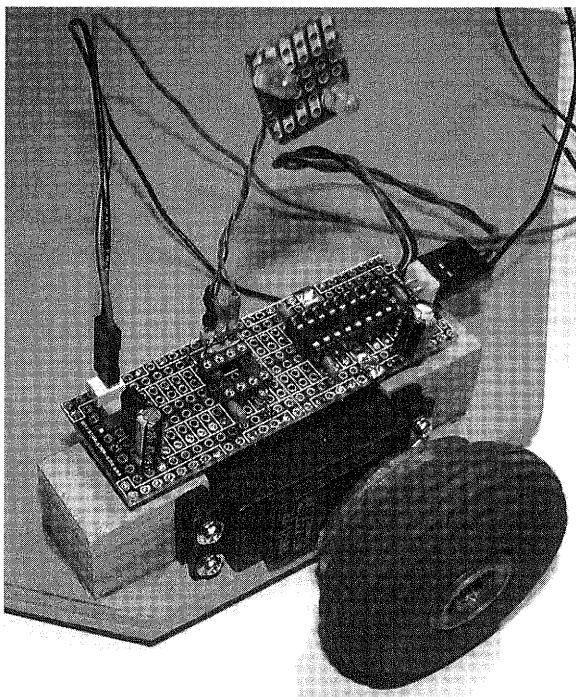


Figure 9.8 — The modified servo motor and RC wheel ready for testing. [Bill Prats, K6ACJ, photo]

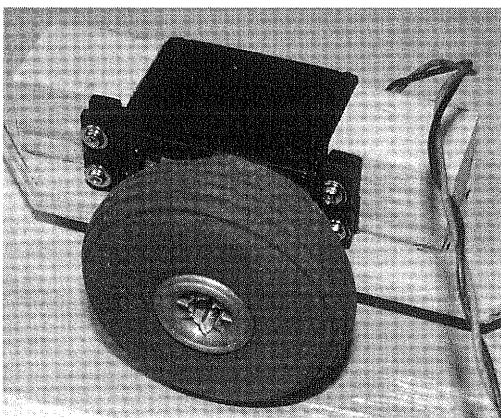


Figure 9.9 — The finished wheel drive. [Bill Prats, K6ACJ, photo]

Mount the motor to the solar platform on 1 inch wood blocks glued and screwed to the platform. The perimeter of the 2 inch diameter rubber wheel should extend below the bottom of the platform by $\frac{1}{4}$ inch.

Figure 9.8 shows the test rig I built to verify operation. **Figure 9.9** shows the finished wheel drive attachment. The large hole in the wheel center allows the shaft mounting screw to pass through the hub for attachment.

Drill out the center of the wheel large enough to pass the motor shaft retaining screw through it, and attach to the shaft. Cut a disk of plastic and carefully center it onto the four-arm mount included in the servo box, and then hot glue the disc and arm together. Next, center the disk and arm assembly onto the wheel and use #2 wood screws through the arm and into the side of the wheel to secure it. Slide the wheel/disk/arm assembly onto the shaft then push the shaft mounting screw through the wheel center hole to secure the assembly to the servo output shaft. The mount is very secure.

Test 360 degree operation

Servo Motor Modification

I used the HiTec HS-425BB servo for its cost, robustness and torque. I made two modifications: I removed the control board and removed the motion stops to allow continuous rotation.

Tools needed: small Phillips screw driver; 15 W soldering pen and solder; side cutters and needle nose pliers.

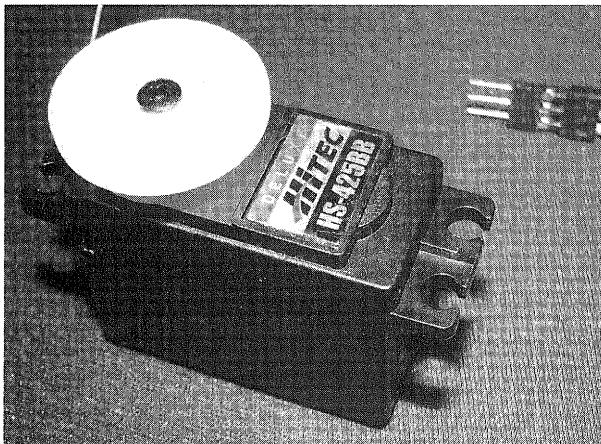
Parts needed: small signal wire and cable connector; HiTec HS-425BB servo.

Summary: Remove the internal circuit board and feedback potentiometer to get access to the gears. Find and excise the stopper protrusion on the output gear. Reassemble carefully. Refer to the accompanying photos for help.

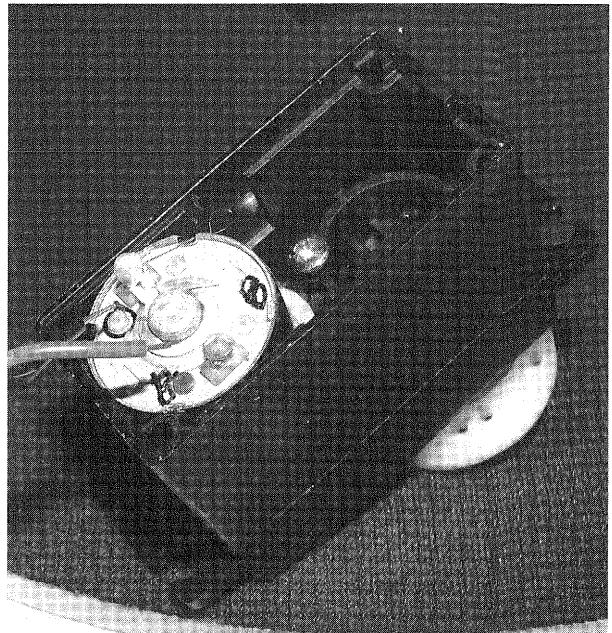
Details: Remove four screws and open the servo case. Mark the wire color to the motor terminals if you want to reconnect these parts in the future. Remove the circuit board then remove the screw that holds the feedback potentiometer in place then remove it. Carefully cut the wires at the motor.

Use a sharp hobby blade and carefully slice down each side of the stopper protrusion on the gear side then use your smallest side cutters to remove the material. Solder the 0.01 μF capacitor across the motor terminals and solder two small signal wires from the motor that will attach to the controller board and SN754410. Reassemble the gear box top, align the gears and snap the top to the case.

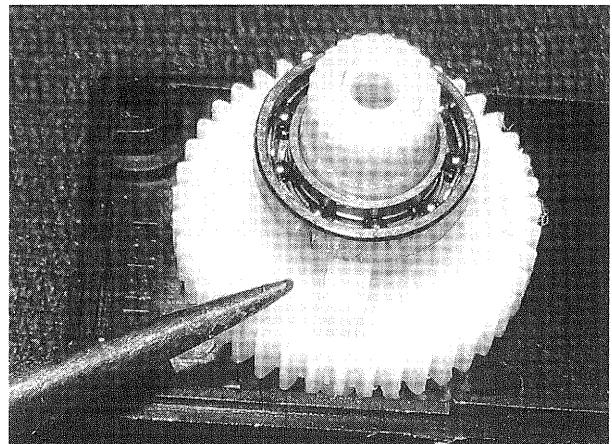
Reassemble the complete package and apply power from two AA cells to test forward and reverse motion.



The HiTec servo motor must be modified for this project. [Bill Prats, K6ACJ, photo]



First, open the case and remove the circuit board. [Bill Prats, K6ACJ, photo]



Locate and remove the stopper tab as described in the text. [Bill Prats, K6ACJ, photo]

by applying voltage from two AA batteries to the motor. The action should be smooth. The motor draws about 90 mA with no load.

Programming the Sunflower

The PICAXE 08M2 can be programmed in circuit with the serial or USB cable and the free IDE (Integrated Development Environment) for *Windows*, *Mac OS* and *Linux*. You can download this program from this book's companion website (see the References section at the end of this chapter), so you don't have to type it in. Load the program into the editor and select the PICAXE 08M2 type processor in the menu. Once you press the PROGRAM button, it will upload the compiled file to the PICAXE, and the tracker will begin to run immediately. If you have your tracker assembled while programming it, take care that it does not move itself off your workbench unexpectedly!

If you use the PICAXE DEBUG command, serial output pin 7 is also connected to the SN754410, so you will get unwanted motor operation. Remove the cable while testing the software.

```
#rem
Sunflower PV Solar Tracker
Copyright (C) 2012 Bill Prats K6ACJ
Licensed under GPL. See file COPYING.

C.0 Pin 7 to SN754410 Pin 2 Logic 1A Enable 1
C.1 Pin 6 Green LED
C.2 Pin 5 Green LED
C.4 Pin 3 to SN754410 Pin 7 Logic 2A Enable 2

Truth Table Direction SN754410
#1 #2 #7
EN 1A 2A
H L H Turn Right
H H L Turn left
H L L Fast motor stop
H H H Fast motor stop
L X X Fast motor stop

#endif

init:      ;initialize ports and variables

        adcsetup = %0000000000000000110
        ;M2 parts, define ADC port/pin C.1 & C.2

        let b0=0 b1=0 b2=0 b3=0 b4=0    ;clear variables
        let b10=1                      ;software bias
        pause 500                      ;
```

```

main:      ;read adc
;With bias, test A<B or B<A to set direction
;Pulse motor into position

gosub read_adc           ;get ADC input into B0 & B1

let b3=b0+b10 max 255    ;variable b0 8 bit math 255 max
let b4=b1+b10 max 255    ;variable b1 8 bit math 255 max

if b0 > b4 then gosub fwda
if b1 > b3 then gosub reva
pause 500                 ;motor runs 1/2 second
gosub all_stop            ;stop motion
pause 10000               ;pause 10 seconds to eliminate jitter
goto main

read_adc:    readadc C.1,b0          ;read sensor 1
pause 100
readadc C.2,b1          ;read sensor 2
pause 100
return

all_stop:     ;stop all
low c.0
low c.4
return

fwda:        ;rotate
high c.0
low c.4
return

reva:        ;rotate the other direction
low c.0
high c.4
return

```

Using the Sunflower

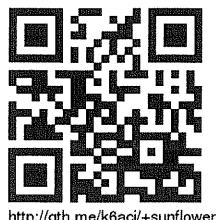
Following assembly and testing, place the Sunflower electronics on the solar panel and the panel on the platform and attach the motor and power cables. For best results the Sunflower should be on a hard smooth surface. Testing with a bright flashlight gives mixed results, so wait for the sun to come out. Point the panel to the general direction of the sun and apply power to the electronics. If the motor rotates in the wrong direction, reverse the motor power leads. If there is no reaction, make sure the SN754410 chip select pin is at +5 V and the sensor LEDs are properly wired with the diode cathodes to ground.

Further Development

The one-wheel system works and is simple. For use on uneven ground, upgrade to three wheels: place one on the motor and one on each end of the

support leg. Increasing the wheel size to 3 inches can also help during the summer months when the sun makes a longer arc in the sky.

This circuit is applicable to other projects where input voltage controls output drive. For example, if the LED sensors are replaced with 5 k Ω potentiometers the driver board becomes a universal motor driver for remote control projects such as antenna tuners. For shaft position feedback, place one of the two 5 k Ω potentiometers on the output shaft. Maximum current capability of the SN754410 is 1 A, so use a larger driver module for larger motors.



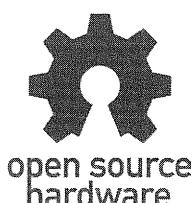
<http://qth.me/k6acj/+sunflower>

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<http://www.sparkfun.com/categories/125>
<http://www.phanderson.com/picaxe/>
<http://www.kei.co.nz>
- Other parts sources
<http://www.goldmine-elec.com/>
<http://www.allelectronics.com/>
<http://www.jameco.com>
- Sun path and elevation
<http://www.esrl.noaa.gov/gmd/grad/solcalc/>
<http://aa.usno.navy.mil/data/docs/AltAz.php>
- Solar tracking benefits
http://www.wattsun.com/pdf/Wattsun_Tracking_Advantage.pdf
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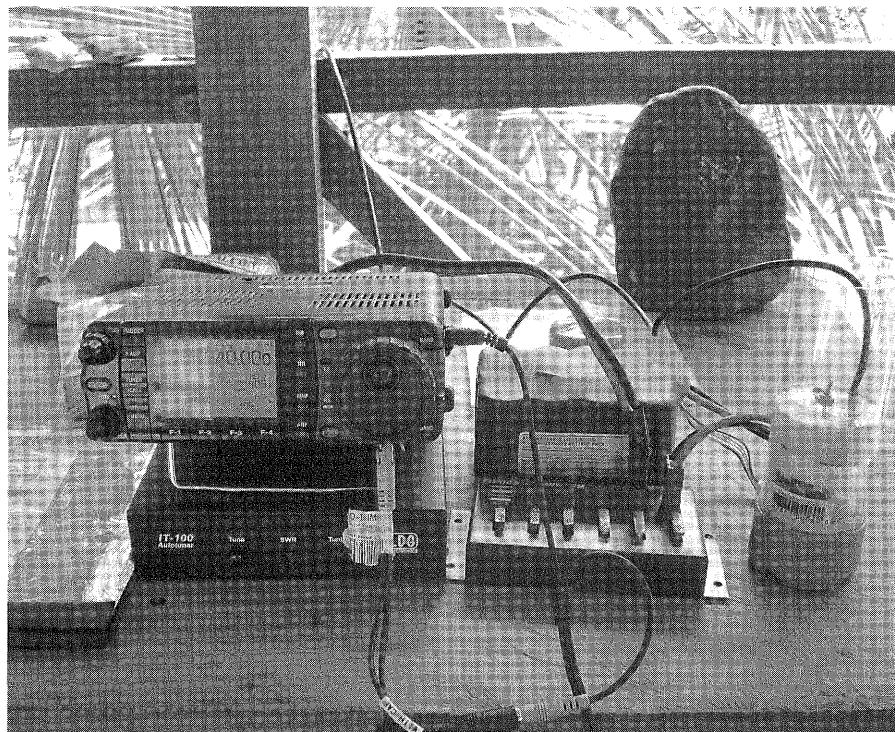
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Pharos: A PICAXE CW Beacon Keyer

Bill Prats, K6ACJ



Here's the OA1/K6DMT operating position in the jungle in Peru. The station includes an IC-7000 transceiver, LDG antenna tuner and battery power source. The Pharos beacon keyer (far right) is housed in a plastic tube to protect it from the elements. [Sidney Sudberg, K6DMT, photo]

A DXpedition to an exotic location is the dream of many a ham. Some dream of being a coveted contact, working lengthy pileups stretching around the Pacific or the Atlantic. Others imagine operating lazily under shady palms and sharing camaraderie with fellow hams after the bands close. The hardiest souls cross the stormy seas, hunker down against the bitter cold wind, and even operate while perched on nothing more than rock jutting a few feet out of the ocean.

When one of our ham club members, Sidney Sudberg, K6DMT, announced he was soon leaving for a trip to the Peruvian Amazon and wanted advice for taking his HF portable rig, everyone had grand ideas for his schedule. The club members were excited to help plan operation from a very remote location and

were eager to give needed advice for HF operation and station setup. After a lengthy discussion we determined that operating time and band choices would be difficult given the HF propagation conditions and Sidney's personal schedule, so we made a virtue of necessity and developed the idea to use a CW beacon that club members would attempt to copy.

After listening to various 10 meter and 20 meter beacons, I determined the beacon would transmit his call sign twice every few minutes and then terminate to preserve precious battery power. Many modern transceivers include electronic keyers that are capable of sending repeated CW messages, but we needed better control of the timing and overall duration. We realized that nothing commercial met our exact needs, so to solve our problem and get Sidney on the air, a CW beacon keyer project was born.

CW beacons have been operating on the bands from 160 meters through 2 meters to help radio amateurs test propagation to different parts of the world. Beacons can be found on the 20 and 10 meter bands daily. There are desktop programs and smart phone applications that identify beacon call signs, time of operation and frequency.

A quick search for "amateur radio beacon construction" will display many websites with additional details and information. One project caught my eye: "A Mini 10 Meter Beacon on 28.322 MHz," by Steve Page, VK6HV. It used a PICAXE microcontroller, one that I was already familiar with from other projects, and which I knew to be inexpensive and easy to program. Steve's project included an on-board QRP transmitter, but Sidney's plan was to use his 100 W ICOM IC-7000 transceiver. After an email exchange with Steve, I found he was happy to have me adapt (and eventually publish) a project sharing some of his PICAXE software. (For a QRP beacon project using the ATtiny microcontroller, see the *QRSS: Very Slow Sending* project earlier in this book by Hans Sommers GØUPL.)

The purpose of this beacon keyer is to send very short term identification with grid locator information to assist with on the air schedules and contacts. It also assists operators who are new to CW by sending at slow speeds. Since the configuration of the beacon is done by reprogramming it completely, there is no user interface to limit access to features. Once built, it is simple to reprogram it for other activity.

PICAXE 08M2

The PICAXE 08M2 microcontroller is easy to work with, both in software and in circuit construction. It features an 8 pin DIP form factor and ports for digital I/O, ADC (analog-to-digital conversion) for analog input, DAC (digital-to-analog conversion) analog voltage output, serial communication, and pulse width modulation (PWM) output. It has 2048 bytes of program memory space, room for about 1800 lines of code. It supports the industry standard I2C/TWI bus to connect to external EEPROMS, real time clocks, compass chips, and a wide variety of sensors. Clock speed is from 4 MHz to 32 MHz, and up to four parallel tasks can be executed. We won't use many of those features in this simple project, but it is good to know the chip has room to grow.

All PICAXE chips are programmed using a BASIC language, and

Revolution Education provides a free IDE (Integrated Development Environment) with an editor, compiler and debugger for *Windows*, *Mac OS* and *Linux*. PICAXE chips are very easy to program — only two resistors and a cable connector are necessary to upload programs and read debug data via a PC serial port or USB/serial cable. The program editor is very robust and fast, and it also includes a very good DEBUG command and simple terminal for testing. The integrated program simulator is often used to run and test code, and when used with the DEBUG command it will display register contents. Program breakpoints are easy to implement and program step delay time is adjustable. You'll find memory usage is very compact, with far more available memory than necessary for the average project. In fact, this program takes surprising little memory space. Since the PICAXE chips can be programmed thousands of times, development is cheap, rapid and fun.

The Beacon Circuit

The circuit diagram in **Figure 10.1** includes the programming header, PICAXE 08M2 and output transistor switch. The robust 2N2222 NPN transistor (Q1) interfaces the PICAXE output to key an ICOM IC-7000 transceiver through a short cable at the KEY jack input. Before sending the package off with Sidney, I tested the beacon on several other transceivers — an ICOM IC-706 and a Yaesu FT-1000 and FT-817. The transceiver setup menu must be set to the STRAIGHT KEY option. You can also use a 2N7000 FET instead of the 2N2222 in the circuit. Schottky diode D1 on pin 2 was added for ADC stability in case analog sensors are used in a future project.

The beacon assembly includes a pack of three AA cells for power and a key cable to the transceiver. High-quality alkaline batteries were chosen for voltage, safety and long term operation. Three good alkaline AA cells in series will

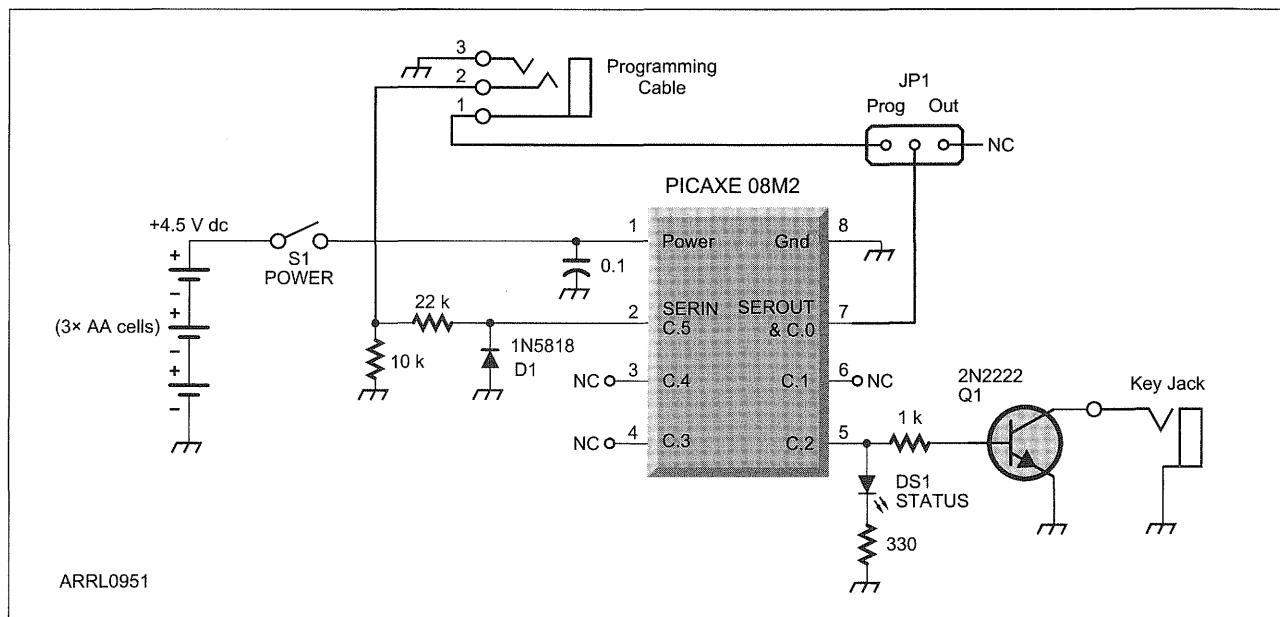


Figure 10.1 — The beacon keyer schematic is fairly simple — the PICAXE 08M2, PC interface and 2N2222 keying circuit.

supply operating voltage for many weeks or months because the power drain is less than 20 mA when powered on.

A voltage regulator is not necessary for this circuit as long as the ADC input is not used. The PICAXE 08M2 will operate as low as 1.8 V, though typical operation is 5.0 V dc and maximum voltage is 5.5 V.

Construction

Proto board examples are shown in **Figure 10.2**. At the bottom right is a PICAXE 08 Proto Board part number AXE021 (this one has another circuit built on it). At the top right is the Kiwi Patch Kit from KEI in New Zealand. Final assembly is shown in **Figure 10.3**. This version uses the PICAXE-08 Proto Board Kit AXE021, which includes the PC board, 8-pin DIP socket and all parts for the program header. Mount the parts that were included with the kit. A 2N2222, keyer cable and related parts are soldered to the proto area on the same board. I used two AA battery holders (a two cell and a single cell) and

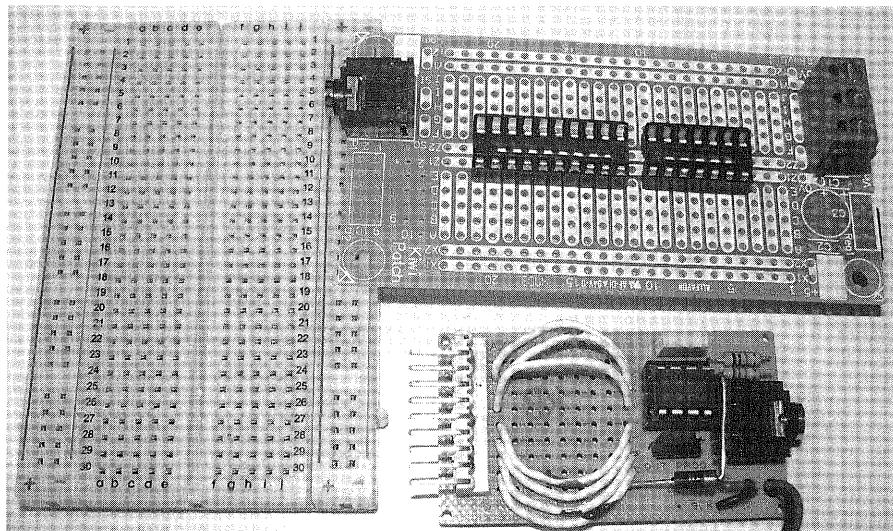


Figure 10.2 — You can build the beacon keyer on the proto board of your choice. There are a few options available.

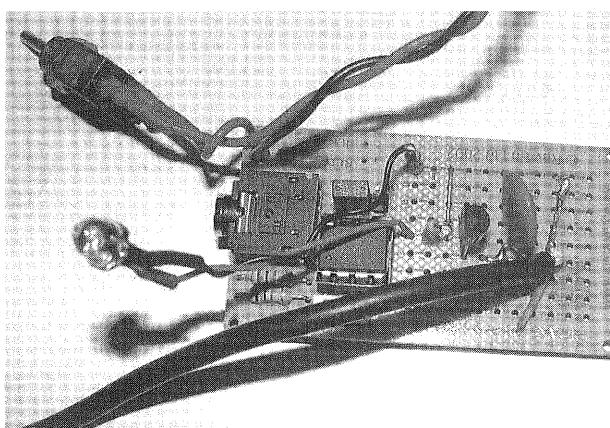


Figure 10.3 — The author's beacon circuit is built on a PICAXE AXE021 proto board. The PC interface components (left edge) are included with the kit. The STATUS LED and POWER switch mount on a tiny front panel. A shielded cable connects to the transceiver's CW key jack.

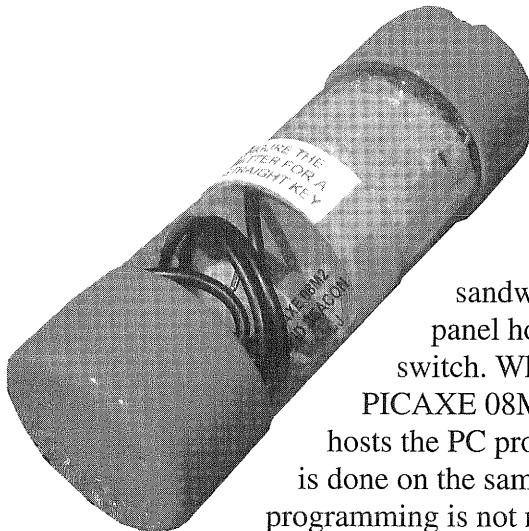


Figure 10.4 — Here's the finished CW beacon keyer in its plastic case.

sandwiched them to the board. A tiny front panel holds the STATUS LED and tiny POWER switch. When you're done soldering, insert the PICAXE 08M2 in its socket. The AXE021 board also hosts the PC programming header, so all programming is done on the same board; removing the chip for programming is not necessary.

The circuit board and battery assembly are wrapped in a few layers of fiberglass tape and bubble wrap then pushed inside a Viewtainer brand clear plastic 2 inch diameter tube cut to 6 inches long. See **Figure 10.4**. With the end caps secure, the beacon keyer returned from the jungle free of crud and moisture. To relieve pressure from changes in altitude, I drilled a tiny hole into the front panel to let pressure equalize.

PICAXE 08M2 Programming

If you have no experience with the PICAXE program editor, start with the *Getting Started* guide available online (see the References section at the end of this chapter). Attach the proto board to your computer via serial or USB cables for programming. Make sure the jumper on PICAXE pin 7 on the AXE021 board is set to the programming mode. With the board powered up, start the programming editor, select 08M2 as the chip type and select 4800 baud communications.

Open the file containing the program .bas file and load the code as-is for testing first. Upload the program to the PICAXE by clicking the PROGRAM button. If the cable is connected to the board correctly and power is on, progress bars will appear immediately showing the upload status. After a few seconds the upload is complete and the chip will execute the code immediately.

When you have confirmed operation, then make the modifications for your call letters in the EEPROM line. Don't forget to SAVE your file.

I modified the original VK6HV beacon code to transmit the station ID and grid locator twice, then repeat every few minutes for a maximum of three complete loops. The PICAXE 08M2 offers a new time variable that reads directly in seconds, making it easy to take elapsed time into consideration without using any external timing chips. Incorporating this new feature and using symbolic variables made the code much easier to read and modify. I also modified the output character string for CW located in EEPROM to include the station call sign and grid locator, and replaced the analog speed control with a fixed constant for approximately 13 WPM output.

The symbol string_length contains the character count of the entire CW message, so setting it properly is critical to operation of the MORSE routine. Each alpha character in the transmission string is represented by a

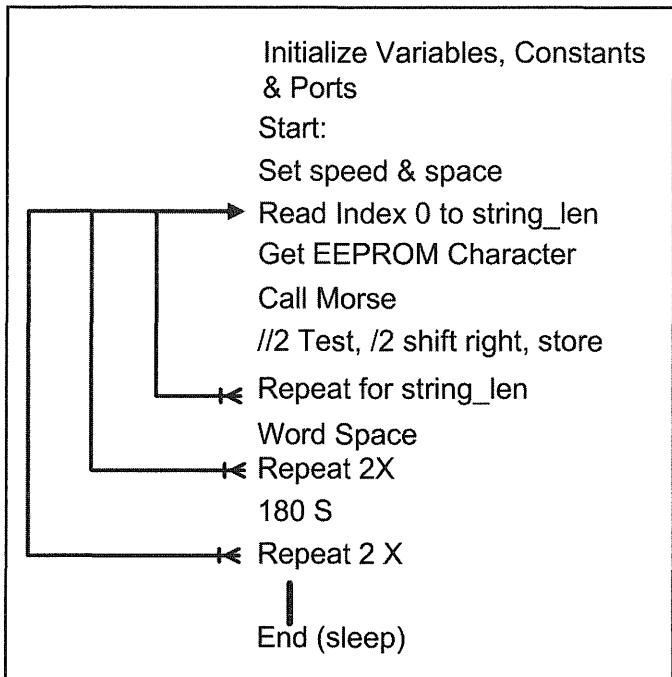


Figure 10.5 — Beacon keyer program flow.

complete, upload the new program to the PICAXE.

Program Flow

The program flow (Figure 10.5) includes various sections to define constants and variables, define the output port and define the contents of the EEPROM storage. The 13 WPM CW speed is determined from `cw_speed` and is followed by the timing for dit, dah, character and word spacing. The program main flow has two timing loops. A short loop is entered two times to call the MORSE routine to beacon the EEPROM string two times, and a longer timing loop waits the remainder of 180 seconds before repeating the routines to repeat the MORSE CW beacon again. During this long timing loop, another counter `repeat_all` is tested to continue or halt the beacon after three complete cycles of beacons twice. The PICAXE command `end` terminates the beacon and puts the 08M2 into a very low power idle state. To repeat the beacon, perform a manual power off / power on cycle to reboot the code.

Morse Routine Program Flow

Command `//2` tests the remainder of a divide. Storage is *not* performed. Command `/2` divides and *stores* the whole number quotient of the divide. Dividing by 2 shifts register contents (binary data) one bit to the right, which is the low order end of the register byte or word.

Referring to the program code for numbers used to program each alpha character into your beacon message, send letter “C” represented by “21” in Morse code:

numeric group that is shifted through the PICAXE registers using variations of the divide command. The resulting value is tested for odd or even to output dots, dashes and space timing. Refer to the program flow chart (Figure 10.5) and the MORSE routine for details.

Morse code generation begins at the EEPROM line where the output string is represented by small numeric groups. The alpha character to Morse character conversion is in the program comments under the heading `*** MORSE CODE CONVERSION TABLE ***`. Simply write out your desired beacon text and put the numeric equivalent delimited by a comma in the EEPROM line. A numeric zero is a word space. Count the number of character *groups* in the new string, and put that value into the symbol `string_len`. If you omit this step, the beacon will not work. When

Morse:

```
Test    //2      21/2 = 10      remainder = 1 = dah
Shift   /2      21/2 = 10      store into memory
If memory = 1 then terminate else loop
```

```
Test    //2      10/2 = 5      remainder = 0 = dit
Shift   /2      10/2 = 5      store into memory
If memory = 1 then terminate else loop
```

```
Test    //2      5/2 = 2      remainder = 1 = dah
Shift   /2      5/2 = 2      store into memory
If memory = 1 then terminate else loop
```

```
Test    //2      2/2 = 1      remainder = 0 = dit
Shift   /2      2/2 = 1      store into memory
If memory = 1 then terminate else loop
```

```
End Morse Routine and return to address another Morse character from
the EEPROM. Loop until the string length count is reached then
terminate this loop.
```

The MORSE routine is the heart of the program. As the content of the EEPROM string is addressed one memory location at a time, the resulting EEPROM character is converted to Morse code and sent out to the keyer. To convert the number to Morse code output, the number is divided by 2 using the //2 command and the remainder of the quotient is tested for zero or one. If the result is 0, a CW dit is output; if the result is 1 a CW dah is output. The //2 only returns the remainder of the quotient and does not store the result back to memory.

The next line of code character=character/2 divides the whole number by 2 which is the same as a shift right and stores the resulting whole number to memory for use in the next loop. When the series of //2 tests and character /2 divides results in a value of 1, the Morse output is complete for this character, a character space is sent and the calling loop increments the address index into EEPROM for the next character and the process repeats until string_len limit is reached.

When string_len is reached, the entire contents of the EEPROM have been transmitted one time and a word space is output. The program returns to the short timing loop to immediately repeat the cycle a second time then waits the remainder of 180 seconds to repeat the entire process a total of three times. Of course all the parameters can be modified to your requirements.

Operation

Putting the CW beacon on the air is simple. Change the contents of EEPROM to your requirements, upload the new program then set up your transmitter menu for straight key operation. Apply power to the transmitter and beacon. The beacon STATUS LED will show output by blinking Morse code and

Morse code will be heard from the transmitter sidetone.

The station call is transmitted twice, then transmission pauses for three minutes before repeating the sequence three times. At the end of the program loops, the program terminates and puts the microprocessor into a very low power sleep mode or the operator can switch the power off. To restart the beacon, the power switch must be cycled off then on.

The program is available for download at the companion website for this book (see the References section at the end of this chapter).

```
#Rem
* You're more than welcome to change, add or modify!
* Written by:      VK6HV, modified by K6ACJ FOR 08M2
* http://members.westnet.com.au/page3/picaxe-08m_mimi_28mhz_beacon.htm
*
* PIN#  Project Use          Picaxe Pin Definition
*
* Pin #1 +5 Volts           [+5 Volts Power]
* Pin #2 Serial In          [Programming]
* Pin #3                     [Out4/In4 Analog In4]
* Pin #4                     [In3]
* Pin #5 cw_out              [Out2 In2 Analog In2]
* Pin #6                     [Out1 In1 Analog1]
* Pin #7 Serial Out          [Programming]
* Pin #8 0 Volts            [0 Volts]
*
* Speed: cwSpeed 255 fast, 130 appx 13WPM
* send call_loop_count times then wait picaxe_time and loop repeat_count
#ENDREM
```

Init:

```
;Constants
Symbol string_len = 17           ;Number of characters in the EEPROM command
Symbol call_loop_count = 2        ;Send call twice
Symbol long_delay = 180           ;delay between calling
Symbol repeat_count = 3           ;Repeat string before 'end'
Symbol cw_speed = w6              ;CW Speed
    w6 = 130                   ;13 WPM
;W7, W8, W9                      ;General purpose 16 bit registers
Symbol picaxe_time = W10
```

```
;Variables
Symbol Character = b0
Symbol Even_Or_Odd_Character = b1
Symbol Index = b2
Symbol call_loop_counter = b4     ;Send loop then pause picaxe_time
Symbol repeat_string = b6
    b6 = 1
```

```

;Ports
Symbol cw_out = Output2           ;output to 2N2222 Switch

;Change EEPROM to your call and beacon text
;Change string_len to the total character count in eeprom string
;A cheat sheet is at the end of the program.

EEPROM 0,(24,24,24,0,9,2,0,6,25,2,63,39,0,9,7,63,56)
;Load eeprom with VVV de AXE08 DM03.string_length=17

    picaxe_time=time          ;Start picaxe Timer
    picaxe_time=picaxe_time+180 ;Add 180 seconds for the next transmission

Start:
    Pause 1000

    w7 = cw_speed * 5/10 + 25      ;Dit length
    w8 = w7 * 3      ;dah length = Dit length X 3
    ;Character Space = Dit Length X 3
    w9 = w7 * 5      ;Word Space = Dit length X 5

    For Index = 0 to string_len
        Read Index, Character
        Gosub Morse
    Next

    call_loop_counter = call_loop_counter + 1
    if call_loop_counter < call_loop_count then goto start

    call_loop_counter = 0          ;clear at end

    do until time > picaxe_time   ;wait until present time > than past time
        pause 500                 ;delay 1/2 second
    loop
    picaxe_time=time          ;Load picaxe with new time
    picaxe_time=picaxe_time + long_delay     ;+ 180 seconds

    if repeat_string = repeat_count then end      ;terminate and go to Sleep
    endif

    repeat_string = repeat_string + 1
    Goto Start

Morse:
    If Character = 0 then Word_sp
    Do
    ;Modulus Divide returns odd/even remainder for dit or dah

```

```

Even_Or_Odd_Character = Character // 2
Character = Character / 2 ;Binary Shift right
If Even_Or_Odd_Character = 0 then Gosub Dit
If Even_Or_Odd_Character = 1 then Gosub Dah
Loop until Character = 1
Gosub Char_Sp
Return

```

```

Dit:
High cw_out
    Pause w7
Low cw_out
    Pause w7
Return

```

```

Dah:
High cw_out
    Pause w8
Low cw_out
    Pause w7
Return

```

```

Char_sp:
    Pause w8
Return

```

```

Word_sp:
    Pause w9
Return

```

#REM
FOR THOSE WHO DON'T KNOW MORSE CODE:)

A .-	B -...	C -. .	D -..	E .	F ..-.
G ---.	H	I ..	J .---	K --.	L .-..
M --.	N -.	O ---.	P .--.	Q ---.	R .-.
S ...	T -	U ..-	V ...-	W .--	X -...-
Y ---.	Z ----.				

1 .-----	2 -----	3 ...--	4-	5
6 -.....	7 --....	8 ----..	9 ----.	0 -----

FULL STOP	[.]	.-.-.-	COLON	[:]	---...
COMMA	[,]	--.--	SEMICOLON	[;]	-.-.-.
QUESTION MARK	[?]	EQUAL SIGN double dash	[=]	-....-
APOSTROPHE	[']	.----.	PLUS	[+]	.---.
EXCLAMATION MARK	[!]	-.-.--	HYPHEN minus	[-]	-....-
FWD SLASH	[/]	-...-	UNDERSCORE	[_]-.

PARENTHESIS open	[()]	-.-.	QUOTATION MARK	["]	.-.-.
PARENTHESIS closed	[()]	-.-.-	DOLLAR SIGN	[\$]	...-.-
AMPERSAND	[&]	.-..	AT SIGN	[@]	.--.-.

*** MORSE CODE CONVERSION TABLE ***

NUMBERS USED TO PROGRAM EACH ALPHA CHARACTER INTO YOUR BEACON MESSAGE

A	6,	B	17,	C	21,	D	9,	E	2,	F	20,
G	11,	H	16,	I	4,	J	30,	K	13,	L	18,
M	7,	N	5,	O	15,	P	22,	Q	27,	R	10,
S	8,	T	3,	U	12,	V	24,	W	14,	X	25,
Y	29,	Z	19,								

1	62,	2	60,	3	56,	4	48,	5	32,
6	33,	7	35,	8	39,	9	47,	0	63,

FULL STOP	[.]	106	COLON	[:]	71
COMMA	[,]	115	SEMICOLON	[;]	85
QUESTION MARK	[?]	76	EQUAL SIGN double dash	[=]	49
APOSTROPHE	[']	94	PLUS	[+]	42
EXCLAMATION MARK	[!]	117	HYPHEN minus	[-]	97
FWD SLASH	[/]	41	UNDERSCORE	[_]	108
PARENTHESIS open	[()]	45	QUOTATION MARK	["]	82
PARENTHESIS closed	[()]	109	DOLLAR SIGN	[\$]	200
AMPERSAND	[&]	34	AT SIGN	[@]	86

*** ALL 54 LETTERS, NUMBERS AND PUNCTUATION, FOR TESTING PURPOSES ***

'EEPROM 0, (6,17,21,9,2,20,11,16,4,30,13,18,7,5,15,22,27,10,8,3,12,24,14,25,29,19,62,60,56,48,32,33,35,39,47,63,106,115,76,94,117,41,45,109,34,71,85,49,42,97,108,82,200,86)

#ENDREM

Future Directions

What else can this beacon do? Three unused input/output ports are available and there are a number of nifty features to add. The rest of the development is up to the reader's imagination since this is what makes these projects fun.

Most breakout boards and sensors for Arduino and PICAXE and other popular hobby microcontrollers will work with the PICAXE 08M2 if only one or two pins are necessary. SparkFun and Adafruit carry a very good line of components, chips, and analog and digital sensors. You could incorporate temperature into the beacon text, or use a light-dependent resistor (photoresistor) and have the beacon operate only during daylight hours.

You might try combining the programmed-message functions of this beacon with the paddle-operated keyer in the *Axekey* project presented by Rich Heineck, AC7MA, earlier in this book. You could make a contest or Field Day

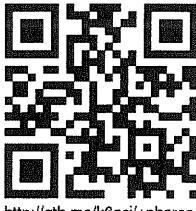
keyer for your lightweight operation.

If you expand your project to include a sensor using an ADC, it is important to use a voltage regulator because the ADC depends on regulated voltage as the reference. In my other projects I use a 78L05 for 5 V dc and a Schottky diode on to the Serial-In pin as shown in the schematic. If you leave out the diode, ADC operation will be erratic, especially when the serial cable is added or removed, and debugging with the PICAXE IDE will be difficult and confusing.

I hope you have as much fun as I did exploring the PICAXE chips.

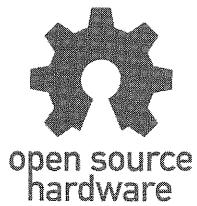
On the Air

Although you can build this project without holding an Amateur Radio license in the US and many other countries, before putting it on the air you must obtain an appropriate license. In the US, a Technician license from the FCC is sufficient for use on some frequencies, but a General or Amateur Extra license is required for others. Please check the regulations of your country before building and transmitting with this project.



References

- Online references
<http://qth.me/k6acj/+pharos>
- Source code for this project
<http://qth.me/k6acj/+pharos/code>
- ARRL band plan with beacon frequency information:
<http://www.arrl.org/band-plan-1>
- PICAXE *Getting Started*
<http://www.picaxe.com/Getting-Started/PICAXE-Manuals/>
- PICAXE information and user manuals
<http://www.picaxe.com/>
- Axepad IDE for *Windows, Linux* and *Mac OS*
<http://www.picaxe.com/Software/PICAXE/AXEPAD/>
- PICAXE Programming Editor for *Windows*
<http://www.picaxe.com/Software/PICAXE/PICAXE-Programming-Editor/>
- PICAXE 08M2 data sheet
<http://www.picaxe.com/docs/picaxem2.pdf>
- PICAXE chips and boards
<http://www.picaxe.com>
<http://www.sparkfun.com>
<http://www.phanderson.com/picaxe/>
<http://www.kei.co.nz>
- Keyers and keying interfaces
<http://en.wikipedia.org/wiki/2N7000>
ARRL Handbook, 2010-2013 editions, “The Universal Keying Adapter,” pp 24.29-24.31
ARRL Handbook, 2010-2013 editions, “The TiCK-4 — A Tiny CMOS Keyer,” pp 24.31-24.33.
<http://www.arrl.org/shop/>



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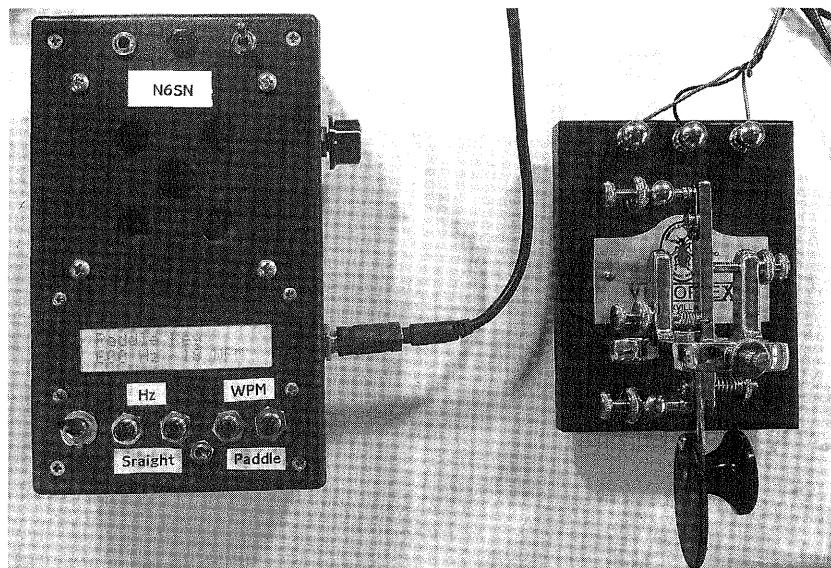
- The design and schematics in this project are licensed under the CC-BY-SA 3.0 license: <http://creativecommons.org/licenses/by-sa/3.0/>. The software is licensed under GPL 3.0.

About the Author

Bill Prats, K6ACJ, licensed in 1957, is active on HF and VHF at home, mobile in his VW Westfalia, and HFPack from Quartzsite, Arizona, to Madrid, Spain. He retired from a lifelong career in high end computer hardware, software and IT management. His favorite projects combine RF electronics, firmware and packaging to make something durable for use in shack or field. Visit his website, <http://www.biztek.com/k6acj/>.

N6SN Nanokeyer

Project by Bud Tribble, N6SN
Article by Leigh L. Klotz Jr, WA5ZNU



The original Nanokeyer built by Bud Tribble, N6SN, and shown with his Vibroplex keyer paddle. [Bud Tribble, N6SN, photo]

I met Bud Tribble, N6SN, at the PAARA (Palo Alto Amateur Radio Association) Arduino Project night. I had brought my *Cascata* project (an Arduino waterfall described in a later chapter in this book), and Bud sat right across the aisle with an intriguing box containing an old Vibroplex keyer paddle.

When it was Bud's turn to take the podium, he said he had become attracted to ham radio in 2010, and had gotten his ticket in September. Bud is one of a growing number of local hams attracted to ham radio after the requirement to use CW was lifted, but who, once licensed, found the simplicity and utility of Morse code attractive.

We're fortunate in our area to have a group of dynamic new hams interested in learning CW. They have established the SF Bay CW Enthusiasts slow-speed CW net on VHF, using multimode radios capable of SSB and CW on the net frequency of 144.23 MHz. Bud wanted to get on the air with his Vibroplex paddle, and to do so in style.

Hams have built keyers since the 1950s, using vacuum tubes, transistors and special-purpose keyer integrated circuits (the famous Curtis keyer chip). In

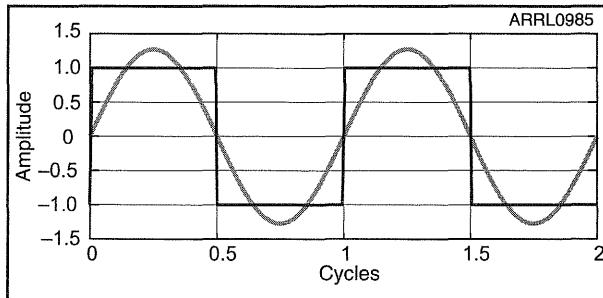


Figure 11.1 — A square wave can be decomposed into an infinite number of odd harmonics of the fundamental frequency, with the amplitude (strength) of each harmonic decreasing according to its harmonic number: the 3rd harmonic is $\frac{1}{3}$ the height of the fundamental.

include an attractive `tone()` function. You saw how to use it in the *CQ DX* chapter, and it was used again with the ATtiny85 8-pin DIP microcontroller in the *Time Out* project. The tone generated by this library function sounds a bit harsh to the ear because it is a square wave.

The square wave has an off-on-off-on signal waveform. **Figure 11.1** shows what a square wave looks like on an oscilloscope screen, compared to a sine wave of the same *fundamental* frequency. A square wave can be decomposed into an infinite number of *odd harmonics* of the fundamental frequency, with the *amplitude* (strength) of each harmonic decreasing according to its harmonic number: the 3rd harmonic is $\frac{1}{3}$ the height of the fundamental, and so on.

Some listeners prefer the pure sine wave that sounds like a CW signal received over the air, but generating a sine wave using an Arduino requires some programming skill. Bud accomplished this feat using a technique called *direct digital synthesis*, which we will explore in the next section.

For additional flair, Bud also mimicked the rise and fall time of a properly modulated CW signal to prevent the abrupt sound of the sine wave turning off and on. (On the air, that sound spreads up and down the band, producing *key clicks* that interfere with other stations.) Bud used techniques known in computer music as *attack* and *decay*.

A few more features round out the set: Bud included an optically isolated switch for keying his transmitter, along with an LCD with a few pushbuttons for setting the sidetone frequency (300-1200 Hz) and code speed (5-30 WPM). While there is no iambic keying, it does have a straight key mode. (Some keyer paddles have separate dot and dash levers. When both levers pressed simultaneously, the output of an iambic keyer alternates between dots and dashes. The *Axekey* project earlier in this book includes more information on iambic keying.)

Signal Synthesis

The audio output is generated using *direct digital synthesis*, or DDS. Also called *numerically-controlled oscillator*, a DDS can be implemented in a special-purpose integrated circuit, such as Analog Devices 9851 used in the

recent years, they've turned to microcontrollers.

One of the great things about designing your own project is that you can focus on the features you like, and leave out the ones you don't need. Bud doesn't much care for iambic keying, but he was concerned about having a pleasing sidetone oscillator with a proper rise and fall time for on-air use and for use as a code-practice oscillator.

The Arduino libraries

include an attractive `tone()` function. You saw how to use it in the *CQ DX*

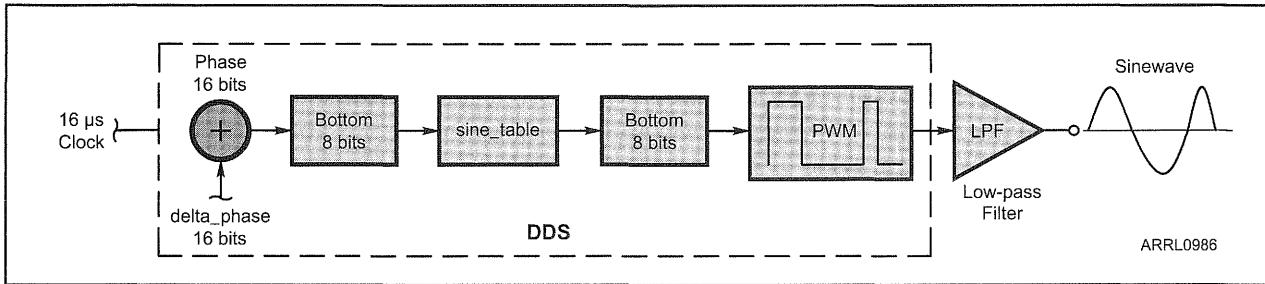


Figure 11.2 — Block diagram of a direct digital synthesis (DDS) oscillator. [Leigh Klotz, WA5ZNU]

DDS-60 module for the *Sweeper* project presented later in this book by Alan Biocca, W6AKB. This project uses a software implementation.

A DDS system uses a variable called *phase accumulator*, and a fundamental *clock*. On every clock tick, a constant value is added to the phase accumulator, resulting in a value from 0 to 360 degrees of phase angle. The `sin()` of this ranges from -1 to 1, and that result is used to drive an ADC (analog to digital converter) to produce a varying output amplitude. Instead of using a `sin()` function, DDS systems use a sine wave lookup table to convert phase angle directly into a number suitable for the ADC. These steps are often combined to take advantage of efficiencies and avoid numerical limitations. For example, in the Nanokeyer project, the phase angle is a 16-bit number 0–65535, and the `sine_wave` table has 256 values, ranging from 0 to 255. Instead of using a special-purpose DAC chip, Nanokeyer uses a pulse-width modulation (PWM) output of the ATmega 328 and an analog RC low-pass filter. See **Figure 11.2** for a block diagram of the Nanokeyer DDS. For more information about DDS, consult the References section at the end of this chapter, or see *The ARRL Handbook*.

The ATmega328 in the Arduino has three internal timers or counters, and this project uses two of them. A timer can be set up to create an *interrupt*, just like your kitchen timer. That is, you load the timer register with a value, and set up the speed at which the value decrements, and when the timer goes off, instead of ringing a bell, it calls a special function called an *interrupt handler*. Since this sketch uses two timer interrupts, it has two interrupt handlers, much as you might have a three-minute timer for a soft-boiled egg and a two-hour timer to tell you that the roast is done.

The sketch sets up `timer0` to generate the pulse-width modulated output signal. Every 16 µs, it outputs a pulse with a duty cycle ranging from 0% to 100%. The duty cycle is determined by the `value` variable, which varies from 0 to 255 as a result of the `sine_table` calculation and modulation factor. The analog low pass filter converts this variable duty cycle signal into an average amplitude between 0 and 5 V. The rate of stepping through the pre-computed sine table is controlled by the 16-bit variable *phase counter*, and this rate determines the audio frequency of the output tone.

Interrupts

Just like kitchen timers, interrupt timers can be annoying, as they literally

interrupt whatever the processor is doing, even if it is in the middle of some other computation. Since computer code generally executes in a linear fashion, one instruction after another, these interrupts are exceptional cases and demand care in coding. For example, note that some of the variables in the code have the unusual keyword `volatile` in front of them. That tells the Arduino compiler that these variables can change in the middle of use, so that even while one function is accessing them, it could have the rug pulled out from under it by an interrupt handler, and so the value might change.

For example, consider the following piece of Arduino code:

```
int x = 0;
int y = 7;
x = y + y;
```

You can easily tell that, at the end of this code segment, the variable `x` will hold the value 14. The Arduino compiler can do this too, and will *optimize* the `x` computation into a constant and eliminate `y`, just as if you had written this:

```
int x = 14;
```

Now let's see what happens in the presence of an interrupt routine that is allowed to change `y`:

```
int x = 0;
volatile int y = 7;
x = y + y;
```

The interrupt could happen at any time; if it happens before the addition, then `y` will no longer be 7. And the annoying interrupt might even happen during the addition, so the computation might wind up adding 7 and 8. There is no way to know what the value of `x` is going to be, because we cannot predict when the interrupt will happen.

More concretely, the variable `wpm` (for code-speed words per minute) is declared `volatile` because it is changed in an interrupt routine, and so it needs to be freshly checked each time it is used. The same is true for the `phase` accumulator and `phase_delta` variables, because they are changed by interrupt routines.

Timer Usage

The Arduino library also uses `timer0`, as a counter for the `millis()` function. This project uses `timer0` for generating the sine wave output and `timer1` to control element (dit and dah) timing. Since `timer0` is set up by the sketch, it is not available for Arduino library use, and so you cannot use the `millis()` function. Some functions and libraries such as `analogWrite()`, `tone()` and `Servo` use timers as well, so exercise care when combining your own interrupt routines with Arduino library functions.

Keying Waveform

One of the reasons Bud built this project (other than fun) was to get a really nice sounding sidetone for practice. The modulation factor is a value multiplied by the beginning and end of the dit or dah to provide a more gradual turn on and turn off lasting a few milliseconds. Waveshaping is important because it prevents key clicks. **Figure 11.3** shows the waveform of a single dit as seen on an oscilloscope.

Construction

Bud built his keyer on a white solderless protoboard using an Arduino

Nano, and he placed it in an amply sized project box. **Figure 11.4** shows the inside of his Nanokeyer.

Bud's project includes an LCD for showing speed and frequency, an optically-isolated transceiver keying output, an audio amplifier based on the LM386, a speaker and a 9 V battery. Bud also built his project using an assortment of normally-open and normally-closed switches,

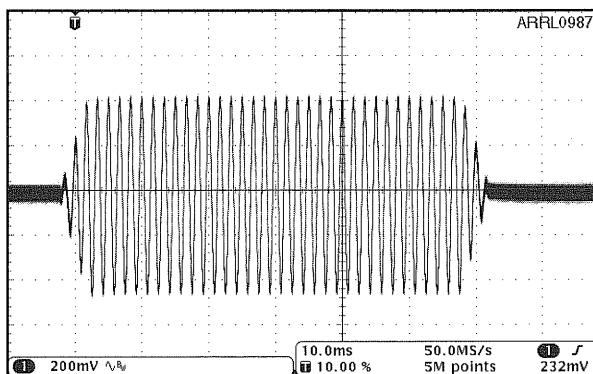


Figure 11.3 —The keying waveform produced by the waveshaping code in the Arduino sketch, shown here with a single dit. [Bud Tribble, N6SN]

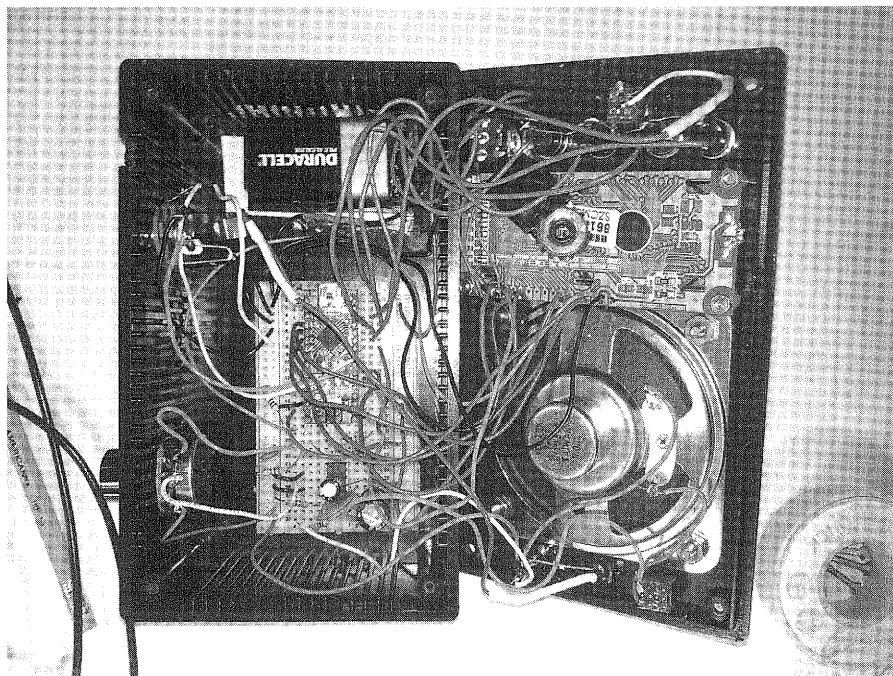


Figure 11.4 —Bud built his keyer on a white solderless protoboard, using an Arduino Nano, and placed it in an amply-sized project box. [Bud Tribble, N6SN, photo]

and he adjusted the sketch code accordingly. The sketch in this chapter assumes all normally-open switches.

This article is not intended to provide the information needed to reproduce all of the features in Bud's keyer. For my build, I chose to experiment only with the DDS aspect of the software and the sidetone generator waveshaping, since that is what attracted me most about this project. The sidetone was loud enough for me without an additional audio amplifier, and since my focus was learning about the DDS, I did not build a transceiver keying interface or include an LCD.

If you want to do more with this project, transceiver keying circuits are available in the *Axekey* and *Pharos* projects earlier in this book, as well as in the References section at the end of this chapter. Numerous LM386 audio amplifier circuits are available online or in the *ARRL Handbook* (see References). This book's *LCD Shields* appendix offers information on a variety of displays that could be added.

Protoboard Layout

Since I had an inexpensive Solarbotics Ardweeny I had not yet built, I used this project as an excuse to build one. (They're actually fun to put together. You can read more about Ardweeny in the *Hardware* appendix.)

A schematic of my partial build of Bud's keyer is shown in **Figure 11.5**. R1 and C1 form a low pass filter on the sidetone output. Switches S1 and S2 adjust the sidetone frequency up and down, while S3 and S4 adjust the keyer speed. Keyer output to a transceiver, if used, would be on pin D12 through a suitable interface as mentioned earlier. My solderless protoboard layout is shown in **Figure 11.6**, and my bench project is shown in **Figure 11.7**.

Sketch

The sketch for the Nanokeyer is slightly unusual, in that it does not include a `setup()` or `loop()` function. Instead, it defines a `main()` function. The Arduino library normally provides the `main()` function, and so by replacing it, Bud takes over the initialization of the Arduino pins and timers completely.

In my version I did not include an LCD. If you choose to use an LCD, add `#define USE_LCD 1` to the code, and use an LCD library. For the bench version, I just used a Serial port.

The sketch starts with pin definitions and PWM description:

```
// Keyer for AVR
// Copyright 2011, 2012 Bud Tribble, N6SN
// License: http://www.opensource.org/licenses/mit-license

// UP      B0          D8
// DOWN    B1          D9
// QRS     B2          D10
// QRQ     B3          D11
// TX      B4          D12
// LED     B5          D13
// DIT     D4  [TIP]    D4
```

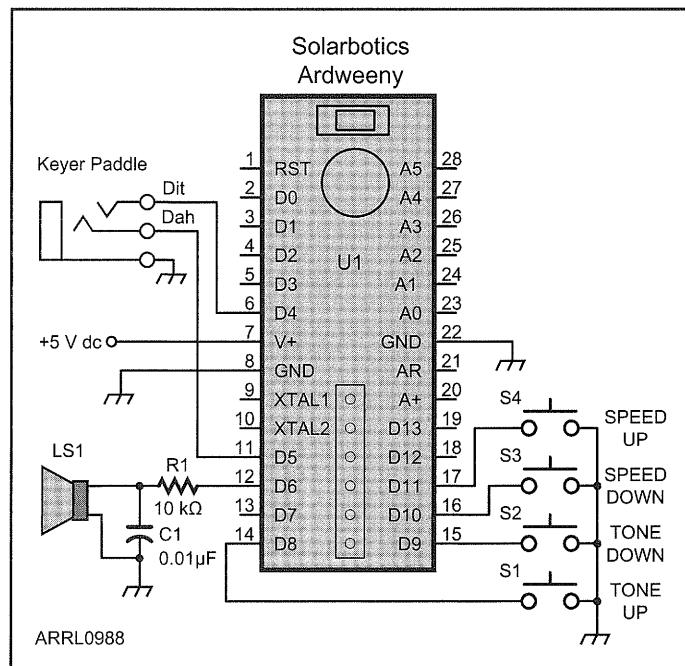


Figure 11.5 — Schematic diagram of the simplified version built by Leigh, WA5ZNU, to experiment with the DDS and sidetone waveshaping. Leigh omitted the LCD, audio amplifier and transceiver keying interface that Bud included in his original version.

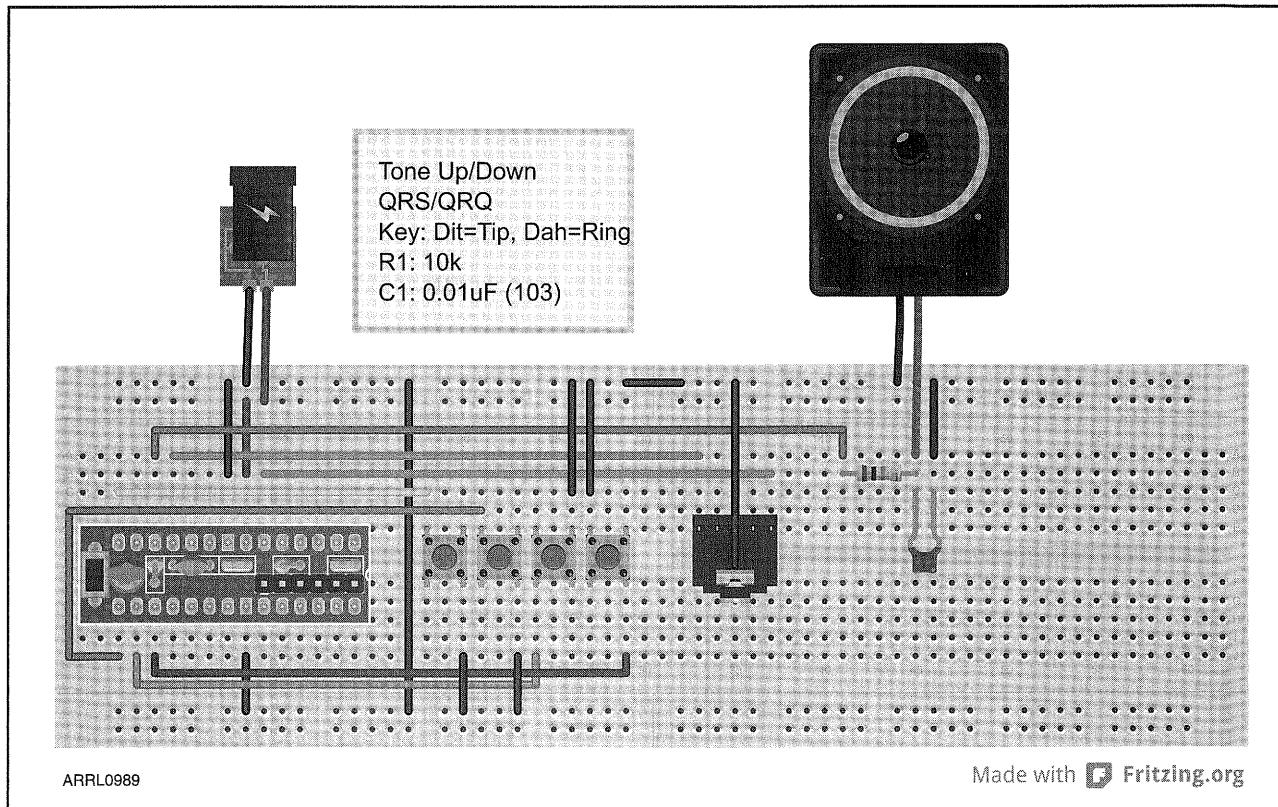


Figure 11.6 — Protoboard layout of Leigh's Nanokeyer from Figure 11.5 on a solderless breadboard, using the Solarbotics Ardweeny. This drawing was created using the free program Fritzing. [Leigh Klotz, WA5ZNU]

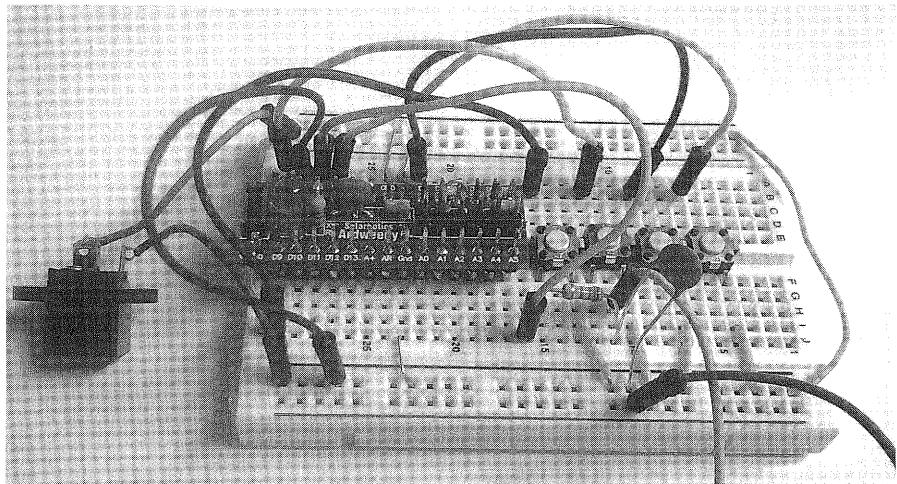


Figure 11.7 — Leigh's Nanokeyer built from the layout in Figure 11.6 and ready for testing. [Leigh Klotz, WA5ZNU, photo]

```

// DAH      D5  [RING]      D5
// TONE     D6           D6
// MODE     D7           D7

// The PWM output (pin D6 on the Arduino Nano) goes through a simple
// low pass RC filter before it goes to the LM386 amplifier.

// The PWM frequency is 62.5KHz. The 3dB corner of the filter is
// about 16KHz. (R = 10K, C = .001uF) The default modulation
// frequency for the code signal is 600Hz (can be changed up or down
// with pushbuttons).

```

Header files include a few of the AVR (Atmel) files for lower-level access to interrupts.

```

#include <Arduino.h>

#include <stdint.h>
#include <stdio.h>
#include <avr/io.h>
#include <avr/interrupt.h>
#include <util/delay.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>

```

Bud used a particular LCD module, but for my version, I did not attach an LCD, so I used the #define facility to convert the LCD operations into Serial port debugging strings.

```
#ifdef USE_LCD
#include <lcd.h>
#else
#define USE_SERIAL
#define lcd_init() Serial.begin(19200)
#define lcd_line1(x) Serial.println(x)
#define lcd_line2(x) Serial.println(x)
#else
#define lcd_init()
#define lcd_line1(x)
#define lcd_line2(x)
#endif
#endif
```

Definitions for constants used in the sketch:

```
#define UI_DELAY 80
#define STRAIGHT 0
#define PADDLE 1
```

Definitions of byte (`uint8_t`) variables used in the sketch.

```
uint8_t mode;
uint8_t reverse_polarity;
uint8_t left_key_down, right_key_down, key_down;
```

The buf is used for formatting text to print to the LCD.

```
char buf[64];
```

The value `dot_time` is 1200/wpm. It is an `int` but could be a `byte` because the maximum value 1200/5 is less than 255.

```
int dot_time;
```

These values control the waveshaping and code speed, and are marked as `volatile` because they are changed inside the interrupt handlers, and the `volatile` declaration tells the compiler that in the main program that it cannot make any optimization assumptions about when the values may change.

```
volatile int wpm;
volatile uint8_t modulation;
volatile uint8_t rl_modulation = 0; // rate limited modulation;
volatile uint8_t timer1_busy = 0;
```

These values control the sidetone frequency and implement the DDS. This simple code does not take advantage of symmetries in the `sin` function, but if necessary, the size of the `sine_table` could be reduced to 64 bytes.

```
int frequency;
int8_t sine_table[256];
volatile uint16_t phase;
volatile uint16_t delta_phase;
```

This routine with the strange ISR(TIMER0_OVF_vect) declaration is the handler for the waveshaping and DDS generation. It runs every 16 µs, like clockwork, and steps the sine save forward one tick.

```
ISR(TIMER0_OVF_vect) {
    int value;

    if (rl_modulation < modulation) {
        rl_modulation++;
    } else if (rl_modulation > modulation) {
        rl_modulation--;
    }

    value = sine_table[phase >> 8];
    value = value * rl_modulation;           // [- (127*256)..(127*256) ]
    value = value + (127*255);
    value = value >> 8;
    phase += delta_phase;

    OCR0A = value;
    return;
}
```

The timer1 interrupt handler ends the dit or dah production.

```
ISR(TIMER1_OVF_vect) {
    modulation = 0;
    timer1_busy = 0;
}

void start_timer1(int msec) {
    uint16_t count;
    TCCR1B = 0;                                // Turn off timer1
    TIFR1 = TOV1;                             // Make sure overflow bit is clear
    timer1_busy = 1;

    // timer will count up to 0xFFFF
    count = trunc(65536.0 - (msec * 1000.0)/16.0);
    cli();
    TCNT1 = count;
    sei();
    timer1_busy = 1;
    TCCR1B = 0x04;                            // Turn on timer1
    // 16 usec ticks
}
```

The `check_key` function checks the paddle and sets `left_key_down` or `right_key_down` or neither.

```
void check_key() {
    // D4 = Tip, D5 = Ring
    if (reverse_polarity) {
        right_key_down = ((PIND & _BV(PORTD4)) == 0);
        left_key_down = ((PIND & _BV(PORTD5)) == 0);
    } else {
        left_key_down = ((PIND & _BV(PORTD4)) == 0);
        right_key_down = ((PIND & _BV(PORTD5)) == 0);
    }
}
```

The `space` routine delays for the specified number of `dot_time` periods.

```
void space(uint8_t i) {
    while (i > 0) {
        start_timer1(dot_time);
        while (timer1_busy != 0);
        i--;
    }
}
```

The `dot` function generates a dit and also checks for the press of the dash key to call `dash` if necessary.

```
void dot(uint8_t key_xmitter) {
    uint8_t got_dash = 0;
    modulation = 255;
    if (key_xmitter) PORTB |= _BV(PORTB4);
    PORTB |= _BV(PORTB5);
    start_timer1(dot_time);
    while (timer1_busy != 0) {
        // check for dash
        check_key();
        if (right_key_down) got_dash = 1;
    }
    modulation = 0;
    PORTB &= ~_BV(PORTB4);
    PORTB &= ~_BV(PORTB5);
    space(1);
    if (got_dash) dash(key_xmitter);
}
```

The `dash` function is the symmetric opposite of `dit` but with dah timing.

```
void dash(uint8_t key_xmitter) {
    uint8_t got_dot = 0;
```

```

modulation = 255;
if (key_xmitter) PORTB |= _BV(PORTB4);
PORTB |= _BV(PORTB5);
start_timer1(dot_time * 3);
while (timer1_busy != 0) {
    // check for dot
    check_key();
    if (left_key_down) got_dot = 1;
}

modulation = 0;
PORTB &= ~_BV(PORTB4);
PORTB &= ~_BV(PORTB5);
space(1);
if (got_dot) {
    dot(key_xmitter);
}
}

```

The update_display function keeps the user informed of straight key, paddle and polarity, frequency and code speed.

```

void update_display() {
    if (mode == STRAIGHT) {
        lcd_line1("Straight Key");
    } else {
        if (reverse_polarity)
            lcd_line1("Paddle Key (rev)");
        else lcd_line1("Paddle Key");
    }
    sprintf(buf, "%d Hz %d WPM", frequency, wpm);
    lcd_line2(buf);
}

```

Instead of using setup, this sketch uses main(), which overrides the usual setup and takes over the lower-level interrupt and PWM control.

```

int main( void ) {
    int i;

    // Initialize sine_table
    for (i = 0; i < 256; i++) {
        sine_table[i] = 127 * sin((2*M_PI*i)/256.0);
    }

    DDRB |= _BV(PORTB5); // LED output
    DDRD |= _BV(PORTD6); // PWM output
    DDRB |= _BV(PORTB4); // xmitter key output
}

```

```

// Turn on pull-ups for inputs
PORTD |= _BV(PORTD4) | _BV(PORTD5) | _BV(PORTD7);
PORTB |= _BV(PORTB0) | _BV(PORTB1) |
         _BV(PORTB2) | _BV(PORTB3) | _BV(PORTB4);

TCCR0A = 0x83;
TCCR0B = 0x01;
OCR0A = 128;
TIFR0 = 0x01;                      // Make sure overflow bit is clear


TIMSK0 = 0x01;
TCCR1A = 0x00;
TIFR1 = 0x01;                      // Make sure overflow bit is clear


TIMSK1 = 0x01;
PORTB &= ~_BV(PORTB4);           // Make sure key is off

lcd_init();
if (!(PIND & _BV(PORTD7))) {
    mode = PADDLE;
} else {
    mode = STRAIGHT;
}

frequency = 600;
wpm = 15;
dot_time = 1200/wpm;
phase = 0;
// 1/16us sample rate
delta_phase = round((256.0*256.0*16.0*frequency)/1000000.0);
modulation = 0;
rl_modulation = 0;
timer1_busy = 0;

// if key down on power up, reverse the dot dash polarity on paddle
check_key();
reverse_polarity = left_key_down || right_key_down;
update_display();
sei();

dot(0); dot(0); dot(0); dash(0);

while (1) {
    check_key();

    if (mode == STRAIGHT) {

```

```

// STRAIGHT mode
if (! (PIND & _BV(PORTD7))) {
    mode = PADDLE;
    update_display();
}

key_down = left_key_down || right_key_down;

if (key_down) {
    modulation = 255;
    PORTB |= _BV(PORTB4); // key xmitter
    PORTB |= _BV(PORTB5); // LED
} else {
    modulation = 0;
    PORTB &= ~_BV(PORTB4); // unkey xmitter
    PORTB &= ~_BV(PORTB5); // LED
}
} else {
    // PADDLE mode
    if (PIND & _BV(PORTD7)) {
        mode = STRAIGHT;
        update_display();
    }

    if (left_key_down) {
        dot(1);
    } else {
        modulation = 0;
    }

    if (right_key_down) {
        dash(1);
    } else {
        modulation = 0;
    }
}

if (((PINB & _BV(PORTB2)) == 0) || ((PINB & _BV(PORTB3)) == 0)) {
    // change wpm
    if (PINB & _BV(PORTB2)) wpm--; else wpm++;
    if (wpm >= 30) wpm = 30;
    if (wpm <= 5) wpm = 5;
    dot_time = 1200/wpm;
    update_display();
    dot(0);
}

if (((PINB & _BV(PORTB0)) == 0) || ((PINB & _BV(PORTB1)) == 0)) {

```

```

// change frequency
if (PINB & _BV(PORTB0)) frequency -= 10; else frequency += 10;
if (frequency <= 300) frequency = 300;
if (frequency >= 1200) frequency = 1200;
// 1/16uS sample rate
delta_phase = round((256.0*256.0*16.0*frequency)/1000000.0);
update_display();
dot(0);
}
}

return 0;
}

```



<http://qth.me/wa5znu/+nanokeyer>

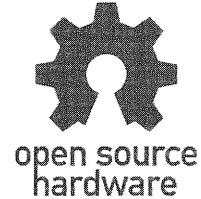
References and Further Reading

- Online references
<http://qth.me/wa5znu/+nanokeyer>
- Project source code
<http://qth.me/n6sn/+nanokeyer/code>
- PWM/DDS Sine Wave Generation on the ATmega 328P (Gary Hill)
http://www.csulb.edu/~hill/ee470/Sine_Wave_Generator.pdf
- ATmega timers and counters
<http://www.mythic-beasts.com/~markt/ATmega-timers.html>
- ARRL's *Digital Signal Processing Technology* by Doug Smith, KF6DX
See Chapter 7, Direct Digital Synthesis. Note that this book may be out of print.
<http://www.arrl.org/shop/>
- *ARRL Handbook*, 2010 or later edition, Chapter 9 — Oscillators and Synthesizers
<http://www.arrl.org/shop/>
- ELM Chan AVR DDS
http://elm-chan.org/works/asg/report_e.html
- *DDS and the Electronic Music Box, Nuts and Volts Magazine*, April 2012 (Craig Lindley)
http://www.nutsvolts.com/index.php?/magazine/article/april2012_Lindley
- Solarbotics Ardweeny
<http://www.solarbotics.com/product/kardw/>
- Keyers and keying interfaces
<http://en.wikipedia.org/wiki/2N7000>
ARRL Handbook, 2010-2013 editions, “The Universal Keying Adapter,” pp 24.29-24.31
ARRL Handbook, 2010-2013 editions, “The TiCK-4 — A Tiny CMOS Keyer,” pp 24.31-24.33.
<http://www.arrl.org/shop/>

- LM386 audio amplifier

LM386 audio amplifier circuits are included as part of several receiver and audio filter projects in the *ARRL Handbook*, 2010-2013 editions. Examples may be found in Chapters 10, 11, 12 or 24, or search the CD-ROM included in the book.

<http://www.arrl.org/shop/>



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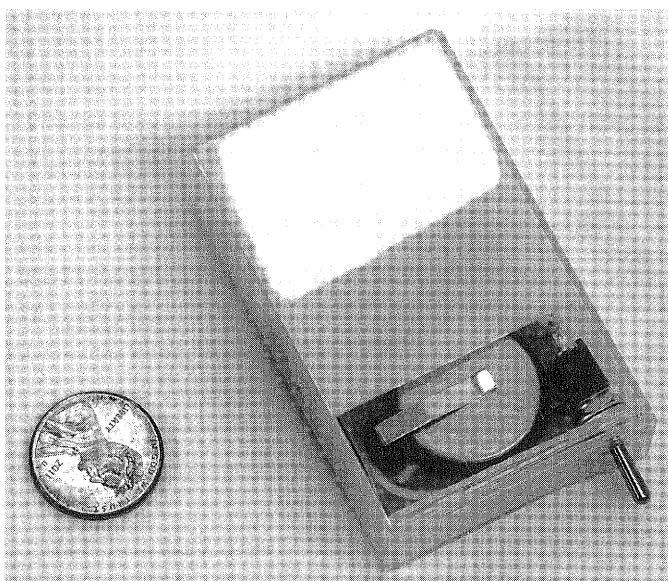
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Time Out: A Handheld Radio Talk Timer

Keith Amidon, KJ6PUO
Peter Amidon, KJ6PUN



The final version of the Time Out timer, mounted in a compact case. The cover is a piece of plastic from a fluorescent light diffuser that gives the illuminated LED a soft glow. [Keith Amidon, KJ6PUO, photo]

“This is KJ6PUN, net control for Silicon Valley Youth Net. We will now take check-ins from hams 18 and younger.”

With these words, my son Peter took on a responsibility familiar to many hams around the country: running a local net on a 2 meter repeater. When Ryan Lee, K3SFG (ARRL East Bay Section assistant for Youth Activities) started the Youth Net, his goal was to get more young hams talking to each other, and gain experience with different types of radio operations. I was proud of Peter’s accomplishment, but one skill that many of the young hams (and some adult ones!) needed help with was judging when the 90 second timeout timer on the repeater was about to expire.

Our family also attends the local Foothills Amateur Radio Society (FARS) meeting, and when we heard that the FARS cosponsored project booth at the SF Bay Area Maker Faire was to focus on Arduinos and ham radio, Peter and I knew we wanted to get involved. After some discussions with the organizers,

we settled on an Arduino project to sense RF from a nearby handheld transceiver and start a 90 second timeout timer. Since we already had some Arduino experience in projects unrelated to radio this seemed like the ideal first radio-related project for us to try and we dove right in.

Description

We quickly decided we wanted to build a portable battery operated device that could give both audible and visual warnings of an upcoming repeater drop. After a bit of experimentation, we picked a design that used an analog input to sense RF, a piezo buzzer for audible warnings, and a red/green bi-color LED to give visual warnings and provide status information. The title page photo shows the final device we built, sized just right for use with a compact handheld radio.

The design did not pop into our heads fully formed. We began by prototyping a minimal implementation on a breadboard so that we could see something in operation as quickly as possible.

Boarduino Prototype

We used an Arduino compatible called the Boarduino because we had one on hand and it works well in a prototyping board. To start with, we just fed a short wire into one of the analog pins for an antenna, with a $10\text{ M}\Omega$ resistor between the antenna and ground. Because we thought the RF signal would be a high impedance source, we also added a small ($0.01\text{ }\mu\text{F}$) capacitor to provide a steadier signal for the Arduino ADC. We also added a bypass capacitor on the AREF pin. There is a schematic of the setup in **Figure 12.1** and a picture of the corresponding circuit on a breadboard in **Figure 12.2**.

After some consultation with a local Elmer, we wrote a simple program to test whether the idea would work.

The program first established a background RF level in the setup function. Since the background level naturally fluctuates over time, we read the analog value of the pin connected to the antenna wire every 20 ms for a total of 2 seconds and selected the maximum value measured to establish the threshold.

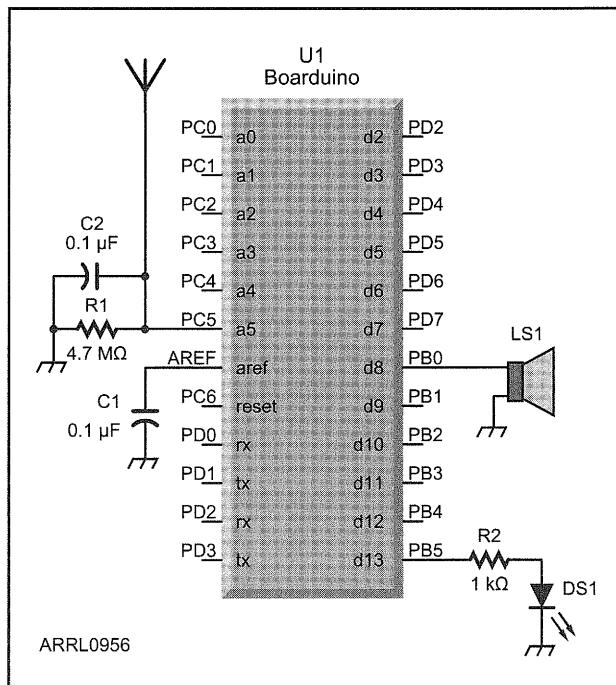
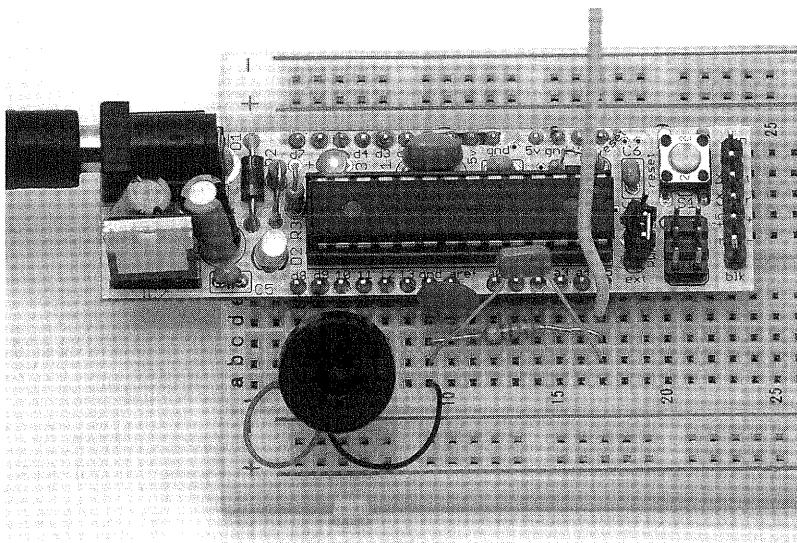


Figure 12.1 — Schematic of the Boarduino prototype. Only a few external components are used, and the component values shown are the final values after some experimentation. See the text for discussion.

Figure 12.2 —
The Boarduino
prototype
mounted on
a breadboard.
[Keith Amidon,
KJ6PUO, photo]



```
#define IN 5
#define LED 13
int threshold = 0;

void setup() {
    Serial.begin(9600);
    pinMode(LED, OUTPUT);
    // Set up for 1.1v internal reference, to be most sensitive.
    analogReference(INTERNAL);
    // Calculate current max value of RF field.
    for (int i = 0; i < 100; i++) {
        threshold = max(threshold, analogRead(IN));
        delay(20);
    }
    threshold += 10;
    Serial.print("Threshold is "); Serial.println(threshold);
}
```

The loop function reads the value of the antenna pin and compares it to the threshold to see if a radio is transmitting. Not being sure of the best way to implement the timeout function yet, we decided just to turn on the built-in LED connected to pin 13 whenever we detected a transmission.

```
void loop() {
    int x = analogRead(IN);
    if (x > threshold) {
        digitalWrite(LED, HIGH);
        Serial.println(x);
    } else {
        digitalWrite(LED, LOW);
    }
}
```

Table 12.1 —
Debugging the Prototype

<i>Change Made</i>	<i>Result</i>
Shortening the wires of the breadboard, because the breadboard had long wires.	Readings went down a little, but there were fluctuations in the RF level from small environmental factors, such as placing our hands near it.
Setting the threshold 100 ADC readings higher than the measured value, lowering resistance between antenna and ground to $1\text{ M}\Omega$.	Reliable detection of transmitter, but only if it was close by (within a few inches). Small environmental factors were still a problem.
Looping antenna (inserting both ends into breadboard).	Slight reduction of sensitivity to environmental factors, but not enough. Sensitivity still low.
Adding $0.1\text{ }\mu\text{F}$ capacitor in parallel with the $1\text{ M}\Omega$ resistor.	Larger reduction of sensitivity to environmental factors. Sensitivity to transmission still too low.
Changed the number that was added to the threshold from 100 to 0.	Threshold became 0, so the RF levels could never be below it.
Changed the number that was added to the threshold from 0 to 10.	Returned to how it was before changing 100 to 0.
Changed $0.1\text{ }\mu\text{F}$ capacitor between the antenna and ground to $0.01\text{ }\mu\text{F}$.	Transmissions detected from ~5 feet away; slightly increased sensitivity to environmental factors.
Unlooping antenna.	Increased sensitivity; transmissions detected from ~10 ft. away. Slightly increased sensitivity to environmental factors.

Now the trouble — and the troubleshooting — began. Even a simple project like this one can go wrong in a myriad of ways. Using a low-power handheld radio we found a free simplex frequency and began making short transmissions to test the timer, periodically identifying ourselves and the purpose of our transmissions. Observing the LED in our circuit we saw nothing happen at all.

Even the output of debugging information on the serial port showed only unintelligible characters instead of the series of signal levels we expected. Verifying the serial settings and testing again led to the same result. With nothing else obvious to try, we reflashed the bootloader on the board and after that everything worked fine. Sometimes problems just come out of left field!

With that out of the way, our serial port debugging quickly showed us that we were always reading the maximum value possible on the analog pin, which meant the measured threshold could never be exceeded to trigger the detection of a transmission. Guided by our somewhat meager theoretical knowledge of RF analog circuit behavior, we began experimenting to see how we could overcome the issue. The changes we made, and their effects, are shown in **Table 12.1**.

We finally decided to use this combination:

- 4.7 M Ω resistor between antenna and ground
- 0.1 μ F capacitor between antenna and ground
- Unlooped antenna
- 20 added to the threshold

We replaced the LED with a piezo buzzer and the `digitalOut()` in the sketch with a call to the `tone()` function to verify that we could make an audible alert. This change significantly reduced the range but a little more experimentation restored it.

To complete the repeater drop warning function we needed to implement the timer countdown. Unfortunately, the Arduino has no real-time clock; the only time functions implemented in the Arduino library are ones that will return the milliseconds or the microseconds since the microcontroller was initialized. Since we did not need microsecond accuracy we used the `millis()` function. Whenever the code detects the beginning of a transmission it reads the current value of `millis()` and saves it. As long as RF is detected, it checks the difference between the new value of `millis()` and the old and creates increasingly urgent warnings when half the time to drop remains, when $\frac{1}{4}$ of the time remains, and when there are only 5 seconds left. If the transmission ceases, everything resets and waits for the next transmission.

Since we were going to be programming and using the device ourselves, there was no need to include any switches or complex means to set the timeouts, so we just specified the available time as a constant in the program.

When we tested our implementation, it did not work. A careful inspection of the code revealed a few errors, and we were confident fixing them would resolve the problem. We tested again and did get three alerts, but the alert that should have gone off with $\frac{1}{4}$ of the time remaining happened much earlier, shortly after the start of a transmission. We looked and looked but couldn't find any errors that we thought would induce this behavior. Everything looked correct.

To find the solution we had to think about the range of numbers represented in an integer in Arduino. Since the ATmega 328 is an 8-bit microcontroller, literal numbers in programs are treated as the data type `int`, or 16 bit numbers, with a range of -32,768 to +32,767. Our calculation of the $\frac{3}{4}$ time threshold was exceeding this range and resulting in unexpected values. Changing the constants to long integers by appending a capital `L` to the end of the constant number fixed the problem and our timer worked as we planned.

ATtiny85 Production Version

The Boarduino was a great platform for testing, but even though it is smaller than a regular Arduino it is too big for our project. We ordered a few ATtiny85 chips in the 8-pin DIP package and built two hardwired versions of the circuit. Surprisingly, we found that many of the modifications required when we were prototyping on the breadboard were no longer required and in some cases actually prevented correct operation. So, more experiments led us to a final design.

In normal operation, the device indicates it is monitoring for RF by slowly

pulsing the green section of a bi-color red/green LED. When it detects a nearby transmitter, it beeps and sets the green LED to full brightness. When the user has been transmitting for 45 seconds (half of time before the repeater drop), the LED lights orange, and a piezo buzzer emits a 600 Hz tone. If the operator continues transmitting until $\frac{1}{4}$ of the time remains, the red section of the LED shows solid and the buzzer moves to a higher 700 Hz pitch. Past the drop timeout the red LED starts to flash and a continuous 900 Hz tone sounds until the transmitter is unkeyed. The device then returns to the slowly pulsing green LED.

When first powered up, both LED colors and the buzzer turn on for 1 second, showing that everything is in working order. The device then quickly calibrates the background RF level to determine an *on* threshold for the analog sensor reading. Just the red LED turns on as a warning not to transmit for about two seconds during calibration.

We also found it valuable during debugging to know the threshold, so the last phase of initialization shows the transmission threshold on the LED by flashing in the following sequence:

- Start sequence: single beep, show solid green (green on, red off)
- Hundreds digit value: the green LED flashes once for 100 and twice for 200.
- Tens digit value
- Ones digit value: Just the red LED flashes
- End sequence: green on, red on, green off, red off

The Sketch

The sketch for Time Out is broken up into a few sketch files. The Arduino IDE makes this an easy task, and the tabs at the top of the window make the organization easy to navigate. The main file is named `TimeOut.ino` and it contains the main definitions and the `setup` and `loop` functions. Other files are broken up by their functionality, to make it easy to understand in mind-sized bites. As long as each file is a `.ino` file in the same sketch, there is no need to worry about using `#include` directives or specially ordering the file names.

The source code download is available at the book resources website (see the References section at the end of this chapter), and it has a Zip file containing all these sketch components so you don't have to type them in. Read the following sections to understand how the sketch works so you can modify it to meet your own needs.

TimeOut.ino

The top of the sketch defines the pins used and the timing thresholds. This is where we had to be careful about using `L` after big numbers.

It is also good practice to use parentheses around any definitions that have calculations in them because the value of the `#define` gets substituted where its name occurs in the sketch, and sometimes surprising things can happen with order of operations rules.

The timer values used are all specified in `#define` preprocessor directives at the beginning of the sketch so that they can be easily modified. We set the

drop time to a short 30 seconds in the version presented here as it allows for reasonably quick and accurate testing. After everything was working, we set it back to 90 seconds for use with our local repeater.

```
#define ANT 0
#define RED_LED 2
#define GREEN_LED 1
#define BUZZER 0

#define LOOP_DELAY 25
#define MAX_IDLE_FADE_BRIGHTNESS 192
#define INIT_SAMPLE_CNT 92
#define MOVING_AVG_SIZE 16
#define REPEATER_MAX_TIME 30000L
#define REPEATER_LAST_ALERT_RELATIVE 5000L
#define REPEATER_EARLY_ALERT (REPEATER_MAX_TIME/2)
#define REPEATER_MED_ALERT ((REPEATER_MAX_TIME*3)/4)
#define REPEATER_LAST_ALERT (REPEATER_MAX_TIME-REPEATER_LAST_ALERT_RELATIVE)
#define REPEATER_LAST_ALERT_FLASH_DURATION 500
```

With most of the complexities in other functions, the setup and loop functions are very simple.

```
int threshold = 0;

void setup() {
    setup_and_verify_hardware();
    threshold = calculate_rf_threshold();
    delay(500);
    flashNumber(threshold);
}

void loop() {
    if (update_moving_avg(analogRead(ANT)) <= threshold) {
        do_idle_behavior();
    } else {
        do_transmitting_behavior();
    }
    delay(LOOP_DELAY); // No need to run as fast as possible.
}
```

Hardware.ino

This file initializes the hardware pins and flashes and buzzes to let us know the hardware is working.

```
void setup_and_verify_hardware() {
    // Attempt to force pin low to minimize analog value read from environments
```

```

pinMode(ANT, INPUT);
digitalWrite(ANT, LOW);
analogReference(DEFAULT);

// Setup LED pin
pinMode(RED_LED, OUTPUT);
pinMode(GREEN_LED, OUTPUT);

// Verify LEDs & tone are working
digitalWrite(RED_LED, HIGH);
delay(200);
digitalWrite(GREEN_LED, HIGH);
tone(BUZZER, 800);
delay(1000);
noTone(BUZZER);
digitalWrite(GREEN_LED, LOW);
delay(200);
digitalWrite(RED_LED, LOW);
}

```

The `calculate_rf_threshold()` function samples the antenna `INIT_SAMPLE_CNT` times and determines an average reading from a subset of those and the maximum reading seen. It returns the result that `setup` uses to set the threshold. The value is the average reading, plus $\frac{1}{4}$ of the difference between the average and the maximum, to minimize false positives.

```

int calculate_rf_threshold() {
    digitalWrite(RED_LED, HIGH); // Turn on red LED while determining threshold
    int max_v = 0;
    for (int i = 0; i < INIT_SAMPLE_CNT; i++) {
        int v = analogRead(ANT);
        if (i % (INIT_SAMPLE_CNT/MOVING_AVG_SIZE) == 0) {
            update_moving_avg(v); // Deliberately ignore return value;
        }
        max_v = max(max_v, v);
        delay(LOOP_DELAY);
    }
    digitalWrite(GREEN_LED, LOW);
    int t = calculate_moving_avg();
    t = threshold + ((max_v - threshold)/4);
    digitalWrite(RED_LED, LOW);
    return t;
}

```

Idle.ino

The Arduino `loop` function calls `do_idle_behavior()` when the RF level falls below the threshold. When the sketch is no longer detecting a trans-

mission, the idle behavior is to turn everything off, then pulse the green LED to slightly less than full brightness to indicate that the device is still powered on. (The ARDUINO BASICS|FADE example from the IDE was a big help here.)

```
int brightness = 0; // Initial brightness for idle LED pulsing
int fadeAmount = 2; // Magnitude of next change of brightness
                    // for idle LED pulsing

// Millisecond timer at which transmission started, 0 for none
unsigned long start_millis = 0;
void do_idle_behavior() {
    start_millis = 0;
    digitalWrite(RED_LED, LOW);
    noTone(BUZZER);
    analogWrite(GREEN_LED,brightness);
    brightness = brightness + fadeAmount;
    if (brightness <= 0 || brightness >= MAX_IDLE_FADE_BRIGHTNESS) {
        fadeAmount = -fadeAmount;
    }
}
```

Transmit.ino

To determine the length of transmission, the sketch again uses the `millis()` function. As in the prototype, when a transmission starts it records the value returned by `millis()` at that time. The sketch calculates the difference from more recent calls to get the current duration of the transmission, and it keeps track of the alarms have been triggered by incrementing a count of alarms as each occurs.

```
// Index of next alarm that should occur
int next_alarm = 0;
void do_transmitting_behavior() {
    // Trigger alarms when appropriate amount of time has passed
    if (start_millis == 0) {
        start_millis = millis();
        next_alarm = 0;
    }
    int duration = millis() - start_millis;
    if (duration < REPEATER_MED_ALERT && next_alarm < 1) {
        // A short high-pitched chirp and solid green LED indicate
        // the timer has started
        digitalWrite(GREEN_LED, HIGH);
        tone(BUZZER, 900, 200);
        next_alarm = 1;
    } else if (duration >= REPEATER_EARLY_ALERT && next_alarm < 2) {
        // A longer beep and orange (red + green) LED color indicate
        // the early warning has passed
    }
}
```

```

tone(BUZZER,600,500);
digitalWrite(RED_LED, HIGH);
next_alarm = 2;
} else if (duration >= REPEATER_MED_ALERT && next_alarm < 3) {
// Another longer beep and solid red LED color indicate the
// late warning has passed
tone(BUZZER,700,200);
digitalWrite(GREEN_LED, LOW);
digitalWrite(RED_LED, HIGH);
next_alarm = 3;
} else if (duration >= REPEATER_LAST_ALERT && next_alarm < 4) {
// A continuous tone and flash solid red LED color indicate
// the timer has expired
tone(BUZZER,900);
int i;
while (update_moving_avg(analogRead(ANT)) > threshold) {
if (i % (REPEATER_LAST_ALERT_FLASH_DURATION/LOOP_DELAY) == 0) {
if (i % (2*REPEATER_LAST_ALERT_FLASH_DURATION/LOOP_DELAY) == 0) {
digitalWrite(RED_LED, LOW);
} else {
digitalWrite(RED_LED, HIGH);
}
}
delay(LOOP_DELAY);
i++;
}
}
}
}

```

Average.ino

The simplicity of the RF measurement hardware poses a challenge to the software. Since there is no bandpass filtering on the antenna, the RF value measured will be influenced by signals received across the entire spectrum.

Significant fluctuations in measured levels that are uncorrelated with an intended transmission are often observed. To eliminate false detection of transmissions, this sketch uses a moving average of recent measurements. The `update_moving_avg()` and `calculate_moving_avg()` functions implement this capability. An array of recently measured values is maintained as a circular buffer by `update_moving_avg()` with `calculate_moving_avg()` generating the average for the current set of measurements. Notice the use of pointers and pointer arithmetic to implement this concisely.

```

int moving_avg_readings[MOVING_AVG_SIZE]; // Array for storing old readings
int *moving_avg_head = moving_avg_readings; // Location most recent reading
int *moving_avg_tail = moving_avg_readings; // Location of oldest reading

int update_moving_avg(int value) {

```

```

// Update a moving average of the last MOVING_AVG_SIZE readings.
// Returns the new average.
*moving_avg_head = value;
if (++moving_avg_head >= &moving_avg_readings[MOVING_AVG_SIZE]) {
    moving_avg_head = moving_avg_readings; // wrap on overflow
}
if (moving_avg_head == moving_avg_tail) {
    // This is only true if we've already read MOVING_AVG_SIZE values,
    // in which case we need to move the tail pointer.
    if (++moving_avg_tail >= &moving_avg_readings[MOVING_AVG_SIZE]) {
        moving_avg_tail = moving_avg_readings; // wrap on overflow
    }
}
return calculate_moving_avg();
}

int calculate_moving_avg() {
// Calculate the moving average based on existing readings
int *p = moving_avg_tail;
int total = 0;
int cnt = 0;

while (p != moving_avg_head) {
    cnt++;
    total += *p;
    if (++p >= &moving_avg_readings[MOVING_AVG_SIZE]) {
        p = moving_avg_readings; // wrap on overflow
    }
}
return total/cnt;
}

```

Flash.ino

This file contains the flashNumber function, which displays a number using only the red and green LEDs.

```

void flashNumber(int num) {

    // Start sequence
    digitalWrite(RED_LED, HIGH);
    delay(100);
    digitalWrite(GREEN_LED, HIGH);
    delay(100);
    digitalWrite(RED_LED, LOW);
    delay(100);
    digitalWrite(GREEN_LED, LOW);
    delay(500);
}

```

```

// Flash hundreds
delay(500);
for (int i = 0; i < num / 100; i++) {
    digitalWrite(GREEN_LED, HIGH);
    delay(200);
    digitalWrite(GREEN_LED, LOW);
    delay(200);
}
// Flash tens
delay(500);
for (int i = 0; i < (num % 100) / 10; i++) {
    digitalWrite(RED_LED, HIGH);
    digitalWrite(GREEN_LED, HIGH);
    delay(200);
    digitalWrite(RED_LED, LOW);
    digitalWrite(GREEN_LED, LOW);
    delay(200);
}
// Flash ones
delay(500);
for (int i = 0; i < (num % 100) % 10; i++) {
    digitalWrite(RED_LED, HIGH);
    delay(200);
    digitalWrite(RED_LED, LOW);
    delay(200);
}
// End sequence
delay(500);
digitalWrite(GREEN_LED, HIGH);
delay(100);
digitalWrite(RED_LED, HIGH);
delay(100);
digitalWrite(GREEN_LED, LOW);
delay(100);
digitalWrite(RED_LED, LOW);
}

```

Programming the ATtiny85

Download the `time-out.zip` file from the book resources website and unzip it into your Arduino sketchbook directory.

You program the ATtiny85 before putting it into the circuit. Although you can use an Arduino as an intermediary to program an ATtiny (as described in the *QRSS ATtiny* project), to program our device we chose a USBTinyISP in-circuit programmer. This device has a 6 pin header that must be connected to the proper pins of the microcontroller. For ease of insertion/removal we placed our microcontroller in a solderless breadboard and connected jumper wires from the programmer's header to the pins of the microcontroller used for programming.

To set up the Arduino IDE for this project, load the sketch in the Arduino IDE, and then select the ATtiny85 board and USBTinyISP programmer from the TOOLS menu.

The ATtiny microcontrollers also have *fuses* (internal options settings) that must be set to specific values to work correctly with the Arduino core. It is unlikely that the part has the correct values as received, but they can be easily programmed by selecting TOOLS|BURN BOOTLOADER. The ATtiny does not actually use a bootloader (and so no bootloader is programmed), but this menu function sets the fuses correctly.

With those steps out of the way, select FILE|UPLOAD or press the right-arrow button. Once the microcontroller is successfully programmed remove it from the breadboard and begin the assembly steps below.

Assembly

We built two prototypes, and you can find photos of the early ones on the book resources website. The schematic for the final ATtiny version is shown in the **Figure 12.3**, and a parts list is shown in **Table 12.2**.

Table 12.2

Time Out Timer Materials

Part	Description
BT1	CR2032 3 V lithium battery
DS1	Bi-color red/green LED with 3 leads
LS1	Piezo buzzer
R1	4.7 MΩ resistor
R2, R3	47 Ω resistor
S1	SPST miniature toggle switch
U1	Atmel ATtiny85 MCU
Antenna:	6-inches of 24-gauge stranded wire
Misc:	CR2032 battery holder, 8-pin DIP socket, perfboard, strip board or similar, plastic case, card stock, aluminum foil, diffuser plastic

By assembling the connections in the following order the device can be neatly constructed with point to point wiring.

- Begin with the 8-pin DIP socket for the ATtiny85. Using a socket is important to allow for removal of the microcontroller to reprogram it as the project circuitry prevents reliable programming.
- Connect the negative terminal of the battery holder to pin 4 of the DIP socket. This will be the ground connection. The socket should have a small notch at one end. The pin to the left of the notch is pin 1. Pins 2, 3, and 4 are in sequence on that side of the socket. Pin 5 is directly across from pin 4 and pins 6, 7, and 8 follow in sequence so that pin 8 is opposite pin 1.
- Connect R1 between pin 1 of the socket (PB5/ADC0) and pin 4 (ground).
- Connect the antenna wire (A1) to pin 1 of the socket (PB5/ADC0) with one end connected and the other end left free-hanging.
- Connect pin 7 of the socket (PB2/ADC1) to R2
- Connect the other side of R2 to the anode of the red side of DS1.
- Connect the cathode of DS1 to ground.
- Connect pin 6 of the socket (PB1/D0) to R3
- Connect the other side of R3 to the anode of the green side of DS1.

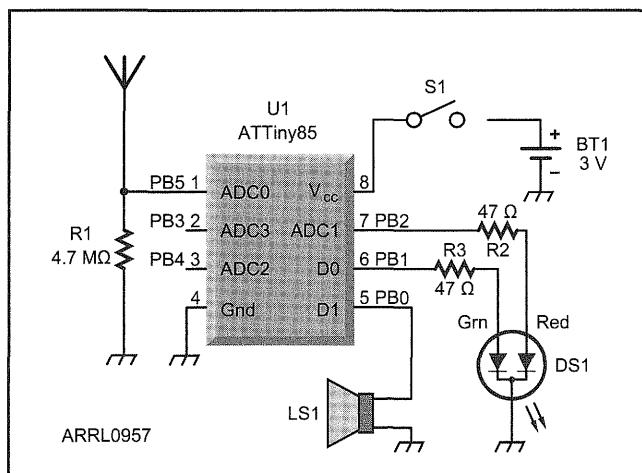


Figure 12.3 — Schematic of the final ATtiny85 version of the Time Out timer. See Table 4.2 for a parts list.

- Connect pin 5 of the socket (PB0/D1) to ground through LS1 (the piezo buzzer). The buzzer may be connected in either direction.
- Connect pin 8 of the DIP socket to one side of the SPST switch
- Connect the other side of the SPST switch to the positive terminal of the battery holder.

Figures 12.4 and 12.5 show the top and bottom of a second prototype made on a solder-clad perfboard. We packaged this prototype in a small plastic case with an LED reflecting box made of card stock and aluminum and a translucent white plastic diffuser cut from a fluorescent light fixture diffuser. (For more project photos, see the online references.)

Conclusion

We've found our timer operates quite reliably as long as we keep the timer within a few inches of the transmitter. For portable use, you could use a hook-and-loop fastener to attach the timer to your handheld. Our third version is compact, functional, and meets all of our initial requirements. We haven't been bitten by the repeater "alligator" since completing it!

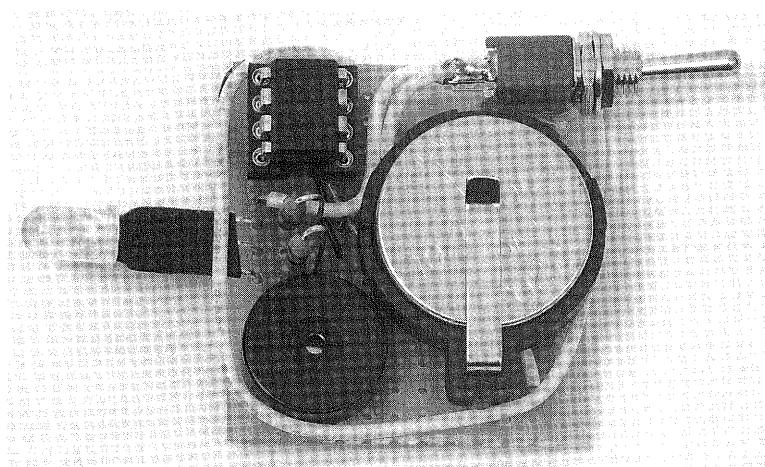


Figure 12.4 — Top view of the ATtiny85 version built on perfboard. The white antenna wire loops around the board.
[Keith Amidon, KJ6PUO, photo]

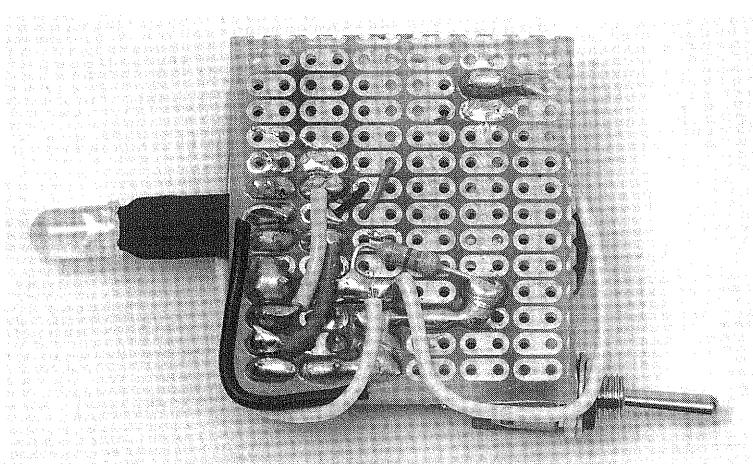
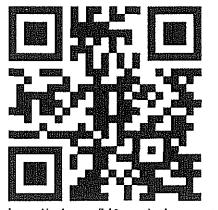


Figure 12.5 — Bottom view of the ATtiny85 version.
[Keith Amidon, KJ6PUO, photo]

Future Directions

There are a number of enhancements we'd like to further develop however. We'd like to create a PC board to make a more compact version of the circuit, possibly using surface mount components. Check the book resources website to see our progress on building an all-in-one PC board version of this project.

There are two extra inputs available on the ATtiny85 that we'd like to connect to momentary switches and use to allow the operator to modify the device. Our plan is to use them as up and down buttons to manually modify one or more parameters affecting operation. The two parameters that seem most interesting to modify are the length of time until the repeater drop and the transmission detection threshold. The user adjusted value of both of these could be stored in the ATtiny's EEPROM memory so that they remain in effect after the device is



<http://qth.me/kj6puo/+time-out>

powered off and back on again.

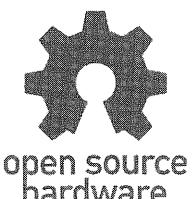
Once we have the ability to modify the transmission threshold value we'd also like to experiment with detection with the device at a greater distance from the transmitter as the operator could then modify the preferred distance by manually adjusting the initially detected threshold.

In the sketch, there are more efficient ways to calculate the moving average and handle array wrap. Would you like to implement them?

References

- Online references
<http://qth.me/kj6puo/+time-out>
- Source code for this project
<http://qth.me/kj6puo/+time-out/code>
- Schematics
<http://qth.me/kj6puo/+time-out/schematics>
- Boarduino
<http://www.ladyada.net/make/boarduino/>
- Arduino Tiny
<http://code.google.com/p/arduino-tiny/>
- Adafruit USBTinyISP
<http://www.ladyada.net/make/usbtinyisp/>
- SparkFun AVR-ISP Shield
<http://www.sparkfun.com/products/11168>
- Aaron Lai EMF Detector
<http://www.aaronalai.com/emf-detector>
- MOSFET E-Field Sensor
<http://home.comcast.net/~botronics/efield.html>
- Field Strength Meter
<http://www.zen22142.zen.co.uk/Circuits/rf/sfsm.htm>

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About the Authors

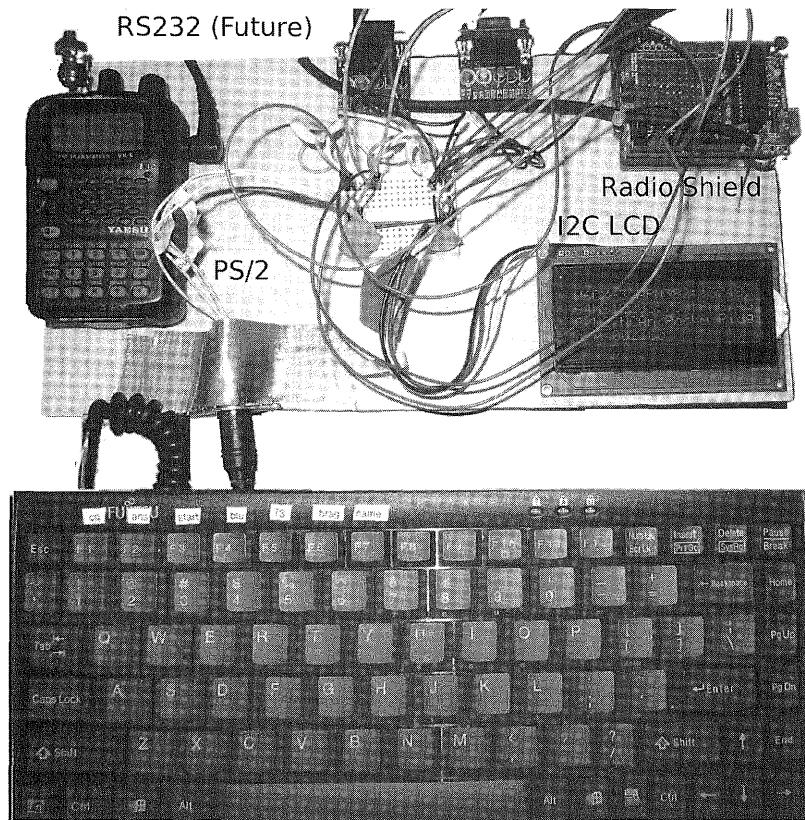
Keith Amidon, KJ6PUO, is a General class Amateur Radio operator, licensed in 2011. He has dual Bachelor of Science degrees in electrical and computer engineering from the University of Michigan and is currently developing next generation data networking technologies at Nicira, Inc. He can be reached through email addressed to camalot@picnicpark.org.

Peter Amidon, KJ6PUN, is a General class Amateur Radio operator, also licensed in 2011. He is currently a sixth grade student with deep interests in math, science and anything related to computers. Recently

he has helped pass on those interests to other students by assisting in the development and teaching of a course on the fundamentals of computer operation and programming that included a segment on programming the Arduino platform using both the Arduino IDE and an implementation of the Forth language.

Hermes APRS Messenger

Michael Pechner, NE6RD



Hermes is an APRS messenger system build of Arduino components and peripherals. The working version shown here is built using prototype-level construction techniques for easy bench operation. Using smaller components and PC board construction could radically reduce the size. [Michael Pechner, NE6RD, photo]

During parachute mobile jumps with Mark Meltzer, AF6IM, and Michael Gregg, KF6WRW, my first concern is the safety of the jumpers. My *Timber* project, described in an earlier chapter, records APRS telemetry data. Using it we can monitor speed, altitude and blood oxygenation levels of the jumpers. However, our only two-way means of communication is FM voice. The jumpers are also trying to make as many QSOs as they can during the jump, so the frequency is in constant use. This project is my first prototype for an alternate communications channel for getting important information to the jumpers.

Ultimately, I'd like to make a compact, wristwatch-sized device. I have

made two prototypes so far, one that is transmit only, and now *Hermes*, which both transmits and receives APRS messages.

Block Diagram

Figure 13.1 shows a block diagram of the system. For the digital side, the *Hermes* prototype uses an Arduino, Argent Data Radio Shield, a PS/2 keyboard and a display LCD. As with *Timber*, on the RF side I use a handheld radio and antenna.

Display LCD

A four-line display is necessary for this project because the user interface for sending and receiving messages has more text and interaction than most other Arduino projects, which work well with a two-line display. The display I used had an on-board jumper setting (R1) to set the mode to I2C. The I2C display uses only two pins.

Four-line LCDs are controlled by two separate display controllers. One controller is for lines one and two and the other is for lines three and four, so you need to break the 80 screen characters into four 20-character segments.

Hermes keeps only the last eight APRS messages, and of those only the first 80 characters. The memory on the Arduino is only 2048 bytes. So taking 640 characters to hold 8 messages is a significant portion of the available memory.

Operation

In the code you will need to make some changes before you upload the sketch. In `setup()`, these lines need to be modified:

```
memcpy(eeprom_map.mycall, "NE6RD-1 \0",10);  
memcpy(eeprom_map.msgto, "NE6RD-2 \0", 10);  
eeprom_map.msgto_flag='1';  
strcpy(eeprom_map.path, DEFAULT_PATH);
```

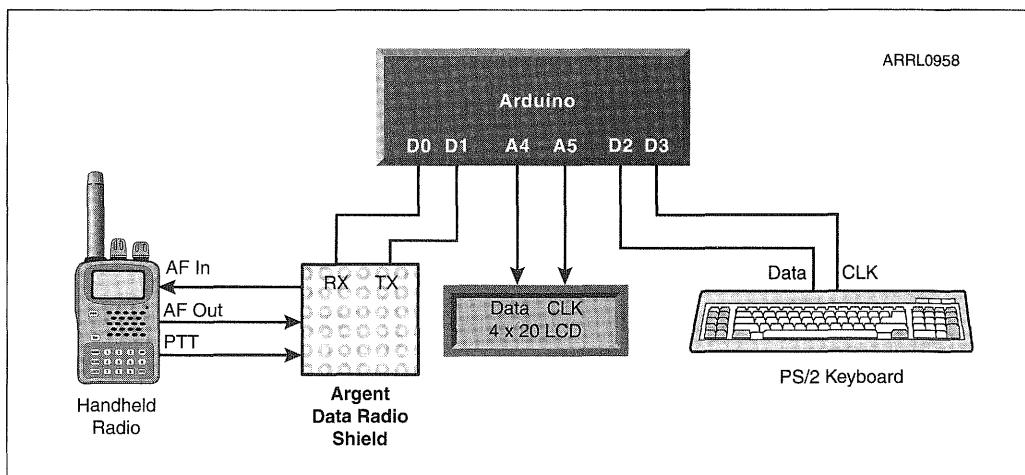


Figure 13.1 — Block diagram showing the main interconnections between *Hermes* components.

Since this is a memcpy, the null at the 10th character is required. If you want to be set for station to station, then also set eeprom_map.msgto to the call sign. And make sure eeprom_map.msgto_flag is the character 1. If you want the messages to be generic beacons, then set eeprom_map.msgto_flag to the character 0.

The default digipath is:

```
#define DEFAULT_PATH "WIDE1-1,WIDE2-1"
```

Change it as needed — but make sure you check <http://aprs.fi> for the sent packets. If they complain about a bad path, consider changing it. If you need the path cast a little wider, consider WIDE1-1,WIDE2-2.

Connect the speaker/mic jack from the Radio Shield to the radio. Turn on the radio and power up the Arduino. Set the squelch so it just barely cuts off noise. For the volume level, I set it so the volume knob is about half between low and high. This works with both the Yaesu VX-5 and FT-60 handhelds.

Once power is applied, you will see the startup screen. A few seconds later the screen will blank or the first received message will pop up. Use the up and down arrow keys to scroll through the received messages.

To send a message, just start typing it. It will accept the first 59 characters. After that it will just flash the last characters. When you press the enter key, the message will be sent. If you stop typing for more than 10 seconds, the message will be discarded and *Hermes* will go back to receiving messages. When you use the up and down arrow key, the current message will stay displayed for 15 seconds. After that, the next received message will be displayed.

Sketch

Below is the main *Hermes*.ino sketch file. The whole sketch file and supporting libraries are available for download at this book's website (see the References section at the end of this chapter).

```
#define VERSION "1.1"

#include <stdlib.h>
#include <Wire.h>
#include <inttypes.h>
#include <EEPROM.h>
```

Define NEWHAVEN_LCD for the New Haven Display I2C LCD display. Use ADAFRUIT_LCD for the Adafruit version. For either one, you must install a library; see the References. SparkFun also sells a similar board, but it is TTL serial.

```
#define NEWHAVEN_LCD

#ifndef NEWHAVEN_LCD
#include <LCDi2c.h>
LCDi2cNHD lcd = LCDi2c(4,20,0x50>>1,0);
#endif
```

```
#ifdef ADAFRUIT_LCD
#include <LiquidCrystal.h>
LiquidCrystal lcd(0);
#endif
```

The PS2Keyboard library from the book companion site has more keys defined than the Arduino / PJRC download; again, check the References.

```
#include <PS2Keyboard.h>
PS2Keyboard keyboard;
```

Here are EEPROM definitions. Call signs are 9 characters, space padded.

```
#define CALLS_SIZE 9
// APRS max 63 characters including the "{999" message counter.
#define MSG_SIZE 59

//A reasonable APRS digipath
#define DEFAULT_PATH "WIDE1-1,WIDE2-1"
```

If you change the LCD, make sure you change the next few defines: number of lines in the LCD, number of characters on each line of the LCD, and maximum number of characters the LCD can display.

```
#define LCD_LINES 4
#define LCD_LINE_SZ 20
#define LCD_LEN 80
```

Here are the number of messages we will track and the maximum length of any APRS message we will save.

```
#define Q_SIZE 8
#define Q_LINE_LEN 80
```

This is the structure we will use to store parameters between uses. If doing station to station, msgto stores that call sign. The flag msgto_flag is 1 for station to station and 0 for general status message, and path is the digipath.

```
struct eeprom_map_struct{
    char mycall[10];
    char msgto[10];
    char msgto_flag;
    char path[25];
} eeprom_map;
```

The message queue is in line_buffer:

```
char line_buffer[Q_SIZE][Q_LINE_LEN+1];
```

`q_char_cur` tracks which character we have read in the current message being received between -1 and `Q_LINE_LEN`. `q_line_cur` is the line we are filling between 0 and `Q_SIZE`.

```
int q_char_cur = -1;
int q_line_cur = -1;
```

`d_line_cur` shows which line in `line_buffer` is being displayed on the LCD.

```
int d_line_cur = 0;
```

To keep things from getting too jumpy we track the last time the up or down arrow is pressed. If the arrow key has not been pressed for more than 15 seconds, then when a new line is received `q_line_cur` and `d_line_cur` will be the same so the new received message will be displayed.

```
long last_arrow = millis();
```

Four-line LCDs do not display in order. The lines are interleaved. So to insert the second line: `line[1]` returns 2. The second line starts at character `2 * LCD_LINE_SZ` or 40. The first line starts at character 0. The second line starts at 40, the third line at 20, and the fourth at 60!

```
char lcdbuff[(LCD_LINES * LCD_LINE_SZ)+1];
int line[4]={0,2,1,3};
```

Here are the hardware pin definitions:

```
//LCD I2C A4 and A5
#define LCD_CLK 5
#define LCD_SDI 4

// PS/2 keyboard D2 D3
const int DataPin = 2;
const int IRQpin = 3;
```

The main loop processes modem input and keyboard input, and handles the up and down arrow keys. Message receiving is suspended while the typing is processed. The up and down arrow are scroll through the received messages. All the other keys are captured to create and send an APRS message.

```
void loop() {
    if (Serial.available() > 0) {
        process_radioshield();
    }

    if (keyboard.available()) {
        int c = keyboard.read();
```

```

    if (c == PS2_DOWNARROW || c == PS2_UPARROW) {
        int dir = (c == PS2_DOWNARROW) ? +1 : -1;
        d_line_cur -= dir;
        check_line(&d_line_cur, dir);
        last_arrow=millis();
        display_lcd();
    } else if (is_print(c)) {
        process_kb(c);
    }
}
}

```

The `check_line` function will correct the value if it is outside the allowable values for line number used for up and down arrow key presses:

```

void check_line(int* line, int dir) {
    int start = *line;
    if (*line < 0) {
        *line = Q_SIZE - 1;
        while (line_buffer[*line][0] == '\0' && *line != start) {
            *line = *line + dir;
        }
    }
    if (*line > Q_SIZE || line_buffer[*line][0] == '\0') {
        *line=0;
    }
}

```

The `next_line` function returns a valid next line for the LCD.

```

void next_line(int* line) {
    (*line)++;
    if (*line >= Q_SIZE) {
        *line=0;
    }
}

```

Because of the odd arrangement of the four lines, we can't just copy the `line_buffer` into the `lcdbuff`; instead, we need to grab each chunk of 20 characters and place it in the correct segment of `lcdbuff`. Function `display_lcd` displays the text at `line_buffer[d_line_cur]`.

```

void display_lcd() {
    memset(lcdbuff, ' ', LCD_LINES*LCD_LINE_SZ);
    lcdbuff[80]=0;

    int line_len = strlen(line_buffer[d_line_cur], Q_LINE_LEN);

    int ii = 0;

```

```

int to_copy=0;
int pos = 0;
while(ii < 4 and pos < line_len) {
    to_copy = (line_len - pos) > 20 ? 20 : (line_len - pos);
    strncpy(&(lcdbuff[line[ii]*LCD_LINE_SZ]),
            &(line_buffer[d_line_cur][pos]), to_copy);
    pos += to_copy;
    ii++;
}
lcd.clear();
lcd.setCursor(0,0);
lcd.print(lcdbuff);
}

```

The sendline function sends either a station-to-station message or a general *status* message.

- Station to station

\!:TOCALL : message \{999\\r\\n

- General Message

\!> the message text \{999\\n\\r

The text should be no more than 63 characters. The “{999” is a “{” followed by a random number. This prevents APRS stations from considering this a duplicate if you send the same message too often. I use the built in random number generator to generate the 1-3 digit number. The “{999” is part of the 63 characters.

```

void sendline(char* message) {
    int len = strlen(message, Q_LINE_LEN);

    if (len >= Q_LINE_LEN)
        *(message + Q_LINE_LEN) = '\0';

    if (eeprom_map.msgto_flag == '1') {
        // makes sure the i/o channel is cleared of debug messages
        Serial.print("W \\r\\n");
        Serial.print("!:");
        Serial.print(eeprom_map.msgto);
        Serial.print(":");
    } else {
        Serial.print("!>");
    }
    Serial.print(message);
    Serial.print("{");
    Serial.print(random(999));
    Serial.println("\\r\\n");
    Serial.println("Wsend message\\r\\n");
    delay(3000);
}

```

Function which_pos takes pos (a message offset) and returns the position in the LCD buffer to write the character, again with the challenging line offsets for a four-line LCD.

```
int which_pos(int pos) {
    return ((line[ pos/LCD_LINE_SZ] * LCD_LINE_SZ) + (pos % LCD_LINE_SZ));
```

```
boolean is_print(int c) {
    return (c >= 32 && c <=128);
```

The first character read on loop () is passed in to be processed. It reads the data from the keyboard, and at end of line, adds to the message list. If nothing is typed for 10 seconds, it assumes the message was abandoned.

```
void process_kb(int c) {

    if (! is_print(c))
        return;

    //line buffer for keyboard input
    char kb_line[Q_LINE_LEN + 1];
    int cur_char = 0;
    //timer var
    unsigned long st_millisec = millis();
    //how long a pause in typing we accept
    const long max_milli = 10000L;

    lcd.clear();
    lcd.setCursor(0,0);
    memset(lcdbuff, ' ', LCD_LINES*LCD_LINE_SZ);
    memset(kb_line, '\0', Q_LINE_LEN + 1);
    lcdbuff[80]=0;

    //place the first character that was passed in.
    lcdbuff[0]= (char) c;
    kb_line[0]=(char)c;

    int char_num = 1;

    while (true) {
        if (keyboard.available()) {
            c = keyboard.read();
            //if return id some non printable key is pressed,
            // Send the message and update the LCD
            if (c == '\n' or ! is_print(c)) {
```

```

        if(strlen(kb_line) > 0) {
            next_line(&q_line_cur);
            strncpy(line_buffer[q_line_cur], kb_line, Q_LINE_LEN);
            sendline(kb_line);
        }
        display_lcd();
        return;
    }
    st_millisec = millis(); //restart the 10sec timer
    //store the character
    lcdbuff[which_pos(char_num)] = (char)c;
    kb_line[char_num] = (char)c;

    char_num++;
    //update the LCD
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print(lcdbuff);

    //just keep overlaying the last character
    if (char_num >= MSG_SIZE) {
        char_num--;
    }
}
//if we stopped typeing for too long, exit
if ((millis() - st_millisec) > max_milli) {
    display_lcd();
    return;
}
display_lcd();
}

```

Function `process_radioshield` reads the messages from the Radio Shield. This function times out and exits if reading the Radio Shield for longer than 500 ms, or if something is being typed on the keyboard.

```

void process_radioshield() {
    char inbyte = 0;
    //max time to run this method
    const long max_milli = 500L;
    unsigned long st_millisec = millis();

    // -1 means the last time in we finished processing the last line
    if (q_char_cur == -1) {
        next_line(&q_line_cur);
        // Get next offset in line_buffer to fill
        // If the user is scrolling through the messages,

```

```

// don't move d_line_cur.
// If what is displayed for 15 seconds
// after the last time the up or down
// arrow key was pressed.
// Set both cursors to the same spot.
if ((millis() - last_arrow) > 15000L)
    d_line_cur = q_line_cur;
//start at the first character
q_char_cur=0;
}

//while something is there and we are here
// less than max_milli, read from the shield
while (Serial.available() > 0 &&
        ((millis() - st_millisec) < max_milli)) {
    inbyte = Serial.read();           // Get the byte

    //end of line or message too long
    if (inbyte == '\n' or q_char_cur >= Q_LINE_LEN) {
        display_lcd();
        //if too many characters, read until end of line found
        if (q_char_cur >= Q_LINE_LEN) {
            while(inbyte != '\n' and inbyte != '\r')
                inbyte = Serial.read();
        }
        //set position for ack we processed a while message
        q_char_cur = -1;
        return;
    }
    else if (isprint(inbyte) and q_char_cur < Q_LINE_LEN) {
        // Only record printable characters
        //is printable and we have not read too much
        line_buffer[q_line_cur] [q_char_cur++] = inbyte;
        line_buffer[q_line_cur] [q_char_cur]=0;
    }
}

//keyboard data waiting leave
if (keyboard.available()) {
    return;
}
display_lcd();
}

```

The `setup()` function initializes the serial baud rate to 4800, and sets up the LCD and keyboard. It initializes the parameters as well. If the setup does not complete, make sure you have a keyboard installed.

```
void setup() {
#define NEWHAVEN_LCD
    lcd.init();
#endif
#define ADAFRUIT_LCD
    lcd.begin(20, 4);
#endif
    lcd.setBacklight(5);
    lcd.clear();
    lcd.setCursor(0,0);

    Serial.begin(4800);

    //Makes sure that the line array is correct for a 2 line LCD.
    if (LCD_LINES == 2)
        line[1]=1;

    memset(line_buffer, 0, sizeof(line_buffer));

    keyboard.begin(DataPin, IRQpin);
    //initialize the random number generator - used in send_line
    randomSeed(analogRead(0));

    //until I get the eeprom menu settings done, just hardcode them.
    // NOTE: make sure mycall and msgto are space padded to 9 characters
    memcpy(eeprom_map.mycall, "NE6RD-1  \0",10);
    memcpy(eeprom_map.msgto,  "NE6RD-2  \0", 10);
    eeprom_map.msgto_flag='1';
    strcpy(eeprom_map.path, DEFAULT_PATH);

    //initialize the radio shield to it's callsign and the digipath
    Serial.print("M");
    Serial.print(eeprom_map.mycall);
    Serial.print("\r\n");
    Serial.read(); //flush the return value from the input
    Serial.print("P");
    Serial.print(eeprom_map.path);
    Serial.print("\r\n");
    Serial.read(); //flush the return value from the input
    delay(10);

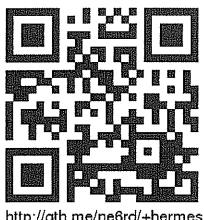
    lcd.print("APRS TERMINAL");
    lcd.setCursor(1,0);
    lcd.print(" by NE6RD");
    lcd.setCursor(2,0);
    lcd.print(" Have Fun");
    delay(3000);
    lcd.clear();
    lcd.setCursor(0,0);
}
```

Future Ideas

- Build the project using a perfboard or a PC board and put it in a case.
- Use a larger display or an OLED that is easier to read outdoors.
- Use a DE9 with the Kantronics TNC pinout, or use a four-pin right angle header. (The PTT resistor then moves to the cable housing for radios that need it.)
- More messages: Before you change `Q_SIZE` to increase the number of stored messages keep in mind that on 2000 bytes of SRAM is available. If you want to receive and store more than 80 characters, change `Q_LINE_LEN`, but you will need to figure out how to display the text, as the total display size is only 80 characters. You could write the messages to an SD card flash memory, or use us an external 23K256 RAM device and a 3.3 V level converter.
<http://www.arduino.cc/playground/Main/SpiRAM>
<http://www.adafruit.com/products/395>
<http://www.sparkfun.com/products/8745>
- Add a GPS.
- Write configuration UI for the EEPROM data.
- Read data from an attached device, such as a weather station, to beacon messages.
- Find a use for the extra LCD screen you can add to the Radio Shield.
- PSK31 or RTTY instead of APRS. The Elecraft KX3 and K3 feature an RS-232 protocol for sending PSK31 and RTTY, in effect acting as a radio modem. Replace the Radio Shield with the LinkSprite RS232 Shield and use a PS/2 keyboard with your Elecraft radio.
http://www.linkspritedirect.com/product_info.php?products_id=114
- Use an external PS/2 converter. You can simplify the sketch and get back more Arduino memory by using an external PS/2 keyboard converter instead of the PJRC Keyboard sketch library.
<http://www.adafruit.com/products/1136>

On the Air

Although you can build this project without holding an Amateur Radio license in the US and many other countries, before transmitting with the hand-held radio used in this project you must obtain an appropriate license. In the US, a Technician license from the FCC is sufficient for operating on the VHF and UHF frequencies used by the APRS network. Please check the regulations of your country before building and transmitting with this project.



References

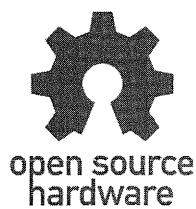
- Online references
<http://qth.me/ne6rd/+hermes>
- Source code for this project
<http://qth.me/ne6rd/+hermes/code>

Libraries

- PS/2 keyboard library
 - I modified this library to add symbols for more keys.
<http://www.arduino.cc/playground/Main/PS2Keyboard>
 - The original is from the Teensy developer:
http://www.pjrc.com/teensy/td_libs_PS2Keyboard.html
- NE6RD PS/2 additions
 - My modified version of PS2Keyboard is available for download here
<http://qth.me/ne6rd/+hermes/code>
- New Haven Displays 4×20 LCD Library
 - <http://arduino.cc/playground/Code/LCDi2c>
- Adafruit I2C/SPI Library
 - For the Adafruit I2C LCD Backpack:
<http://www.ladyada.net/products/i2cspilcdbackpack/>
 - Install the modified LiquidCrystal library:
<https://github.com/adafruit/LiquidCrystal>

Components

- Argent Data Systems Radio Shield
 - Build the Radio Shield as in the *Timber* project.
https://www.argentdata.com/catalog/product_info.php?products_id=136
- Argent Data Yaesu cable
 - https://www.argentdata.com/catalog/product_info.php?products_id=68
- LCD choice 1:
 - New Haven Displays 4×20 5 V I2C Serial LCD
<http://www.newhavendisplay.com>
 - <http://www.jameco.com>
- LCD choice 2:
 - Adafruit I2C/SPI LCD Backpack:
<http://www.adafruit.com/products/292>
 - Adafruit 4×20 Display:
<http://www.adafruit.com/products/198>
- PS/2 connector
 - <http://www.adafruit.com/products/804>
 - <http://www.sparkfun.com/products/8509>
 - <http://www.sparkfun.com/products/8651>
 - <https://www.jameco.com/Jameco/Products/ProdDS/2111441.pdf>
- PS/2 keyboard, US English
- Arduino header set
 - <http://www.sparkfun.com/products/10007>
- #22 AWG wire in multiple colors or male-male jumper cables
- Small breadboard or PC board
 - <http://www.sparkfun.com/products/7916>
- Machined male and female headers
 - <http://www.sparkfun.com/products/743>
 - <http://www.sparkfun.com/products/117>

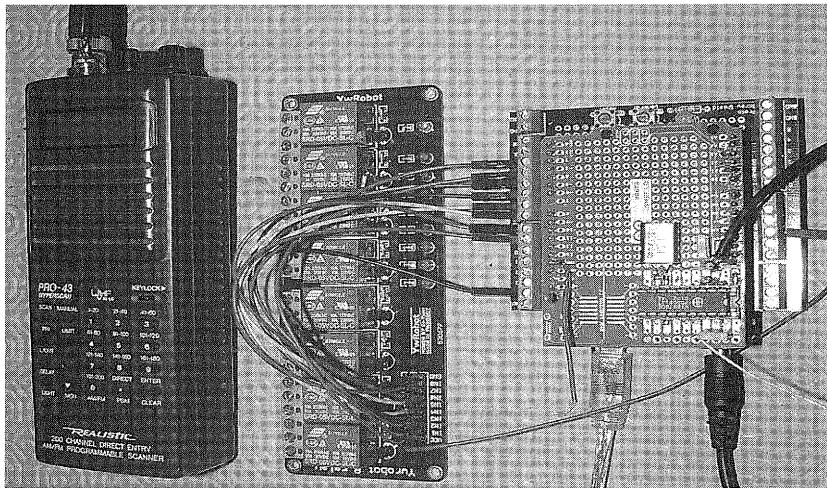


License

- The main sketch in this project is distributed under the terms of the MIT license:
<http://www.opensource.org/licenses/mit-license>
- The schematics and hardware design are licensed under CC-BY-SA 3.0:
<http://creativecommons.org/licenses/by-sa/3.0/>
- The Teensy PS/2 Keyboard Driver is licensed under the GNU Lesser General Public License, v2.1, as are my modifications:
<http://www.gnu.org/licenses/lgpl-2.1.txt>

Dozen: A DTMF Controlled SSTV Camera

Leigh L. Klotz Jr, WA5ZNU



This Arduino-based repeater controller for the F1ZRX repeater club combines DTMF decoding, relay boards and an Arduino. You can use some or all of these elements to build your own repeater or SSTV controller for use with equipment at remote locations. The system gives full control over the operation with your own easy-to-write software. [Alain Riboteau, F1HBV, photo]

Alain Riboteau, F1HBV, and his fellow hams of the F1ZRX repeater club in France have built the repeater controller shown in the title page photo for their fast-scan ATV/DATV repeater. ATV is amateur television, and DATV refers to digital amateur television. Hams use ATV and DATV to send and receive full motion video images and sound over the air, just like broadcast TV. (See the References section at the end of this chapter for more information on television and ham radio.)

The controller allows the F1ZRX club members to link and unlink repeaters, to select among three different cameras using a relay board, and, with a MAX7456, to provide on-screen display information. The control is done over the air by DTMF tones. Dual tone multi-frequency (DTMF) codes were developed by Western Electric and introduced by AT&T in 1962 as a reliable way of sending small amounts of digital information — telephone numbers — over voice-grade channels. While little used in HF communications, DTMF codes are nearly ubiquitous in providing convenient access to VHF and UHF repeater functions.

The *autopatch* — an interface between a repeater and telephone line — enabled handheld toting hams to make phone calls from their radios and enjoy benefits of mobile phones as early as the 1970s, decades before cell phones became available to the general population. DTMF codes also control repeater features such as linking, signal strength reports and announcement recording.

As the name implies, DTMF uses two frequencies, not harmonically related, to encode each symbol. One tone represents the row and another represents the column. For 12 keys, only seven tones are necessary, but full DTMF includes an extra tone for a fourth column. That gives 16 keys, with the last column labeled alphabetically ABCD. The historical military AUTOVON (Automatic Voice Network) phone system built in the 1960s made extensive use of these keys. Some repeater control systems do as well, to prevent inadvertent or unauthorized access to features or settings that could inconvenience repeater users.

While there are software methods for decoding a small number of tones using a CPU the size and speed of the Arduino, the level of coding complexity is high. Running DSP sampling software would interfere with many of the timer settings on the Arduino and make it more difficult to program logic functions such as repeater control. You might wind up using two Arduino boards just to have enough CPU resources to interact with the repeater or other device.

The 8870 integrated circuit is inexpensive and readily available solution purpose-built for the DTMF decoding problem. It houses a set of switched-capacitor filters, and required only a 3.58 MHz NTSC “color burst” crystal and a few RC components. Using the 8870 allows a small sketch size and frees the Arduino developer to focus on the tasks at hand, rather than worrying about complications arising from the DTMF decode software timing.

Slow Scan Television (SSTV)

In this project, we will build a small version of Alain’s project, using SSTV (slow-scan television), which is less expensive. With SSTV, still photos or computer generated images are sent one at a time using audio tones. Transmitting a complete image can take from 8 seconds to more than a minute, depending on the type of image and mode of transmission used. A radio-controlled SSTV camera is something you might find useful around the shack or the ham club or hackerspace.

The SSTV camera and modulation is done by a peripheral unit, the Argent Data SSTV Camera. The Argent device takes care of the photos and the modulation, and the keying if necessary, and the hardware and software in this project handles the control and radio interfacing.

This project does not include a way to receive (demodulate and display) SSTV signals. That’s easy to do with a PC and soundcard software. See the References section at the end of this chapter for information on SSTV equipment and operation.

SSTV is often associated with HF operation, particularly on 14.230 MHz and 7.170 MHz, but it has a thriving and enthusiastic community of operators on VHF and UHF. We’ll use a UHF transmitter for this project because the 2 meter band is congested in many areas, whereas frequencies in the 70 cm

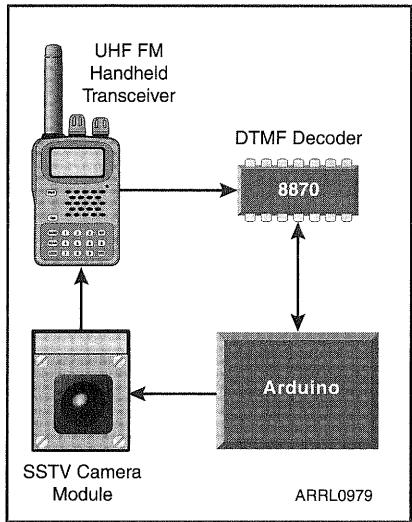


Figure 14.1 — Block diagram of the SSTV system using a handheld FM transceiver, Arduino, DTMF decoder and Argent Data Systems SSTV camera module.

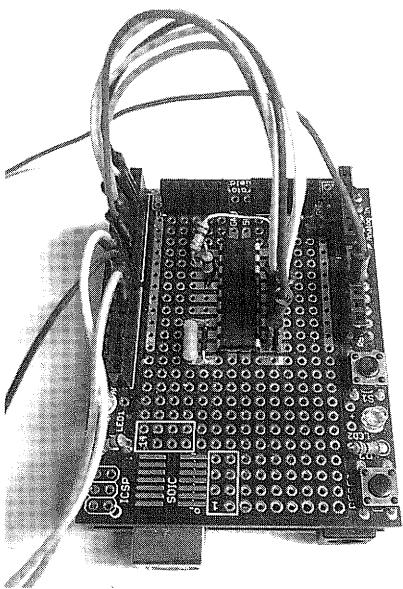


Figure 14.2 — A prototyping shield populated with an 8870 decoder integrated circuit and associated passive components decodes DTMF tones in audio and provides digital inputs to the Arduino. [Leigh Klotz, WA5ZNU, photo]

band are often available for simplex operations. SSTV over SSB, for example with a Yaesu FT-817 HF/VHF/UHF transceiver, would fit in the weak signal portion of the 70 cm band. If you're using SSTV over FM, stick to a recognized FM simplex frequency such as 446.500 MHz. Be sure to check to see if the frequency is in use before transmitting.

Project Plan

The diagram in **Figure 14.1** shows the major project components. We'll get them working in isolation first, and then combine them into a single, working system. First, wire up the DTMF decoder IC to the Arduino and verify its operation. Then, connect the SSTV camera to the Arduino and make sure we can control it. Finally, hook all three together and test it with your UHF handheld transceiver.

DTMF Decoder

Alain, F1HBV, built his DTMF decoder on an Arduino proto shield, which includes a convenient offset area with DIP pads for an IC such as the 8870. I built two versions of the DTMF decoder: one on a protoshield for use with an Arduino, and another on a half-sized protoboard so I could test it with the Ardweeny.

DTMF Shield

The proto shield version (**Figure 14.2**) was easier to build, and I tested the DTMF decoder with it first. The Zarlink application note for the 8870 offers some guidelines for using the IC in a variety of electrical circuits. Unlike a telephone system, in a radio system there is usually an audio signal and a ground, so we use the single-ended (unbalanced) input design. See **Figure 14.3**. The input network is simple, consisting of coupling capacitor C1 that blocks any dc level present, and a resistor network (R1, R2) to set the gain of the op amp internal to the 8870. The

resistor values shown in the application note for the British Telecom standard are a good starting point, but they are not critical.

DTMF Test Sketch

The test sketch reads the tone bits from the 8870 pins and prints the decoded tone information to the Serial port. Use the Arduino IDE MONITOR button to display the text, and select 9600 baud.

```
#define STD 6
#define Q4 5
#define Q3 4
#define Q2 3
#define Q1 2

void setup() {
    Serial.begin(9600);
    pinMode(2, INPUT);
    pinMode(3, INPUT);
    pinMode(4, INPUT);
    pinMode(5, INPUT);
    pinMode(6, INPUT);
}

void loop() {
    if (! digitalRead(STD)) {
        byte tone = readTone();
        Serial.print(tone);
    }
}

byte readTone() {
    byte tone = 0;
    tone += digitalRead(Q1) * 1;
    tone += digitalRead(Q2) * 2;
    tone += digitalRead(Q3) * 4;
    tone += digitalRead(Q4) * 8;
    while (digitalRead(STD)) { /* wait */ }

    return tone;
}
```

Using this sketch, I found that the numbers 1 through 9 were themselves, but 0 came out as 10. On reflection, this makes sense. If you have seen an old fashioned rotary dial phone, you may remember that 0 was the last number, and it generated 10 pulses. The * and # keys came out as 11 and 12. Some amateur handheld radios included the full 4x4 (16 key) DTMF pad, and although I don't have a 4x4 DTMF pad to test, an online DTMF generator showed me that A=10, B=11, C=12, and oddly D=0.

If I were doing this project with 74xx series TTL Boolean logic chips,

I would resign myself to this confusion, but since I have the Arduino at my service, I decided to make the results simpler. I wrote a `convertTone` routine, first making the 0 key generate 0, and then moving A through D to 10 through 13, to match their use as hexadecimal digit place values. That left 14 and 15 for * and #, read left to right on the keypad.

Here is the `convertTone` function:

```
byte convertTone(int tone) {
    if (tone == 0) tone = 13; // 'D'
    if (tone == 10) tone = 0; // '0'
    if (tone == 11) tone = 14; // '*'
    if (tone == 12) tone = 15; // '#'
    return tone;
}
```

And the last line of `readTone` changes to this:

```
return convertTone(tone);
```

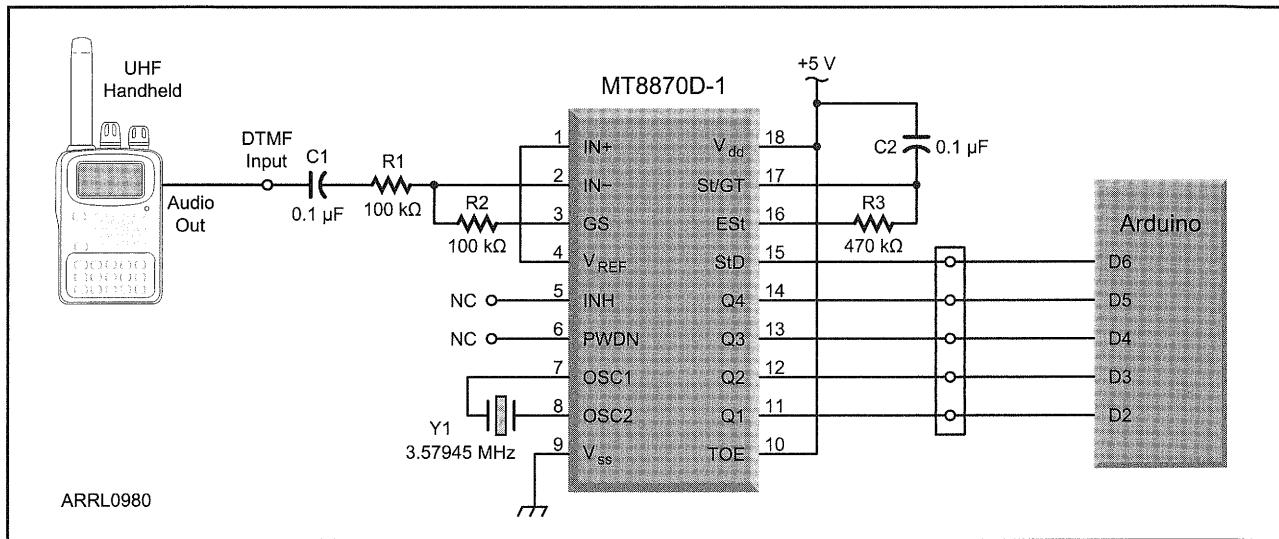


Figure 14.3 — Schematic for a DTMF decoder Arduino shield using the 8870 decoder integrated circuit.

With these changes, I was confident in my new DTMF decoding skills and was ready to move on to the SSTV camera.

SSTV Camera

The SSTV camera from Argent Data has a 10×2 row of header pins that are inconvenient for breadboard use. Although the pins will fit physically in a protoboard, the two rows would be shorted together. I used female jumper cables (not the ones for your car; see the References section at the end of this

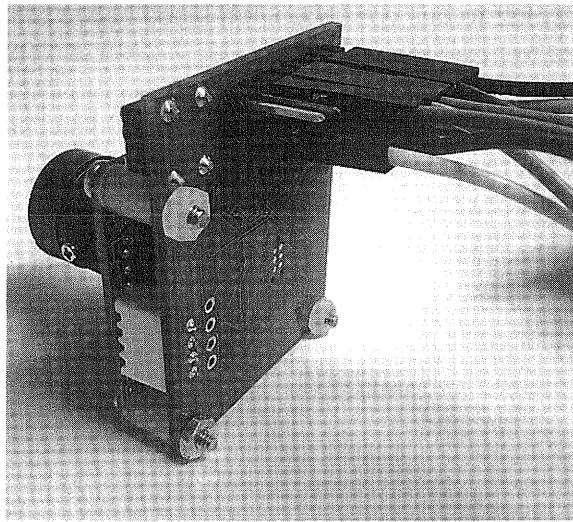


Figure 14.4 — The Argent Data SSTV Camera uses a 10x2 row of header pins that are inconvenient for breadboard use. Pre-cut female jumper cables make connecting this board to the Arduino and handheld radio a breeze. [Leigh Klotz, WA5ZNU, photo]

taken from the Arduino `blink` example. The SSTV camera `SEND` pin is active low, it starts out high in `setup()`, and then after 5 seconds the `loop()` brings it low for 100 ms, and then waits a minute. This sketch verifies that the SSTV camera and Arduino connection are working.

```
// SSTV Send. Wait 5 second, then bring PIN13 low. Loop every minute.
void setup() {
    pinMode(13, OUTPUT);
    digitalWrite(13, HIGH);
}

void loop() {
    digitalWrite(13, HIGH);
    delay(5000);
    digitalWrite(13, LOW);
    delay(100);
    digitalWrite(13, HIGH);
    delay(60000);
}
```

Ardweeny Protoboard

At this point I switched to a protoboard version (**Figure 14.5**) using the Solarbotics Ardweeny Arduino compatible, because the size of the Arduino and the shield dwarfed the diminutive SSTV camera. The Ardweeny needs a TTL level serial cable for programming, commonly called an FTDI cable. See the *Arduino Hardware Choices* appendix for a discussion of this cable.

chapter) and male header pins to make male-to-female cables. These cables are available in ribbon format, so I ordered a set of 6 inch cables and peeled off the connectors in twos and threes as I needed them.

At this point I used an Arduino Uno, with no shield attached, and just connected the SSTV camera to it via the pins. See **Figure 14.4**. The pins on the SSTV camera are marked on the board mask layer. Connect PWR and GND to the Arduino 5V and GND headers. Connect SEND to Arduino D13 (the LED pin). For audio, connect GND and OUT to headphones or a small audio amplifier.

The following sketch is

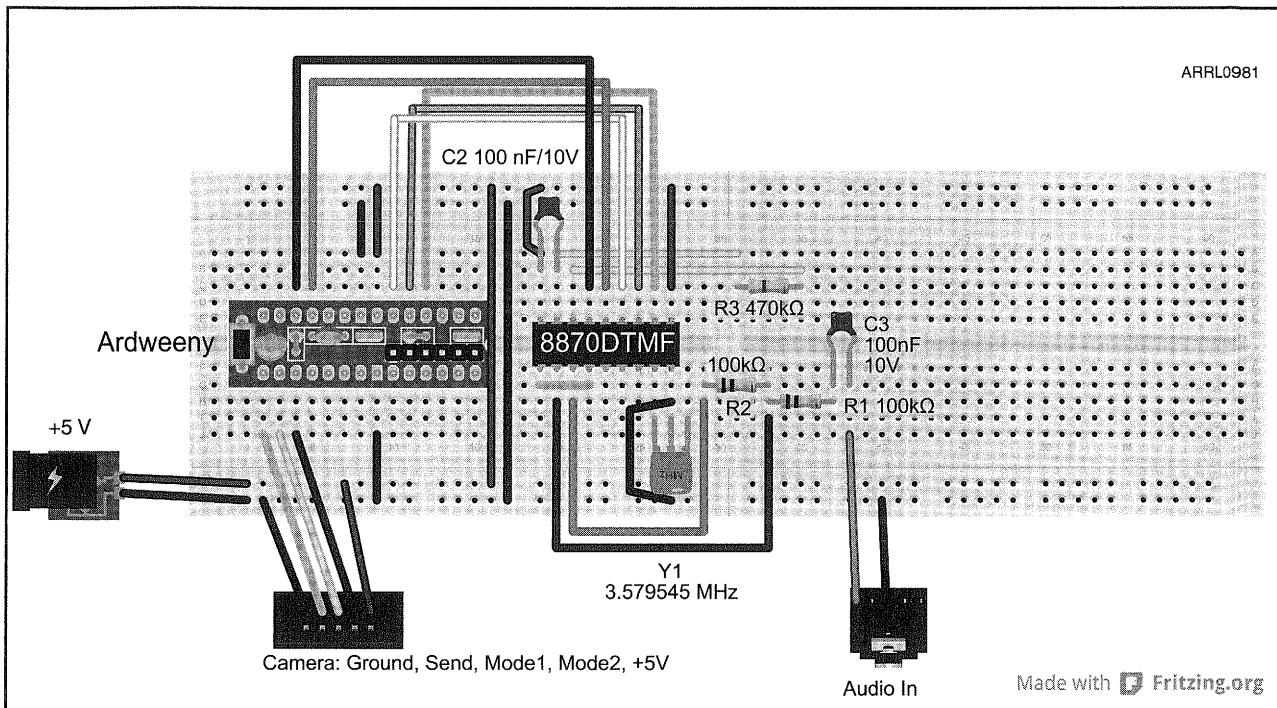


Figure 14.5 — Instead of a full-sized Arduino and the DTMF decoder shield, you can also use a Solarbotics Ardweeny and a solderless breadboard to build the same decoder circuit in your shack. This diagram shows the wiring connections. [Leigh Klotz, WA5ZNU]

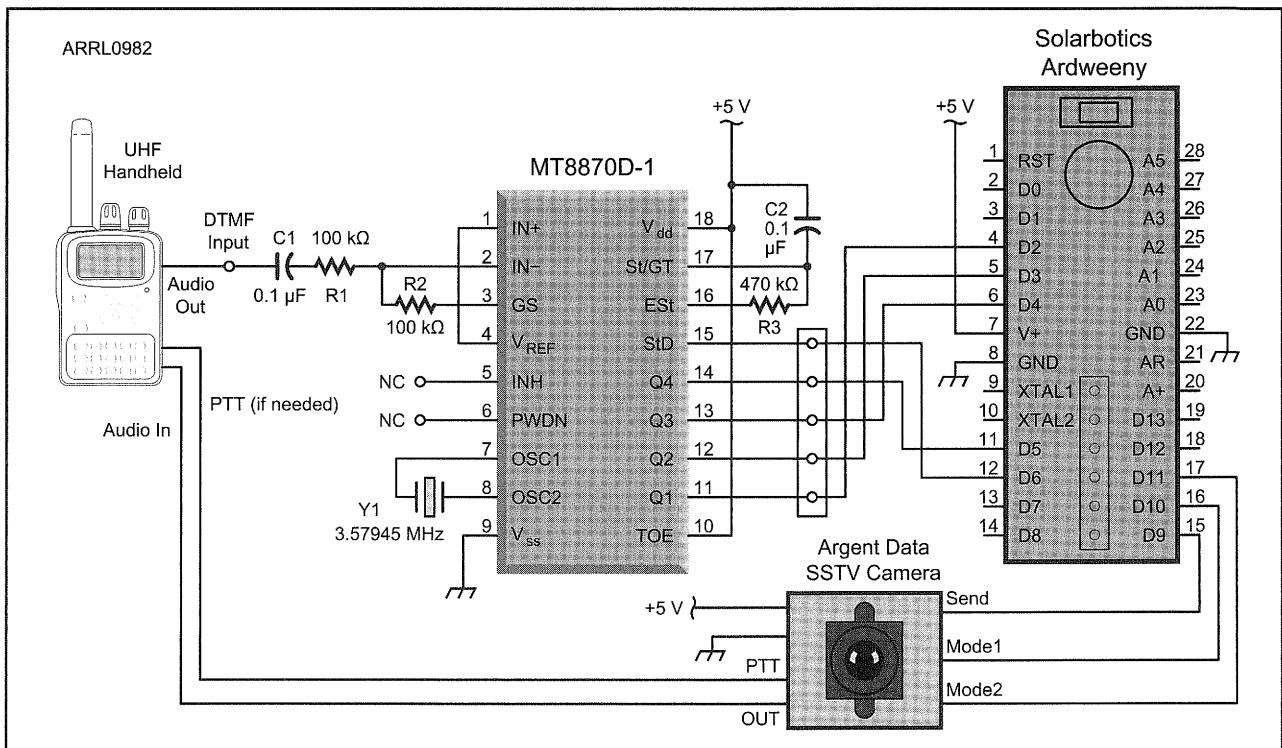


Figure 14.6 — Schematic for the Ardweeny and 8870 decoder system, along with connections to the SSTV camera module and handheld radio.

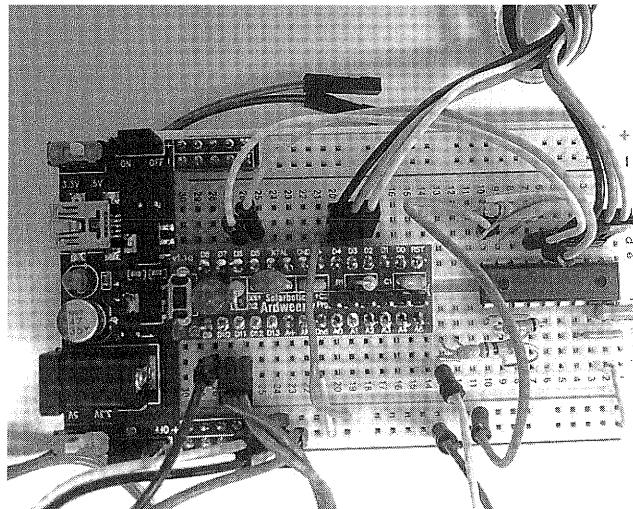


Figure 14.7 — Here is the Ardweeny module and 8870 decoder IC and related components constructed on solderless breadboard. For information on the power supply at the left side of the board, please see the References. [Leigh Klotz, WA5ZNU, photo]

day I would like to reduce it to a small PC board or perfboard and mount it in a case. **Figure 14.7** is a photo of my solderless breadboard version.

Handheld Radio Connection

For details of connection to your handheld radio, refer to the Argent Data SSTV Camera documentation page. You may need to use a resistor with the PTT connection.

DTMF_SSTV Sketch

This sketch is available for download at companion website for the book listed in the References section at the end of this chapter.

```
// LED
#define LED (13)

// 8870 DTMF Decoder Pins
#define STD (6)
#define Q4 (5)
#define Q3 (4)
#define Q2 (3)
#define Q1 (2)

// Converted 8870 DTMF Values: 0-9 and A-D are themselves.
#define STAR (14)
#define POUND (15)
```

Figure 14.6 is the schematic showing the final connections for the Ardweeny, SSTV camera and 8870 DTMF detector. I switched the SSTV SEND to D9 so I could use D13 to indicate tone detection. The SSTV camera features four different SSTV modes. I used two outputs from the Ardweeny (D10 and D11) to pick the four modes, and used the DTMF codes to pick which mode was in use.

Although I kept this as a bench project, some

```

// Argent Data SSTV Camera
#define SEND (9)
#define MODE1 (10)
#define MODE2 (11)

#define ROBOT36 (0)
#define ROBOT72 (1)
#define SCOTTIE2 (2)
#define SCOTTIE1 (3)

void setup() {
    // Set the SEND pin high ASAP to avoid false transmits.
    pinMode(SEND, OUTPUT);
    digitalWrite(SEND, HIGH);

    pinMode(MODE1, OUTPUT);
    pinMode(MODE2, OUTPUT);
    pinMode(Q1, INPUT);
    pinMode(Q2, INPUT);
    pinMode(Q3, INPUT);
    pinMode(Q4, INPUT);
    pinMode(STD, INPUT);

    setMode(ROBOT36);
}

void loop() {
    if (digitalRead(STD)) {
        byte tone = readTone();
        switch(tone) {
            case 0: case 1: case 2: case 3:
                setMode(tone);
                break;

            case STAR:
                send();
                break;
        }
    }
}

/**
 * Convert the 8870 output to a hex-like representation for ease of use.
 * Without this conversion, '0'=10, and '*'=11, etc.
 * 0,1,2,3,4,5,6,7,8,9
 * A=10 B=11 C=12 D=13
 * *=14, #=15
 */

```

```

byte readTone() {
    digitalWrite(LED, HIGH);           // show tone detect
    byte tone = 0;
    tone += digitalRead(Q1) * 1;
    tone += digitalRead(Q2) * 2;
    tone += digitalRead(Q3) * 4;
    tone += digitalRead(Q4) * 8;
    while (digitalRead(STD)) { /* wait */ }
    digitalWrite(LED, LOW);          // end tone detect
    return convertTone(tone);
}

byte convertTone(int tone) {
    if (tone == 0) tone = 13; // 'D'
    if (tone == 10) tone = 0; // '0'
    if (tone == 11) tone = 14; // '*'
    if (tone == 12) tone = 15; // '#'
    return tone;
}

/***
 * All of the digital inputs on the SSTVCAM are active low - grounding
 * a pin sets it 'on'. The SSTV format to be used is selected by the
 * MODE1 and MODE2 inputs, as follows:
 * MODE1 MODE2      Format
 * HIGH  HIGH      Robot 36
 * LOW   HIGH      Robot 72
 * HIGH  LOW       Scottie 2
 * LOW   LOW       Scottie 1
 */
void setMode(byte mode) {
    digitalWrite(MODE1, mode & 0x1 ? LOW : HIGH);
    digitalWrite(MODE2, mode & 0x2 ? LOW : HIGH);
}

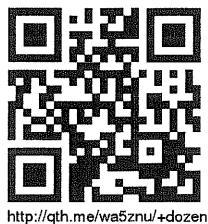
/***
 * SSTV Camera SEND pin is active LOW, so pull it low for 100ms to send.
 */
void send() {
    digitalWrite(SEND, LOW);
    delay(100);
    digitalWrite(SEND, HIGH);
}

```

On the Air

Although you can build this project without holding an Amateur Radio license in the US and many other countries, before putting it on the air you must obtain an appropriate license. In the US, a Technician license from the FCC is sufficient for use on the UHF frequencies described in this chapter, but a

General or Amateur Extra license is required for the SSTV frequencies on HF. Please check the regulations of your country before building and transmitting with this project.



<http://qth.me/wa5znu/+dozen>

References and Further Reading

- Online references
<http://qth.me/wa5znu/+dozen>
- Project source code
<http://qth.me/wa5znu/+dozen/code>
- Amateur television (ATV/DATV)
<http://www.arrl.org/atv-fast-scan-amateur-television>
<http://www.arrl.org/image-modes>
- Slow Scan Television (SSTV)
<http://www.arrl.org/sstv-slow-scan-television>
<http://www.qsl.net/kb4yz>
- ATV/SSTV information in print
ARRL Handbook, 2010 or later editions, Image Communications chapter.
ARRL Operating Manual, 10th edition, Image Communications chapter.
- F1ZRX ATV/DATV repeater
<http://f1zrx.camstreams.com>
- DTMF
http://en.wikipedia.org/wiki/Dual-tone_multi-frequency_signaling
- Zarlink Semiconductor MT8870 DTMF receiver
<http://www.zarlink.com/zarlink/mt8870d-datasheet-oct2006.pdf>
- Zarlink Semiconductor application note MSAN-108
http://www.zarlink.com/zarlink/hs/82_MT8870D.htm
- Solarbotics Ardweeny
<http://www.solarbotics.com/product/kardw/>
- Argent Data SSTV Camera
https://www.argentdata.com/catalog/product_info.php?products_id=150
<http://wiki.argentdata.com/index.php?title=SSTVCAM>
- Female jumper cables
<http://adafru.it/266>
<http://www.sparkfun.com/products/8430>
- Extra-long male header pins
<http://adafru.it/400>
<http://www.sparkfun.com/products/10158>
- RadioShack mini audio amplifier
RadioShack catalog # 277-1008
- Half-sized solderless breadboard
<http://adafru.it/64>
<http://www.jameco.com>
- Breadboard power supplies
<http://www.seeedstudio.com/depot/5v33v-breadboard-power-supply-p-566.html>
<https://www.sparkfun.com/products/114>
<http://www.adafruit.com/products/184>
<http://www.ebay.com>

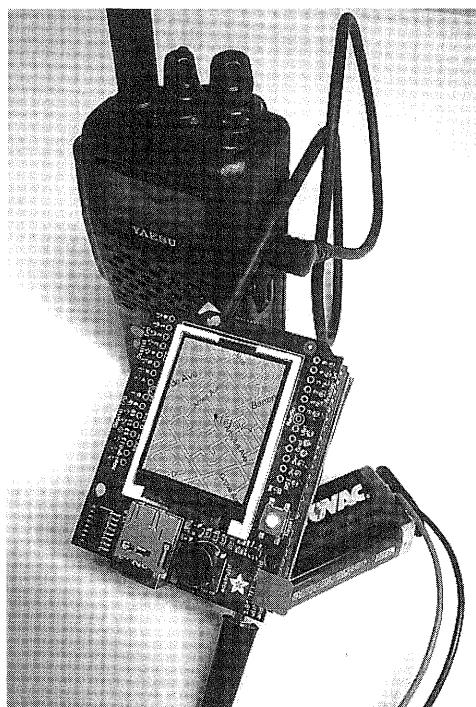
- Arduino prototype shields
<http://arduino.cc/en/Main/ArduinoProtoShield>
<http://www.sparkfun.com/products/7914>
<http://www.ladyada.net/make/pshield/>
http://www.makershed.com/MakerShield_p/msms01.htm

License

- The Arduino sketch is released under the terms of the MIT License
<http://www.opensource.org/licenses/mit-license>.

Marinus: An APRS Display

Leigh L. Klotz, Jr, WA5ZNU



Project Marinus provides a live APRS display using Open Street Map data with positions decoded directly from a handheld transceiver. No Internet connection or laptop is required, and all the software and maps are free. [Leigh Klotz, WA5ZNU, photo]

While preparing for the 2012 Maker Faire, I set out to fulfill a long-held dream of building a handheld APRS map display. Once I started this journey, it took a few weeks of part-time work, but I had help from both an online community of volunteers and a local network of interested and helpful hams.

The history of this device goes back much further than a few weeks, to Marinus of Tyre. Little of his writing survives, but even in the absence of any QSL cards, we are fairly sure he did not have a ham license. In the year 114, Marinus of Tyre faced a small problem: he wanted to show everything in the world. At least, he wanted to show the four corners of world known to the Greek and Roman Empires. Marinus and his contemporaries knew that the Earth was round, and they knew of Europe and the Mideast. They had reports from travelers to India and China, and parts of Africa, and of course the Atlantic Ocean. But

organizing this antediluvian “DXCC” list required a point of reference. Marinus imagined a rectangular grid of lines projecting the spherical Earth onto a flat map. He catalogued each place on his list with a pair of numbers, starting from a prime meridian at the Canary Islands and a parallel at the Greek isle of Rhodes. With this leap, he brought the stargazing latitude and longitude concepts from his fellow Greek philosophers to Earth, and created waypoints and map grids.

Inspired by Marinus of Tyre and his grid of the known world, I set out to build an APRS mapper, combining the Argent Data Systems Radio Shield (an APRS modem), the Arduino, and a small LCD panel. But first I needed to learn about maps, latitude and longitude, and grid squares (geographical areas based on the Maidenhead Locator System).

Maidenhead Locator System

Hams use a grid system based on latitude and longitude and overlaid on maps to define geographical areas for globe-spanning communications over HF, and for local information on VHF and UHF and above. We divide the world up with a rectangular grid just like Marinus did, using a system that names sections of the grid with *grid locators* labeled with alternating letters and numbers. This is called the *Maidenhead Locator System* and was adopted by radio amateurs at a meeting in Maidenhead, England, in 1980.

So what are these grid locators? Note that hams usually call them grid *squares*, even though they are rectangular as we’ll see in a moment, and I’ll use the terms interchangeably in this book.

Each grid locator has a unique two-letter/two-number identifier. The first two letters identify one of 324 worldwide *fields*, which cover 10° latitude by 20° longitude each. The two-letter field designations start with longitude “A” at the International Date Line, and latitude “A” the South Pole. **Figure 15.1** shows the fields for North America. For example, a big chunk of California is in field CM.

Each field is subdivided into 1° latitude by 2° longitude sections of the Earth (these rectangles are the *locators*). A grid locator in the center of the US is about 68 by 104 miles, but grids change size and shape slightly, depending on their latitude. Exactly 32,400 grid locators cover the entire Earth. There are 100 locators (grid squares) in each field, and these are identified by the two numbers, 00 to 99. For example, grid square CM87 contains San Francisco, the western half of Silicon Valley, and a fair sized piece of the Pacific Ocean. See **Figure 15.2**.

Grid squares can again be subdivided for a more exact location with the addition of two more letters.

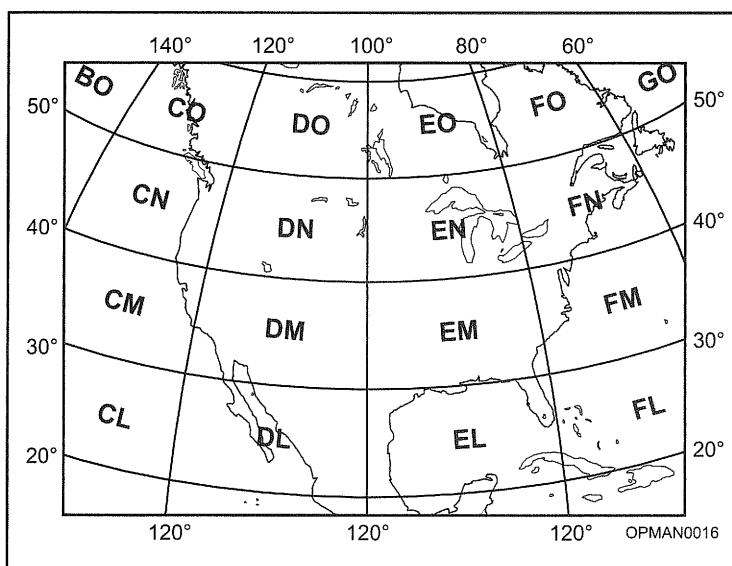


Figure 15.1 — This map shows the Maidenhead Locator System fields for North America. Each field is 10° latitude by 20° longitude.

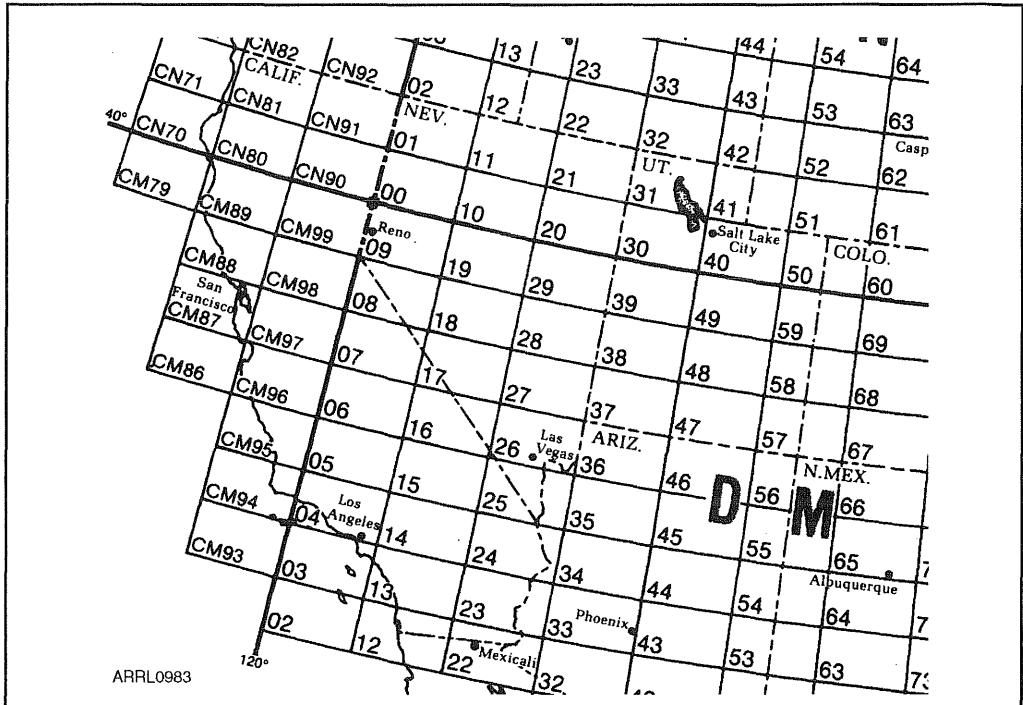


Figure 15.2 — Here is a section of an ARRL grid locator map showing grid squares in the western US. There are 100 1° latitude by 2° longitude grid squares in each field.

For example, station W1AW at ARRL Headquarters near Hartford, Connecticut, is located at FN31pr. The extra two letters uniquely identify a locale, called a *sub-grid* or *sub-square*, measuring about 4×3 miles in the central US.

You can easily tell that the direction from field CM to FN is considerably east (C-D-E-F) and a bit north (M-N). While a four character (four digit) grid square such as CM87 is close enough for an HF beam heading from anywhere in the world, VHF and UHF operators often continue the series to six characters. APRS users continue the series up to 10 characters. For example, at ARRL HQ, there is a tower located at FN31pr21rn and another south at FN31pr21rl, and a third southeast at FN31pr21sk. Here, rn is north of rs and sk is southeast of rl. To get an idea of the precision of the 10 character grid locator, note that these towers are all located on the ARRL HQ property, grouped around the W1AW building.

You can download grid square maps of the world or your country, or you can find interactive ones online. The ARRL offers a colorful wall map shows North American grid squares, as well as a printed booklet showing grid squares worldwide.

Maps

Just a decade ago, printed maps and books of maps were commonplace in daily life. In recent years, digital maps have largely displaced them. Experts may debate whether the ubiquity of online maps and GPS devices has harmed our mental skills, but there is no doubt that they have greatly enhanced our abilities.

In the ham community, hams have made use of the new technology with APRS, the Automatic Packet Reporting System. Envisioned by Bob Bruninga WB4APR, as a two-way messaging and information system for amateurs, APRS has found a natural fit with the large, no-charge, online map databases offered by companies such as Google, Microsoft, Yahoo and MapQuest. Websites such as aprs.fi by Heikki Hannikainen, OH7LZB, and OpenAPRS by Gregory Carter, NV6G, leverage this investment to present an easy-to-use interface to the APRS system for desktop or connected mobile devices.

As Amateur Radio operators, we often act in situations where the extensive infrastructure of modern digital life is distant or unavailable. Desktop and laptop software such as *Xastir* and *UIView* can use public map data such as the US Census TIGER map database, but neither program is suitable for my goals. The source code for the popular *UIView* was never made available to the ham community and now has been tragically lost, so it is sadly frozen at its 2004 version. *Xastir* is vibrant, with a strong community of contributors, but its emphasis is on advanced functionality and so it does not have the user friendliness of the leading online APRS map websites.

For offline APRS use, earlier in this book Michael Pechner, NE6RD, showed his *Timber* APRS data logging system for storing APRS packets to an SD card and later rendering a graphical display using *Google Earth*. But for use in the field, nothing beats the immediacy of a portable GPS display. Of inexpensive commercial products, the Garmin Nuvi 350 series stands alone in its ability to display moving waypoints such as ham call signs. Most other GPS products with serial interfaces replicate waypoints instead of moving them, resulting in an unreadably cluttered display after a few minutes. While the Nuvi 350 is still readily available in secondary markets, the cost of updating its maps often exceeds the purchase of the unit itself.

In fact, finding a source of free maps good enough to show APRS tracks turned out to be a more difficult task than I had thought. The online maps available at no charge are legally restricted and not free for us to use as we please, and as a result they are not available for offline use.

Then I discovered the *Open Street Map* project. The project uses a technique called *crowdsourcing* to create free geographic and map data. The OSM project founders set up a Wikipedia-like system where individuals can add map data a little at a time, by driving around with their own GPS systems, and by contributing their local, personal geographic knowledge.

OSM stores its data not as maps, but in a form similar to Marinus's catalog: a table of objects and their locations. Despite the name, open reusable maps are not readily available from Open Street Map. The reason is that producing the map images themselves is a computationally intensive task that requires a lot of expensive resources to do the drawing and to operate the web servers for the bulk data. OSM partners with others who use its data to render map *tiles* (small square sections) and provide those as a free or paid service on the Internet.

I wanted to make sure I was using the OSM data in a legal and responsible matter, so I contacted local hams and quickly found Benjamin Elliot, KJ6SEQ, who has worked with OSM before. Ben suggested I use the MapQuest Open Street Map tile service, and it turned out to be nearly perfect for this application. Getting the OSM tiles into a form usable on the Arduino turned out to be a

challenging programming task itself, separate from the work of displaying APRS positions on the Arduino LCD.

Hardware

I started with an Arduino Uno and added an Argent Data Systems Radio Shield. I wanted to use a Yaesu FT-60 handheld that I had won as a prize at the local PAARA ham club meeting, and I borrowed a Radio Shield with a Yaesu 4-pin connector and strain relief from Michael, NE6RD.

For display, I had used Arduino LCD shields and breakout boards from a number of suppliers, but while I was starting this project, Adafruit announced an attractively-priced 1.8-inch *TFT* (thin-film transistor) LCD display with bright, sharp images and an SD flash memory card reader attached. I ordered one and started experimenting with the examples included in the library.

The test program `spitftbitmap` reads files in the BMP image format from the SD card and displays them on the screen. BMP is an ancient image format, but it does not require much CPU horsepower to read and decode. Even though it is uncompressed, a 160×128 pixel color image is less than 64 kB, so a 2-GB SD card costing \$5 can hold tens of thousands of images.

The sample code worked great, but began to fail when I clipped map images using the *GIMP* (Gnu Image Manipulation Paint) program to fit the 160×128 pixel format of the display. The early version of `spitftbitmap` had two problems: I could read an image only a few times before the Arduino would reset. And while the demo image `parrot.bmp` image looked good, on close inspection I realized that both it and the map images were mirror reversed.

I tracked down these two problems and used the bug reporting system on the open-source *github* site where many Arduino vendors maintain the source code for their libraries. The first problem turned out to be a missing call to the `close()` function for bitmap files in the example code, and the second turned out to be a problem in the BMP file reader library itself. I provided suggested fixes (called *patches*) for the first, and the Adafruit engineers quickly incorporated my changes! For the second, they acknowledged the problem, which required rewriting the BMP reading routine, which they did in a few weeks.

This hiatus gave me time to go back to the map generation I needed to write.

Making LCD Tiles

There is a straightforward conversion from grid square to latitude/longitude, and from latitude/longitude to Open Street Map tile numbers. The overall flow to create LCD map tiles is to use a Python program to retrieve the OSM tiles from the Internet, combine and re-crop them, and convert the resulting files to BMP format to save on an SD card.

I picked a center *point of interest* (POI) by 10-character Maidenhead grid square, converted that to latitude and longitude, and retrieved nine 256×256 OSM tiles, starting with the center image and then the eight surrounding tiles. I combined these into one image, and clipped out one 160×128 map image centered on the POI, and followed by eight more tiles surrounding the new center.

Writing that desktop Python program took a few days, and it was confusing because of a difference of opinion between the Greek philosophers and the

modern computer scientists: Latitudes are negative in the southern hemisphere, and increase to become zero at the equator and then are positive in the north. Bitmapped *raster graphics* start with zero at the top and increase downward, and are never negative. While longitudes increase to the right (east) just as do raster graphics, unfortunately longitudes are negative in the western hemisphere! Finally, as the Greek sages knew, the distance covered by a single degree is different for latitudes and longitudes, and is also different in different parts of the world. So the calculations necessary to convert from latitude and longitude positions to raster graphics coordinates were a morass of additions, negations and reversals in which mistakes are easily made. But it works now, and to save you the trouble, I have made this program available as a web service, so you can just download the maps. (See the References section at the end of this chapter.)

OSM Map Tiling

To make the map of the Maker Faire area shown in **Figure 15.3**, I visited aprs.fi and saw the position report from a nearby ham as CM87un31wa. I ran my Python program and converted that to the URL of the central tile:

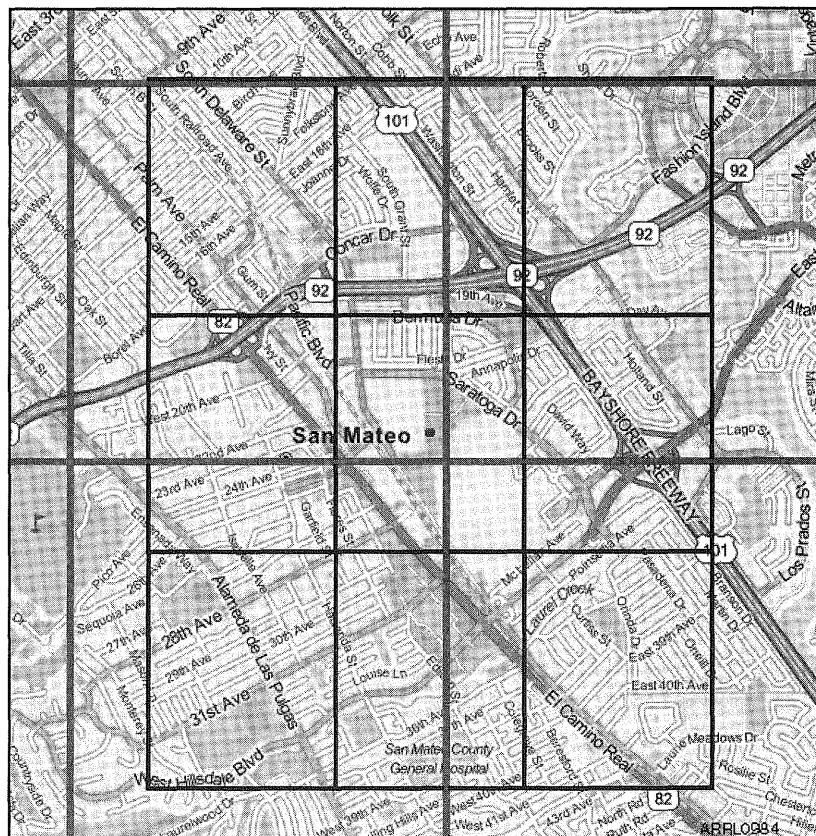


Figure 15.3 — A map of the San Mateo, California area, centered on the 2012 Maker Faire site. The map is made from portions of nine 256x256 pixels tiles of map data from the OpenStreetMap.org project, as rendered by MapQuest. The smaller squares indicate the 160x128 pixel tiles clipped out to produce the map tiles for the Marinus portable LCD. [Leigh Klotz, WA5ZNU; tiles courtesy of MapQuest]

<http://otile2.mqcdn.com/tiles/1.0.0/osm/14/2625/6345.png>

In this URL, 14 is the zoom level, 2625 is the X ordinate and 6345 is the Y ordinate. The Python program downloads the OSM tiles from MapQuest and creates a single 768×768 image, with the point of interest somewhere in the center tile. After piecing together these images, the program creates a new grid of 160×128 pixels, centered exactly on the POI, and clips out the smaller rectangles you see marked on the map image. (For this illustration, I cropped the result so that only the four OSM tiles used are shown.)

The map program also saves out two numerical answers used for the Arduino display. The first is the latitude and longitude of the upper left of the central LCD tile, for use as a reference point, much as the Canary Islands served for Marinus. The second is the number of pixels per degree of latitude and longitude. Although this number varies from place to place, the variation across the small map area we use here is much less than one pixel, so a constant will do for Marinus.

Although the Arduino has floating point numbers, the precision of the small float numbers is not sufficient for working with the maps, and so the sketch represents latitude and longitude as long integer numbers. In this case they are latitude and longitude multiplied by 10^7 . In my area, the latitude degree per pixel is $68/10^7$, and the longitude is $86/10^7$. During program development, I accidentally swapped these values (and note that they are also palindromes), and so the program worked to some extent, but positions were slightly off. Debugging this problem was difficult, since everything else in the both the Python program and the Arduino program was correct. Old-timers may recognize this problem by the adage *Garbage In, Garbage Out*.

The first version of the OSM map tiler I wrote only did a 3×3 grid of tiles, but once that was working, I generalized it to an arbitrary number of tiles. I picked an odd number of X and Y grid sizes so there is always a clear central tile. I also made the map zoom factor settable. I find that a zoom of 14 gives the best results for seeing streets on the LCD I picked, but you can use a smaller number to cover more area in less detail.

LCD Image Files

The Arduino SD card library has a limitation: it supports only 8.3 filenames, so I named the files map xx yy.bmp, with names map0000.bmp through map0202.bmp, for the 3×3 grid, with map0101.bmp being the central LCD tile. This naming scheme limits the number of map tiles to $99 \times 99 = 9801$. Even though that is nearly 10,000, all the maps tiles will fit fine on a 2-GB SD card.

Creating Map Files

To get a set of maps for your area, you first need to find the 10-character grid square for your location. One way to find your precise grid square is to visit a recent APRS position on the aprs.fi site and click the *Info* link on the position of the APRS station you want to track.

Visit the map download site listed in the references and enter the 10-character grid square to download a zip file of the maps. The zip file will contain

map*.bmp files and a poi.csv file to put on your SD card; these files must go in the root directory, since the Arduino SD libraries do not support directory structure.

Arduino Sketch

The Arduino sketch for Marinus is available on the companion site for the book, and is explained below.

Main Sketch File

I used the Adafruit_GFX and Adafruit_GFX_ST7735 libraries for the LCD, the SD library, and the ArgentRadioShield library from the companion website for this book. I started with the bmpDraw function from the Adafruit GFX_ST7735 library example, and the packet reading code from the *Timber* project in this book, and ultimately from the Argent Data Radio Shield wiki examples. The sketch `Marius.ino` is released under the MIT License, the same license used by the ST7735 LCD library and the `bmpDraw.ino` file.

```
#include <Adafruit_GFX.h>
#include <Adafruit_ST7735.h>
#include <SPI.h>
#include <SD.h>
```

The ArgentRadioShield library includes a `decode_posit` function, which takes a packet string and returns the latitude, longitude and call. I wrote this routine initially as part of the Marinus sketch, but I moved it to the ArgentRadioShield library because it is easy to use, but it was hard to write.

The Tyranny of Strings

I encountered a few problems writing this sketch, and one of them was especially frustrating. If your Arduino sketch has a problem and you sprinkle a few too many `Serial.print` statements in to check on its progress, sometimes the sketch will crash, and then you have *two* problems. The cause is running out of SRAM (static random access memory), which is the type of memory that the Arduino uses for storing variables, strings and function returns. When the Arduino runs out of SRAM, it simply reboots itself, leading to mystifying behavior instead of clear debugging printouts. Especially in larger sketches, the difference between working and crashing may be just a few typed-in strings. Each string takes one byte per character, and the Arduino compiler stores all strings into SRAM, so just the text of a paragraph this size could fill up 50% of the Arduino Uno SRAM!

The unusual-looking `F("...")` construct in the `setup()` function of Marinus makes it easy to save

on SRAM. While the Uno has only 2 kB of RAM, it has 32 kB of flash memory. The `F("...")` syntax stores the string in PROGMEM (flash program memory) instead of SRAM. Only a few library functions support PROGMEM strings, but the `print` related functions do, including `Serial.print` and the `print` method used by the LCD.

It's a good idea to get in the habit of using `F("...")` for strings, because the last thing you need when you dealing with a frustrating sketch problem is to have the debugging code itself cause more problems.

In Marinus, just one use of `F()` saves more than 160 bytes of SRAM, of the 2048 available. Especially with debugging `Serial.print` statements, using PROGMEM strings can make the difference between a working program and a crashing one.

```
#include <ArgentRadioShield.h>
```

The Adafruit TFT comes in two varieties, with different memory offsets for the display mapping. If the TFT has green plastic tab, use the `INITR_GREENTAB` definition instead of `INITR_REDTAB`.

```
#define TAB_COLOR (INITR_REDTAB)
```

The breakout board and shield version of the TFT display use different pin settings. These pin definitions are for the shield version. The TFT display and SD card share the hardware SPI interface.

```
#define SD_CS    4 // Chip select line for SD card
#define TFT_CS   10 // Chip select line for TFT display
#define TFT_DC   8
#define TFT_RST  0
```

The TFT LCD I used is 160×128, but there are other sizes of LCD available, including a luxurious 320×240 display. Although the Python code and the Arduino sketch are untested for these resolutions, I did my best to parameterize the sizes to minimize the amount of rewriting and debugging necessary to change sizes.

```
#define LCD_HEIGHT (160)
#define LCD_WIDTH (128)
```

I used a fixed set of colors for the call sign text, the icon (really just a circle), and the lines between icons. Here, I just defined the colors as constants so that I could experiment. Although I like green, I found that red and blue were the most visible colors.

```
#define CALL_TEXT_COLOR ST7735_RED
#define ICON_COLOR ST7735_BLUE
#define LINE_COLOR ST7735_BLUE
```

The character buffer for storing incoming packets uses the bulk of the RAM of this sketch. I set it to 260 bytes as recommended by Scott Miller, N1VG. Marinus ignores comments and telemetry information, however, so you could reduce this to just enough to cover the call sign, packet path and destination, and then the first part of the data that contains the position. If your Radio Shield (or TNC) includes an option to return or suppress the entire path, you could set it to suppress the path information to make the returned packets shorter. By default, the Radio Shield suppresses path, but some firmware versions may allow you to enable it.

The buflen variable keeps track of the next byte to be written, as in other sketches for the Radio Shield.

```
// APRS Buffers
#define BUflen (260)
char packet[BUflen];
int buflen = 0;
```

The variables below keep track of which map is currently displayed, and what the most recent call sign and map location were. When a new position packet is received, if it is on the same map, then the map is kept on screen and the new position is added. If the call sign is also the same, then Marinus draws a line from the previous position; if the call sign is a different one, it draws a new icon and also marks the icon with the call sign.

```
// Maps and calls
int last_map_n;
char last_call[10];
int last_pix_down;
int last_pix_right;
```

The latitude and longitude of the top left corner of the central tile are marked as 32-bit long constant numbers. Note that, in the western hemisphere, longitude is negative. Strictly speaking, the DEGREES_PER_PIXEL_LAT should also be negative, to account for the fact that latitude increases up and pixels increase down, but this unfortunate fact is coded for explicitly in multiple places in the Python map tiler and the Arduino sketch, and so the negative part is omitted in poi.csv.

```
long POI_TL_LAT;
long POI_TL_LON;

int DEGREES_PER_PIXEL_LAT;
int DEGREES_PER_PIXEL_LON;

byte MAP_WIDTH_IN_TILES;
byte MAP_HEIGHT_IN_TILES;
```

The ArgentRadioShield and Adafruit_ST7735 libraries made this sketch much easier to read, by keeping the details of packet parsing and bitmap manipulation out of the main code. The white-on-blue boot screen provides a convenient place to meet the legal requirement to acknowledge the happy, helpful folks of MapQuest and the Open Street Map project. At the end of setup, drawMap(0, 0) shows the central POI map, and incidentally initializes the last_map_n variable.

Note the use of F() for PROGMEM strings to save SRAM.

The FLOOR macro makes the integer division used for map tile calculation consistent.

```
Adafruit_ST7735 tft = Adafruit_ST7735(TFT_CS, TFT_DC, TFT_RST);
ArgentRadioShield argentRadioShield = ArgentRadioShield(&Serial);

#define FLOOR(a,b) (a < 0) ? (a/b)-1 : (a/b)
```

```

void setup(void) {
    Serial.begin(4800);
    tft.initR(TAB_COLOR); // initialize a ST7735R chip, red or green tab
    tft.setTextWrap(true);
    tft.setCursor(0,0);
    tft.fillScreen(ST7735_BLUE);
    tft.setTextColor(ST7735_WHITE);
    tft.print(F("Marinus APRS Mapper\n\n(C) 2012 WA5ZNU\nMIT license\n\n"
                "Data imagery and map\n"
                "information provided\n"
                "by MapQuest,\n"
                "openstreetmap.org,\n"
                "and contributors:\nCC-BY-SA-2.0\n\n"));
}

if (!SD.begin(SD_CS)) {
    tft.setTextColor(ST7735_RED);
    tft.print(F("SD failed!"));
    return;
}

if (! readMapPOI()) {
    return;
}

delay(2000);

// start with center map.  inits last_map_n as well.
drawMap(0, 0);
}

```

The `loop()` function should also be familiar from other Radio Shield projects. Note that MIC-E perversely uses ASCII control characters for some of its content, and APRS programs that omit all control characters will mangle MIC-E packets. (MIC-E, for mic-encoder, sends a short APRS data burst at the end of a voice transmission to report position.) The use of functions and libraries keeps the `loop` function small.

```

void loop() {
    while (Serial.available()) {
        char ch = argentRadioShield.read();
        if (ch == '\n') {
            packet[buflen] = 0;
            show_packet();
            buflen = 0;
        } else if ((ch > 31 || ch == 0x1c || ch == 0x1d || ch == 0x27)
                   && buflen < BUFLEN) {
            // Mic-E uses some non-printing characters
            packet[buflen++] = ch;
        }
    }
}

```

If the `decode_posit` function is able to decode the packet, it writes the call sign, packet type, posit, latitude and longitude into the variables. The & character before those variable names is what provides permission to the `decode_posit` function to write into those variables. If you omit that character, the Arduino IDE will notice and give you an error.

To find the position on the screen, first consider the entire map to be a single raster image, take the `dy` and `dx` variables as the number of pixels down and right from the central tile's top left to the position of the current packet. The map is of course divided into tile files, and the `map_down` and `map_right` variables hold how many map tiles to move right or down. That calculation is done using the / integer division operator. To find the pixel position within the correct tile, the % modulo operator calculates the remainder of the division operation. After this bit of arithmetic is over, Marinus calls the `display()` function.

```
void show_packet() {
    char *call, *posit;
    char type;
    long lat, lon;
    if (argentRadioShield.decode_posit(packet, &call, &type, &posit,
                                         &lon, &lat)) {
        long dy = (POI_TL_LAT - lat) / DEGREES_PER_PIXEL_LAT;
        long dx = (lon - POI_TL_LON) / DEGREES_PER_PIXEL_LON;
        int map_down = FLOOR(dy, LCD_HEIGHT);
        int map_right = FLOOR(dx, LCD_WIDTH);
        int pix_down = dy % LCD_HEIGHT;
        int pix_right = dx % LCD_WIDTH;
        display(call, posit, map_down, map_right, pix_down, pix_right);
    }
}
```

The `display()` function checks to see if the selected map is too many tiles away from the center. If so, it is out of range, so it returns immediately. The next line determines the map file name from the `map_down` and `map_right` parameters. If you decide to support more than nine maps, this `display()` function will need the most attention.

```
void display(char *call, char *posit, int map_down,
            int map_right, int pix_down, int pix_right) {
    if ((abs(map_down) > MAP_HEIGHT_IN_TILES/2) ||
        (abs(map_right) > MAP_WIDTH_IN_TILES/2)) return;

    // Find the map number, and display it if it's not the current map.
    drawMap(map_down, map_right);

    // Find the spot within the map. Adjust negative coordinates
    if (pix_right < 0) pix_right = LCD_WIDTH + pix_right;
    if (pix_down < 0) pix_down = LCD_HEIGHT + pix_down;
```

```

// If it's the same callsign as last time, draw a line.
if (strcmp(call, last_call) == 0) {
    if (last_pix_down != 0) {
        tft.drawLine(last_pix_right, last_pix_down, pix_right, pix_down,
                    LINE_COLOR);
    }
} else {
    // If not the same callsign, draw the callsign and start a new spot.
    bmdrawtext(call, CALL_TEXT_COLOR, pix_right, pix_down);
    // Remember the new callsign
    strlcpy(last_call, call, sizeof(last_call));
}
// Remember the last point we drew for this callsign.
last_pix_down = pix_down;
last_pix_right = pix_right;

// Draw a simple icon at the position.
tft.fillCircle(pix_right, pix_down, 2, ICON_COLOR);
}

```

The drawMap function finds the name of the map file and displays it, unless it is already displayed. If we displayed it each time, it would erase the positions already shown on the display, as they are not stored anywhere but on the LCD. If a new map must be loaded, drawMap also resets the variables that store the most recent call sign and its position, since they are no longer on screen.

```

void drawMap(int map_down, int map_right) {
    char name[] = "map####.bmp";
    map_down += MAP_HEIGHT_IN_TILES/2;
    map_right += MAP_WIDTH_IN_TILES/2;
    int n = map_right * 100 + map_down;
    if (n != last_map_n) {
        char *p = name+3;
        *p++ = '0' + map_right / 10;
        *p++ = '0' + map_right % 10;
        *p++ = '0' + map_down / 10;
        *p++ = '0' + map_down % 10;
        bmpDraw(name, 0, 0);

        // Set the map number and reset callsign and last icon positions.
        last_map_n = n;
        last_call[0] = 0;
        last_pix_down = -1;
        last_pix_right = -1;
    }
}

```

The `bmdrawtext` function does everything necessary to make sure that text displays properly in color at the specified location.

```
void bmdrawtext(char *text, uint16_t color, byte x, byte y) {
    tft.setCursor(x, y);
    tft.setTextColor(color);
    tft.setTextWrap(true);
    tft.print(text);
}
```

Although my first sketch used a header file `poi.h` to set the map constants at sketch compilation time, that was cumbersome when I wanted to switch maps. Using the Arduino SD card stream functions `parseInt`, it was easy to read the map POI from a data file on the SD card. The `readMapPOI` function uses some program memory, so if you do not mind recompiling the Arduino sketch when you change maps and want to save memory for use with other features, you can instead use the `poi.h` file included with the maps download.

```
boolean readMapPOI() {
    File poi;
    char *fn = "POI.CSV";
    if ((poi = SD.open(fn)) == NULL) {
        tft.print(fn);
        return false;
    }

    // skip first line of header text
    while (poi.read() != '\n') {
        ;
    }

    if (LCD_WIDTH != poi.parseInt()) return false;
    if (LCD_HEIGHT != poi.parseInt()) return false;

    {
        char qra[16];
        // skip comma after previous field
        poi.read();
        // read QRA string
        qra[poi.readBytesUntil(',', qra, sizeof(qra))] = 0;
        byte zoom = poi.parseInt();
        tft.print(F("\n"));
        tft.print(qra);
        tft.print(F(" zoom "));
        tft.println(zoom, DEC);
    }

    POI_TL_LAT = poi.parseInt();
```

```
POI_TL_LON = poi.parseInt();
DEGREES_PER_PIXEL_LAT = poi.parseInt();
DEGREES_PER_PIXEL_LON = poi.parseInt();
MAP_WIDTH_IN_TILES = poi.parseInt();
MAP_HEIGHT_IN_TILES = poi.parseInt();

poi.close();
return true;
}
```

Sample Track

Figure 15.4 shows a sample track showing a map at zoom level 14. I prepared two SD cards each with 5×5 files, one with zoom level 11 and one with zoom level 14, with tiles covering a larger area.

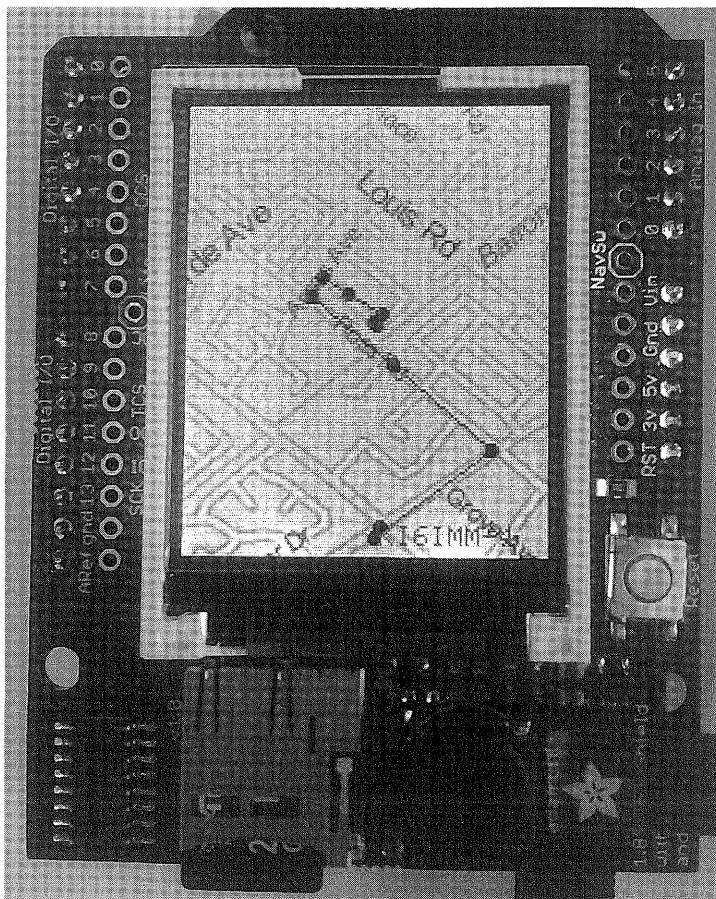


Figure 15.4 — Marinus showing track of 10 APRS posits from KI6IMM [Leigh Klotz, WA5ZNU, photo]

Adding Features

I hope you have fun building and using the Marinus project. Here are a few suggestions for ideas that should be easy to do with the sketch, yet challenging enough to give you a good experience programming and debugging.

A complicated user interface that allows you to change operation on the fly may require more memory than is available, so with a simple system such as the Arduino, consider just recompiling to change major options.

- *Filtering.* Marinus displays every APRS position received in the area that the map set covers. If you pick a 3x3 map area, that is okay but if you pick a larger map area, there may be many stations transmitting. If you are interested only in certain stations and there are other stations in the area, put in an appropriate call to `strcmp` after `decode_posit` and to compare the call before drawing the position.
- *Better multiple station tracking.* Right now, only the most recent station gets track lines drawn. If you need two stations tracked at once, edit the code to use more than one `last_call` and `last_pix_down` and `last_pix_right` variable. Use the Arduino `strcmp()` function to compare call signs. You could use different colors for the lines and icons for the two stations. While it is easy to make this work for two stations, there isn't enough SRAM memory to do an arbitrary number of stations.
- *Panning.* The four-direction joystick control is unused in this sketch. Make it pan around the maps stored on the SD card.

Other Directions

You can also take the ideas and techniques in this project in a different direction:

- *GPS navigator.* Remove the Radio Shield and replace it with a GPS. You might want to use a side-by-side shield to avoid blocking the satellite view with the LCD. Decode the GPS position NMEA sentences instead of the APRS packets, and build your own portable GPS navigator. The joystick control also has a button; use this to switch between different zoom levels of maps.
- *Ethernet networked version.* An Ethernet version that uses an APRS-IS server (see the *Airgate* project) instead of a Radio Shield should be an easy project if you have a little networking experience. Flash program memory usage may be an issue.
- *APRS alert.* Remove the mapping entirely, but keep the Radio Shield and the Ethernet. Instead of having it fetch maps for the decoded positions, implement the Internet SMTP protocol and have the sketch send email to you when call signs of interest appear, or when they cross certain boundaries. For example, when you see any stations enter the parking lot area of your local ham club, you could have the sketch send email announcing the call sign and their arrival.

On the Air

Although you can build this project and receive APRS transmissions without holding an Amateur Radio license in the US and many other countries, before transmitting with the handheld radio used in the project you must obtain an



http://qth.me/wa5znu/+marinus

appropriate license. In the US, a Technician license from the FCC is sufficient for use on the VHF and UHF frequencies used by the APRS network. Please check the regulations of your country for licensing information and appropriate APRS frequencies.

References and Further Reading

- Online references
<http://qth.me/wa5znu/+marinus>
- Source code for this project
<http://qth.me/wa5znu/+marinus/code>
- Online Open Street Map Tile Generator for Marinus
<http://qth.me/wa5znu/+marinus/osm>
- Marinus of Tyre
http://en.wikipedia.org/wiki/Marinus_of_Tyre
<http://www.encyclopedia.com/doc/1G2-2830905894.html>
- Equirectangular_projection
http://en.wikipedia.org/wiki/Equirectangular_projection
- Maidenhead Locator System
<http://www.arrl.org/grid-squares>
http://en.wikipedia.org/wiki/Maidenhead_Locator_System
- Maidenhead locator map (10 characters)
<http://no.nonsense.ee/qthmap/>
- APRS and online maps
<http://www.g4ilo.com/aprs.html>
- aprs.fi presentation
<http://aprs.fi/doc/presentations/20080614-nordic-vushf-saphee/aprsfi-20080614-saphee-nordic-vushf.pdf>
- Xastir Open Source APRS
<http://www.xastir.org>
- UIView
http://www.wa8lmf.net/aprs/UIview_Notes.htm
- Open Street Map and crowdsourcing
<http://arstechnica.com/information-technology/2010/06/crowd-sourced-world-map/>
- Open Street Map
<http://www.openstreetmap.org>
- Adafruit 1.8-inch, 18-bit color TFT shield w/microSD and Joystick
<http://www.adafruit.com/products/802>
- Adafruit TFT shield tutorial
<http://www.ladyada.net/products/18tftbreakout/>
- Adafruit graphics tutorial
<http://learn.adafruit.com/adafruit-gfx-graphics-library>
- Adafruit ST7735 LCD library
<https://github.com/adafruit/Adafruit-ST7735-Library>
- BMP file format
<http://www.fileformat.info/format/bmp/egff.htm>

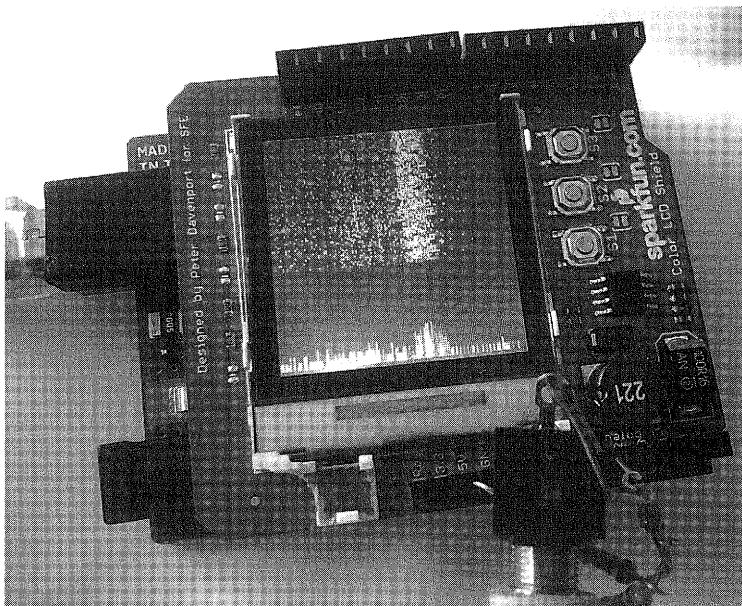
- MapQuest OSM
http://wiki.openstreetmap.org/wiki/Mapquest#MapQuest-hosted_map_tiles
- MapQuest OSM tiles
 Tiles courtesy of <http://www.mapquest.com>
http://wiki.openstreetmap.org/wiki/Mapquest#Tile_URLs http://wiki.openstreetmap.org/wiki/Mapquest#MapQuest-hosted_map_tiles
- APRS packet parser in Perl
<http://search.cpan.org/dist/Ham-APRS-FAP/>
- APRS packet parser in C
<http://pakettiradio.net/libfap/>
- K6DBG MIC-E decoder in Perl
<http://www.tapr.org/pipermail/aprssig/2005-April/005709.html>
- Arduino stream functions
<http://arduino.cc/en/Reference/StreamReadBytesUntil>
<http://arduino.cc/en/Reference/StreamParseInt>
- GNU image manipulation program
<http://www.gimp.org/>
- PAARA (Palo Alto Amateur Radio Association)
<http://www.paara.org/>
- Python programming language
<http://python.org>
- Python imaging library
<http://www.pythonware.com/library/pil/handbook/introduction.htm>

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Cascata — An Arduino Waterfall

Leigh L. Klotz, Jr, WA5ZNU



An Arduino-based waterfall visualizer using a SparkFun Color LCD shield and an ac-coupled audio input with dc bias.
[Leigh Klotz, WA5ZNU, photo]

Ham radio operators use a signal visualization display called a “waterfall” to plot signal strength and frequency against time on a scrolling display. This type of display is common in both digital mode radio programs such as *fldigi* and in software defined radio (SDR) displays such as *Quisk*. Both are open-source ham radio programs to which I have made minor contributions.

Cascata is Italian for “waterfall,” and my Cascata is an Arduino waterfall display program built using the Italian designed Arduino and the SparkFun Color Nokia LCD shield. It is a simple project that provides a pocket-sized display for field operations or for computer-free operations. It requires only a small amount of soldering and can serve as an introduction to the Arduino for ham radio operators, or as an introduction to ham radio for Arduino enthusiasts.

Cascata has a selectable 0-4 kHz or 0-2 kHz audio range. It can display a waterfall, a spectrum graph, or both. It features variable attenuation and automatic dc centering.

After buying the SparkFun Color LCD shield, I wrote a few Arduino

sketches to draw lines, and then set about trying to find some guidance from other experimenters. I learned a lot from Paul Bishop's *Arduino Realtime Audio Spectrum*, which pointed the way to a suitable 8-bit FFT and to a simple, interrupt-free method of capturing audio signals. Paul's program uses the TVOut library and a smaller FFT, and so he didn't encounter some of the issues with resolution and code performance that I had to solve.

Analog to Digital Conversion

The Arduino includes the helpful `analogRead()` function, which reads a voltage from one of the analog input pins. The voltage is compared to a reference voltage, and then converted to a number 0–1023, with 0 being 0 V and 1023 being the reference voltage, minus one significant bit. (A value equal to the reference voltage itself would be 1024, and cannot be represented.) The reference voltages on the Arduino come from the power supply, an internal setting, or an external setting. The voltage is always present on the Arduino AREF pin, and I installed a small 0.01 μF bypass capacitor between AREF and ground because the Arduino Uno does not have one. See **Figure 16.1**. (Some Arduino compatibles, such as the Seeeduino, do have this bypass capacitor, so check your schematic first.)

For the AREF setting, 5 V is too high for audio signal input. Although you could get a cleaner signal by using an audio amplifier on the input stage and hooking AREF to the 3.3 V regulated supply, I chose to use the internal 1.1 V *band gap* reference and read the radio AF output signal directly. The number of voltage levels that can be displayed on the small screen is limited, so the reduced parts count afforded by omitting the amplifier is worth the tradeoff.

The ADC (analog to digital converter) cannot read negative voltages; the minimum value is zero. If you couple the output of your radio audio signal through a small capacitor, the values will range equally from negative to positive voltages. A resistor divider using standard value resistors produces

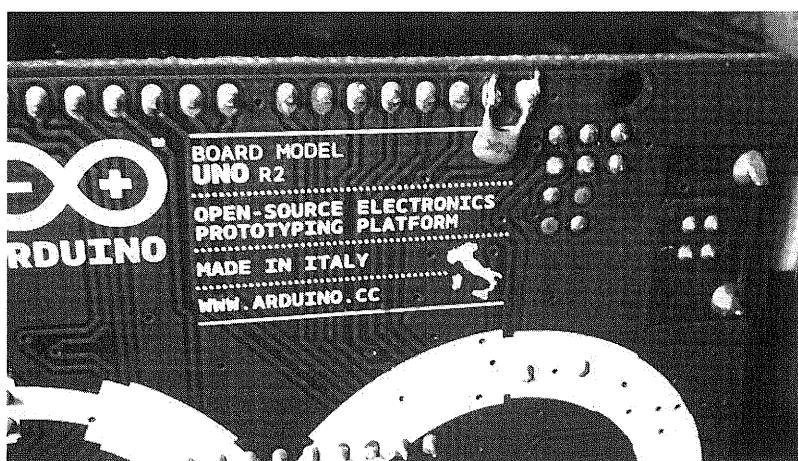


Figure 16.1 — AREF bypass capacitor added to underside of Arduino. Some Arduino compatible boards such as the Seeeduino and the Mega already have this capacitor. [Leigh Klotz, WA5ZNU, photo]

0.55 V from the 5 V supply voltage (half of the 1.1 V maximum), and that dc voltage biases the ADC input pin. The capacitor-coupled audio then swings the voltage up down around this center. The center voltage is called the *dc reference*, and the sketch automatically calculates the dc reference point.

Construction

The main soldering task is the SparkFun Color LCD shield, which requires headers be soldered on. A convenient option is the SparkFun stackable header set. These headers allow easy access to the Arduino pins, but they stick up a bit above the LCD board and may make it hard to put in a case. If you plan to build this project in a case, you may want to use a nonstandard Arduino (such as

the Ardweeny). In that case you may want the SparkFun Color LCD Breakout Board, but you will sacrifice one of the three input buttons (see the Operation section below).

For the audio connection, I tested my input network on a protoboard first, and then used “flying lead” style directly on a 3.5 mm audio jack. You could use a small piece of perfboard with header pins to attach to the SparkFun Color LCD shield. I plugged the audio jack into the headphone jack of my Elecraft KX1 radio.

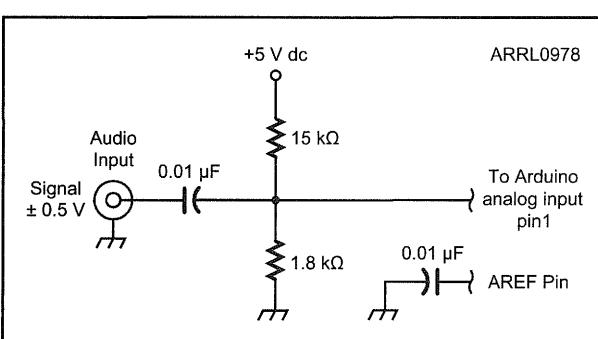


Figure 16.2 — Cascata schematic showing the main points of interconnect. From the 5 V dc source, the $15\text{ k}\Omega/1.8\text{ k}\Omega$ voltage divider produces about 0.54 V — almost half of the 1.1 V ADC reference voltage used in this project. Other Arduino and LCD bus connections are not shown.

Figure 16.2 shows the simple circuit and connections. Follow these steps:

- As mentioned previously, tack a $0.01\text{ }\mu\text{F}$ capacitor on the bottom of the Arduino from AREF to ground (Figure 16.1).
- Install the SparkFun Color LCD shield on the Arduino with socketed headers.
- Solder one end of a $1.8\text{ k}\Omega$ resistor to the ground pin below the LCD and put the other end into analog input pin 1 on the Arduino.
- On the shield headers, solder one end of a $15\text{ k}\Omega$ resistor to the Arduino 5 V pin. Solder the other end of this resistor to the lead of the $1.8\text{ k}\Omega$ resistor connected to the Arduino analog input pin 1.
- Solder one lead of a $0.01\text{ }\mu\text{F}$ capacitor to the lead of the $1.8\text{ k}\Omega$ resistor connected to Arduino analog input pin 1.
- Solder the other lead of the $0.01\text{ }\mu\text{F}$ capacitor to the audio signal input jack. This is the connection to the receiver audio output.
- The input capacitor blocks any dc component of the audio signal. The ac component of the input voltage should be $\pm 0.5\text{ V}$ max. For example, a 0-1 V peak-to-peak signal would also work.

Operation

The SparkFun Color LCD shield has three buttons. I used the top button to change what the other two buttons do. The three modes are Display, Bandwidth and Attenuation. The other two buttons cycle up and down in the current mode. The SparkFun LCD Breakout Board non-shield version does not have the third button. Both buttons cycle through all the choices, so you can use this firmware with the two button version.

- Display mode: Choices are both Waterfall and Spectrum, Waterfall only, and Spectrum only.
- Bandwidth mode: The buttons toggle between 0-4 kHz and 0-2 kHz.
- Attenuation mode: Attenuation values are: -3, -2, -1, 0, 1, 2, 3 in attenuation factor (not dB). Since the value is attenuation, you can consider negative values to be gain. If your input signal voltage is too low, turn up the volume, or use the Attenuator adjustment to change to lower values.

Libraries Used

The sketch is built using two libraries: the LCD library from Mark Sproul, and the fixed-point Roberts/Slaney/Bourras/DEIF FFT library. Neither is used as a real Arduino library in this project. All files are included in the Zip file on this book's website (see the References section at the end of this chapter), which you can extract into your Arduino sketches directory. It will create a new project called *Cascata*.

I enhanced the LCD library to use the Nokia LCD commands for drawing straight lines and successive points more quickly because the both the spectrum display and the waterfall display use this feature. I found a few bugs in the conversion from 16-bit to 8-bit FFT and fixed them. The resulting source is included.

Main Sketch File

This sketch file and the support libraries are available for download at the companion website for this book (see the References section at the end of this chapter).

```
// Cascata, An Arduino Waterfall program for ham radio use
// Copyright 2011-2012 Leigh L. Klotz, Jr.
// WA5ZNU May 30, 2011 and May, 30 2012
// Display code based on Mark Sproul LCD library, with my additions
// FFT Code is Roberts/Slaney/Bourras/DEIF FFT library with bug fixes
// in 8-bit conversion.
// Ideas also from http://blurttime.blogspot.com/2010/11/
// License: http://www.opensource.org/licenses/mit-license

#include <Arduino.h>
#include "fix_fft.h"
#include "LCD_driver_progmem.h"
#include "logtable.h"
```

The Automatic Offset Correction finds zero level for dc offset of the ADC

```
#define AOC_THRESHOLD (1)
```

The sampling options are here. This idea came from the Paul Bishop (see references).

```
#define SAMPLE_US_8KHZ (125)
#define SAMPLE_US_4KHZ (250)
#define IN_SAMPLES (256)
#define LOG2_IN_SAMPLES (8)
#define OUTBINS (IN_SAMPLES/2)
```

I used ADC pin 1 for audio input, biased with 0.55 V from a voltage divider referenced to the 5 V supply (Figure 16.2).

```
#define ADC_PIN (1)
```

These colors and locations control the use of the LCD.

```
#define BGCOLOR (BLACK)
#define SPECTRUM_COLOR (GREEN)
#define SPECTRUM_Y_OFFSET (127)
```

The real and imaginary part of the FFT data is stored here. The data is signed going into FFT, signed coming out of FFT, but is converted to unsigned byte once we compute log power.

```
char data[IN_SAMPLES];
char im[IN_SAMPLES];
```

This section implements the software attenuator. We shift ADC samples right by this number, to divide by 2^n . Using a value of at least 1 cleans up ADC noise without using CPU sleep. Low levels of audio input will require attenuation=0.

```
#define MAX_ATTENUATION (4)
static char attenuation = 1;
```

The color palette is 16 bytes of colors chosen. Each detected power level in an FFT bin is represented by a color. Lower values are darker colors, and the highest values shift to yellow and then blue and finally red. This palette could be stored in Arduino PROGMEM to save SRAM if necessary.

```
byte palette[16];
```

The button modes use this list to control what function is called when a button is pressed. Each successive top button press cycles through the next mode in the modes list.

```
struct Modes {
    char *name;
    void (*pushed) (byte dir);
};

byte mode = 0;
#define NMODES (3)
struct Modes modes[NMODES] = {
    { "Disp", &handleDisplayButton },
    { "BW ", &handleSampleRateButton },
    { "Attn", &handleAttenuatorButton }
};

int showWaterfall = 1;
int showSpectrum = 1;
```

The lastpass variable keeps track of the previous spectrum display value in spectrum mode, to speed up drawing.

```
byte lastpass[OUTBINS];
```

The adc_offset starts with assuming a dc component of 0. The automatic offset correction (AOC) will correct it.

```
int adc_offset = 512;
// scale/2 to fit in short; maxval=1023, max samples=128, so scale maxval/2.
int sample_sum = 0
byte sample_us = SAMPLE_US_8KHZ;
```

Setup initializes the analog reference and the LCD.

```
void setup() {
    ioinit();
    LCDInit();
    LCDContrast(44);
    analogReference(INTERNAL); // INTERNAL=1.1v on Arduino UNO

    initPallette();
    clearLastPass(127);
    repaint();
    {
        LCDPutLin("Cascata", 0, 52, SPECTRUM_COLOR, BGCOLOR);
        LCDPutLin("WA5ZNU", 16, 52, SPECTRUM_COLOR, BGCOLOR);
        delay(1000);
        repaint();
    }
}
```

I marked calculatePixel as inline so that it will be copied in flash memory wherever it is used, for speed.

```
static inline int calculatePixel(byte i) {
    byte color = ((byte *)data)[i];
    if (color > 15)
        return 0xf00; // Full RED
    else
        return palette[color];
}
```

This function initializes the palette of colors.

```
void initPalette() {
    for (byte i = 0; i < 16; i++) {
        if (i > 9)
            palette[i] = i * 0x110; // Yellow scale
        else if (i > 5)
            palette[i] = i * 0x010; // Green Scale
        else
            palette[i] = i * 0x001; // Blue Scale
    }
}
```

This loop is similar to Paul Bishop's from his Arduino Realtime Audio Spectrum project. It uses the `micros()` function and if sufficient time has elapsed, it takes a sample. If there are not enough samples for a full FFT yet, it accumulates more. Once it is done getting samples, it checks for buttons and then does an FFT and displays the results.

Sampling at 8 kHz takes 125 μ s, and it takes 100 μ s for each ADC operation. That leaves only 25 μ s per sample, or 6.4 ms for a 256 sample row. There is not enough time to do the FFT or Display, so we drop samples between lines.

```
void loop() {
    static int row = 0;
    static int sample = 0;
    static unsigned long ttt;
    unsigned long next = micros();
    if (next-ttt < sample_us)
        return;
    ttt = next;
    if (sample < IN_SAMPLES) {
        int val = (analogRead(ADC_PIN) - adc_offset);
        val = val >> attenuation;
        sample_sum += val;
        data[sample] = constrain(val, -128, 127);
        im[sample] = 0;
        sample++;
    } else {
```

The FFT takes a long time, and we miss incoming audio data during that time. Since Cascata is just a display, that's okay, but it would be a problem for a digital data decoding program.

Automatic Offset Correction finds zero level for dc offset of ADC. Average of samples should be near zero. It uses 2^7 samples but is already scaled by 1/2 so divide sum by $2^{(7-1)}$ or 64.

```

handleButtons();

{
    short sample_avg = sample_sum >> (7-1);
    if (abs(sample_avg) > AOC_THRESHOLD) {
        adc_offset += sample_avg >> 2; // correct over two rows
    }
    sample_sum = 0;
}

sample=0;
fix_fft(data,im,LOG2_IN_SAMPLES,0);

```

To calculate the power, start at bin 1 because bin 0 is dc (0 Hz) and uninteresting.

To convert to dB, normally we would multiply by 20 but there is also a required square root, so we just multiply by 10. The maximum power value is $-128 * -128 * 2 = 32768, 10 \log_{10}(32768) = 45.15$. For spectrum we draw the whole thing, since even 45 pixels isn't too much to fit on the screen. It's slow to draw, so we want to encourage smaller values, and so for waterfall we just use the range [0,15] and anything above that is over-range. We accept up to about 500 on the spectrum.

```

for (byte i=1; i < OUTBINS; i++) {
    ((byte *)data)[i] = db(data[i] * data[i] + im[i] * im[i]);
}
if (showSpectrum) {
    for (byte i=1; i<OUTBINS; i++) {
        byte d = ((byte *)data)[i];
        byte y = SPECTRUM_Y_OFFSET-d;
        byte lasty = lastpass[i];
        if (y != lasty) {
            if (y > lasty) {
                LCDSetLine(SPECTRUM_Y_OFFSET,i,lasty,i,BGCOLOR);
            }
            LCDSetLine(SPECTRUM_Y_OFFSET,i,y,i,SPECTRUM_COLOR);
            lastpass[i]=y;
        }
    }
}
if (showWaterfall) {

```

```

LCDStartPixelArea(row, 1, row, OUTBINS-1);
for (byte i = 0; i < OUTBINS; i++) {
    LCDSetNextPixel(calculatePixel(i));
}
LCDEndPixelArea(row, OUTBINS-1);
}
row = (row+1) & 0x7F;
if (row == 0) {
    repaint();
}
}
}
}
}

```

In spectrum mode, we must keep track of the previous screen of data to know what to draw and what to erase.

```

void clearLastPass(byte v) {
    if (showSpectrum) {
        for (byte i=0; i<OUTBINS; i++) {
            lastpass[i]=v;
        }
    }
}

```

The handleButtons function is responsible for button pushes.

- Button 1: Step through modes
- Button 2: +1 on mode. Wraps around.
- Button 3: -1 on mode. (Button 3 is not available on some LCD boards.)

```

void handleButtons() {
    if (!digitalRead(kSwitch1_PIN)) {
        handleModeButton(0);
        modes[mode].pushed(-1);
        while (!digitalRead(kSwitch1_PIN)) delay(20);
    } else if (!digitalRead(kSwitch2_PIN)) {
        handleModeButton(0);
        modes[mode].pushed(1);
        while (!digitalRead(kSwitch2_PIN)) delay(20);
    }
    else if (!digitalRead(kSwitch3_PIN)) {
        handleModeButton(1);
        while (!digitalRead(kSwitch3_PIN)) delay(20);
    }
}

void handleModeButton(char dir) {
    mode = mode + dir;
}

```

```
    mode = mode % NMODES;
    LCDPutLin(modes [mode].name, 0, 52, SPECTRUM_COLOR, BGCOLOR);
}
```

Display mode: Both waterfall and spectrum (default), waterfall only, or spectrum only.

```
void handleDisplayButton(byte dir) {
    static byte displayFlag = 1|2;
    displayFlag = (displayFlag+1) % 4;
    if (displayFlag == 0) displayFlag = 1;
    showWaterfall = (displayFlag & 1) != 0;
    showSpectrum = (displayFlag & 2) != 0;
    repaint();
}
```

Bandwidth Mode: 0-4 kHz (default) or 0-2 kHz

```
void handleSampleRateButton(byte dir) {
    char * msg;
    if (sample_us == SAMPLE_US_4KHZ) {
        msg ="0-4 kHz";
        sample_us = SAMPLE_US_8KHZ;
    } else {
        msg = "0-2 kHz";
        sample_us = SAMPLE_US_4KHZ;
    }
    LCDPutLin(msg, 16, 52, SPECTRUM_COLOR, BGCOLOR);
}
```

Attenuator mode: 0, 1, 2, 3. Each is a factor of 2.

```
void handleAttenuatorButton(byte dir) {
    attenuation += dir;
    if (attenuation <= -MAX_ATTENUATION)
        attenuation = MAX_ATTENUATION-1;
    else if (attenuation >= MAX_ATTENUATION)
        attenuation = -MAX_ATTENUATION;
    char msg[5]; // length("-255\0") = 5
    itoa(attenuation, msg, 10);
    LCDPutLin(msg, 16, 52, SPECTRUM_COLOR, BGCOLOR);
}
```

Using a function for repaint saves a small amount of memory.

```
void repaint() {
    LCDClear(BGCOLOR);
}
```

Logarithm Sketch File

The FFT output is a “power” value, measuring the amount of signal power in the FFT bin, a few Hz wide. Radio and audio displays nearly always use a logarithmic display. While the Arduino library includes a `log()` function, and I used it initially, the code space for the floating point functions and the time it took were noticeable. Since I needed the logarithm for the waterfall colors to pick which of 16 colors to display, I knew that my `log()` function needed to return only 16 values. I later expanded it to 25 so that the spectrum display could be up to 25 pixels high, but even so, the size of a lookup table for this logarithm function remains small.

Below is the code for the logarithm table. Note the use of PROGMEM to save memory.

```
#include "logtable.h"
#include <Arduino.h>

#define LOG_TABLE_SIZE 25
static const prog_uchar log_key_table[LOG_TABLE_SIZE] PROGMEM =
{0, 2, 3, 4, 6, 7, 8, 10, 13, 16, 20,
 26, 32, 40, 51, 64, 80, 100, 126, 158,
 200, 251, 316, 398, 501};

static const prog_uchar log_value_table[LOG_TABLE_SIZE] PROGMEM =
{0, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13,
 14, 15, 16, 17, 18, 19, 20, 21,
 22, 23, 24, 25, 26, 27};

static uint8_t findclosest(uint8_t first, uint8_t last, int key) {
    while (first <= last) {
        uint8_t mid = (first + last) / 2;
        uint8_t akey = pgm_read_byte(log_key_table+mid);
        if (key > akey) first = mid + 1;
        else if (key < akey) last = mid - 1;
        else return mid;
    }
    return last;
}

uint8_t db(int x) {
    return pgm_read_byte(log_value_table
        + findclosest(0, LOG_TABLE_SIZE, x));
}
```

Future Directions

Cascata is designed to be a project for you to undertake and extend. Here are some ideas for ways to move forward:

- *Reduce noise.* The default value of the Attenuator is 1, which eliminates the LSB of ADC and cuts down on some of the noise. The 0.01 μF capacitor

added to the bottom of the Arduino board before AREF and ground helps with the noise some, but doing any better would require quiescing the CPU before the ADC measurement, further reducing the signal bandwidth and processing time available. (See the *Thermic* project by Hans Summers, GØUPL, for more information about ADC accuracy.)

- *Decode PSK31.* Add a mode to disable display and decode PSK31. Is there enough time in 6.4 ms/row to do the decimation, filtering, phase detection, bit decoding and Varicode conversion? If not, can you use an Arduino Duo or Maple Leaf processor instead?
- *Expand the bandwidth.* Can you use aliasing to sample a much wider bandwidth? Since the output display size is limited to about 128 pixels, you would need to do decimation anyway. Or switch to a large LCD such as 128×160 or 320×240 pixels.
- *Narrow the bandwidth.* Narrow the bandwidth to 200 Hz for use as a display with QRSS or other ultra-low bandwidth modes. I think you need to integrate over time.
- *Oscilloscope output.* Instead of using an LCD, display the signal value on an oscilloscope using a PWM and an integrator. (See *Oscilloscope Tree* in the references.) Use one of the digital out pins for X trigger. You could use a green-screen CRT scope or a portable digital scope that you already have. You won't get a waterfall, but instead a spectrum display.
- *Add a better display.* Replace the Nokia LCD with a better quality one, such as the Adafruit 1.8-inch TFT used in the *Marinus* chapter.

Similar Projects

- *Arduino Realtime Audio Spectrum.* This turned up in searches when I looked for Arduino FFT and I got a lot of ideas from here. It's good to be able to share ideas across ham and Arduino projects. I found a link to the FFT from reading this post, but had to fix a few bugs to make it work at 256 samples.
- *Gabotronics XProtolab GT-0010.* This is a great board and I recently bought one. The framework source is available, including an ASM version of FFT, but the digital storage oscilloscope program source itself isn't open.

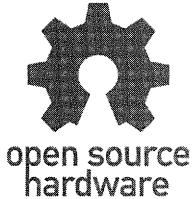


References and Further Reading

- Online references
<http://qth.me/wa5znu/+cascata>
- Source code
<http://qth.me/wa5znu/+cascata/code>
- SparkFun Color LCD Shield
<http://www.sparkfun.com/products/9363>
- SparkFun LCD Breakout Board
<http://www.sparkfun.com/products/11062>
- SparkFun Stackable Header Set
<http://www.sparkfun.com/products/10007>
- Arduino Realtime Audio Spectrum
<http://blurttime.blogspot.com/2010/11/arduino-realtime-audio-spectrum.html>

- Gabotronics XProtolab GT-0010
<http://www.gabotronics.com/development-boards/xmega-xprotolab.htm>
- Hack-a-day Writeup
<http://hackaday.com/2011/07/11/waterfall-signal-visualizer-from-arduino-and-cellphone-lcd/>
- *fldigi* digimode program
<http://www.w1hkj.com/Fldigi.html>
- *Quisk*
<http://james.ahlstrom.name/quisk/>
- Oscilloscope Tree
<http://www.johngineer.com/blog/?p=648>
<http://wa5znu.org/2011/arduino-2500/>
- Elecraft KX1 transceiver
<http://www.elecraft.com/KX1/KX1.htm>

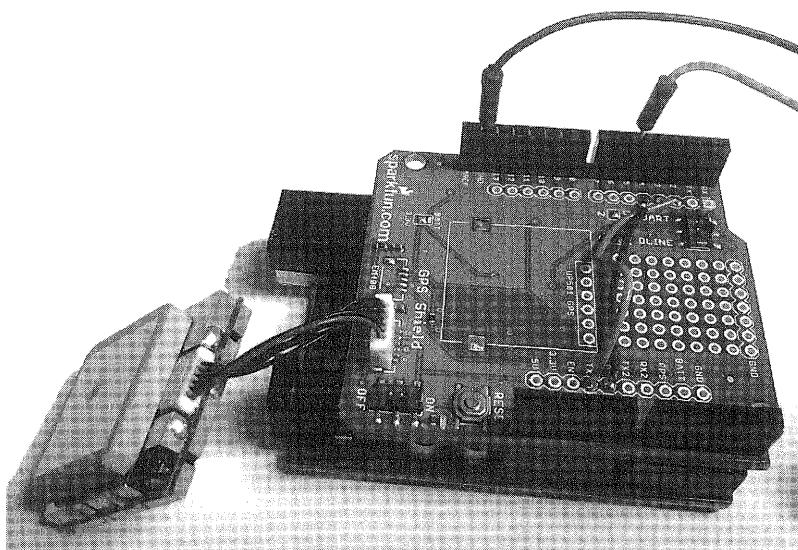
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- Display code is based on the Mark Sproul (KB2ICI) LCD library, with my additions for efficient sequential-pixel drawing. It is included in the sketch.
- FFT Code is the Roberts/Slaney/Bourras/DEIF FFT library with my bug fixes in 8-bit conversion. It is included in the sketch.
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Buddy: A Rover's Best Friend

Leigh L. Klotz, Jr, WA5ZNU



The Buddy System: An Arduino, GPS shield and GPS receiver combine to provide a CW output grid square annunciator for VHF and up rovers. A small speaker connects to ground and pin 5 via a 0.1 μ F capacitor. [Leigh Klotz, WA5ZNU, photo]

One Field Day a few years ago, I visited to the Palo Alto Amateur Radio Association site, where I met Joel Wilhite, KD6W. As part of the club's educational activities, Joel was demonstrating a microwave rover station. I'd heard about using Gunn diode oscillators to operate on the 10 GHz (3 cm) band when I was first licensed, but the wideband FM "Gunnplexer" systems seemed to be very unstable. Joel explained that operation above UHF had changed a lot since the early days, and building a 10 GHz or even a 24 GHz system stable enough for narrowband SSB and CW work was well within reach of most hams today.

Joel went on to explain that microwave operators in contests exchange their *Maidenhead locator*, either four or six digits, and many VHF/UHF/microwave contests award points based on the number of grid locators worked. (Hams often just say *grid squares* when referring to Maidenhead locators, and we'll use the terms interchangeably in this article. See my *Marinus* earlier in this book for a full discussion of grid squares.) Some contestants go *hilltopping*, and others drive their mobile stations as *rovers*. Joel asked me if I could build

a small box that would display or sound out the grid square for hilltoppers. He also wanted the box to sound out the grid square whenever it changed, so that the rovers would know when they'd driven far enough.

I bought a few surplus GPS units and some microcontrollers, but I found the project more difficult than I had anticipated. Debugging the serial output of the GPS units was difficult, and programming and debugging the bare microcontrollers in assembly language turned out to be enough effort that I set the project aside and eventually forgot about it.

Then, at the 2012 Maker Faire, I met microwaver Mike Lavelle, K6ML, face-to-face for the first time, and he showed me a 79.8 GHz transceiver that Tony Long, KC6QHP, had built. While we were talking, I heard "CQ 79 GHz this is W6BY." I answered with "You're 5 x 9," and then peered over the dish to see Brian Yee, W6BY, on the other end of the QSO. A quick calculation of 10 GHz (3 cm) and the transverter that converted the signals to and from 79.8 GHz showed me I'd made a contact on the 3.75 mm band. It wasn't just a microwave contact, it was millimeter wave!

Back at home, as I wrote out a QSL card, I noticed had forgotten a crucial part of the exchange: the grid square! Joel's request came back to mind, and I realized my troubles getting started with the project had long since been solved by the Arduino.

Designing Buddy

I looked through my parts drawer and found an EM-411 GPS module that I'd bought for \$30. It's not as quick to start or update as some of the more recent modules you can buy (see the References section at the end of this chapter), but I had it on hand, and it was compatible with the SparkFun GPS Shield, which I'd also bought. I soldered the extended headers, and plugged in the GPS module, and puzzled over the documentation on the SparkFun product page. Some people had reported having to swap the TX and RX lines. And I'd read that `SoftwareSerial` interfered with PWM (pulse width modulation) on Arduino pin D3, so I decided just to avoid D3. I wired the GPS TX pin to Arduino D2 and the GPS board RX pin to Arduino D4, set the board switch to DLINE, and uploaded a sketch, modified from the `SoftwareSerial` examples.

Here is the `SerialTest.ino` sketch that I used for testing:

```
#include <SoftwareSerial.h>

SoftwareSerial mySerial(4, 2); // RX, TX

void setup() {
    Serial.begin(9600);
    delay(500);
    Serial.println("setup!");
    mySerial.begin(4800);
}

void loop() {
```

```
if (mySerial.available())
    Serial.write(mySerial.read());
if (Serial.available())
    mySerial.write(Serial.read());
}
```

Outside, with a full view of the sky, the GPS began blinking its red LED, and I soon saw the following GPS *sentences* appear on the Arduino IDE serial monitor:

```
$GPGSA,A,3,32,23,01,11,31,20,,,,,,3.7,1.7,3.3*31
$GPRMC,161944.000,A,3725.7347,N,12206.8974,W,1.37,344.86,310512,,,A*7E
$GPGGA,161945.000,3725.7349,N,12206.8977,W,1,06,1.7,-15.1,M,-25.7,M,,0000*79
$GPGSA,A,3,32,23,01,11,31,20,,,,,,3.7,1.7,3.3*31
$GPRMC,161945.000,A,3725.7349,N,12206.8977,W,1.40,336.66,310512,,,A*79
```

GPS sentences are strings of data output from the GPS receiver in a standard format. Usually they follow a standard developed by NMEA, the National Marine Electronics Association, but some manufacturers use a proprietary format. In less than 10 minutes, using the Arduino IDE, the wealth of open source vendors, and a community of supporters, I was able to read the crucial GPS data.

Attaching the GPS Module

The SparkFun GPS shield has a connector for the GPS module I used and for the others listed in the references. The connector is near the edge, so if you decide to put a display or other shield on top, you can outboard the GPS module and avoid blocking the antenna.

The Adafruit GPS logger shield has the module connector located closer to the center of the board, so you may need to use a longer cable if you choose to use that board and also place another shield on top. The Adafruit shield includes an SD card interface.

Neither shield includes a backup battery holder, but both have solder pads on the board for adding one. Using a backup battery can reduce the time it takes to lock on to the GPS satellites at power-on.

TinyGPS Library

I started to write an NMEA GPS sentence parser, but took a minute to look for a library and found that Mikal Hart of Arduiniana.org had already written one. I downloaded it, restarted the Arduino IDE, and modified one of the examples in the library as shown below.

I used SoftwareSerial, which gives a second serial port on the Arduino Uno, and TinyGPS, which parses the GPS output and makes it available as long or float numbers.

Below is the TinyGPSTest.ino sketch that I used for testing:

```
#include <SoftwareSerial.h>
#include <TinyGPS.h>

TinyGPS gps;
SoftwareSerial nss(4, 2);

unsigned long fix_age = 0;
```

The Arduinana example uses a Serial baud rate of 115200, because it prints out a lot of tabular data about GPS status. I changed the baud rate to 9600, but left the SoftwareSerial port for the GPS at the required 4800.

```
void setup() {
    Serial.begin(9600);
    nss.begin(4800);
    delay(1000);
}
```

Building in a failsafe is a good idea, and the TinyGPS makes it easy by returning the time since the last GPS fix. If that's more than a few seconds old, it means that the module has lost its sync with the GPS satellites. I decided to test that and add a warn_lost_fix function that would be called after 60 seconds of no data. If there is data from the GPS, the loop function just prints it out with reportGPS.

```
void loop() {
    if (fix_age > 60000) {
        warn_lost_fix();
        fix_age = 0;
    }

    if (readGPS()) {
        reportGPS(gps);
    }
}
```

The readGPS function returns true once it has finished reading a whole NMEA sentence fix from the GPS serial data.

```
static bool readGPS() {
    while (nss.available()) {
        if (gps.encode(nss.read()))
            return true;
    }
    return false;
}
```

Although the Arduino supports floating-point numbers, the accuracy

is not as good as you might need for some applications. The library uses a considerable amount of program memory, so I decided just to use the long (32-bit integer) methods. The Arduino compiler automatically eliminates functions that you have not called. If you don't use them, they take up no space on the Arduino even though they are present in the library. The long interface returns decimal degrees, divided by 10^5 .

```
static void reportGPS(TinyGPS &gps) {
    long lat, lon;
    // retrieves +/- lat/long in 100000ths of a degree
    gps.get_position(&lat, &lon, &fix_age);
    Serial.println(lat);
    Serial.println(lon);
    Serial.println(fix_age);
}
```

After another half hour with this sketch, I found that I had the ability to get the numbers I needed to calculate grid square, and I set aside the `SerialTest.ino` and `GPSTest.ino` sketch files and started on the main project. The files below are all available for download from the companion website for the book.

Grid Square Calculation

In the *Marinus* project earlier in this book, I converted grid square to latitude and longitude. In this project, I needed to go the other way, and I have written routines to do that in other programming languages, but not for the Arduino. A quick web search didn't find any Arduino libraries, but I knew the Arduino is based on the C/C++ language, so I looked for an easy C implementation.

I found that Neoklis (Nick) Kyriazis, 5B4AZ, had written a package called `gridloc` that he released under GPL license. Nick's code was for floating point arithmetic, and I adapted it to the fixed-point 32-bit long data that I had chosen. If there are any errors in this routine, they are mine, not Nick's. In the end I was pleased with the way the SCALE factor multiplications worked out. I tried a few different ways of writing the scaling, watched both the test results and the compiled code size, and picked the smallest one that worked.

Here is the `grid.ino` sketch file:

```
// Adapted by Leigh WA5ZNU
// from http://www.qsl.net/5b4az/pkg/locator/gridloc/gridloc-0.6.tar.bz2
// http://www.qsl.net/5b4az/pages/utils.html
// by Neoklis Kyriazis, 5B4AZ

#define SCALE (100000L)

static void convert(long lat, long lon, char *qra) {
    // shift to positive and round up 1/2sec
    lon += 180 * SCALE + 14;
```

```

lat += 90 * SCALE + 14;

{
    // Calculate first letter of field
    long rest = lon / (20 * SCALE);
    qra[0] = rest + 'A';

    // Calculate first number of square
    lon -= rest * SCALE * 20;
    rest = (lon / 2) / SCALE;
    qra[2] = rest + '0';

    // Calculate first letter of sub-square
    lon -= rest * SCALE * 2;
    rest = (lon * 12) / SCALE;
    qra[4] = rest + 'A';
}

{
    // Calculate second letter of field
    long rest = (lat / 10) / SCALE;
    qra[1] = rest + 'A';

    // Calculate second number of square
    lat -= (rest * 10) * SCALE;
    rest = (lat / SCALE);
    qra[3] = rest + '0';

    // Calculate second letter of sub-square
    lat -= rest * SCALE;
    rest = (lat * 24) / SCALE;
    qra[5] = rest + 'A';
}

qra[6] = '\0';
}

```

Morse Code Output

Although it would be easy to add on an LCD output using one of the displays described in this book's *LCD Shields* appendix, I decided to honor Joel's initial request to make the device output the grid square in Morse code. I copied the `charCode()` routine by Hans Summers, GØUPL, from an earlier chapter in this book and wrote a new `morse()` function that did not need to include any switch polling, so it is a little simpler. With headphones or a speaker coupled with a 0.1 µF capacitor to Arduino D5, the output is quite loud, and no amplifier is necessary.

Here is the `morse.ino` sketch file:

```
#define KEY 13
#define SPEAKER 5
#define PITCH 700
// about 12 WPM
#define SPEED (100)

static byte charCode(char c) {
    ... same as in QRSS ATTiny project by Hans GOUPL ...
}

// Adapted from Hans GOUPL
// Disables SoftwareSerial during operation to avoid interrupt conflicts
static void morse(char *msg) {
    nss.end();

    for (byte msgIndex = 0; msg[msgIndex] != 0; msgIndex++) {
        char c = msg[msgIndex];
        byte character = charCode(c);
        // Set the symbol counter to the leftmost bit of the symbol code
        byte symbol = 7;

        // Look for 0 signifying start of coding bits
        while (character & (1<<symbol)) {
            symbol--;
        }

        if (character == charCode(' ')) {
            delay(SPEED*7);
        } else {
            while (symbol>0) {
                // Decrement symbol index, which moves right one bit in the symbol code
                symbol--;
                if (character & (1<<symbol)) {
                    tone(SPEAKER, PITCH);
                    delay(SPEED*3);
                    noTone(SPEAKER);
                    delay(SPEED);
                } else {
                    noTone(SPEAKER);
                    tone(SPEAKER, PITCH);
                    delay(SPEED);
                    noTone(SPEAKER);
                    delay(SPEED);
                }
            }
            delay(SPEED*3);
        }
    }
    nss.begin(4800);
}
```

Buddy Main Sketch

At this point I was ready for the main sketch. The first part is unchanged from the test:

```
#include <SoftwareSerial.h>
#include <TinyGPS.h>

TinyGPS gps;
SoftwareSerial nss(4, 2);

unsigned long fix_age = 0;
```

I decided I wanted to know when the 6-digit grid square changed, so I used two variables, one for the old grid and one for the new one. The variables start out with 0 (ASCII NUL) characters, so the `old_grid` starts out empty.

```
char old_grid[7];
char new_grid[7];
```

A Morse character V is a good indication that Buddy is ready.

```
void setup() {
    morse("V"); // also does    nss.begin(4800);
    delay(1000);
}
```

The loop starts out the same:

```
void loop() {
    if (fix_age > 60000) {
        warn_lost_fix();
        fix_age = 0;
    }
}
```

But instead of using `Serial.print`, it uses the Arduino `strcmp` function to compare two strings. The `strcmp` function returns 0 if the two strings are equal, so don't forget to put the != 0 on the end of the test.

When I first tried this code, I heard a buzzing noise between code elements. The SoftwareSerial Pin 3 problem is actually related to the use of Atmel PWM (pulse width modulation) and interrupts, and the `tone()` library function also uses PWM. I found that I needed to turn off the SoftwareSerial with `nss.end()` before calling `tone()` and then turn it back on after using `nss.begin(4800)`. That means that Buddy misses any GPS serial data that appears while it is notifying the user via `tone()` but since GPS data is sent once per second, it is not a problem. Another solution would be to go back to using the UART-based `Serial` instead, but that would mean flipping a switch on the GPS shield every time I wanted to program the Arduino. This solution is two lines of software written once. In the final version (as you see here) I put the begin and end calls inside the `morse` routine.

```
if (readGPS()) {
    parseGPS(gps, new_grid);
    if (strcmp(old_grid, new_grid) != 0) {
        note_new_grid();
    }
}
```

The parseGPS function converts to grid square.

```
static void parseGPS(TinyGPS &gps, char *grid) {
    long lat, lon;
    // retrieves +/- lat/long in 100000ths of a degree
    gps.get_position(&lat, &lon, &fix_age);
    convert(lat, lon, grid);
}

static bool readGPS() {
    while (nss.available()) {
        if (gps.encode(nss.read()))
            return true;
    }
    return false;
}
```

The warn_lost_fix function sends an approximation of a Morse ? character. (If you want to add the ? character correctly, you can edit morse.ino and add it in.)

```
static void warn_lost_fix() {
    nss.end();
    morse("IMI");
    nss.begin(4800);
}
```

The note_new_grid function just sends the new grid in CW on the speaker and uses the strlcpy library function to copy the new_grid to the old_grid variable.

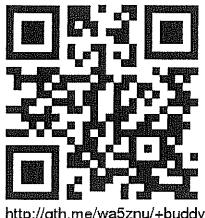
```
static void note_new_grid() {
    morse(new_grid);
    strlcpy(old_grid, new_grid, sizeof(new_grid));
}
```

Operation

In operation, just make sure that Buddy has a clear view of the sky to start. You might want to follow the SparkFun suggestions and put a coin cell on the bottom to maintain GPS ephemeris data during power-off periods. This will make system startup faster.

Further Ideas

- Add a two-line LCD to show the grid square at all times. You can show the time from the TinyGPS library as well, to help with logging.
- Use a VoiceBox shield from SparkFun to sound out the grid square in spoken words instead of using Morse code.
- Combine with the *Marinus* project for a GPS map display.



<http://qth.me/wa5znu/+buddy>

References and Further Reading

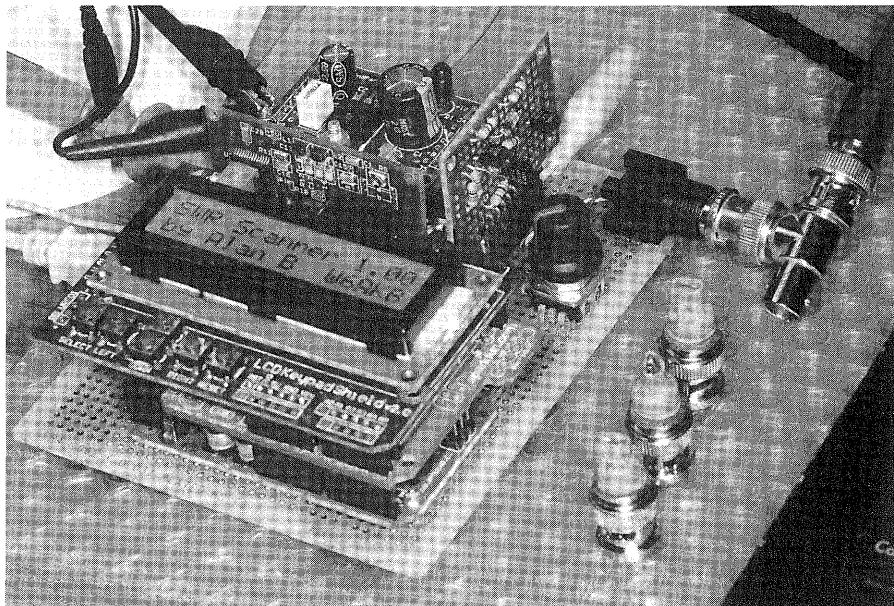
- Online references
<http://qth.me/wa5znu/+buddy>
- Source code for this project
<http://qth.me/wa5znu/+buddy/code>
- Grid locator background information
<http://www.arrl.org/grid-squares>
<http://www.arrl.org/about-grid-squares>
- Grid locator conversion
<http://www.qsl.net/5b4az/pages/utils.html>
- Arduino TinyGPS library
<http://arduiniana.org/libraries/tinygps/>
- SoftwareSerial
<http://arduino.cc/en/Reference/SoftwareSerial>
- SparkFun GPS shield
<http://www.sparkfun.com/products/10710>
- Adafruit GPS shield
<http://www.ladyada.net/make/gpsshield/index.html>
<http://www.adafruit.com/products/98>
- Voicebox shield
<http://www.sparkfun.com/products/10661>
- Inexpensive GPS receiver modules
<http://www.dealextreme.com/p/em-411-gps-engine-board-module-with-sirf-star-iii-chipset-80037?item=2>
<http://www.sparkfun.com/products/465>
<https://www.adafruit.com/products/99>

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Sweeper: An Arduino SWR Scanner

Alan Biocca, W6AKB



The Arduino SWR Scanner project by Alan Biocca, W6AKB, includes the Arduino Uno and several shields and PC boards mounted on a main prototyping board. [Alan Biocca, W6AKB, photo]

When working with adjustable mobile and portable antennas, an important question is, "What frequency is the antenna tuned for?" This is especially important for motor tuned antennas that can easily be remotely adjusted, such as the Scorpion, Don Johnson (W6AAQ) Screwdriver, Hi-Q or Tarheel antennas. Automated systems exist for tuning motorized antennas, but they don't always work as expected or desired. A simple readout of the antenna's resonant frequency would make it easy for the operator to know where it is resonant and tune the antenna as needed.

This instrument is also useful for other antennas that can be adjusted easily for different frequencies, for example the Buddipole portable antennas. After making an adjustment, an immediate readout of the resonant frequency helps to refine the adjustments and set the antenna to the desired operating frequency.

This article is about a simple project to automate the measurement of the antenna's resonant frequency. We will combine a few basic building blocks into an instrument and add software to make it perform this task. It can be constructed in a weekend. This hardware and software can be expanded later

into other projects such as an automated motorized antenna tuning system, which might be the subject of a future article.

Hardware Overview

To measure the antenna, we excite it with a low power RF signal. For this project we are using a *direct digital synthesizer*, or DDS. We selected the DDS-60 board from the American QRP Club because it contains the synthesizer and supporting components as well as a filter and amplifier to produce a clean signal with enough amplitude to drive a sensitive SWR bridge. This board is available from their website as a kit or as a built unit. (See the References section at the end of this chapter.) We built ours from a kit using hot air and solder paste. **Figure 18.1** shows the completed board.

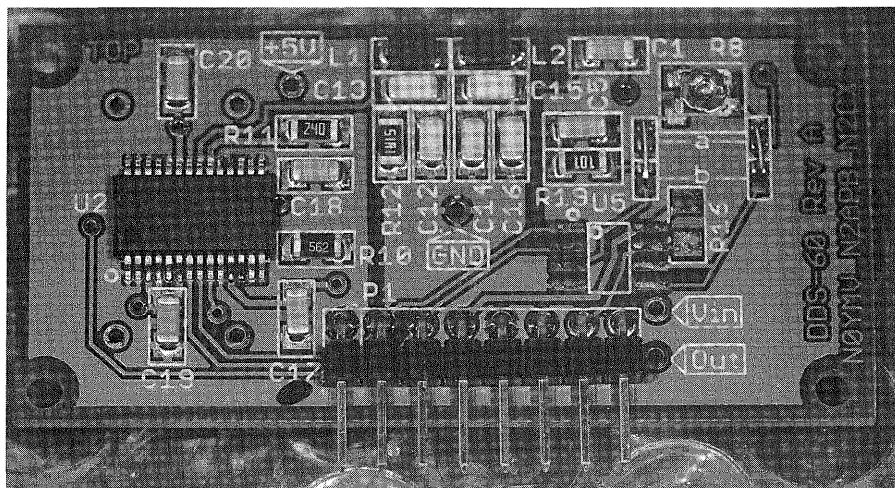


Figure 18.1 — The DDS-60 RF synthesizer board kit from the American QRP Club, built and ready to plug into the main board. [Alan Biocca, W6AKB, photo]

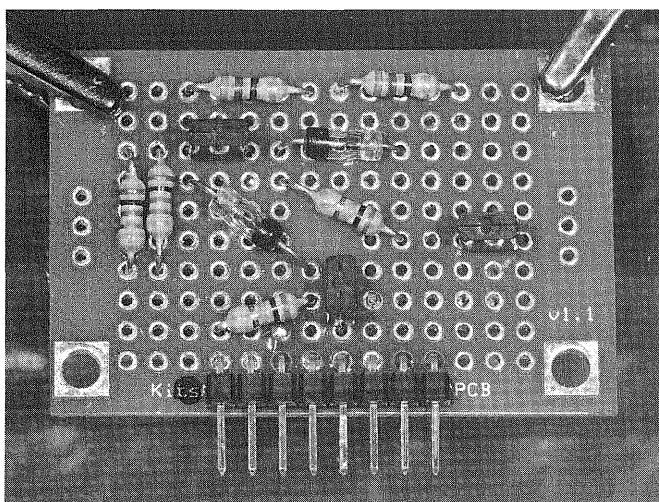


Figure 18.2 — The SWR bridge board also plugs into the main board. See Figure 18.9 for circuit details. [Alan Biocca, W6AKB, photo]

To measure the antenna a detector is required. For this project, we will use a simple resistive SWR bridge (**Figure 18.2**). Circuit details are given later in this article. This will provide a measurement of antenna SWR as the oscillator is swept across the frequency range. For this approach, the antenna impedance will be compared with a $50\ \Omega$ reference resistor. The frequency will be adjusted and repeated measurements made to find the low SWR point. Any SWR less than about 3:1 should be sufficient for detection. For antennas that have minimum SWR and resonance at different frequencies, this instrument will report the minimum SWR rather than the resonant frequency. This difference is generally very small (for properly matched antennas) and is the most favorable tune setting for the transmitter.

The Arduino Uno will control the process of searching and measuring, and drive a display of the results.

The user interface employs an Emartee Keypad LCD shield, a PC board that plugs into the Arduino and provides a liquid crystal display (LCD) and pushbuttons. See **Figure 18.3**. This display is easy to program and provides flexible display options, though the project could easily be adapted to other displays (see the *LCD Shields* appendix). This unit has a two line, 16 character per line LCD and six pushbuttons.

This article describes our experience building this instrument as well as some of the selection process needed to employ an Arduino on a project. Choosing how to connect things to the Arduino is a key part of a successful design. We use an incremental success process of “build something, then improve it,” starting with the core hardware and working up to a functioning project, and testing for success along the way.

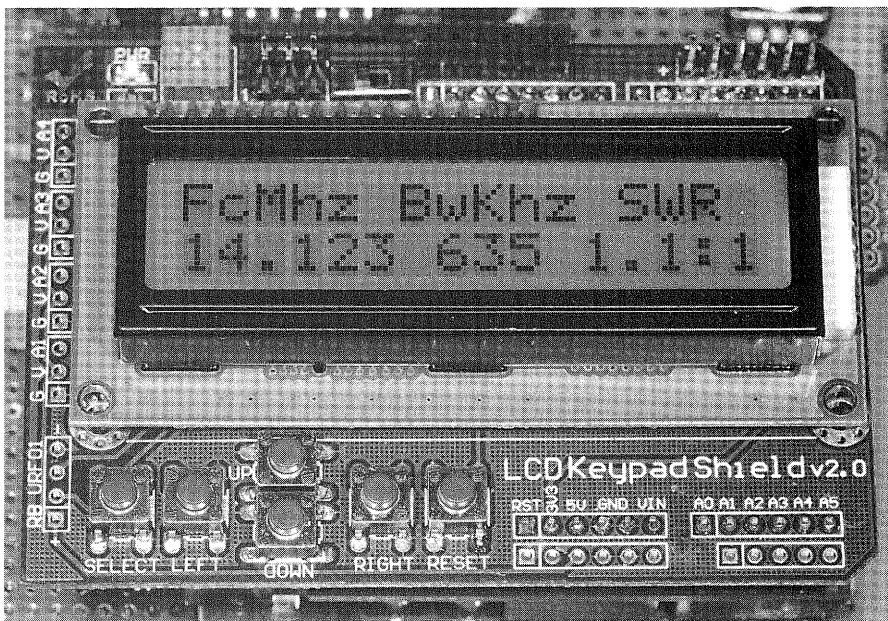


Figure 18.3 —The LCD Keypad Shield provides a two-line display that will be used in this project to show center frequency, bandwidth and SWR.
[Alan Biocca, W6AKB, photo]

Getting Started

If you don't already have experience with the Arduino software, start with a smaller project first. This project builds on concepts and skills from other chapters of this book and assumes some knowledge of Arduino hardware, software and techniques. Even within this project, we build and test one piece at a time. We start with the LCD shield, because once it is working, it can be used to monitor and give feedback about the other system components. The next section details the steps needed to make sure the LCD shield is working properly with your Arduino.

Testing the LCD Shield

- Install the shield on the Arduino Uno, taking care to ensure that all the pins line up, mate and seat properly.
- Look for and clip off any wires that stick out from the PC board and might short out to the Arduino pins.
- Load the manufacturer's software library for the LCD shield into Arduino library folder.
- Close and restart the Arduino integrated development environment (IDE) to make the library available.
- Put the LCD shield test project file in place.
- Open the LCD shield test project file.
- Compile, load and run the LCD shield test software.
- Observe the LCD and test keyboard buttons. Pushing each button reads out the different ADC values.

Project Software

The software provided for this project is available for download as a zip file from the book website. Unzip it to your Arduino sketches folder. Then you can open the project from the Arduino integrated development environment (IDE). This one file contains the eight programs that will be used in this article. To select among the programs, open the project in the Arduino IDE, scroll to the bottom of the file and review the `void loop()` function. Within that function are the calls to the test programs. They are commented out when the line begins with `//`. They will run when those two slashes at the start of the line are deleted. Only one program function at a time should be left uncommented. The comment slashes after `... () ;` are not to be removed because beyond those slashes are real comments.

Push the UPLOAD button or select FILE/UPLOAD TO I/O BOARD to compile and load the software into the Arduino board. Watch for error messages at the bottom of the IDE. If it displays the size of the binary sketch then there were no compilation errors and it will load the file into the Arduino and start running it.

To get started, uncomment the `kbd_test() ;` line and comment out any other lines in the loop function (leave the delay function at the bottom uncommented). Press the UPLOAD button to compile and load the LCD and keyboard test program. This program is a bit different than the manufacturer's test program we ran in the previous section. It puts some messages on the LCD

and then waits for keyboard activity. It displays the ADC value from each key while it is pressed. Test the keys and observe the ADC values.

Write Your First Program

Now uncomment just the `user_program` function call in the `loop` function, and then scroll up to the code for the `user_program` function. It begins with `void user_program()`.

Change the text in the `lcd.printIn()` statements in this `user_program` function as you wish; just remember that there are only 16 characters on each LCD line that can be displayed. Make sure you preserve the punctuation of the program (such as quotation marks, parenthesis and semicolons) or any of the other statements. The best technique is to change a little, then test for success and repeat.

Press the UPLOAD button on the IDE application. It will compile the program, and if no errors are found, it will load it and run it in the Arduino in a few seconds. Your text should show up on the Arduino's LCD display. Now you're programming! On to building the hardware.

Main Board Construction

There are many ways to do this project, and we are going to show but one. You are of course free to modify the implementation to suit your own parts and needs.

The various modules and connectors mount on a 4 × 5 inch main prototyping board (**Figure 18.4**). See **Table 18.1** for a list of materials used. Here is a list of the steps we followed to set up this project. See the following sections for a detailed discussion of the various components.

- Arrange the basic blocks on the main board and mark where they should go
- Drill the main board and mount the Arduino using two #4-40 machine screws and nuts. Put three stick-on feet on underside of the Arduino to space it above the main board.
- Mount sockets for the header pins on the power preregulator, DDS and SWR detector PC boards.

Table 18.1
Bill of Materials

- Arduino Uno board and development software, www.arduino.cc
- USB cable, standard A to B type
- Main prototyping board, Twin Industries 4 × 5 inch, 8000-45, www.twinind.com
- SWR detector prototyping board, www.kitsandparts.com
- SparkFun Arduino proto-shield kit, www.sparkfun.com
- LCD Keypad Shield v2.0, <http://www.emartee.com/product/42054>
- DDS-60 RF synthesizer board, www.amqrp.org
- Voltage regulator board, www.kitsandparts.com
- Rotary encoder, www.adafruit.com/products/377
- PCB mount BNC connector, www.jameco.com or www.digikey.com

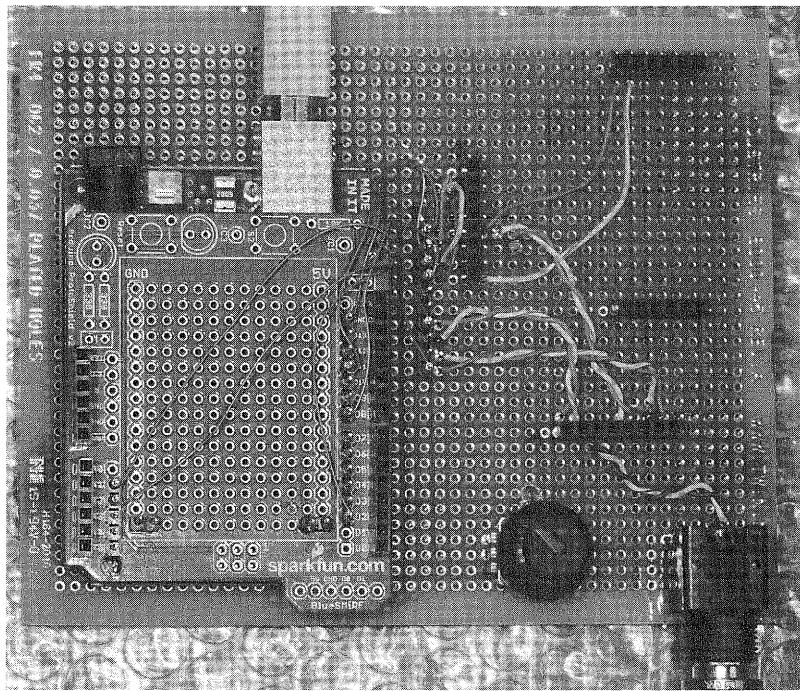


Figure 18.4 — The main board supports the Arduino and shields, sockets for the power supply preregulator, DDS-60 and SWR bridge boards, and the antenna connector. [Alan Biocca, W6AKB, photo]

- Mount pins for the Arduino I/O to facilitate wire wrapping from the proto-shield to the main board (see Planning the I/O below).
- Mount a BNC connector that will be used for the antenna connection — drill two holes, solder and epoxy.
- Mount the rotary encoder — two tab clearance holes and solder. The encoder is optional, not yet used in this project.
- Add stick-on rubber feet under the project main board

Powering the Instrument

The USB cable provides power to the Arduino and LCD shield during development and initial testing, but when the instrument is separated from the computer, power must be applied to the Arduino's dc connector. Power must also be applied to the DDS board that will be added in a following step.

Power Requirements

- The Arduino Uno requires 7-20 V, and heats up at 12 V and above; 8-9 V is optimal.
- The DDS-60 board requires 8-16 V at 120 mA, and heats up at 12 V and above, 8-9 V is optimal.
- The LCD shield takes 5 V from the Arduino (and will contribute to the dissipation there).

The 12 V input for the main board is preregulated down to 8 or 9 V by the

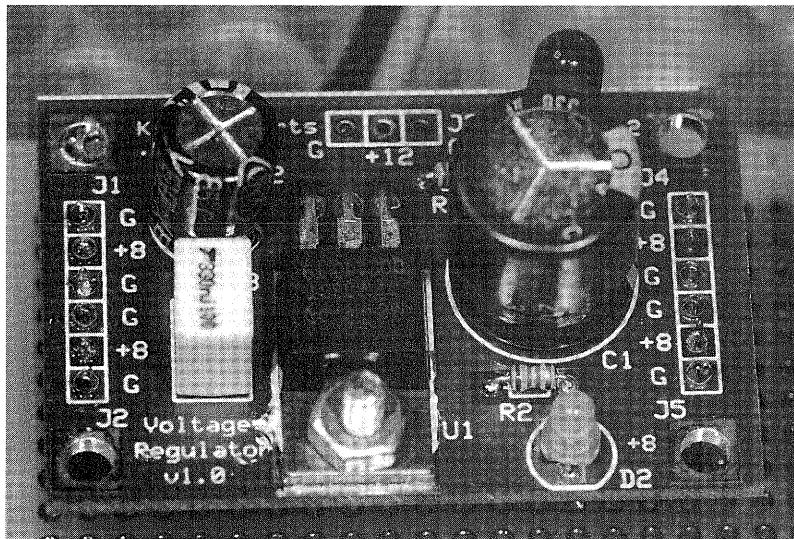


Figure 18.5 —The author's preregulator board was built from a kit, but you can build your own simplified version (see Figure 18.6).
[Alan Biocca, W6AKB, photo]

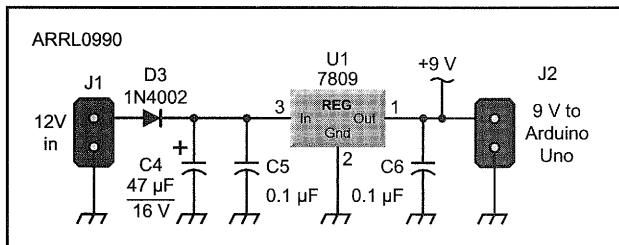


Figure 18.6 —Simplified power preregulator schematic. The LM7809 regulator provides 9 V dc, but an LM7808 (8 V) will also work. The Arduino Uno is powered from the USB jack when connected to a computer; J2 goes to the Arduino Uno coaxial power plug for standalone operation.

regulated voltages during operation. Both get rather toasty if operated directly from 12 V. Diode D3 gives polarity protection. A 9 V pack of six AA batteries would also be suitable for powering this instrument.

Planning the I/O

The Arduino Uno has a number of I/O pins available for projects. Some are also used by the Uno, so care must be taken to understand what is available for use and how to use shared pins in a compatible way. Here is our master pin list:

- D13 SPI SCK (reserved) (also Arduino LED)
- D12 SPI MISO (reserved)
- D11 SPI MOSI, LCD RW, DDS-60 CLOCK P1-2
- D10 SPI SS (reserved)
- D9 LCD Enable (strobe)

regulator board shown in **Figure 18.5**. The board I used is the Universal Voltage Regulator kit from Kits and Parts (see References), but you can build your own. The schematic in **Figure 18.6** is similar to the Kits and Parts board but simplified. Using a preregulator keeps the DDS-60 and Arduino boards cooler by providing them minimum but

D8 LCD RS (cmd/data register select), DDS-60 DATA P1-3
D7 LCD data
D6 LCD data
D5 LCD data
D4 LCD data
D3 (available)
D2 DDS-60 LOAD P1-1, AD9851 FQ
D1 Uno Serial TXD (Arduino monitor)
D0 Uno Serial RXD (Arduino monitor)
A5 ADC 5, I2C SCL (reserved)
A4 ADC 4, I2C SDA (reserved)
A3 ADC 3 (available)
A2 ADC 2, SWR Vf
A1 ADC 1, SWR Vr
A0 ADC 0, LCD shield buttons (analog input)

The D pins are digital and they can be configured to be either inputs, outputs or floating. In some cases they have special capabilities as well, such as I2C, SPI or serial. The A pins have analog to digital conversion (ADC) input capability in addition to being digital pins. A 10 bit analog to digital conversion can be programmed to read the voltage present on these pins.

If a project is going to use SPI or I2C protocols to communicate with other expanded I/O, then the appropriate pins need to be saved for that purpose. We will not be using those protocols in this project, but we will avoid using those pins or use them in a compatible way to preserve future options. The Serial pins (D0, D1) are needed for downloading programs from the Arduino development environment, so those should be preserved. The LCD shield uses a number of pins, so those should be avoided or used in a compatible way, and have been noted in the list above. ADC 1-3 and Digital 2-3 are available. So let's assign ADC2 to the forward SWR voltage (Vf), and ADC1 to the reflected SWR voltage (Vr). D2 will be used for the DDS-60 LOAD strobe. The other two DDS digital lines may be shared, so they are assigned to share pins D8 and D11 with the LCD.

Stacking Shields

Figure 18.7 shows the stack of shields used for this project. To facilitate wiring, a SparkFun Arduino prototyping shield (proto-shield) is used to access the Arduino's I/O pins and bring them out to the project main board to interface with the other project boards. Alternatively, wires could be connected directly to the LCD Keypad shield, but more flexibility is retained by using the prototyping shield. We may want to change displays on this project and use a graphical display later on, or use this display and processor on some other project. The proto-shield is stacked on top of the Arduino Uno, and the LCD Keypad shield is in turn stacked on top of the proto-shield board. Only the through connectors and some wire wrap pins are loaded on the proto-shield board to access the A and D pins for this project. The buttons and LEDs on this board were not required for this application.

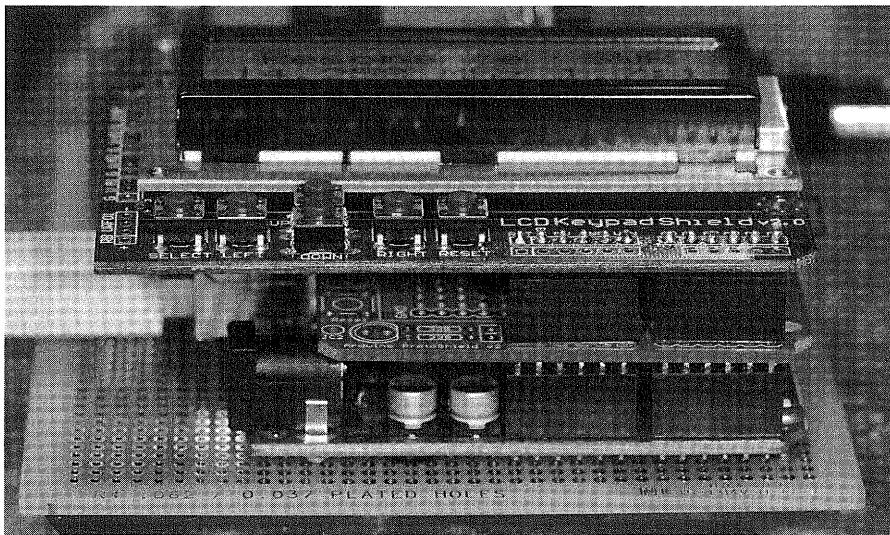


Figure 18.7 — Here is the final shield stack assembled on the main board: Arduino Uno, SparkFun proto-shield, LCD Keypad. See the text for discussion. [Alan Biocca, W6AKB, photo]

We used both point to point wiring and wire wrap interconnects on this project. Point to point soldered wiring was used on the main board and on the SWR detector board. Wire for this was recovered from scraps of CAT5 network cable. Wiring from the main board to the Arduino board stack uses wire wrap for flexibility and ease of modifications. In wire wrapping, the square 0.025-inch pins cut into the tightly wound wire and make very reliable connections that can be easily removed. We used the OK Machine and Tool WSU-30M low cost hand wiring tool, or there is a RadioShack tool that may also work. New 30 gauge Kynar insulated wire wrap wire was used for these connections. Gold plated square pins are soldered to the board for the wire wrapped connections to land on.

Synthesizing RF

The DDS-60 board generates RF output from 1 to 60 MHz using the Analog Devices AD9851 direct digital synthesis chip and the onboard amplifier provides up to 4 V peak to peak output into a $50\ \Omega$ load. The DDS chip requires three control signals from the Arduino — Data, Clock and Load. **Figure 18.8** shows the interconnections. The chip is controlled by loading a 40 bit control word. The control word contains the 32 frequency determining

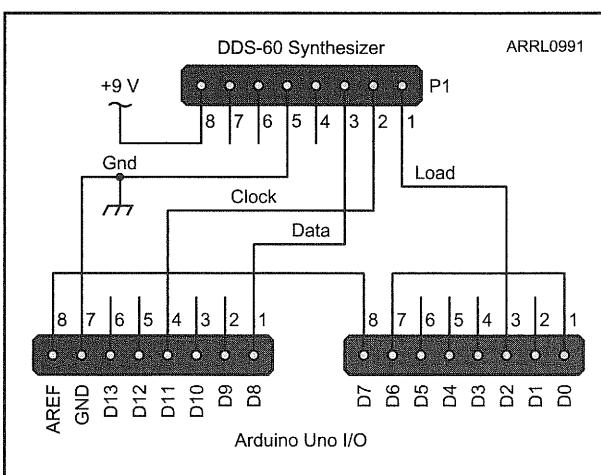


Figure 18.8 — The DDS-60 synthesizer board requires power and three connections to the Arduino's I/O digital pins.

bits, plus phase and other control information. Each time a frequency change is needed the control word must be reloaded.

Note that the DDS-60 board gets warm. The DDS chip is operating internally at 180 MHz using a 6x on-chip clock multiplier from the 30 MHz crystal oscillator input. This heating is normal and within its design. Some air circulation is required to prevent it from overheating. The DDS-60 is mounted vertically on the project base board to allow good air circulation. The software should turn off the chip when the RF output is not needed. This not only keeps the chip cooler, but also avoids the RF interfering with receiving weak signals. It also saves power, which is important if battery powered operation is planned.

When configuring the DDS-60 board, note that the small amplitude adjusting potentiometer at R8 should be fully clockwise. Also, two small jumpers labeled "a" on the DDS-60 schematic should be in place to generate maximum RF output level. Connect power, ground and the control signals to the Arduino to check it out.

Programming the DDS Frequency

The frequency generated by the DDS is determined by a tuning word from the equation:

$$\text{Tune} = (\text{Freq} \times \text{Scale}) / \text{Clock}$$

where Freq is the desired frequency in Hz and Clock is the 180 MHz clock rate of the DDS.

The scale factor is used to perform the calculations in 64 bit integer arithmetic because the Arduino float type is not precise enough to produce the correct 32 bit tune word result.

The other byte of the control word contains 5 bits of phase control that we don't use, and control bits for power down mode, test mode enable and the 6x clock multiplier. Note that if the test mode gets engaged, the chip must be reset or power cycled to recover normal operation. If the DDS doesn't seem to work, try power cycling it. On the DDS-60 board, the reset function is not connected to the Arduino, so only power cycle causes a reset. Here is the code to convert the frequency to the tune word and send it to the DDS-60:

```
void DDS_freq(unsigned long freq) { // set DDS freq in hz
    unsigned long clock = 180000000L; // 180 mhz, may need calibration
    int64_t scale = 0x100000000LL;
    unsigned long tune; // tune word is delta phase per clock
    int ctrl,i; // control bits and phase angle

    if (freq == 0) {
        tune = 0;
        ctrl = 4; // enable power down
    } else {
        tune = (freq * scale) / clock;
        ctrl = 1; // enable clock multiplier

        digitalWrite(DDSLLOAD, LOW); // reset load pin
        digitalWrite(DDSCLOCK,LOW); // data xfer on low to high so start low
```

```

for (i = 32; i > 0; --i) { // send 32 bit tune word to DDS shift register
    digitalWrite(DDSDATA,tune&1); // present the data bit
    digitalWrite(DDSCLOCK,HIGH); // clock in the data bit
    digitalWrite(DDSCLOCK,LOW); // reset clock
    tune >>= 1; // go to next bit
}
}

for (i = 8; i > 0; --i) { // send control byte to DDS
    digitalWrite(DDSDATA,ctrl&1);
    digitalWrite(DDSCLOCK,HIGH);
    digitalWrite(DDSCLOCK,LOW);
    ctrl >>= 1;
}
// DDS load data into operating register
digitalWrite(DDSLOAD, HIGH); // data loads on low to high
digitalWrite(DDSLOAD, LOW); // reset load pin
}

```

DDS Testing

Getting the synthesizer going is a major step in this project. For it to work, the DDS-60 board must be built properly and working, the power must be applied, the interface to the Arduino must be correct, and the software to drive the DDS must be right. Also the output gain adjustment (R8) must be turned up and the proper jumpers installed as described earlier. Any problems with any of this, and the DDS won't synthesize.

When I got to this point in my construction, I wanted to make sure I could tell if the DDS was working, so I monitored it three ways. One way is by power supply current consumption using the built in meter in my supply. The regulator idled at about 10 mA with no load; with the DDS idle, the total current was about 50-60 mA and when producing an RF output the total current was about 150 mA. This does not include the Arduino, which was powered from the USB.

I also tuned a nearby receiver to 7.151 MHz lower sideband. The tone was programmed to be at 7.150 MHz, so this should produce a 1 kHz tone in the receiver when RF is present. I was not sure the calibration of the DDS was going to be that accurate out of the box, so I also connected a 50 MHz scope to the oscillator output.

When I first tested my setup, it did not work. So I made another test program that produces distinct pulse durations on each of the three communications pins to the DDS and used the scope to verify the signals. A miscounting of the pins was found and the wire easily replaced as this was one of the wire wrapped connections. Check everything twice!

After the wire was corrected and the DDS test software reloaded, there was a nice 4 V_{p-p} sine wave on the scope, and a 1 kHz tone in the receiver, and the power supply indicated 150 mA of current. The DDS-60 board that I had soldered with hot air worked fine! Nice!

SWR Bridge Construction

To measure the antenna, a Wheatstone bridge is used to compare the impedance of the antenna to a $50\ \Omega$ resistor. The bridge circuit (Figure 18.9) produces two analog dc voltage signals that are input to the Arduino ADCs. One is a sample of the output level of the DDS referred to as V_f , and the other is the bridge balance error signal, V_r . From these values the Arduino can compute the standing wave ratio (SWR):

$$\text{SWR} = (V_f + V_r)/(V_f - V_r)$$

The diodes in the bridge can be chosen from several different types (though the two should be the same type). Germanium diodes such as the 1N34A have the lowest forward voltage drop, which leads to the greatest sensitivity for the bridge. The 1N5711 Schottky signal diode has slightly higher voltage drop, and the silicon signal diodes such as the 1N4148 have the highest voltage drop. Any of these diodes are suitable for finding the resonant frequency, but slightly more accurate SWR readings and improved dip detection will result from using diodes with lower voltage drop. Since we are most interested in the dip of the SWR rather than its precise actual value, the choice of diode is less critical.

Note that if 1N34A diodes are used, their forward voltage drop often varies from unit to unit so it is best to get a set of 10 or so and select the two for the bridge for the lowest and most equal voltage drop. Most modern meters have a diode measurement setting that measures forward diode voltage drop, or if not use a $10\ k\Omega$ resistor and 12 V dc power supply to produce a small forward current in the diode and measure the voltage drop across the diode. Sort them by this value and select the two nearest matching with the lowest value of forward voltage. The 1N34A diodes I used have forward voltage drops of 0.33 V and produce about 500-600 mV of signal for the ADC at 7 MHz which is half scale on the Arduino's ADC. Other diode types will produce smaller signals.

The two analog voltage signals from the bridge need to be sampled by the Arduino. This is done by connecting them to inputs that have analog to digital converters in the chip. With proper software configuration the voltages can be read in by the program and the SWR can then be computed. Not all the Arduino pins have this analog input capability, so we need to select pins that have this feature, and are not needed for some other purpose. We selected available analog inputs A1 and A2 for the V_f and V_r inputs.

I built the SWR bridge on

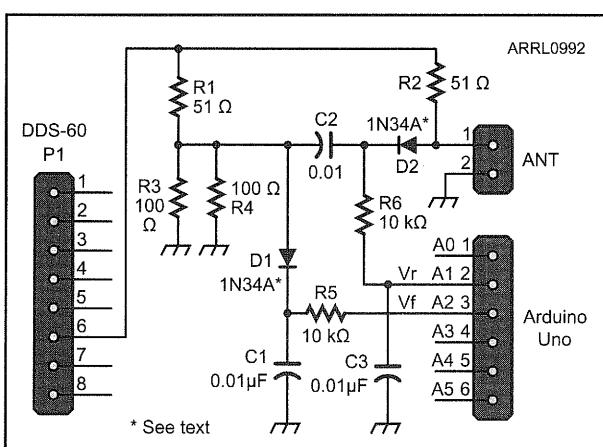


Figure 18.9 — SWR bridge schematic. Resistors are $\frac{1}{4}$ W, and R1-R4 must be noninductive. R1 and R2 can be 47, 49.9 or $51\ \Omega$. D1 and D2 can be 1N34A or similar germanium signal diode, or 1N5711 Schottky diode, or 1N914 or 1N4148 silicon signal diode. Note that both diodes should be the same type. See text for discussion.

a section of prototyping board and put a connector on the main board to plug it into. It connects to the output of the DDS oscillator, the Arduino analog inputs, and the antenna connector. Layout is not too critical, but keep component lead lengths to a minimum for best performance at the higher frequencies. I used twisted pair wiring for RF and dc signals to reduce radiation and coupling. Solid conductor CAT5 network cable scraps are a good source of small twisted pair wires.

With the SWR bridge built and wired to the synthesizer, Arduino and antenna we can start testing it. Install the SWR detector test code into the Arduino:

```
void swr_test() { // measure Vf Vr and display them and computed SWR
    lcd.cursorTo(1,0);
    lcd.print(" 7.150 SWR Test ");

    int s = swr(7150000);      // set frequency
    lcd.cursorTo(2,0);         // update display
    print_spc();
    prInt(vf);                // display forward voltage ADC counts
    print_spc();
    prInt(vr);                // display reverse voltage ADC counts
    print_spc();
    print_swr(s);             // compute and display swr
    lcd.print("      ");
}
```

It will display the name of the test on the first line of the LCD, and the forward and reflected voltages on the second line of the LCD. These voltages are displayed 0-1023. With no connection on the antenna port, the forward and reflected values should be nearly equal and in the range of about 400-600 with 1N34A diodes in the bridge. The values will be lower with other diode types.

Figure 18.10 shows the SWR bridge test setup. Small test loads are built into BNC connectors. Applying a $50\ \Omega$ terminator will cause the reflected

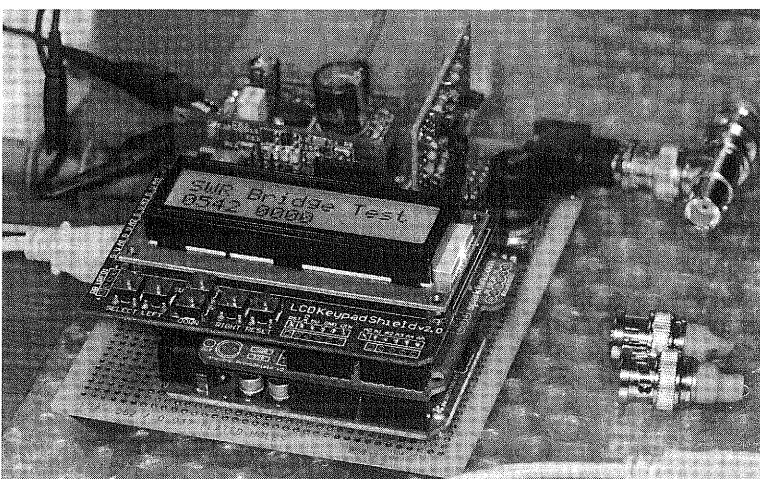


Figure 18.10 —
Test the SWR
bridge with the
test code and a
 $50\ \Omega$ load. [Alan
Biocca, W6AKB,
photo]

voltage to drop to zero or a value very close to it. Applying a short will cause both forward and reflected values to be reduced (due to heavier loading on the synthesizer) but near the same number.

Bring It All Together — SWR Scanning

Now that the basic components are all working we can combine them and begin to search for the SWR dip near resonance. The program loop begins at the low frequency end of the range and scans upward for the first SWR drop. At each frequency step it measures the forward and reflected voltages and tests to see if the reflected voltage is less than half the forward voltage. This is the 3:1 SWR point. When the SWR drops below 3:1, the low frequency is recorded, and when the SWR rises above 3:1 again, the high frequency point is recorded. The frequency range is displayed (**Figure 18.11**). Here is some of the code:

```
low = high = 0;
for (freq = START; freq <= END; freq += (freq>>11)) {
    // scan over the frequency range
    int s = swr(freq); // set frequency and read SWR, return is 10x SWR

    if (s < 30) { // if swr below 3:1
        high = freq;
        if (low == 0) low = freq; // grab first low swr frequency
    } else { // swr is above 3:1
        if (high) { // passed through a dip
            lcd.cursorTo(2,0); // display the region found
            print_mhz(low/1000);
            lcd.printIn("-");
            print_mhz(high/1000);
            lcd.printIn("      ");
            break;
        }
    }
}
```

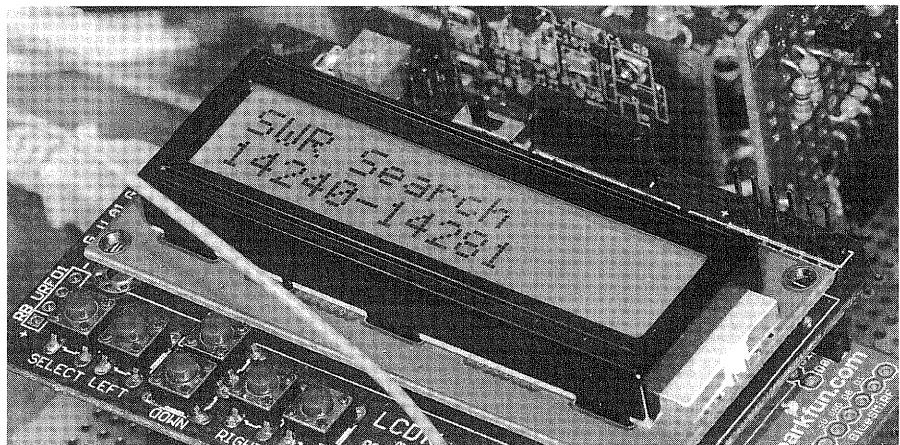


Figure 18.11 — Testing with the SWR search test code should display a frequency range. [Alan Biocca, W6AKB, photo]

Adjust the commenting on the functions in the project's loop code so only the `swr_search()` function is not commented out, and hit the UPLOAD button. It should compile, load and start scanning. Connect a resonant antenna to test with. You should see the frequency scanning with the scope if you have one, and hear the oscillator flick by if you have a receiver, and you can see the current consumption jump up while the DDS is operating, then drop for a moment as it takes a break between scans.

So now it is working! This is great progress! However the scan takes a bit too long, and the information displayed could be enhanced. Now begins the improvement process. We have made something that works, now it is time to move on to making it better.

Smarter Scanning

To avoid missing the SWR dip we must scan in adequately small steps. Scanning in steps that are too small results in scans taking longer than necessary. So how large can the scan step be? This is a function of the bandwidth of the antenna. The step must be small enough to avoid "stepping over" the resonance and missing it:

$$\text{Bandwidth} = \text{Center Frequency} / Q$$

If you have an estimate of the antenna Q, you can adjust the step size to be small enough that it won't step over the resonant SWR dip.

Experience will yield bandwidth information that can be used to adjust the Q and optimize the scanning steps later on. The code needs to be improved to find the resonant dip quickly with larger steps, and then search out the edges of the dip more accurately using smaller steps. It is more efficient to shift than divide, so we can more efficiently use a step size based on a binary shifting. Shifting 7 bits is equivalent to dividing by 2 to the 7th power (2^7) which is 128. This is sufficient for finding the dip of an antenna up to a Q of about 100, which should be adequate for our purpose. The Q of antenna loading coils may be higher, but the loaded Q of the whole antenna includes radiation resistance and all losses, so Q is rarely that high. At 80 meters, this would correspond to an antenna bandwidth of 35 kHz — a pretty narrow bandwidth antenna. We can always adjust this factor later if needed.

I wrote and tested a number of variants of several SWR search algorithms. The one I settled on uses a quick scan to find the SWR dip, then refines the edges and scans the region for the best SWR. It displays 2:1 SWR bandwidth, best SWR frequency and best SWR.

The display can be enhanced to show more useful information. The center frequency in megahertz, bandwidth in kilohertz and SWR is a more useful presentation. Including the decimal in the frequency and the decimal and ":1" in the SWR to make the display more easily recognized without documentation or labels, for example:

FcMhz	BwKhz	SWR
14.234	520	1.2:1

This display expresses 14.234 MHz center frequency, 520 kHz 2:1 SWR

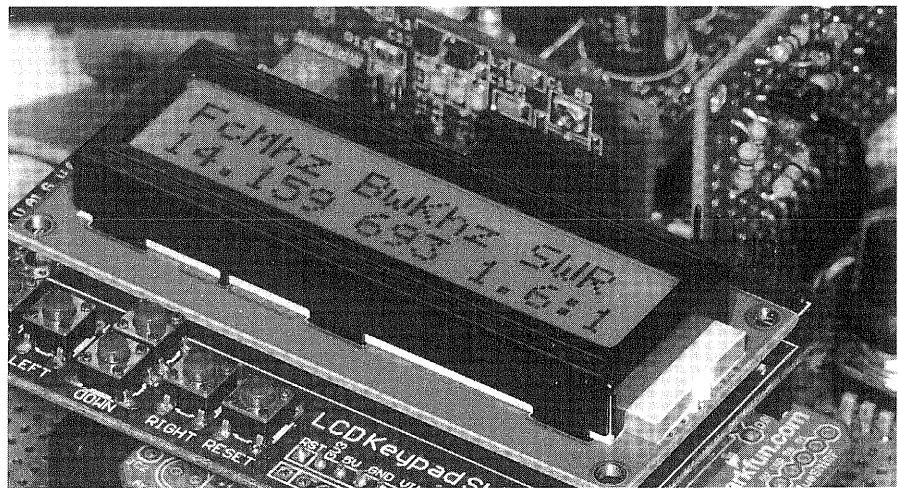


Figure 18.12 — SWR scanning shows frequency of lowest SWR (FcMHz), bandwidth (BwKhz) and SWR. [Alan Biocca, W6AKB, photo]

bandwidth and 1.2:1 SWR. The bandwidth is set to limit at 999 kHz and the SWR at 9.9:1 so values above these numbers don't break the display formatting.

Now adjust the project's loop code so the `smart_search()` is not commented out (and the other functions are), and hit the UPLOAD button. In a few seconds it should start scanning with the more sophisticated smart algorithm and present a display similar to the one shown above with frequency, bandwidth and SWR values. **Figure 18.12** shows an example.

Test Antenna: Buddistick with Triple Ratio Switch Balun

The SWR smart scan code is running here while I write this, reading the SWR frequency and bandwidth of the Buddistick testing antenna clamped to the desk (**Figure 18.13**). The antenna is equipped with the triple ratio switch balun. Switching the balun to 1:1 we see 14.110 597 1.0:1 on the display, indicating good SWR and wide bandwidth. Changing the balun to 2:1 changes the display to 14.110 470 1.5:1, so the SWR goes up a bit and the bandwidth goes down a bit. In the 4:1 balun setting the reading is 14.110 0 2.6. There is no 2:1 SWR bandwidth

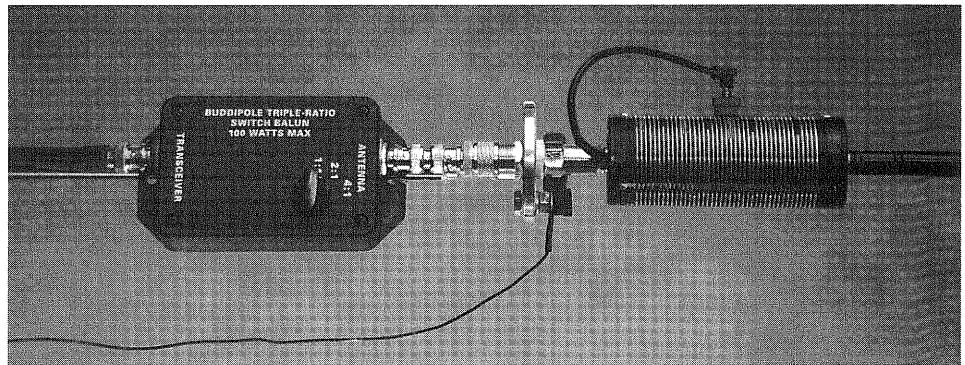


Figure 18.13 — The Buddistick with triple ratio switch balun provided a convenient test antenna. [Alan Biocca, W6AKB, photo]

in the 4:1 setting because the best SWR found was 2.6:1. The simple diode detectors used in this bridge tend to read low on weaker signals, and this tends to make good SWR values look a bit better. The software finds the dip in the SWR curve effectively with this simple SWR detector.

Possible Enhancements

- *Rotary encoder knob:* Earlier we installed a rotary encoder knob on the main board. These are excellent human interfaces for things like frequency tuning control. They have two contact closures that open and close in an encoder quadrature pattern that makes it easy for the microprocessor to tell which way and how much the knob is turning. This can be used to manually control the frequency of the DDS through the software or select other operational parameters. This unit also has a push switch on the knob that provides for a selection function in addition to the rotary tuning action. We will leave implementing this knob for a future upgrade.
- *Graphical display:* A graphical display shield can be used instead of the text LCD. This allows more information to be displayed, and it can display graphs in addition to text.
- *Speech output:* A speech output shield such as the SparkFun VoiceBox is priced competitively with graphical LCDs, and can make a huge difference in operating capability for visually challenged hams. Modifying commercial equipment to have speech output capability is difficult, but it is easy with the modular approach of this project and the Arduino system.

Project Development

In the period between the writing of this article and the time you are reading it the software and design of this project have likely progressed. There may also be a printed circuit board kit available to make this project even easier to build. Consult with the book project website to get updated information, color photographs and program files.

Further Development

This chip is less than 30% full now, and the libraries for extended precision integer arithmetic take much of the space, so the code size grows slowly as lines are added. There is a plenty of space for enhancements and features. There are many possible development paths that can be followed from this starting point.

The ability to generate an RF signal and measure the SWR can be used in a large number of ways. For example, by adding a motor control interface and appropriate software this device could tune the antenna automatically to a desired frequency. By adding a serial interface and reading the frequency from the radio, it could determine what frequency to tune the antenna to and “follow” the radio. It could memorize the antenna versus frequency relationship and pre-adjust the antenna without using a test signal at all. By adding amplifiers to increase precision and measuring a few more parameters from the bridge it could perform the calculations of an antenna analyzer, and a graphical display could produce the familiar frequency swept data or even Smith Chart displays. It could warn the operator, or interlock the radio (or an amplifier) and prevent transmission when the antenna was not tuned, or when the SWR was too high.

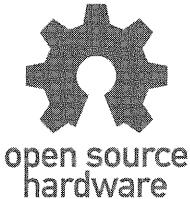


<http://qth.me/w6akb/+sweeper>

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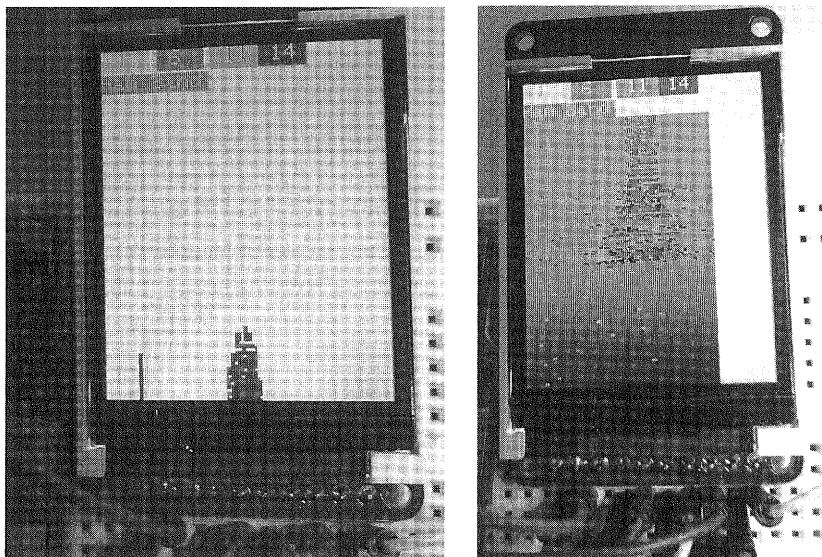
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- The hardware designed for this project is licensed under the CC-BY-SA 3.0 license:
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About the Author

Alan Biocca is an Amateur Extra class Amateur Radio operator licensed since 1967. He has a bachelor's degree in Electrical Engineering and a master's degree in Computer Science from UC Berkeley. He works at Lawrence Berkeley National Laboratory where he manages software projects and leads the controls group at the Advanced Light Source. He is also known for the design and manufacture of pneumatic antenna launchers (www.antennalaunchers.com) as well as the triple ratio balun and the *FDLog* Field Day logging program. Alan's other hobbies include hi-tech flashlights, photography and electric bicycles. He recently changed his call sign from WB6ZQZ to W6AKB.

Swamper: A Cypress Waterfall for 2.4 GHz

Leigh L. Klotz, Jr, WA5ZNU



The Swamper project can show signals received in the 2.4 GHz band using a spectrum (left) or waterfall (right) display. [Leigh Klotz, WA5ZNU, photo]

The explosion of Part 15 devices on the 2.4 GHz (13 cm) “WiFi” band has been a boon for consumers, businesses and radio amateurs. Since the introduction of networking equipment and devices in the 13 cm *ISM* (Industrial, Scientific and Medical) band, the availability of dual-use equipment has skyrocketed. Under FCC Part 97 regulations, US hams have a patchwork of primary and secondary allocations from 2300 to 2450 MHz, partially overlapping the ISM band in the range from 2400 to 2483.5 MHz. The ARRL has recently developed a band plan recommendation for 13 cm use. The plan takes into account various modes and activities: satellite, EME (Earth-Moon-Earth, or moonbounce), weak signal SSB, CW and digital modes, and short-range wideband data communication modes such as the OFDM and DSSS modes used by the IEEE 802.11 standards. The 2400-2450 MHz range is marked for the spread-spectrum and wideband data modes.

Nonham experimentation with 2.4 GHz Part 15 gear in the ISM band goes back to at least 2001, when Andy Clapp designed a antenna for the ISM band that he called the *Pringles Can Antenna*. Later Rob Flickenger of O'Reilly

Media simplified the design, and DIY nonham interest in microwave antenna construction and RF was launched. Inexpensive spectrum analyzers based on 802.11 chipsets began to appear around the same time. Dale Dougherty cites the excitement surrounding this antenna experimentation as one of the key events that lead to the founding of *MAKE* magazine and the Maker Faire.

A Web of Projects

One RF product for 2.4 GHz that quickly captured the imagination of DIY nonhams was the MetaGeek WiSpi, a spectrum analyzer USB device for laptops. At under \$200, it shattered price barriers for UHF spectrum analyzers, but it seemed to many hackers, makers and even some hams that a cheap DIY solution ought to be at hand. Interest quickly focused on the Cypress Semiconductor CYWUSB6935 RF/modem IC, and web is full of projects interfacing this device to the Arduino, laptops and other devices. There are literally too many projects using these Cypress parts to list in the book references, so see the online references for a longer list, or just use a search engine to find them. Semiconductor technology has moved on and the CYWUSB6935 is now an older part, but it is a good choice for an inexpensive spectrum analyzer with 1 MHz channel bin width.

Since so many technically oriented nonhams have their first experience with RF on the 2.4 GHz band, I decided to build my own a spectrum display using the CYWM6935 evaluation board and an Adafruit 1.8 inch 160×128 TFT color LCD. Even though I was following in a well-worn path, I still found a few surprises and challenges on the way. I started with the *This Old Geek* blog, and followed citations and links from one project to another. Eventually I found a project by Richard Ulrich, who used the *github* open-source code hosting site to publish his Arduino spectrum analyzer using a black-and-white Nokia cell phone display. Armed with the Cypress data sheet and the results of others, I set about converting his sketch to a color waterfall display and turning the Cypress code into a library.

How It Works

The Cypress chip is a full radio modem, but the spectrum analyzer projects do not use all the features. Instead, they use only the on-channel signal strength measurement feature known as *RSSI* (received signal strength indicator). You can think of RSSI as very similar to an S meter reading, as it is reported in arbitrary units. On the Cypress chip, the value is a five-bit number and so runs from 0 to a full-scale reading of 31, and you read the RSSI for a “channel,” which is a 1 MHz wide slice of spectrum from 2400 MHz to at least 2495 MHz. The task of the sketch is then to set up the CYWM6935 and repeatedly scan the channels and read RSSI values, then display them on the LCD.

SPI vs Spi

The first challenge I faced was with the data communications. The Cypress chip and evaluation board use the *SPI* (serial peripheral interface) bus, a master-slave serial protocol developed by Motorola for connecting microcontrollers and peripheral devices. SPI uses four wires: a clock, two data lines, and one

select line for each device. The more parsimonious I₂C/TWI bus created by Philips (used in the character based LCD shields in the *Timber RTC* project earlier in this book) requires only two wires, with device selection done by data address. (Of course, each peripheral also needs power and ground connections.)

Arduino 1.0.1 supports SPI via the SPI library. Earlier versions of Arduino libraries had no support, so projects using these devices had to include their own code. In the switchover, the name changed from Spi to SPI, so you will see sketches from earlier years using the old name.

Another change that has happened in the SPI world is that all the signal pins were renamed. The old names are SCLK (clock), MISO (master in slave out), MOSI (master out slave in) and SS or CS (chip select) for the individual enable/select pins. The new names are SCK for clock, SDO for slave data out, and SDI for slave data in. CS is now called \overline{CS} because it is active low, and the overbar indicates negation. If you are like me, you may suffer from some confusion when deciding whether a peripheral chip is old SPI, new SPI, I₂C or TWI. Luckily old and new SPI are 100% compatible, and TWI is just the generic name for the Philips I₂C! In any case, where you used to connect MISO and MOSI to each other, now you connect SDI and SDO to each other.

Even though the SPI bus is designed for multiple slave devices, actually using several devices together can be a challenge. Each SPI device requires a dedicated enable line, using up one pin on the Arduino (though you could add more outputs using a shift register such as the 74HC595). Unlike I₂C/TWI, which has only a few clock speeds, SPI is more open ended and operates at a wide range of bus speeds. The Cypress chip documentation says it works at speeds of up to 2 MHz, but most projects I saw were using it at the leisurely 125 kHz rate.

When I read the RSSI value, I found it ran from 15 to 31, as if the most significant bit of the five-bit result was always on. I had a terrible time debugging this problem, and only resolved it when I made a *test case*, that is, a smaller program that has only the bare essentials. By switching between the two sketches, I found that as soon as I initialized the SPI LCD device I began to get erroneous results. A quick look at the ST7735 library showed that the library itself was setting the SPI bus speed to 4 MHz, well outside the supported range of the CYWM6935. I reasoned that changing SPI bus speeds on the fly should work, since each SPI device has a separate digital enable/disable line, and so it should be indifferent to any bus activity when its attention line is disabled. Once I used the 125 kHz bus rate for the Cypress board and the 4 MHz rate for the ST7735 display, the full range of sensitivity for RSSI appeared.

Along the way I spent a lot of time reading the Cypress board data sheet and application notes, and made some minor changes to the initialization sequence and RSSI-read sequence. Since the setup and teardown times for the RSSI add up when done repeatedly, I wrote a new `RSSI_peak()` function that follows the data sheet recommendations and reads the RSSI multiple times, finding the peak value. Using the peak produced a better display for both spectrum and waterfall.

Connections

The CYWUSB6935 IC itself a 48-pin QFP-packaged 2.4-GHz DSSS (*direct sequence spread spectrum*) combined radio and modem. The Cypress

CYWM6935 Wireless USB Radio Module is a small PC board that includes the CYWUSB6935 IC, antenna, external components, and a 12-pin header. The price seems to fluctuate between \$10 and \$25 per module, perhaps because the device has been replaced by more advanced RF modems and stocks are low.

The first problem I faced was the slightly unusual connector. It is a dual-row 2x6 male header, but the spacing is not the usual 0.1 inch center-to-center. Instead it uses slightly smaller 2 mm (0.075 inch) spacing. I first tried using female jumper cables (see the *Dozen* project), but I found that I could not fit all the required connections on the header because the connectors were too big. A quick trip to HSC/Halted Electronics Supply in Sunnyvale, California, provided a mostly compatible female connector for \$0.45, though I had to press quite hard with needle-nosed pliers to assure a good connection. I then tack-soldered male jumper leads to the header, so that I could make a quick attachment to a solderless breadboard and the Arduino headers.

It is always a good plan to start with a chart of Arduino pin usage, and the chart below uses the old names because those are the ones you will find in the documentation for the Cypress chips. Note that for SPI on the Arduino, you must leave the SPI_SS pin as an output, even if you do not use pin 10 in your design. The SPI library does this for you, but you should be aware of its important role in SPI and not use it for any purpose other than SS for one of the devices.

<i>Pin</i>	<i>Name</i>	<i>Use</i>
13	SPI SCLK	SPI Clock
12	SPI MISO	Data from devices to Arduino
11	SPI MOSI	Data from Arduino to devices
10	SPI SS	set to output
6	RADIO SS	
5	RADIO RESET	
1	TX	Serial Port
0	RX	Serial Port

Here are the pins used on the Cypress 12-pin connector, from the Cypress data sheet. Note that $V_{CC} = \text{logic} = 3.3 \text{ V}$.

<i>Name:</i>	GND	VCC	IRQ	RESET	MOSI	SS	SCK	MISO	GND	PD
<i>Pin:</i>	1	2	3	4	5	6	7	8	9	10
<i>Arduino:</i>	GND	3.3V	NC	D5	D11	D6	D13	D12	GND	PULLUP

As others have done, I tied the PD connection to 3.3 V through a $4.7 \text{ k}\Omega$ resistor directly on the Cypress board connector, since we do not need to enter POWER DOWN mode on the device.

Voltage Conversion

The Cypress device is specified for 3.3 V nominal V_{CC} and data, and most Arduino boards use 5 V. I followed a recommendation from the *This Old Geek* blog to use the Seeeduino, which has a 3.3 V/5 V logic switch on it. Another

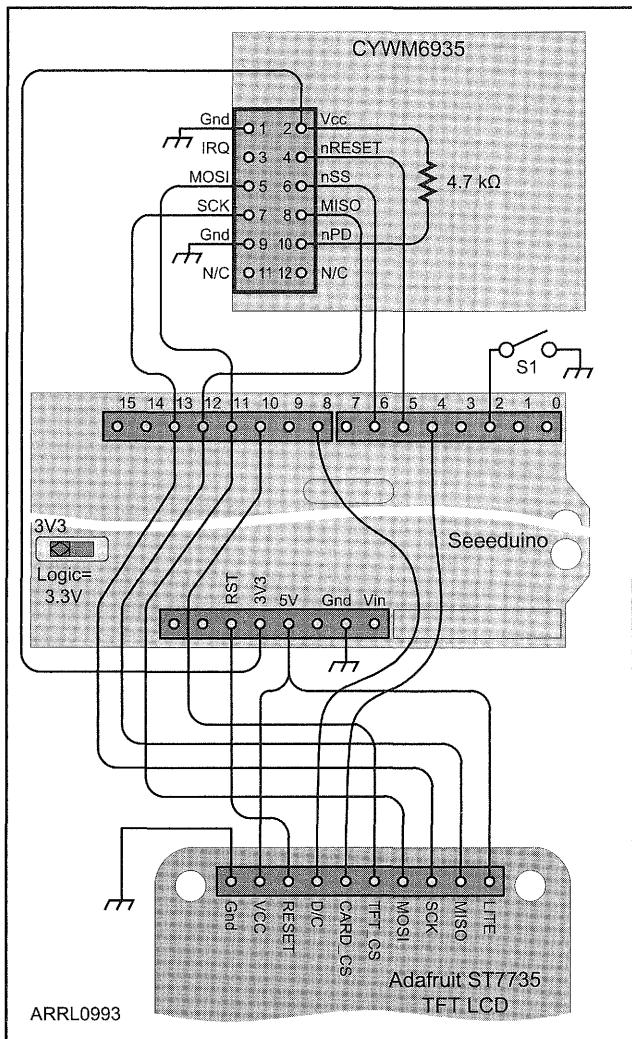


Figure 19.1 — Schematic showing the interconnections of the Seeeduino, Cypress CYWM6935, and Adafruit ST7735 LCD. The pinouts described are the main connections used. Be sure to set the Seeeduino to the 3.3 V logic setting. Route 5 V from the Seeeduino to the LCD backlight and to the LCD V_{cc} .

back to the version on the *github* site with the command-line tool. In addition to the RSSI changes, I added my bare-bones test code in an `examples` directory and renamed my fork from `ArduinoSpectrumAnalyzer` to `CYWM6935`. This set of commands completed publication of a standalone CYWM6935 library derived from the original sketch. In choosing *github* for hosting his code and selecting an open-source license, the sketch author encouraged others to make derivatives of his code.

Here is the `CypressTest` example, based on code written by Miguel A. Vallejo, Jason Hecke and Richard Ulrich. As with the sketches that I derived it from, it is licensed under GPL 3.0. You will find a copy of this code at the book's website (see References).

option would have been to use a logic-level converter; suitable boards and devices in both SMT and DIP packages are available from SparkFun and Adafruit. I found (accidentally) that the Cypress device was not destroyed by a brief application of 5 V, but it did not receive very well until I reset the Seeeduino to 3.3 V.

Figure 19.1 shows the connections for the Cypress board, Seeeduino and LCD.

Published Library

Once I had the basics working, I began the process of publishing a library dedicated to the CYWM6935. On the *github* website, I pressed the `fork` button to make a copy (licensed under GPL) of the `ulrichard` sketch for `ArduinoSpectrumAnalyzer`. I used the `git` command-line program to retrieve a read-write copy. Then I removed all files except the two CYWM6935 files and folded in my changes one at a time. Once done, I pushed the changes back to the version on the *github* site with the command-line tool.

```
#include <CYWM6935.h>
#include <SPI.h>

#define RADIO_RESET 5
#define RADIO_SS 6
#define SPI_SS 10

#define CLOCK_RADIO SPI_CLOCK_DIV64

// From 2400 to 2500 MHz
#define NBINS 100

CYWM6935 radio(RADIO_RESET, RADIO_SS);

void setup() {
    Serial.begin(57600);
    pinMode(SPI_SS, OUTPUT);

    SPI.begin();
    SPI.setClockDivider(CLOCK_RADIO);
    // Send most significant bit first when transferring a byte.
    SPI.setBitOrder(MSBFIRST);
    // Base value of clock is 0, data is captured on clock's rising edge.
    SPI.setDataMode(SPI_MODE0);

    radio.init();
}

void loop() {
    for (byte i=0; i<NBINS; i++) {
        byte n = radio.RSSI_peak(i, 2);
        if (n != 0) {
            Serial.print(i);
            Serial.print(" ");
            Serial.println(n);
        }
    }
}
```

Display Code for Spectrum

Once I had the SPI data connection working reliably, I went back to the display code. First I worked on a spectrum display that shows individual signals and their relative strengths (**Figure 19.2**). I started with the *Cascata* code I wrote for the SparkFun Nokia color LCD, but simplified and adapted it for the Adafruit ST7735 1.8-inch TFT display. The TFT initialization code is the same as in the *Marinus APRS* display project, and is present in the sketch you can download as well, so I will not cover it here.

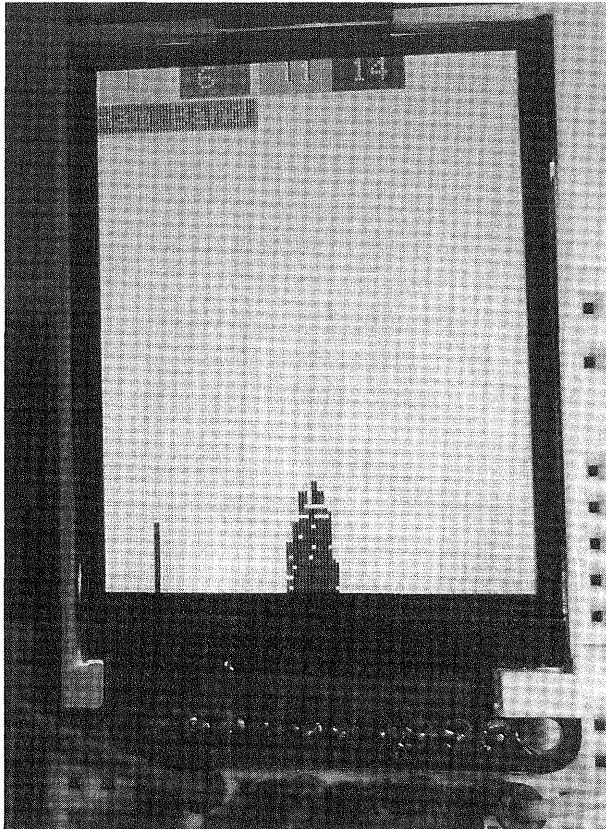


Figure 19.2 — Spectrum plot of 2.4 GHz signals using the Cypress project hardware. [Leigh Klotz, WA5ZNU, photo]

Here is the updated the pin usage, with the LCD and its attached SD card reader (unused in this project):

<i>Pin</i>	<i>Name</i>	<i>Use</i>
13	SPI SCLK	SPI Clock
12	SPI MISO	Data from devices to Arduino
11	SPI MOSI	Data from Arduino to devices
10	SPI SS	TFT CS
8	TFT_DC	TFT DC
4		SD CARD CS

Here are the Adafruit ST7735 LCD pins, read left to right on the top of the breakout board:

ST7735	Gnd	VCC	Reset	D/C	Card_CS	TFT_CS	MOSI	SCK	MISO	LITE
Arduino	GND	5V	RESET	D8	D4	D10	D11	D13	D12	5V

Using 5 V for the backlight makes the display bright. The breakout board has a 3.3 V LDO (low-dropout regulator), so it can use either 5 V or 3.3 V for the V_{CC} connection. Due to the constraints of the Cypress board, you must use 3.3 V for the logic pins.

With the new pin assignments and wiring out of the way, I changed the

`loop` in my test code above to call just the new `spectrum()` function.

The `static` declaration saves a few bytes in the sketch by making the function unavailable to the Arduino libraries to call; you can safely put this on most of your functions, except for `loop` and `setup`. There are two items to note in this code.

The `spectrum` function loops through the 1-MHz-wide radio channels one at a time, and calls the library function `RSSI_peak` on each to get a peak value of 10 samples on frequency, and draws a vertical line from the bottom of the LCD to the point representing that signal strength. I used `n *= 3` to multiply the signal reading by 3, giving three pixels per signal unit. That makes a maximum height of 93, leaving comfortable room for a legend at the top of the 160-pixel LCD.

The calls to `SPI.setClockDivider` bracket the `RSSI` and assure that the SPI bus speed is slowed for talking to the radio, as described above. The `buffer` variable stores the samples from the previous run and optimizes the time required to draw vertical bars. The naïve approach of clearing the screen (or clearing the bar area) and redrawing works, but it unnecessarily slows the spectrum display rate, so this optimization allows `spectrum` to either lengthen or shorten each bar, depending on what the value was the last time, saving time in the calls to the display drawing.

The `#define INV` line is a *macro*, which you have seen before used to define constants, but can also define quick function-like substitutions. Here I use it to make it easy to convert between coordinate systems: I wanted smaller RSSI numbers at the bottom of the screen, growing upward, but the actual positions of pixels on the LCD itself start at top the, and larger numbers grow downward, so `INV` inverts the Y dimensions of the screen display. I could also have used the `tft.setRotation` function, but that would turn the entire display upside down, and I wanted to put legend text at the top.

```
#define NBINS 100
#define SPECTRUM_SAMPLES 10
byte buffer[NBINS];
#define INV(x) (LCD_HEIGHT-x)

static inline void spectrum() {
    for(byte i=0; i<NBINS; i++) {
        SPI.setClockDivider(CLOCK_RADIO);
        byte n = radio.RSSI_peak(i, SPECTRUM_SAMPLES);
        SPI.setClockDivider(CLOCK_TFT);

        n *= 3;
        byte old = buffer[i];
        if (n == old) {
            // no change, so draw nothing
        } else if (n > old) {
            // longer line, so draw in red from old to n
            tft.drawLine(i, INV(old), i, INV(n), ST7735_RED);
        } else if (n < old) {
```

```

        // shorter line, so draw in white from n+1 to old
        tft.drawLine(i, INV(n+1), i, INV(old), ST7735_WHITE);
    }
    buffer[i] = n;
}
}

```

Display Code for Waterfall

With the spectrum display now working on the color TFT LCD, I added a waterfall display as shown in **Figure 19.3**. The waterfall proceeds by row, and instead of CPU-intensive scrolling as on laptop and desktop displays, I used the simplification from *Cascata* and have the display wrap from bottom to top. The ST7735 library defines constants for many bold colors, such as ST7735_RED and ST7735_MAGENTA, but I wanted 32 colors for the 32 different levels, so I wrote a palette routine and placed it in the `palette.ino` file, to keep the sketch organized. The ST7735 has several color modes, but the one used by default with the library is RGB 565 mode, where red and blue have 5 bits (or 32 values) and green has 6 bits (or 64 values). The sum 5+6+5 is 16, which works out nicely to an Arduino `int` of two bytes, and our eyes are most sensitive to green, so giving it the odd extra bit makes sense.

The act of packing together 5, 6, and 5 bits into a two-byte word is technically called *bit twiddling* and is something that programmers either love or hate. I happen to be in the latter category, so I was pleased to discover that the library contains a `tft.Color565(red, green, blue)` routine that does the work for me. The low values are blue, mid values green, and the high values are red. Each color starts at 128 (50% brightness) and moves to roughly 100% brightness in uniform steps. (You may want to experiment with other palettes, for example by reading the `fldigi` source code and looking at `colorbox.cxx` and `digipan.pal`.)

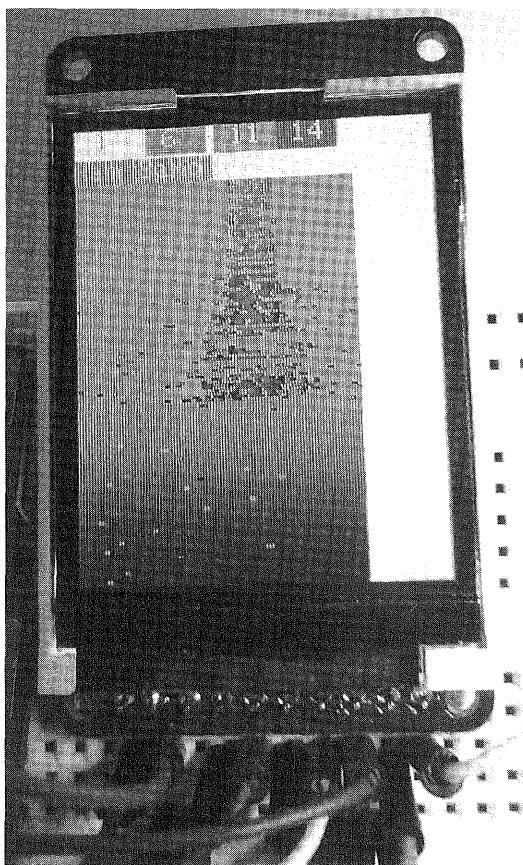


Figure 19.3 — Waterfall plot of 2.4 GHz signals using the Cypress project hardware. [Leigh Klotz, WA5ZNU, photo]

Here is the sketch file palette.ino, which sets up the 32-word palette in 64 bytes of SRAM:

```
static void setupPalette() {
    byte i = 0;
    // low values are blue
    {
        byte n = 128;
        for (; i < 12; i++) {
            palette[i] = tft.Color565(0, 0, n);
            n += 10;
        }
    }
    // mid values are green
    {
        byte n = 128;
        for (; i < 22; i++) {
            palette[i] = tft.Color565(0, n, 0);
            n += 12;
        }
    }
    // high values are red
    {
        byte n = 128;
        for (; i < 32; i++) {
            palette[i] = tft.Color565(n, 0, 0);
            n += 12;
        }
    }
}
```

To use the waterfall function, change `loop()` to call `waterfall()` instead of `spectrum()`, and add the function definition. The main technique is the use of `tft.setAddrWindow` and `tft.pushColor`. I used similar optimizations in with the Nokia color LCD *Cascata*, and here the pair of functions does the same thing. The first sets a rectangular area of pixels, which in this case is one row long (represented curiously by 0) and the second sends successive pixels out over the SPI bus. Further optimization is possible, but doing it this way rather than using `tft.setPixel` saves enough time that the cost of doing the 10 or 20 RSSI_peak samples at the 125 kHz bus speed with 50 µs delays begins to dominate, and so going further makes the code harder to read and yet gives diminishing returns.

```
#define WATERFALL_SAMPLES 10
#define WATERFALL_TOP 20
int row = WATERFALL_TOP;
int palette[32];
```

```

static inline void waterfall() {
    SPI.setClockDivider(CLOCK_RADIO);
    for(byte i=0; i<NBINS; i++) {
        byte n = radio.RSSI_peak(i, WATERFALL_SAMPLES);
        buffer[i] = n;
    }

    SPI.setClockDivider(CLOCK_TFT);
    tft.setAddrWindow(0, row, NBINS-1, 0);
    for (byte i=0; i<NBINS; i++) {
        tft.pushColor(palette[buffer[i]]);
    }
    if (++row == LCD_HEIGHT)
        row = WATERFALL_TOP;
}

```

If you don't want to keep editing your sketch to change displays, you can use a button to flip between spectrum and waterfall modes. In *Cascata*, the display shield includes a button, and the Adafruit 1.8-inch LCD shield also includes a button. I used the ST7735 breakout board instead of the shield version for this project because it was inconvenient to attach the 2-mm-spaced Cypress connector to a shield, and I built this project on a solderless breadboard. For simplicity, I used a single jumper wire from Arduino pin D2 to the 3.3 V bus or ground to toggle between waterfall and spectrum modes. The sketch enables the internal pullup resistor on pin D2, so you can just use an SPST switch. If you use a switch, connect it between pin D2 and ground.

Here is the new pin usage:

<i>Pin</i>	<i>Name</i>	<i>Use</i>
2	mode	Spectrum or Waterfall Mode

To enable the internal pullup resistor on the mode pin, I used `INPUT_PULLUP` pin mode, instead of the old method of setting the pin to `INPUT` and then calling `digitalWrite(MODE_PIN, HIGH)`. The old method still works, and in fact internally `INPUT_PULLUP` does that, but the new way is easier to read and is supported in Arduino 1.0.1 and later.

```

#define MODE_PIN 2
void setup() {
    ...
    pinMode(MODE_PIN, INPUT_PULLUP);
    ...
}

```

Here is the final `loop()` function:

```

void loop() {
    if (digitalRead(MODE_PIN) != mode) {
        tft.fillRect(0, WATERFALL_TOP, LCD_WIDTH,
                    LCD_HEIGHT-WATERFALL_TOP, ST7735_WHITE);

```

```
    row = WATERFALL_TOP;
    mode = !mode;
}
if (mode)
    spectrum();
else
    waterfall();
}
```

The file legend.ino completes the sketch.

```
#define ORIGIN_MHZ 2400
#define HAM_BAND_WIDTH (2450-ORIGIN_MHZ)
#define WLAN1 (2412)
#define WLAN6 (2437)
#define WLAN11 (2462)
#define WLAN14 (2484)
#define WLAN_WIDTH (22)

#define CHANNEL_LEGEND_HEIGHT 11

static void drawLegend() {
    tft.setTextColor(ST7735_YELLOW);
    drawChannel(1, WLAN1-ORIGIN_MHZ, ST7735_MAGENTA);
    drawChannel(6, WLAN6-ORIGIN_MHZ, ST7735_RED);
    drawChannel(11, WLAN11-ORIGIN_MHZ, ST7735_BLUE);
    drawChannel(14, WLAN14-ORIGIN_MHZ, ST7735_BLACK);
    drawHamBand();
}

static void drawHamBand() {
    // can't draw 2300-2310 or 2390-2400 as it's outside of range.
    tft.fillRect(ORIGIN_MHZ-2400, CHANNEL_LEGEND_HEIGHT,
                HAM_BAND_WIDTH, WATERFALL_TOP-CHANNEL_LEGEND_HEIGHT,
                ST7735_GREEN);
    tft.setCursor(ORIGIN_MHZ-2400, CHANNEL_LEGEND_HEIGHT);
    tft.print(F("Ham Band"));
}

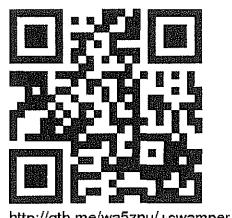
static void drawChannel(byte n, int x_center, int color) {
    tft.fillRect(x_center-WLAN_WIDTH/2, 0, WLAN_WIDTH, 10, color);
    tft.setCursor(x_center-5, 0);
    tft.print(n);
}
```

Summary and Further Directions

The complete sketch and libraries are available for download at the book resources website.

I had a lot of fun with this project, and I learned more about the SPI bus and about the various RF model devices available. While the Cypress CYWM6935 is capable of sending and receiving data, the board is obsolescent, so you might want to switch to a newer device for an extensive data project. Here is a selection of devices to consider for RF-based communications projects:

- *Microchip MRF24J40MB*. The MRF24J40MB supports standard 802.15.4 networking. You can read more about it in the references.
- *Nordic Semi nRF24L01*. The nRF24L01 has its own “ShockBurst” mode, and I was not able to find out exactly what the modulation is. It has an RSSI indicator, but it is only a single bit, so it is not appropriate for a waterfall display, but it may be a better device for communications projects. You can buy useful modules with SMA antenna connectors from SparkFun, or find modules with on-PCB patch antennas for very low prices on eBay.
- *JEE Labs*. JEE Labs makes a line of Arduino-compatible devices with 433 MHz or 900 MHz radio modems built in. If your goal is data communications, you might try their US reseller Modern Devices and experiment with our ham allocations on these bands.



References and Further Reading

- Online references
<http://qth.me/wa5znu/+swamper>
- Source code for this project
<http://qth.me/wa5znu/+swamper/code>

802.11 RF Hacking

- Andy Clapp Pringles Yagi
<http://www.netscum.com/~clapp/wireless.html>
- Seattle Wireless antennas
<http://www.seattlewireless.net/PringlesCantenna>
- Rob Flickenger antenna
<http://www.oreillynet.com/cs/weblog/view/wlg/448>
- MetaGeek WiSpi
<http://www.metageek.net/products/chalyzer-4/>
- US FCC Part 97 (Amateur Radio) regulations
<http://www.arrl.org/part-97-amateur-radio>
- Amateur Radio allocations and Part 15 bands
<http://www.qsl.net/kb9mwr/projects/wireless/allocations.html>

Projects

- This Old Geek
<http://thisoldgeek.blogspot.com/2010/12/24ghz-wifi-arduino-spectrum-analyzer.html>
<http://thisoldgeek.posterous.com/>
- Richard Ulrich Arduino spectrum analyzer
<http://blog.ulrichard.ch/?p=39>
<https://github.com/ulrichard/ArduinoSpectrumAnalyzer>

- Miguel Vallejo, EA4EOZ, spectrum analyzer
<http://ea4eoz.ure.es/hsa.html>
- WiFi spectrum analyzer
<http://arduino.cc/forum/index.php/topic,67218.0.html>
- Simple AVR wireless communication using Cypress Wireless USB modules
<http://larsenglund.blogspot.com/2007/04/simple-avr-wireless-communication-using.html>
<https://code.google.com/p/cywusb/>
- AVR Forum — Experiences with CYWM6935 as spectrum analyzer
<http://www.avrfreaks.net/index.php?name=PNphpBB2&file=printview&t=78540&start=0>
- Spectrum analyser 2p4Ghz
http://www.piemontewireless.net/Spectrum_Analyser_2p4Ghz
- fldigi Palette
<http://www.w1hkj.com/Fldigi.html>

Other Devices

- “Some IEEE 802.15.4 Transceiver Magic,” *Nuts and Volts* June 2012, Fred Eady
<http://nutsvolts.texterity.com/nutsvolts/201206/?pg=69>
- nRF24L01+ Module with Chip Antenna
<http://www.sparkfun.com/products/691>
- Jee Labs
<http://jeelabs.com/products/jeenode>
<http://shop.moderndevice.com/collections/jeelabs>

Parts and Tutorials

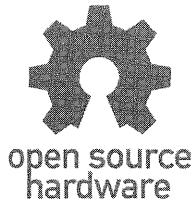
- CYWM6935 SPI 802.11 transceiver data sheet
<http://www.cypress.com/?docID=24401>
- Jameco Electronics (search for CYWM6935)
<http://www.jameco.com>
- Mouser Electronics (search for CYWM6935)
<http://www.mouser.com>
- Halted (HSC Electronics Supply)
<http://www.halted.com/>
- Arduino SPI library
<http://arduino.cc/en/Reference/SPI>
- Adafruit 1.8-inch 18-bit Color TFT Breakout Board w/microSD
<http://www.adafruit.com/products/358>
- Adafruit TFT shield tutorial
<http://learn.adafruit.com/1-8-tft-display>
- Adafruit graphics tutorial
<http://learn.adafruit.com/adafruit-gfx-graphics-library>
- Adafruit ST7735 LCD library
<https://github.com/adafruit/Adafruit-ST7735-Library>

- SPI
http://en.wikipedia.org/wiki/Serial_Peripheral_Interface_Bus
- 74HC595 shift register to add output pins
<http://bildr.org/2011/08/74hc595-breakout-arduino/>

Git Open-Source Operations

- Forking a repository
<https://help.github.com/articles/fork-a-repo>
- WA5ZNU CYWUSB6935 library
<https://github.com/wa5znu/CYWM6935>

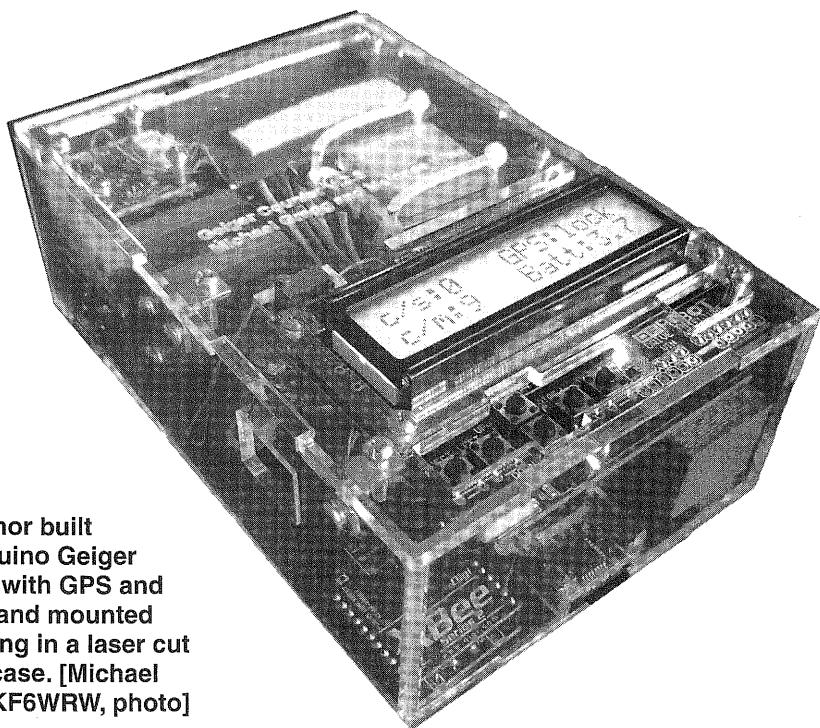
License



- This sketch and library are released under GPL 3.0
<http://www.opensource.org/licenses/gpl-3.0>
- The schematics in this project are licensed under the CC-BY-SA 3.0 license:
<http://creativecommons.org/licenses/by-sa/3.0/>

Laser Cut Project Case

Michael Gregg, KF6WRW



The author built this Arduino Geiger counter with GPS and display and mounted everything in a laser cut acrylic case. [Michael Gregg, KF6WRW, photo]

You might know me as *Jumper Two* from the Parachute Mobile activity that Mark Meltzer, AF6IM, and I organized, and which Michael Pechner, NE6RD, and others have supported with their Arduino projects such as the *Timber APRS* data logger described earlier in this book. I also do my own Arduino projects, one of which I showed at the 2012 San Francisco Bay Area Maker Faire.

The idea for my project began to take shape when I saw SparkFun selling a Geiger counter and decided to make an APRS-enabled Geiger counter. I ordered a collection of parts from SparkFun, and while I could have put them together on the bench, I decided to build a case for them out of laser-cut acrylic sheet.

Since I already have experience using 3D modeling packages, I modeled rough designs of all of the parts in a professional package called *SolidWorks*. While *SolidWorks* is expensive, you can use it at a hackerspace or a nearby Make TechShop (as I did). Or you might try your hand at some of the high quality hobby software from Autodesk, such as *123D*. The model I produced is shown in **Figure A1.1**.

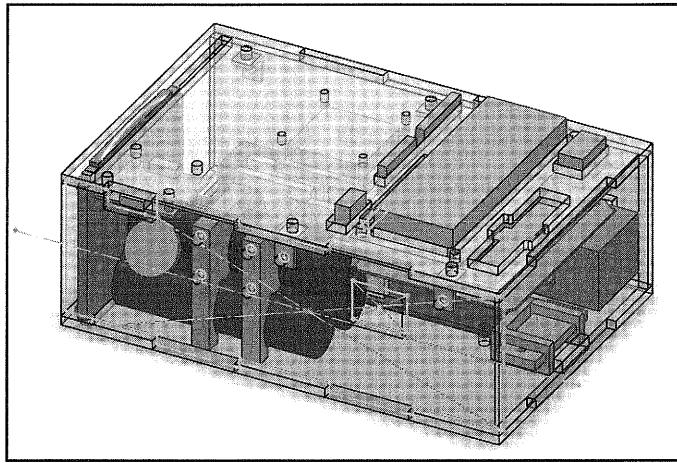


Figure A1.1 — This rendering of the Geiger counter case shows the placement of major components, and was produced with *SolidWorks* 3D CAD software. While *SolidWorks* is out of the price range of most hobbyists, it is available for group use at some “hackerspace” clubs, such as TechShop. Alternatively, you can use Autodesk hobby software such as *123D*. [Michael Gregg, KF6WRW]

Once at TechShop, I used a laser cutter to “print” the cuts into acrylic sheet, and then hand cemented the box to fit it together. The finished project is shown in the title page photo.

Timber Case

When Michael Pechner, NE6RD, finished his *Timber* data logger for our Parachute Mobile jumps, he asked me to design a case for it. I used the same tools and came up with the design shown in **Figure A1.2**.

You can read more about the hardware and software from my project at my website (see the References section).

I hope my experience inspires you to use 3D modeling and acrylic for housing your projects.

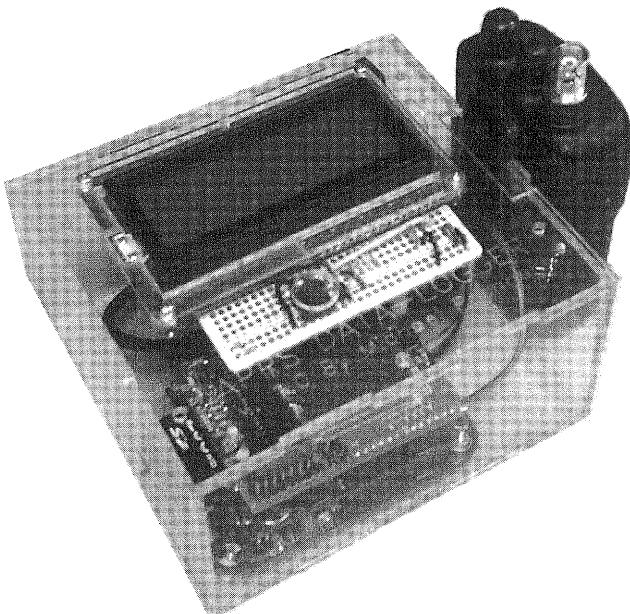


Figure A1.2 — This finished case for the project described in the *Timber* chapter encloses a data logger and was made using the same tools as the Geiger counter. It is easy to design a simple case that fits exactly.



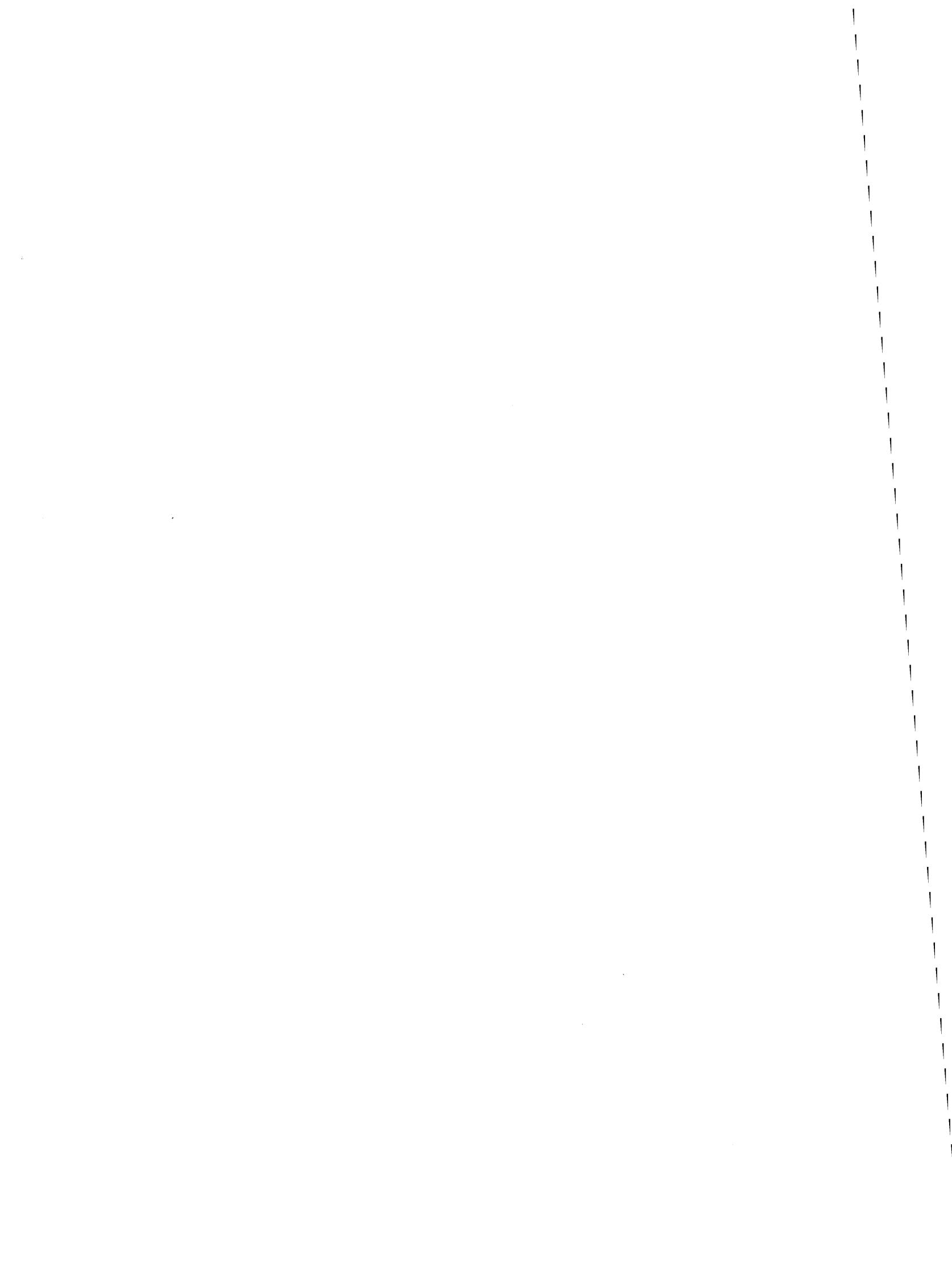
http://qth.me/kf6wrw/+counter

References

- Online references
<http://qth.me/kf6wrw/+counter>
- Parachute Mobile
<http://www.parachutemobile.org>
- SparkFun Geiger Counter
<http://www.sparkfun.com/products/11345>
- GPS Logging Geiger Counter finished project
http://wordpress.michaelgregg.com/?page_id=233
- Autodesk 123D
<http://www.123dapp.com>
- TechShop
<http://www.techshop.ws/>
- TechShop Laser Cutter
http://techshop.ws/take_classes.html?storeId=4&categoryId=10

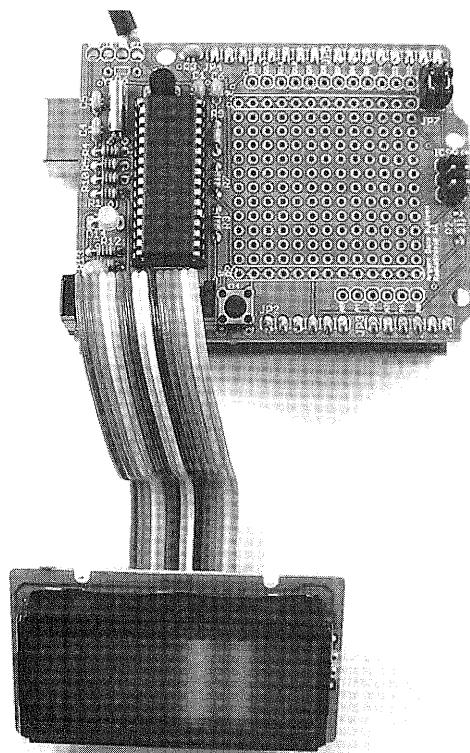
About the Author

Michael Gregg, KF6WRW, is a home experimenter and active Amateur Radio operator. His other hobbies include skydiving and 3D fabrication. See the author's other open hardware projects and products at <http://www.michaelgregg.com>.



LCD Shields

Leigh L. Klotz, Jr, WA5ZNU



Some projects benefit from adding a display for setup or operation. Options range from simple two line LCDs to TFT color displays similar to what you might see on a digital camera or mobile phone. The Argent Data Radio Shield, used in several projects in this book, offers a parallel connection for a 2-row, 16-column LCD. Use this display if you need a remote-mounted, inexpensive LCD for your Radio Shield. [Photo courtesy Scott Miller, N1VG, Argent Data Systems]

A number of projects in this book offer status reporting, require some setup, or feature user interaction. In the shack, the Arduino serial port is often enough for doing setup and debugging program operation, but in the field or on the go, nothing beats an integrated liquid crystal display (*LCD*).

LCD Shield Types

This appendix describes a number of LCD options, discusses their pros and cons, and provides libraries and sketch files for using LCDs in the projects described in this book and in your own projects. All photos of products are

courtesy of their manufacturers, and we thank DFRobot, SparkFun, Argent Data and Adafruit for allowing us to use them. You can find out more about them and see color photos by visiting the manufacturers' websites listed in the References section at the end of this Appendix.

Argent Data Radio Shield LCD

Some shields used in this book, such as the Argent Data Radio Shield, have provision for attaching an inexpensive parallel-connected 2-row, 16-column (“16x2”) LCD as shown in the title page photo. This route is inexpensive and may be the way to go if you mount your project in a case and want to remotely attach the LCD, but the 4800 baud limitation of the serial connection used may be troublesome. Or, you may want to add some buttons or other features and are looking for a convenient solution.

DFRobot Display

The DFRobot LCD Keypad shield (**Figure A2.1**) combines an LCD and a “D-pad” arrangement of up/down/left/right/select buttons (familiar to video game players) in a shield package at a rock bottom price. It’s a quick and easy way to add interactivity to any of your projects, and I have a few around the shack to use whenever I need a quick display.

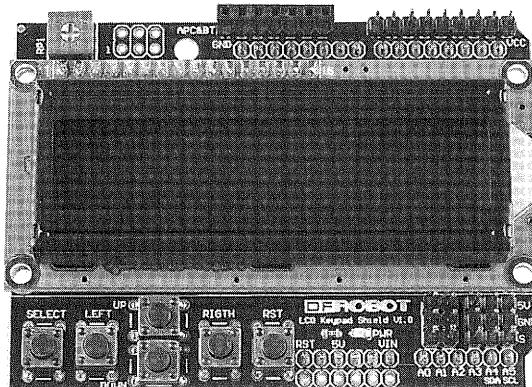


Figure A2.1 — The DFRobot LCDKeypad shield combines an LCD and a “D-pad” arrangement. It offers a quick and inexpensive way to add an interactive display to the top of your shield stack. [Photo courtesy DFRobot.com]

The DFRobot shield uses a resistor divider network and ADC line A0 to read the buttons, digital pins D4-D9 for display I/O, and dedicates pin D10 to the backlight PWM. If your project depends on using the ATmega328 CPU ADC for critical tasks, you may be troubled by the signal noise or delay introduced by the multiplexer switching from your project’s pin to the keypad pin. If you need to use an analog voltage reference AREF other than 5 V, you will have to modify the shield’s resistor voltage source connection. If these tradeoffs are not a problem for your project, the cost and wide availability of the DFRobot LCD Keypad shield make it a great choice for many projects.

Although it is possible to download character graphics into character displays to make bar charts, for full graphics you need to step up to an addressable-pixel LCD.

SparkFun Displays

SparkFun offers a tremendous variety of breakout board LCDs in both bitmapped and character formats, with too many to list here. If you are searching for just the right form factor for your finished project, take a look online and you are sure to find just what you need. Here are a couple of examples.

The SparkFun Color LCD shield (**Figure A2.2**) has a 128×128 pixel color display originally used for a Nokia mobile phone, and it offers the ability to draw graphics, text and images directly. Projects such as *Cascata* use it to display a waterfall, and the effect is great. It includes buttons that make a simple user interface a snap.

Another popular SparkFun product is a monochrome graphical LCD with 64×128 pixels (**Figure A2.3**). If you need a graphic display but do not need color, this product is a cost-effective and highly readable solution.

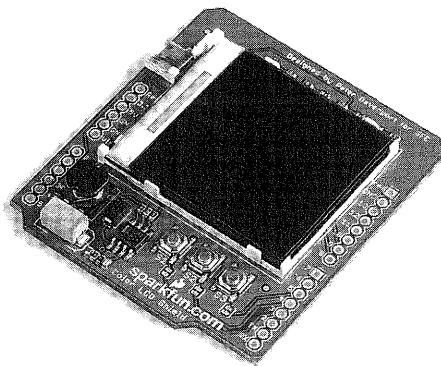


Figure A2.2 — The SparkFun Color LCD shield uses a 128×128 pixel color display originally used for a Nokia mobile phone, and it offers the ability to draw graphics, text and images directly. [Juan Peña, SparkFun, photo]

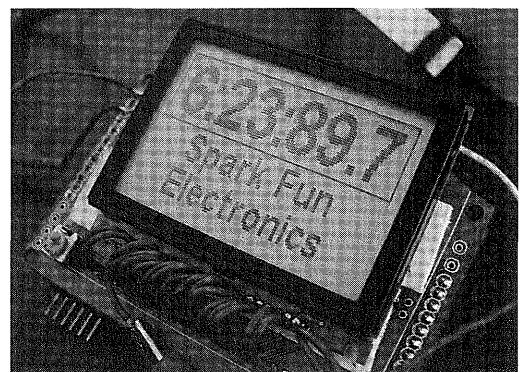


Figure A2.3 — SparkFun Monochrome Graphic LCD 128×64 STN LED Backlight. [Juan Peña, SparkFun, photo]

Adafruit Displays

The Adafruit RGBLCD shield (**Figure A2.4**) has a form factor similar to the DFRobot shield, with a similar button layout but with fewer restrictions on pin usage. The Adafruit product uses the TWI (I2C compatible) protocol and dedicates two Arduino pins to the TWI interface. You don't lose use of those pins either, since TWI is a multi-device bus, so other compatible devices can share the pins. Additionally, the RGBLCD shield has a seven color backlight, so you can give status information such as RED for error and GREEN for go to clarify the on-screen 16×2 messages.

If you need to remotely mount an LCD display, but don't want to use a lot of pins, consider a serial product from SparkFun or the Adafruit LCD Backpack (**Figure A2.5**), which uses either the SPI or TWI bus standard to connect a parallel LCD of your own choice.

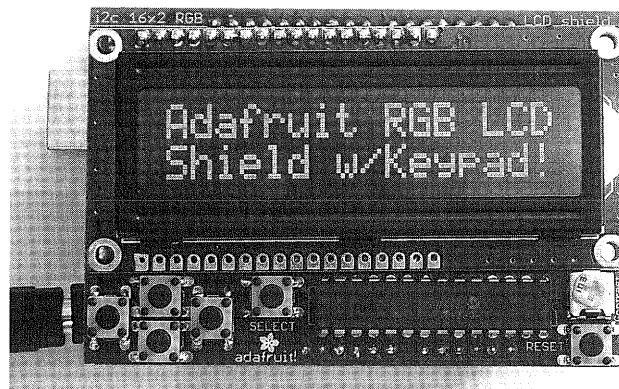


Figure A2.4 — The Adafruit RGBLCD uses a two-wire interface and offers a seven-color backlight for status indication. Its low price makes it a contender for any project using character graphics and buttons. [Photo courtesy Adafruit]

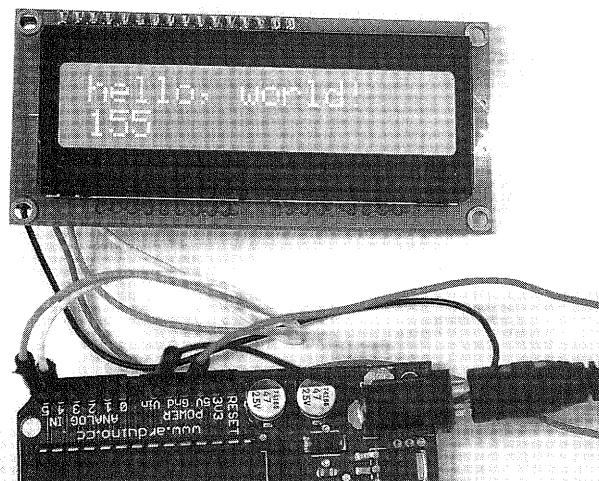


Figure A2.5 — The Adafruit I2C/TWI LCD Backpack lets you mount your own parallel LCD display remotely using only a small number of connections and Arduino pins. [Photo courtesy Adafruit]

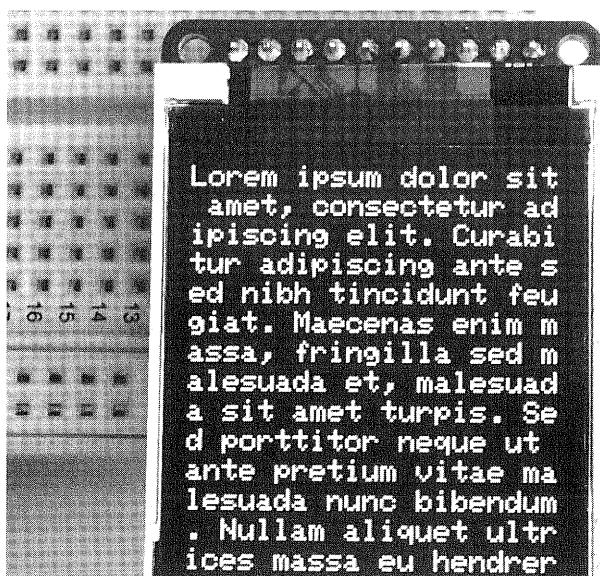


Figure A2.6 — The Adafruit 1.8-inch TFT is a step up in size and image quality, and it offers 24-bit color and an onboard microSD card reader. It can display photos and maps, and not just text. [Photo courtesy Adafruit]

A step up in size and image is the Adafruit 1.8-inch TFT display, which sports 24-bit color and a microSD card (**Figure A2.6**). The card is a great addition, because you may be using this “giant” display for images, which could be stored on the card. The breakout board connection is fairly simple, and this product works well for applications such as the APRS Mapper. It has no buttons, so it is a good choice if you want to mount the display and buttons in a case. For experimenting in the shack, the same display comes in shield format with a D-pad joystick using the resistor-divider input on pin A3, though you can change the pin by cutting a trace.

If you want a smaller display, a number of OLED (*organic LED*) displays are available and fairly easy to use. They can provide a precise display of a small amount of information. Adafruit offers monochrome and color OLEDs about the size of a key on your home computer keyboard, for very attractive prices. Using one of these, a Bluetooth board, and a small Arduino compatible, maybe you can build a Dick Tracy wristwatch APRS communicator, or a DX spotter alert clip that you can place next to your rig. **Figure A2.7** shows an Adafruit OLED and breakout board. SparkFun also sells a range of these OLED displays. For a non-ham watch project using them, see the Instructables article *Arduino Watch* listed in the references.

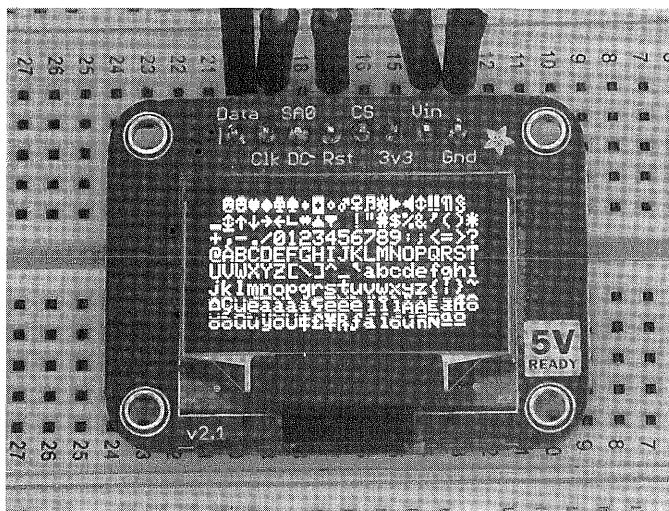


Figure A2.7 — The Adafruit line of monochrome OLED displays is compact and easy to use. [Photo courtesy Adafruit]

Libraries and Sketches

A few common libraries and sketches used throughout this book are collected together in this chapter, and are available from the resources website (see the References section).

These files go into your sketch directory to let you use one of a variety of LCDs in your project without having to edit your main sketch. The projects that use these files will tell you which are necessary.

This file is used by all the LCD tools:

- `LCD.h`

This file is used by projects using the RGB LCD, to define constants for the colors:

- `colors.h`

Pick one of these three files, depending on which LCD you use:

- `ArgentLCD.ino`

- `DFRobotLCD.ino`

- `RGBLCD.ino`

These files go into your sketch directory to add multiline wrapping and date printing facilities for projects that use those facilities. You can also edit `LineWrap.h` to control whether lines wrap or are truncated at one screenful, and if the screen scrolls, how long the delay between screens is.

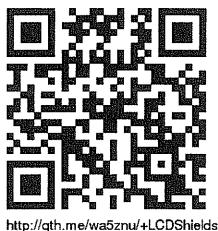
- `LineWrap.h`

- `PrintDate.ino`

Other Libraries

Libraries for the Adafruit displays are available from the Adafruit site. The DFRobot LCDButtonShield libraries are in a few places on the web, but this version includes enhancements and simplifications used in sketches in this book.

- `LCDKeypad.zip`



References

- References for this project:
<http://qth.me/wa5znu/+LCDShields>
- Source code for sketch files and LCDKeypad Library:
<http://qth.me/wa5znu/+LCDShields/code>
- ArgentRadioShield Library:
<http://qth.me/wa5znu/+ArgentRadioShield/ArgentRadioShield.zip>
- SparkFun Color LCD Shield
<http://www.sparkfun.com/products/9363>
- SparkFun LCD Character Breakout Boards
<http://www.sparkfun.com/categories/148>
- SparkFun Color LCD Breakout Boards
<http://www.sparkfun.com/categories/147/>
- SparkFun Monochrome LCD 128x64
<http://www.sparkfun.com/products/710>
- Adafruit LCD Backpack
<http://www.adafruit.com/products/292>
- Adafruit 1.8 inch TFT display+microSD
<http://www.adafruit.com/products/358>
- Adafruit 1.8 inch TFT display+microSD Shield
<http://www.adafruit.com/products/802>

- Adafruit color and monochrome OLEDs
https://www.adafruit.com/category/63_98
- DFRobot TWI/I2C Display
http://www.dfrobot.com/index.php?route=product/product&product_id=135
- DFRobot LCDKeypad Shield
http://www.dfrobot.com/index.php?route=product/product&product_id=51
- Adafruit RGBLCD Shield
<http://www.adafruit.com/products/714>
- Instructables Arduino Watch
<http://www.instructables.com/id/Arduino-Watch-Build-Instructions/>

Argent Radio Shield Library

Leigh L. Klotz, Jr, WA5ZNU

The Argent Data Systems Radio Shield used in a number of projects in this book was developed by Scott Miller, N1VG, and offers an easy route to using APRS and packet data with the Arduino. It attaches to the serial port of the Arduino and communicates at 4800 baud, and it offers AX.25 unproto packet TX and RX. It features a 2x8 pin header for cabled attachment of a parallel HD44780-compatible LCD and lets you operate the LCD by `Serial.print` commands from the Arduino.

Instead of using a dedicated modem chip, the shield uses a Freescale HC908JL16 CPU. To control it, you send commands over the serial port. Each command is a single line, starting with a one-letter command character. The Radio Shield Wiki (see the References section at the end of this Appendix) has the latest documentation on the command characters and is kept current when new firmware is released for the onboard CPU.

For example, to instruct the shield to send a packet, you print a line beginning with ! and ending with CR/LF, like this:

```
Serial.println("!>APOTW1:!3725.74N/12206.91W\r");
```

Before sending the packet, though, you need to configure your call sign and the sending path, using the M and P commands. Additionally, note that commands that cause the Radio Shield to transmit require either an explicit delay call after the call to `Serial.print`, or you must account for the delay in other parts of your program logic; although the `print` command returns immediately, the shield will still be busy sending data.

The Radio Shield Wiki includes full Arduino sketches for sending packets, receiving packets, and using the optional attached LCD.

The Library

The ArgentRadioShield Arduino library provides more abstract access to the Radio Shield functionality. With this library, you can write code that expresses your intent, using functions with names such as `sendPacket` or `setCall` rather than directly writing the cryptic single-character commands in your sketch. Additionally, the ArgentRadioShield library implements LCD

methods such as `setCursor` and `print` so that you can use it with the sketch and library code in the *LCD Shields* appendix. Write your sketch once and the surrounding files to switch from the ArgentRadioShield parallel LCD to a different model LCD.

```
#include <Arduino.h>
#include <ArgentRadioShield.h>

// Use Hardware Serial for ArgentRadioShield.
ArgentRadioShield argentRadioShield = ArgentRadioShield(&Serial);

void setup() {
    Serial.begin(4800);
    argentRadioShield.setCall("W1AW");
}
```

Installing the Library

Download the library from the online references and unzip it into your Arduino *sketchbook* directory under a directory called `libraries`. The location of your *sketchbook* directory will vary depending on the operating system of your desktop computer; for example, on *Linux*, it is in the `~/sketchbook` directory. For more information, see the Lady Ada tutorial on installing Arduino libraries.

Using the SoftwareSerial Library

The shield uses the hardware serial port of the Arduino (pins D0 and D1), so you need to remove the shield or otherwise disconnect it electrically before

uploading a new sketch to your Arduino. The shield includes a pair of shorting-bar jumpers labeled JP7 (**Figure A3.1**) to make this task easier. They're inaccessible if there is another shield (such as an LCD) stacked atop the Radio Shield, and it's inconvenient to share the serial port if you have another use for it in your sketch.

Arduino 1.0 and later feature

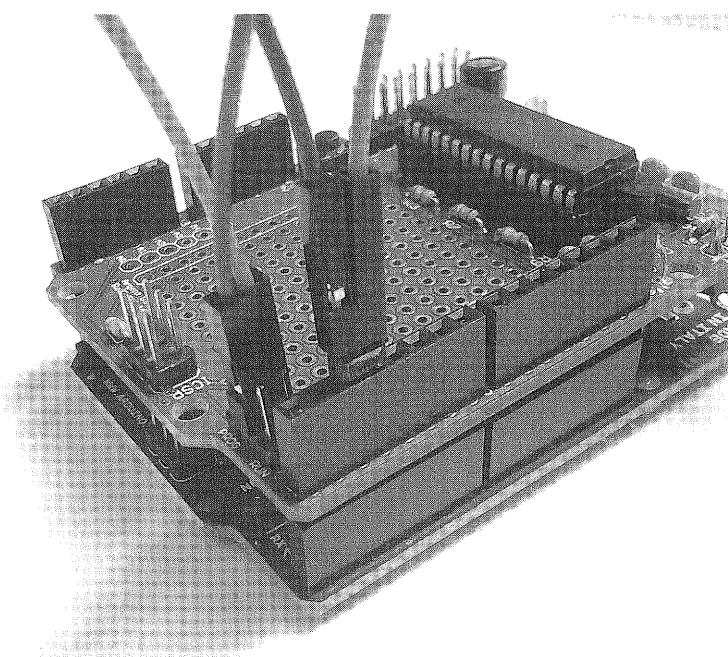


Figure A3.1 —The Radio Shield includes a pair of shorting bar jumpers labeled JP7, to connect the Arduino D0/D1 serial pair to the Radio Shield. To communicate with the Radio Shield using SoftwareSerial, jumper the middle pair of male pins on JP7 to the Arduino pins of your choice. [Leigh Klotz, WA5ZNU, photo]

a system library called `SoftwareSerial` that allows the sketch author to use just about any pair of pins as a serial port. (In earlier versions of the Arduino IDE, this package was downloadable and called `NewSoftSerial`. That library is no longer used with Arduino 1.0 and later.)

To test rerouting the Freescale CPU serial pins to different pins on the Arduino, remove the shorting jumpers in PROG position and connect the center pair of male headers to the Arduino pins you want to use for Radio Shield I/O. For example, connect the right pin to D2 and the left pin to D3. For a test, you can use female-to-male jumper cables, available from many of the suppliers mentioned in this book or from auction sites such as eBay, or you can use female-to-female jumpers and a single pin extracted from a male header. (I always seem to break off one too many or too few, so I have a number of one-pin male headers around the shack.) If you decide to make this change on a more permanent basis, you can tack-solder a pair of wires from JP7 on the underside of board to the shield breakout pins. When choosing pins to use for software serial communication with the Radio Shield, check the other shields you plan to use with the Arduino Shield Pin List at ShieldList.org (see the references).

To use `SoftwareSerial` with the `ArgentRadioShield` library, change your sketch like this:

```
#include <Arduino.h>
#include <ArgentRadioShield.h>
#include <SoftwareSerial.h>

// Use Software Serial for ArgentRadioShield
// RX is D2 (RadioShield TX)
// TX is D3 (RadioShield RX)
SoftwareSerial rSerial = SoftwareSerial(2, 3);
ArgentRadioShield argentRadioShield = ArgentRadioShield(rSerial);

void setup() {
    serial.begin(4800);
    argentRadioShield.setCall("W1AW");
}
```

If, instead of using the `ArgentRadioShield` library you use the `Serial.print` method to control your Radio Shield, you can still use `SoftwareSerial` to separate the Arduino serial and programming port from the Radio Shield data connection. Change from using `Serial` directly like this:

```
void setup() {
    Serial.begin(4800);
    Serial.print("MW1AW\r\n");
}
```

to using SoftwareSerial like this:

```
#include <SoftwareSerial.h>

// Use Software Serial for Argent RadioShield
// RX is D2 (RadioShield TX)
// TX is D3 (RadioShield RX)
SoftwareSerial radioShield = SoftwareSerial(2, 3);

void setup() {
    radioShield.begin(4800);
    radioShield.print("MW1AW\r\n");
}
```

APRS Packet Decoding

APRS packets, even APRS position packets, appear in an astonishing variety of formats, both documented and undocumented. Manufacturers who did not quite understand the specification also released firmware in radios and other devices, leading to further requirements for supporting variations and odd formats. The old radios cannot be updated, so the specifications and documentation have become more and more baroque over time.

There are three main formats for encoding the latitude and longitude:

- Uncompressed
- Base 91
- MIC-E

The uncompressed format is the easiest. This example from *Timber* shows an uncompressed packet:

AF6IM>APOT21:/213231h3750.14N/12137.79W^053/042/A=012814HR
165 SpO2 87 <http://ParachuteMobile.org>

In the above example split into two lines for the book, the first character after the : is a /, which means that the packet begins with a date; the date ends with either an h or a z, depending on time zone. A @ packet also has the same format. The ! and = packet formats have no date. In any of these cases, the latitude and longitude appear next and begin with an ASCII digit, and the latitude and longitude are separated with either a / or a \\", depending on which icon symbol table is in use. The position of the above packet is 37° 50.14' N, 121° 37.79W, or 37.835667, -121.629833. The decode_posit function ignores icons, times, and comments, as well as non-position packets, though you are of course free to add any features you want!

Base 91 encoding is a way of encoding numbers, but instead of using ten digits 0-9, it uses 91 “digits,” which are printable characters such as letters and punctuation. Just as a binary (base 2) rendition of a number is longer than the base 10 version, the base 91 version is much shorter, and base 91 encoding is used as a compression technology, giving more precision in less space. Argent Data products can encode in Base 91, and the format is widely parsed by the

popular online APRS sites, though built-in APRS in handheld radios does not support it. (Yet another reason to write your own software and be able to update yourself instead of buying equipment with baked-in firmware.) Base 91 packets begin with any of the four characters !=/@ and the next character is always either a / or a \ (and not a digit), and again the slash character style indicates which symbol table is in use. Some telemetry formats use Base 91, and others (as above) use uncompressed text.

MIC-E encoding is the earliest form of compression, and it suffers the most from format incompatibilities, because it was implemented in a variety of different radios and radio accessories. The compression format itself is quite difficult to follow, and I was able to write a decoding routine for it only after reading open-source implementations in several other programming languages, all cited in the references. Even so, I made no attempt to parse out speed, course, direction, icons or comments, as they are not used in the sketches in this book.

Using decode_posit

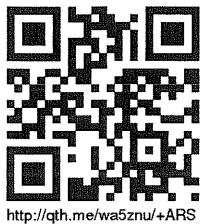
The decode_posit function which takes a packet string and returns the latitude, longitude and call sign. I wrote this routine initially as part of the *Marinus* sketch, but I moved it here because it is easy to use, and hides lots of details.

Below is an example of how to use decode_posit: Note the use of the PROGMEM string construct F() to prevent the Arduino crashes due to running out of SRAM.

```
{  
char packet[260];  
... read packet here ...  
char *call;  
char type;  
char *posit;  
long lat;  
long lon;  
  
if (argentRadioShield.decode_posit(packet, &call, &type, &posit,  
                                    &lon, &lat)) {  
    Serial.print(F(" call ")); Serial.print(call);  
    Serial.print(F(" packet type ")); Serial.print(type);  
    Serial.print(F(" posit ")); Serial.print(posit);  
    Serial.print(F(" lat ")); Serial.print(lat, DEC);  
    Serial.println(F(" lon ")); Serial.print(lon, DEC);  
}  
}
```

There are a number of finer points of APRS position decoding that decode_posit does not handle, such as !DAO! markers for additional digits in uncompressed formats, and extra locations for the ! packet type in certain old TNC devices. If you choose to add support for these features, please consult

the references for this chapter and for the *Marinus* sketch; but be warned: here be dragons.



References and Further Reading

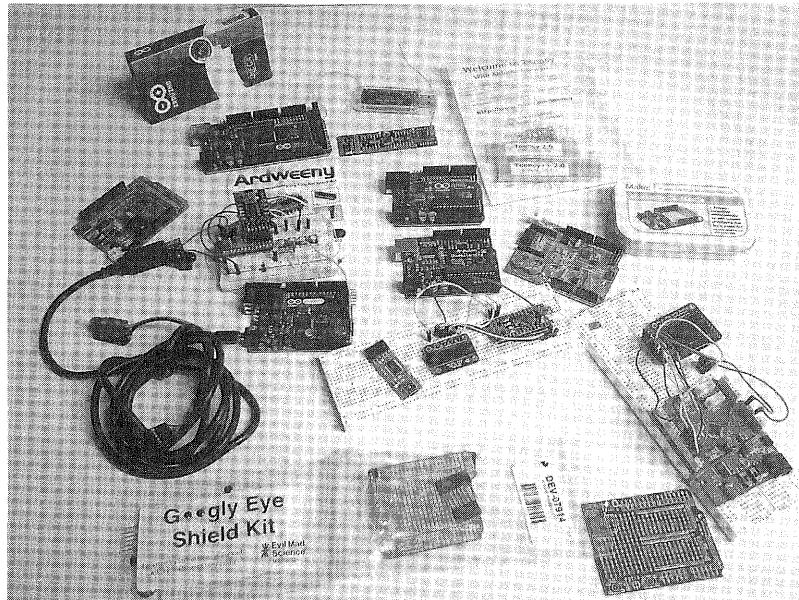
- Online references
<http://qth.me/wa5znu/+ARS>
- Library download
<http://qth.me/wa5znu/+ARS/code>
- LadyAda Tutorial on Installing Arduino Libraries
<http://www.ladyada.net/library/arduino/libraries.html>
- Argent Data Systems Radio Shield
https://www.argentdata.com/catalog/product_info.php?products_id=136
- Radio Shield Wiki
http://wiki.argentdata.com/index.php?title=Radio_Shield
- Arduino Shield Pin List
<http://shieldlist.org/>
- SoftwareSerial
<http://arduino.cc/en/Reference/SoftwareSerial>
- Types of Arduino Memory
<http://www.arduino.cc/playground/Learning/Memory>

License

- The ArgentRadioShield Arduino library is released under two licenses, so you can choose to use it under either the MIT license or LGPL 3.0:
<http://www.opensource.org/licenses/mit-license>
<http://www.gnu.org/licenses/lGPL-3.0.txt>

Arduino Hardware Choices

Leigh L. Klotz, Jr, WA5ZNU



Because the Arduino design is Open Source and Open Hardware throughout the stack, it has spawned an incredible ecology of compatible devices. The shields and libraries are well known and valuable, but there is also a parallel universe of devices compatible with the Arduino, or almost compatible, and further afield are those similar in spirit. This appendix explores a few of the inhabitants of that universe, starting from the official Arduino trademarked products, and moving on to the more basic, the more advanced, and those that are, well, *different*.

Basic Arduino

Arduino Uno

For a basic Arduino, it's hard to go wrong with the Arduino Uno. It's a jack of all trades, and with its Atmel ATmega328P, has all the flash (program/data) memory and RAM (variable) storage you need to do any of the projects in this book. It continues the slightly odd pin spacing for the headers that dates to the very first Arduino boards, but that also ensures compatibility with the many Arduino shield peripheral boards.

The Uno retains the USB interface that makes it easy to program with desktops and laptops, and yet still offers TTL level RS-232 from pins D0 and D1, not to mention SoftwareSerial support for the use of RS-232/TTL devices on other pins. Discarding the FTDI RS-232 to USB conversion chip of earlier models, the Uno uses an Atmel ATmega16u2 CPU as the USB interface. While for most users this just means you may have to load a driver (depending on your desktop OS), it gives a tremendous new capability for the Uno to emulate another type of USB device, such as a keyboard or mouse. Even if you don't need this functionality, the Uno is a great board to buy and use, and it's widely available.

Some quirks, though, have marred the otherwise sterling Uno, and having another Arduino around the shack can be an inexpensive and useful insurance policy against the time when you have that odd need. For example, programming a blank ATmega328 chip or an ATTiny 8-pin DIP can be done with the Uno, but it does not work smoothly with all versions of the Arduino IDE software. The Uno also replaces the quartz crystal of other models with a ceramic resonator to drive the 16 MHz system clock, so timings are less accurate, though you can work around this by using a shield with its own clock. See the *Thermic* and *Timber RTC* projects for inspiration.

Arduino Duemilanove

The Duemilanove (Italian for 2010) was the last full-sized Arduino to use the FTDI RS-232 chip. It offers the same programming structure as the Uno, and for most projects they are interchangeable. A Duemilanove can make some of the tasks mentioned above go more smoothly, and so for this reason, keeping one is a good plan.

You may also see references to the Diecimila, the predecessor to the Duemilanove. It used the ATmega168 chip with half the memory, but was easily upgraded with a new DIP IC. The USB power supply circuit was also different, and while you are not likely to encounter a Diecimila in the wild, products that claim to be compatible with it usually have all the modern features of the Duemilanove, such as the 328 chip.

Diavolino

Unfortunately, the Duemilanove is no longer manufactured, so if you can't find one inexpensively, the Diavolino from Evil Mad Science is an excellent alternative. It has *no* onboard USB, so you will need a cable with an FTDI USB to RS-232 converter chip in it, but those are inexpensive. The Diavolino is stylish, really inexpensive, and 100% compatible with Arduino shields. You can even buy just the bare board and populate it with parts you already have. The Diavolino is an excellent example of how the Open Hardware license used for the Arduino can spur others to develop useful, innovative products that are not just clones or part-for-part copies.

Menta

Since the QRP vacuum tube days, hams have been building projects in small tins such as Sucrets tins, or more recently Altoids tins. The trend has broadened,

and now blank tins and bespoke preprinted tins are widely used in the electronics hobby community. The Menta, developed by Adafruit for MAKE, continues in the ham tradition and offers a Arduino-compatible, and includes a prototyping area with DIP rails. Their voltage regulators are sized to support the prototype area as well.

Added Functionality

We've gone down market and seen the inexpensive shield-compatibles and what advantages they offer, but it's also possible to go upscale and gain *deluxe* features. No, not whitewalls and AM/FM/cassette player, but almost.

Arduino Ethernet

Just about any project in this book can be extended by connecting it to the Internet or to your shack or Field Day local network. There are a variety of Ethernet add-on shields available, but for my money, the Arduino Ethernet official product is the best — though it's not quite perfect. It combines the Ethernet module into the Arduino directly, replacing the bulky USB connector with an even bulkier RJ45, so you may need to put your shields on stilts (extra extended headers) to fit. But for ease of use and setup, it can't be beat. Program the Arduino Ethernet as usual, with an FTDI cable or similar device.

Seeeduino

Based in Shenzhen (China), Seeed Studios is a rare collective of international *hackers* who are bent on doing the world good. They build their own products, and they also accept Open Hardware designs from others and offer them for sale on their site. You can literally spend days reading through their online catalog, blog and forums, and if you have a hankering to get involved and contribute, they are a welcoming bunch. Of all the Seeed Studio products, the one I recommend here is the latest version (whichever version that happens to be) of the Seeeduino. Seeed Studios also offers a number of variations, such as the Seeeduino Ethernet. The feature set changes over time due to continuous improvement, but here is a list of a few advantages:

- *Switches.* Is that fancy new OLED screen only 3.3 V compatible? Dispense with a logic-level conversion DIP and just slide the 3.3 V/5 V switch to set the logic voltage level, regardless of your power supply source. Bothered by the auto-reset on RS-232 connection? Flip the auto-reset switch and it's disabled.
- *Mini-USB connector.* Duemilanove compatible USB, but a lot smaller than the full-sized USB connector, and the cables are plentiful.
- *Shield compatible and on 0.1-inch centers.* The Seeedstudio sports a second, inner set of header mounting points that offer 0.1-inch center compatibility, so you can homebrew your own shields with perfboard just by soldering in an extra set of headers or pins.
- *And more pins.* UART pins DSR/RTS/CTS etc. Two ADC pins. Both JST connectors and headers for extra pins

Ruggeduino

Arduinos are hardy boards, and in most versions the ATmega328P processor is an easily-replaced, socketed DIP. But it is possible to damage one, if you try hard enough. I once vaporized a trace on the bottom of an Uno by wiring its 5 V and 3.3 V regulator outputs both to GND, but after I repaired the trace the board worked just fine. Still, if you are working with higher voltages, you might be a candidate for the *Ruggeduino*. The Ruggeduino is a hardened version of the Uno, tolerant of up to 24 V on all its I/O pins and voltage regulator outputs. It's fully ESD protected, and as a bonus uses a 16 MHz quartz crystal instead of the Uno's less accurate ceramic regulator. Their catch phrase: "It's less than the price of two Arduinos!"

Arduino Mega

The Arduino Mega is an official Arduino product with more of everything: more RAM, more flash, more pins, more CPU speeds, more hardware UARTs and more interrupt timers. About the only thing it doesn't have more of is shield compatibility. If your project needs some of the extra features, you may pay for it by having to debug pin usage or other slight library incompatibilities, so the Mega is not recommended for beginners.

Small Sized

If you abandon shield compatibility in exchange for size, you can move down as well as up. The number of tiny boards that are software compatible and electronically compatible with the Arduino is astounding, and just a few are listed below.

Arduino Nano

The Arduino Nano is the official Arduino product in this space. It is quite small, has a quartz crystal and mini-USB, and fits well onto a breadboard or other circuit board. You may find it a bit pricey, and if you do not need the exact set of features only it offers, another product may suit your needs better.

Ardweeny

At \$9.95, the Ardweeny from Solarbotics is so cute and so inexpensive that I buy another one every time I see one. The physical package idea is brilliant: the board is a backpack soldered onto the ATmega328P chip itself, so it is guaranteed to fit in your design. If you need more pins than the ATTiny85 can offer, and want to port your big Arduino design to a perfboard, this may be the path of least resistance (ahem). As usual, you will need to pick up an FTDI programmer device or cable, but you can reuse that for everything. One modification I make to the design is to build it with the headers oriented with long poles up, so that it's a little easier to clip female header pins or scope probes into the pin leads if necessary.

You'll also need your own external voltage regulator for this device. If you need to power it on a protoboard for development, try the Itead Studio Breadboard Power module for \$6. Or, use the Wicked Devices Ardweeny

Prototyping Shield to prototype with the Ardweeny and regular-sized Arduino shields, then reduce your project to a perfboard and plug in the Ardweeny itself. Solarbotics also has some Ardweeny accessories; check their site for more information.

Boarduino

The Adafruit Boarduino is lot like the Menta, but it fits right on a protoboard, where you already do most of your work anyway. If that is your style, you may find yourself nodding your head in agreement. Don't do that; just go buy one.

Digispark

Even smaller than the Ardweeny, the Digispark ecosystem grew out of a Kickstarter.com “crowdfunded” project, where website participants vote with their dollars on which promising projects should be funded. The Digispark describes itself as a “micro-sized, Arduino enabled, USB development board — cheap enough to leave in any project.” And even though it is smaller than a quarter, it sports the ATtiny85 CPU and accepts dozens of mini-sized shields, ranging from MOSFET switches to I2C patch boards. Even if Digispark doesn’t become as popular as the original Arduino, expect to see more micro-sized boards with increasingly powerful CPUs.

Further Afield

A bit further afield from the Arduino world are products and devices that are still mostly Arduino compatible, but take the platform in significant new directions.

Teensy

The Teensy is teensy only in size, because it supports so much other stuff. The Teensy 2.0 uses the ATmega32u4 chip, a cousin of the 16u2 chip that handles USB for the Uno. Still, it has plenty of flash and RAM, and it has onboard USB. It’s great choice for a more advanced USB project, and is startlingly inexpensive: only \$16. The Teensy 2.0++ is has a huge amount of flash for an embedded processor — 128 kB, which is four times that of the Uno, and only costs a couple five-spots more than the Teensy. Teensy can be used with the Arduino IDE after downloading *Teensyduino*. One quirk of the Teensy: there’s a separate step necessary to initiate upload of your program. The designer has good reasons for it, but it’s just something to be aware of when using the Teensy. If you need a lot of code and timer interrupts in a small space, or if you need to do extensive USB work, the Teensy may be a better choice for you than the Uno.

Arduino Leonardo

If USB emulation of keyboards or mice is your main goal, check out the new Arduino Leonardo, SparkFun Pro Micro or Adafruit ATmega32u4 Breakout. Like the Teensy, these boards use the ATmega32u4 microcontroller,

and they offer surprising functionality in a small package.

JEE Nodes

Just as the Arduino Ethernet combines the Arduino board with a peripheral, the JEE node combines a small-format Arduino compatible package with another useful device, and one quite attention-getting for radio amateurs: an RF transceiver. The JEE Node system combines a RFM12B 915 MHz or 434 MHz radio modem with an Arduino software package. The initial sketch lets you send data back and forth, but you can write your own and start communicating on 33 cm or 70 cm with ease. A USB version is also available for direct attachment to your desktop or laptop.

Maple Leaf

The Maple Leaf from Leaf Labs is physically and mostly electronically compatible with the Arduino, but the CPU it uses is completely different. All of the microcontrollers in the above products are fundamentally 8 bit devices, like the CPU in the pre-PC home computers of the 1980s, though with more memory and better onboard peripherals. The Maple Leaf vrooms along with a 32 bit, 72 MHz ARM Cortex M3 chip. While shield compatibility and library details make this board unsuitable for novices, if you are ready to dive into the implementation details, or have a few friends who are, this board could make a fantastic jumping-off point for your fantasy projects.

Arduino Due

The Due is the Arduino Team's *open development* effort to build a 32 bit version of the Arduino announced at the New York City Maker Faire in 2011 and released to Beta testers at the San Francisco 2012 Maker Faire. The team is making sure it will have the community's seal of approval by the open process they are following to finalize the design. The Due uses the ARM Cortex M3 MCU (Atmel SAM3), and runs at 96 MHz. While this board won't replace the existing 8 bit Arduino boards for most tasks, it will have the chops to let you take the *Cascata* waterfall display project and convert it into a full-fledged PSK digimode program. Or with an external dual-channel ADC, you could even design and build an entire software defined radio (SDR). Needless to say, these aren't weekend projects, but when you are ready to step up to the plate, the tools and the skills you've learned with the Arduino will go a long way toward getting you started on these advanced projects.

Hamstack

The Hamstack from Sierra Radio is an exclusively ham-oriented board mostly compatible with Arduino shields, but programmed in BASIC or Microchip C18 using the Microchip PIC18F4620 microcontroller.

Raspberry PI

With an unlikely name, the Raspberry PI is an entire GNU/Linux computer whose claim to fame was initially the \$25 (and later \$35) price point. The Rasp-

berry PI does not use the Arduino tools at all, but it may be the right device to use for an advanced ham SDR project. Now available with 512 MB RAM, the Raspberry PI heralds a new era in ease-of-use for small hardware projects, and with its 700 MHz CPU, it promises to surpass the Maple Leaf in any race to the computation finish line. The Raspberry PI may be a good choice for you if your idea of embedded computing is installing your own *Linux* distribution and writing Python scripts, or if you aspire to run laptop-sized programs such as *fldigi* or *Quisk* SDR. Look for more small computers competing in this space, built using components designed originally for the mobile computing and wireless router markets. Hobbyists have been repurposing these devices for ages, and the practice is about to hit the main stream.

Beaglebone

The Beaglebone is a cute mint-tin package from Texas Instruments, roughly the same size as an Arduino, but using the 700 MHz ARM Cortex A8 processor. Again, it does not work with the Arduino tools, but runs *Linux* like the Raspberry PI. Unlike the PI, though, it has no display controller, so you will need to add that on. It does have a layout of headers for its own shield-like boards (which Adafruit calls “capes”), but programming for it is a considerably more challenging than is developing Arduino sketches.

Prototype Shields

Having a collection of blank shields around for prototyping and building is handy when you get the idea to put something together. There are a few different design styles, and which ones you choose depends on what type of circuits you expect to build.

SparkFun Prototype Shield

The SparkFun proto-shield is a good all-around digital, analog and RF shield. It offers a few LEDs, resistors and buttons, but it leaves the central area a plain grid of holes, without predetermined IC placements that can interfere with RF circuit layout.

Freetronics

If you’re sure you need to do RF work (for example, for the *Multimode Transmitter Shield* project), Freetronics offers a board-only product. Combine it with your own stacking headers and avoid paying for parts you don’t need.

Evil Mad Science Googly-Eye Shield

Hot on the heels of their success in stabilizing a local oscillator to the sub femtosecond range, the Evil Mad Scientists designed a proto-shield that is excellent for RF work: it is an insulator shield that has *no* connections whatsoever, beyond a pass-through of Arduino headers and some nearby pads. If your RF project would be disturbed by capacitive coupling to a nearby

ground plane, the Googly-Eye Shield will still let you bring your great ideas to fruition in shield format. They have assured me that actually attaching the googly-eyes is optional, though the dielectric constant is not specified for either the board or the eyes. And as it is an Open Hardware design, you are free to build your own and improve on it.

USB Connections

You need some method to program all the devices without onboard USB. There are two basic ideas: an all-in-one cable, or a board with a mini-USB connector. These devices come in 5 V logic and 3.3 V logic versions. For safety, buy the 3.3 V version, and you will likely never find a 5 V device that it can't program.

All of these devices are pretty much the same, except the cable versions usually cost more, because, well, they come with a cable.

Jumpers, Wires, Headers, Protoboards

Throughout the book you have seen jumper wires, stacking headers and ribbon cables. When you order something cool from your favorite suppliers, add one or two of these items to your order, as it helps the vendor make money and it helps you, as they seem to disappear into projects, and there are never enough around. Or look for a value deal on bulk packages of them at your favorite auction site, as most of these parts are industry commodities, and not the result of a long, creative design process.

Summary

That's a wrap! I cannot possibly list all the interesting devices I have purchased while writing this book, much less the ones I wish I had bought. And this space is exploding with new shields, new boards, and new ideas. Explore the book companion web site and join in the fun. When you learn something, share it with your fellow hams, and we'll return the favor.



<http://qth.me/wa5znu/+hardware>

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Or your favorite auction site for bulk orders.

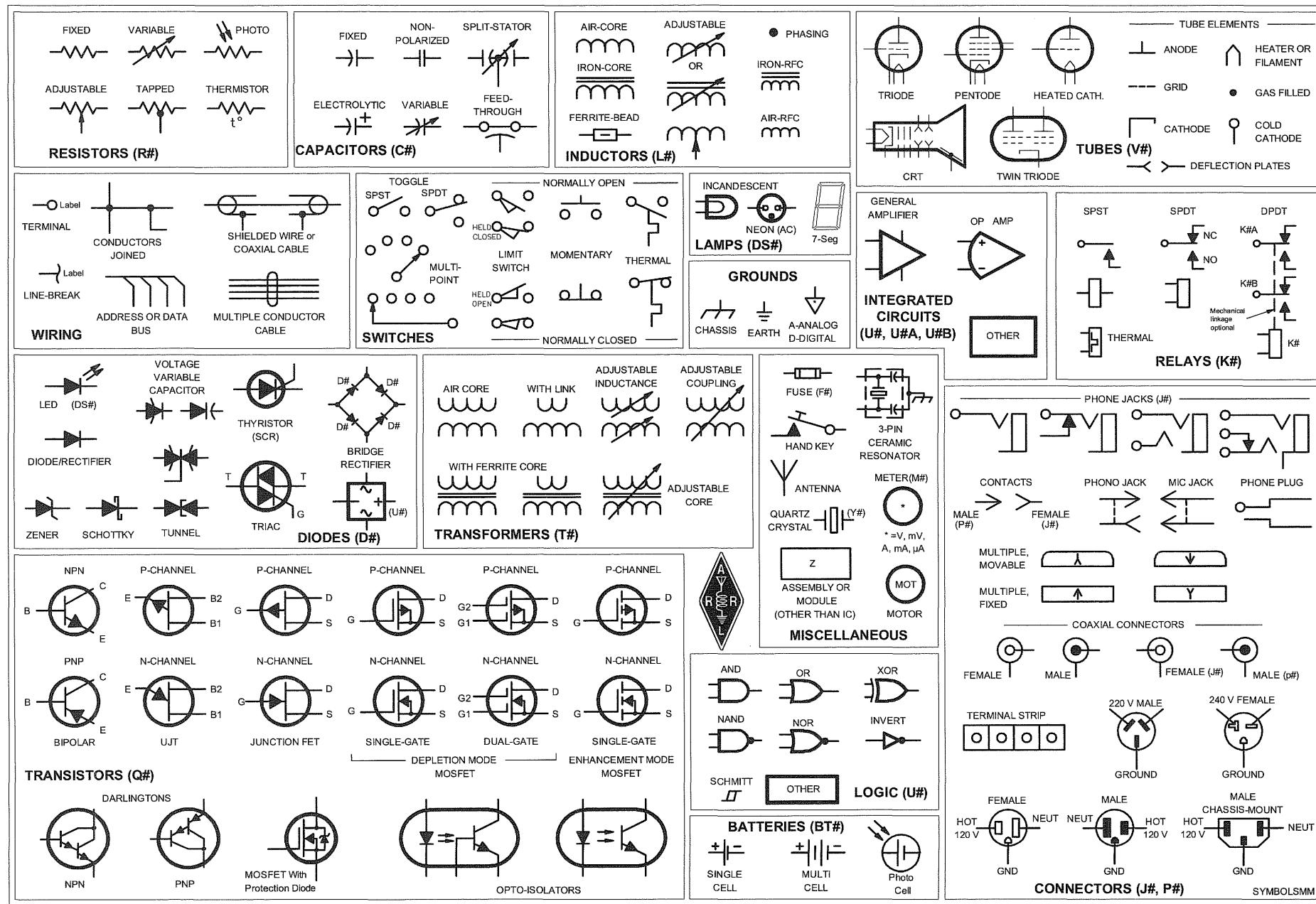
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Common Schematic Symbols Used in Circuit Diagrams



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