Make:

technology on your time

The Most Useless Machine!
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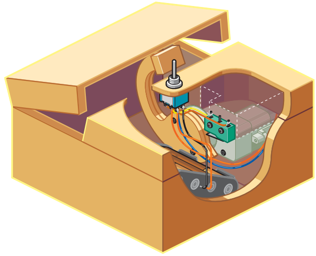

AMAZING GADGETS YOU CAN BUILD!

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- » TINY AUTO GYROCAR
- » SOLAR SUBWOOFER
- » HULA HOOP POOL WARMER

3ric Johanson and Intellectual Ventures' new malaria weapon, the Photonic Fence.

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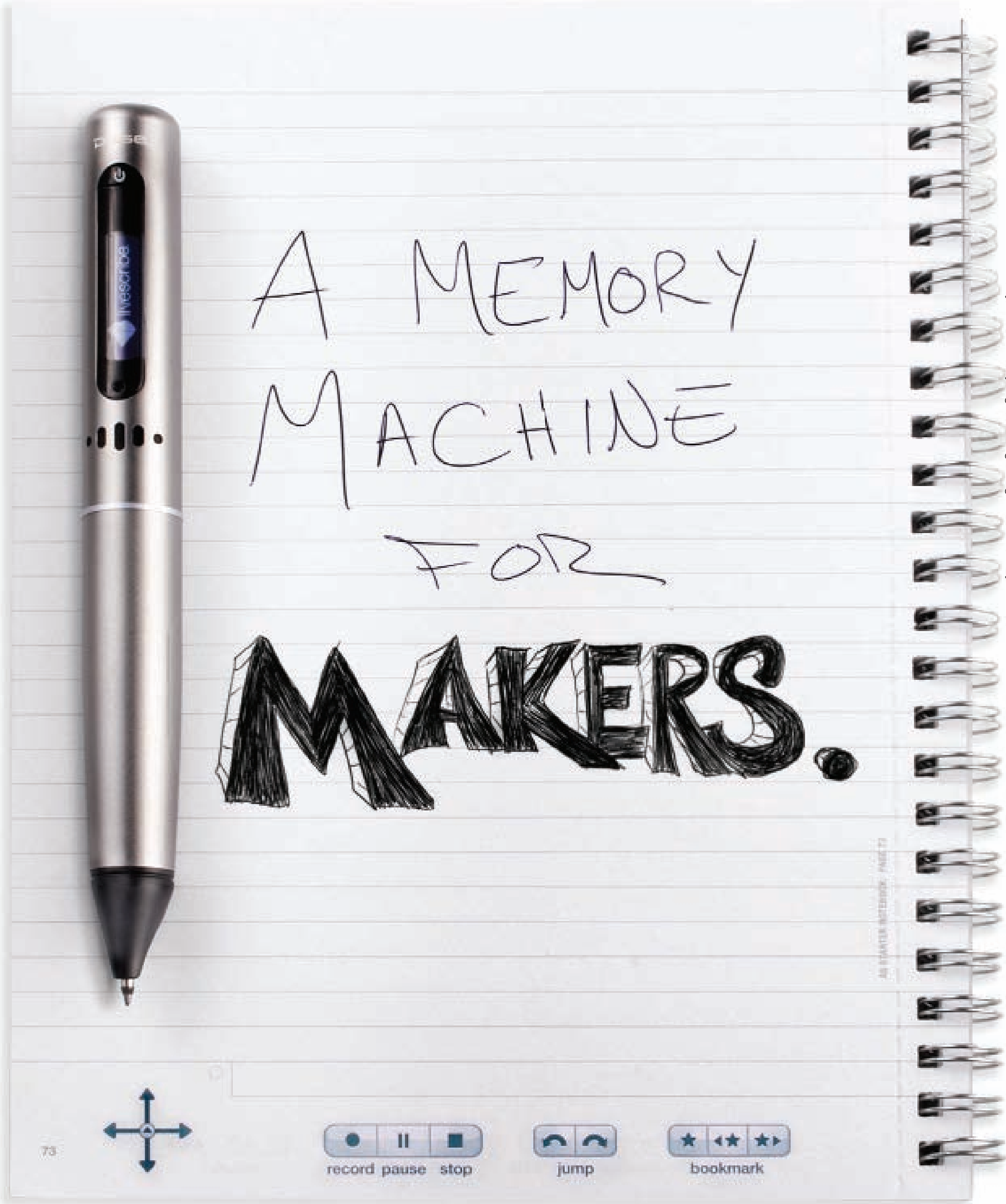
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WELCOME

BY MARK FRAUENFELDER

Our New Tool for Community Collaboration

Having built seven cigar box guitars over the past couple years (see my how-to in MAKE Volume 21), I wanted to try building a battery-powered cigar box amplifier.

Naturally, I referred to our Cracker Box Amplifier project in MAKE Volume 09. And when I visited makezine.com to read the comments about the project, I discovered that several readers had posted additional instructions and clarifications that really helped me understand how to build the amp.

This experience drove home our belief that MAKE's readers are our most important resource. In addition to writing our how-to articles, our readers often improve on those projects after we print them. But there hasn't been a well-defined place online to document these modified instructions, so readers tended to post them on their own blogs or other non-obvious places.

That's why we're so excited about Make: Projects (makeprojects.com), our brand new beta library of project instructions written by you, the readers. We're developing Make: Projects in partnership with the folks behind ifixit.com, a powerful, easy-to-use system for writing online repair manuals. The iFixiteers helped us adapt the platform for use as a project website.

Make: Projects is collaborative, not only in the sense that individuals can create and improve on how-to instructions, but also in the sense that communities (hackerspaces, collectives, educators, and so on) can share their own projects and contribute to the creation of the ultimate makers' manual.

We invite you try Make: Projects. Start by taking a look at the dozens of great projects we've already seeded there, such as a green surfboard, a spy microphone, and a wind turbine. You can make changes to any of the articles by clicking the Edit button. Or click Make A New Project, and start writing instructions for something entirely new.

Make: Projects is currently in beta, a work in progress, which means we need your help and your ideas to maximize its potential. Please send your feedback to us at projects@makezine.com.

We're looking forward to your contributions!

Mark Frauenfelder is editor-in-chief of MAKE.


Let your geek shine.
Meet Dwight Eppinger, SparkFun customer and Interactive Marketing Manager at Colorado's Copper Mountain Ski Resort. Using SparkFun's LED matrices and XBee modules, Dwight created a status board that updates the resort trail map signs on the condition of ski runs. From one computer, Dwight can instantly let ski patrol, Copper Mountain staff, and the people zipping down the slopes know which trails to hit.
Whether you're building a status system for an entire mountain or just wirelessly reaching across the room, the tools are out there. Find a new way to communicate, and let your geek shine too.
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©2010 SparkFun Electronics, Inc. All rights reserved. All other trademarks contained herein are the property of their respective owners. Get the scoop on Dwight's project at crossingwiresarduino.blogspot.com. You can also read more about Copper Mountain Resort at www.coppercolorado.com.

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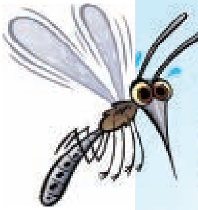

ON THE COVER: 3ric Johanson fires up the "photonic fence" Mosquito Defense Shield, photographed by John Keatley at Intellectual Ventures, Bellevue, Wash. Mosquito illustrations by Adam Koford. Useless Machine illustration by Rob Nance.

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Make: Projects

Bare Bones Amp
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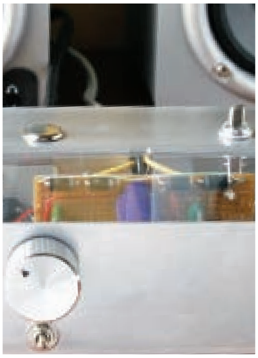

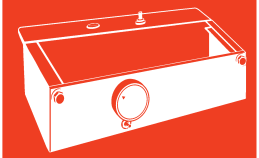

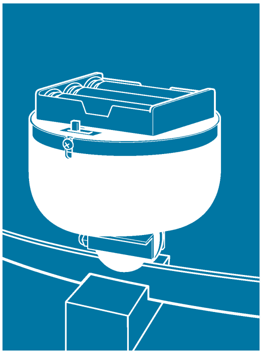

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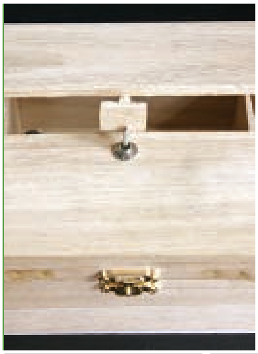

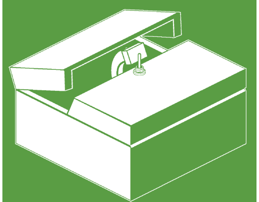

Building with PLCs
Programmable logic controllers never fail.
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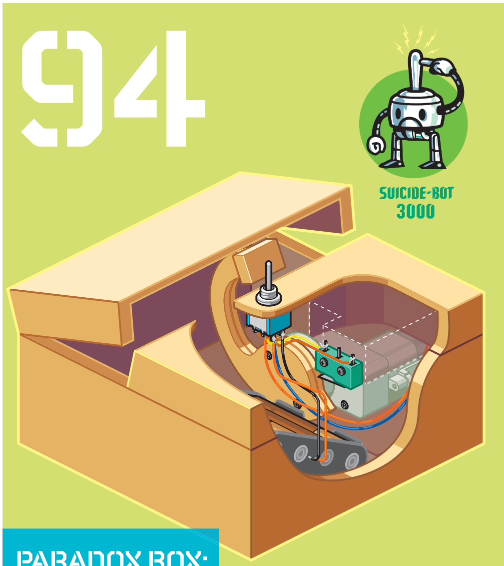

PARADOX BOX:
The Most Useless Machine that broke Stephen Colbert's heart.

READ ME: Always check the URL associated with a project before you get started. There may be important updates or corrections.

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Low-budget workshop setup, hardware container system.

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"Whether you think you can or think you can't, you're right."
—Henry Ford

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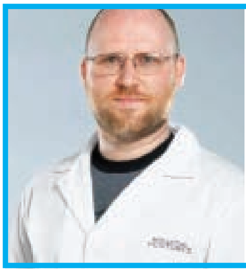


3ric Johanson (*Mosquito Zapper*) has been a hacker for many years. He's been involved with several successful projects, most of which he can't talk about and which never really happened. What we do know is that he's designed and built a system that shoots mosquitoes with lasers. His past work includes excessive voltages, ShmooCon, Hackerbot Labs (a Seattle-based hackerspace), Vend-O-Rand, and rainbow tables. By day, he is a project scientist and entropy generator at Intellectual Ventures Laboratory; by night, he's been spotted wearing his "so sue me already" T-shirt while drinking overcaffeinated coffee. His hobbies include building and breaking things in secret underground lairs.

Jamie O'Shea (*Immaculate Telegraphy*) is an artist living in New York City. He creates inventions to test the boundaries of the impossible and impractical. He usually fiddles with memory, light, and time, and lately he can't stop thinking about all that extra gravity out there. Jamie creates his work at the Eyebeam Art & Technology Center and frequently looks for excuses to go play in the woods.

Brian Melani (MAKE engineering intern) lives in Rohnert Park, Calif., and has a pet snake named Legato. He got into "building and designing various things from a very young age, when my father would bring home stuff from work for me to take apart so I could see how it works." He has many hobbies but is most involved in FIRST Robotics and machining. In his free time, one of the projects he's working on is an LED dot-matrix display using a few PIC microcontrollers. Brian is a student at Santa Rosa Junior College, but his goal is to transfer to Cal Poly to earn degrees in mechanical and aerospace engineering.

While in the fifth grade, **Matthew Gryczan** (*Gyrocar*) completed his first invention: a "talking matchbox" that produced spooky sounds to mystify people attending a séance. Equally practical projects soon followed, such as a chocolate milk mixing machine using a tin can for a brain, and a spinthariscope that makes radiation visible. He's written a book on how to win carnival games, served as a newspaper reporter and editor, and worked as an engineer specializing in electrochemical machining. Based in Grand Rapids, Mich., Matt now operates a public relations firm for science and technology issues.

John Keatley (cover photography) settled in Seattle by way of Northern California, trading steady sunshine for sun breaks. He specializes in advertising and editorial portrait photography with a diverse group of clients, and is frequently traveling for work. He's a huge baseball and soccer fan — the Dodgers come first, but the Mariners have been added to the list since he moved to Seattle. He and his wife recently became the proud parents of a baby girl, whom they take on walks to the beach near their house as often as possible. In summer, John can be found skimboarding at low tide.

J. Tregre (*Mystery Electronic Switches*) is an electrical design engineer and *Star Trek* model builder. Originally from New Orleans and a graduate of Louisiana Tech, he lives in the Dallas area, where he has worked for Texas Instruments as a submicron failure analysis engineer. He's affiliated with the IPC Designers Council, IEEE Reliability Society, and IEEE Electromagnetic Compatibility Society. For fun, he designs futuristic LED lighting effects circuits for his very large-scale *Star Trek* models. You can see more at buildingultimatemodels.com.

READER INPUT

Rosy CupCakes, router safety, shocked kids, and pirate booms.

MAKE Volume 21 (Desktop Manufacturing) is brilliant — I'm subscribing. As an engineer in the mid-90s, I drove usage of tools like SLA, SLS, and NC machining to create rapid prototypes, and they quickly showed their benefit in lower cost, better and faster design iterations, and improved understanding. It's awesome to see these tools getting to a broader community — it will allow more creativity, capability, and fun! *—Jeff Zemsky, Glenmont, N.Y.*

"The Revolution Will Be Squirted" (Volume 21) was a bit too rosy about the CupCake CNC. The article does a good job of pointing out its major differences from commercial offerings, but not its shortcomings, such as the quality of the objects it outputs. The article does state that it uses a 0.3mm filament, but fails to show a close-up shot to reveal the objects' coarseness and irregularity.

Another shortcoming is repeatability. Running a print is hit-or-miss. A part can degenerate halfway through because the open-loop motion control is drifting or the filament's properties have changed.

Hopefully this article will spur many readers to join the desktop manufacturing revolution. I just wish it didn't sound so much like a promotional piece for MakerBot Industries.

—Charles Erignac, Seattle, Wash.

EDITOR'S REPLY: Thanks for the clarifications. We could have shown finer detail, but with its typical 0.37mm layer thickness, the CupCake isn't about ultra-precision — it's about rapid prototyping, invention, and fun.

MAKE has changed my life and the lives of my children, and a few hundred kids at their grade school. I built the electrostatic generator ("Remaking History," Volume 21) and presented it — you should have heard the kids gasp when just turning a PVC handle with some rabbit fur made a piece of neon tubing light up. They couldn't wait to line up and get shocked by the Leyden jar.

My kids can't wait for Saturdays when we get to build. *—Ron White, Helena, Mt.*

I found "Instant Paddle" (Volume 21) intriguing — a new and simple way to construct a paddle. However, as a woodworker I was shocked at the unsafe router technique shown. When rounding over the corners of thin stock, the safe way is to securely mount the router in a router table with a fence. The fence guides your stock and also "hides" the majority of the router bit, keeping your fingers safe. The use of feather boards would make the procedure even safer.

I built a basic router table (wordsnwood.com/2007/p.rt) for about $20. Pat Warner's website (patwarner.com) is dedicated to routing and router tables; a Google search will produce dozens more.

—Art Mulder, contributing editor, Canadian Home Workshop *magazine, London, Ontario*

My student teams in the Destination ImagiNation program (idodi.org) have used MAKE's ideas to help them succeed. In this video (makezine.com/go/di), one of my teams uses two "Boom Sticks" (Volume 13) to make loud cannon booms during their pirate skit.

—Jeff Harris, Delano, Minn.

MAKE AMENDS

On our "Traditional Cigar Box Guitar" (Volume 21) the tuners were mounted upside down. Flip them so the string tension pulls the shaft toward the gear. Thanks to Bill Ludeman of Palatka, Fla., for spotting our error.

In the breadboard diagram for "Motion-Sensitive Camera Trap" (Volume 22), the LEDs should be wired to ground (not power), and the wire from pin 10 should meet a blue LED's positive lead (it overshot by one hole). The corrected diagram is at makezine.com/22/cameratrap. Also, 3 standoffs and 6 screws are needed to mount the Arduino.

In "Puzzle of the Crowned Pulleys" (Volume 22), Figure C was misinterpreted. In fact the upper edge of the cylindrical pulley (line *b*) is not parallel to line *a*, and line *b* is not perpendicular to the incoming portion of the belt. Thanks to reader Miguel Dimase of Buenos Aires, Argentina, for catching our slip.

TALES FROM MAKE: ONLINE

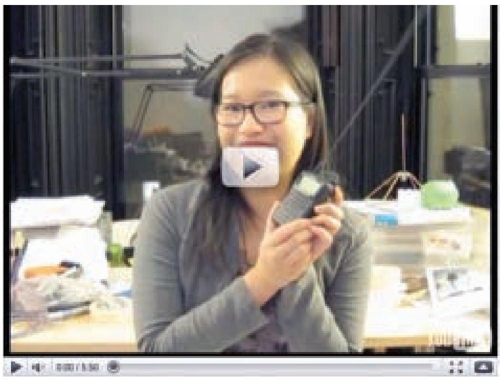
BY GARETH BRANWYN

Online Videos: Maker See, Maker Do

Who doesn't like video tutorials of people making things? There's just something endlessly entertaining (and pedagogically efficient) about watching someone start with a pile o' parts and a bright idea, and end up with a working widget. We learn, and we live vicariously the excitement of creating.

MAKE has built up an impressive library of instructional video series on our website, on a breadth of DIY topics and projects. Here are a few highlights — explore makezine.com for many more.

M: Weekend Projects Since 2006, hosts Bre Pettis and Kip Kay have shown how to make everything from a rodent-powered nightlight to a Rubik's-style puzzle cube made of dice to a pole-mounted aerial camera rig and a potato Gatling gun. Here, Kip builds the **compressed air rocket** from MAKE Volume 15: makezine.com/go/weekendprojects



M: Ham Radio with Diana *Project Runway* contestant Diana Eng is also an avid ham operator and MAKE correspondent. She's done video projects from ham hiking to making your own (working) *Star Trek* Communicator to **how to detect radio waves with a light bulb**. makezine.com/go/dianaeng

M: Collin's Lab Collin Cunningham's curiosity gets the better of him as he explores IC innards, the effects of sound on liquids, infrared heart monitors, and how to make a conductive **iPad stylus** from desk-drawer junk. makezine.com/go/collinslab

M: *Make:* television If you missed our Emmy-nominated TV show when it first aired, you can catch every episode online. In this installment of Maker to Maker, Bill Gurstelle describes the unique back-cutting action of a samurai-sharp **Japanese pull-stroke saw**. makezine.tv

To see lots more MAKE video offerings, see:

» Podcasts/Videos: makezine.com/podcast

» Projects: makezine.com/projects

» YouTube channel: youtube.com/makemagazine

Smiley Face Technologies

There are innumerable things to make one depressed these days. Oil spills, a dysfunctional economy, worsening political extremism, and an awful long-term environmental outlook.

Fortunately for me, I have an antidote that keeps me upbeat, something special and beautiful that keeps me optimistic about the human condition, the human mind, and the power of thinking. I apparently have a high enough public profile that I receive something like "fan mail." People share their ideas with me.

Many are just ideas — not well-developed, and thousands of hours and many over-turnings of the original idea away from becoming an idea that will change the world in the manner in which the thinker hopes. Which is not to say they're bad ideas; I don't think any ideas are bad. Ideas are just ideas, things to play with, things to inspire, thought experiments. "Wouldn't it be cool if?" "If only I had a ..." "The world really needs a ... !"

I get all these ideas sent to me, but I'm not sure what people think I'm going to do with them. I'm struggling to get through my own pile of ideas! I keep mine in a stack of numbered notebooks, and look at them every New Year's Eve to remind myself that there is more to do next year, including ignoring a lot of the ideas that were good at the time but silly upon reflection.

A lot of the ideas people send me are accompanied with a note: "I hope you can do something with this idea. I don't have the resources, but I know the world needs it." I really, really love those — but more on that later. The ideas I don't like are the ones with a note like this: "I have this idea, and it's so good, you'll have to promise me all sorts of things before I tell you about my idea." No thanks. Keep your idea and your paranoia and don't send me intellectual extortion of that kind.

To all the people who send me ideas saying, "Please do something with this idea," I thank you. I can't promise you that I'll do something with them (like I said before, I'm struggling with my own), but I thank you anyway. And the next best thing is to celebrate you and your ideas. Congratulations! You have ideas, and what's more, you have generosity. You could just sit at home and watch television, but you don't. You tinker about, having ideas.

One of my favorite correspondents is a fellow in prison. Yes, prison. I don't know what he did to get there (let's assume it was an unpaid traffic infringement), but here's the thing: he's a guy, in prison. Society has given him the ultimate "no thank-you" and locked him up. But from within that prison, he still has the audacity, and the hope, to have ideas. Not ideas for him to escape prison — no, these are his ideas that he feels could benefit humanity!

And right there is the reason my eyes well up with every one of these letters. People believe that their ideas can help the world. And they do! There is nothing more beautiful, more generous, more hopeful.

To all of you out there with ideas, I salute you. Keep having those ideas. Some of those ideas will make it. Some of them will cure cancer. Some of them will make a better dishwasher. Your hope is mine, the hope that with the collection of our ideas, good and ill-formed, we'll make the world a better place for us and our children to live in.

I have a wonderful friend, Dan Paluska. He has ideas — lots of them. He's got some wisdom, too. He categorizes the world of technology and ideas into two kinds: good practical ideas and technologies (things you use every day), and "smiley face technologies." I love the very concept of the latter. When I first heard him describe it, I naturally asked, what are these smiley face technologies? He said, "The Slinky, Pac-Man, rubber duckies — you know, the things that aren't necessarily useful for anything other than putting a smile on your face."

So here's what I ask. Don't just concentrate on good, practical ideas for saving a small or large piece of the world. Be sure to include the odd "smiley face technology." If we're going to celebrate any ideas at all, we should also celebrate the ones that have no purpose other than making us smile. We do have a lot of problems that need ideas, but we shouldn't be so serious about humanity's purpose as to forget that making people smile and inventing silly things might actually be the highest purpose of all.

Saul Griffith is a new father and entrepreneur. otherlab.com

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Apr	May	Jun
July	Aug	Sept
Oct	Nov	Dec

MAKER'S CALENDAR

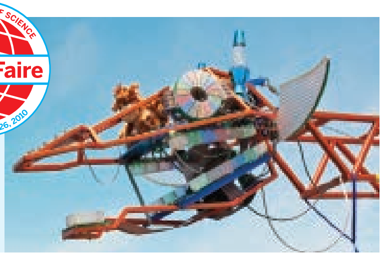
COMPILED BY WILLIAM GURSTELLE

Our favorite events from around the world.

World Maker Faire New York

Sept. 25–26, Queens, N.Y.

Finally, the East Coast gets a Maker Faire of its very own! MAKE magazine partners with the New York Hall of Science to bring the two-day celebration of DIY enthusiasm and hands-on technology to the Big Apple. makerfaire.com/newyork/2010



AUGUST

» BrickFair

Aug. 7–8, Chantilly, Va.

This festival is the place for die-hard Lego builders. If you've ever wondered what you could build with unlimited bricks, now you can find out. BrickFair includes millions of Lego bricks assembled into amazing creations big and small. brickfair.com

» Classic and Wooden Boat Show

Aug. 7–8, Door County, Wis.

Now in its 20th year, this festival features activities and exhibitions related to boat building. DIY boats from around the country are exhibited and judged, and demonstrations, seminars, and music are presented. dcmm.org/boatshow.html

» Pyrotechnics Guild International Fireworks Convention

Aug. 7–13, Appleton, Wis.

PGI is where pyrotechnicians go to see and be seen. This huge event for fireworks makers features nightly displays, an art show, a convention, and a trade show. The general public is invited to the gigantic display held on the last evening. pgi.org/2010conv.aspx

SEPTEMBER

» Historical Construction Equipment Association Exposition

Sept. 10–12, Richmond, R.I.

HCEA's International Convention & Old Equipment Exposition is a must-see for makers who like to do things on a big scale. This year's convention features a rare 1928 Wilford Model B power shovel taking on a large hill, and lots more hot machine-versus-dirt action. hcea.net

» Old Car Festival

Sept. 11–12, Detroit, Mich.

The streets of Greenfield Village will be filled with the sights, sounds, and smells of hundreds of authentic vehicles at America's longest-running antique car show. Enjoy the expo, watch games of skill, and see a Model T assembled in just minutes. thehenryford.org/events/oldcarfestival.aspx

» TechFest in September

Sept. 12–19, Aberdeen, Scotland

This annual festival showcases what's new in science, technology, and mathematics. Past years' programs have included an evening on the "Secret Life of Elephants" and a fast-paced presentation on "Building the World's Fastest Car." www.techfestsetpoint.org.uk/tis

OCTOBER

» USA Science & Engineering Festival

Oct. 10–24, Washington, D.C.

The inaugural festival promises to be the ultimate multicultural, multigenerational, and multidisciplinary celebration of science in the United States. More than 500 science and engineering organizations will present fun, hands-on science activities. usasciencefestival.org

» PopTech

Oct. 20–23, Camden, Maine

Cool projects and hot ideas are served up annually at PopTech, a conference that entertains and provokes its audience of technologists, entrepreneurs, and thinkers with world-changing technologies and ideas. poptech.org

✱ IMPORTANT: Times, dates, locations, and events are subject to change. Verify all information before making plans to attend.

MORE MAKER EVENTS:

*Visit **makezine.com/events** to find events near you, like new hackerspace classes, exhibitions, cool conventions, workshops, festivals, craft fairs, Make Clubs, Dorkbots, and more. Log in to add your own events, or email them to **events@makezine.com**. Attended one of these events? Talk about it at **forums.makezine.com.***

BY CORY DOCTOROW

Walled Gardens vs. Makers

When I was a grub, we traded in forbidden knowledge: "If you unscrew the receiver on a pay phone and short the screws on the back of the speaker by touching them to the chrome on the side of the phone, you get an open dial tone."

Or: "Here is how you fold an origami crane." Or: "Thus and so and thus and so, and now you've taken the motor out of your old tape recorder and attached it to your Meccano set." Or: "If you `POKE` this address on your Commodore PET, you'll shut the machine down." The knowledge diffused slowly, and each newly discovered crumb was an excitement and cause for celebration.

Today, as a nearly senescent 38-year-old, I look back on that period with a kind of wonder and dismay. I knew ten interesting things I could do with the gadgets, devices, and materials around me, and I thought myself rich. I knew that the Whole Earth Catalog, the Amok catalog, Paladin Press, and other purveyors of big secrets could send me *dozens* of new interesting things in mere *weeks*.

Thinking on my collection of hacks in those dim, pre-internet days, I'm reminded of the book fanciers of the Middle Ages who might, in a lifetimes, amass five or ten books and think themselves well-read.

Because, of course, today I have millions of hacks and tips and tricks and ideas at my fingertips, thanks to the internet and the tools that run on top of it. When I invent or discover something, I immediately put it on the net. And when I find myself in a corner of the world that is not to my liking, I Google up some hack that someone else has put on the net and apply it or adapt it to my needs.

Making, in short, is not about making. Making is about sharing. The reason we can make so much today is because the basic knowledge, skills, and tools to make anything and do anything are already on the ground, forming a loam in which our inspiration can germinate.

Consider the iPad for a moment. It's true that Apple's iTunes Store has inspired hundreds of thousands of apps, but every one of those apps is contingent on Apple's approval. If you want to make something for the iPad, you pay $99 to join the

Making is about sharing. The reason we can make so much today is because the basic knowledge, skills, and tools to make anything are already on the ground, a loam in which our inspiration can germinate.

Developer Program, make it, then send it to Apple and pray. If Apple smiles on you, you can send your hack to the world. If Apple frowns on you, you cannot.

What's more, Apple uses code signing to restrict which apps can run on the iPad (and iPhone): if your app isn't blessed by Apple, iPads will refuse to run it. Not that it's technically challenging to defeat this code signing, but doing so is illegal, thanks to the 1998 Digital Millennium Copyright Act, which makes it a crime to circumvent a copyright-protection technology. So the only app store — or free repository — that can legally exist for Apple's devices is the one that Apple runs for itself.

Some people say the iPad is a new kind of device: an appliance instead of a computer. But because Apple chose to add a thin veneer of DRM to the iPad, the Digital Millennium Copyright Act applies here, something that's not true of any "appliance" you've ever seen. It's as if Apple built a toaster that you can only use Apple's bread in (or face a lawsuit), or a dishwasher that will only load Apple's plates.

Apple fans will tell you that this doesn't matter. Hackers can simply hack their iPads or shell out $99 to get the developer license. But without a means of distributing (and receiving) hacks from all parties, we're back in the forbidden-knowledge Dark Ages — the poverty-stricken era in which a mere handful of ideas was counted as a fortune.

Cory Doctorow's latest novel is *Makers* (Tor Books U.S., HarperVoyager U.K.). He lives in London and co-edits the website Boing Boing.

Report from the world of backyard technology

Photography by Douglas Sonders

Rolling Like Luke

The R2-D2 that **Daniel Deutsch** built at age 14 pretty much charted his career in movie props and animatronics. It also foretold the day he would cruise the streets in his own full-sized, drivable landspeeder.

Deutsch, 43, moved to Orlando, Fla., in 1987 to work for Disney, and was soon tapped to build the R2-D2 that has appeared for years at Walt Disney World. He's created dozens of mechanical animated characters since then.

Today he does custom design and fabrication, out of a shop with "all the toys we need to fabricate anything": a multi-axis CNC mill, a laser cutter, chrome-plating equipment, and the Dimension 1200 3D printer and NextEngine 3D scanner he bought from Jay Leno. "We recently were sent the original stunt Ark from [*Raiders of the Lost Ark*] to be re-gold-plated — that was a really cool project! A piece of cinematic history," he enthuses.

Deutsch invented Tireflys, those little LED lights that screw into tire valve stems, and lately he's been developing special effects using soap bubbles.

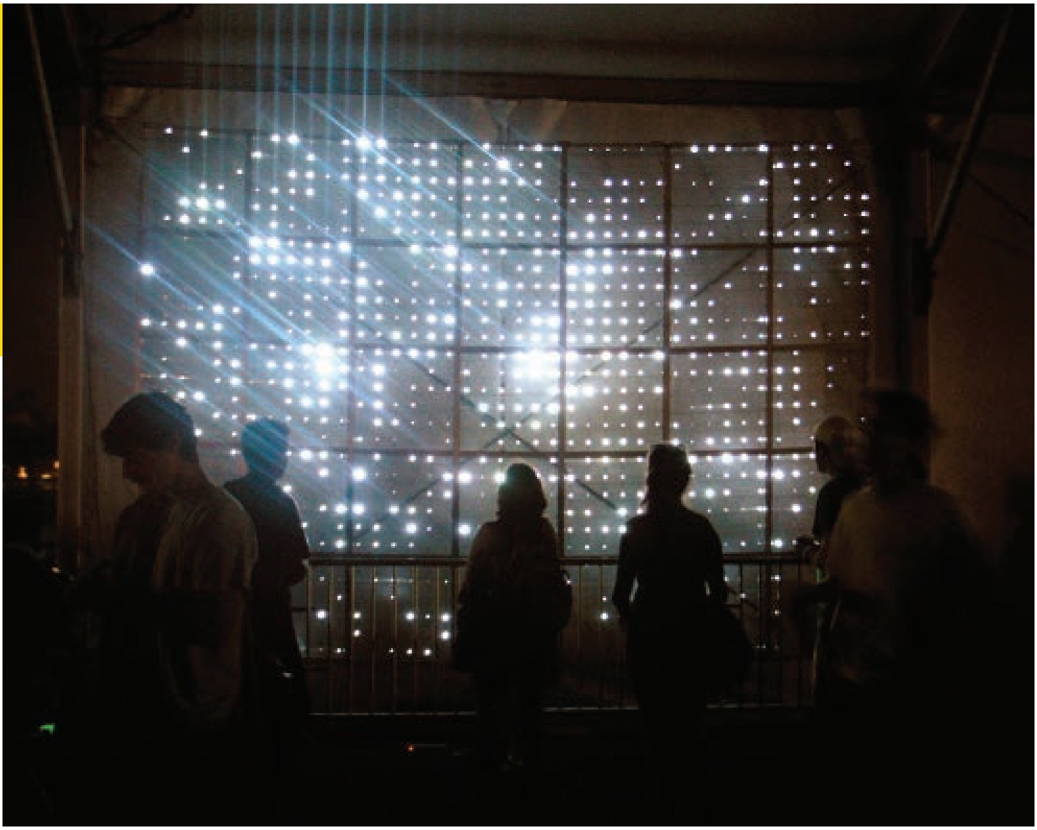
In 2007 he got the idea to build his landspeeder. "I realized that nobody had built a faithful replica of the speeder that would actually drive. So, why not?"

With its electric motor and aluminum chassis, Deutsch's three-wheeled speeder will do 30mph. To make the body, his team of five designed a "buck" model in CAD, laser-cut it from wood, and filled out its curves with urethane foam. Then they cast the final parts in fiberglass and resin. The side grills are water-jet-cut PVC, and the windshield is PET plastic vacuum-formed over a drape mold.

For the fanboys, Deutsch and colleague "Super Ted" Hyde added digital sound effects and engine lights. The build was done in six weeks, just in time to debut at the Star Wars Celebration IV convention in Los Angeles.

But wait. Star Wars Celebration V is this August in Orlando. Is Deutsch working on anything special? "I intend to have a full-scale replica of the speeder bike done before the event," he says. "Although this time it won't be drivable." —*Keith Hammond*

Life-Sized Landspeeder: makezine.com/go/speeder



Bright Lights, Big Installation

Kinetic light sculptor **Jason Krugman** has followed a circuitous path to success. Raised in Boston, the 27-year-old recent graduate of NYU's Interactive Telecommunications Program (ITP) obtained a bachelor's degree in economics from Tufts University and spent two years working on Wall Street before leaving to pursue art full-time.

"I wanted a skill set that wasn't so disparate," says Krugman, "allowing me [to do] creative and commercial work at once."

His first project — the needy *Single White Android* — was an instant hit, and his interest in nature's intricacies paved the way for larger, more organic pieces. "I really like the slogan, 'It is what it does,'" says Krugman. "LEDs or resistors, they have very basic functions, but are also aesthetically enticing."

This is apparent in *Firefly 1440*, a wind-actuated 8'×20' display comprised of 40 individual plexiglass panels and 1,440 LED/switch pairs. "The entire piece is a massive array of sensors and outputs," he says. As wind encounters it, switches activate each LED individually, forming dancing light patterns based on the wind's force, timing, and direction.

"My goal is to produce work that's intensely stimulating to the senses," says Krugman. "*Firefly* looks complicated, but what's happening is simple."

Firefly 1440 is intended for large outdoor spaces like building exteriors and bridges, though it remains under development.

"I'm in the process of pushing the pieces I've made to the limits," he says, "to see where and how they will fail." Next he'll add metal plating to the LED legs, to increase weather resistance.

Encouraged by recent interest in his work (*Firefly 1440* was shown at the All Points West festival in Jersey City, N.J., and *Firefly 870* is on display at the New York Hall of Science in Flushing, Queens), Krugman plans to approach building owners, architects, and museums about realizing site-specific installations. Most of his recent work, including LED mesh chandeliers, is available for sale on a customized basis. *—Laura Kiniry*

Krugman Studio: jasonkrugman.com

Photograph by Jason Krugman

Shelter from the Bus

Sculptor **Christopher Fennell** prefers to use materials that have been cast out by society, so the idea of creating a bus stop shelter out of actual retired buses seemed like a natural.

Fennell responded to a call for bus stop designs by the city of Athens, Ga., with a vision of a shelter that would look like a moving bus in stop-motion photography, and would utilize large pieces from three old school buses.

Scavenging for old school buses to use wasn't without adventure. "I ended up in someone's front yard cutting off bus sections and briefly catching his lawn on fire," recalls Fennell.

The most challenging part of the project was retaining the distinguishing markings, such as bus numbers and serial numbers, because it was important to Fennell that he maintain as much of the buses' original history and charm as possible.

Like all his sculptures, Fennell's bus stop is made almost entirely of recycled materials. Part of the project build is documented in a video on YouTube that shows the scaffolding, crane, and heavy lifting required to assemble the large bus sections.

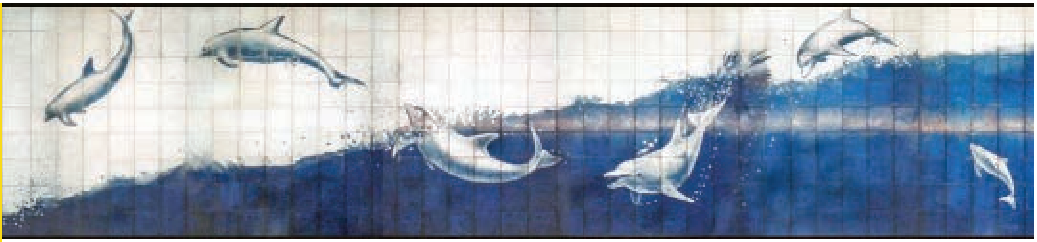
Residing now in Birmingham, Ala., Fennell received a degree in mechanical engineering from the University of South Florida and worked in robotics and aerospace before deciding to go back to school to study sculpture.

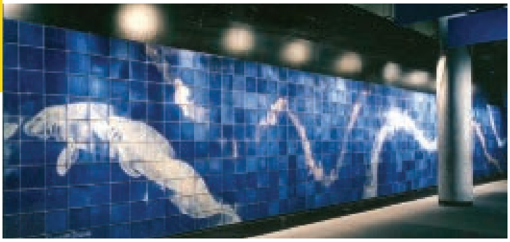
"Making engaging public art was more challenging for me than designing flight simulators at my engineering job," Fennell says about the unorthodox career change.

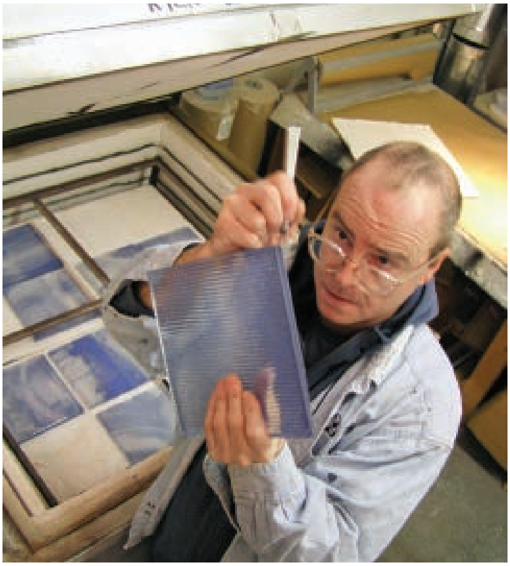
Fennell's engineering background comes in handy for figuring out the structural challenges of his massive sculptures, however. *Bus Stop Shelter* is actually a small piece for Fennell, whose work verges on the colossal. For his next project he's looking for 44 truck chassis to make into a 63-foot-long guitar for the location where Elvis performed his first concert. We can't wait to see the video of that one. —*Bruce Stewart*

More Shelter Photos: cfennell.org/pages/bs.html
Shelter Assembly: makezine.com/go/bus

Photograph by Christopher Fennell







Living Walls

In a hallway of the National Aquarium in Baltimore, a boy stares, entranced by a long glass mural that shows sea lions diving in the waves. He's discovered that as he walks, the creatures swim along with him.

The animated mural is the work of **Rufus Butler Seder**, an inventor, filmmaker, and artist whose interactive panels or Lifetiles can be found in museums and public spaces across the United States — from the Smithsonian, where he's brought Duke Ellington to life at the keyboard, to Zoo Miami, where he's set toucans and anacondas gliding through an Amazonian jungle.

Seder constructs his pieces like mosaics, assembling anywhere from a handful to hundreds of tiles, which he casts in his Boston foundry.

The process is meticulous and time-consuming — a mural can take up to six months — but the underlying principle draws on the same low-tech techniques used in lenticular art (e.g. those animated cards in Cracker Jack boxes) or flipbooks.

"Anything that creates the illusion of motion without electricity or motors has always fascinated me," Seder explains, and he cites his collection of antique zoetropes and optical toys as inspiration.

Seder starts by breaking a motion sequence into several digital images. On the computer, he slices each image into super-thin vertical stripes, then merges all the images into one frame that he then sandblasts onto the back of a glass tile.

The front of each tile has a ribbed pattern that acts as a lens, magnifying and revealing the sliced images underneath, one at time. When viewed rapidly in succession, the images appear to move.

For his next project, Seder brings his optical magic to San Francisco with an animated mural of the construction of the Golden Gate Bridge — just in time for the 75th anniversary of the legendary span.

—Jeanne Storck

More Lifetiles: eyethinkinc.com

Photography by Rufus Butler Seder; Robert Reyes (portrait); Cambridge Seven Associates (aquarium)

Photograph by Andrew Trombetta

Hardcore Thread

Pink knitted motorcycle cozies and tool belts may not be the stuff that boys *or* girls dream of, but for **Theresa Honeywell** they speak to both her feminine and masculine sides. Plus, they look great.

"It makes things more interesting to contrast opposites," she says. "Whether it's textures (hard vs. soft) or mediums (metal vs. knitting) or ideas (masculine vs. feminine, or crafts vs. Art)."

While getting a master's degree at Tennessee's Arrowmont School of Arts and Crafts, Honeywell explored her macho side using "feminine" arts such as knitting and embroidery. Tattoos and "lowbrow art" were represented in colorful thread and yarn.

She found her first Kawasaki in a junkyard. "I was very particular about the style of bike; I wanted an early-80s, rugged macho-bike," she remembers.

Honeywell, who lives in Jacksonville, Fla., began with machine guns and handguns, then tools and tool belts, a jackhammer, an electric guitar, and finally the *Knit Motorcycle Series*. She's knit three motorcycles to date, and embroidered hundreds of tattoos.

"The tattoos that I stitch are typically macho-associated icons, but I'm redrawing them out of thread — a softer and typically domestic-associated material," she says. "The images are based on vintage tattoo imagery, and my designs are made in the similar labor-intense way that a tattoo is made."

Each piece of tattooed embroidery takes about two weeks to complete, the knitted pieces even longer. "The motorcycles can take up to two months," she says. "Many people are shocked at the time involved, but the labor process is a huge conceptual part of the piece. I am a woman using domestic techniques to change the appearance and associations of typically masculine-associated objects."

Honeywell's work has been displayed in San Francisco, New York, and lots of places in between. Next up is the Country Club Plaza in Kansas City, Mo., where she's planning a few surprises. "I would love to do something really large and crazy; maybe a bulldozer or something for tearing up the ground or buildings," she says. —*Shawn Connally*

More Hardcore Crafts: theresahoneywell.com

Photograph by Dale Sander

DIY Truss Telescope

Dale Sander proudly continues the amateur telescope maker's tradition of building upon the work of others. Sander's latest innovative design, which he calls a "truss telescoping telescope," was inspired partly by his friend Tom Noe, who built the first telescoping Dob scope that Sander had ever seen.

John Dobson is credited with popularizing the type of large, portable, easy-to-make telescopes that became known as Dobsonian telescopes (or "Dobs") and are now a mainstay of amateur astronomy.

Dobson admits he didn't invent anything particularly novel; his telescope design was based on military cannon mounts that had been in use for hundreds of years.

Sander, 58, had already built two Dob telescopes that used detachable four-pole support systems, but he was looking to design a new one that was even easier to set up and move around.

Using mostly parts left over from previous telescope projects, along with some high-quality Baltic birch plywood, six camera tripod legs, and a Lycra spandex shroud, Sander created a truss-based telescope that's his most lightweight and easy-to-assemble model to date.

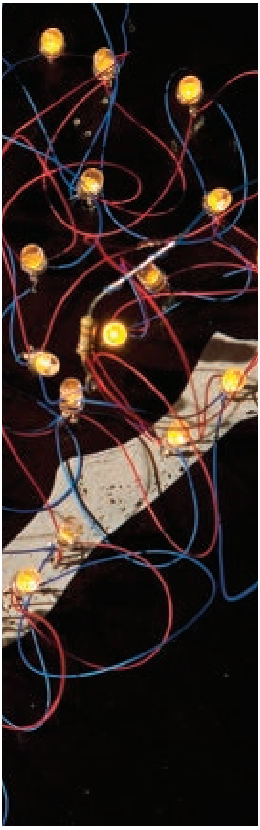
"Many people buy telescopes only to find out they are too difficult to move and too slow to set up, so the scopes just sit in their closet unused," Sander points out.

For this reason, his primary design criteria were light weight, for easy portability, and fast setup time. He achieved both: the 10-inch truss telescope weighs in at a slender 38 pounds and can be set up in approximately 1 minute.

A longtime amateur astronomer, Sander lives and stargazes in Dallas, where he works as a printing press operator. He's been making telescopes since he was 8 years old. Not surprisingly, Sander has posted meticulous build notes and photos online so that others can build on his work.

—Bruce Stewart

Telescoping Telescope: makezine.com/go/truss



Come On, Sweat!

"We squeezed and squeezed and squeezed!" say **Daniela Kostova**, 36, and **Olivia Robinson**, 34, former grad students of Rensselaer Polytechnic Institute (RPI). They aren't talking about making OJ — they're talking about extracting salt from sopping T-shirts.

Kostova and Robinson are the creators of Waste to Work, a project exploring sweat as a catalyst for energy. Commissioned by the Schenectady Museum, the project is inspired by the relationship between Schenectady's General Electric factories (the company's former headquarters) and their workers.

"We saw a connection between sweat used as electrolytes for batteries, and as a metaphor for labor," says Robinson. They enrolled in a residency program at RPI's Center for Biotechnology to learn more about electrochemical principles, tapping into a larger network of people working in BioArt, including faculty member Robert Linhardt, developer of a supercapacitor that runs on blood, sweat, and urine.

Waste to Work's first phase ran at the museum in 2008 and was made of 250 galvanic cell batteries, each connected through artery-like wires to an illuminated LED map based on a NASA satellite photo of the Earth at night.

They crafted the batteries from recycled containers, artist charcoal (carbon), nails (zinc), and sweat, which they gathered through random T-shirt exchanges at construction sites, saunas, and parades.

At the opening, audience members could activate the batteries — and light up sections of the map — using a turkey baster. "Two things became apparent," says Kostova. "People were amazed at how [the world's] electricity use is concentrated, and [they were] really grossed out by each other's sweat."

For the second phase, Robinson and biomed students at Syracuse University prototyped a wearable integration of the batteries that doubled as a sweat- harvester. Now she's working on a sweat harvesting caravan. Waste to Work will be on exhibit — sans body odor — at the Pratt Manhattan Gallery in New York City, this fall. *—Laura Kiniry*

Kostova and Robinson: iamwhateveryouwantmetobe.com

Photography by Olivia Robinson

COUNTRY SCIENTIST | BY FORREST M. MIMS III

The Infrared Thermometer: An Essential Science Gadget

Your Science Tool Kit

If you do casual or even serious amateur science, you might already have some first-class science gadgets in your science tool kit. They might include a computer, a digital camera, and a thermometer. But do you have an infrared (IR) thermometer?

While I've spent 20 years measuring sunlight, haze, the ozone layer, and the water vapor layer using various homemade instruments, a couple of IR thermometers are among the most important gadgets in my science toolbox.

IR thermometers allow you to measure the temperature of objects without actually coming in contact with them. This is why they're called noncontact thermometers. They're ideal for basic chores like measuring the temperature of car engines, cooking surfaces, refrigerators, heaters, and streams and lakes. They also have many scientific applications.

IR Thermometers

Everything with a temperature above absolute zero emits IR radiation. IR thermometers use a thermal sensor such as a miniature thermopile to detect the IR emitted by objects. The signal from the sensor is corrected for the ambient temperature and sent to a digital readout. Some IR thermometers include an analog output for use with a data logger. Prices vary from $20 up to thousands. The Omega OS540 shown in this article cost $85; newer versions start at $95.

IR thermometers are usually employed to measure the temperature of surfaces, which may have different *emissivities*. According to the *Handbook of Military Infrared Technology* (Office of Naval Research, 1965), emissivity is the ratio of the IR emitted by a surface to the IR that would be emitted by a *blackbody* at the same temperature.

A blackbody, which may not appear visually black, is a perfect absorber and emitter of IR, which means it has an emissivity of 1. Most surfaces aren't perfect blackbodies, and their emissivity is less. For this reason, most IR thermometers are set for a default emissivity of .95, which is close to the emissivity of most organic materials, including you and me. But shiny metallic surfaces, snow, brick, cotton fabric, and other materials may have lower emissivities. Some IR thermometers allow the emissivity setting to be adjusted so that temperature measurements are consistent.

Selecting an IR Thermometer

An online search will lead you to many different IR thermometers from a dozen or more manufacturers. Some are intended mainly for measuring hot objects, while others have a much broader temperature response. Because I frequently measure the IR temperature of the sky, I prefer IR thermometers with the lowest temperature capability, which is around −76°F. Most IR thermometers have a minimum range of −20°F to −50°F.

IR thermometers are specified according to their field of view (FOV), which is expressed as a distance-to-spot ratio: the ratio of the distance to a target compared to the diameter of the spot viewed by the thermometer. For example, an FOV of 1:1 means the instrument will be looking at a circle 1 foot in diameter at a distance of 1 foot. A narrower FOV of 30:1 means it will be looking at a 1-foot circle at a distance of 30 feet.

For measuring very large objects, an FOV of from 1:1 to 10:1 should usually work. For smaller targets, select an instrument with an FOV of 30:1 or narrower.

Using an IR Thermometer

Be sure to read the instructions that come with an IR thermometer to learn how to operate the display backlight (if present), how to switch between Fahrenheit and Celsius temperature scales, and how to adjust the emissivity.

Keep in mind that IR thermometers are not designed to measure the temperature of shiny metal surfaces, which tend to have low emissivity. When pointed at objects on the far side of a glass window, they'll measure the temperature of the glass. Similarly, steam, smoke, and dust will also interfere with temperature measurements. Some

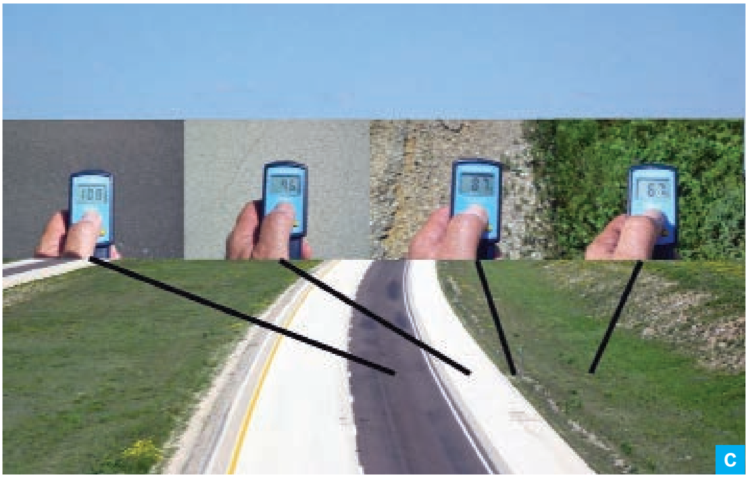


Fig. A: The open sky is always much cooler than the bases of cumulus clouds. The temperature straight overhead can be less than −75°F.
Fig. B: Paved sections of Hawaii's Mauna Loa Observatory road (left) are much warmer than nearby lava rock (right), presumably because of the lava's porosity.
Fig. C: Four temperature readings, across and adjacent to Interstate 10 in West Texas on a clear spring day.

Photography by Forrest M. Mims III

manufacturers advise that their IR thermometers aren't intended for medical applications or for measuring body temperature.

CAUTION: Many IR thermometers include a laser pointer that illuminates the portion of an object that is being measured. Be careful to avoid pointing the thermometer at a person's face or at shiny surfaces that might reflect the laser beam into your eyes or someone else's.

Applications for IR Thermometers

There are dozens of applications for IR thermometers, some of which can provide very useful scientific information.

» Studying Heat Islands

Heat islands are most often described as the dome of warm air that forms when sunlight heats buildings, streets, and other manmade things in cities. Actually, a heat island can be anything in the environment that becomes warmer than its surroundings, including rural roads, gravel, boulders, and remote farmhouses.

You can sometimes see evidence of these heat islands, for example, when they cause snow around them to melt faster (*see my column "Snow Science" in MAKE Volume 21*). The cedar elms on either side of my tiny rural office always leaf out faster than their neighbors due to the warmth of the building.

An IR thermometer is ideal for studying heat islands. Instead of simply assuming that an asphalt road is warmer than the grass that borders it, you can measure the exact temperature of both the road and the grass.

The temperatures of different building materials illuminated by full sunlight are of special interest. I've studied such materials by placing various bricks, concrete blocks, wood, and asphalt on a common background and measuring their temperatures over time. Also interesting are their rates of temperature decline when the sun is low in the sky.

» Studying Clouds

Both amateur and professional astronomers use IR detectors to detect clouds that might interfere with their telescope observations. An IR thermometer works well as a cloud detector because the base of a cloud is warmer than the clear sky.

Cumulus clouds form when the temperature of moist air falls to the dew point. The temperature indicated when an IR thermometer is pointed at the base of a low cumulus cloud is often within a few

COUNTRY SCIENTIST

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Fig. D: Sarah Mims measured a newly paved asphalt road at 225°F during a heat island study. Fig. E: The temperature of this fire ant hill on a cool spring day was 114°F, while the adjacent ground was only 66°F. Fig. F: Prickly pear cactus pads become much warmer in direct sunlight than most leaves. Fig. G: The temperature of this spring-fed creek on the Mims property changes much more slowly than the air temperature.

degrees of the dew point measured at the Earth's surface. I've also learned that the temperature indicated when an IR thermometer is pointed at the clear zenith sky is well correlated with the total water vapor overhead. I'll soon have two years' worth of water vapor data and will write a scientific paper about this finding.

» Energy Conservation and Storage

IR thermometers are very useful for evaluating the insulation in houses and other buildings. They're especially good at indicating temperature leakage through glass windows, and hot spots in electrical wiring.

An IR thermometer is also useful in developing solar water heaters. You can quickly try this method by placing a gallon of water in a black plastic trash bag. Seal the bag and lay it flat on a surface exposed to full sun. Measure the temperature of the bag every minute or two for 30 minutes and plot the data to see the increase in temperature over time.

» Other Studies

Plants and animals provide many interesting temperature studies. For example, prickly pear cactus pads become much warmer than the leaves of trees and most other plants.

Fire ant hills can easily exceed 100°F on a warm day. I recently measured the surface of one at 114°F, then removed a 1-inch layer of soil from a portion of the hill, which then measured only 92°F. I wanted to continue this investigation by going deeper, but hundreds of angry fire ants forced my retreat.

Going Further

By now I hope you understand why an IR thermometer is one of the most important gadgets in my science kit. The ideas given here merely scratch the surface of what can be done with one of these remarkable devices, especially if you photograph the thermometer readout, as shown in the accompanying figures. Chances are you'll find entirely new uses when you begin probing your home, workplace, and environment with an IR thermometer.

Forrest M. Mims III (forrestmims.org), an amateur scientist and Rolex Award winner, was named by *Discover* magazine as one of the "50 Best Brains in Science." He edits *The Citizen Scientist* (sas.org/tcs).

MAKER'S CORNER

BY DAN WOODS

Summer's Here

Time to get serious about that long-overdue MAKEcation.

One comment I hear constantly from makers is, "I have more ideas about things I want to make or repair than I have time." Sadly, I can relate all too well. Here I am, surrounded by hundreds of cool maker-made project kits, amazing tools, inspirational makers ... but oh, so little time.

This summer, I'm doing something about it. The Woods family is planning at least two MAKEcations: time away from the office, without email or cellphones, no Facebook (the horror), and no TV. So I polled my Maker Shed comrades: what would make for the ultimate MAKEcation with three kids and a wife who loves to repair things? What must-have tools and kits would you take on a MAKEcation?

Make: Electronics Book

This book's cover says it best: "Burn things out, mess things up — that's how you learn."

Charles Platt's primer for the new electronics enthusiast is wildly popular, because it's all about learning electronics by discovery. Start working on excellent projects the moment you crack open this unique, hands-on book. Build the circuits first, then learn the theory behind them.

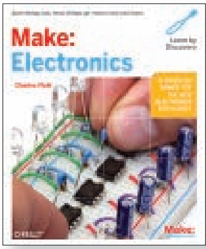
And if your dream MAKEcation is more about making and doing than scouring the internet for supplies, consider these companion packs to our *Make: Electronics* book. We've spent hours sourcing these parts so you don't have to. Pack 1 includes everything you need to tackle the first two chapters, experiments 1–11. Pack 2 covers experiments 12–24.

The awesome thing about these kits is that they aren't limited to just one experiment or outcome, but rather support a myriad of different projects. Perfect for the aspiring electronics enthusiast.

Deluxe Make: Electronics Toolkit

Do you want to learn to solder? Does someone in your family? This toolkit takes the trouble out of searching for the right tools.

The kit includes everything you need to get started in the wonderful world of electronics — from a 30-watt adjustable soldering iron to a digital



multimeter to the Panavise Jr. for holding those PCBs while you solder. We even included your first project, the WeeBlinky, and a Maker's Notebook to help you document your next project.

ShapeLock

One of the hottest products at Maker Faire! If you haven't played around with ShapeLock yet, you owe it to yourself to buy a sack and check it out.

ShapeLock is a space-age plastic that melts at 160°F then remains safely moldable by hand until locking rigidly as it cools to room temperature.

The stuff is reusable (just reheat and remold), tough, safe, and nontoxic, and it's machinable (easy to saw, drill, tap, and mill) and paintable (readily accepts acrylic hobby paints, dyes, and pigments).

Prototype your invention right now — without machine tools. Create super-strong custom parts, prototypes, molds, servo brackets, robot housings, sculptures, science projects, and more. No maker space or workshop should be without ShapeLock.

Now in all honesty, in their zeal for the MAKEcation concept, the Maker Shed crew nominated more than a dozen fabulous tools and kits they considered indispensable for a range of interests. But alas, I'm allocated just so many words. For the complete list, check out makershed.com/makecation.

Happy MAKEcationing!

Dan Woods is MAKE's associate publisher and general manager of e-commerce.

Maker

YOU NEVER MET A MAKER QUITE LIKE ME: Andrew Archer, 22, fronts the team at Robotics Redefined, based in Detroit and Ann Arbor, Mich.

Kid Robot

Young makers are seizing breakout opportunities on the wild frontier of Detroit.

By Dale Dougherty

Hobbyists. That was the keyword Andrew Archer used in his help-wanted ad on Craigslist. Andrew needed help completing a large robot he was developing for use in auto factories. He wanted to target hobbyists who were curious and willing to figure things out for themselves. Jeff Sturges saw the ad and responded. Like Andrew, Jeff had moved to Detroit within the last year.

Andrew was offering only $10 to $12 an hour, but Jeff thought it was more interesting than any IT job he might find. On the phone, Jeff told Andrew about a community meeting for Maker Faire Detroit at the Henry Ford Museum that Sunday, and they agreed to meet there. That's where I met both of them in January of this year.

Jeff had moved from New York City, where he'd been involved in the Sustainable South Bronx Fab Lab. In Detroit, he was able to buy a house for $500, and he rode his bike around town to live on the cheap. Jeff, who grew up in the Boston area, has a degree in architecture from Cranbrook Academy of Art in Bloomfield Hills, Mich., so he knew the area. He returned hoping to create a hackerspace and develop school programs to get kids involved in making things.

Andrew had moved to Detroit from Duluth, Minn., where he'd started his company, Robotics Redefined. He was using off-the-shelf components to design new kinds of robots for factories. He said he had a dozen contractors working for him and had sales worldwide. I had to ask how old he was. "Twenty-one," he said. I immediately thought that finding people like Andrew and Jeff was a good sign for Detroit, and that makers were already connecting with each other.

Photography by Brian Kelly

Jacqueline Campbell Archer is Andrew's mother and his financial officer. As a single mom raising Andrew, she recognized that he had unique gifts that amazed and baffled her. "As a kid," she said, "if he went to sharpen his pencil, he'd end up taking apart the pencil sharpener."

From age 6, he took over the garage, bringing home things from yard sales or dumpsters. "Andrew liked anything with a cord," said Jacqueline. Once he hauled home a toilet so he could see how it worked. He then turned it into a fish tank. She would buy him tools as birthday presents. He built a capacitor from cookie sheets and mineral oil.

For a ninth-grade science project, he built a two-foot-tall Tesla coil, something his teacher didn't believe he — or anyone his age — could do. He did a demonstration in class, and the teacher was so afraid of electrocution that he made him shut it down. "I was really comfortable that I was a person making weird stuff," said Andrew.

Andrew was mostly bored in school, feeling held back from exploring what interested him. He didn't like sports. He didn't connect easily with his peers. He dreamed of building a private spacecraft in his garage that would take him away to a new world.

More practically, he noticed that the rich kids in town all had mopeds to get around on. Unable to buy one himself, he began hacking one together from four bikes and an industrial weed-whacker engine.

Jacqueline worried about her son. When he was young, she had taken him to the Mayo Clinic, to consult with specialists. She learned that Andrew had a genius-level IQ, but she could easily see him dropping out of school or getting involved in drugs. She determined that high school was not challenging enough for him, and she sought to enroll her 14-year-old in courses at Lake Superior College. To do that, she had to sue the local school board.

One very positive experience for Andrew was his involvement in SkillsUSA and its annual competitions. In 10th grade, he entered the robotics competition and won third place in the state. "They gave us a robotic arm and a boxful of components to build an automated assembly," recalled Andrew. "You had no knowledge going in of what you'd have to build." The next year he was the state champion, traveling to the national competition in Kansas. A year later he was the national champion, requiring just four of the eight hours allotted to complete his project.

Andrew graduated from high school in 2006 and a year later completed his degree in robotics at the community college. He'd already completed a degree in machining at 16. "I was planning on going to Carnegie Mellon in fall of 2007, but I decided not to," said Andrew. While he liked CMU, he didn't want them owning what he worked on as a student. "I decided instead to pursue my own thing," he said, and started his robotics company that year.

At high-school graduation, Andrew saw his biological father, Bryan Fisher, for only the second time. Fisher, an inventor, had developed industrial baling equipment and built a successful company, Excel Manufacturing.

From the short time they spent together, Andrew thought that the two of them were identical. "What he was thinking, I was thinking. He'd approach problems the way I'd approach problems, and we'd come up with the same solutions and say it the exact same way," said Andrew. "It was very strange."

Nonetheless, Fisher remained distant. He "had his own set of issues and stayed away thinking he would probably be more of a negative influence on Andrew," said Jacqueline.

Both Andrew and Jacqueline say that Fisher was consumed with his own success, living life in the fast lane. In April of this year, Fisher was found murdered in his home, part of a triple homicide by a tattoo parlor owner involved in selling drugs and running an escort service.

Fisher's company website said about the 46-year-old founder: "All who knew Bryan knew he possessed an all-consuming passion for power and precision, which manifested itself through his love of airplanes, cigarette boats, Ducati motorcycles, and scary fast sports cars. That same passion guided his equipment designs and broke the industry mold."

Andrew visited Excel Manufacturing the week after his father's death to meet his employees and take them out for an informal dinner, something they said that his father would have done. "I tried to take away just the positive things," said Andrew.

For a ninth-grade science project, he built a two-foot-tall Tesla coil, something his teacher didn't believe he — or anyone his age — could do.

YOUTH MOVEMENT: (Top) Bilal Ghalib, Jeff Sturges, and Archer are movers in the Metro Detroit maker scene. (Bottom) The three join Claire Fisher and Alexander Honkala at the All Hands Active hackerspace in Ann Arbor.

BRIGHT BOT: Archer's factory robot, called the Orange Twinkie, uses computer vision to move along a defined path and detect obstacles along the way.

Like his father, Andrew has a fascination with motorcycles. On a summer night in 2009, Andrew was riding a Ducati Hypermotard and hit a broken culvert. "When I crashed, my first thought was — oh God, my bike."

He didn't notice at first that he'd nearly torn his thumb off and his foot was crushed. Regardless, he rode the motorcycle to the hospital. His injuries, which included a lacerated spleen, kept him in the ICU for several weeks. Doctors worked to reconstruct his foot, and he used a walker for the rest of the summer. His planned move to Detroit would have to wait until October.

Jacqueline helped Andrew find a place overlooking the Detroit River in a brick building near the downtown area. He set up a small workshop where he could work whenever he wanted. There's orange tape on the wooden floor for testing some of his line-following robots, and his furniture comes from antique stores.

After Andrew connected with Jeff in January of 2010, they began working together to meet a March deadline for the factory robot. "I give everyone a test to find out what they can do," said Andrew. "Jeff got 94% on the test. It's really hard. Electrical engineers coming out of school would get about 64% on the test. That Jeff did so well is really odd because he has an architectural background."

Jeff, a young 33, started out by assembling circuit boards, doing surface-mount assembly, and learning how to test the boards. With his excellent people skills, he soon began doing project management.

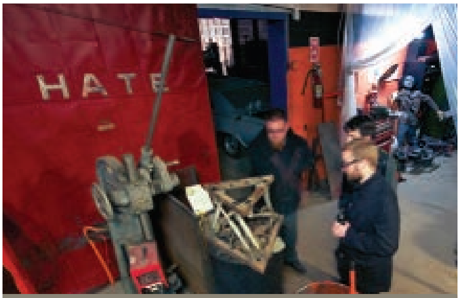
Jeff also recruited Bilal Ghalib, a maker from Ann Arbor, Mich., who organized the All Hands Active hackerspace there. Bilal's job was to write the laser-scanner interface for the robot. "I just threw him at it," Andrew said. "I didn't give him any instructions, and he did it."

Meanwhile, Jeff was also looking to find a place in downtown Detroit to set up a hackerspace. On a cold March day, he was in the Eastern Market district looking at vacant buildings in the old meatpacking area. The buildings smelled of dried blood and worse, and they were in terrible shape.

Pieces of mail were strewn about the floors, a good many of them delinquent tax notices. Jeff could see only the possibilities for each space, believing that they could be transformed. He liked the support he was getting from the

Photography by Andrew Archer

Andy Malone builds mechanical automata in his Detroit-area garage.



Chip Flynn has created The Destroy Space in Detroit.

MAKERS AND SPACES IN METRO DETROIT

Dale Grover, Bob Stack, and Eric Kauppi set up the A2 MechShop in Ann Arbor, Mich., a co-engineering space where several small companies share warehouse space, tools, and the open exchange of ideas. Current Motor Company, a small team of former Ford engineers creating electric motorcycles, is one of the companies located at A2 MechShop. Dale and Bob also host monthly meetings of GO-Tech Makers, which offers locals a chance to show off their stuff. Dale, Bob, and Jim Deakins put together the Ann Arbor Mini Maker Faire, which was held for the second time in June. a2mechshop.com

Bilal Ghalib is an excitable hacker who instigated the All Hands Active hackerspace in Ann Arbor. Last year, he bought a JetBlue ticket that was good for unlimited travel in America for one month and visited every hackerspace he could, creating footage for a possible documentary. He also teaches silk-screening at a local teen center. allhandsactive.com

Andrew Sliwinski is a very creative, energetic maker at O2 Creative Solutions in Royal Oak. He and his multidisciplinary team create interactive devices and design experiences for clients around the country. His Sketch3D is a variant of Etch A Sketch that lets you draw and view drawings in 3D. Most recently, he created sketching software integrating HP technology into a fashion design solution for *Project Runway*. o2creativesolutions.com

Russ Wolfe and Nicholas Britsky are behind i3 Detroit, a hackerspace that started in Royal Oak and moved to larger quarters in Ferndale, just north of Detroit. Taking advantage of cheap real estate and a growing membership, i3 Detroit is one of the largest hackerspaces in the country. i3detroit.com

Lish Dorset is a social media monger by day, helping companies connect on Twitter and Facebook. She's also one of the leaders in the local craft community, organizing Handmade Detroit, a thriving craft fair in downtown Detroit. handmadedetroit.com

Andy Malone lives on a quiet suburban street, but his mechanical automata are born of the city, especially his 1967 Rebellion Chess Set. The chess pieces are kinetic sculptures based on the history of the Detroit riot (or rebellion). The rook is a speakeasy, which is where things first got ugly. The king is a politician and the queen is the media. A designer of museum exhibits by day, Andy has a ShopBot in his garage, where he builds his automata. andymalone.com

Bethany Shorb has her own eco-friendly screen-printing business, Cyberoptix Tie Lab, in downtown Detroit. She transforms neckties into something with a punk attitude, selling them direct online and from her own Etsy store. She says that while you can make things in Detroit, it's hard to sell enough there — that's why she relies on selling over the internet. cyberoptix.com

Workantile Exchange is a co-working space in Ann Arbor where regulars share an open work environment, right behind a coffee shop. On my recent visit, James P. Sweeney was working on the MAKE Controller as the brains of a RFID door-entry system for members. workantileexchange.com

Chip Flynn moved to the Bay Area from Detroit and worked with Survival Research Labs (SRL). Now he's doing his own thing back in Detroit in a downtown warehouse guarded by rather softhearted junkyard dogs. He calls it The Destroy Space, a place where old machinery is waiting to be used or broken down and Chip's mechanical robots wait to be activated. His "apetechnology" machines are loud and dangerous, qualities that don't seem particularly out of place in Detroit.

Photography by Bethany Shorb

> "The hobbyist way is a really effective way to do things. We're utilizing tools that are available to everyone. I'm wanting to do some things that are unconventional."

management of Eastern Market, the location of the city's largest farmer's market and an area in need of new occupants now that the butchers had left town.

Andrew's nickname for his factory robot is the Orange Twinkie. About three feet long and a foot-and-a-half tall, the Orange Twinkie consists of subsystems for vision, drive, safety, and human interface, all tied together by a core system running under the Microsoft .Net Micro Framework, which is what Andrew programs.

I saw a demonstration of the Orange Twinkie, moving autonomously around a test track defined by orange tape. Its goal was to approach a heavy item, pick it up, and relocate it. All the while the robot was busy, it played a chiptune from the Nintendo 64 game Mega Man, which Bilal had added.

A well-built Lego Mindstorms robot could follow tape using a sensor to detect contrast between the floor and the tape; however, a factory environment is not a typical Lego playfield. The tape can be removed easily to disrupt the robot, and the robot needs to be able to know if there are any obstacles in the way.

Andrew's robot can follow the tape, but it also knows what to do if it gets bumped off the path. One of its upgrades is a vision system that can tell if people are in its path. If pushed away from the tape, the robot can reorient itself and get back on track. Andrew explained: "We have forward-looking vision and see ten feet out. We can cross aisles without having to put tape there."

He's learning about just how harsh the factory environment is. The robot will get kicked and even abused by workers who don't like that a robot may be doing a job previously done by humans. One engineer who's been in the field for 20 years told Andrew about examining a damaged robot that had numerous holes drilled in it, making it look like Swiss cheese.

The March deadline for the Orange Twinkie was set so that a safety inspector from one of the auto companies could put the robot through a battery of tests. "I am here to try and destroy your robot," he said.

Andrew couldn't believe it as the inspector slammed the robot, tried to kick in its sensors, and pushed against it to spin it violently off its path. Andrew perceived it as abuse and took a personal dislike to the inspector.

Jeff said it was "shocking that the guy took incredible pride in trying to defeat what the robot wanted to do." The robot withstood the beating, but it didn't pass all the tests that day.

Andrew knew the robot would perform better over time. He was mainly satisfied that he and his band of hobbyists worked so well together.

"The hobbyist way is a really effective way to do things," Andrew told me. "We're utilizing tools that are available to everyone." He wants Robotics Redefined to become a kind of think tank for building things. "I'm wanting to do some things that are unconventional," he said with boundless enthusiasm.

By mid-April, Jeff had found a place in Eastern Market and formed hackerspace Omni Corp Detroit with a group of makers including Bethany Shorb and Andrew Sliwinski. With a grant from the Kresge Foundation, he's developing an entrepreneurial community workshop to build tools for urban farming, in association with Earthworks, a leader in Detroit's urban agriculture movement. And he's teaching electronics classes for kids.

"This is what I wanted to be doing," Jeff said. "This is why I came here."

Detroit's a wide-open frontier.

Dale Dougherty is the founder of MAKE magazine and GM of the Maker Media division of O'Reilly Media.

Photograph by Michelle Andonian, from the collections of The Henry Ford

58 Bagley Ave.

The workshop where Henry Ford made his first car. By Marc Greuther

A workspace, tools, a project or two — hardly an unfamiliar scenario for readers of MAKE, except that this is Henry Ford's workshop, his first car, and on the bench, his first engine.

But not exactly. In fact, the engine and car, even the workshop itself, are reproductions.

The original space, a small brick outbuilding behind Ford's modest house on Detroit's Bagley Avenue, was intended to store coal and wood. Ford established a workshop there and equipped it with a small lathe, drill press, and basic tools. After reading about an engine design in *American Machinist* he decided to build a vehicle he came to call the Quadricycle; his neighbor, fascinated by the project, allowed expansion into his half of the structure.

In early June 1896 — the precise date is uncertain — the finished vehicle was ready for its first run. The workshop's door onto the alley, too narrow for the now fully assembled vehicle, was swiftly modified with the help of a handy axe.

By the time Henry Ford began to collect historic buildings for Greenfield Village — his educational site in Dearborn, Mich. — the original workshop had been demolished. Charles Brady King, an old friend (and the first person to drive a horseless carriage on the streets of Detroit) did the detective work needed to re-create the little building.

In a 1932 letter to Ford, King pondered the vast changes brought about by his friend's accomplishment. Marveling at how Ford had achieved such success from humble beginnings, King made a startling suggestion regarding the power of a workspace: "Perhaps '58 Bagley' did it. Who knows?"

A space for storing fuel instead becomes the fuel? It's not too alien a notion for Ford, who, after all, regarded the artifacts and buildings he was then assembling as capable of teaching "more than books will teach."

The re-created Bagley Avenue workshop stands not only as testament to the convergence of talents, dreams, and fingertip knowledge that played out there in 1896, but also as inspiration — and provocation. How about your space — where is it pointing you?

Marc Greuther is chief curator at The Henry Ford in Dearborn, Mich.

Slag Social

The art and community of the DIY iron pour. By Joe Sandor

Cracking iron is one of the most difficult, labor-intensive processes in art making. Busting up old cast-iron bathtubs and radiators into little pieces with a sledgehammer can be very taxing on an artist's delicate hands.

When I first went to art school, the counselors told me to take a life drawing class or a pottery class because they're so calming. But I'm pretty sadistic, and I like to smash things and set things on fire, so by the end of my first year I found myself down in the dark dungeon known as the foundry, pulverizing iron so that we could melt it down and make some sculpture.

In the past 30 years or so, cast-iron art has grown into a vast, nationwide network of artists building their own iron-melting furnaces. These furnaces, known as cupolas, are taken to get-togethers called iron pours that are held anywhere and everywhere — alleys in Brooklyn, farm fields in Wisconsin, even in the lonely deserts of Arizona. Most of the gear is homemade, a lot of the materials for melting are either scrap metal or donated, and almost all the labor comes free with the iron-pouring community.

Some cupolas are custom fabricated, while others are repurposed objects such as water heaters or garbage cans. Basically anything that's tube-shaped will work, as long as you can line it with 3 inches of high-temperature refractory material. Add a few tuyeres (holes for blasting air), one spout for slag and another for the metal to tap out of, and a trap door on the bottom, and you've got an iron furnace. I've even seen a soda can used as a cupola.

Once you have the cupola, you fill it up with bits of iron and enough charges of black, chunky coke

Photograph by Jeffrey Kalstrom

FIRE IN THE HOLE: (Opposite) Starting a bonfire at Broc Allen's studio. (This page, from left) George Beasley's Elm Tree Cupola; Hans Wolfe and SAIC students; Joe Sandor's *Towers* sculpture of nickel-plated cast iron, steel, wood, and brick.

Photography by Joe Sandor

and limestone to melt the metal, at which point a steel spike is driven into the tap spout, releasing the clay plug holding back the well of molten iron.

Then sweet, glowing orange metal comes spewing into a ladle and is poured into premade sand molds which are usually made at a mold-making workshop the week before. Patterns for molds can be abstract or representational, as small as a belt buckle or as large as a cannon.

Pours are usually two-day events. The first day is for setting up all the portable gear, lighting the furnace in the evening, and melting iron until all the molds are filled. The night culminates in the ever-popular "dropping bottom," where the trap door in each cupola is kicked open and all the white-hot coke and slag comes flaming out, relieving the furnace of the high temperatures. This is the most fiery spectacle for a gathering of pyromaniacs, and usually the most popular with photographers.

Everything is left to cool overnight (most participants camp nearby), and in the morning, individuals break apart their sand molds to check out how well the metal cast. The castings are packed up to be cleaned and polished later, and everything else is broken down and put away for the next pour.

I initially got into metal casting as a way of making art but ended up discovering a whole community of makers. And as satisfying as it is to drive a sledgehammer through an old bathtub, it's all about producing work.

In 2008, with the help of some friends, I built a furnace and started an annual pour at the Broc Allen Ceramics Studio in northern Wisconsin near where I grew up, on the south shore of Lake Superior. It's a small pour, but it has a good vibe, and it's nice having control over how much metal I can actually cast (a lot of pours have weight limits).

And this last spring, the School of the Art Institute of Chicago (SAIC), where I first learned casting, had its 20th annual Lake Bluff Iron Pour. It was a three-day event, filled with fire performances, a chili cook-off (I won for Hottest Chili), and a people-powered cupola trolley blasted with bellows made of old foundry leathers. I even got to make some art.

+ Iron pour resources: makezine.com/23/ironpour

Joe Sandor is a sculptor, painter, photographer, poet, and bartender working in Chicago. joesandorphoto.com

Hacking Club-Mate

A popular hacker energy drink gets homebrewed. By John Baichtal

Computer programmers have always loved caffeinated beverages, whether Mountain Dew, Jolt, or plain old coffee. It helps them keep their groove going overnight as they crank out code. German hackers, however, prefer a lightly carbonated yerba maté iced tea called Club-Mate (kloop MAH-tuh) and lately this beverage has made its way to the United States where it's caught on among the homegrown hackerati.

Emmanuel Goldstein, publisher of hacker zine *2600: The Hacker Quarterly*, first encountered Club-Mate at a convention in Germany.

"I noticed all of these German hackers running around with these glass bottles filled with some sort of energy drink. It was a pretty weird scene," Goldstein says. "Then the Americans tried it out, and all they could do was talk about how amazing it was. In front of my eyes they became addicted."

Hackers seem to love the fact that Club-Mate keeps them up at night without the crashes and jitters that accompany other energy drinks. "The buzz just slowly dissipates and you can go to sleep if you need to," Goldstein explains.

At the same time, the beverage has a taste that the most adventurous of foodies would describe as unique. Many people find it repulsive when they first taste it, and yet, Club-Mate has found legions of fans around the world.

Manufactured in Münchsteinach, Germany, by Brauerei Loscher KG, a fifth-generation family brewery, Club-Mate's unofficial but oft-repeated slogan is "Man gewöhnt sich daran" which translates roughly as "You get used to it!"

In 2008, Goldstein set about importing Club-Mate to the United States, intending to feature it at Hackers on Planet Earth (HOPE), a hacker conven-

Photography by John Baichtal

DAVE-MATE RECIPE

(Makes about 1 liter)
1L water
50mL (3½Tbsp or 20g) yerba maté tea leaves
15mL agave syrup
15mL simple syrup
1.25mL (¼tsp) molasses
1.25mL (¼tsp) guarana
0.6125mL (⅛tsp) citric acid
Drop of orange bitters

Heat the water to 75°C/167°F, then steep the yerba maté in the water for 5 minutes.

Strain the tea into another container. You may need to filter multiple times to remove all the sediment.

Add the sweeteners, citric acid, bitters, and guarana. (Simple syrup is 1 part sugar dissolved in 1 part hot water.) The guarana simply serves as concentrated caffeine — it doesn't add any flavor, but it may affect the overall flavor of the beverage.

Stir until blended, then carbonate. Toews used a 1L soda bottle with a carbonator cap, then added CO_2 from a cartridge using a method called forced carbonation. This equipment and instructions on the process may be found in any home brewing store.

tion he helps organize. It was quite an undertaking. The pallets had to be shipped from Europe via freighter, and there were frequent delays.

On top of that, the shipping costs at least equaled the cost of the beverage. Goldstein overcame the hurdles and Club-Mate made its U.S. debut at the convention. "People who haven't had a bottle since then still remember it vividly," Goldstein says. "That can be seen as either a good or a bad thing."

Goldstein is now the sole U.S. distributor of Club-Mate. A 12-bottle case costs about $60 with shipping. A pallet of 800 bottles comes to about $3 per bottle. Either way it's a pricy proposition, which has led some fans to question the need to ship the product from thousands of miles away when theoretically, it could be brewed in anyone's kitchen.

Case in point is David Toews of Minneapolis, Minn., who was intrigued by Club-Mate's punch and its odd flavor. "I've always had a thing for weird caffeinated beverages," he says. "I used to order Bawls from ThinkGeek during my college's 40-hour trivia marathon when the only place you could get it was online."

Faced with the steep costs of shipping Club-Mate, and knowing that he could easily acquire the basic ingredients, Toews decided to brew his own.

Toews (pronounced TAYVZ) began with a kilogram sack of yerba maté (yur-buh MAH-tay), the heavily caffeinated herb that provides the core flavor of the beverage. Known to scientists as *Ilex paraguariensis*, yerba maté is a species of holly used to make a traditional South American tea, drunk from a gourd.

For his first batch, Toews skipped Club-Mate's high-fructose corn syrup (HFCS) in favor of agave syrup, a sweetener produced in Mexico. "I'm not sold on the whole HFCS health controversy, but I tend to prefer sugar-based beverages due to the smoother flavor profiles," Toews says. "I sort of stumbled upon the agave at Costco, and decided to give it a try."

After steeping the yerba maté for five minutes, Toews strained the tea and added the other ingredients — the agave and a bit of citric acid for tartness — then carbonated the result in his kegerator.

And how did the batch turn out? "Absolutely mouth-puckering," Toews admits. "I thought that carbonating it might mitigate the sourness, but it was not to be. It was very encouraging, though, to be able to taste the tea flavor and tell that I might be able to replicate it with a bit more tweaking."

Intent on matching the flavor of the original beverage, Toews set out to equal its sweetness. His wife, Sarah, provided invaluable assistance, suggesting various combinations of simple syrup, corn syrup, and molasses in place of some of the agave. Toews also reduced the steeping temperature a few degrees to help mitigate the astringency of the first batch.

Toews continued refining his recipe, producing 1-liter batches, tweaking the mix, and then trying again. "Whenever you reduce a liquid to extract form, you lose some of the subtlety. I think this is also why the Club-Mate has that malty aspect to it," he says. "When I brew beer, and want to create that profile, I'll boil the wort longer, creating more Maillard reaction compounds that are associated with malty and caramel flavors."

With batch six, Toews called it done. The resulting beverage, which he calls Dave-Mate, is extremely close to the original, while displaying a unique twist. So what's next? "I think I'd like to try a hybrid process in which I melded the maté with a light-style beer to make a hacker-friendly alco-pop," he says.

He's excitedly producing batches of Dave-Mate for the new Twin Cities hackerspace, the Hack Factory. "It would be my small contribution to insomnia for the sake of creativity," he says.

John Baichtal is a contributing writer for makezine.com and *Wired*'s geekdad.com.

Stone Age Telegraph

Armed only with information, I turn rocks and sticks into an electronic signal. By Jamie O'Shea

All of my tools are made by bigger tools somewhere else. How far back does this lineage of tools go? I wondered if someone alone in the woods could make an Information Age object, armed with nothing but information?

In the summer of 2009, I headed out for the wilderness of Mineral County, Montana, to test this question. With no tools or materials except the ability to search the internet, I endeavored to learn how sticks and stones lying on the ground have been transformed into a metallic, electric society. The question would ultimately demonstrate whether electronic technologies could have existed at any point in history, if only people had had the know-how.

My goal was to create a telegraph switch and battery, capable of producing and modulating an electrical signal — the start of an ahistorical internet.

Quest for Fire

The project became a study of fire. In order to produce a voltage, I would need to melt metals from their rock ores, and this requires a very hot fire.

Beginning empty-handed, I needed something to collect piles of material from the surrounding area — so my first tool was a simple basket, woven with tree bark that a beaver had chewed down.

Next came axes, ropes, and knives made of chipped stones and plant fibers. This suite of caveman tools was in the interest of making fire. I opted for a bow drill fire starter (*see MAKE Volume 21, page 123*), and bloodied my hands for days spinning two sticks together in an attempt to create wood

Photography by Liz Filardi

PALEOLITHIC ELECTRONICS: (Top) Every tool and material O'Shea used to produce a telegraph in the wilderness. (Below, left) The Immaculate Telegraph, a powered momentary switch built entirely without modern tools or materials. The lever is a sapling switch, and the battery is made from copper and iron disks sandwiched between slices of potato held in a clay cup. (Below, right) A multimeter measures the telegraph producing 0.36 volts.

dust and heat it to 800°F.

The tiny ember produced in this way represented a crucial step, releasing energy on its own, so I wouldn't have to do all the work anymore. Before this, for every chipped stone, gouged log, and dug hole, the energy had to come through my own muscles. It's quite humbling to realize how little impact a human with no tools can have — the activities of beavers seemed like impossible feats to me after a few days, let alone the roads and houses I would return to at the end of the day.

Finally, once I conceded to using a nylon rope for my bow drill, I was able to whoop for joy as I created a campfire. Given more time and less rainy weather, I'm confident I could have made it work with plant fiber rope, but I had to move on. For now, the nylon persists in my process like an umbilical cord to industry.

Google provided enough information to teach me the bow drill — which types of wood to use, what the ashy dust should look like, and how to bring an ember to a fire once I had kindled it. But a campfire didn't prove anything yet; it would be a long time before I got this fire to the transformative temperatures of the Metal Ages.

Ore Country

Collecting metal ores wasn't too difficult in my location. Dozens of out-of-use mines pockmark the mountains in Mineral County. Copper ores often look metallic, or show vibrant greens and blues. Iron ore can look like chunks of rust.

If I had relied only on internet information to find these locations, I would have ended up on the tops of mountains for no reason. I found precise coordinates that were precisely a mile off. Some mines had no record at all, merely piles of leftover rocks at the collapsed entrances. Once again I needed local advice, as well as paper maps, to find them.

Smelter Fail

The task of constructing a metal smelting furnace exceeded the information I found freely available online. My first furnace was hopelessly naive; I was wasting my energy pumping bellows for hours and sucking poisonous gases.

In retrospect, it's possible I got mild arsenic poisoning twice, from roasting ores containing the heavy metal in open air and breathing it. This blunder illustrated that more-natural technologies are not automatically more environmentally sound: my

FIERY FURNACE: The furnace, used to extract copper from ore and forge iron, was the biggest challenge in making the Stone Age telegraph. After many setbacks, a charcoal fire was hot enough to smelt copper, and a few days after that the author was able to make iron. (Left) A view into the furnace through the air intake, as the fire approaches 2,000° F. (Right) After the wooden chimney on the first smelting furnace went up in flames, the author built a chimney of river clay and flat stones.

furnace had no emissions control and consumed charcoal very inefficiently.

This first trial probably never got above the temperature of a campfire. I had to give up on Session One of the project after picking through the remnants of this failed furnace and coming up with handfuls of ash. I was mired in the Paleolithic, nothing more than a caveman with big dreams.

When I returned in the fall, I came armed with a dozen detailed articles from paid-access archives, about ancient furnaces in the Andes, Africa, and the Middle East. I started construction of a new, much smaller furnace with a chimney set into a hillside. Foolishly, I started with a wooden chimney. It went up in flames.

I mortared a new chimney with river clay and flat stones, and set to work building bellows. The most effective one ended up looking like a classic European fireplace bellows. At most points in this process, however, a classic mental picture of a tool led me astray; making something that looked like an axe was a waste of time, when just the head of an axe in my hand did the job.

Metal Triumph

Within a couple weeks of refining my technique, I was melting rocks and achieving the right temperatures, and soon I had tiny lumps of metal: first copper, and then wrought iron. Pounding these into disks and placing wedges of potato between them, I arrived at the simplest electric battery.

In the end, I triumphed, and was able to assemble a switch producing Morse code at 0.7 volts — a working telegraph possible in the Stone Age.

Of course, this success is incomplete by itself. What good is a signal with no receiver? To go any further, I would need the cooperation of many other people, to build a wire network, and receivers, and to learn a code system.

In fact, I had already relied heavily on cooperation to make my metal switch. In order to have six weeks of free time to do this project, I had all my needs taken care of by modern society.

It may very well have proved impossible for a lone Paleolithic human to convince the people around her to participate in electronic communication. Even in the 1840s, Samuel Morse's telegraph was mocked in Congress as a conjuring trick.

DIY goes only so far, because there is no communication with only one person.

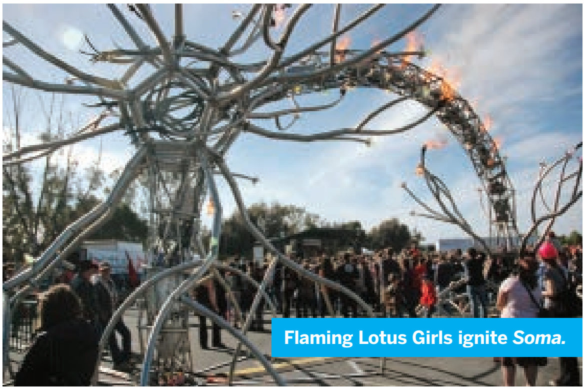
Videos and more information about Immaculate Telegraphy can be found at immaculatetelegraphy.tumblr.com.

This project was supported by the Eyebeam Honorary Residency and hosted at the Johnson Creek Ranch, with big thanks to Liz Filardi for producing the video and web content.

Jamie O'Shea (substitutematerials.com) is an artist and inventor in New York City. His projects include automating memory, finding new ways to sleep, and bending the definition of time.

ArcAttack frontman (in Faraday suit) is zapped by singing Tesla coils.

The four-story *Raygun Gothic Rocket.*



Flaming Lotus Girls ignite *Soma.*

Steam fanciers have a field day.

Maker Faire 2010: Going East

Born in 2005 as a maker meetup, Maker Faire (makerfaire.com) is the world's largest DIY festival, celebrating homegrown technology from robots and rockets to food, arts, and crafts. This May's Faire in the San Francisco Bay Area topped 600 makers and 80,000 attendees. Next up: Maker Faire Detroit at the end of July, and the first-ever World Maker Faire at the New York Hall of Science in September. For the creative and curious, it's a family-friendly gathering of the tribes not to be missed.

Photography by Becky Stern (ArcAttack), Blake Maloof (*Soma*), Cris Benton (*Rocket*)

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Make: GADGETS

DEVICES OF WONDER: Arthur C. Clarke famously said, “Any sufficiently advanced technology is indistinguishable from magic.” In this special section, MAKE presents a menagerie of magically delightful gadgets: a mosquito death ray, an interactive spirit behind a mirror, an illuminated prop only you can control, and four other surprising gizmos.

BEAM WEAPON FOR BAD BUGS
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BEAM WEAPON FOR BAD BUGS

How to make a Mosquito Defense Shield.

BY 3RIC JOHANSON

I have a nice gig: I get paid to invent ways to use lasers, optics, and computers to destroy mosquitoes. I work at Intellectual Ventures Lab, which is part of Intellectual Ventures, founded in 2000 by Microsoft's former chief technology officer, Nathan Myhrvold. At the lab, which is in Bellevue, Wash., we turn ideas into proof-of-concept inventions, such as a deep-brain surgery tool, a system to weaken hurricanes, and a super-thermos to transport vaccines.

In 2007, Bill Gates (who co-chairs the Bill & Melinda Gates Foundation with his wife and father) asked us to think differently about how to wipe out malaria. Mosquitoes are a big problem in many parts of the world, and not just because they ruin barbecues.

Infected mosquitoes transfer a parasite that causes malaria. When you're infected with malaria, not only do you feel miserable, you may die — particularly if you're very young. It's a tragic sickness that infects nearly 250 million people every year and kills close to a million of them, mostly in Africa.

If you take mosquitoes out of the equation, people with malaria either get better or die without transmitting it, and the disease goes away. At one time, DDT was commonly used to kill mosquitoes, but because of its unfortunate environmental impact, its use has become very limited.

Today, big money is being invested in a number of ways to attack malaria, including vaccines and defenses such as bed nets and wall sprays. However, these aren't completely effective (drugs are misused, resulting in drug-resistant malaria parasites, and bed nets are frequently removed from beds). In short, the current tools aren't adequate, and something additional is needed to help.

As inventors, we're constantly discovering how we can use computers to change the world. So we asked ourselves: could we leverage Moore's Law to help reduce the population of mosquitoes? More specifically, could we design and build a system capable of detecting mosquitoes and blasting them out of the air with lasers?

Honestly, when the idea was first proposed to me two years ago by physicist Lowell Wood, Myhrvold, and Jordin Kare (a colleague at Intellectual Ventures Lab), I was skeptical at such an outlandish notion. Others broke out in laughter. But I began thinking about it seriously, and I came around to the idea because I realized it might actually work. You see, I'm a hacker, and I love to work on both hardware and software projects. The skills I've picked up as a hobbyist could be applied to this project.

Five years ago, I opened a hackers' workshop in Seattle. We have an assortment of tools: an 11,000-pound mill, sewing machines, CNC lathes, and MakerBots. Every Saturday we host Hackerbot Labs (hackerbotlabs.com), where friends come over to break and/or make things for fun.

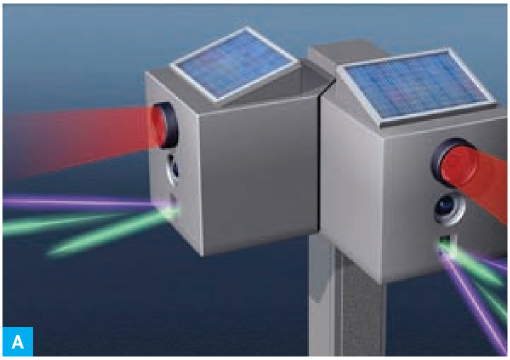
It was on one of these nights about four years ago that some friends and I built a sentry robot to enter into a competition at the annual Def Con hacking conference in Las Vegas. In this competition, teams compete to shoot white targets off shelves. It's like a shooting gallery for airsoft guns, but instead of people shooting the guns, it's robots.

We hacked our contraption together using some

COMPONENTS OF THE MOSQUITO DEATH RAY

- **A** Tracking camera and LED illuminator
- **B** Fresnel lens for focusing the return wing-beat frequency signal
- **C** Photodiode for sensing the return wing-beat frequency signal
- **D** Laser control box
- **E** Mirror galvanometer for aiming the laser
- **F** Laptop for controlling the device
- **G** Power supplies and UPS (enclosed)
- **H** 3ric Johanson, project scientist at Intellectual Ventures

Photography by John Keatley; illustration by Adam Koford



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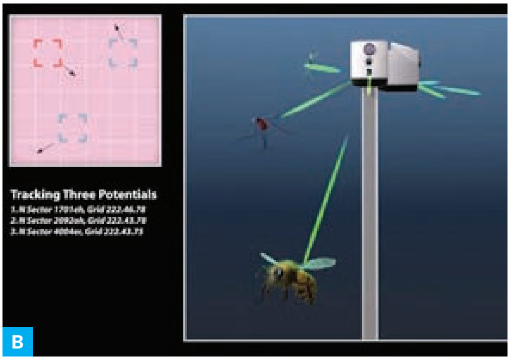

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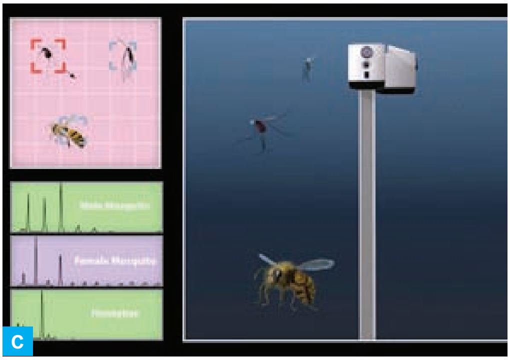

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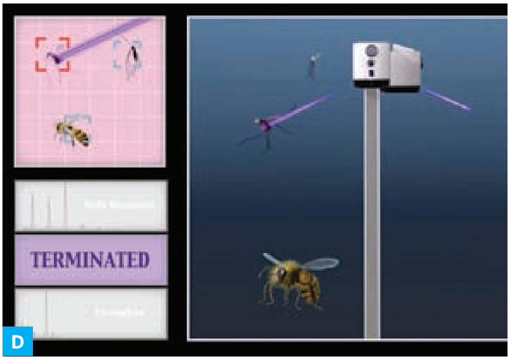


D

facial recognition software adapted to identify small white targets instead of faces, and implemented a MAKE Controller to control servos for making the gun pan and tilt. We used web cams as the robot's eyes; it was a messy robot with plenty of duct tape holding it together. There were a lot of autonomous robots competing, and somehow our bundle of parts managed to win third place — not because it was the fastest, but because it was reliable.

Shortly after that I started making my own laser light show by shining lasers into a mirror and moving the mirror so I could make patterns on the wall. I got hooked on lasers.

Ultimately I realized that a mosquito tracking and zapping system was not only possible, but it could be done using less than a couple of thousand dollars' worth of hardware. I could combine my love of lasers with my hacking experience to make something new and exciting that could be an important part of a comprehensive solution Intellectual Ventures is working on to improve and save millions of lives by helping to eradicate malaria.

Making the Photonic Fence

I had the honor of teaming up with a few ridiculously smart people, such as Jeremy Bruestle, Phil Rutschman, Dave Nash, Nathan Pegram, Daniel MacDonald, Geoff Deane, Jordin Kare, Lowell Wood, Nathan Myhrvold, and Nels Peterson. Starting from scratch, we identified the key hardware and software challenges in making what we came to call the "photonic fence insect tracker." They were: spotting and tracking tiny flying insects at a distance, singling out mosquitoes from other flying insects, and zapping the mosquitoes in midflight. What follows is a description of how we did it.

Fig. A: ILLUMINATE: LEDs (red) light a backdrop.
Fig. B: SCAN AND TRACK: The camera sees bugs, software tracks them, and a laser spotlights them.
Fig. C: IDENTIFY: Software compares wing-beat frequencies to pick out the female mosquitoes.
Fig. D: TARGET AND KILL: *Pew pew pew!* A high-powered laser kills the target insects.
Fig. E: LONG RANGE: The photonic fence demonstration system tracks and IDs insects 100 feet away.

Where Is It?

How do you (or a computer vision system) spot a 2mm black insect from distances up to 100 feet away, in the dark? Under such conditions, direct illumination is out of the question. A better solution is to project light on a retroreflector and look for

Illustrations courtesy Intellectual Ventures

black dots flying in front of the illuminated backdrop. (A retroreflector is simply a surface that reflects light back in the direction of its origin, with a minimum of scattering. It works by having thousands of little corner prisms along its surface. They're commonly used on street signs.) We purchased a large sheet of retroreflector material, which cost about $1 per square foot.

Next, we looked at different ways to illuminate the retroreflector. Possibilities included LEDs, flashlights, flood lamps, and even very low-power lasers. As it turned out, standard consumer-grade LED flashlights worked well enough for our purpose.

We mounted the LED flashlights in a square pattern with a 35mm camera lens (hooked up to a CMOS or CCD sensor) in the middle. In this setup, the camera sees the silhouette of anything between it and the retroreflector. We then placed a 10-gallon fish tank filled with mosquitoes into the field of view, and we were able to see them flying around. (During early testing, we also made use of a fake insect dangled from a fishing line by waving it around with an electromechanical device.)

Now that we had a way to see the mosquitoes, we could track them using image recognition and machine vision software (OpenCV is an amazing software package that makes the process of tracking moving objects trivial). Tracking allowed us to lock the bugs into the machine vision software's crosshairs. But we weren't ready to start blasting away at them yet. We decided to raise the bar by inventing a system that would shoot only mosquitoes and leave honeybees and other flying insects alone. That led to the second challenge of our system.

What Is It?

How can a computer tell the difference between a mosquito and a bee? There are several ways: by measuring the size of the target, how fast it's moving, or how fast it beats its wings. Mosquitoes beat their wings at a much higher frequency than most other insects and have a distinct harmonic component. By looking at all of these data points, we can confirm the genus and gender of an insect. (Only female mosquitoes bite, and male mosquitoes beat their wings more quickly due to smaller body size.) How do you hear the wing-beat frequency of a tiny insect from hundreds of feet away? Optically!

First, we had to see if it was even possible to optically measure wing-beat frequency. We had a camera that could record up to about 2,000 frames per second, but we were limited to a mere


F

64×64 pixels resolution. It's not easy to convince a mosquito to stay in a frame at such a low resolution. After several failed attempts to record them in flight, we developed a method for keeping them still: we anesthetized them with carbon dioxide, then dipped the tip of a needle in super glue and gently touched it to a bug's thorax. Ta-da! Mosquito on a stick.

Now we could test our wing-beat detection plan. This took a while — we learned that mosquitoes only want to flap their wings for so long while glued to a needle, so we had to keep a ready supply of rested mosquito shish kebabs on hand for testing. (Here's a tip about maintaining a supply of mosquitoes: make sure you have the hoses on your mosquito aspiration system connected in the correct direction, lest you spray live insects into your friend's face by mistake.)

To optically measure the wing-beat frequency, we created a kind of "photonic microphone" by pointing a low-powered laser beam at the mosquitoes. This returned a very strong retroreflective signal of the mosquito's shadow. We sent the modulated signal to a photodiode purchased through an online auction, which provided very fast, very accurate information about the wing-beat frequency.

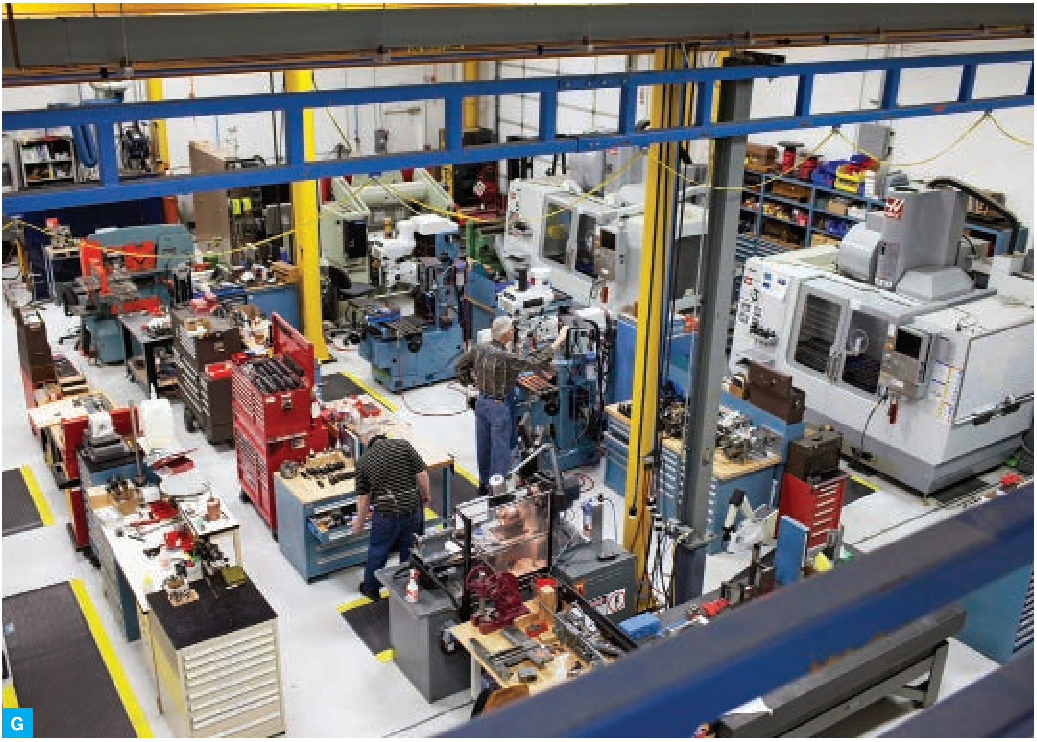
After working out all of the, um, bugs, we needed some kind of beam-steering technology so that the low-powered laser could track the free-flying mosquitoes. That's where a galvanometer (or as we call them, a galvo) came in handy. We got ours for about $100 on eBay. A galvo is basically a mirror mounted on a servomotor, and it can point a reflected beam of light in any direction.

Driving the galvo could be done from something like an Arduino acting as a digital-to-analog bridge, but I eventually figured out that we could do it with a sound card (by removing the DC blocking caps). Insects move fast, and I spent a lot of time addressing the latency of the image processing to the galvo position loop, because failure to have a timely response to new image data results in poor tracking.

With two challenges — Where is it? and What is it? — out of the way, we focused on our third:

Extermination!

Killing the mosquitoes required another galvo and another, more powerful laser. You can see videos at intellectualventureslab.com that show our early experiments with shooting mosquitoes, in which we literally burned mosquitoes to death in midflight. But we soon realized we didn't want to do that, and not only because burned mosquitoes smell really bad. We also wanted the photonic fence to be solar-



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powered, so energy conservation was critical.

By testing lasers of different wavelengths, we figured out the minimum photonic dose that would kill a mosquito within a few hours of exposure, which would render it a nonproductive member of the malaria transmission cycle. (It happens to be about 50 to 100 millijoules of energy.)

If you want to design your own insect tracking system at home, that's great, but let me offer some strong words of warning: lasers are dangerous. Just a few milliseconds of laser exposure at 5 milliwatts are enough to hurt yourself or others. If you decide to play with lasers, be careful and be aware that you face blindness if you make a mistake.

I personally always wear laser goggles, and even though I take massive amounts of caution, I've singed my beard and had to shave when the smell of burning hair wouldn't go away. I am specifically not advocating the construction of a high-powered laser system.

It's really quite satisfying just to see the insects tracked and identified. A system costing $300 could be programmed to recognize certain kinds of flying insects, or even birds, monkeys, and so on. It could even be a boon to citizen scientists who conduct migration counts.

ULTIMATE WORKSHOP: Fig. F: Intellectual Ventures Lab's electronics shop is stuffed with high-end gear purchased at auction for pennies on the dollar. Fig. G: The Lab's machine shop is fully equipped with the latest CNC tools for building prototype devices.

The Future of the Photonic Fence

We're building "rev 3" of the photonic fence. It will be much more compact and consume much less power. At Intellectual Ventures Lab, we don't make products — we prove or disprove ideas. Folks keep asking when such a device will be available for purchase. We're looking to partner with someone who can help us produce these things for mass markets. Working on projects that could help make the world a better place is something I find very satisfying.

Intellectual Ventures Lab videos and posts about the project: makezine.com/go/photonicfence

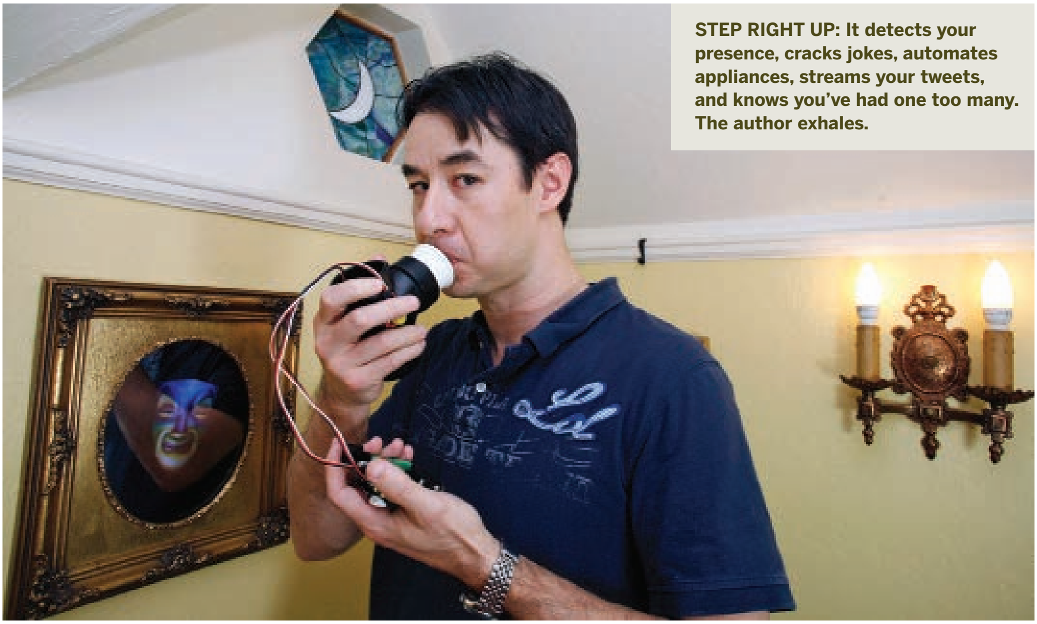
More photos of the lab and the mosquito zapper: makezine.com/23/mosquito

3ric Johanson (3ricj@intven.com) is a project scientist and entropy generator at Intellectual Ventures Laboratory.

MAGIC MIRROR

Make a know-it-all animated reflection that talks back.

BY AL LINKE



STEP RIGHT UP: It detects your presence, cracks jokes, automates appliances, streams your tweets, and knows you've had one too many. The author exhales.

Photograph by Sam Murphy

Who's the fairest of them all? Ask the Magic Mirror, which plays prerecorded animations keyed to real-world data like how close you're standing, the current weather, stock market data, even alcohol level readings from an onboard breathalyzer.

Touch a magic "weather" spot on a rainy day, and a courtly visage greets you with, "Rain I see, in all its glory. When will it end? Ask tomorrow, for the story." Or blow into the breathalyzer after a few too many, and a smart-alecky pumpkin cracks, "You're drunker than a skunk — someone get this guy's keys!"

The animations play on an LCD monitor that's hidden under a 2-way mirror and built into an ornate frame. When the screen is off, the arrangement looks like a regular mirror, but when the Magic Mirror comes to life, an eerie talking image appears behind the glass.

I made my first Magic Mirror for a playhouse that I built for my 2 girls. Since then, I've upgraded the hardware, software, and content, turning it into a kit that you can build and configure to do lots of fun things.

How It Works

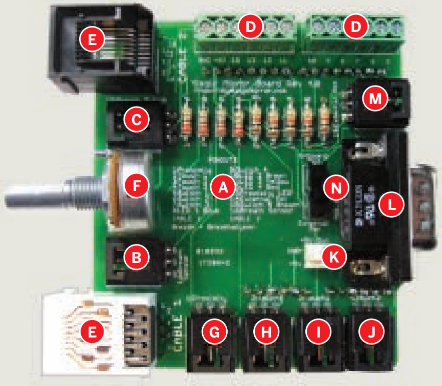
Running the show is a Seeeduino microcontroller board, an Arduino clone from Seeed Studio (seeed studio.com). For easy assembly, I made a custom Magic Mirror Shield board that fits on top of the Arduino and has plug-and-play connectors labeled for all of the controller's different inputs and outputs, plus all the necessary pull-down resistors (following page).

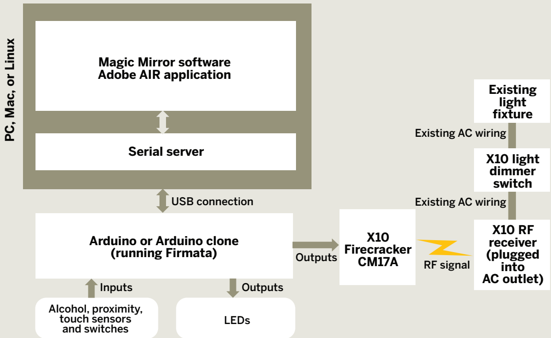
The video plays from a computer (Windows, Mac, or Linux) that's connected to the Arduino via USB. The computer uses Adobe Flash ActionScript 3.0 to run the video clips, communicating with the Arduino using the AS3glue library (code.google.com/p/as3glue).

On the Arduino side, Firmata software tells ActionScript when to trigger the clips, and also

MAGIC MIRROR SHIELD COMPONENTS AND CONNECTORS

- **A** Sensor pinout cheat sheet
- **B** Plug-and-play alcohol sensor
- **C** Plug-and-play breathalyzer switch
- **D** Screw terminal sensor connections
- **E** CAT5 cable sensor connections
- **F** Onboard potentiometer — changes the character
- **G** Proximity sensor
- **H** Plug-and-play switch or touch sensor — weather forecast
- **I** Plug-and-play switch or touch sensor — stock performance
- **J** Plug-and-play switch or touch sensor — X10 on/off control
- **K** +5V and GND Out — power for sensors connected to screw terminals and/or CAT5 cables
- **L** Connection for the optional X10 CM17A home automation transmitter
- **M** External potentiometer — changes the character
- **N** Slide switch — toggles between internal pot and external pot





Photography by Al Linke

MATERIALS

Magic Mirror kit and software $219 assembled kit with case and onboard breathalyzer from diymagicmirror.makersmarket.com, or $119 assembled kit only, from diymagicmirror.com.

PC, laptop, or netbook A 3- or 4-year-old model is fine. Software installation and setup are automated on Windows PCs; Macs or Linux boxes will also work, although they're a little more effort to set up. To save space and equipment, you can dispense with a keyboard and mouse by using a remote control program such as TightVNC (free, tightvnc.com) to install the Magic Mirror software.

LCD flat panel monitor, 15" $50 used on Craigslist

LCD flat panel wall mount

Dielectric glass mirror (2-way mirror), 12"×12" Mirror TV (hiddentelevision.com) sells a "sample" this size for $20.

Picture frame with oval matte Antique shops are good places to find a vintage frame.

LEDs (5) (optional) Use blue, green, yellow, and red for the breathalyzer indicator, or all high-intensity red for the fake fire effect.

CAT5 cable (optional) for long-distance and in-wall sensor connections. The cable should use the T-568B wiring convention as opposed to T-568A.

FOR THE INPUTS (YOUR CHOICE):

Proximity sensor MaxBotix LV-EV1, part #SEN-00639 from SparkFun Electronics (sparkfun.com)

Potentiometer

Breathalyzer (alcohol sensor) part #MQ303A from Seeedstudio (seeedstudio.com) or #SEN-08880 from SparkFun

Capacitive touch sensors (up to 3) part #ELB142D2P from Seeedstudio, or #1129 or #1110 from Phidgets (phidgets.com)

Switches, momentary or toggle (up to 5)

FOR X10 CONTROL (OPTIONAL):

FireCracker CM17A RF transmitter around $6 on eBay

X10 plug-in RF base receiver $13 from Smarthome (smarthome.com) or try eBay

LM465 lamp module, WS467 wall switch, or AM466 appliance module $8 from Smarthome, or try eBay

FOR THE BREATHALYZER HOUSING:

ABS pipe tee connector, 1½" Don't use PVC for this part; PVC emits a gas when heated that makes the alcohol sensor give a false reading.

PVC pipe reducer, 1½" to 1"

PVC pipe reducer, 1" to ½"

PVC pipe risers, ½" Get one for each guest at your party, to keep things more sanitary.

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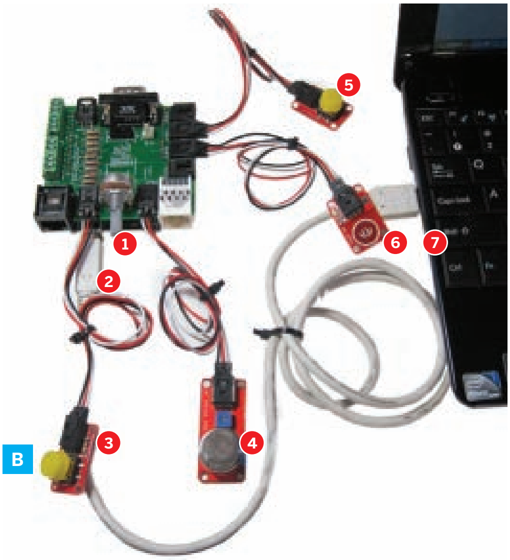

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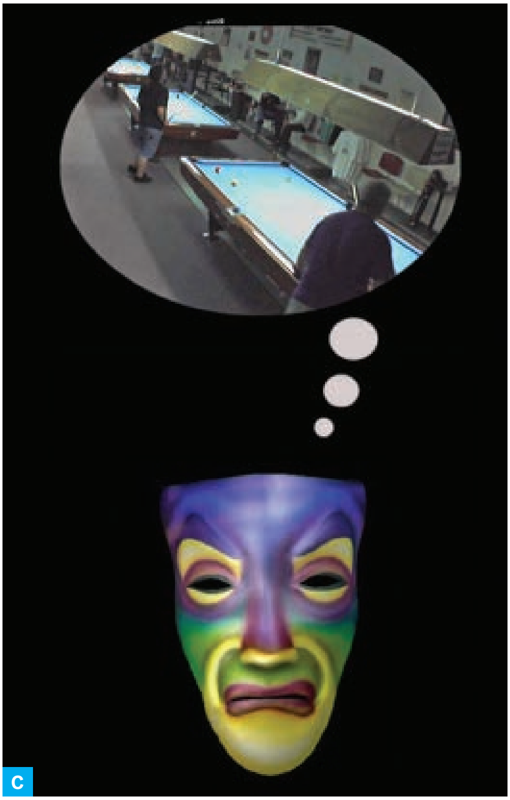
1. Changes character
2. USB to laptop
3. Triggers breathalyzer
4. Alcohol sensor
5. Stock button
6. Touch sensor weather
7. Netbook



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controls 5 LEDs: a proximity indicator, and 4 more that can operate as either a breathalyzer reading indicator or a flickering fake fire effect. With certain special clips, Firmata also switches a light (or other appliance) on and off remotely, synched with the mirror's magic incantation, via an X10 home networking module.

You can use your own animations with the Magic Mirror, but the kit software comes complete with 80 video clips that feature 4 different characters: a courtly "Princess" mask, a scary Halloween skull, pirate skull, and a "New York cabbie" jack-o-lantern that dispenses insults with a Bronx accent (Figure A).

To switch between characters, you turn an onboard potentiometer knob on the MM Shield. I went upmarket on this content, licensing digital puppet renderings from ImaginEERIEing (www.imagineerieing.com) and hiring professional voice actor Alan Harrison (alansvoice.com) for the audio. The results look and sound great. You can see all 4 sets of 20 clips at diymagicmirror.com.

In addition, the Magic Mirror can also speak your tweets from Twitter as well as speak custom sensor responses set by you using the recently added text-to-speech feature.

There are 2 versions of the Magic Mirror kit, both of which come pre-assembled: a version that's boxed up and has the character select knob and breathalyzer attached, and the raw kit version.

Either way, the electronics are basically plug-and-play; you supply compatible sensors and switches, and if they have standard headers (for 3-lead sensors) or lead pairs (for simple switches), you just


D


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F


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plug them into the MM Shield; no soldering required (Figure B).

The circuitry is easy; what takes more doing is building the display itself and embedding the sensors and wiring into your walls or wherever else you want to put them. Also, the breathalyzer needs a housing for users to blow into, so I'll show you how to make one of those, and how I installed the whole thing.

BUILD YOUR MAGIC MIRROR

Time: **1–2 Weekends**
Complexity: **Moderate**

Choose and Connect the Inputs

The Magic Mirror's range of functionality depends on which inputs you connect. The proximity sensor detects if someone is there and how far away; if they're far, the mirror asks them to come closer.

The breathalyzer detects alcohol (this sensor isn't installed in my daughters' playhouse version). On the MM Shield itself, a potentiometer knob selects which of the 4 animated characters will appear.

Capacitive touch sensors trigger weather and stock market clips; ActionScript 3.0 calls the Yahoo API for current data and then selects an appropriate clip based on whether the weather is warm, cold, or rainy, or a selected stock portfolio is up, down, or unchanged. A third capacitive sensor triggers the X10 clip, in which the animated character seems to magically turn something on and off in the room.

I used capacitive touch sensors because you can embed them into walls or other surfaces to make "magic spots" that don't look like switches. But you can also install 3 regular momentary (or toggle) switches to trigger the weather, stock, and X10 clips.

These are less expensive. You can even use both

H

I

J

in parallel; in my playhouse installation, you get the weather by either touching the wall or taking a small magnetic figurine off a shelf that has an embedded reed switch.

Two more regular switches activate additional functions. One functions as a doorbell, triggering a bell sound and showing streaming video from a webcam installed at the front door (Figure C, page 56). Another switch puts the Magic Mirror into slideshow mode, in which it displays Picasa photo albums.

There are 2 ways to go on the wiring. For short distances, it's easier to plug the sensors into the headers, and the switches and LEDs into the screw terminals. But for long runs and in-wall installation, it's better to use T-568B standard CAT5 cable, splitting out and soldering the wires on the far end.

For all connections, you can use the pinout "cheat sheet" printed in the middle of the MM Shield, and also refer to the logical and physical wiring diagrams at makezine.com/23/magicmirror. There are detailed step-by-step manuals and video tutorials at diymagicmirror.com.

Make the Mirror Display

The Magic Mirror looks like a normal mirror when the monitor is off, but when the animations are running, you can see them along with some reflection in the mirror, which is a cool effect. Here's how to make the display, which you can use for magic mirror projects of your own design.

For an in-wall installation, frame out an opening for the monitor and attach the LCD monitor mounting bracket (Figure D, previous page). Also drill openings for routing cables for the monitor's VGA and power cables.

Be sure to leave some room for ventilation, then drywall as needed. Check your local electrical code for compliance. If in-wall isn't an option, build a custom box. Attach the monitor to its mount (Figure E).

Attach the 2-way mirror to the back of the picture frame (Figure F). Note that the mirror will look transparent until it's mounted. One side has to be darker than the other for the effect to work.

For my daughters' playhouse, I added a fake fireplace below the Magic Mirror. A green LED lights up when the subject is within range, and red LEDs flicker like a fire (Figure G).

Make the Breathalyzer Housing

Hot-glue the breathalyzer into the middle of the ABS tee fitting (Figure H), and attach the PVC reducers to the stem. Connect the sensor to the MM Shield. When it's time to party, hand out ½" PVC risers as mouthpieces for your guests. To use the breathalyzer, insert the mouthpiece into the reducers, touch the trigger sensor, and blow (Figure I).

CAUTION: The Magic Mirror breathalyzer is not a professional breathalyzer and should be used for novelty purposes only. Drive safely!

K

Install and Configure the Software

The Firmata code for the Arduino is included with the Magic Mirror software. Upload it to the Arduino via USB. Then launch the Magic Mirror configuration program to turn on the sensors you've connected, and enter configuration options and data: sensor and webcam ports, location for weather forecast, stocks in portfolio, X10 codes, Picasa album info, your Twitter account, etc. (Figure J).

The Configuration pane also lets you display text to accompany the animations, and if your mirror is framed with an oval matte, you'll need to adjust the text's size and position to make sure it isn't covered up.

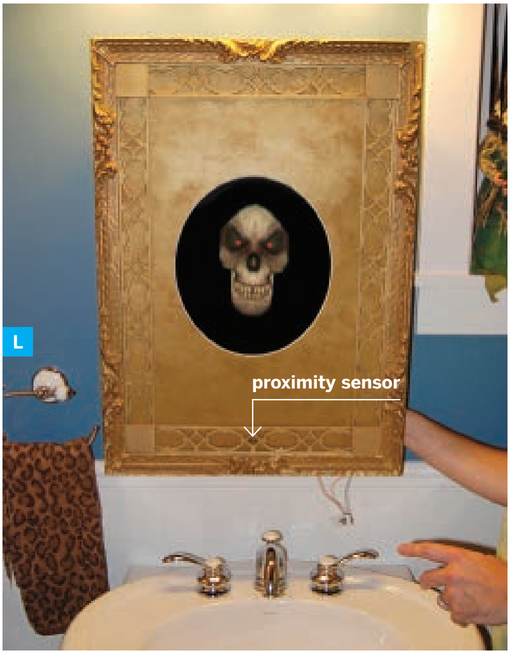
After configuration, run the Magic Mirror application itself in verbose mode. This displays all the sensor values, allowing you to test everything out. Once that's done and you see that the sensors all work, turn off verbose mode, add the Magic Mirror software to your computer's startup folder so it launches automatically, and you'll be off and running.

Applications

The Magic Mirror is a centerpiece of my daughters' playhouse. It's also a natural for Halloween parties; I use the same wall setup, changing the character to the Halloween skull. The Goblyns Glen Haunt (goblynsglen.com) in Los Gatos, Calif., has one at the bottom of a well (Figure K).

In stealth mode, the Magic Mirror can also masquerade as a normal bathroom mirror, giving guests a surprise when they approach the sink to wash their hands (Figure L).

I've also exhibited the Magic Mirror at Maker Faire, and there's one installed at the Table Rock Motel, in the town of Bandon on the southern coast of Oregon. Their Magic Mirror is embedded in a suitcase in the lobby (Figure M), where it's always available to tell guests the weather forecast.



L

M

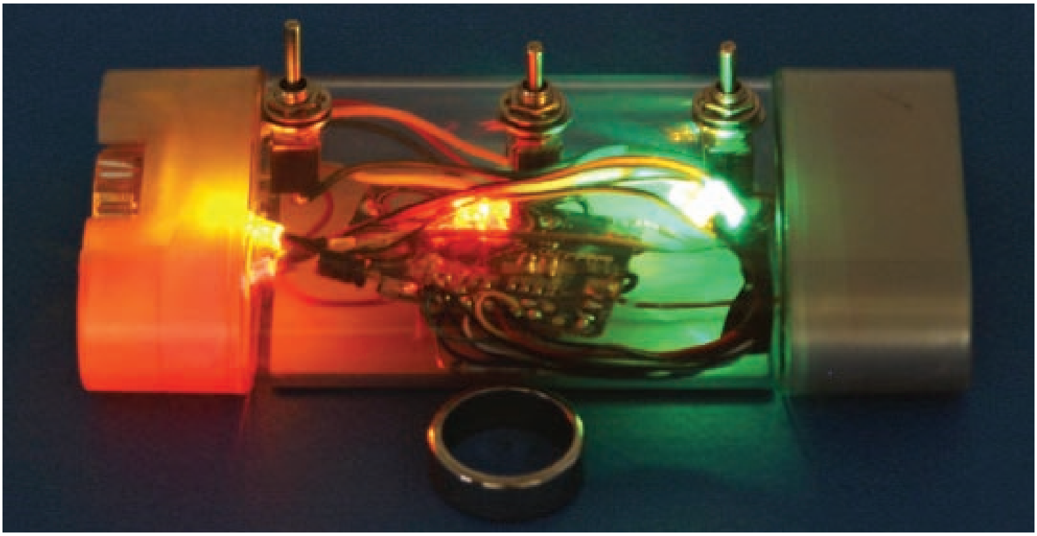
+ For wiring diagrams and configuration screenshots see makezine.com/23/magicmirror, or visit the mother lode of Magic Mirror information, including video demonstrations and tutorials, at diymagicmirror.com.

Al Linke (alinke@yahoo.com) is an IT director by day and, wife permitting, a maker by night.

MYSTERY ELECTRONIC SWITCHES

Only you know how to make this nifty magic gadget light up.

BY J. TREGRE



Everyone loves a good mystery. This project only took about 2 evenings to design, build, and test. So, what's so mysterious about it? You're the only one who knows how to toggle the 3 switches to the correct positions that make its LEDs light up. No matter who else tries it, or how long they keep toggling the switches, the LEDs will never be able to light up for them.

Revealing the Mystery

A good illusionist never discloses the secret that makes a trick work, Once you do, the magic has ended. With that said, I'll break my own rule and reveal how my circuit really works: inside the container are 2 reed switches that can be activated by a magnet, and you'll wear a special magnetic ring to activate them. Whenever you display your ability to make the LEDs light up, you must make sure that your finger with the magnetic ring is placed right alongside one of the magnetic reed switches.

Build the Circuit

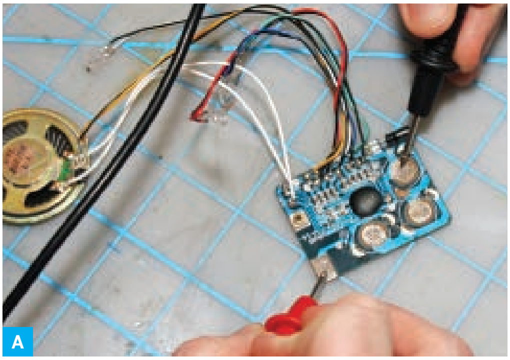
Remove the printed circuit board (PCB) from the LED greeting card. Find the positive and negative contacts on the PCB for the battery pack (Figure A). I used a Hallmark Christmas card because its LED display circuit was very flat and required only 3 volts to operate. Different cards have different circuits, so this step will vary. Some cards also have a speaker for sound — I wish mine had sound!

Refer to the schematic diagram (Figure B) to build the circuit. My PCB had the trigger between the ground (–) and battery, but others have the trigger between the positive power (+) and battery.

I used a clear plastic antiperspirant container, so that my audience could see all the working electronics of this circuit. The circuit board fit perfectly into this container, allowing 2 AAA batteries in their holder to fit on the underside.

Place the reed switches inside your container on the left and the right, so they'll be close to the magnetic ring whichever way you hold the container. Figure C shows a bit of perf board used to keep the reed switches in place; they're connected in parallel, then placed in series with the 3 toggle switches.

Photography by Ed Troxell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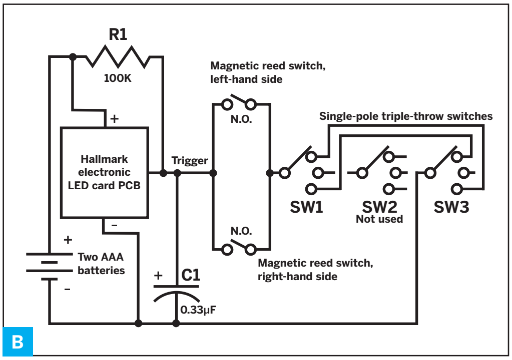

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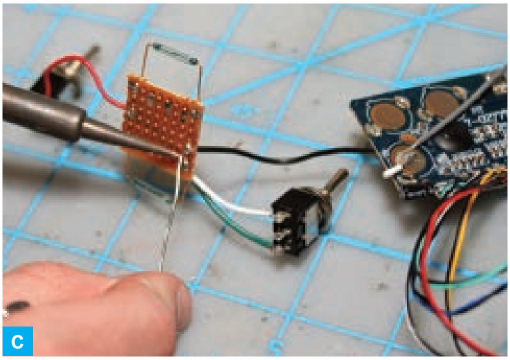
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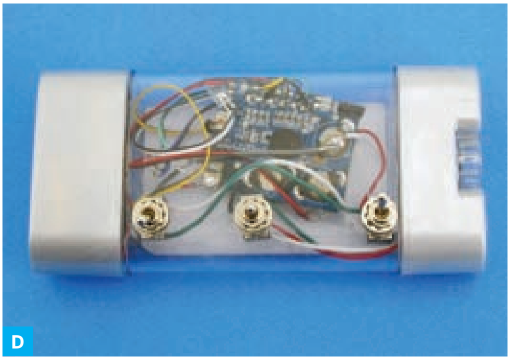

D

NOTE: I added the 100K pull-up resistor from power (+) to the PCB trigger to avoid EMI noise (electromagnetic interference). I also added a 0.33µF capacitor from the trigger to ground; without this, the LEDs may activate prematurely whenever the 3 switches are touched.

Fool Your Friends

Now just flip the switches in the correct pattern and the LEDs light up and remain lit for several seconds. Whichever way SW1 is toggled, SW3 must be in the opposite direction (Figure D). SW2 isn't used at all; it's just there, all wired up for show.

Practice your performance; the more confident you are, the more your audience will be determined to beat you at your own trick. Never display your trick to the same people more than 2 or 3 times, because someone will figure it out and reveal your secret. I tell my audience it's a mathematical algorithm and only I know the sequence to toggle the 3 switches, then I dare them to match my ability to get the LEDs to light up. "Well, do you feel lucky?"

J. Tregre is an electrical engineer from New Orleans. His interests are in professional model building and robotics. Visit him at buildingultimatemodels.com.

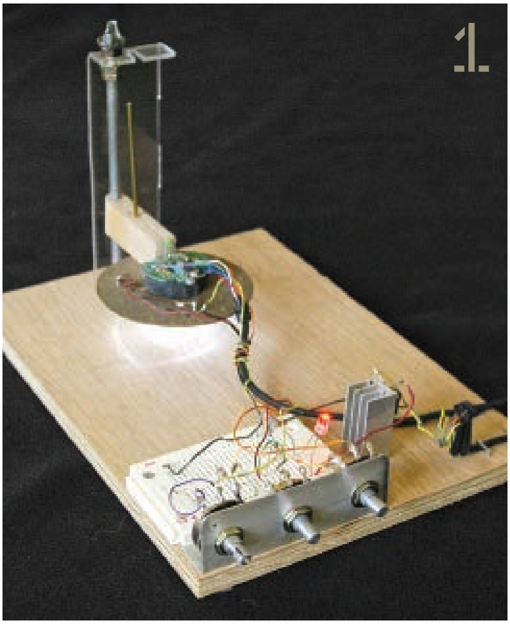
MATERIALS

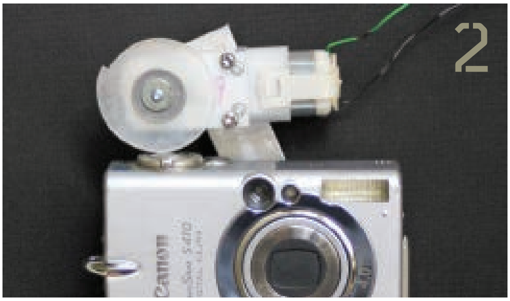
AAA batteries (2)
2xAAA battery holder
Clear plastic antiperspirant container as big as possible
Capacitor, 0.33µF Jameco part #609086, jameco.com
Resistor, 100kΩ Jameco #691340
Electronic Hallmark Halloween or Christmas card with LEDs You might want to buy a few different ones; some circuit boards are easier to use than others.
Magnetic reed switches (2) Jameco #171872
Single-pole triple-throw switches (3)
Magnetic ring Search online for Wizard PK rings. These come in silver and gold and are available in 8 different metric sizes (convert U.S. ring sizes at onlineconversion.com/ring_size.htm).
Soldering iron and solder
Hookup wire
Miscellaneous tools (optional) to disconnect the circuit board and its batteries, if needed. You might use needlenose pliers, wire cutters/strippers, or a heat gun or hair dryer to melt glue or shrink heat-shrink tubing.
Multimeter or ohmmeter (optional) but handy

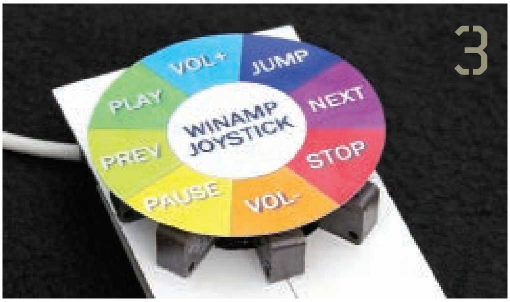
MY FAVORITE GADGETS

Three handy gizmos that snap, magnify, and play.

BY LARRY COTTON







I love gadgets, but I must see a specific need for them, and the gadget must be a good value. When I can't find what I'm looking for, I make it. Here are three of my favorite and most useful homemade gadgets.

1. **The Close-Up Webcam** began life as a $10 webcam. After hacking, it's now capable of over 100x magnification. I've used it to photograph everything from coins to arachnids to flower pistils.

2. **The Camera Shutter Control** repeatedly presses a digital camera's shutter at an adjustable regular interval. I recently flew it from a kite to take aerial photographs, and there are lots of other uses for it.

3. **The Winamp Joystick** saved me from having to buy a complicated remote control just for playing music. The hard-wired Joystick controls 8 common Winamp functions, including Play, Next, Pause, and Volume Up and Down. My favorite is Jump. I still use the Webcam and Shutter Control occasionally, and I use my Winamp Joystick almost every day.

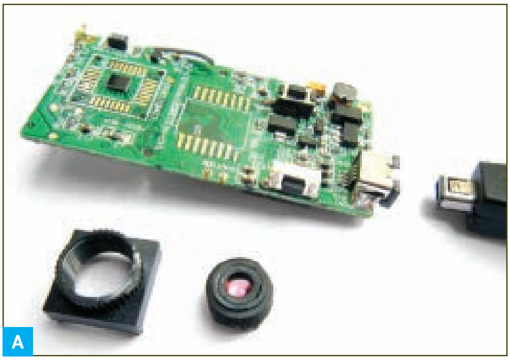
1. Close-Up Webcam

When I inherited some silver coins, I had to decide whether to keep them for their collector's value or sell them. To get expert advice, I needed close-up photos that showed the coins' conditions.

But microscope camera adapters and photographing microscopes can be expensive. Instead, I figured I could hack a cheap webcam and build a simple stand and illuminator for it. It wouldn't need an adjustable focus because you can just move the webcam toward or away from its subject.

The trick is to get into the tube in the webcam that holds its lens so you can move the lens a bit farther out than designed. A small change in lens position can make a big difference in the camera's magnifying power. This blurs photography at normal distances, but makes close-ups razor sharp.

Photography by Larry Cotton



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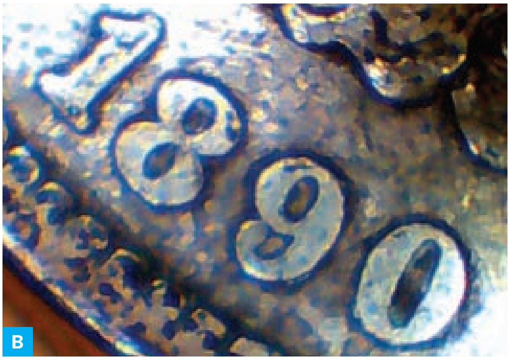

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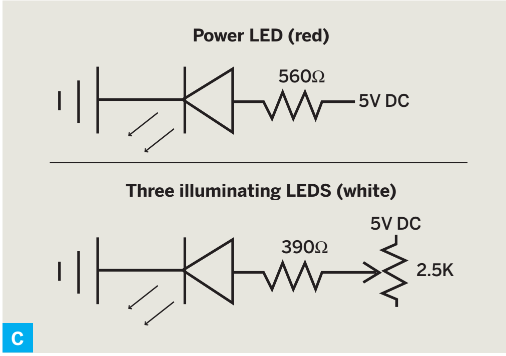

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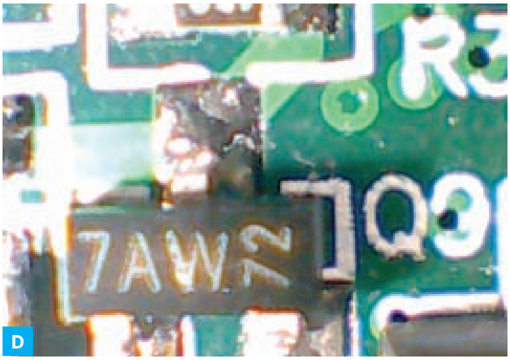

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WEBCAM MATERIALS

NOTE: Your mileage may vary.
Webcam
Wood or other material for base
Threaded rod with matching nuts
Thin metal rod
LEDs: white (3) and red
Resistors: 390Ω (3) and 560Ω
2.5kΩ potentiometers (3)
5V DC power source I used a 12V wall wart with a voltage regulator and heat sink.
Solderless breadboard and solid-core hookup wire
White cardboard
Epoxy and glue
Dremel tool, drill, scissors

I've made a few of these using different webcams I had on hand. With one of them, I discovered that the lens had once been totally adjustable, screwing in and out of a plastic sleeve that snapped over the image sensor on the board (Figure A), but the manufacturer had melted it in a fixed position! I only had to Dremel away a bit of melted plastic, and voilà — the lens screwed out about ⅛", perfect for close-ups.

Your webcam's design will probably be different from mine, so you'll have to adapt. Epoxy is probably all you need, and maybe a bit of plastic tubing to hold the lens farther out from the board (although I've never needed this).

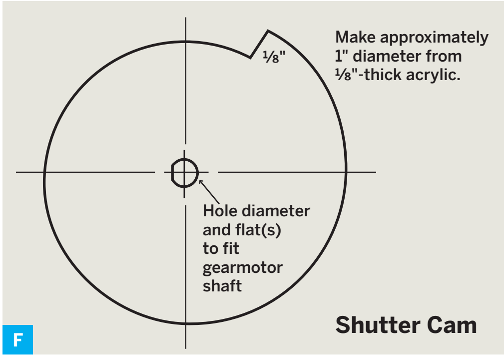
While you're hacking, look for a shutter-release button. Not all webcams have this, but if you find one, you can wire it to a remote shutter switch.

Minor jitters will appear 100 times larger, so you need a stable base to hold the camera and subject still. I made a wooden base with a small rectangular shuttle that carries the camera. Two rods attach to the base and run vertically through the shuttle: a threaded rod that holds the shuttle up and turns to adjust its position, and a thin guide rod that prevents the shuttle from rotating around.

The Close-Up Webcams I've made usually wind up ½" or so above the subject and move maybe ⅛" each way. Precise construction is not critical, and your mileage will vary depending on your camera.

Because the camera is so close, you'll need to illuminate the subject. I ringed the webcam lens with a circular reflector cut out of white cardboard and mounted 3 white LEDs underneath, about 120° apart and pointing toward the center. I installed 3 potentiometers to independently control their brightness, which is useful for adding shadows to


E



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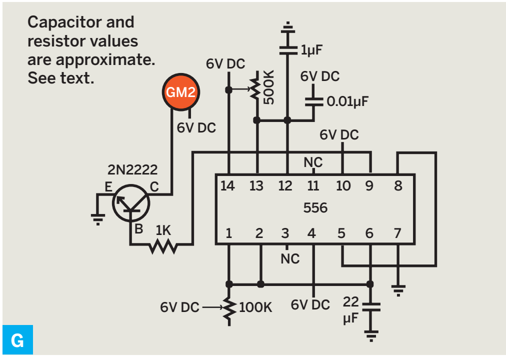

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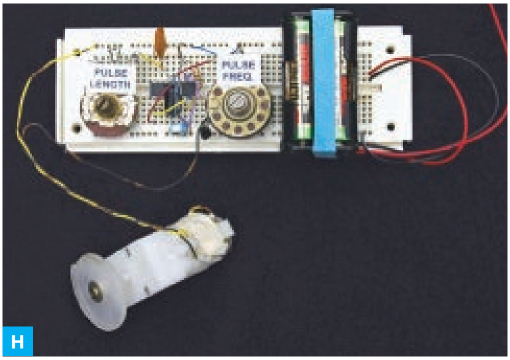

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highlight raised markings on coins (Figure B).

I also wired in a red "On" indicator LED. All the wiring was done on a solderless breadboard; Figure C shows the schematic. For the power, I connected a 12V wall wart through a 5V voltage regulator mounted to a heat sink. It might also work to split 5V DC off the USB that connects the webcam, but I didn't try it.

One of the most satisfying things about webcam close-ups is that you see the results on your computer monitor in real time as you position the subject and focus the camera. To capture still images (Figures B and D) use the shutter button (if present) or look for a screen-capture mode in your webcam's software.

2 Camera Shutter Control

One of my hobbies is kite aerial photography (KAP). Nowadays, almost all KAPers take photos with radio-controlled digital cameras. But I sometimes favor kites that just go up and up, out of radio range, almost out of sight until you can't tell which way the camera is pointing. With these rigs, I need some way to snap the shutter repeatedly.

Most cameras can't do this. Yes, there are few digicams with a built-in intervalometer (repeat-shutter) functions, and the Canon Hack Development Kit (chdk.wikia.com/wiki/CHDK) firmware adds the ability to some PowerShots. But my Camera Shutter Control physically presses the shutter button, so it should work with almost any camera.

SHUTTER MATERIALS

Digital camera
Flat hard plastic, 1/8" thick, at least 2" square
  I used a scrap of acrylic.
Solarbotics GM2 gearmotor, item #SBGM2 from Maker Shed (makershed.com), $6. Or you can try other gearmotors in this family, which have different torques and axle configurations.
556 timer chip
2N2222 transistor
Potentiometers: 100kΩ and 500kΩ
Resistor: 1kΩ
Capacitors: 0.01µF, 1µF, 22µF
4×AAA battery pack with batteries or other source of DC power between 5V and 9V
Solderless breadboard and solid-core hookup wire
Small mounting screws and washers for gearmotor
Aluminum stock, 3/4"×1/8", about 5" long
Screw that fits camera tripod mount probably 1/4-20
Soldering equipment, drill, narrow blade saw, small files


I

WINAMP MATERIALS

Computer running Winamp (winamp.com) music/ media player
USB (or PS/2) keyboard Make sure it works with the Winamp computer and doesn't conflict with its normal keyboard.
Micro switches such as momentary-on SPST buttons or SPDT lever changeover switches with the metal levers removed (8 or 9); item #275-016 or #275-002 from RadioShack (radioshack.com)
Insulated wire 22- to 24-gauge telephone wire works great
Small piece of stiff plastic laminate aka Formica a bit larger than the PCB inside the keyboard
Small box to hold keyboard's PCB. I made one out of wood.
Heavy paper and laminating sheets
Small wooden dowel
Fine-tipped soldering iron and solder
Glue gun and hot glue

You can set up on a crowded street or beach, turn on the Shutter Control, and walk away until the memory is full or the batteries die. (Chain the camera to a parking meter or lifeguard stand so it isn't stolen.) Later, dump your shots into a photo editor, and I can almost guarantee that you'll get some with serendipitous timing and framing, like my lucky shot of a lighthouse beam (Figure E).

The shutter button is pressed by a cam (Figure F) that's driven by a DC gearmotor. I used a band saw to cut ⅛"-thick acrylic into a shallow spiral cam about 1" across with a ⅛" drop. The drop should slightly exceed the throw of your shutter button, so that the shutter is pressed gradually and releases fully. For the flattened hole that fits the gearmotor axle, I drilled undersize and filed the hole to shape.

A simple circuit uses a 556 timer chip to run the motor continuously or in pulses, with 2 potentiometers adjusting the pulse length and frequency. If you're using a low voltage to save battery weight, pulsing the motor provides enough torque to press the button when continuous power might not.

Slow speeds and mechanical triggering also let point-and-shoots focus normally before each shot. Occasionally the cam will press the shutter while the camera is still "digesting" the last shot, but this has done no harm to any cameras I've tried.

Figure G shows a schematic of the circuit, which I often just leave on a prototyping board (Figure H). Substitute different capacitor and resistor values to change the possible pulse and delay interval ranges.

Mounting the gearmotor so the cam sits the right distance directly above the shutter button will require some tweaking.

I made a bracket out of ¾"×⅛" aluminum that attaches at the tripod mounting-screw hole in the bottom of the camera. It bends up and over to hold the gearmotor, which is attached through its mounting holes. The aluminum is strong enough to minimize play, but flexible enough that it springs back a little when the shutter button bottoms out.

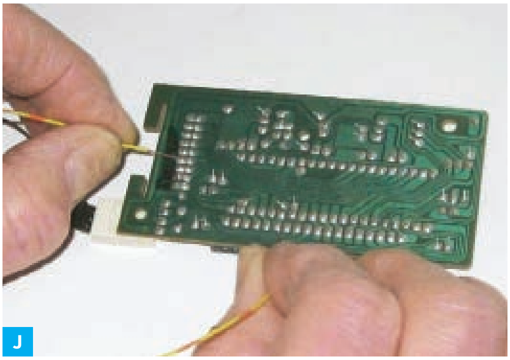
3 Winamp Joystick

I love Winamp, but I don't like having to use a mouse or hotkeys with it. When I'm multitasking, it bugs me to have to Alt-Tab over, then click around or remember that X is Play and V is Stop.

So I built a joystick (more of a "joywheel," actually; Figure I) that emulates 8 of what I consider to be Winamp's most important functions: Play (hotkey: X), Stop (V), Jump to File (J), Pause (C), Previous Track (Z), Next Track (B), Volume Up (↑), and Volume Down (↓). To this list, you might want to add a ninth switch in the middle to emulate the Enter or Esc key.

Most control functions require a single satisfying push on the big, bright wheel, and if I want to hear a particular tune, I simply hit Jump, type a few letters unique to the song title, and hit Enter.

The arrangement worked so well that I converted an old IBM ThinkPad into a dedicated music player. (Note: Laptop or desktop computers work equally well for this project; I tend to lean toward portability.)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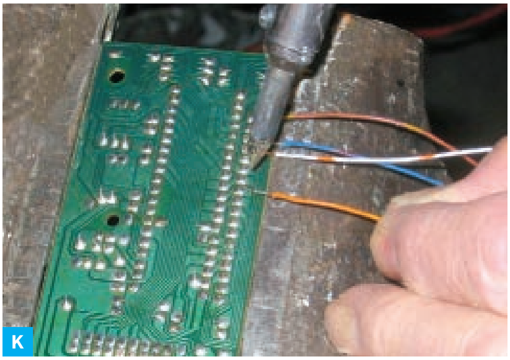
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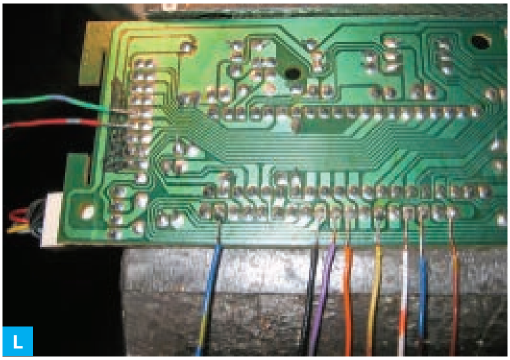
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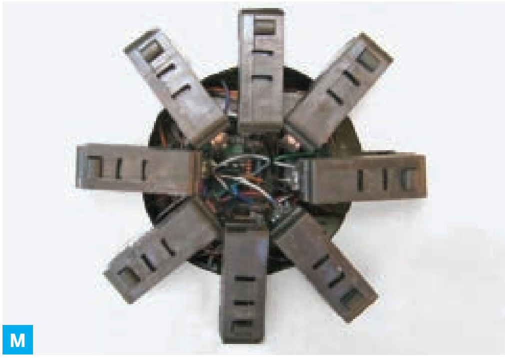
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I cleared its hard drive of everything but the OS and Winamp and copied a huge MP3 collection to it. Then I plugged in my newly minted joystick and tuned out.

The joystick works just like pressing Winamp's hotkey buttons on a second keyboard — literally. You make the joystick out of an old keyboard by removing its circuit board and wiring switches across the traces that are normally bridged by the hotkeys. I used SPDT microswitches because they're small, cheap, and have short button travel.

Modifying the keyboard is easy — unscrew and dismantle everything but the hard printed circuit board and its connection to the cable. Remove the big mylar strips that connect onto the board and carry traces out from the small board to the full keyboard layout.

Now comes the tricky part: finding the solder pads for the hotkeys you want to control. These contacts usually sit in 2 long rows under the mylar sheets. I've decoded 3 keyboards now, and the contacts were arranged differently on all of them.

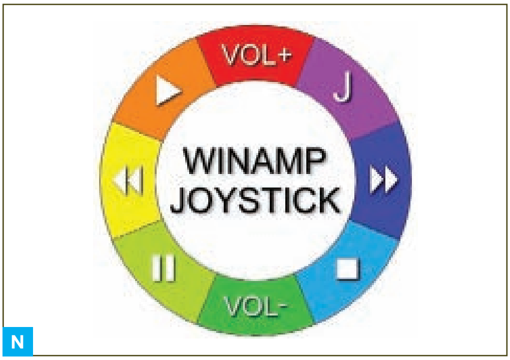
To locate the pads you want, you could painstakingly follow the traces from the key positions on the mylar sheets to the circuit board, but I prefer using this trial-and-error method:

1. Draw a diagram of the rows of solder pads that formerly accepted the mylar sheets. I labeled my short row a1–a9 and the long row b1–b18.

2. Using your normal keyboard, fire up Notepad. Plug in the circuit board cable. Use a short wire jumper to bridge pairs of solder pads (Figure J), and watch Notepad to see which pairs generate the hotkey letters you want. Note that some solder pads serve multiple keys. When you find one, write it down. For example, on my latest circuit board, bridging a5 to b2 produces a J. Test every pair of pads multiple times, always with the keyboard cable plugged in. With patience, you'll find what you need.

Be especially careful of the number pad, if your keyboard has one, and make sure the Num Lock key is off. Your Winamp's volume should be controlled by the ↑ and ↓ keys, not the 2 and 8 keys on the number pad, which translate to ↑ and ↓ when Num Lock is on.

Next cut and strip some leads a few inches long, and tin the ends with solder. Solder them to the pads you identified (Figures K and L). The pads are very close together, so don't add any more solder; the solder on the pad and lead should be enough.



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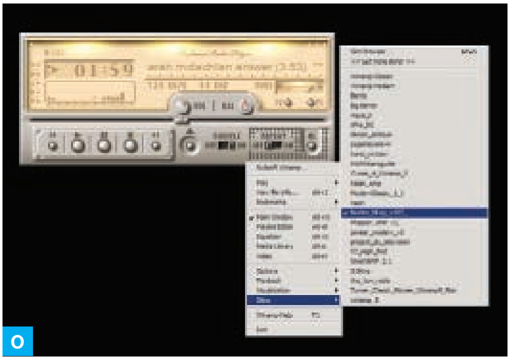

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Test the leads by touching their 2 ends together and confirming that the character you want appears in Notepad. When they're all working, consider gluing them down with hot glue.

Now for the "stick" part. Mount 8 momentary switches in a circle, 45° apart, to some surface that lets you wire them to the PC board underneath. If your switches have metal levers, remove them. I arranged SPDT microswitches around a hole in a piece of Formica, and they all just touched in the middle (Figure M). I mounted them with hot glue, which is fine for microswitches. For a ninth Enter/Esc switch, you can add it in the center.

Solder the leads from the circuit board cable to the appropriate switches. If you use SPDT switches, be sure to wire to the common (C) and normally open (NO) legs, leaving the normally closed (NC) leg unconnected.

Plug the joystick into the Winamp computer. It should emulate the 8 hotkeys you've selected. Of course the computer's keyboard should also work normally, like for entering song titles.

Make a box to hold the circuit board and support the switches, and cover the switch push buttons with a colorful "function circle" (Figure N). I printed mine on heavyweight photo paper and then laminated it.

See makezine.com/23/favoritegadgets for my printable designs. The circle must be flexible enough that when you press one of the sectors, only one switch is actuated.

To keep the circle fixed and centered over the switches, I glued a short wooden dowel in the middle underneath, so it hangs down between the switch bodies. You may want to wrap a few turns of tape around the dowel to make it a light press-fit within the switch bodies; also consider double-faced tape to stick the bottom of the function circle to the switches.

I love the Winamp skin *Nucleo_NLog_v102* (Figure O), which seems appropriate for my ThinkPad Winamp player, or sometimes I use the *Wurlitzer_v2* skin (Figure P), which complements the 1966-vintage Wurlitzer jukebox I have in the same room.

Larry Cotton is a semiretired power-tool designer and community college math instructor. He loves music and musical instruments, computers, birds, electronics, furniture design, and his wife — not necessarily in that order.

ONE-WAY TICKET

Pressurize with a plunger that pushes but doesn't pull.

BY JON THORN

When you insert a plunger into the toilet bowl, you create a seal around the exit of the toilet so that when you push down, a positive pressure is created that moves the blockage downstream. The drawback to this design is that when you pull the plunger back up in preparation for the next push, you create a vacuum that moves the blockage back to its original position.

So, to effectively clear your toilet, you either need a plunger with a stroke volume large enough to move the blockage to a larger cross section of drainpipe with a single push, or you must plunge so aggressively that you not only dislodge the blockage but break it up, which allows the toilet to flush properly. Most plungers don't have an adequately large volume to succeed in just one stroke, and aggressive plunging makes messes.

After much contemplation, it occurred to me that a one-way valve installed in your plunger would allow you to create a positive pressure on the push stroke, but avoid pulling the undesirable vacuum with the plunger bell. This would allow you to steadily pressurize a pipe, thus moving the offending blockage downstream with each stroke.

My solution was built for just a few dollars. I took a cheap rubber plunger bell and drilled a hole in its handle socket. The socket was built to accept a wooden handle with threads carved into it, but you can use a length of ½" PVC pipe as the handle instead. Carefully shave the threads of the plunger bell with a pocketknife (not too much, or your handle will fall out), or if you're strong enough, just force your new handle in there. This modification creates an airway connecting the stroke volume of the plunger bell to the hollow PVC handle.

Stick a one-way valve on the end of your ½" pipe and you now have a plunger that pushes but doesn't pull. Or, if you'd like, you could turn your one-way valve around and create a plunger that can pull your blockage back into the toilet bowl ... but I'm not really sure you want to do that.

Photograph by Sam Murphy

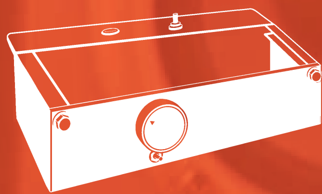
Jon Thorn's building skills have been honed to the point where an occasional invention actually does what it's supposed to.

Make: Projects

Ramp up your gadget arsenal by making a see-through audio amplifier with parts picked up at the hobby shop and the plumbing aisle. Then craft a toy monorail locomotive that zips along the rim of a pot or other thin track, balanced on just one wheel. And charm everyone with the Most Useless Machine, whose only function is to turn itself off.

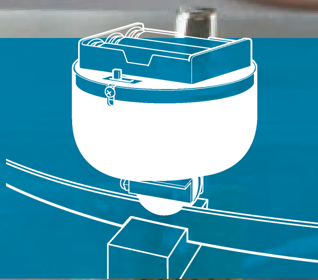
Mini Chip Amp

70



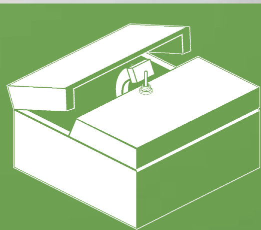
Gyrocar

84



Most Useless Machine

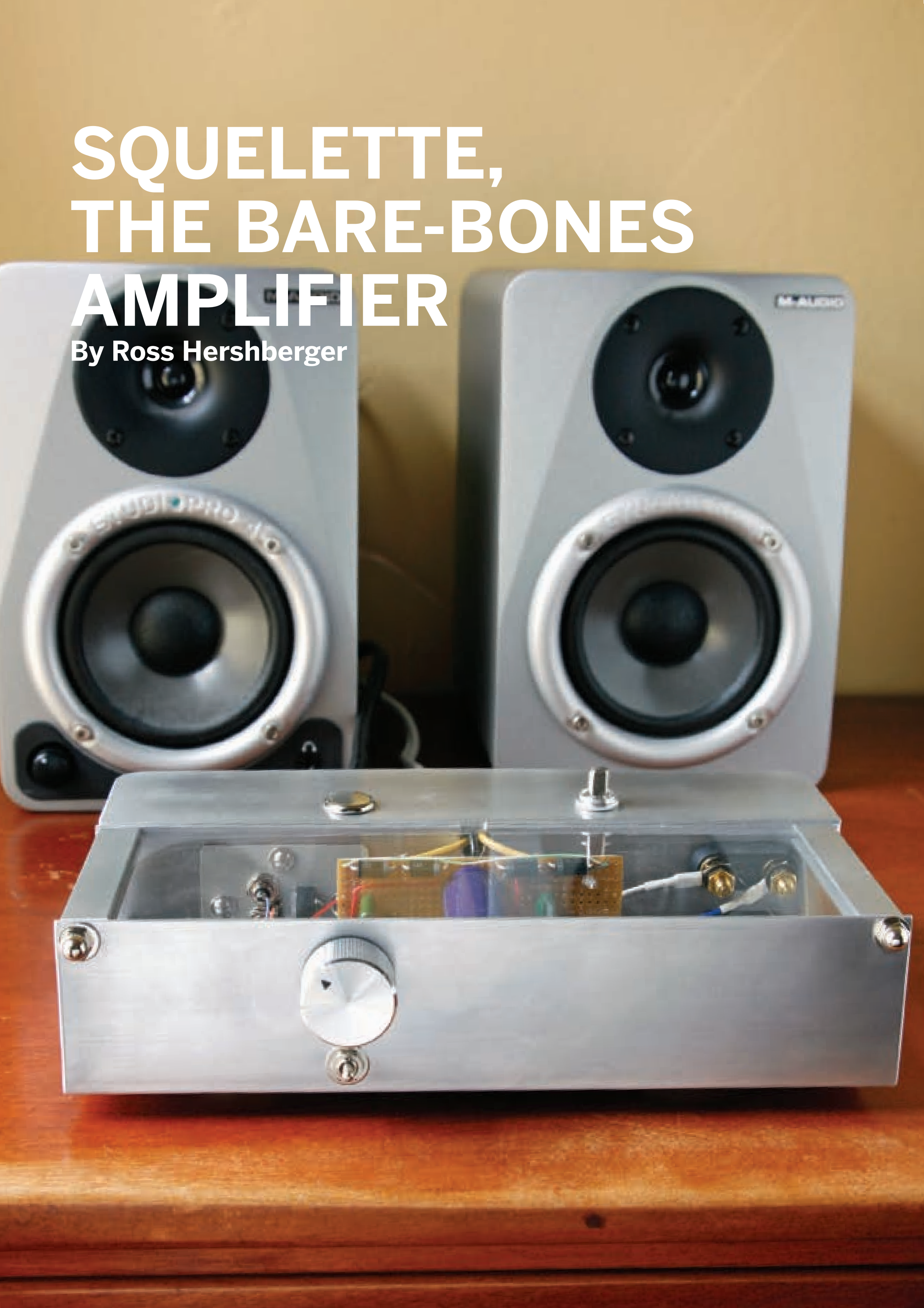
94



Photograph by Sam Murphy

SQUELETTE, THE BARE-BONES AMPLIFIER

By Ross Hershberger



SKELETAL SYSTEM

Squelette is a see-through amplifier that sounds ridiculously good while showing off your soldering (it looks nothing like a typical audio product). Build it with common materials and enjoy music played through a component you made yourself.

I love to build audio gear: speakers, turntables, preamplifiers, tube amps, transistor amps, and anything else that reproduces music. A few years ago I read rave reviews of an exotic audiophile amplifier based on a National Semiconductor amplifier chip. After more research, I learned that NatSemi's Overture series of audio amp ICs pack a ton of musical goodness into one robust and flexible chip, combining all the features of a well-designed transistor amp.

I decided to use their LM1875 chip to make a small, simple stereo amplifier. I dubbed the result Squelette (skeleton in French), after mechanical wristwatches that show their internal workings. Squelette is a chip amp in its simplest form: it has 2 source inputs and a volume control, and it puts out a useful 11 watts per channel. Building it requires no exotic parts; I made careful design choices and sourced everything except for the LM1875 from RadioShack and the plumbing aisle at the hardware store. Here's how you can build your own, from materials costing less than $50.

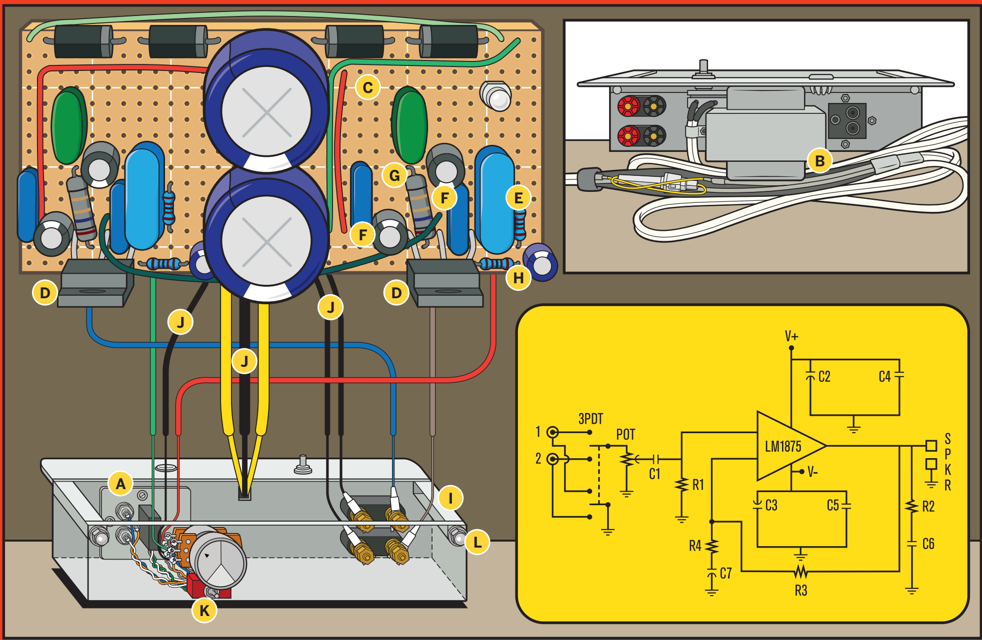
Set up: p.73 **Make it: p.74** **Use it: p.83**

Photograph by Sam Murphy

Ross Hershberger was working with hobby computers long before IBM coined the term PC. He worked as a mainframe systems analyst for 20 years before returning to technical electronics as a restorer of vintage audio gear.

Sound Design Practices

A good design makes every part earn its keep. Here's how the Squelette amplifier's common components team up to make a whole that's greater than its parts.



A The **input jacks** connect to the audio source.

B The power cord connects to one side of a 25.2V 2A **transformer**. The LM1875 chip can handle larger transformers, but scaling the other components and the heat-sinking design to match would make the amp significantly bulkier, more complicated, and more expensive.

C The heart of the amp is a small, hand-built **circuit board**. The grid pattern of the board's perforations lends itself to easy, solder-by-numbers instructions. The **power supply** components (along the top and middle of the board as shown here) convert AC from the transformer into DC for the amplification circuits.

D Each of the 2 identical amplification channels is built around a NatSemi **LM1875 amplifier** chip.

E Capacitor **C1** isolates the chips' pin 1 inputs from DC, and resistor **R1** provides a ground reference.

F Capacitors **C2**, **C3**, **C4** and **C5** bypass the power supply to the V+ and V– pins of the LM1875, ensuring a low-impedance power source at high frequencies.

G Resistor **R2** and cap **C6** form a Zobel filter, presenting a low-impedance load to the output at very high frequencies. This loads down and damps out oscillations and spurious signals outside the audio band.

H Resistors **R3** (on back of board) and **R4**, AC-coupled to ground through **C7**, form a global negative feedback loop from the chip's output pin back to its negative input signal terminal. This feedback sets the overall voltage gain, reduces the output impedance, and reduces internally generated noise and distortion.

I The circuit board is housed in a **cabinet** made from stock aluminum angle and plexiglass. The aluminum attaches to the LM1875 chips as a heat sink, as well as serving as the circuit ground. The plexiglass lets you see the circuitry.

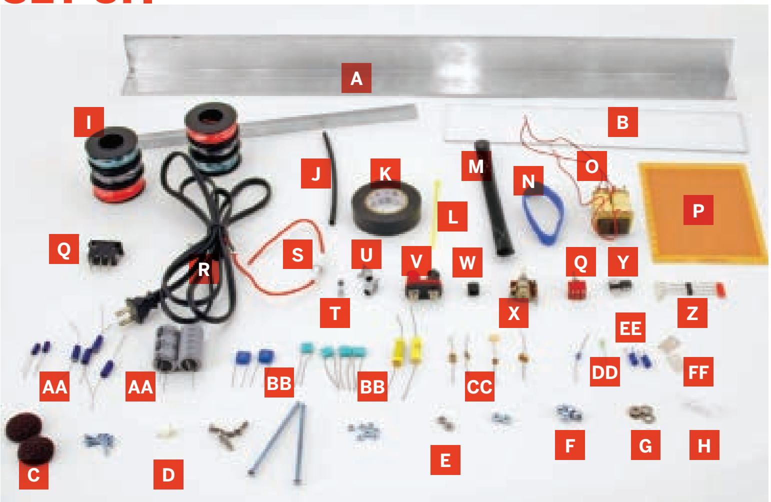
J All ground connections run directly to one shared **"star" ground**, a large loop of wire centered on the back of the PCB that connects to the cabinet. This wiring prevents interactions between circuit features that could cause noise and instability.

K The 3P2T (triple-pole, double-throw) **input selector** switches both the signals and the grounds of 2 input devices, to completely isolate the deselected input device. This avoids ground currents and noise that can come from connecting different inputs' grounds together. Wired for "center off," the switch also lets you mute the amp without changing the volume setting.

L Two **acorn nuts** at the upper corners of the chassis let you expose the amp's innards to open air, and 5 more screws let you remove the Squelette's circuitry from the chassis completely, without unsoldering.

Illustration by Timmy Kucynda

SET UP.



Photograph by Ed Troxell

MATERIALS

[A] Aluminum stock: 2" angle, 1/16" thick, 28" long; 5/8"×½" channel, ¼" inside cavity, 13" long Online Metals part #6063 T52; National Mfg. #N258-525

[B] Clear acrylic (plexiglass), 3/16" thick, 13"×2 7/8"

[C] Plastic furniture feet, about 1"×½" thick (2)

[D] Screws: #4-40×3/8" (7); nylon #6-32×½" (2); #8-32×½" (4); #8-32×3½" (2)

[E] Nuts: #4-40 (7); #6-32 (2); #8-32 (2)

[F] Acorn nuts, #8-32, chrome plated (4)

[G] Washers, #8, chrome or nickel plated (4)

[H] Nylon P-clip, ¼"

[I] Insulated solid-core wire: 18 gauge, black, red, and green: 24 gauge, various colors

[J] Heat-shrink tubing, 3/16" diameter, at least 4"

[K] Electrical tape

[L] Small zip tie

[M] Tech Weave braided cable sleeving, 7" long

[N] Velcro tape, 2"

[O] Transformer, 25.2V CT 2A RadioShack #273-1512

[P] Perf board with copper pads on one side, 2"×3½" RadioShack #276-1395

[Q] Panel-mountable switches: power (any type) and 3P2T toggle

[R] Extension cord

[S] In-line fuse holder RadioShack #270-1238

[T] 500mA fuse

[U] RCA jacks (2) RadioShack #274-346

[V] Speaker terminals RadioShack #274-718

[W] 1/8" audio (headphone) jack RadioShack #274-249

[X] 100kΩ dual potentiometer RadioShack #271-1732

[Y] National Semiconductor LM1875 IC chips (2)

[Z] Rectifier diodes, ≥4A and ≥40V (4) Schottky B540, B560, 1N5822

[AA] Capacitors, electrolytic: 22µF (2), 100µF (4), 4,700µF (2)

[BB] Capacitors, film: 0.1µF (4), 0.22µF (2), 1µF (2)

[CC] Resistors: 1Ω, 1W; 830Ω, ½W; 1kΩ, ¼W (2); 22kΩ (4); 220kΩ (2)

[DD] LED any color

[EE] Crimp-on spade terminals, 18–22 gauge (5)

[FF] TO-220 insulated chip mounting pads (2)

[NOT SHOWN]

Knob for potentiometer

TOOLS

Drill press or drill with bits: 1/8", 5/32", 11/64", ¼", 5/16", 3/8", ½" or use a step bit

Disk or belt sander

Band saw or hacksaw with fine-toothed metal blade

Sheet metal nibbler

Soldering iron, fine point, with solder, flux paste, and desoldering plunger

"Third hand" holder and magnifying glass

Wire cutter/stripper, needlenose pliers, and crimping tool or pliers

3" C-clamp

Needle file, knife, or Dremel tool with tapered diamond bit

Digital multimeter

Signal generator or computer running a signal generator app, or CD player with a CD of sine waves

Clip-on heat sinks (2)

Resistors, 10W, 10–25Ω (2)

Alligator clip leads (3)

Carpenter's square and metal ruler, at least 12"

Hammer and metal punch

Metal files, flat and round

Screwdrivers and wrenches

Reamer and cutting oil

Masking tape, scrap cardboard, and Sharpie marker

400-grit sandpaper

Small brass wire brush and disposable paintbrush

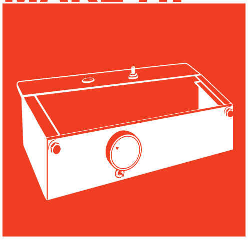
Butane pocket lighter

Scotch-Brite scouring pad

Rubbing alcohol, cotton swabs, and paper towels

Eye protection and leather shop gloves

MAKE IT.

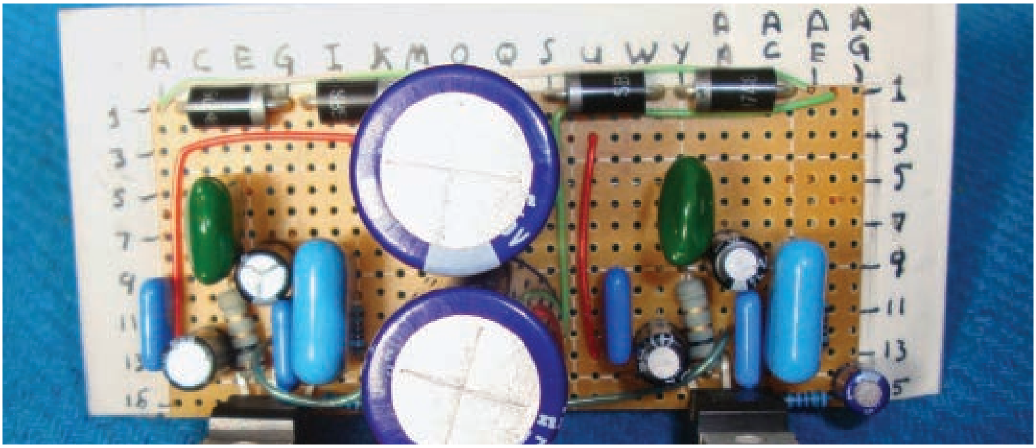


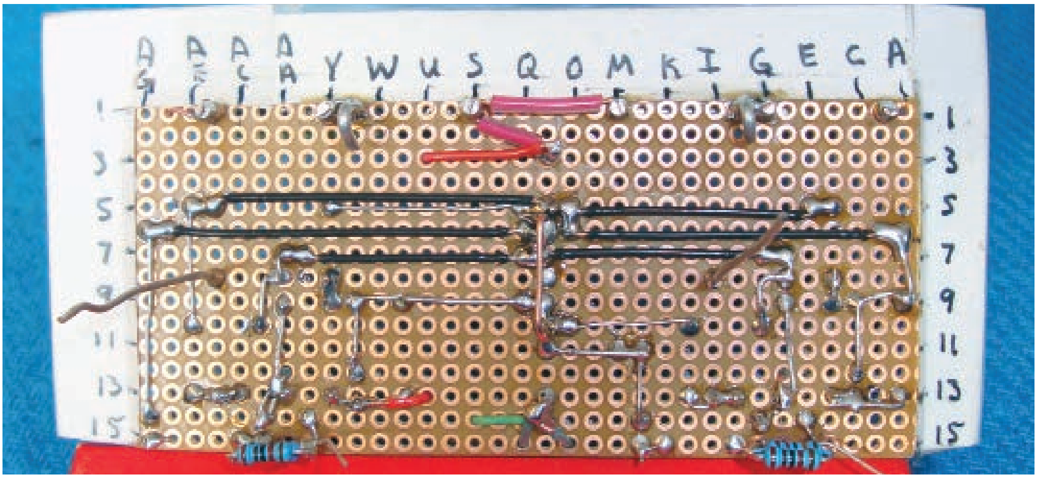
BUILD YOUR MINI AMPLIFIER

START **Time:** 2 Weekends **Complexity:** Moderate

1. BUILD THE CIRCUIT BOARD

This board looks complex, but each LM1875 chip contains 46 transistors; imagine hand-wiring all of those!





Photography Ross Hershberger

1a. Cut a 33×15-hole piece of perf board, then sand the edges. Scour the copper side with a Scotch-Brite pad and wipe with alcohol. Tape a cardboard frame around the edges and label the rows 1–15 and the columns A–AG, with the origin at upper left on the component (non-copper) side.

NOTE: You can download a schematic diagram for the Squelette at makezine.com/23/chipamp.

1b. Start with the power supply. Connect the following hole pairs with diodes, cathode side (marked with a line) listed second: B1 to G1, H1 to M1, X1 to S1, and AD1 to Y1.

On the copper side, jumper G1 to H1, X1 to Y1, and M1 to S1. Clip the leads at H1 and X1 off to ½" and bend them under in a tight loop. Clip all other leads off completely.

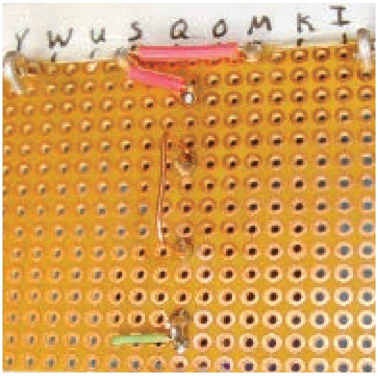
TIP: If any holes are too small, ream them from the component side with a needle file, a knife point, or (fastest) a Dremel tool with a tapered diamond bit.

1c. Strip some 24-gauge wire, thread it through A1, and solder it in back to bridge A1 and B1. Route it over the 4 diodes, and strip, thread, and solder the other end to connect AE1 and AD1.

1d. Stuff a 4,700μF cap into P3 (+) and P6 (–) and another into P10 (+) and P13 (–). Jumper S1 to P3. Electrolytic capacitors have the (–) terminal labeled.

1e. On the component side, pass a 24-gauge wire through AF1 and connect to AD1. Route it between rows 1 and 2, then down between columns S and T. Thread the other end through S14, insulated, then cut, strip, and connect only to P13.

1f. Connect P6 to P10 in back with a raised loop of bare 18-gauge wire. This is the star ground node, and a lot of wires attach here, so leave some room.



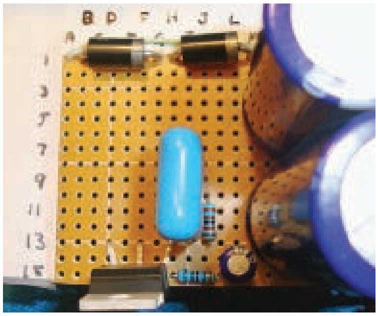
1g. To test this circuit, clip-lead (alligator jumper) the transformer's secondary center tap lead (black) to the 0V star ground at P6/P10, and its secondary (yellow) leads to X1 and H1. Temporarily solder one side of the fuse holder to one of the transformer's primary leads (black) and tape the joint. Insert a 500mA fuse. Split a power cord (not plugged in), connect it between the free side of the fuse and the free primary transformer lead, wrap with electrical tape, and use a switched power strip to apply power to the transformer.

If nothing sparks or pops, measure the DC voltages across both capacitors. You should get around –18V from P10 to P13 and around +18V from P10 to P3. If the voltages read 0V, check the fuse. If it's blown, there's a wiring error. If the voltages check out, turn it off and clip a 22K resistor between P3 and P13 to bleed off the charge on the caps.

1h. Stuff and solder the following left channel components:

- LM1875 into D13–H13, perpendicular to and facing the center of the board (pin 1 in H13, heat-sink side out)
- 1K resistor into H15, K15
- 22μF capacitor into L15 (+), L14 (–)
- 22K resistor into J10, J13
- 1μF cap into I8, I13.

On the back of the board, solder K15 to L15 and clip off. Solder H15 to G15. Solder J13, I13, and H13 trogether and clip off. Clip the other leads except for I8, J10, and L14.



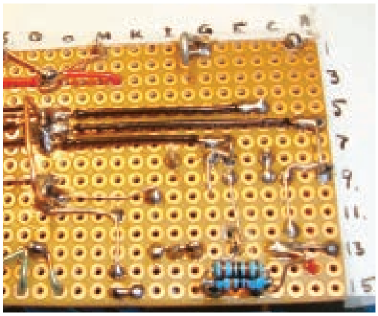
1i. Stuff and solder a 0.1μF cap into G10, G14; and a 100μF cap into F8 (+), F9 (–). On the back, bend lead F9 down and solder it to F13 and G14. Bend lead G10 up and solder it to F8. Clip the other leads, except for F8.

1j. Stuff and solder a 1Ω resistor into D9, E14; and a 0.22μF cap into D5, D8. In back, solder E14 to E15, and D8 to D9. Clip except for D5 and E15.

1k. Stuff and solder a 100μF cap into C12 (–) and C13 (+); and a 0.1μF cap into A9 and A13. Bend lead C12 up to A9 and solder, then solder A13, C13, and D13 together.

1l. Use separate jumpers to wire A9, D5, F8, J10, and L14 to the ground wire loop in back. Put a red 24-gauge jumper through L3 from the component side and connect it to P3. Pass the other end through B14 and connect it to D13. Put a green jumper through O15 from the component side and connect it to P13; pass the other end through F12 and connect it to F13.

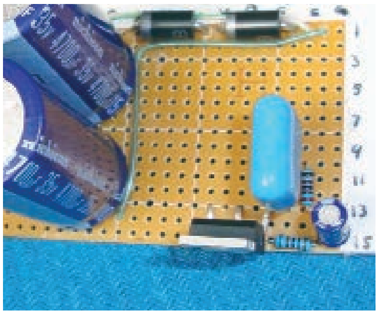
Finally, connect a 20K resistor (or a 22K and 220K in parallel) on the copper side between G15 and E15, making sure it doesn't project past the edge of the board. This is the feedback resistor. Clip off its lead at G15 and leave its other lead in place.



1m. Stuff and solder the following right channel components (just like building the left channel):

- LM1875 chip into AC13, AB15, AA13, Z15, and Y13, perpendicular to and facing the center of the board (pin 1 in Y13, heat-sink side out). The chip should clear the bottom edge of the PCB.
- 1K resistor into AC15, AF15
- 22μF cap into AG14 (–), AG15 (+)
- 22K resistor into AE10, AE13
- 1μF cap into AD8, AD13.

On the back of the board, solder AF15 to AG15 and clip off. Solder AC15 to AB15. Solder AE13, AD13, and AC13 together and clip off. Clip the other leads except for AD8, AE10, and AG14.

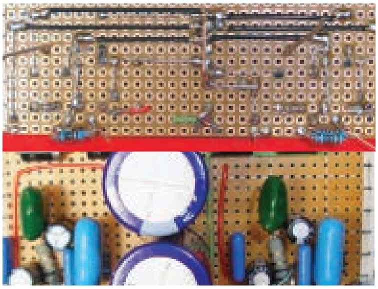


1n. Stuff and solder a 0.1μF cap into AB10 and AB14; and a 100μF into AA8 (+) and AA9 (–). On the back, bend lead AA9 down and solder it to AB13 and AA14. Bend lead AB10 up and solder it to AA8.

1o. Stuff and solder a 1Ω resistor into Z14 and Y9, and a 0.22µF cap into Y5 and Y8. In back, solder Z14 to Z15, and Y8 to Y9. Clip except for Y9 and Z15.

1p. Stuff and solder a 100µF cap into X12 (–) and X13 (+), and a 0.1µF cap into V9 and V13. Bend lead X12 up to V9 and solder it, then solder V13, X13, and Y13 together.

1q. Use separate jumpers to wire V9, Y5, AA8, AE10, and AG14 to the ground wire loop in back. Put a red 24-gauge jumper wire through U3 from the component side and connect it to P3; pass the other end through U13 and connect it to Y13. Put a green jumper through S14 from the component side and connect it to P13; pass the other end through AA12 and connect it to AA13.



For the right channel feedback, connect a 20K resistor (or a 22K and 220K) on the back between AB15 and Z15. Clip off lead AB15.

2. TEST THE AMP

2a. For the power indicator light, stuff your favorite color LED into AC3 (anode, longer leg) and AD3 (cathode). Bend and solder the cathode lead to AD1. Stuff an 830Ω, ½W resistor into Z3 and V3, then solder V3 to the ground wire loop, and Z3 to AC3.

2b. The circuit board is done now, and the only unconnected leads remaining should be I8 (left channel input), E15 (left channel output), AD8 (right channel input), Z15 (right channel output), X1 and H1 (AC input), and the ground at P6–P10.

To set up testing, hook up the transformer to the power supply as in Step 1g. Clamp a heat sink to the tab of each LM1875 chip, making sure they don't touch anything conductive. For dummy loads, clip-lead a 10Ω–25Ω, 10W resistor from E15 to ground, and a second resistor from Z15 to ground. Connect AD8 to I8. Connect I8 to ground for the moment.

2c. Power up the circuit as in Step 1g. The power LED should come on. Measure the DC voltage across each dummy load resistor. If it's over 0.05 volts, power down and look for wiring errors.

2d. For signal testing, disconnect I8/AD8 from ground and connect them to any signal generator source with a volume control. Power the circuit back up and test across the load resistors, measuring AC voltage this time. Briefly increase the volume of the input, and look for the voltage to read up to about 9V AC output. But keep all signal testing brief, to avoid overheating the chips. If you have an oscilloscope, look for clipping at about 25V peak-to-peak. Reduce the signal to 1V AC output on one channel, and then test the other channel; it should also measure 1V AC. Switch the meter to DC and confirm that both channels measure 0V DC. Try a speaker in place of the load resistor to make sure the output signal sounds like clean sine wave. If it all checks out, your board is done and working.

3. MAKE THE CABINET

3a. Download and print the mechanical drawings at makezine.com/23/chipamp. Part A is the chassis front, B is the inside back, and C is the outside back. Parts D and E are rails that hold the plexiglass ends and top.

3b. Cut three 9" lengths of the 2" aluminum angle and four 3" lengths of the ⅝"×½" aluminum channel. Sand the edges smooth.

3c. To protect the aluminum and mark the patterns for drilling and cutting, cover the surfaces with masking tape. Transfer the markings from the drawings.

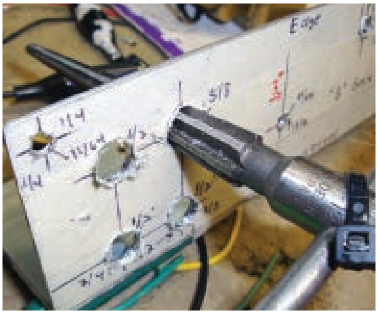
3d. On Part C, position the transformer and check the clearance between the switch and transformer underneath. Adjust the position of the switch hole to suit your switch, and mark it.

3e. Time to drill. Use a sharp punch and a hammer to dimple the center of each hole to be drilled. Drill the smallest holes first.

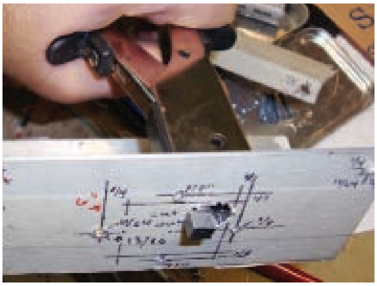
TIP: Some holes need to align for assembly: the row of four 5⁄32" and 11⁄64" holes on parts A and B; the ⅛" holes in the D spacers and the bottom corners of A and B; and two 11⁄64" holes on parts B and C. For these, drill one part, clamp it up to the other part, and mark the hole locations with a Sharpie. Punch and drill on your marks, and the holes will match up. This is cheating but it works.

3f. For larger holes, drill a small hole first to make the bit easier to center. You can also cut large holes with a step bit (aka castle bit or unibit).

3g. Use a tapered reamer or round file to open the large holes up to their final size. Deburr the small holes with a large drill bit or chamfering tool. Deburr the large holes with a round file. Holes C at the bottom of part A must be completely smooth. Any burrs there might poke into and short out the LM1875 chips.

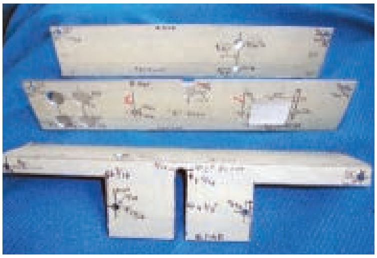


3h. For the square hole on part B, the input panel, you can drill a ⅝" hole and use a ¼" metal nibbler to cut the perimeter. Finish the hole with a flat file.



3i. Part C has 2 large areas to cut out. Saw these with a hacksaw or band saw and deburr. Make two 1"×¼" shims out of the cut-out material. These will fill a gap between parts B and D.

3j. For the long slots in parts B and C, drill a ¼" hole at the end, and saw up to the holes, making ¼" slots with round ends.

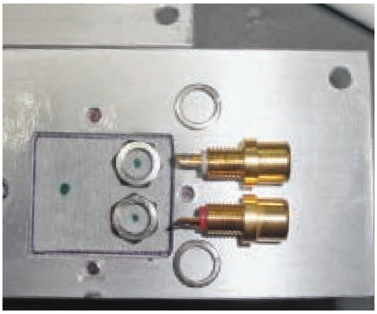


3k. Assemble the metal parts to check for hole alignment: two 3½" screws with acorn nuts at the tops of parts A and B, through rails E; #8-32×½" screws and nuts through the matching 11⁄64" holes on A and B, and B and C; and #4-40×3/8" screws securing rails D to the bottom corners of A and B. Adjust the positions of any off-center holes with a needle file.

3l. Cut 3⁄16"-thick plexiglass into one piece 8½"×2⅞" (for the top) and 2 pieces 2⅞"×1½" (for the sides). Notch out the lower corners of the side pieces so they clear the nuts in the D rails. Test-fit these pieces and trim to fit.

3m. For the input terminal panel, cut a 1½"×2" piece of Formica or other thin, stiff plastic. Tape it inside the input terminal cutout on B, then transfer the screw hole positions and cutout shape to the plastic with a Sharpie.

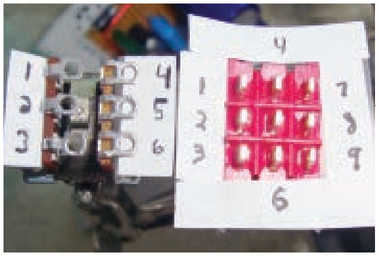
Drill the 3 smaller holes for #4 screws (0.100") and the larger hole for the #8 screw (0.16") to mount the transformer. Find positions on the cutout area where the input jacks will not touch part B's metal, then drill the plastic and install the input connectors there.



4. CONNECT THE OFF-BOARD COMPONENTS

4a. Test-fit the volume knob onto the dual potentiometer shaft. Cut the shaft to length, being careful to keep metal bits from getting inside the potentiometer.

4b. Referring to the photo of the potentiometer and 3P2T switch at right (and the tip below), use 4" wires to connect the following input jack and switch terminals: input 1 left to switch 7, input 1 right to switch 9, input 1 ground to switch 8, input 2 left to switch 1, input 2 right to switch 3, and input 2 ground to switch 2.



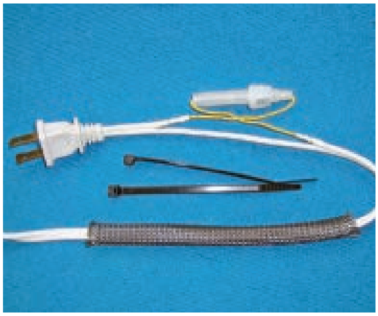
Use 3" wires to connect switch 6 to volume pot 4, switch 5 to volume pot 3 and 6 (both), and switch 4 to volume pot 1.

With 6" wires, connect volume pot 3 and 6 to the star ground wire on the PCB, volume pot 5 to PCB lead AD8, and volume pot 2 to PCB I8.

TIP: Recall that with headphone plugs, the tip is the left channel, the ring is the right, and the body or "shield" is ground.

4c. Cut the socket end off your extension cord. Near the plug, cut out a section of the live wire (the wire connected to the plug's narrower prong). Splice in the inline fuse holder with enough slack so you can open it up, and insulate these solder joints with heat-shrink tubing. Write "½ A" on the fuse holder, or otherwise label it in case the fuse is lost.

Slide cable sleeving up over the fuse holder and position it so it can be pushed back for changing the fuse. Fix one end of the sleeve to the cord with shrink wrap or a zip tie, and the other end with a loop of double-sided velcro.



4d. Install the speaker terminals, power switch, and transformer on parts B and C, running the transformer secondary (yellow and black) wires in through the slots. Temporarily screw the PCB to part B with screws through the LM1875 tabs. Bend the 2 yellow leads to the hooked diode leads H1 and X1, and carefully mark where they meet. Do the same for the 1 black center tap lead to connect to the ground wire loop at P6–P10. You'll connect these 3 wires later, but their lengths are critical because they support the upper edge of the PCB.

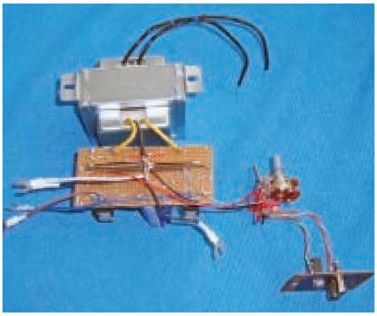
4e. Measure and note the distances from the PCB ground to the speaker terminal black posts, and from the speaker terminal red posts to the amplifier outputs at E15 and Z15. Remove the PCB from the chassis and set it aside.

4f. Test-fit the power line cord to the chassis with a nylon P-clip on the transformer mounting screw under the switch. Measure, cut, and solder the cord's neutral (wide prong) side to one transformer primary lead, and its live (narrow prong) side to one switch lead. Solder the other switch lead to the remaining transformer primary lead. Insulate all solder joints with heat-shrink, and refit the power cord and P-clip.

4g. Disassemble everything and then cut and strip the transformer wires (yellow and black) where you marked them in Step 4d. Flip everything over and solder the transformer leads to the PCB.

4h. Solder two 18-gauge stranded wires to the PCB's ground wire loop and run them to the speaker terminal black posts, trimming their lengths and connecting them to the posts with spade terminals crimped and soldered onto the wires. Similarly connect 2 more 18-gauge wires between the PCB's E15 and Z15 positions and the speaker terminal red posts. Be careful not to damage the feedback resistors soldered to those output terminals.

4i. Crimp and solder a spade lug to one end of a 2" length of 18-gauge stranded lead, and solder the other end to the PCB's star ground loop P6-P10. This will be the ground connection, screwed down at the transformer's right mounting screw. The circuit is now electrically complete. You can test it again to make sure it still works.



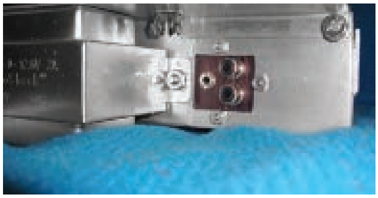
5. ASSEMBLE EVERYTHING

5a. Put two #8 screws through the plastic feet, pass them up through the 11/64" holes from underneath parts A and B, and secure them with nuts on top. Part A overlaps on top of part B. Install rails D as in Step 3k, filling the gap between B and D with the 1"×1/4" shims you cut in Step 3i.

5b. Install the speaker binding posts.

5c. Place TO-220 mounting insulators over the 5/32" holes on part A, where the chips will bolt down. Use thermal grease if they're mica insulators.

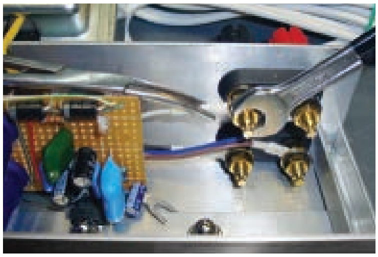
5d. Carefully place the assembled electronics into the A/B assembly. Secure the input switch and volume control to the front of A with nuts. Install the volume knob. Install the three #4 screws that hold the input panel to B, and nut them on the back.



5e. Slide part C between the transformer and part B. Install the power switch in part C. From the back, pass a #8×½" screw through the transformer mounting hole, parts C and B, and the input panel. Pass #8×½" screws through the P-clip holding the power cord, the transformer mounting hole, and parts C and B on the speaker side. Nut these 3 screws on the inside, trapping the PCB ground wire lug under one nut to ground the PCB to the chassis.

5f. Screw down the LM1875 chips with #6 nylon screws from below and metal nuts on top. Don't use metal screws. The chip tabs must be electrically insulated from the chassis.

5g. Connect the speaker ground leads from the PCB to the black speaker terminals. Connect the speaker signal leads to the red speaker terminals, right to lower and left to upper.



5h. Drop the plexiglass side panels in place in rails D. They're left loose for airflow.

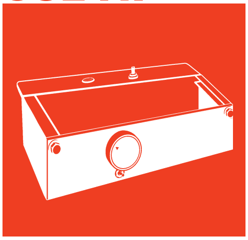
5i. With washers, pass the #8×3½" screws through the upper corner holes in parts C, B, and A from the back. Install washers and acorn nuts on them at the front. Slide one rail E over the long screw from the side. Tighten the nut on the screw to hold the E rail in place. Slide one end of the plexi top into the E rail. Slide the E rail over the other end and tighten the long screw's nut to hold it in place.

5j. You're done. Hook it up and take it for a spin!

FINISH X

NOW GO USE IT »

USE IT.



ENJOY YOUR SIZZLIN' SQUELETTE

OPTIONS

Simple Power Amp If you plan to use a single signal source, you can omit the 3P2T source selector switch and wire your input connectors directly to the volume pot.

And if your source has a volume control of its own, you can build the Squelette as a plain power amp by replacing the 100K volume pot with a 100K resistor to ground for each channel.

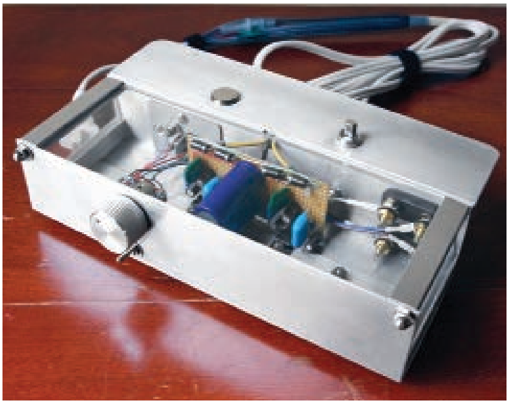
Headphones There's no headphone jack in this build, but you can add one by connecting it to pin 4 of each chip through 150Ω resistors in series with the signal leads. This configuration limits current, preventing you from accidentally smoking your 'phones. Insulate the headphone jack body from the metal chassis and ground it to P6–P10.

Radio A good mini amp deserves a good mini source. For FM stereo, AM, and shortwave listening, I recommend Grundig's compact radios. RadioShack sells the high-performance G8 model for $50.

Speakers Quality speakers make a huge difference to music reproduction. I polled the speaker experts on audiokarma.org for suggestions on good-sounding compact speakers under $250. We recommend the JBL Control 1, the Paradigm Atom, the PSB Alpha Series, and the Sony SS-B1000. Any of these will provide clean, well-balanced sound from your Squelette.

The basic Squelette circuit can be used for other applications as well. Install a chip amp inside a speaker cabinet. Convert an old tube table radio to a powered iPod dock. Make an amplifier to match your customized Chumby.

Build your own steampunk amplifier, complete with brass meters, knife switches, a japanned steel cabinet, and a fly-ball governor for voltage regulation. Please! I so want to steampunk one of these, but I have always opted for minimalism.



+ Visit makezine.com/23/chipamp for a schematic diagram and plan drawings for the Squelette's chassis.

GYROCAR

By Matthew Gryczan

COLLABORATE ON
Make:Projects
» makeprojects.com

BALANCING ACT

Outfit a toy gyroscope with an electric motor to make it run continuously, and add an adjustable drive wheel that lets it chug along a monorail, balance on a string, circle the rim of a pot, and perform other tricks.

Anyone who's played with a gyroscope toy powered by pulling a string wound around its axle knows that it's fascinating, but also frustrating because it runs down so quickly and has to be rewound. I decided to make an electric version that runs for as long as its AAA batteries hold out — which can be at least a half-hour, since the spinning gyroscope wheel stores some energy, easing the load on the motor.

I went through 3 iterations before arriving at this simple design, which is easy to build and works well. In addition to battery power, the Gyrocar has a small track wheel at the bottom that's friction-powered by the main gyroscope wheel. The track wheel drives the Gyrocar along any thin, horizontal edge while it bears the gyroscope's weight, but otherwise it doesn't press against the main wheel, to avoid draining energy. Three screws let you adjust the track wheel or disable it entirely so that the Gyrocar stays idling in one place.

I'm sure MAKE readers will improve on my design. And if you've got access to a metal lathe, you can make an original version that isn't based on the toy.

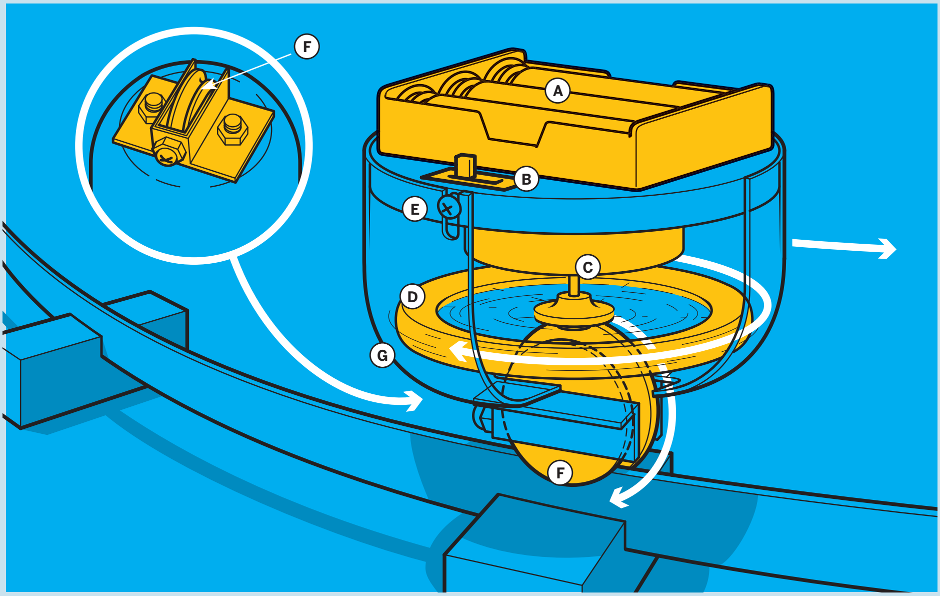
Photograph by Sam Murphy

Set up: p.87 **Make it: p.88** **Use it: p.93**

Matthew Gryczan is a former manufacturing engineer and newspaper reporter, and a lifelong basement tinkerer. In his day job, he writes news releases for science and technology companies at SciTech Communications.

Staying Up

When a gyroscope (or top) isn't spinning, gravity just pulls down one side and it falls. But when it spins fast, gravity's force on that side is quickly rotated to other positions before the gyro has a chance to fall. As a result, the gyro self-corrects, with its axle tending back toward a right angle to gravity.



(A) Three AAA **batteries** power the Gyrocar's motor for 30+ total minutes.

(B) The plywood **motor mount** holds the batteries on top and the motor underneath.

(C) The motor's **axle** points downward and attaches inline directly to the gyroscope axle.

(D) The **gyroscope wheel** hangs down and rotates horizontally, creating gyroscopic forces. There's no axle underneath.

(E) **Three screws** let you adjust the plastic cap's position to precisely engage (or disengage) the gyroscope wheel with the drive wheel.

(F) The **drive wheel** turns vertically, centered underneath the gyroscope wheel. It's shaped like a biased pulley, and its larger side is friction-driven by the gyroscope wheel close to the center.

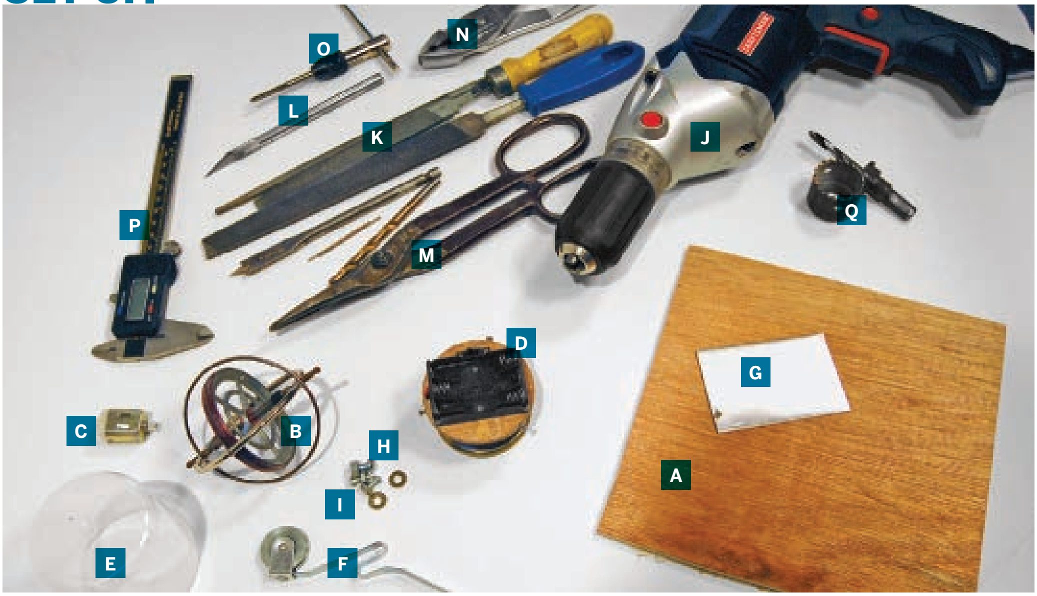
(G) A **plastic cap** attaches the motor mount to the bracket that holds the drive wheel, enclosing the gyroscope. The cap's thin plastic material flexes under the weight of the gyroscope, so that the gyroscope only engages with the drive wheel when the drive wheel bears the Gyrocar's weight.

THE KASHMIR LIMITED: BRENNAN'S GYRO MONORAIL

Our Gyrocar was inspired by the work of Louis Brennan, the inventor who made a fortune by creating the first guided torpedo for the British Royal Navy in the 1870s. Brennan spent the rest of his life trying to commercialize monorail systems that used huge gyroscopes for balance. He even built a 24-ton gyro locomotive for the British War Office and the Maharaja of Kashmir. But his ideas never caught on — neat factor aside, it's not practical to devote so much weight and energy to gyroscopes when you can simply balance on 2 rails.

Illustration by James Provost; photography by Getty Images

SET UP.



Photograph by Ed Troxell

MATERIALS

[A] Scrap of 3⁄16" plywood or similar; 6"×6" is plenty

[B] Toy windup-style gyroscope or small metal wheel that can act as a gyroscope

[C] Small DC electric motor, 4.5V or 5V
I scrounged mine from an old CD drive, but any standard small motor should do. Solder wire leads to its terminals if it doesn't have them.

[D] 3xAAA battery holder shown here on the plywood motor mount. RadioShack part #270-412, $2

[E] Round plastic cap or container big enough to enclose the gyro wheel. Use a sealable storage container or the cap from a spray can or detergent. Cap sides should be straight, not tapered.

[F] Tension roller, 1" diameter × 1⁄4" width for a sliding door, concave, steel, from a hardware store, or part #111731 from Slide-Co (slide-co.com), $8

[G] Sheet steel or brass, 22 gauge, at least 2"×3"
from a hardware store.
I bought a 6"×24" sheet for $9 that will come in handy for other projects as well.

[H] #6-32 machine screws, 3⁄8", with matching nuts and flat washers (2)
or similar

[I] #10-32 machine screw, 3⁄8", with matching nut

[NOT SHOWN]

Small switch (optional)
convenient for turning the Gyrocar on and off.
I scrounged one from a toy.

Small plastic rod (optional)
the same diameter as the gyroscope's axle, or slightly thicker. Use this if you're able to tap the toy gyro's axle out with a hammer (in which case you're lucky).

Small wood screws (5) for mounting the battery holder and plastic cap to plywood.

Wood glue

TOOLS

[J] Electric drill and drill bits

[K] Metal files or grinding wheel

[L] Hobby knife

[M] Tinsnips

[N] Pliers

[O] 10-32 NF (National Fine standard) tap

[P] Caliper or micrometer (optional)

[Q] Router or saw for cutting circles out of thin plywood. You could use a jigsaw, saber saw, band saw, or a hole saw mounted in a drill.

[NOT SHOWN]

Hammer

Sandpaper or rotary tool with sanding drum

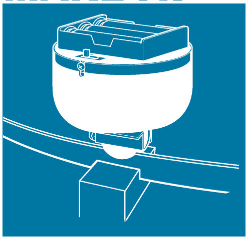
Pencil and ruler

Try square and metal center punch (optional)

Glue gun and hot glue (optional)

Lathe (optional)

MAKE IT.



BUILD YOUR GYROCAR

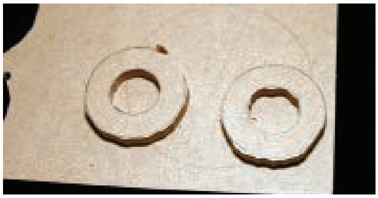
START **Time:** A Day **Complexity:** Easy

1. MAKE THE MOTOR ASSEMBLY

1a. Trace around the plastic cap on the plywood sheet. Use a saw or router to cut out a disk that size, then file and sand it down until it fits flush just inside the cap.

TIP: If you use a hole saw, back the plywood with another piece of wood. This ensures that the saw won't rip the grain on the exit side, so the disk will have clean edges. A hole saw also drills a hole in the center, which is fine.

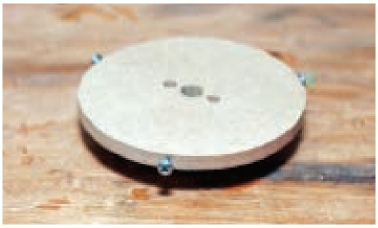
1b. Measure the diameter of the motor, then scribe, cut, and sand 2 plywood rings whose inner diameters are just smaller than the motor and whose outer diameters are about twice the motor's diameter. File or sand the holes until the motor fits snugly inside. You can also cut a matching hole in the larger disk, which will give the gyroscope wheel more vertical space to fit inside the cap.



1c. The battery pack attaches flat on top of the large disk, so you need to make a way for the wires to run through the disk to the motor underneath. If you cut a motor-sized hole, use a small file or hobby knife to make a small channel deep enough to accommodate the wires under the battery pack. Otherwise, drill small holes that the wires can pass through, as shown here.

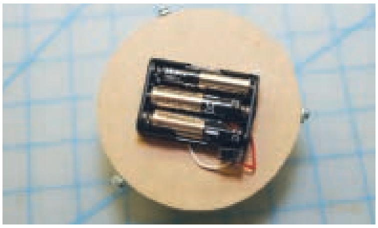
Photography by Ed Troxell

1d. Drill 3 roughly equidistant pilot holes into the circumference of the large disk, and temporarily insert 3 small wood screws.



1e. Glue the 2 small rings together on the bottom of the large disk, with all their centers aligned so that the motor fits in vertically.

1f. Test-fit the motor into the disk assembly and route the leads out the top. Use the remaining 2 small wood screws to attach the battery holder centered to the top of the large disk.



2. CONNECT THE GYRO WHEEL AND MOTOR

Now we'll attach the gyroscope wheel to the motor shaft. Getting this connection precise and strong is the most important part of the build, and you may want to use some ingenuity based on what your gyro wheel and motor are like.

2a. Remove the gyroscope wheel from its wire housing and try tapping the axle out with a hammer. If it comes free, you can fit in a plastic rod, which will make things easier. If the rod is a bit too wide to press-fit through the hole, chuck it in an electric drill and turn its diameter down by running it against a file.

If you can't extract the axle, saw it off and file or grind it down on both sides of the wheel.

2b. Use a caliper or micrometer to measure the diameter of the motor shaft. Find a drill bit that's the same size, or a few thousandths of an inch smaller if you've fit in a plastic rod. I used a #55 drill bit. The center hole you'll drill in the wheel must grip the shaft tightly, so that it doesn't detach at high speeds.

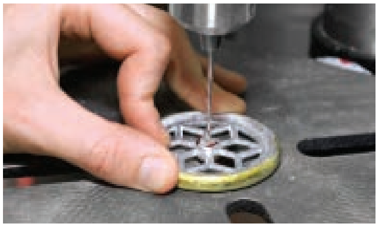
2c. As best you can, find the exact center point of the gyroscope wheel. (If you have access to a lathe, you can chuck the wheel on its outer diameter and drill a center hole on the lathe, skipping to Step 2e.)

If you inserted a plastic rod, push a pin into it where you think the center should be, then hold the pin pointing upward and gently spin the wheel like a top to see if it wobbles. Keep adjusting the pinpoint location and spinning the wheel, using trial and error until you find a good balancing point.

If you filed down the original metal axle, you can scribe crosshairs with a try square set to 45°, mark the point with a hammer and center punch, and test-spin the wheel with the pin in the mark.

NOTE: If you have a metal lathe, you might even try making your own gyroscope wheel.

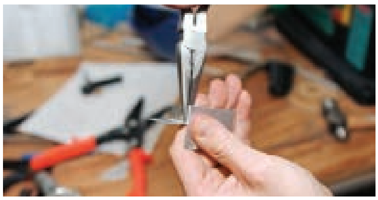
2d. After you've found the center point, drill the hole for the motor shaft precisely at that point, as perpendicular to the wheel as possible.



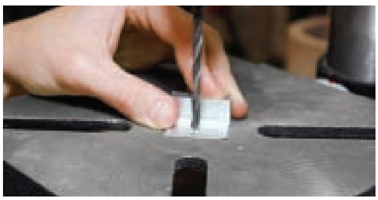
2e. Press or tap the wheel onto the motor, as close as possible without interfering with it turning freely. This connection needs to be tight and strong. You can reinforce it with hot glue.

3. MOUNT THE TRACK WHEEL

3a. Download the track wheel mounting bracket template at makezine.com/23/gyrocar and print it at full size. Cut and trace the outline onto sheet metal, then cut it out with tinsnips and bend it with pliers, following the notes on the template.



3b. Drill the holes in the mounting bracket, as noted on the template.



3c. Use a file or grinding wheel to remove the head of the rivet that connects the tension roller to its spring steel leg. This will leave you with a free-turning wheel held by a small metal bracket; this is the drive wheel, or track wheel.

File or grind down one edge of the track wheel to reduce its diameter all around. The track wheel will be centered underneath the gyro wheel, but you want only one of its circular edges to touch the gyro wheel.

3d. Thread the existing hole in the wheel bracket with the 10-32 NF tap, and attach it with a #10-32 machine screw and nut to the mounting bracket you made. The screw should be about ⅜" long; it mustn't interfere with the free turning of the track wheel.

3e. Fit the motor into the plywood rings and route the wires back through as you did in Step 1f.

3f. The depth of the plastic cap from rim to inside bottom should be about ¼" greater than the height of the motor assembly from the top of the large disk to the bottom of the gyroscope wheel. If the cap is too deep, mark and trim its rim down evenly.

3g. Turn the cap over and mark a ⁵⁄₁₆"×⅞" rectangle centered on the cap, plus 2 points ⁵⁄₁₆" from the long sides, matching the bracket mount holes. Cut out the rectangle and drill the holes with a ⅛" bit.

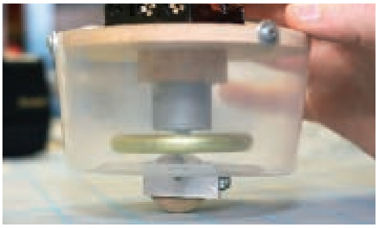
3h. Secure the bracket and drive wheel to the bottom of the cap using two 6-32×⅜" machine screws, washers, and nuts.

4. ASSEMBLE AND ADJUST

4a. To simplify construction, you can trim and connect both motor wires to the battery pack directly. This way, you turn the car on and off by popping one of the batteries in or out. But to make my latest Gyrocar easier to operate, I wired a small switch into one connection.

4b. In the rim of the plastic cap, cut 3 slots about ¼" long each, sized and spaced to accommodate the 3 screws on the circumference of the large disk.

4c. Now put the Gyrocar together by fitting the cap over the 3 screws on the disk. Run the motor and fix the cap's position so that the gyroscope doesn't press against the track wheel constantly, but only when the Gyrocar is resting on the track wheel and the thin plastic cap flexes slightly under the gyroscope's weight.

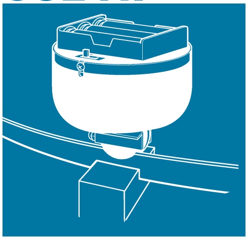


4d. Finally, adjust the screws that hold the drive wheel bracket to the cap so that the Gyrocar remains upright as it runs, rather than leaning to one side. You want to center the Gyrocar's center of gravity, and the holes in the bracket are large enough for some adjustment room. That's it; you're done! After these 2 adjustments are made, you won't have to make them again.

FINISH X

NOW GO USE IT »

USE IT.



TAKE GYROCAR FOR A SPIN

HIGH-WIRE ACTS

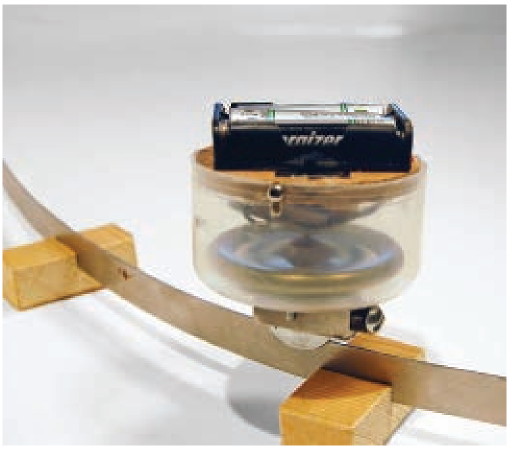
You can use a large cooking pot as a simple track for your Gyrocar, or you can make a track that offers more interest. I used an old band saw blade ½" wide by 64½" long that worked very well as a track for my Gyrocar.

To hold the blade upright, I cut some 1"-wide blocks of wood out of standard 2" wooden furring strip and cut a ¼" deep slot in each with a thin saw blade. You can watch videos of the Gyrocar running on this track at makezine.com/23/gyrocar.

If you adjust the Gyrocar so that its track wheel doesn't turn, it will rest comfortably on a taut string — even travel along the string if it's raised or lowered.

I've built a few Gyrocars with different designs. For one of them, I used foamcore board instead of plywood, which I covered with colored foil wrapping paper. I also covered the battery pack with a hemispherical spray-can lid, all of which gave the Gyrocar a flying-saucer look.

+ For Gyrocar templates and videos of the Gyrocar in action, visit makezine.com/23/gyrocar.



Photography by Matthew Gryczan

THE MOST USELESS MACHINE

By Brett Coulthard

AS SEEN ON TV

PARADOX BOX

Last year I saw a video of the "Leave Me Alone Box" built by Michael Seedman. Flip its switch on, and an arm reaches out of a door to turn the switch back off. That's what it does, that's *all* it does, and it will not stop until its circuit is dead.

I had to have one of my own, so I made one. Seedman's design uses a microcontroller to run two servomotors: one to open the lid, and another to push the switch. This makes for an impressive performance, but seemed too complicated, and actually, his circuit remains powered even when the box is idle.

For existential purity, I wanted a super-simple machine that *really* turned itself off. So I came up with a single-motor design controlled by a 555 timer chip, with a curved arm that both lifts the lid and flips off the switch. I called it the "Most Useless Machine" and posted it on Instructables along with a YouTube video of the box in action. The project soon went viral, attracting millions of viewers, thousands of comments, and many builds and design variations. Whew!

Along the way, Instructables member Compukidmike came up with an even simpler version that dispenses with the 555 circuitry entirely by using a gearmotor and two switches. The resulting project, presented here, is the ultimate in technology for its own sake, a minimal assemblage of parts that, through its one meaningless act of defiance, speaks volumes.

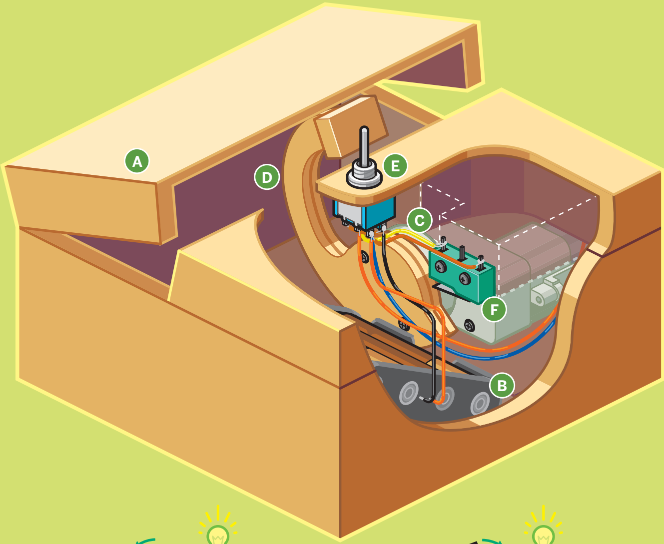
Photograph by Sam Murphy

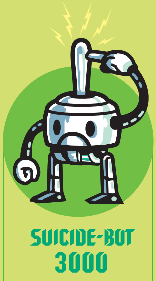
Set up: p.97 **Make it: p.98** **Use it: p.102**

Brett Coulthard (saskview.com) has a short attention span, which explains his varied interests. He lives and pushes buttons near Moose Jaw, Saskatchewan.

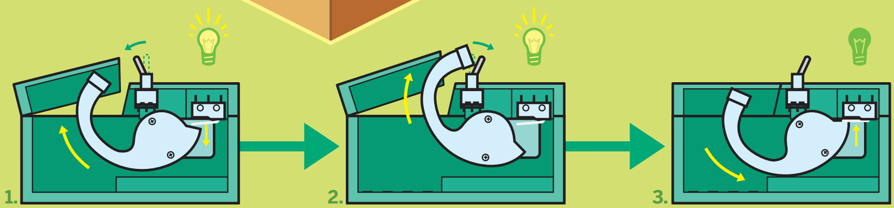
Turn-ons and Turn-offs

The Most Useless Machine has a toggle switch, a motor, and a micro lever switch. The toggle runs the motor forward or backward, depending on which way it's flipped. Running forward, the motor swings a wooden arm that flips the toggle switch the other way. The motor then runs backward, and as the wooden arm returns to its original resting position, it triggers the lever switch to cut the power off.





BONUS: Download this custom design and stencil by Rob Nance for your useless machine at makezine.com/23/useless machine



The plain-looking **box** (A) has a hinged lid and a toggle switch on the outside.

Inside the box, a 4×AA **battery pack** (B) powers the motor.

The **motor** (C) is a gearmotor whose built-in gearing gives its small DC motor enough torque to move a wooden arm.

When the motor runs forward, the curved wooden **arm** (D) swings up, pushes open the lid, and knocks into the toggle, switching it the other way.

The **toggle switch** (E) is a double-pole double-throw (DPDT) switch that's wired to feed power to run the motor forward or backward, depending on how it's switched.

The **micro lever switch** (F), located under the wooden arm, is a single-pole double-throw (SPDT) switch. It's wired from its normally closed (NC) pin to cut the motor-backward power when the wooden arm pushes down on its lever.

CONTROL SEQUENCE:

1. When the machine is idle, the circuitry is fully powered down. The toggle switch is in its "off" position. Inside, the lever switch is held down in its Off position by the wooden arm.

2. When a person flips the toggle switch "on" (forward), it powers the servo to rotate the arm into the toggle switch and flip it back "off" (reverse).

3. Once the toggle switch is flipped "off," the servo moves in reverse until the arm rests on the lever switch, which is the real Off switch. This shuts the motor off again.

ORIGINS

The Most Useless Machine has a proud heritage. The first machine that simply switched itself off was built by information theory pioneer Claude Shannon in 1952, based on an idea by artificial intelligence pioneer Marvin Minsky. The device sat on Shannon's desk at Bell Labs, and in 1958, sci-fi author Arthur C. Clarke dubbed it "The Ultimate Machine" in *Harper's Magazine* and in his nonfiction book *Voice Across the Sea*. Since then, knockoffs and variations on the theme have ranged from mass-produced novelties to works of art.

Illustration by Rob Nance

SET UP.

Photograph by Ed Troxell

MATERIALS

[A] Heavy paper, card stock, or scrap cardboard

[B] ¼" plywood scrap about the same size as one side of the wooden box [L]

[C] Wood glue or cyanoacrylate gel glue or other good permanent glue for wood and plastic

[D] AA alkaline batteries (4)

[E] 4xAA battery holder Digi-Key #BH24AAW-ND (digikey.com) or RadioShack #270-391 (radioshack.com)

[F] Insulated solid-core wire, 24-gauge, different colors Scavenge from dead telephone cable, Ethernet cables, thermostat wire, intercom cable, and anything with tiny colored wires. You can't have too many different colors of wire.

[G] Insulated, stranded hookup wire, 22-gauge or thereabouts

[H] Gearmotor part #GM2 from Solarbotics (solarbotics.com) or #SBGM2 from the Maker-Shed (makershed.com). You can also use a standard R/C servomotor modified to ignore signal input and allow for continuous rotation, if it doesn't already. See makezine.com/23/uselessmachine for sources and instructions. A GM2 is less expensive, but if you have an extra servomotor already, the mods are easy.

[I] Gearmotor mount and mounting bracket Solarbotics #GMW and #GMB28, if you're using the GM2 gearmotor.

[J] DPDT toggle switch Digi-Key #EG2407-ND, RadioShack #275-636, or salvage this and the micro switch from common electronics.

[K] SPDT lever micro switch Digi-Key #EG4544-ND or RadioShack #275-016

[L] Small wooden box with lid large enough to fit the battery pack, motor, and arm in resting position (down). The one I used was purchased at a Dollar Giant store. If your lid isn't hinged, you'll also need some small hinges.

TOOLS

Table saw or handsaw that can cut wood straight

Miter box (optional) but helpful for handsaw straight cuts

Jigsaw, coping saw, or scroll saw or other saw that can cut curved wooden pieces

Pencil and eraser

Ruler

Scissors

File and sandpaper

Drill and drill bits: 1⁄16", ¼"

Small screwdriver for hinge and motor mounting screws

Soldering iron

Wire strippers

Side cutter

Hobby knife

Glue gun and hot glue

MAKE IT.

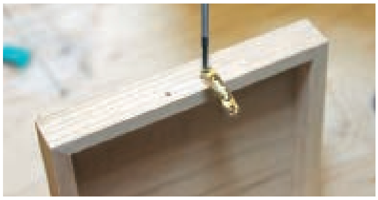
BUILD YOUR USELESS MACHINE

START **Time:** An Afternoon **Complexity:** Easy

1. PREPARE THE BOX

One half of the lid hinges up, while the other half carries all of the machine's workings. The workings all mount onto the same piece so that they'll stay aligned.

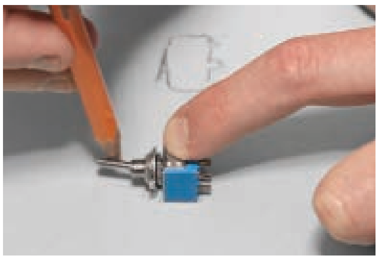
1a. Remove any latches and hinges on the box's lid.



1b. Cut the lid approximately in half through the middle cross-wise, undercutting at a slight angle so that the hinged half won't bind when opening. (You can see this undercut in Step 2c or the overview illustration on page 96.) Before you cut, make sure the machine half has at least enough space to fit both the motor and the micro switch lined up lengthwise.

2. DETERMINE THE LAYOUT

2a. Use the pencil to draw scale paper templates of the motor, toggle switch, micro switch, and the machine half of the lid, all in side-view, and cut them out. Also cut a template for the motor's mounting wheel or horn, and mark the axle on both the motor and mount templates.

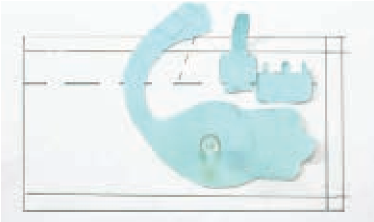


Photography by Ed Troxell

2b. Use the component templates to figure out the shape of the arm and how everything should attach to the lid. Download sample templates at makezine.com/23/uselessmachine. You want the back of the arm (or a mounting horn) to push against the lever switch when it's retracted. Then the arm should rotate and clear the lid while its "hand" swings over and pushes the toggle switch.

Cut templates for the arm and for a standoff bracket that holds the motor and the lever switch. Refine their shapes and sizes and move the pieces of paper around until you're sure that they all work together, while still leaving room for wire connections.

2c. Mark the positions on the templates where they meet: the toggle and bracket's position on the lid, and the motor and switch's position on the bracket.



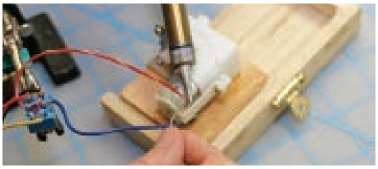
2d. Trace the template shapes onto ¼" plywood and cut the pieces out. File and sand the edges smooth.

2e. Mount the arm to the motor's mounting wheel or servo horn. Drill 1⁄16" pilot holes in the arm and mount it with small screws (usually included).

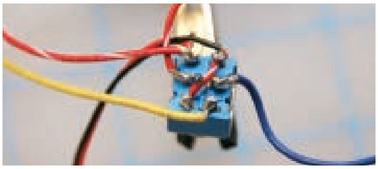
2f. Measure and mark a centerline across the machine half of the lid, perpendicular to its cut end. Then mark the toggle's distance along this line, following its position marked on the templates.

3. BUILD THE CIRCUIT

3a. Now it's time to fire up the soldering iron. If your motor already has leads attached, solder them to each of the 2 middle legs of the toggle switch. Otherwise, cut, strip, and solder wire leads between each motor terminal and the middle toggle pins; 4" long is plenty for all connections in this circuit, and you may want to shorten them later for neatness.

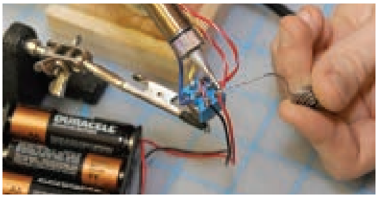


3b. Solder a short jumper wire diagonally between 2 opposite corner legs of the toggle switch, then solder separate leads to the remaining 2 legs at the other corners.



3c. Solder the 2 free leads from the toggle to the lever switch. Connect one to the common tab (marked C), closest to the lever's pivot. Connect the other lead to the normally closed (NC) leg, farthest from the pivot. Don't connect anything to the normally open (NO) tab in the middle.

3d. Solder the battery pack's leads to the 2 legs at either end of the toggle. The circuit is complete! Test it by loading batteries into the pack. The motor should run, the toggle should reverse its direction, and the lever switch should shut it off in one direction. If it all checks out, remove the batteries, leave the toggle thrown in the direction that the lever interrupts, and mark or note this direction on the motor.



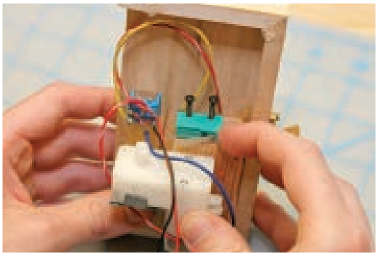
4. ASSEMBLE AND ADJUST

4a. Drill a ¼" hole in the machine side of the lid, at the toggle position you marked in Step 2f.

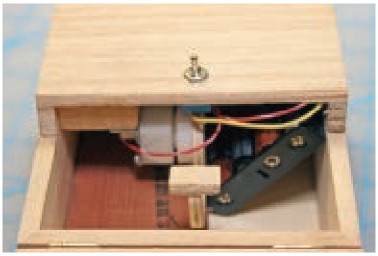
4b. Fit the toggle switch up through the hole, positioned with the toggle thrown in the direction opposite the lid cut. Don't glue it in yet.

4c. Hold the wooden bracket, motor, and lever switch in place against the lid so that they align properly with each other and with the toggle. Mark their positions with the pencil.

If the motor turns in the opposite direction from what you anticipated while determining the layout (if the interruptible direction turns the arm out, not in) you should reverse the connections to the motor, or else position the motor the other way and arrange the pieces in mirror-image on the opposite side of the box.



4d. Temporarily hold all the pieces in place with a bit of hot glue. Put the lid on the box with the other half off, load the batteries, and check to see that everything works perfectly (which is unlikely).



4e. Tweak the components' placement and the shape of the arm as needed, ungluing and regluing with hot glue, until everything does what it should. You may need to file down part of the arm so it clears the bottom of the box, or fine-tune the position of the all-important micro lever switch.

When everything checks out, mark the final locations. Then mount the motor to the bracket with its included screws and attach the other components in place with permanent glue.

4f. For the other half of the lid, replace (or install) the hinges on the narrow end opposite the machine half, drilling 1⁄16" pilot holes.

4g. At this point, you should have a fully functioning Useless Machine. Don't wear it out!

FINISH X

NOW GO USE IT »

USE IT.

LEAVE ME ALONE ALREADY

CUSTOMIZED USELESSNESS

The Most Useless Machine, like Claude Shannon's original, is a desktop or tabletop conversation piece. I went with a minimal aesthetic that leaves it most open to interpretation, but you can dress it up by labeling the switch positions, using a recognizable object like a doll's arm for the arm, or otherwise decorating it.

On a much larger scale, Swiss artist Hanns-Martin Wagner built a version that used an old wooden trunk as a box, a weathered prosthetic arm, and an air compressor for power (see below).

I was amazed at the response to my original Instructable. Everyone wants one of these boxes, and wants to share details of their own build! Its social appeal was also shown this past spring, when the Birmingham, U.K., hackerspace FizzPop (www.fizzpop.org.uk) hosted a Useless Machine-making workshop led by Nikki Pugh (at right).

+ For part templates, videos of the Most Useless Machine in action, alternate versions, how-to videos, and other resources, visit makezine.com/23/uselessmachine.

Photography by Nikki Pugh (top); and Hanns-Martin Wagner/www.sinnwerkstatt.ch (bottom)

1+2+3 Fruit Picker

By Nicholas Barry

You can make it!

Have you ever wanted fruit or vegetables that are out of reach? Ever found it difficult to fit that long, store-bought fruit plucker in your car? Well, here's how you can make your own collapsible fruit picker in about 5 minutes.

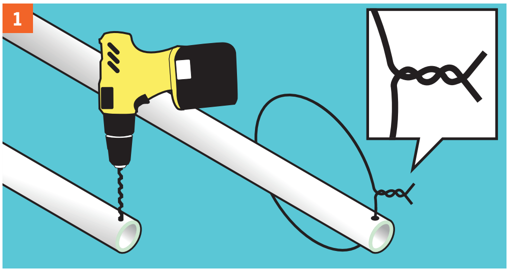
YOU WILL NEED

Rope, about 12'–15'
Strong wire, about 3'
½" PVC pipes, 2' long (6), and ½" PVC couplings (5) or collapsible tent pole
Drill

1. Attach the wire loop.

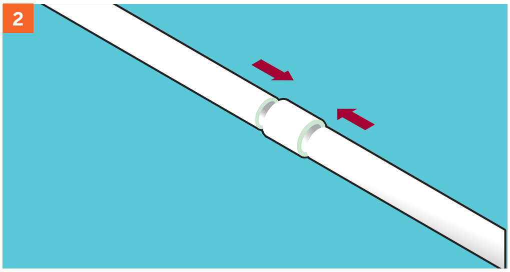
If you're using PVC pipe instead of a tent pole, drill a hole in the end of one pipe segment. Loop the wire through the hole and twist it around itself so it will hold. We made a big loop to pick big tropical fruits, but you can make a smaller loop to pick smaller fruits like apples and pears.

If you're using a tent pole, you can wrap the wire around one end of the pole below the flange, so the wire won't slip off the end.



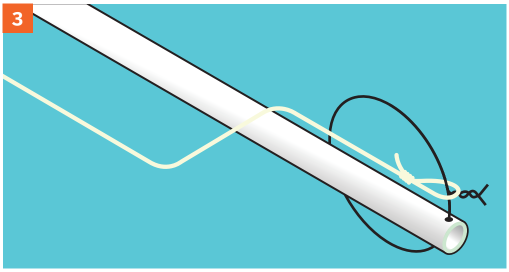
2. Connect the PVC segments together with the couplings.

Don't glue them, just slip-fit them so you can disassemble the picker for easy storage and portability. They should fit together firmly.



3. Tie the rope around the wire loop.

Because the pipe is just held together with a friction fit, you'll need the rope to pull down the fruit.

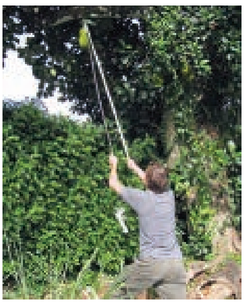


Use It.

Go pick some fruit. Use the pole to raise the wire loop over the fruit you want, until the loop is above the fruit and around its stem. Then pull on the rope to yank the fruit off. Watch for falling fruit!

We use our fruit picker in Hawaii to collect jackfruit (shown here); the edible seeds are the consistency of macadamia nuts, but the flesh surrounding them is what's really good to eat. We also pick breadfruit (delicious when buried in the embers of a beach bonfire for 40 minutes), and coconuts.

These are all large fruits, and they're often out of reach. We went to Hawaii for years without being able to harvest the breadfruit and coconuts we desperately wanted. The fruit picker helps us reach the tantalizing fruit.



Nicholas Barry isn't afraid to meet his maker, because all the makers he's met so far are really cool people.

Illustrations by Julian Honoré/p4rse.com; photography by Dani Lee


PRIMER
MITSUBISHI
Lifetime Warranty
LTW
MITSUBISHI
POWER
RUN
MITSUBISHI
MELSEC

BUILDING WITH PLCs

Programmable logic controllers never fail.

By Tim Hunkin

Programmable logic controllers (PLCs) are industrial computers about the size of a brick. Like microcontrollers, they loop through a list of instructions that repeatedly polls their inputs and generates outputs. But PLCs are larger and more expensive than microcontrollers, and they have much slower cycle times — usually no faster than 10 loops per second, unless you plug in special extra modules. And instead of programming them with C++ or BASIC, you use an arcane language called *ladder logic* (described later in this article).

Given these disadvantages, you'd think PLCs would have become extinct, but they're widely used because they're so reliable, durable, and easy to install. PLCs typically control large-scale machinery like roller coasters or factory production lines, and I use them for all the coin-operated amusement machines I make. Although I often think I'll change to PIC microcontroller chips, I haven't, because PLCs keep improving and many are now affordable secondhand on eBay.

Photography by Tim Hunkin

»

RUGGED AND UNSTOPPABLE

An hour's downtime in a factory is very expensive, so PLCs are designed to work reliably no matter what. I may make lots of mistakes getting a PLC program to run, but once it works, it will usually keep working reliably forever. The bricks work in extremely hot, cold, or humid conditions, and are unaffected by electromagnetic interference. You can switch them on and off at will without worrying about crashing hard disks or corrupting data.

I recently bought a used PLC from a carwash company and it arrived with water dripping out of it. I nearly sent it back, but out of curiosity I tried plugging it in. It worked perfectly, and has ever since. An engineer from Rockwell Automation told me he'd found a PLC in a tea factory that was completely full of tea leaf dust but had been working fine for more than ten years.

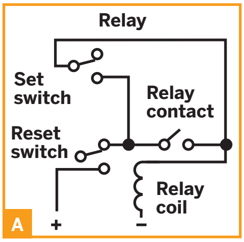
When a PLC does finally fail, you can replace it easily using just a screwdriver — no circuit boards or soldering. Figure C shows a modern PLC "brick" with 2 rows of screw terminals, one for inputs such as switches and sensors, and one for outputs such as transistors and relays (the red rectangles).

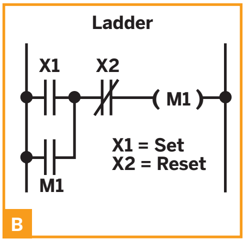
There's even a small, built-in power supply for the sensors. That way, engineers configuring assembly lines or conveyors (Figure D) can plug in standardized sensors and pneumatic rams, rather than having to design and build circuits from scratch.

RELAY AND LADDER LOGIC

PLCs evolved out of the era when all industrial process control and machine tool control was done with *relays*. Entire computers had been made of relays, most famously the Z3, built by German computer pioneer Konrad Zuse in 1941. Machines often had rows of cabinets full of relays wired together, and on an even larger scale, telephone exchanges were literally whole buildings full of relays.

Alongside these relays there were ingenious electromechanical devices like time-delay relays, cam timers, and uniselectors. Time-delay relays have piston dashpots that slow the movement of the relay contacts. Cam timers use geared motors to turn mini camshafts that operate a row of micro switches. Uniselectors are stepping relays that use a series of pulses (particularly the old telephone dialing pulses) to move contact wiper arms to many





different positions.

Relays needed a lot of wires. Figure A shows the circuit for a single flip-flop, which is controlled by a normally open *set switch* and a normally closed *reset switch*. Closing the set switch charges the *coil*, which closes the relay. If you then open the reset switch, the current is interrupted and the relay opens.

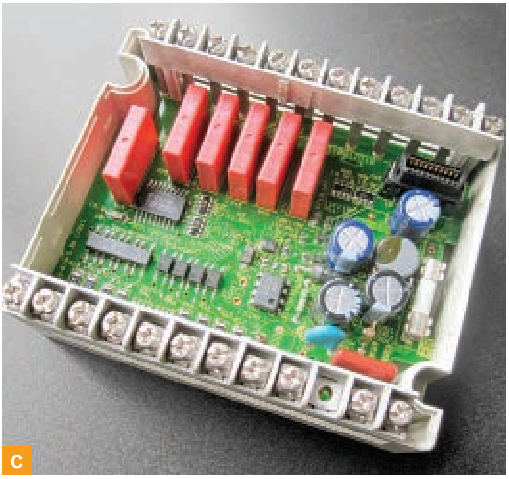
The first PLC, designed in 1968 by a company called Modicon (Modular Digital Controller), used solid-state elements to replace cabinets full of such relays. To program these digital logic arrays, Modicon developed *ladder logic*, a language that mimicked the logic used with relays. Programs were structured like ladders, with each rung representing an IF-THEN rule. IF the conditions of the virtual inputs or relay contacts along the left are met, THEN a relay coil on the right will be energized. The program executes each step of the ladder, then jumps back to the beginning again and continues to loop through the rules indefinitely.

Translated into ladder logic, our flip-flop relay circuit looks like Figure B. Ladder logic was designed so that ladders could be drawn using fixed-width ASCII characters. For example:

Normally open switch:	-| |-
Normally closed switch:	-|/|-
Normally open coil:	-( )-
Normally closed coil:	-(/)-

In our flip-flop ladder rung, `M1` represents one of hundreds of *individually addressable relays* in the PLC. A relay's switch and coil components are treated separately in ladder logic, so `M1` refers to both parts.

To program a PLC, you hook it up to a PC via a serial cable, and then run an *interface application* that lets you write and upload your programs. You



C

D

can draw your programs as ladders, or write them as series of instruction codes, which is the method I prefer. And instead of using a computer, you can also write and edit instruction code from a handheld keypad, but these only show a few lines of code, so it's hard to keep track of what you're writing.

Programmed as instruction codes, our flip-flop relay becomes:

```
LD X1
OR M1
ANI X2
OUT M1
```

The `LD` (load) command starts a new rung on the ladder, `OR` and `ANI` mean logical OR and AND-Inverted, and `OUT` outputs to coil M1.

Converting equipment from relay logic to ladder logic running on a PLC makes it simpler. One of my older coin-op machines, *The Doctor* (Figure G), writes and dispenses an illegible prescription form. I made the original version in 1987 using relays, and its correct operation depended on a lot of micro switches triggering everything in the right order.

A few years ago I replaced the relays with a PLC and was amazed how much less cluttered it became. The accurate timers in the PLC made half the original micro switches redundant. The machine is now much simpler, more reliable, and even has a xenon beacon that flashes when the prescription forms run out.

PLC HISTORY: WIDE TRACES AND RUBBER HAMMERS

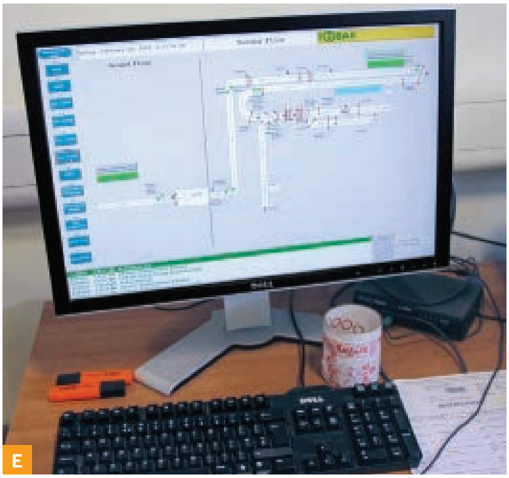
Modicon introduced the PLCs to replace cabinets full of relays with a digital equivalent. They developed a new architecture so processors would be fast enough to simulate ladders of fast-switching relays within a high-level processing language.

To make PLCs more reliable than the computers of the time, they increased signal-to-noise ratio by making everything bigger: larger ferrite cores for memory and wider tracks on the circuit board. They also avoided fans; outside air could carry dirt and cause corrosion.

Modicon engineers built a test chamber called "the blue box." A PLC had to run for a minimum of 24 hours in arctic and tropical conditions. It was then vibration tested, run next to a Tesla coil to test electromagnetic interference, and hit repeatedly with a rubber hammer.

PLCs soon grew more sophisticated, supporting mathematical functions and flowchart programming to run subsections of the ladder. Real-time clocks were added, but never widely used because they were irrelevant to most industrial control. They represented the year with just 2 digits, which I suspect inspired some of the "millennium bug" panic.

Several years ago, *soft PLCs* came out. These turned Windows PCs into ladder-programmable PLC-alikes, but they never caught on. Small, limited operating systems are more reliable than anything running on top of a complete PC operating system.


E


F

PLCs TODAY: SMARTER AND MODULAR

Computers are more reliable today than they were in the 1970s, so PLCs now use many of the same chips, often ARM RISC processors. However, today's PLCs are still built to run in tough environments.

They still have no cooling fans, and work at temperatures up to 140°F (60°C), far hotter than any PC. They also still work next to a Tesla coil; I've tried it. (The input filtering that lets them work in strong electromagnetic fields is the main restriction on their clock speed, limiting it to about 100Hz.)

Today's PLCs have *plug-in modules* for motion control of servomotors, *industrial modems* for remote operation, and *SCADA interfaces* (supervisory control and data acquisition) that diagram and manage entire industrial processes from a touchscreen (Figure E). PLCs can also connect to distant motors or sensors via a network, which saves lots of wiring. Some factories link all their PLCs together, but many network systems are incompatible, and a network failure can make a whole factory grind to a halt. For this reason, some companies, including Ford, prefer to keep their machines separate.

At the other end of the spectrum, there are now simple PLCs called *intelligent relays* (Figure F), designed to replace just one or two relays or timers. These are programmed graphically in logic blocks, quite similar to a Lego Mindstorms controller. It's easy to get a simple program to run on these, but I find them very frustrating. If a program has more than a few logic blocks, it's difficult to arrange them on-screen so that all the connections remain visible. Every edit tends to cover up some of the connections. Last year, while helping a friend put together a giant sculpture clock, I spent three days inside a cramped steel sphere cursing his "intelligent" relay.

Generally, though, I'm a huge fan of PLCs. Even their limitations have advantages for me. Being restricted to a limited number of slow-switching, on/off digital outputs forces me to keep my machines cheap and simple.

For a simulator ride, my PLC will just trigger a CompactFlash card video player to start playing. The PLC then controls the motion by timed on/off outputs to the actuators. There's no communication with the video, but they stay quite adequately in synch, and the jerky, unrealistic movements are amazingly effective.

I wish computers were more like PLCs. They don't need their enormous complexity for most tasks they perform, and they could certainly be more robust. If only every computer were built to be dropped, run next to a Tesla coil, and hit with a rubber hammer.

Trained as an engineer, Tim Hunkin has worked as a cartoonist (*The Rudiments of Wisdom*), a television writer and presenter (*The Secret Life of Machines*), and as a designer, builder, and curator of museum exhibits. Since 2001 he has been obsessed with his amusement arcade, Under the Pier Show, in Southwold, England, when not distracted by building enormous clocks.

G

H

AMUSEMENT MACHINES

The reliability of PLCs is important to me because people get cross if they put money in one of my coin-operated machines and it doesn't work.

Many of my machines use a Mitsubishi FX0-30. This has 14 outputs, which is enough for machines like *Test Your Nerve* and *Microbreak* (Figure H). Some machines need more outputs, so my *Expressive Photobooth* (Figure I) uses an FX0N-60 with 24 outputs. Some, like *Mobility Master-class*, use an FX1S, which has more program memory.

I stick with Mitsubishi for compatibility, but their recent budget PLCs (FX1S, FX1N) are infuriating because the surface-mount LEDs that show input/output status are really difficult to see.

I

ARCADE ADDICT: Fig. G: *The Doctor* is in. Fig. H: The author takes a 3-minute package holiday. Fig. I: This photo booth does things like dropping the seat suddenly to provoke expressions.

1+2+3 Hypsometer

By Cy Tymony

You can make it!

Want to know the height of a person or building? Using simple trigonometric principles, you can closely estimate the height of objects with an easy-to-make hypsometer (*hyps* means height in Greek).

1. Make it.

Tape the straw along the top of the card. Punch a small hole in the right side of the card, 10cm from the bottom. Straighten the paper clip, bend one end into a small hook, and hang it in the hole so it swings freely. Next, write numbers 0 to 12, 1cm apart, from right to left across the bottom of the card, starting with 0 directly beneath the hanging paper clip, proceeding leftward to 12. Here's a tip: If you use a thick plastic bag instead of the card, your hypsometer can be rolled up and carried in your pocket.

2. Test it.

Standing 10' away, look through the straw at the top of a friend's head. When you tilt your head (and the hypsometer), the paper clip will move leftward at an angle as gravity keeps it pointing down at the ground. In Figure 2, it points to number 1.

By measuring your distance from an object (in centimeters) and the angle of tilt indicated by your hypsometer, you can calculate your friend's height.

3. Calculate it.

You'll need 2 more numbers for your calculation: the height of the card (10cm), and the height of your eye line, measured from the ground. You can also measure from the top of your head, then subtract this number from your height. For instance, if you're 5'8" tall and your eyes are 4" from the top of your head, your eye line is 5'4", or 164cm, off the ground.

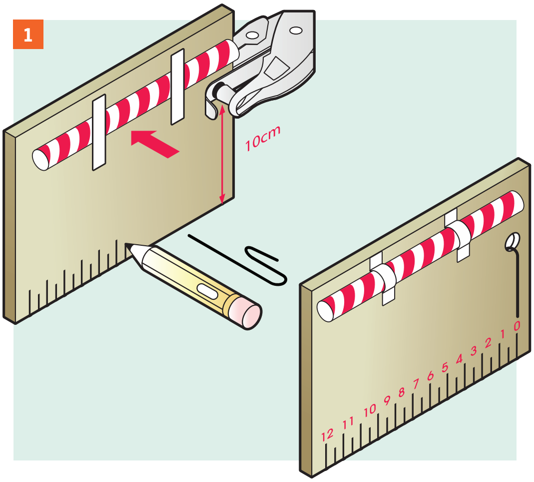
Metric measurements are much easier to calculate with a hypsometer, because metric is a base 10 system. Use a metric ruler, or write equivalents on your hypsometer as shown in Figure 3.

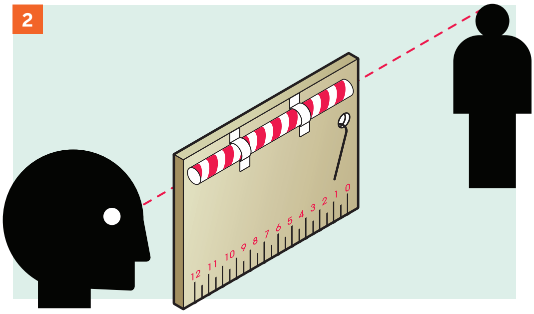
Multiply the distance to your friend (10' or 305cm) by the angle number indicated by the paper clip (1), then divide by the card height (10); in this case, you get 30.5. Add this to your eye line height (164cm), for a total of 194.5cm. That's about 6'3" tall.

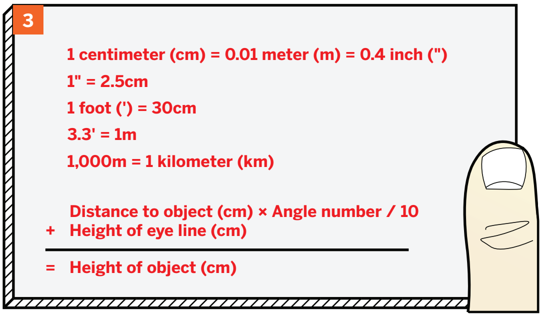
Now test your hypsometer with objects of unknown height, such as doors, walls, and buildings, to calibrate it and sharpen your measuring skills.

YOU WILL NEED

- Drinking straw
- Calculator
- Pen
- Tape
- Large paper clip
- Scissors and hole punch
- 6"×8" piece of cardboard or a thick plastic bag
- Ruler with inch and centimeter markings







Cy Tymony is the author of the *Sneaky Uses for Everyday Things* book series.

Illustrations by Julian Honoré/p4rse.com

WILDERNESS WORKSHOP

Build your own inexpensive yet sturdy worktables and shelving. By Charles Platt

Photography and renderings by Charles Platt

Recently I had a problem and an opportunity. The opportunity was to move my little prototype fabrication business from an industrial park in Southern California to a beautiful wilderness retreat in Northern Arizona.

The problem was that I didn't have much time or money. Could I establish an entire workshop within a couple of months, starting from bare earth and finishing with all the tools and benches in place? And after I paid the construction costs, could I install the fixtures for less than $1,000? (I already owned all the tools.)

In some ways this challenge was a blessing in disguise. If you have to be fast, you can't be fancy, and if you have to be cheap, you can't be self-indulgent. This would not be one of those jobs that drag on for months because the details become an obsession in themselves.

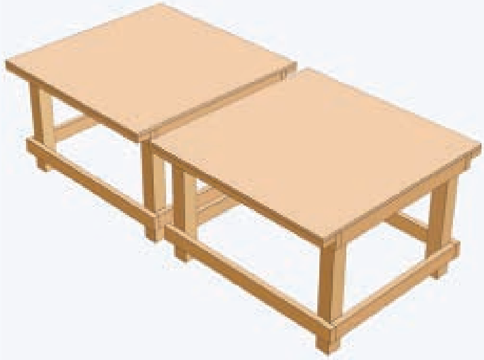
I specified a work area of 19'×24' to allow ample space for lifting, rotating, and cutting 4'×8' sheets of plastic and plywood. To minimize heat loss, increase security, and maximize wall space, I decided not to have any windows, but I did include a massive sectional roll-up garage door. The climate where I live is so benign during most of the year, you can work comfortably with a door wide open. And during the winter, a sectioned door on tracks can be quite well-insulated.

After establishing the basics, I stepped back and let the contractors get to work. There was no way I could do the construction myself in the time available.

Free-Standing Benches

In less than a month I had a bare box standing on a concrete slab. It was insulated, drywalled, and painted. Now for the interesting part: I wanted to

A



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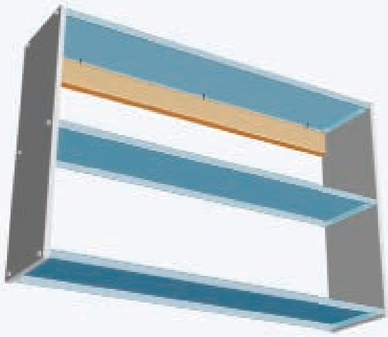


C

Fig. A: The tabletop is a 4'×4' sheet of ¾" plywood, braced and edged with 2×4s. The table legs are 4×4s. Fig. B: Two tables a couple of inches apart allow long cuts across big sheets of plywood or plastic, by running the saw through the gap between the tables. The extended table edge allows quick, easy clamping. Fig. C: The simplest, cheapest, quickest, hang-on-the-wall, non-sagging shelf design.

avoid all the frustrations and errors associated with the workshops I had used previously over the years.

The big central work area allowed me to place 2 free-standing benches of a design that I had always wanted but had never seen. They would be stocky tables, each 4' square. Placing them centrally would allow me to walk around them while building heavy items such as furniture, and a 2" gap between them would facilitate saw cuts.

I stopped using a table saw a few years ago when one of them kicked a piece of plastic at me that almost shattered my arm. Since I don't have enough money or space for the kind of vertical panel saw you see at Home Depot or Lowe's, I like to lay the wood flat and use either a handsaw or a handheld circular saw, which I run along a clamped straightedge. My plan was to align these cuts with the gap between the tables. This would be like using sawhorses, but much more accurate and less aggravating.

With my helper Shawn Hollister, I built the tables lower than a typical workbench, so that we'd be able to reach across them or climb up onto them when making long cuts. We gave them protruding lips so that I could apply clamps easily, and made them heavy to minimize vibration (Figures A and B).

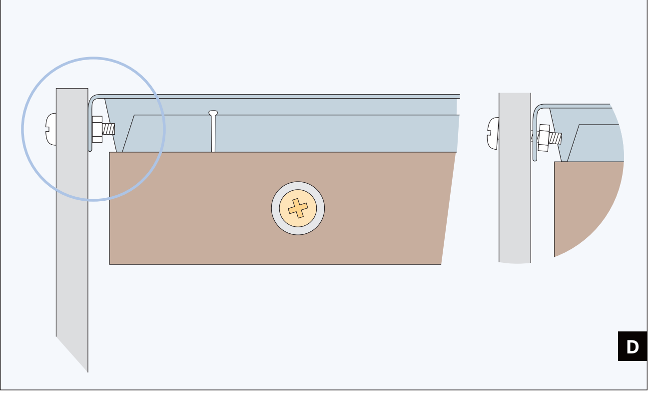
Plastic Bins for Tool Storage

For tool storage, I'm unenthusiastic about the usual options. Tools hanging on pegboard pick up dust and dirt, and when you buy an extra tool, you have to move the others around to make room. As for tool chests, they're expensive, and you have to walk to and fro every time you want something.

My preferred method is so cheap, it's almost embarrassing: plastic tubs from the local big-box store. I group tools in tubs by function, so that when I want, say, a metal file, I pull down the tub containing all the various shaping tools and put it on my worktable. Now I have a full range of options within arm's reach. As for small items such as screwdriver bits and hole saws, I put them in small boxes inside the tubs. At the end of a job, everything is returned to the tubs and stays clean and neat, with the lids snapped on tight.

Shelves That Don't Sag

Where to put the plastic tubs? On shelves, of course, above the side benches where I have a drill press, compound miter saw, band saw, and belt sander, the four tools I consider indispensable for the kind of work I do. But how should the shelves be built? Quickly and cheaply!



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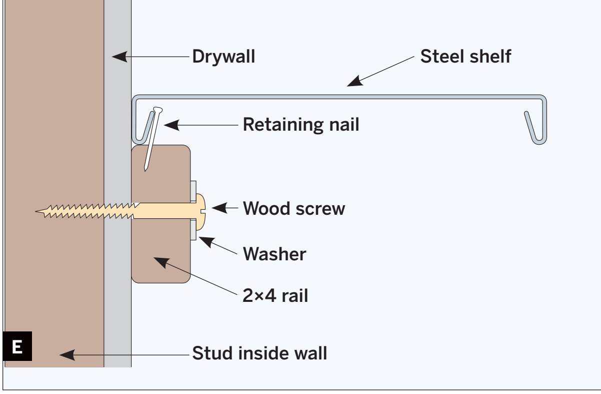

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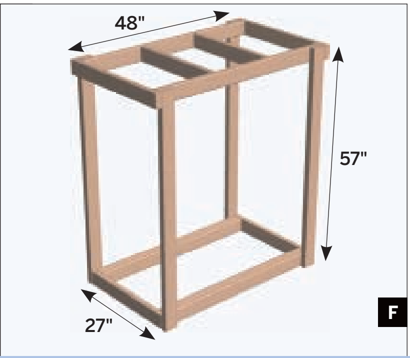

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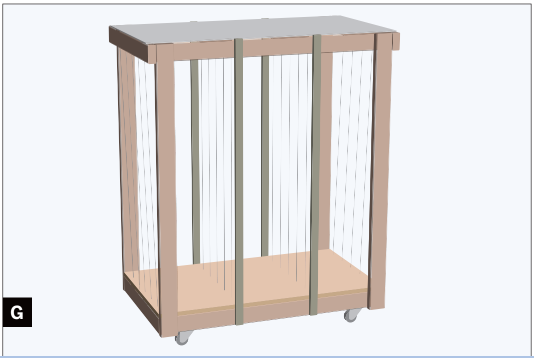

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H

Fig. D: Front view of shelf assembly, with the front edge of the shelf cut away to show relevant features. The inset shows consequences if bolts aren't tightened sufficiently: the bolt can chew right through the wooden upright. Fig. E: Cross section showing how the shelf is attached to the wall. Figs. F–H: A wood rack was made from pine 2×4s with 2½" wheels attached. Galvanized wire separators are secured with screws and washers.

Since I don't like the look of sagging wooden shelves, I chose steel shelves of the type sold for warehouses. A standard length is 4', so you don't need many uprights to support them, but they still take heavy loads without bending. You can bolt them to wooden uprights instead of the ugly perforated vertical bars that are normally used.

I chose melamine-coated particleboard for the end pieces, because it's available in exactly the same 11¼" width as the shelves, and it's prefinished, requiring no painting. I cut the melamine board into sections, drilled them to fit the holes in the ends of the shelves, and bolted them on. Then I cut 2×4s into rails 47" long and screwed them into the wooden studs behind the drywall in my conventional framed construction. We hung the shelves on the rails, adding a couple of nails to prevent the shelves from falling off (Figures C–E). That was that.

The horizontal rails must be a full 47" so that the load carried by the shelves is spread across the entire wooden support. Any unsupported metal section will tend to bend.

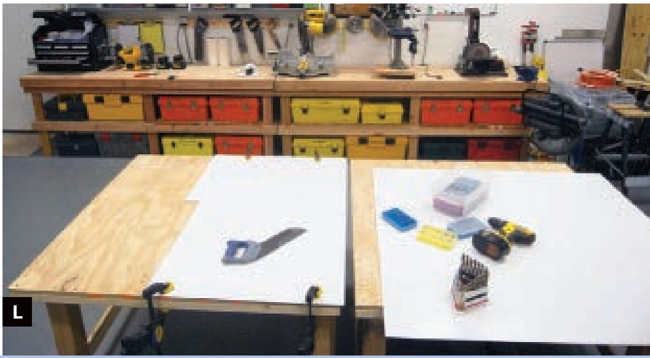
NOTE: Since melamine board is made from compressed wood chips, it can come apart, so you should use pine boards for uprights if you intend to load your shelves very heavily. Or place an additional 47" rail beneath each shelf.

Tighten the bolts to the max, to take advantage of the friction between the end of the shelf and the upright. Friction is proportional to the force perpendicular to the surface, and it supports a load more effectively than just the shaft of a bolt in a hole drilled through wood.

A Wood Rack on Wheels

Another problem was how to store materials efficiently. I have to stock wood and plastic in bulk, because the nearest retail sources are 50 miles away. I dislike stacking sheets against the wall where I can't pull anything out easily, so my answer was a wood rack on wheels (Figures F and G). I've never seen this elsewhere, but it seems an obvious idea to me. When you don't need it, you roll it out of the way, into a corner. I used heavy galvanized wire to make dividers in the rack, so that I would lose as little horizontal space as possible, and I put a flat top on it, where I could stack small pieces of scrap, with even smaller pieces in some more plastic tubs.

As for seldom-used, bulky tools such as bolt cutters and reciprocating saws, I stashed them all



Figs. I–L: With the big door open, it feels as if you're working outside, and eastern exposure gives a nice view of the full moon rising at sunset. Ample floor space will allow the accumulation of miscellaneous junk in the future, or additional work areas. The floor is a concrete slab finished with two coats of epoxy paint. The exterior of the building is covered in Hardie fiber cement siding, which is fire resistant, stable, and durable.

in plastic toolboxes that I placed under the benches against the wall. The boxes aren't strictly necessary; you can just scatter your tools on shelves. But I wanted to keep them clean and categorized. In a shared workshop, when all storage is labeled, you're less likely to misplace things (and less likely to argue with each other when you can't find something).

1.3 Kilowatts of Illumination

The last consideration was in some ways the most fundamental: lighting. If you can't see what you're doing, you can't do good work. I splurged about half of my $1,000 fixtures budget on some GE Ecolux 54-watt high-intensity daylight-spectrum fluorescents, and suspended them from cables stretched from wall to wall below the track of the garage door. When all 24 tubes are glowing they draw almost 1.3kW, and so to reduce energy consumption I installed a separate pull-switch on each fixture, with a chain dangling, so that I can obtain light only where I need it.

During daytime, we don't need the lights at all. We open the huge door and feel as if we're working outside, which is an absolute delight compared with the basement workshops I've used over the years. It's also a lot more pleasant than the industrial park that was my previous environment. When the breeze wafts in and I can look across 30 miles of national forest to a distant mountain, it definitely alleviates the tedium of cutting and shaping components. Bees from a nearby nest sometimes invade the space, but to discourage them we simply sprinkle some xylene on a rag and leave it lying around. They dislike the smell of this industrial solvent even more than I do.

My workshop isn't going to be featured in *Architectural Digest*. It was obviously outfitted on a budget. But I couldn't be happier with its functionality. Tools are easily accessible and don't get lost, the space is uncluttered and easy to clean, the lighting reveals every little detail, and as a result, the work flow is fast and accurate. Most important, the pleasure of working in an outdoor ambience is very special indeed.

It certainly justifies the hassle of moving everything from California.

Charles Platt is the author of *Make: Electronics*, an introductory guide for all ages. He is a contributing editor to MAKE, and he designs and builds medical equipment prototypes.

DIY WORKSHOP

CD/DVD PARTS CONTAINER

A new twist on the old baby-food jar organizer. By Steve Stofiel

If you're organizationally challenged like me, then you probably have a garage or shop full of tools and parts that are just everywhere. That's how it used to be for me; whenever I needed some tool from my shop for a project around the house, it usually took longer to round up everything I needed than it did to actually do the job.

Sometimes I couldn't find what I needed and had to go buy another at the store; later I would stumble upon what I couldn't find earlier. I knew I had to get organized. But how?

There are many products you can buy to help you get organized, such as storage bins, parts bins, cabinets, shelves, and hanging racks. I had tried bins, but they're more for long-term storage and it's hard to see what's in them.

Then I remembered that when I was a kid my dad had these baby food jars hung under a shelf to hold nuts, bolts, and other small parts. It was easy to see what was in them and they were always within reach.

A company I worked for provided a CD/DVD duplication service. They had boxes of empty CD/DVD containers they would throw out. I remembered the baby food jars and thought, why not use

MATERIALS AND TOOLS

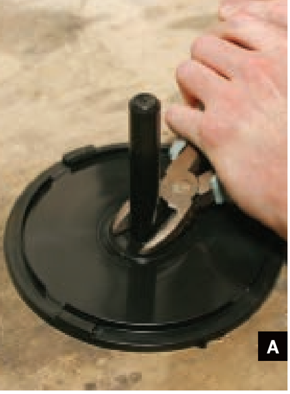
Empty CD/DVD containers The base has a spindle that holds all the CDs or DVDs; the clear plastic cover snaps onto the base with a twist.

Drill and drill bit

Wood screws

Scrap wood and masking tape (optional) I used these to make a quick jig for aligning my containers.

Photograph by Sam Murphy



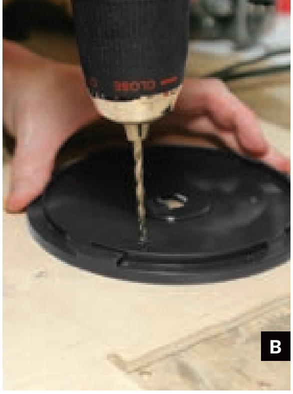


Fig. A: Pop the spindle off the base. Fig. B: Drill mounting holes through the base. Some bases have circular protrusions that are good places to put the mounting holes; 2 or 3 holes spaced evenly around the base ought to be sufficient. Fig. C: Arrange the bases onto a jig. Figs. D and E: Screw the bases onto the bottom of the shelf. Fig. F: Mount the container, which snaps into place. Fig. G: Because it's clear, you can see what's inside.

these to store nuts, bolts, screws, and odds and ends? So I began collecting them. It took me years to finally implement my idea, but the result has helped me organize and easily find what I'm looking for: nuts and bolts, screws, nails, staples, wire-nuts, and any other small parts that usually end up in a junk drawer.

These containers are pretty easy to install. I hung them underneath some shelving. The 100-pack containers are extra deep to hold lots of parts.

1. Remove the spindle from the base. Most brands just pop off with a little effort (Figure A).

2. Drill holes for the mounting screws. I drilled my holes in the existing circular protrusions for added strength (Figure B).

3. Arrange the bases. I could fit 3 containers per section under my shelves so I built a simple jig to place them all the same distance apart. The slots in the base fit right onto the jig.

Once 3 bases were in the jig, I taped them in (Figure C). Then I could just turn the jig over and put them all in place under the shelf.

4. Screw the bases to the shelf. I used 3 screws per container (even though I drilled 4 holes) and they hold plenty of weight (Figures D and E).

5. Mount the container. The container snaps into place with a twist (Figure F) and you can easily see what's in it. Figure G shows a mounted container full of long screws.

While these CD/DVD parts containers didn't solve all my organizational problems, they were a catalyst and a starting point for me to get organized. I put up pegboard, built shelving, put long-term storage in bins, and recycled or threw out stuff I just didn't need.

I can now say that things have greatly improved, and finding stuff no longer takes up more time than actually doing the project. As an added bonus I even save money because I'm not re-buying things that I couldn't find.

Steve Stofiel is a single father who enjoys home improvement, tending to the farm, woodworking, programming, photo retouching, and 3D rendering. He writes custom software to automate tasks in the graphic arts industry.

Photography by Ed Troxell, and Steve Stofiel (Figure C)

COMPRESSED EARTH BLOCK FLOOR

Lay your own earthen brick floor for about $60. By Abe Connally and Josie Moores

When considering what material to use for a floor, few people look beyond a concrete slab, with something like tile or carpet as a finish. For us, however, a brick floor made of stabilized compressed earth blocks (SCEB) was far more appealing.

Why? It's cheaper than concrete, and it's easier to do yourself. It requires less people power, and it doesn't have to be done all in one go. It's beautiful as is — no need for tiles or anything else on top. And it has a better thermal mass quality, saving you heating and cooling costs.

A 130-square-foot floor took 2 inexperienced people — one passing the bricks, one laying them — just 2 hours to pave, once the area had been leveled, and cost only $60. An additional couple of hours and $40 are required to seal it.

Using mortar between the bricks increases the price and time a little, but saves effort and varnish when sealing the floor. However, for the beginner, laying your bricks without mortar and sweeping sand into the cracks is easier, and that's the method we discuss here.

1. Prepare the area.

Prepare your subfloor, perhaps adding a vapor barrier, heating system, or insulation if you wish.

Put a 1" layer of fine-screened sand over the entire area. Compact and level the sand. The easiest way to do this is to bury and level a length of square tubing in the sand on either side of the room, so that

Photography by Abe Connally

MATERIALS

Compressed earth blocks (CEB) You can find these at building supply stores. Most are stabilized with about 5%-10% Portland cement to make them more water-resistant.
Screened sand If you buy sand, it will have been run through a screen to remove large pebbles and other detritus. We made a sifter with some hail screen (1⁄8"–1⁄4" welded mesh) and screened sand from the local riverbed to remove the rocks.
Concrete mix You'll use a little concrete around the perimeter of your floor only.
Sealer Use an acrylic or oil-based concrete sealer or varnish that can handle moisture.

TOOLS

Circular saw with masonry blade (optional) for cutting bricks
Scrap of angle iron, hammer and/or chisel for breaking bricks. Alternatively, you could try a brick bolster, a stone chisel made for breaking bricks.
Levels (2) one small, one longer
Rubber mallet
Boards to stand on (2) You don't want to stand on the sand, because your feet will make large dents. When you stand on a board, your weight is spread out and the smooth surface of the sand isn't compromised.
Surgical tape (optional) When laying the brick, tape your fingertips with surgical tape. This helps protect them without compromising dexterity.
Masonry trowel
Paint roller and paintbrush

the top of the metal is flush with the level you want the sand to be (Figure A). You then bridge another piece of metal across the 2 pieces of square tubing, so that it sits on top of them, and drag it backward and forward over the area until it's smooth.

Set up your boards and tools where you'll begin working. It's often best to start along the room's straightest edge, so that your first row of bricks follows a good line. Also, it's easier to begin near where the bricks are coming from, so that the person handing you bricks can use the finished part of the floor to walk on, instead of having to set up more boards to walk on.

2. Pick a pattern.

Running bond may be the easiest pattern to get your feet wet, but none of them are hard (Figure B). Herringbone can be difficult to visualize, but once you get going, it's not nearly as intimidating as it seems.

3. Cut or break the bricks.

Whichever pattern you choose, you'll need some half bricks. Try and work out roughly how many you'll need for your starting edge, and cut those ahead of time. You can do the ones needed at the other end of your rows, once the rest of the floor is laid. Cut the bricks using a circular saw with a masonry blade. A dust mask is a good idea, as this kicks up a bunch of very fine dust.

If you're not too particular about the edges of your cut bricks, it's far easier to break them instead of cutting. We did this by turning a piece of angle iron upside down, so that its corner is pointing upward. We then hit the metal with the brick at the point where we wanted it to break. It's a little ragged, but you can clean it up with a chisel or hammer.

4. Lay the main section of the floor.

Place each brick, one by one, where you want it to go. With the long level, check that each brick is level with previously placed bricks or with existing floors that you wish to match. With the short level, make sure the brick itself is level in all directions. You also want to check that it's lined up well with the wall. If the first brick is angled just a little, so that one side is closer to the wall than the other side, this will be highly visible by the time you lay an entire row of bricks.

Use the rubber mallet to tap the brick tight against its neighbors (Figure C). Then tap down on it if necessary to get the level correct. Add or remove sand if necessary. Bear in mind that the bricks themselves are not always smooth — they may rise slightly at the edges. If you wish, you can sand these edges down by rubbing them with another brick or a trowel.

When you reach the opposite end of the wall and don't have a brick to fit in the space, leave it. You'll place all the edge bricks at the end.

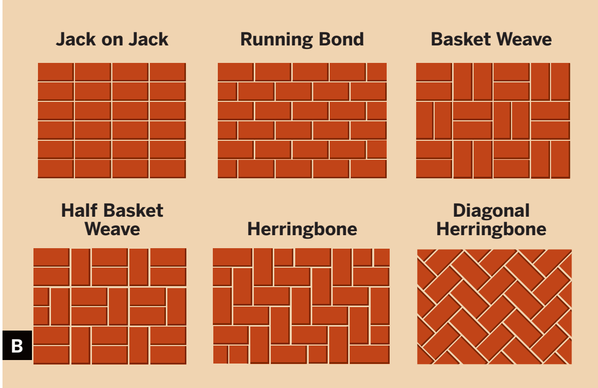
Even before the floor is finished, you can walk on it, but don't tread near the unfinished edges.

5. Lay the edge bricks.

You may have to measure each space and cut or break bricks to fit. Alternatively, you can fill the edge gaps with a very fine concrete when you do the perimeter. Be sure to check that the edge bricks (and pieces) are level with the main floor.

6. Fill the perimeter with concrete.

Once you've laid the main bricks and edge bricks, you can fill in the perimeter — in between the bricks



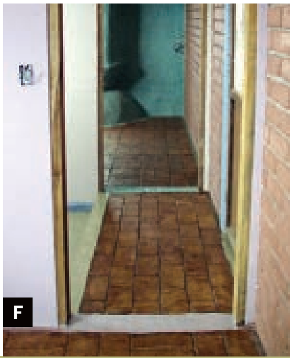


Fig. A: Level the sand subfloor. Fig. B: Choose a pattern that fits your style. Fig. C: Lay each brick, fitting it tightly against the others and leveling in all directions. Fig. D: Continue your pattern throughout the room, lay edge bricks, and fill the perimeter with concrete. Fig. E: Sweep fine sand into gaps between the bricks to provide a tight fit. Fig. F: Finish the floor with a nice, oil-based varnish.

and the walls — with concrete. This doesn't use much concrete, and can be done in half an hour. Mix your concrete with screened sand, and then trowel it smooth and level with the tops of the bricks. Do this along the entire perimeter of your floor, and then let the concrete dry completely (Figure D).

7. Fill the cracks with sand.

After your concrete perimeter is dry, sweep fine sand into all the cracks between your bricks (Figure E).

Allow the floor to settle for a couple of days, and then sweep more sand into the cracks. Repeat this several times until the sand no longer settles.

8. Seal the floor.

To seal the bricks so that you can sweep and mop them, use an acrylic or oil-based concrete sealer or varnish. Until you've sealed them, the bricks will be coated in a fine dust as you gradually wear them down; this is OK for a patio or outdoor floor, but it's not as acceptable indoors.

Use a roller to spread the sealer, and a brush to coat any cracks that the roller can't penetrate. Give it at least 2 coats. The difficulty in sealing arises from the sand in the cracks where the bricks join. As you roll the varnish on, the roller picks up sand and spreads it over the bricks. To avoid this problem, wet the sand down beforehand and use a sealer that's not compromised by moisture (many concrete sealers are designed to help cure concrete, meaning that they trap the moisture inside and allow the concrete to dry more slowly).

NOTE: The sealer will darken the natural color of the bricks (Figure F).

Most concrete sealers and varnishes have a strong smell. Always provide adequate ventilation, and plan to keep those windows open for a few days.

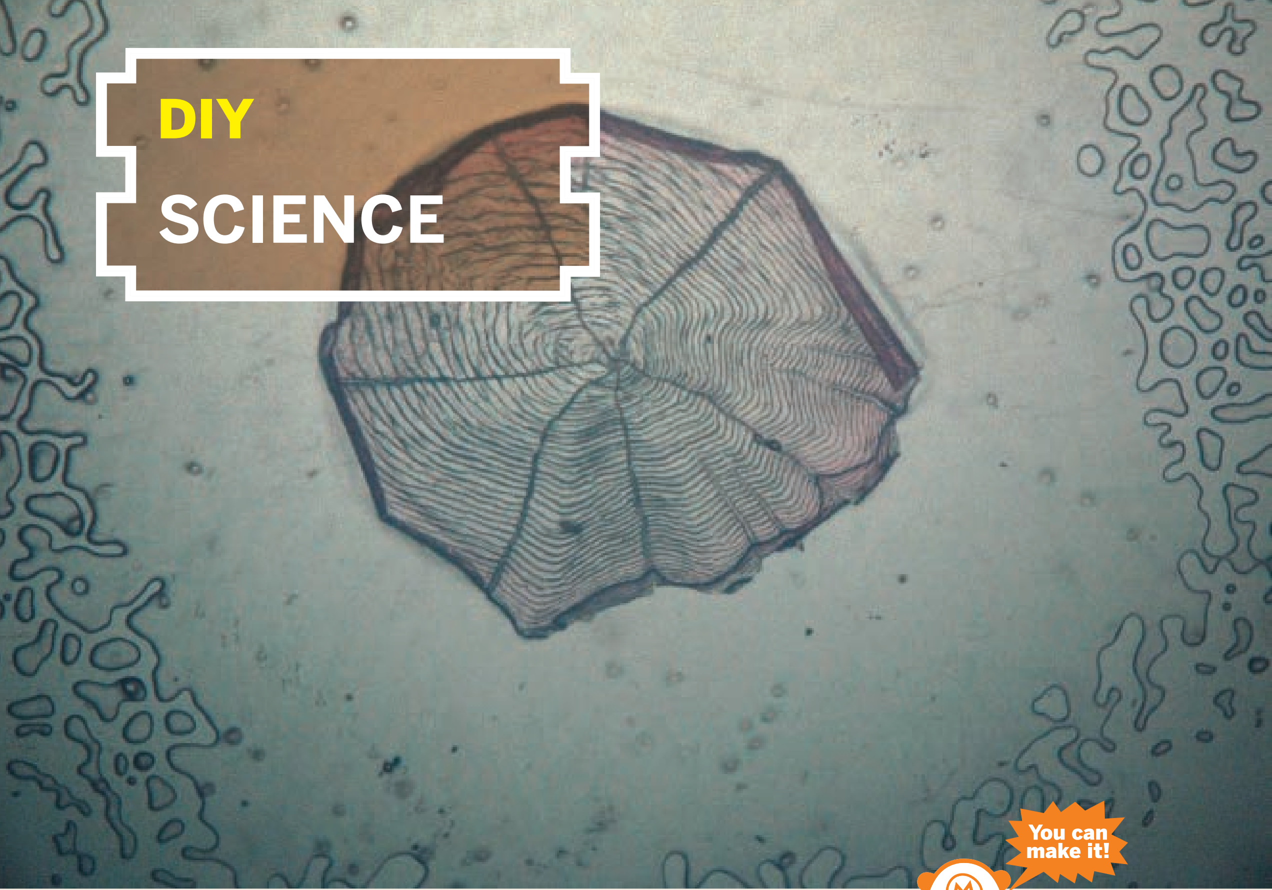
RESOURCES

» *Adobe: Build It Yourself* by Paul Graham McHenry Jr.

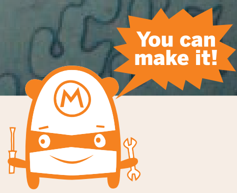
» More on CEB floors: velacreations.com/cebfloors.html

» Open source CEB-making machine: makezine.com/go/ceb

Abe Connally and Josie Moores are a young, adventurous couple living in a secluded off-grid hideaway with their 2-year-old. Their experiments with energy, architecture, and sustainable systems are documented at velacreations.com.



THE MICRODOODLE



Convert an old-school microfiche reader into a magnifying machine. By Mister Jalopy

What is a microdoodle? Well, I made the term up! It's a microfiche reader recast as a social magnifying machine!

Before the internet, businesses used microfiche (pronounced micro-feesh) machines to read transparencies of documents shrunk to micro-size. Real estate agents consulted city plat maps, and libraries had newspapers shrunk to allow easier storage of archives.

Not as powerful as a microscope, an old microfiche reader is a wonderful machine for amateur naturalists, with a big screen that friends can gather around.

MATERIALS AND TOOLS

Microfiche reader
Compressed air dispenser
White lithium grease, window cleaner
Lint-free cleaning cloth I used an old T-shirt.
Prepared slides or other small samples to study

1. Get a microfiche machine.

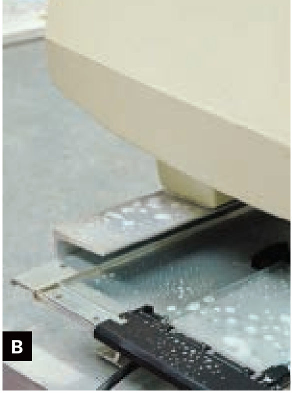
Real estate agents, catalog salesmen, and libraries were top users of microfiche machines, so start your search there. Having found three sub-$20 microfiches within a week, I wouldn't pay much. Be patient and a microfiche will find you (Figure A).

Before buying one, plug it in to verify that the bulb hasn't burned out, as replacements are frightfully expensive. Verify that the focusing knob still works. My microfiche was broken, which made for a little project-before-the-project.

2. Clean it up!

Blow off your microdoodle with compressed air

Photography by Mister Jalopy



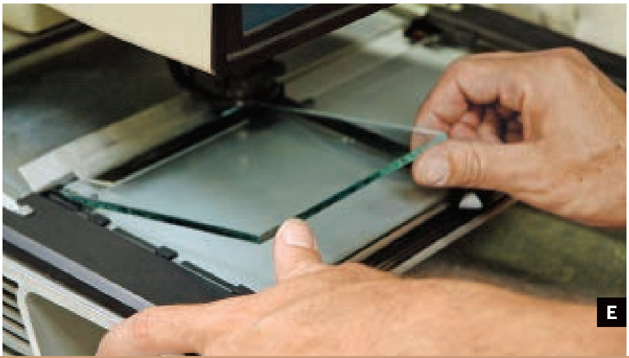


Fig. A: The microfiche reader. Fig. B: Clean the glass with window cleaner. Fig. C: Use a very small amount of lithium grease to clean the rollers. Fig. D: Pop out the screen and use compressed air to clean out any dust. Use a bit of window cleaner to clean the mirror while you're at it. Figs. E and F: Your image capture area will be 4"×5". Place a found item or a prepared slide under the glass for image capture.

and then soap it up with window cleaner (Figure B). An old T-shirt is an almost lint-free cleaning cloth that is ideal for this purpose.

3. Grease the rollers.

Whether you're lubing car door hinges, drawer slides, or a microfiche carriage, white lithium grease is the professional choice for good lubrication. Just a tiny amount will do the job (Figure C).

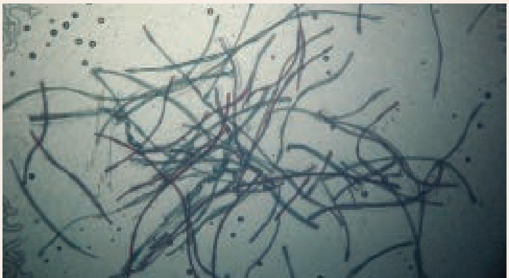
4. Clean the interior optics.

A light is projected through the bottom and reflected off a perfect mirror onto the semi-opaque screen. Since the tiniest dust speck will appear jumbo-size, pop out the screen (Figure D), blow the inside out with compressed air, and use a scant bit of window cleaner on the mirror.

5. Place an object to view.

Microfiche pages were about 4"×5" so there is ample room to place a leaf, butterfly wing, feather, or other thin object in the fiche carrier (Figure E).

For $4, I bought a set of prepared slides that included a fruit fly, wool fibers, a slice of bamboo, and bunch of other great stuff (Figure F). What a deal!



Photos taken off the screen of the microdoodle: Goldfish scale (opposite); fruit fly, wool fibers (above).

Mister Jalopy is a maker, used bike store owner, and MAKE contributing editor. He can be found online at dinosaursandrobots.com and cocosvariety.com.

DIY

IMAGING

TIME-LAPSE PHOTOGRAPHY WITH A MACBOOK

Make mini movies from a command line.

By Nir Yariv

When a blizzard hit New York City last winter, I found myself without a camera, but with a spare MacBook laptop computer. So I decided to try and take some time-lapse photos of the storm with its built-in iSight camera. Here's how I did it.

MATERIALS

MacBook laptop with standard built-in iSight camera

iSightCapture software Get a free download from intergalactic.de/pages/iSight.html. The page says the code isn't maintained anymore, but it works fine for this project.

Snapping the Frames

First I installed free iSightCapture software, which lets you control the MacBook's camera from the command line. To test it, I opened an OS X Terminal (Applications → Utilities → Terminal) and entered:

```
/Applications/isightcapture ~/test.jpg
```

The camera's green light flashed and a newly captured photo named *test.jpg* appeared in my home directory. (Note that before you run iSightCapture, you need to turn off any other program that uses the camera, such as Photo Booth, or you'll get an error.)

My next step was to write code to make iSightCapture take pictures at a fixed interval. I chose Ruby

Photography by Randi Hazan (main) and Nir Yariv (inset) for this task, since it's a nicely readable language that comes pre-installed on every modern Mac.

Here's the script in its entirety, which I saved into a file called *timelapse.rb*. You can also find this code at makezine.com/23/diyimaging_timelapse:

```
# Configuration settings — edit to your needs.
path = "~/lapse" # Directory where images will be
  stored. Must exist and be writable.
duration = 4 * 60 * 60 # Time to run, in seconds
  (4 hours here)
interval = 5 * 60 # Time between each photo, in
  seconds (5 minutes here)

# Start working...
end_at = Time.now + duration

i = 0
while Time.now <= end_at do
 i += 1
 system 'say "cheese"'          # comment out if sound
  not wanted
 system "/Applications/isightcapture #{path}/%05d.
  jpg" % i
 sleep interval
end
```

Move this script into your home directory and create an empty **path** folder in the location specified at the top of the code. Then you can launch the script from Terminal by entering:

```
ruby timelapse.rb
```

The script should start taking pictures at the given interval, and save them to the **path** folder under incremental filenames like *00001.jpg*, *00002.jpg*, and so on (Figure A, inset). It will run for the duration set in the **duration** variable, or you can Ctrl-C to stop it sooner. If you have more than one computer, you might want to make the path a shared folder, which lets you access its contents and check progress from another machine.

The optional **'say "cheese"'** line uses OS X's built-in **say** utility to make a sound when a photo is taken.

Creating a Clip

With a sequence of up to a dozen photos or so, you can string them together into an animated GIF, which will play anywhere, as a loop, and will embed

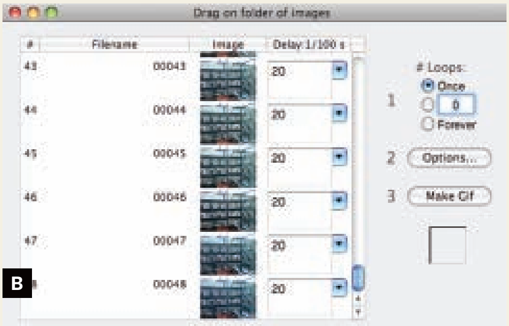


Fig. A: (Opposite) Simple code tells the MacBook to snap and save a photo every few minutes.
Fig. B: Turn a short photo sequence into an animated GIF using free GIFfun software. Longer sequences work better when converted to video formats.

more easily than files in standard video formats. Free GIFfun software (stone.com/GIFfun) lets you easily import all the photos from **path** and assemble them into an animated GIF (Figure B).

With large numbers of frames, the GIF files become unwieldy, so it makes more sense to convert them to a video format, which uses compression. Another free tool, FFmpeg (ffmpeg.org), can help with that. If you have MacPorts installed, you can install FFmpeg with a simple command:

```
sudo port install ffmpeg
```

Manually installing FFmpeg is beyond the scope of this article, but Stephen Jungels has a good guide at makezine.com/go/jungels. Once FFmpeg is installed, you can create a video with:

```
ffmpeg -f image2 %05d.jpg lapse.mpeg
```

FFmpeg is a powerful utility with many other capabilities. It isn't known for its ease of use, but with a little searching you can figure out many more fun ways to use it.

If you create your own MacBook time-lapse videos, I'd love to see them! Please feel free to send me the links at niryariv@gmail.com.

Nir Yariv works with code and people to make stuff. He occasionally blogs at niryariv.wordpress.com.

SOLAR CAR SUBWOOFER

Self-sufficient station-wagon sonic splendor. By Henry Herndon

Toyota has been advertising the "solar roof" option for its Prius, which is basically a solar panel that powers the cabin ventilation fan on hot and sunny days. But what they don't tell you is, you can have a solar roof on any car!

Last July I set up my own solar roof for a 2,300-mile road trip, and it worked like a charm, supplying me with laptop charge and ample stereo bass the whole way. (One of my prime objectives for the system was to power my subwoofer, because what's a road trip without awesome tuneage?)

The setup was simple. Power came from an 80-watt solar PV panel that I bolted to my station wagon's roof rack. I ran the power down through the rear hatchback to a charge controller and 2 lead-acid gel batteries behind the driver's seat.

With the resulting 12V DC power, I was able to run a subwoofer amplifier for the stereo and a small inverter to charge my laptop and other small appliances (Figure A).

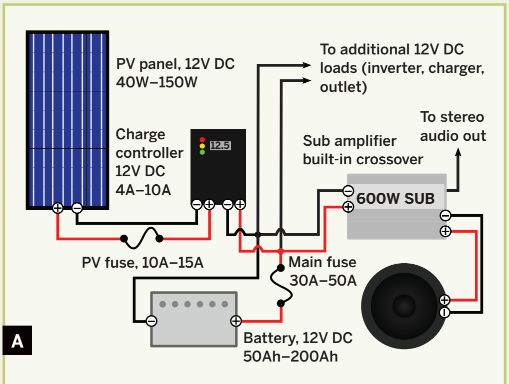


Fig. A: Diagram of the solar car subwoofer system.

Photography and diagram by Henry Herndon

MATERIALS AND TOOLS

Car with roof rack or roof rails
Solar panel, 40W–150W, 12V system compatible See the "Choose a Solar Panel" section. I used an old 80-watt Photowatt module borrowed from my roof.
Small (5A–10A) charge controller (optional) You won't need this if your solar panel has integrated charge control or if it's tiny (less than 10 watts). I used an M20 from BZ Products (bzproducts.net), since replaced by their model M20+.
Subwoofer amplifier and speaker for car stereos, 12V DC I used a 15-year-old Legacy brand 600-watt sub that came OEM in a Chevy Equinox.
Battery or batteries, 12V lead-acid, sealed See the "Choose the Battery" section. Available at RV and boating stores; don't buy online because the weight usually makes shipping very expensive. I used 2 tired old 33Ah Power-Sonic batteries, each 7¾"×5¼"×7".
Electrical tape
2×2 lumber (2) long enough to run the width of your roof rack. Actual dimensions: 1½"×1½".
U-bolts (4) to fit through roof rack
Nylon insert lock nuts (8) matched to U-bolts
Flexible plastic tubing enough for 4 short lengths to fit around U-bolts
Machine screws and nuts (4) for attaching PV panel to lumber
Fuses with fuse holders: 10A–15A and 30A–50A Two good options are ¼" blade type (ATC) fuses or glass cylinder "car stereo" fuses. I neglected to use fuses (aside from the charge controller's internal fuses) but you should! Luckily, I've been spared any disasters. There is some benefit to using a fuse block, but this strays from the KISS (keep it simple, stupid) ideal of the project.
Landscape lighting cable, 12-gauge minimum 10- or 8-gauge is better.
Inverter (optional) to plug in laptops, etc. I used a High Gear 300-watt inverter.
Push-button switch (optional) for turning off the amp. I used a "Hazard" flashers push button scavenged from a junkyard BMW.

Choose a Solar Panel and Charge Controller

You'll need to match the PV panel to the shape and size of your car's roof, but also make sure that its expected daily output (peak watts × typical peak sun hours) will cover your expected daily load (total watts used × usage hours).

Also make sure the panel is designed for 12V battery charging systems; these will typically have 36 cells and open circuit output between 18V–20V. Most panels will fit the bill, but avoid the newer type that works with super-high-voltage grids. And if a panel is priced more than $5 per watt, you can probably find a better deal.

PV systems need a charge controller to keep the battery from getting overcharged. Some PV panels designed for small systems have charge control built in. This can be the simplest way to get a system running, but it's often less cost-effective than using a separate charge controller.

Some controllers, like the Morningstar SunSaver and Steca Solsum 6.6, include a low-voltage disconnect that prevents the battery from draining too low under small loads. Completely draining a lead-acid battery hurts its performance, so this is a nice feature.

Choose the Battery

Pick a battery size using a similar calculation to sizing the panel. Your expected amp-hour (Ah) usage during non-sunny times (watts × hours / 12 volts) should be less than ⅔ times the battery's amp-hour rating (to ensure no more than a ⅔ discharge). For more capacity, connect 2 batteries in parallel, which is what I did.

Also check your charge controller's documentation for minimum battery size recommendations. Controllers are often designed to work with a minimum battery capacity.

In an enclosed car, you must use a sealed lead battery, rather than the less expensive flooded kind that's typically available at auto parts and warehouse stores. Flooded batteries are unsuitable because they emit explosive gases during charging, they tend to accumulate corrosive acidic residue near their vents, and they can spill acid if you don't keep them upright.

Installation

My car's roof rack made mounting the PV panel easy. I attached lengths of 2×2 lumber perpendicular to the rack's rails using U-bolts and Nyloc nuts, slipping plastic tubing around the bolts to protect the rails (Figure B, following page). After more than 3,000 highway miles, I noticed no loosening or deformation of any part.

My PV panel's frame consists of aluminum C-channel with holes in back for mounting. So I drilled holes through the 2×2s and used machine screws to attach the panel to the wood, securing them with nuts inside the aluminum channel.

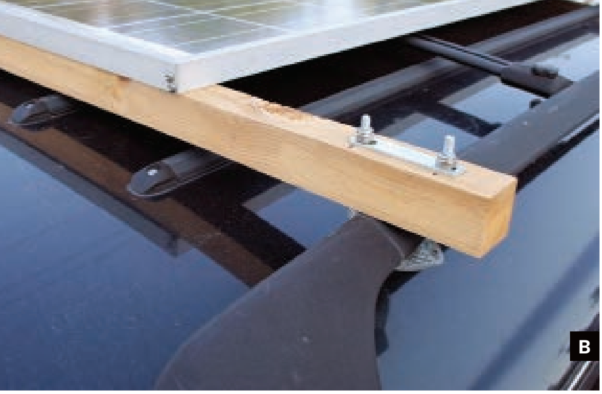


Fig. B: The PV panel bolted to the roof rack.
Fig. C: The charge controller and batteries behind the driver's seat; the amp and subwoofer behind the passenger seat; and the inverter in the middle.

Fig. D: Solar power is routed through landscape lighting cable, threaded through the rear hatch.
Fig. E: An old hazard light switch turns on the subwoofer.

I stashed the charge controller and batteries behind the driver's seat (Figure C), and the sub amp and speaker box under the passenger seat. I located the small inverter in the middle, on a cable long enough to let it reach the front seat and charge my laptop and other gadgets. All of the equipment stayed out of my way and didn't interfere with folding the rear seats down.

To connect it all, I used landscape lighting cable because it's weatherproof, widely available, and inexpensive. For the interior, you could use any insulated wire 12-gauge or heavier.

I ran the output cable from the PV cell through the rear hatch rain gasket (Figure D) and up to the charge controller, simply stringing it over the interior carpet and around the back seat.

For switching the amp on and off (to save battery power), I wired a switch in between the amp's +12V DC and Remote Turn-On terminals. The switch I used was a "Hazard" push button from a dashboard, which seemed appropriate (Figure E).

To protect your equipment, install fuses on the wires from the positive terminals of the battery and the PV panel. Locate the main fuse (30A–50A) on the battery, as close as possible to its positive terminal. A 30-amp fuse will support 350 watts of load.

Insulate all connections well with electrical tape to protect them from short circuits caused by jostling in the car, especially the battery posts and the main fuse holder. Make sure that no wires are in a position to get frayed or yanked. If you use crimp terminals, crimp them tight; the wire should break before it comes out of the crimp.

You can add inverter outlets or cigarette lighter receptacles to a system like this; auto parts stores have many options for serving multiple circuits. I can see systems like this being worthwhile for avid car-campers. Many RVers put up solar panels; why should they have all the fun?

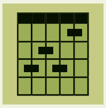
I already had all the equipment for this project, so it was a no-brainer for me, and it kept me supplied with charging power and sweet tunes for two weeks, all the way up and down the West Coast. While powering a car subwoofer may not be the most practical use for solar power, it brought a smile to my face every time I turned it on.

Happy solar sonic travels!

Henry Herndon is a student in the San Francisco Bay Area. In his spare time he builds inventive electric vehicles and posts at acuteaero.com.

DIY MUSIC

EASY PITCH CONTROL HACK



Make audio circuits sing higher and lower.

By Peter Edwards

Here's an easy way to add a pitch adjustment to audio circuits such as the ones in many kids' toys, in order to greatly enhance their circuit-bending potential.

All you have to do is replace the circuit's fixed clock-speed resistor with a variable resistor (aka potentiometer) and a limiting resistor, wired in series (Figure A).

Then, simply turning a knob will dial the circuit's base pitch up or down, which not only raises and lowers the sounds it generates, but can also unlock bizarre hidden behaviors.

Overclocking the pitch of some audio circuits makes them malfunction and spit out random sounds and melodies. And setting the pitch very low can reveal micro-modulated tones that are otherwise impossible to hear. Fun!

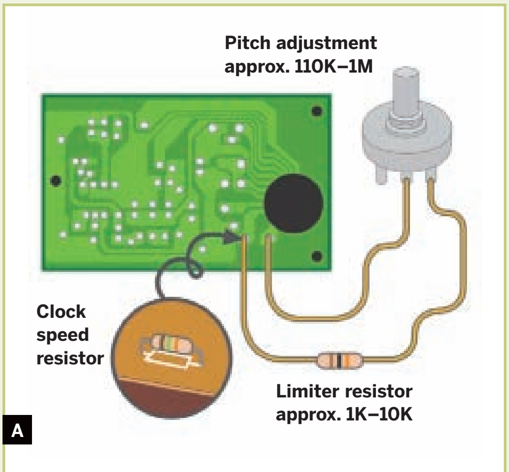


Fig. A: Replace the clock speed (aka pitch) resistor with a potentiometer and a limiting resistor.

Photography and diagrams by Peter Edwards

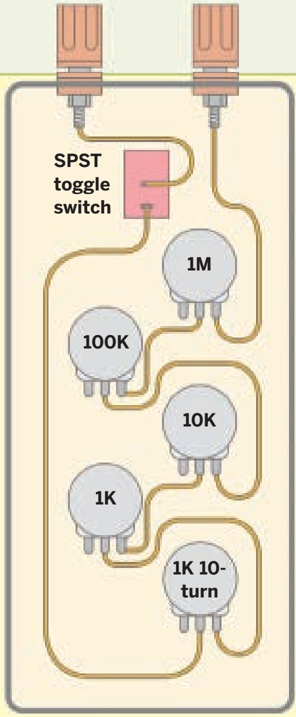
Resistor Substitution Box

For finding ideal potentiometer and limiting resistor values, I use a resistor substitution box. You can buy these, but I built one myself in about an hour. It has 5 pots wired in series: 1kΩ, 10kΩ, 100kΩ, 1MΩ, and a fancy 10-turn 1kΩ pot with a 3-digit dial that I liberated from some old test equipment (substitution: Mouser part #882-DC22-10-1K, $75).

Connecting the box into a circuit and adjusting its knobs from top to bottom lets you zero in on the value that works best for any set resistor. Then you simply read the resistance off the box using an ohmmeter. A toggle lets you switch over from infinite resistance.

I use my resistor substitution box a lot, to dial in resistor values that determine pitch, brightness, motor speed, and other circuit characteristics.

CAUTION: Unless you're a trained electrical engineer, you should only work on circuits that are battery powered, or that use a very low-amperage power supply (50mA or so). Poking around inside high-voltage and/or high-current circuits can be fatal.



MATERIALS

Digital audio circuit, battery-powered and fairly simple Kids' toys are fair game; they're cheap and easy to find, and they usually make lots of different sounds. For this article I used a Multi Voice Changer megaphone sold under the Toysmith and Tech-Gear brands.

Potentiometers The value of the pot used will vary from project to project, so it's good to have an array on hand: 1kΩ, 10kΩ, 100kΩ and 1MΩ.

Resistors The value used will vary between 1kΩ and 10kΩ. I suggest buying in bulk from mouser.com, or getting a sampler pack from radioshack.com or jameco.com.

Knobs to fit potentiometers

Insulated wire, around 22-gauge

Heat-shrink tubing, ⅛" or ¼" diameter

TOOLS

Soldering iron and solder

Wire cutters and strippers

Screwdriver to disassemble toy or other circuit source

Multimeter or ohmmeter

Alligator clip leads (4)

Drill and drill bits for mounting the potentiometer in the housing

Resistor substitution box (optional)

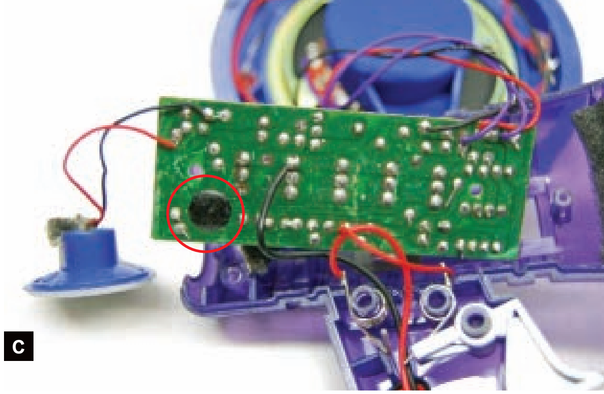
Audio Circuit Clock Speed

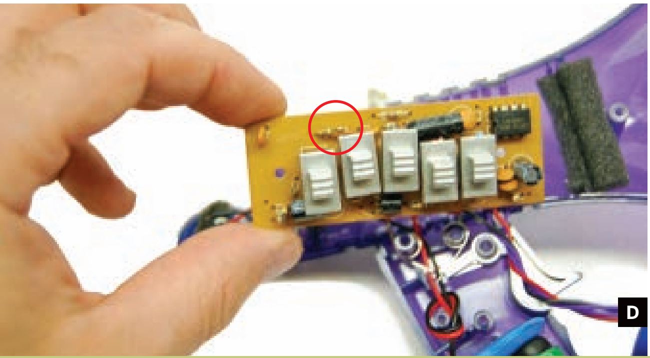
All digital audio electronics rely on a clock, which determines the rate at which the circuit produces and processes data. With circuits that generate audio, the clock speed typically determines a base pitch that all outputs then derive from.

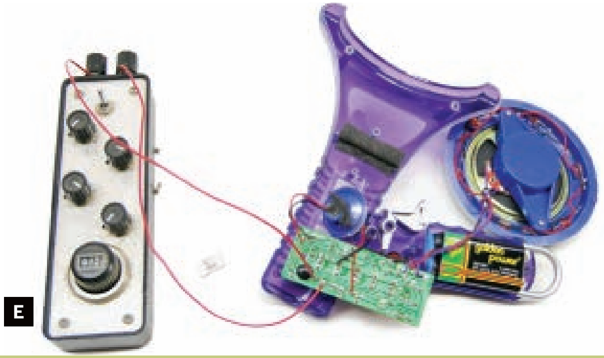
With most cheap audio circuits, this clock speed is set by the value of a resistor sitting between the circuit's power supply and the main chip's clock speed node, or sometimes between 2 clock speed nodes on the chip. This is the clock speed resistor, aka pitch resistor, and the quick hack described here works for circuits like this.

Other audio circuits set their clock speed using a crystal or inductors, so adding a pitch control to them requires more involved circuitry. You'll start this project by determining whether or not your circuit has a clock speed resistor. If you follow the steps below and still can't find it, you probably have one of these other guys, and you should find a different circuit to modify.

NOTE: This project is the simplest way to add a pitch adjustment to audio circuits that have a pitch resistor. More complicated methods allow for a wider pitch range and finer tuning.







Figs. B and C: Search the circuit board for the audio generation IC, which is often a black blob "gumdrop." Fig. D: The pitch resistor is usually the resistor closest to the audio generation IC, often on the back.

Fig. E: Replace the pitch resistor with a potentiometer of a greater value. A resistor substitution box makes the process a lot easier.

1. Find the pitch resistor.

First, open the device you intend to hack. Make sure you put all the screws in a safe place! Examine the circuit board and try to find the audio generator or "brain" of the circuit. This is usually a black blob covering a proprietary chip; these are also called "gumdrop" ICs. With my Voice Changer toy, this was on the green, solder-pad side of the board rather than the yellow, component side (Figures B and C).

If your circuit has no gumdrop, the biggest chip is likely to be where the audio signal is generated. (If your circuit has no chips at all, you're probably dealing with an analog circuit. This is a different beast altogether, and it requires different steps to modify than the ones outlined here.)

Once you've found the brain, look for the closest resistor, which is usually on the reverse side of the board (Figure D), because 9 times out of 10 this will be your pitch resistor. Test your theory by touching the resistor's leads while the circuit is making sound. If you're right, the pitch should jump up or down.

If you hear no change, lick the tip of your index finger and touch other parts of the board to see if they affect the pitch. When you find a spot, narrow down your search (start using your pinky) until you've found a single point or two at a resistor that alter the pitch. If you still can't find this, your circuit may not be using a resistor to set the clock speed.

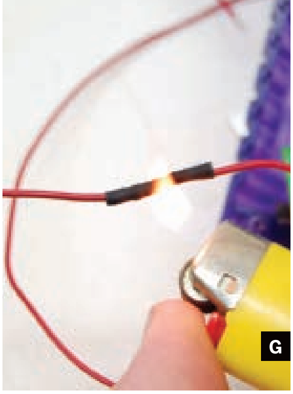
2. Swap in a potentiometer.

Once you've found the clock speed resistor, make a note of its value by reading the stripes. Turn the circuit off or remove its batteries. Unsolder the resistor and remove it from the board, then solder 2 wires about 8" long to the same contacts. These wires will attach to a potentiometer.

To find the best value of potentiometer to install, I use one of 2 different methods. The quick and dirty method is to just multiply the value of the original pitch resistor by 10 and try a pot that's roughly the same value. If the original value is 15kΩ, for example, replace it with a 100kΩ potentiometer.

Clip the pot to the leads with alligator clips, one to the middle wiper leg and the other to either of the fixed contacts. Then power up the circuit and see how the pot performs. You may need to try a few values before you find the right one.

WARNING: Don't turn the potentiometer all the way up at any point during your testing. Turning the pot to zero resistance can fry your circuit.



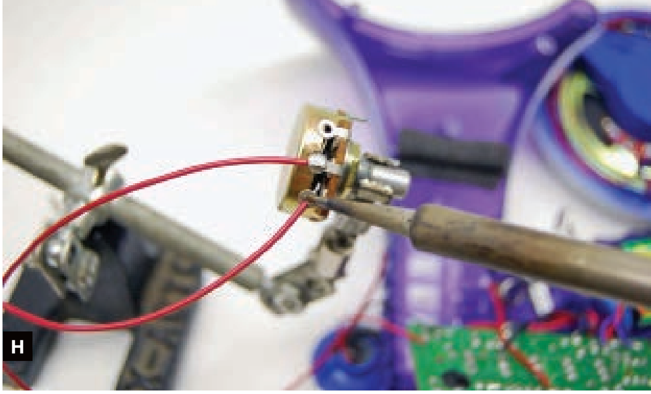


Fig. F: Wire up a limiting resistor to keep the pitch from going too high. Fig. G: Shrink a 1" piece of heat-shrink tubing over the resistor. Fig. H: Wire up your potentiometer.

Fig. I: Another toy with a pitch control pot wired in. Fig. J: Mount the potentiometer in the housing and put it all back together.

A better method for finding a proper potentiometer is to connect in a resistor substitution box (see sidebar on page 128). Twiddle the knobs to find a resistance range that affects the pitch nicely (Figure E, previous page), then measure the resistance across the box and round it up to your nearest potentiometer value.

3. Install a peak-limiting resistor.

To limit the peak pitch and avoid damaging your circuit, you also need to add a limiting resistor. Clip your chosen potentiometer into the circuit, then carefully turn it up until the pitch is as high as you want it to go. Glitching is fine, and part of the fun. You'll be safe so long as the output stays within a pleasant and musical range — but if you go too far, you'll get a one-way ticket to burnt-out-circuit-land.

Use an ohmmeter to determine the potentiometer's resistance when it's turned as far as you dare, and find a resistor that's about the same value. This will usually be between 1kΩ and 10kΩ. If you don't have an ohmmeter, I suggest starting with a 1kΩ resistor. It may need to be increased some, but it will work in many cases.

Solder the resistor to one of the leads from the board (Figure F) and insulate the connection with heat-shrink tubing (Figure G). Then solder and insulate a short lead to the other side of the resistor.

4. Mount the pot and close up the housing.

Solder the potentiometer to the free leads from the board and the limiting resistor (Figures H and I). Then choose a location for your pitch adjustment knob, making sure there's room inside for the back of the pot. For my Multi Voice Changer, I picked a prominent spot on one side of the megaphone's bell (Figure J).

Drill a hole for mounting the potentiometer, and add the knob on the outside. Once that's done, carefully replace the circuit board and close up the housing. Done!

+ Visit makezine.com/23/diymusic_pitch for links to more information on this technique, as well as methods for adjusting crystal set pitch.

Peter Edwards is a circuit-bending and creative electronics pioneer based in Troy, N.Y. He builds electronic musical instruments for a living through his business, Casper Electronics (casperelectronics.com).

LILY PAD POOL WARMERS

Use hula hoops to heat your swimming pool using the sun. By Edward Hujsak

Photography by Edward Hujsak

Here's an easy way to warm your pool that's efficient, low-cost, safe, and actually enhances the beauty of the pool. The Lily Pad pool warmer doesn't need to be removed to swim, sweep, or vacuum, and it meets new requirements in water conservation areas to keep at least half of a pool's surface covered.

Best of all, the Lily Pad pool warmer can be made by anyone who's just a bit handy with tools. It's made of hula hoops, with black polyethylene film stretched over them to actually warm the water they come in contact with.

The Attractive Solution

The Lily Pad pool warmer uses black (low albedo) polyethylene film stretched over hula hoops. The film is in contact with the water, so it captures and transmits most of the sun's incoming radiation directly into the pool, warming the surface of the water. Calorimetric tests have shown that at high noon, a single Lily Pad will transmit more than 500 BTU per hour.

As a bonus, this solution is highly attractive. Since it doesn't need to cover the entire pool, it gives the appearance of a dynamic sculpture as the pads nudge each other and form constantly varying patterns across the surface.

To swim, it's not necessary to remove the pads. Half the pool area is open, and the bow wave ahead of a swimmer causes the pads to float aside. If you want to open the entire area for swimming, the pads can be removed in less than 5 minutes. And they can be seasonally stored in the boxes in which the hula hoops are shipped. My experience has shown that it's also not necessary to remove the pads for sweeping or vacuuming the pool.

THE POOL OWNER'S DILEMMA

The thermal behavior of swimming pools is complex, due to a number of factors that act to cool the water, while the sun and artificial means work to keep the water warm. Cooling forces are at work day and night, and include evaporation, conduction into surrounding soil, air current effects, and nighttime longwave (infrared) radiation into space.

Gas-fired heaters are the most common pool warmers, but up-front costs for equipment and installation run into the thousands of dollars. And then there's the operating cost and the price of natural gas. These heaters are prodigious polluters; for an average-sized pool, a 1°F rise in temperature results in spewing 50lbs to 60lbs of carbon dioxide into the atmosphere.

Roof-mounted solar heaters are a second option. Water from the pool is pumped through solar-heated heat exchangers and returned to the pool. Like gas-fired heaters, solar heaters are costly and are generally unsightly. They're also a problem in frost-prone areas.

Bubble plastic blankets are passive devices that cover the pool. They function mainly as water conservation devices by inhibiting evaporation, thus slowing evaporative cooling. They also block nighttime radiation loss.

Manufacturers claim these blankets also behave as warmers, transmitting additional energy from the sun into the water. But water already has a very low albedo (ratio of incident energy to reflected energy). It's about .10 for deep water, a bit higher in white-bottomed pools, and it's doubtful that bubble covers improve on that.

(The low albedo of water is the reason for the great concern about the receding of the polar ice caps. Open water warms much more rapidly than ice fields, which reflect more than 80% of the sun's energy.)

Moreover, pool blankets destroy the aesthetic appeal of a backyard pool; they're hard to manage, difficult to clean, and unsafe where small children are around; and they're often dumped after a single season.

MATERIALS AND TOOLS

Black polyethylene film, 6 mil commonly used by landscapers and builders
Hula hoops, 30" diameter (50 or more) You need enough to cover at least half your pool's surface. These can be purchased from school sports suppliers all over the web for about $2.50 per hoop; in my experience, the shipping usually costs more than the hoops.
Metal bar, ⅛"×½" for the spot-welding guide. This should be 1½" longer than your soldering iron's shaft.
Small hose clamps (2)
¾" MDF, plywood, or particleboard for the assembly jig turntable. You need a disc the same diameter as your hula hoops, usually 30".
2×4 fir lumber: 6' length (1) and 8" lengths (2) That's one 6-footer and two 8-inchers.
Brads, ½" or longer (8–9) for the assembly jig
Carriage bolt, ½"×6", with matching nut and washers
Metal bar, about 36" long (optional) to cool the spot welds. Aluminum or steel is OK. Instead, you could use the back of the small bar (your spot-welding guide), but you'll have to cool it in water frequently.
Small electric soldering iron
Drill with ½" bit
Box cutter or utility knife with sharp blades
Scissors (optional)
Spring clamps (6) like the one shown in Figure F
Large clamp to secure the 2×4 handle to the tabletop

1. Mod the soldering iron.

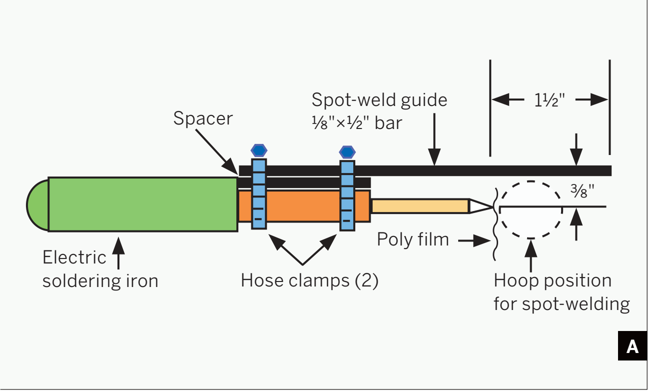
Polyethylene film can be easily spot-welded to hula hoops made of the same material, by using a slightly modified soldering iron.

Add a simple guide to your iron so that it self-guides along a spot-welding path that's uniform around the entire hoop. To do this, just add a bar that extends 1½" past the tip of the soldering iron. Clamp the small metal bar onto the barrel of the soldering iron, using a scrap of metal as a spacer between, so that the guide stands ⅜" away from the iron's tip (half the width of a hula hoop). Use small hose clamps to secure the guide (Figure A).

After you've made the guide, grind the tip of the soldering iron to a flat surface of about ⅛" diameter.

2. Build a jig for assembly.

Since an average pool may require 50 or more Lily Pads, it's handy to build a simple jig for quicker assembly (Figure B).



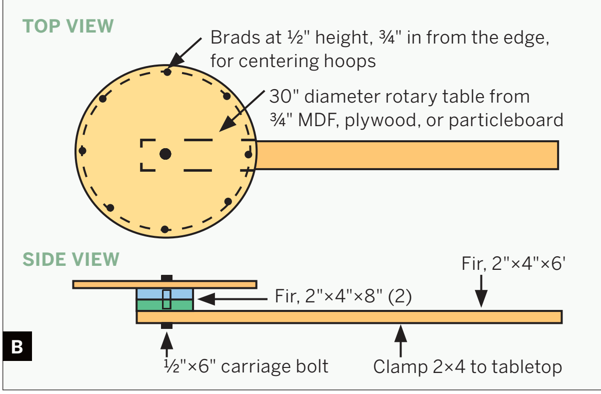


Fig. A: The spot-welding guide is just a bar clamped to your soldering iron. Fig. B: The rotating jig for assembling the Lily Pads. Fig. C: Clamp a few 34"×34" sheets of plastic under a hoop and trim to 1" oversize all around. Fig. D: Wrap electrical tape around the hoop joint and staples to seal against leakage. Fig. E: Mark the turntable at 60° intervals for easy placement of clamps.

Illustrations by Edward Hujsak

Made of common materials, the jig is just a long handle and a rotating circular platform that holds the hula hoop securely while you spot-weld the polyethylene film to it.

Cut a disc of plywood or other flat, sturdy material that's 30" in diameter (or the diameter of your hoops). This is your turntable. Drill a ½" hole in the center.

Center a hula hoop on top of the disc, and mark a circle on the disc along the inner edge of the hoop (about ¾" in from the edge).

Hammer in brads along the inner circle you drew, spacing them evenly about 10" apart.

Lay the three 2×4s flat. Drill a ½" hole in the center of each 8" length, and a ½" hole centered 4" from the end of the 6' length.

Take the 6-footer, stack the two 8-inchers on top, and lay the turntable on top of that, aligning all the holes. Attach them all with the carriage bolt.

3. Prepare the black plastic and the hoops.

The polyethylene film circles should be cut about 1" bigger than the hula hoops all around, 31" for a 30" hoop. Using a hoop for a template, cut out the circles with a sharp box knife or scissors (Figure C). If needed, use a piece of cardboard under the film as a safe cutting surface. Cut all the film circles you need before moving on to the spot-welding.

I discovered the hard way that hula hoops are not watertight. Seal the joint by wrapping a few turns of electrician's tape around the joint and over the adjacent staples (Figure D). Don't worry about spot-welding in this area.

Now we have watertight hoops and circles of black plastic ready to be united. Here's how I did it.

4. Make your Lily Pads.

Lay the hula hoop on the rotating assembly jig. Stretch the polyethylene film over it, and hold the film in place using the 6 clamps, evenly spaced around the circumference (Figure F, following page). I marked the turntable every 60° to make spacing easier (Figure E).

Make 2 spot welds on either side of each clamp, always holding the film taut when you're welding (Figure G). Work from one side to the other, turning the hoop around on its rotating jig.

Immediately after each spot weld is made, it's necessary to flatten and cool it. This is best done with a 36" bar of metal laid across the diameter of the film (Figure H). Alternatively, you can use the


F


G


H


I


J

Fig. F: Stretch plastic film over the hoop and clamp to turntable in 6 places. Fig. G: Spot-weld 2 or 3 spots 1" apart on both sides of each clamp, keeping the film taut. Then spot-weld the rest of the hoop, and poke vent holes. Fig. H: Cool each weld immediately by pressing a metal bar onto it for 2 seconds. Fig. I: Trim excess material using a sharp box knife. Fig. J: Keep Lily Pads clean with a water and detergent solution.

back of the soldering iron guide, chilling it in water after every few welds.

Spot-weld the remainder of the film to the hoop, with spot welds about 1" apart, including the area under the clamps. Soon enough, the feel of the operation will become obvious. A little practice on a test piece is recommended.

Once the spot welding is completed, trim the overhanging film with a sharp box cutter, rotating the table against the knife (Figure I).

Finally, use the tip of the soldering iron to puncture 9 small vent holes in the film, one in the center and the rest distributed in a circle of about 24" diameter. Without these vents, vapor bubbles would form under the stretched polyethylene, and lower the heat transfer.

You're done! Now make more.

Maintenance

Like any pool cover, the Lily Pads will gather dust and dirt over time. The pads are easily cleaned using a water detergent solution, then rinsing (Figure J). In pools where the water hasn't been changed for a long time, evaporation of water from the surface of a pad will leave a salt deposit. In this case, cleaning is best done with an acid solution, while wearing rubber gloves (1 cup of pool acid to 2 gallons of water, then rinse). Cleaning restores the film to a like-new condition. Judging from the condition of the Lily Pads at the end of one season, the useful life could be three or more years. Should a spot-welded bond come apart, it can be easily repaired.

Save the boxes in which the hula hoops are shipped. These make a handy place to store them, off-season.

TIP: When using Lily Pads, it's best to operate the pool pump at night only. When the pump operates, the skimmer will draw warm water (created at the surface by the pads) into the filter and return lines, where heat is lost by conduction. This is true of all blanket pool warmers.

Edward Hujsak is a career rocket engineer who helped design and develop the Atlas and Centaur rockets at General Dynamics. He has authored seven books, writes space commentary, and produces fine furniture, musical instruments, artworks, and the occasional invention.
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COLLEGE BIKE TRUNK

Make a lockable carry-all box from sheet metal. By Frank E. Yost

Growing up, I would often visit my grandparents in Dinkytown, the southeast Minneapolis neighborhood near the University of Minnesota that was named after the freshman cap worn there a century ago. I remember seeing students on ten-speeds carrying their stuff in milk crates that they strapped to the rear rack with bungee cords.

Inspired by that image, I wanted something better and more secure. Car drivers can lock things up while running errands, so why should cyclists have to carry everything around with them?

So I designed this sheet metal bike trunk. I sized it to hold two 1-gallon jugs of milk with a little room to spare. Its top angles away from the seat like a saddle does, so nothing rubs against the rider. And its 2 latches will accept 2 padlocks to secure the contents against casual theft.

Photography by Frank E. Yost

1. Cut and drill the trunk pieces.

Download the project templates from makezine.com/23/diyhome_biketrunk and print them at full size. Cut them out, and tape them onto the sheet metal using double-sided tape, or else cut holes in the templates and stick masking tape over the holes.

Trace around the edge of each template with a fine permanent marker, and use tinsnips to cut out pieces A1/A2, B1, C1/C2, and D1. Don't cut apart A1 and A2 or C1 and C2 yet. After cutting, pound flat any uneven edges with a hammer and wood block, and file smooth the sharp edges.

I used shiny aluminum for the "chrome" tail ornament E1, but stainless would also work. I've found that aluminum doesn't pound back flat well, so I cut it out with a Dremel and cutting wheel.

For the base piece (not shown on the templates) cut a 14"×7¼" rectangle out of thicker aluminum.

A

MATERIALS

Steel sheets, 20-gauge, at least 18"×28" each (2)
Aluminum sheet, 12-gauge, at least 14"×7¼"
I used an old stop sign.
Shiny metal sheet, around 15-gauge aluminum or 20-gauge stainless, 6"×12" (optional)
Pop rivets and matching backup washers, aluminum: ⅛" (100) and 3⁄16" (10)
7" piano hinge
Rubber inner tube for bike tire, used
Brass knob
Draw hasps, 4", black (2) National Manufacturing part #N210-880
Pipe hanging clips, vinyl coated, 5⁄16" (4)
Bolts, ¼-20×¾", with locknuts and washers (5)
Bike rack, rear I used a 27"/700c rack, Sunlite part #45775.
Adhesive rear reflector, 3"
Bondo/Dynatron Glazing and Spot Putty from an auto parts store
Clear silicone glue
E-6000 craft adhesive Don't use cyanoacrylate (crazy/super) glue.
Spray paint: white primer, flat black, and flat white I used Rust-Oleum Painter's Touch.
Small padlocks, 1½" shackle, keyed alike (2) I got a 3-pack, Master Lock part #141TRILF.

TOOLS

Drill and drill bits: ⅛", 3⁄16", ¼"
Tape: double-sided and masking
Wax paper
X-Acto knife
Pop rivet gun
Bending brake
Tinsnips and scissors
Dremel tool with cutting wheels
Metal files and sandpaper
C-clamps and scrap wood blocks
Hammer and center punch
Combination square
Fine-point permanent marker
Pliers

Drill ⅛" holes around the perimeter of body piece A1/A2 as shown on the template (Figure A). For the 8 oval cutouts in E1, drill holes inside each, then work the shapes out with a file.

If you like, you can prototype the project in cardboard before going to metal. For more advice on working with sheet metal, see my Retro Racer project (*MAKE Volume 11, page 97*) and Mister Jalopy's "Q&D: Holes, Rivets, and Bent Metal" (*Volume 05, page 110*).

2. Weatherize the trunk lip.

Cut the inner tube lengthwise, wash it thoroughly with soap and water, and let it dry overnight.

Lay the trunk lip piece D1 on wax paper, then coat it with E-6000 glue. Cover it fully with flat pieces of inner tube, then more wax paper. Clamp it all flat using C-clamps and scrap plywood.

Let the glue dry for 3 days or more, then remove the clamps and wood, and peel off the wax paper. Trim any excess rubber around the edges of the metal with an X-Acto knife.

3. Bend the sheet metal.

Using the sheet metal brake, bend down the 2 middle lines of piece A1/A2 at 42° (Figure B, opposite), then bend the bottom tabs inward at 90°. Similarly bend B1, C1/C2, D1, and E1 along the lines indicated on the templates.

NOTE: Front cap B1 and end cap C1/C2 look very similar; don't mix them up.

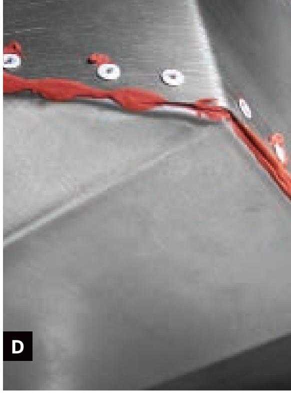
4. Drill matching holes.

Temporarily assemble end caps B1 and C1/C2 to the body A1/A2, clamping them together at the bottom. Fit them at the top and re-drill through one ⅛" hole on each bend plane in A1/A2. Pop-rivet through these holes to hold the pieces in place temporarily, then drill through all the remaining holes (Figure C).

Drill out the pop-rivets using the same ⅛" bit, pull everything apart, and file down any burrs.

5. Rivet and seal the trunk.

Now that everything lines up, put it back together again. Glob the Dynatron putty on the tabs of B1 and C1/C2 and rivet the pieces to A1/A2 through all the holes (Figure D). Wipe the excess putty with a rag and let it dry.



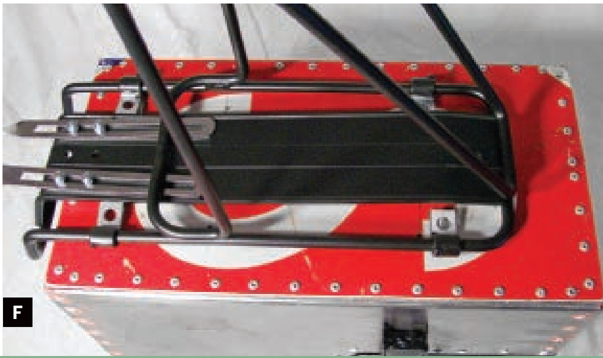


Fig. B: Bend the sheet metal parts in a bending brake. Fig. C: Rivet the body temporarily to the end caps, and drill matching ⅛" holes in the caps. Fig. D: Glob glazing putty onto the end caps, then pop-rivet every hole.

Fig. E: Clamp the trunk lip inside the body, level or angled a bit downward, then drill and rivet it in place. Fig. F: Drill and rivet the base to the body, then drill ¼" holes for the clips that will hold it on your rack.

6. Cut out and mount the door.

Cut templates A1/A2 and C1/C2 apart as indicated, tape them in place on the trunk, and trace them with a marker. Then use a Dremel tool to cut out the door A2 and the hinge joint between C1 and C2.

Cut a ¼" gap between C1 and C2 for the hinge, then clamp on the hinge, mark and drill through its mounting holes, and pop-rivet it in place.

Use a Dremel to widen the gap between door A2 and trunk A1 to ⅛". Bend the trunk lip D1 to fit inside A1, level or angled just slightly downward (Figure E). Clamp it in place, then drill and rivet in place, backing the rivets with washers.

7. Mount the base and the latches.

Drill the tabs around the underside of the trunk with ⅛" holes 1" apart. Fit the trunk over the base, then mark and drill matching holes in the aluminum. Put a bead of silicone glue between the panels over the holes, and rivet the base in place. Wipe excess silicone with a rag and let dry.

Place the 2 hasps, one on each side. Mark and drill through the mounting holes, then rivet the hasps in place using the larger, 3⁄16" bit and rivets, reinforced with washers.

Drill a hole for the brass knob on top of the door. For decorative tailpiece E1, position it on the door and mark and drill ⅛" holes in both pieces, but don't rivet it on yet.

Fit the 5⁄16" pipe clips around the tubing on either side of the bike rack platform. Flip the trunk upside down and center the bike rack on the base (Figure F). Mark the clip mounting hole positions and drill 4 corresponding ¼" holes in the base, plus an extra hole centered in back where the rack already has a hole.

8. Paint and finish.

Paint the inside of the trunk flat black. Sand down the putty on the exterior, then paint it with primer and white paint (to keep cool in the sun). I cut "College Bike Trunk" emblems out of black tape and stuck them to the sides. Finally, pop-rivet the tail on, and stick the red reflector on the back.

Install your new bike trunk on the rack using the ¼-20 bolts. To lock the trunk, use padlocks with shackles 1½" long, one on each latch.

Now you're done. It's time to celebrate like a college student — go to the store, and pick up some beer!

Frank E. Yost is an amateur artist living in Andover, Minn.

Crash! ... and Burn?

The Scenario: Despite the heavy construction they've been doing along this stretch of freeway, you're making really good time on your nightly commute home from work when — 100 yards ahead of you — all hell breaks loose as a multi-vehicle accident unfurls. By the time you hit the brakes and manage a safe stop, you see a jackknifed tanker truck and a battered SUV with its front wheels hung up over the temporary cement divider, telling you, at the very least, you're not moving anytime soon.

Along with others, you jump out to investigate. Everyone's more or less OK except the driver of the SUV, who is unconscious and remains strapped in his seatbelt with his head against the driver's-side window because that side of the car is tilted toward the ground at about a 30-degree angle.

What's more, you clearly see gasoline dripping from both the SUV and the tanker truck, and the SUV's doors are wedged shut by the damage to the car, showing gaps between the doors and the surrounding frame where they've twisted away from each other. Any spark could turn this scene into an explosive inferno and burn that driver alive, which is why almost all the onlookers are backing away fast and calling for help on their cells.

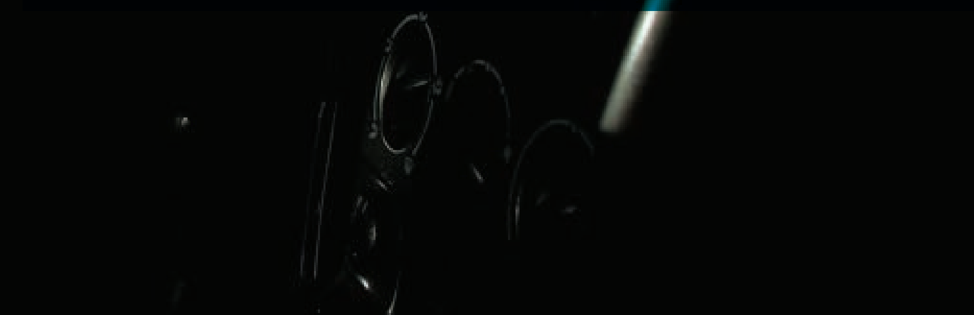
The Challenge: Due to the construction, there's no shoulder, and now that the entire freeway is jammed with cars, you realize it would take emergency crews tens of minutes, if not considerably longer, to reach the scene. Do you just clear out like the others and hope the SUV driver survives until then? Or do you figure out some way to get him out of the car while you can? (The theme of this issue is gadgets, remember?)

What You've Got: A well-equipped roadside emergency pack with tools to do basic auto repair, including all the standard tools to change a flat; a very good first-aid kit with a heavy-duty emergency blanket; a flashlight and extra batteries; 100 feet of strong nylon rope; and — of course — your Swiss Army knife or Leatherman tool. In addition there's whatever would typically be found at a freeway construction area: rebar, steel plate, chain, concrete rubble, shovels, sledgehammers, pry bars, assorted framing lumber, etc.

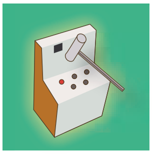
The clock is ticking, the gas is dripping, and the only other people who haven't left yet are both looking at you like you're wearing a T-shirt that says ... *got plan?*

Send a detailed description of your MakeShift solution with sketches and/or photos to makeshift@makezine.com by Nov. 30, 2010. If duplicate solutions are submitted, the winner will be determined by the quality of the explanation and presentation. The most plausible and most creative solutions will each win a MAKE T-shirt and a *MAKE Pocket Ref*. Think positive and include your shirt size and contact information with your solution. Good luck! For readers' solutions to previous MakeShift challenges, visit makezine.com/makeshift.

Lee David Zlotoff is a writer/producer/director among whose numerous credits is creator of *MacGyver*. He is also president of Custom Image Concepts (customimageconcepts.com).



Photograph by Jen Siska



ELECTRONICS: FUN AND FUNDAMENTALS
By Charles Platt

Zap-a-Mole

The first of a series of columns for readers who have relatively little knowledge of electronics and would like to know more.

» I've dropped a lot of quarters, over the years, into machines that offer the peculiar pleasure of hitting moles on their heads with a padded mallet. I'm referring, of course, to the Whac-A-Mole amusement-arcade game in which five oversized, grinning moles pop up at random, inviting you to whack them back into their holes. It's such a perennial favorite that it even has a Wikipedia entry.

I decided to build "Zap-a-Mole," using illuminated push buttons instead of moles. In this column I'll describe an Old School Version powered by logic chips. In my next column I'll show a More Modern Version in which a single microcontroller replaces almost all the chips — and adds more game features.

If you try these projects, you'll learn how chips can talk to each other and how microcontrollers can emulate their function quickly, simply, and cheaply.

The Logical Approach

Logic chips started out inside computers but ended up everywhere from car alarms to pinball machines. In this project I'll show you not just how to build a game with logic chips, but how to design it.

My first step in designing a circuit is to write down what it has to do. For Zap-a-Mole, it looks like this:

1. Power the game for a fixed time.
2. Light an LED at random (representing a mole to be zapped).
3. Wait for the player to press the right button (to zap it).
4. Add 1 to the score.
5. Repeat.

A plain old 555 timer can run the game for a fixed time. I'll call this the Game Timer. Its high output can power a counter chip, which I'll call the Flash Counter. It flashes 5 LEDs in sequence, thousands of times per second, and then stops arbitrarily. This is the usual ploy to achieve a "random" result. I'll need another 555 timer, which I'll call the Burst Timer, to start the Flash Timer and then stop it. Take a look at the block diagram in Figure A to get a better sense of this.

How will the system know if the player presses the right button? Suppose I hook a push button to the input of each LED. This way, if the LED is powered, the button is also powered, but if any other button is pressed, it has no output. Therefore, if button #1 or #2 or #3 or any of the other buttons emits positive voltage, the player has scored a hit.

Those "or" words suggest that I can link all the push button outputs together through an OR logic gate. This is a key concept. The OR gate's output is normally low, unless one or more of its inputs goes high, in which case its output goes high. I'll use this to retrigger the Burst Timer, which restarts the Flash Timer to select another LED at random, so that the game cycle will repeat.

Unfortunately a 555 timer is triggered by a low pulse, not a high pulse. What to do? Well, instead of an OR gate, I can use a NOR gate. Its output is usually high unless at least one of its inputs goes high, in which case its output goes low. To learn more about logic chips, check the Online Resources section of this article, or read my book *Make: Electronics* (makershed.com).

My game will need a Score Counter that advances whenever the player presses the correct button. The trouble is, when you press a button, its contacts vibrate or "bounce" for an instant, and a counter chip is so sensitive, it will count multiple button-presses instead of just one. I need to "debounce" the signal.

This is another thing that a 555 timer can do. It reacts to the first impulse from a button and ignores the subsequent bounces, so long as it's completing its high-output cycle. So, the Burst Timer will debounce the buttons automatically, and I can tap into its high output to trigger the Score Counter. Check Figure A again to trace out the logic of this.

MATERIALS

All parts are available from mouser.com and similar retailers. If the logic chips' part numbers have additional letters appended at the end, this is acceptable.

- **Timer chips (3) Texas Instruments NE555P or STMicroelectronics NE555N. Don't substitute low-power, low-voltage CMOS versions.**
- **Decade counter chip Texas Instruments CD4017BE or STMicroelectronics HCF4017BEY**
- **Counters with decoded output for 7-segment display (2) Texas Instruments CD4026BE**
- **8-input OR/NOR gate Texas Instruments CD4078BE**
- **Dual-digit 7-segment 10mm LED display Kingbright DC04-11PBWA/A (blue) or DC04-11EWA (red)**
- **Illuminated push buttons (5) E-Switch LP4OA1PBBTR. Or use cheap tactile switches such as Alps SKHHAKA010.**
- **Tactile switches or SPST push buttons (2 for start and reset functions**
- **LED for "game over" signal. Everlight HLMPK150 low-current red, or similar. Add 5 more if your push buttons don't have LEDs inside them.**
- **Capacitors: 3.9nF or 0.0039µF (1), 0.01µF (3), 10µF (1), 47µF (1)**
- **Resistors: 390Ω (1), 1kΩ (2), 1.5kΩ (15), 10kΩ (8), 22kΩ (1), 1MΩ (1)**
- **Photoresistor approximately 50kΩ in average room lighting. Often referred to as "photocells," these are becoming uncommon. Check eBay!**
- **9-volt battery and battery clip such as Jameco #11280**
- **9-volt voltage regulator (optional) Fairchild Semiconductor LM7809CT**
- **Multimeter**
- **Breadboards (3) and jumper wire**

I'll use a 4026 CMOS chip for the Score Counter, because it can power 7-segment numeric displays directly. For compatibility, all the other chips should be CMOS, too. They're somewhat archaic now, but that's what you get, here in the Old School Version of Zap-a-Mole. And since old CMOS chips are tolerant of a wide voltage range, I can power the Flash Counter directly from the Game Timer, and run everything with a 9-volt battery.

And to make the Burst Counter run for a truly random time interval, I can adjust its duration with a photoresistor that changes its resistance slightly in ambient lighting.

Putting It Together

The schematics in Figures B and C (on the following pages) are laid out like a breadboard version of the circuit, shown in Figure D. It's simpler than it looks. I like to cut every little piece of wire to the exact length, but if you're less obsessive than I am and use pre-cut wire, you can finish the job in less than 2 hours.

Start by wiring the scoring section (Figure C). Connect the pin labeled 1a on the counter to 1a on

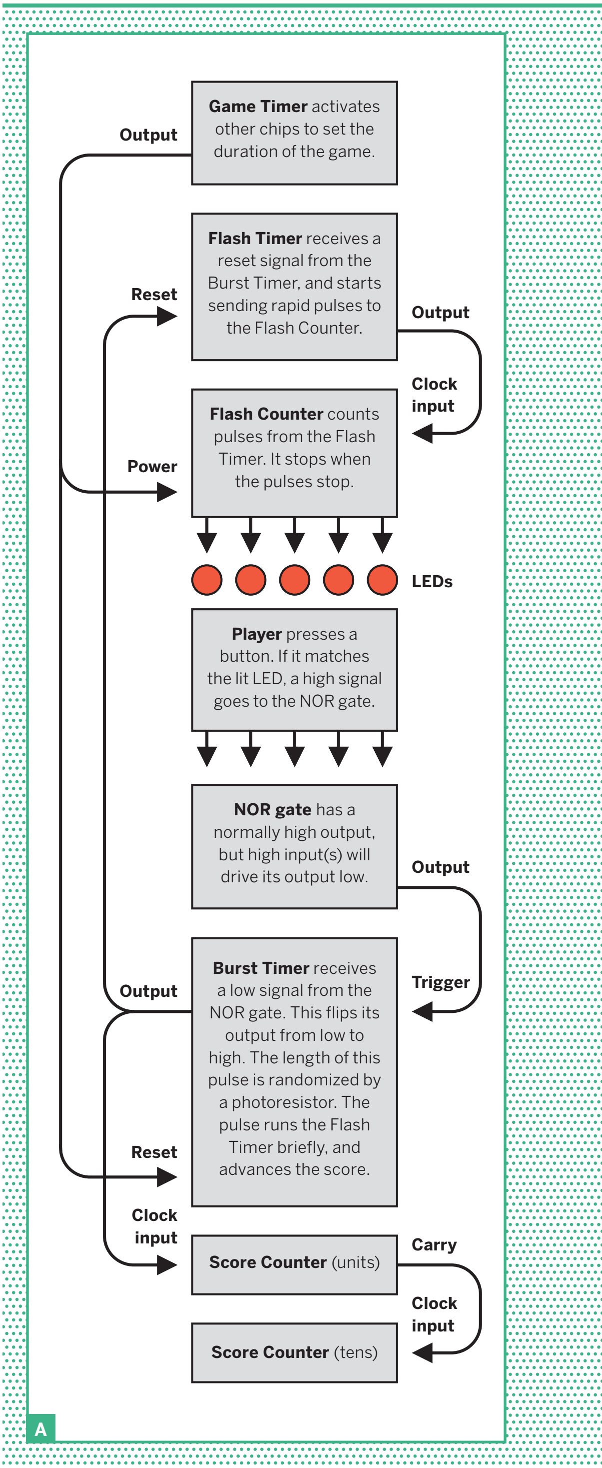
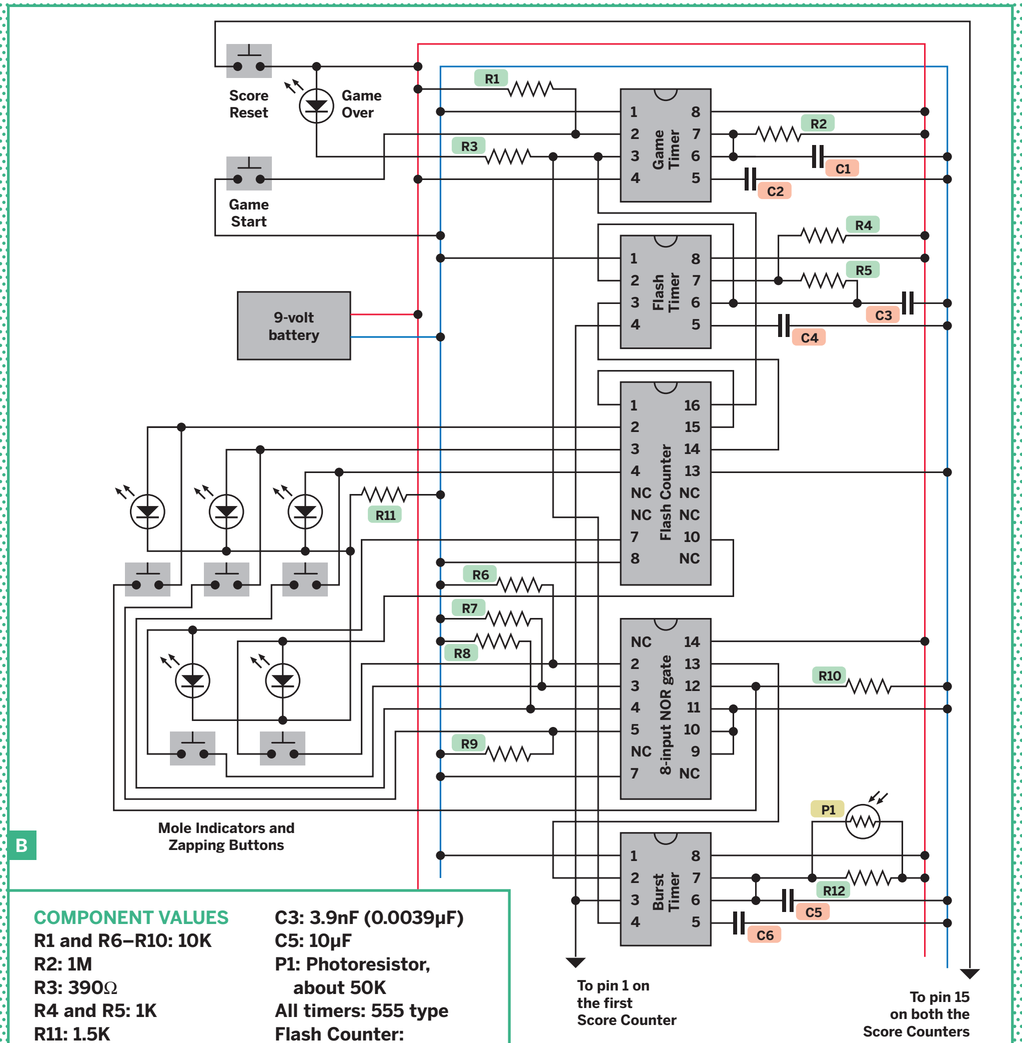


Fig. A: This block diagram shows how the components interact.

Diagrams and photography by Charles Platt



COMPONENT VALUES

R1 and R6–R10: 10K
R2: 1M
R3: 390Ω
R4 and R5: 1K
R11: 1.5K
R12: 22K
C1: 47µF
C2, C4, and C6: 0.01µF
C3: 3.9nF (0.0039µF)
C5: 10µF
P1: Photoresistor, about 50K
All timers: 555 type
Flash Counter: 4017 type
8-input NOR gate: 4078 type

Fig. B: Upper half of schematic diagram. Wires that cross each other don't make electrical contact unless they're connected by a black circle.

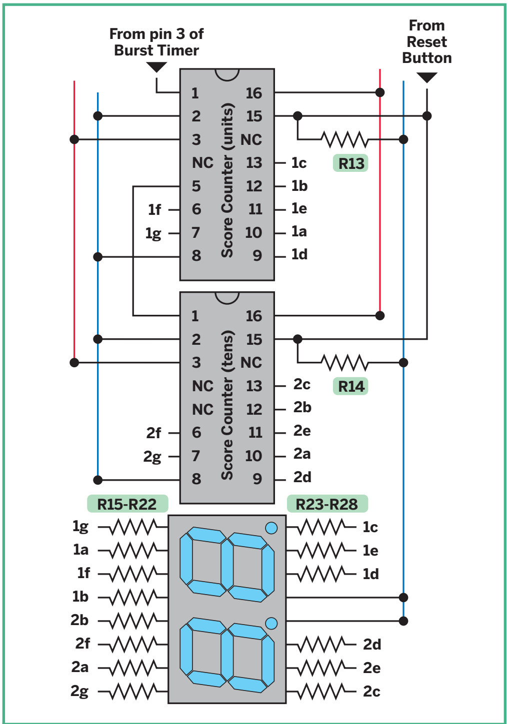
the display; pin 1b on the counter to 1b on the display; and so on. I omitted the actual wires for clarity.

I'm specifying high-value 1.5K resistors to protect the LED numerals because I'm driving the display directly from the 4026 chip, which can only deliver about 3mA per pin. If you check the current passing through one segment of the display by inserting your multimeter, and you see more than 3mA, increase the value of your resistors.

After wiring the display and the score counters, apply power and touch a positive wire to pin 1 of the upper counter. The numbers should advance. If they flicker and "overcount," this is normal, because the wire contact is creating its own "switch bounce."

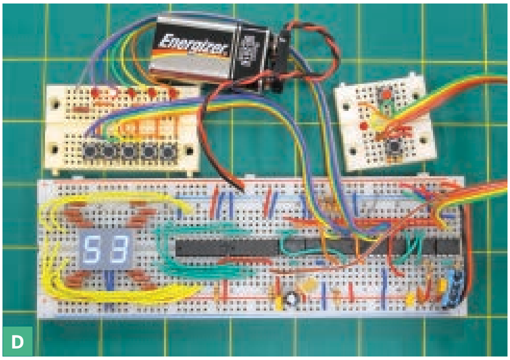
Now build the rest of the circuit. I put the game LEDs and tactile switches on a separate mini-breadboard, to make them easily transferable into an enclosure. For this game, I think push buttons that have their own LEDs inside them are ideal, so that you can whack the thing that lights up. Still, they cost about $5 each. Tactile switches are much cheaper.

What if it doesn't work? The most common error is allowing an input of a CMOS chip to "float" in an undefined state. Note the 10K "pull-down" resistors shown in the circuit on every pin connected with a button. The pull-down resistor holds the pin at a

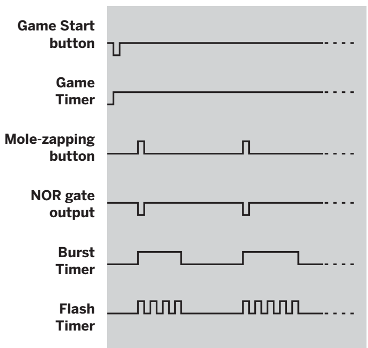


R13 and R14: 10K / R15–R28: 1.5K
Score Counters: 4026 type

C



D



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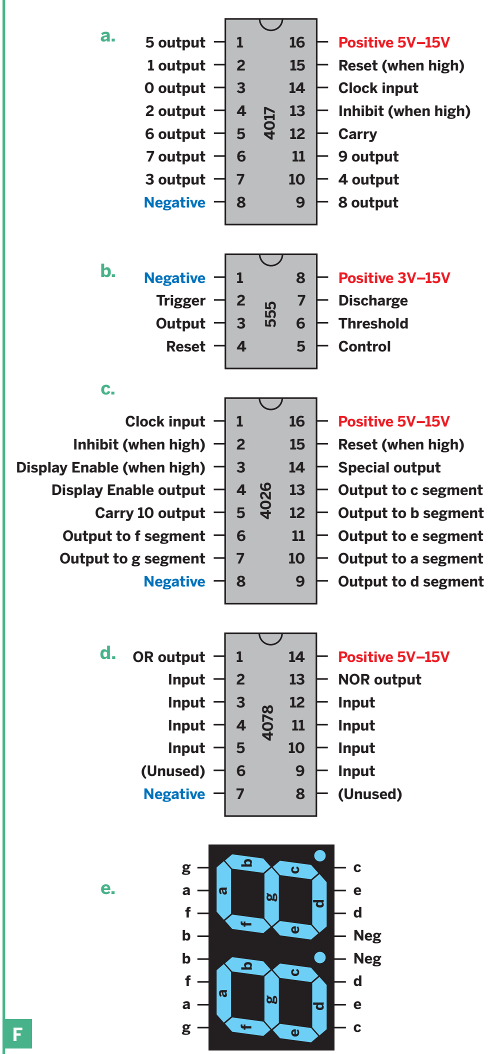

F

a. 4017 decade counter. Reset and Inhibit pins are normally grounded.
b. 555 timer
c. 4026 decade counter with decoded 7-segment display outputs. Reset and Inhibit pins are normally grounded; Display Enable should be positive.
d. 4078 8-input OR/NOR gate.
e. Kingbright DC04-11PBWA/A (blue) or DC04-11EWA (red) dual digit numeric display.

Fig. C: Lower half of schematic. Connect hookup wires between counter pins and display pins that have the same labels. Fig. D: A breadboarded prototype. Next step: Shift the components to perforated board and solder them into place, and mount push buttons and LEDs in an enclosure. Fig. E: This pulse diagram shows how the chips communicate. "Up" pulses are positive. "Down" pulses are negative. Fig. F: Pinouts of the chips used in this project. All components are viewed from above.

Fig. G: After installation in this arcade-style mini-cabinet, Zap-a-Mole allows you to whack an illuminated button into submission, using a suitably downsized mallet.

low voltage until the button overwhelms the resistor with positive voltage. The only pins you can leave unconnected are labeled "NC" (meaning "no connection") in the schematic.

When you power up the game, if the score counter doesn't show 00, press the Score Reset button. Then press the Game Start button. The Game Over LED goes out (if you wired it the right way), and you can start playing.

All the LEDs come on simultaneously as the Flash Counter cycles them, and then one stays lit until you hit the button identified with it. After about a minute, the Game Over light comes on and your score freezes. Another game? Press the Score Reset and the Game Start button again. Happy zapping!

Lessons to Learn

Figure E (previous page) shows the pulses emitted by chips and switches in the schematic. This provides a clearer idea of what's actually happening. If you design a circuit of your own, drawing this kind of diagram will help you get the chips to talk to each other. Figure F shows pinouts for the chips; compare their functions with the way they're wired in Figure B.

The Flash Counter is a decade counter with decoded outputs, meaning that the counter responds to each positive input pulse by moving a positive voltage from one output pin to the next. After it counts from 0 to 9, the counter goes back to 0. In Zap-a-Mole, I have only 5 LEDs, so I connected a jumper wire from pin 1 (the "5 output") to pin 15 (the "reset"). This forces the chip to go back to 0 after counting from just 0 to 4.

We've talked about the 555 timer in MAKE before (*see Volume 10, "The Biggest Little Chip"*), but this game emphasizes the use of its reset pin. Remember: the timer's output goes from low to high when the input pin goes from high to low (assuming the reset pin is held constantly high). But the output also goes from low to high if the reset pin goes from low to high (assuming the input pin is held constantly low). Check Online Resources for more information.

Going Further

Instead of a battery, try using a 12-volt AC adapter (which has a DC output), and passing it through a 9-volt voltage regulator such as the LM7809.

A problem with this game is that it waits for you to press a button, no matter how long you take. In the real Whac-A-Mole, if you don't whack the mole promptly, it drops back down and you miss your chance. Can you figure out how to add this feature using logic chips? A microcontroller would handle it much more easily. I'll show you how in the More Modern Version, in the next issue.

I have mixed feelings about microcontrollers. They're powerful and versatile, but you lose the aesthetics of pure hardware. When you open the back of your Zap-a-Mole cabinet and look at those vintage CMOS chips trading voltage pulses, I think they inspire a fascination that software can never equal.

Online Resources

» General primer on logic gates and counters: makezine.com/go/logicgates

» 555 timer overview, circuits, and simple math: doctronics.co.uk/555.htm

» Fairchild LM7809 voltage regulator datasheet: fairchildsemi.com/ds/LM/LM7809.pdf (*See datasheet page 22 for schematic.*)

» 4017 decade counter datasheet: focus.ti.com/lit/ds/symlink/cd4017b.pdf

» 4017 tutorial with many examples: doctronics.co.uk/4017.htm

» 4026 counter datasheet: focus.ti.com/lit/ds/symlink/cd4026b.pdf

» 8-input OR/NOR gate datasheet: focus.ti.com/lit/ds/symlink/cd4078b.pdf

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Charles Platt is the author of *Make: Electronics*, an introductory guide for all ages. A contributing editor to MAKE, he designs and builds medical equipment prototypes in Arizona.

TOY INVENTOR'S NOTEBOOK

Guitar Amp Bulletin Board

By Bob Knetzger

MORE AT
makezine.com/toyinventor

I'm calling this new column "Toy Inventor's Notebook." It's a loose notebook format: quick sketches without step-by-step instructions or dimensions. I hope you'll enjoy looking over my shoulder while I ideate on a project. Visit makezine.com/toyinventor, where I'll post more details and photos of finished projects.

Sometimes the leftovers from one project can be an inspiration for something else. I had an odd piece of vintage speaker cloth that was too small to use but too cool to throw away ... hmmm ... how about using it to make a mini "guitar amp" bulletin board?

To give it the look of the front of an amp, make a framed tray with quarter-round molding on a piece of plywood. For the look of Tolex amp covering, use contact cement and a staple gun to cover the frame with textured vinyl upholstery material.

For the bulletin board, cut some high-density fiberboard to make a thin backer board to fit inside the frame. Use more staples and contact cement to wrap the speaker cloth around the cork and board. Print out a label for a control panel (I lifted some Fender amplifier script art).

Here's the trick part — the "knobs" are really pushpins! Use RTV rubber to make a mold around a real knob, then cast acrylic to make perfect copies. Suspend a pushpin in the uncured resin. Unmold the cured knob, spray with black paint, then wipe with white paint to fill in the markings. Drill some small storage holes for the knob/pins in the control panel.

Top it off with a red LED stuck directly on a button battery. Build it into a cap from a tube of lip balm to create a glowing bezel.

If you really want to take the concept to "11," add working speakers. The miniature dynamic speakers scavenged from a talking greeting card would fit into this thin design. Cut a circular hole in the cork and insert the wired-up speaker before adding the speaker cloth. Connect it to a mini plug, then hook up to an iPod. Rock on!

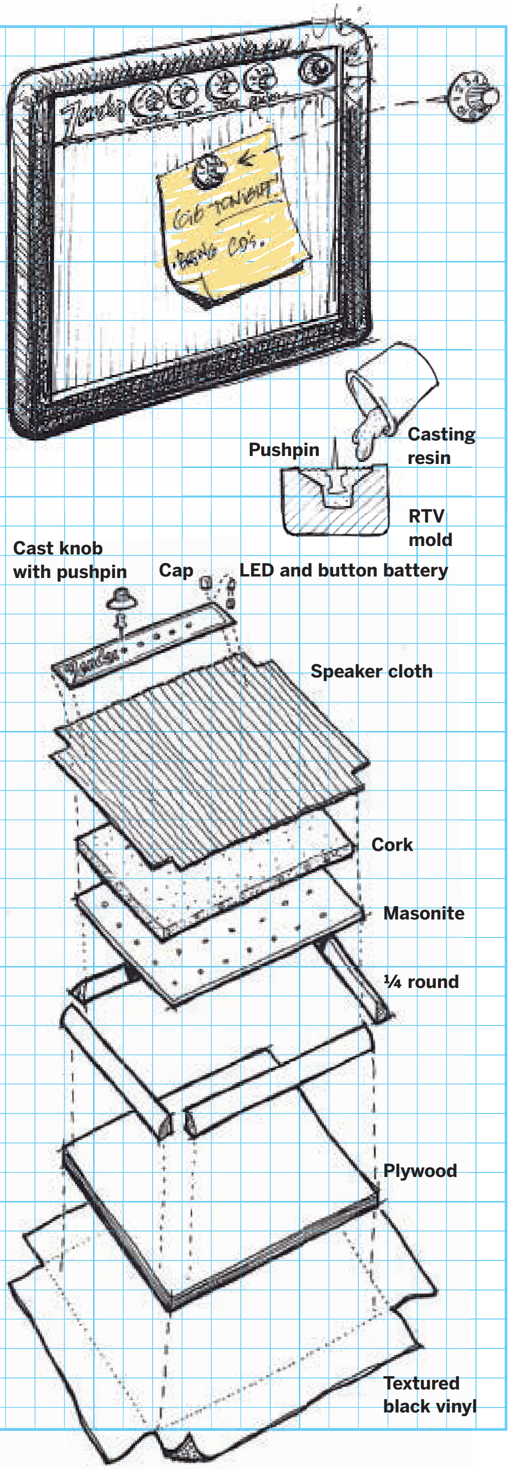
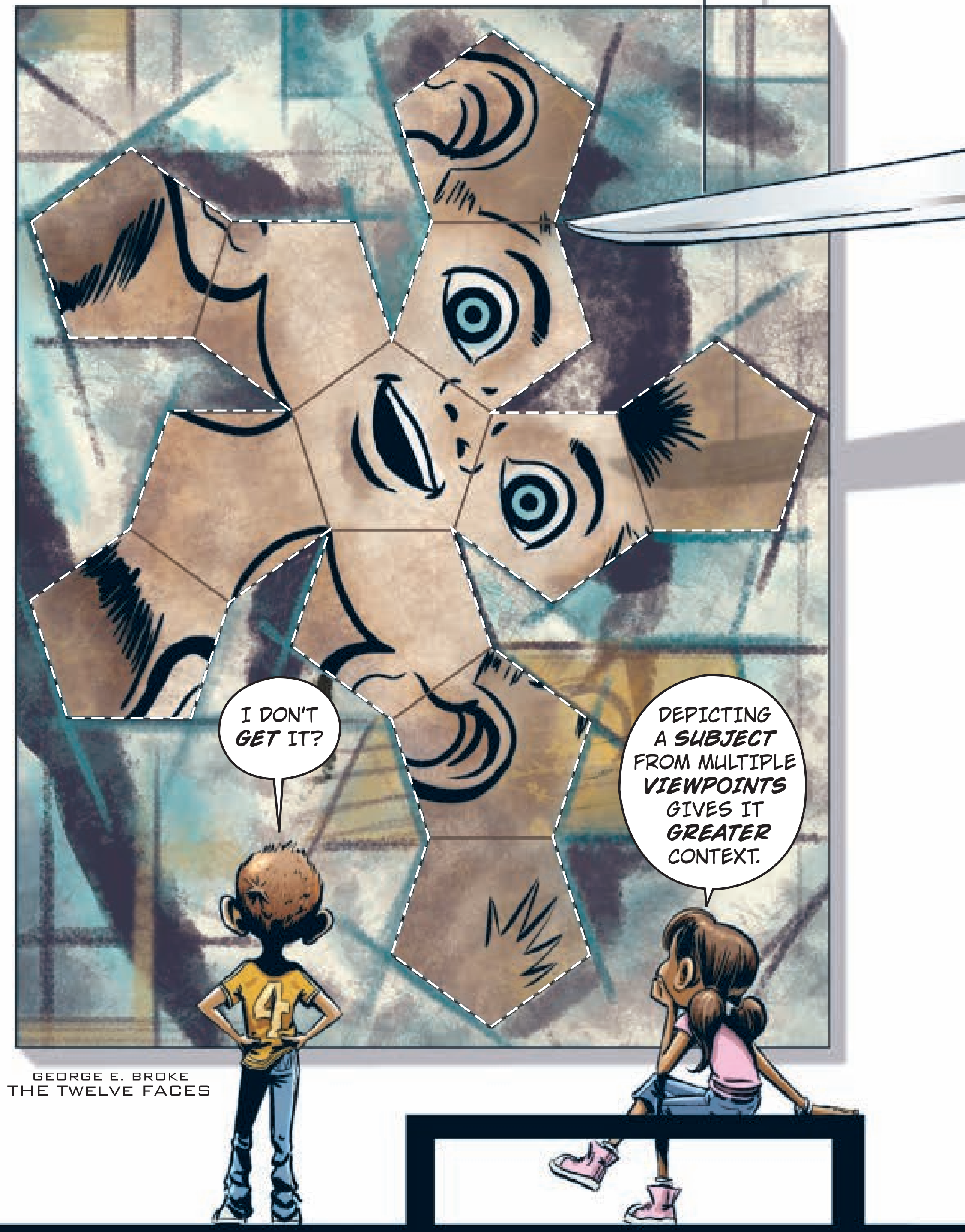


Illustration by Bob Knetzger

Musée du Dodecahedron




INGS E. DEE
SHEARS
I GUESS OUR LOVE WILL ALWAYS BE PLATONIC...
SUALO GRIF'EITH
FOLD AND TAPE
HOWTOONS.COM
SEEK THE TRUTH
DRAGOTTA
DADA-ECA

Make your mark, power up on the go, launch paper rockets, break from proprietary software, and leave the gloves on.

TOOLBOX

Microstamp Maker's Mark

$85 and up microstamp.us

In 2005, I came out with a book from a great small publisher with zero marketing budget. Naturally, my thoughts turned to guerrilla marketing, and I recalled a photo I'd seen years before in *Popular Science*: a penny with the word "Microstamp" imprinted into it. As it happened, a new nickel was coming out, and it had plenty of blank space right in front of Jefferson's eyes. I figured I could stamp a bunch of nickels there with my book's title, and then the coins would circulate and work as mini billboards. Everyone likes examining new coin designs, right?

I found Microstamp online and learned that the stamp I wanted was their custom "Maker's Mark," a hard steel straight stamp that you hammer into metal (or plastic) like a center punch. The product is aimed at jewelers, crafters, and anyone else who wants to put their logo discreetly and indelibly onto flat metal (it's also good for marking metal cases to indicate ownership, in case of theft).

Prices for the Maker's Mark start at $85 but complicated images cost more, and you need to send them an image to get a quote.

I received my stamp in the mail two weeks later, and when I tried it on a nickel, it worked beautifully! It's fun giving it a tap with a hammer and seeing the little image appear underneath. The image size was too small, but that was all my fault — my enthusiasm at the neato-ness of making the letters as tiny as possible clouded a sober analysis of what would actually provoke attention and be legible on a coin.

I went to the bank and got rolls of new nickels, then stamped them and started using them as bus fare. I've never heard of anyone noticing one of these coins, and I don't know if any copies of *The VJ Book* (Feral House) ever sold as a result. But if you look closely — extremely closely — at the change in your pocket, you just might find that you have one of them right now! *—Paul Spinrad*

Want more? Check out our searchable online database of tips and tools at makezine.com/tnt. Have a tool worth keeping in your toolbox? Let us know at toolbox@makezine.com.

LensBaby Muse

$100–$150 lensbaby.com

The Muse is a selective focus attachment lens for a DSLR camera. It's got a flexible, bellows-like neck that lets you change the focal plane manually. If you want to take a normal shot, the Muse pops back to "regular" mode automatically.

Even better, the Muse lets you swap in any LensBaby optics (sold separately) without taking the whole lens out. They offer a plastic-lensed model that simulates the effect of a toy camera, as well as pinhole, fisheye, and soft-focus attachments.

The soft-focus is my favorite. It's customizable, with a passel of hole-punched, stackable aperture disks that give you control over the character of the softness. LensBaby makes getting funky and experimental with your DSLR easy. *—John Baichtal*

Case Pocketknives

$35 and up wrcase.com

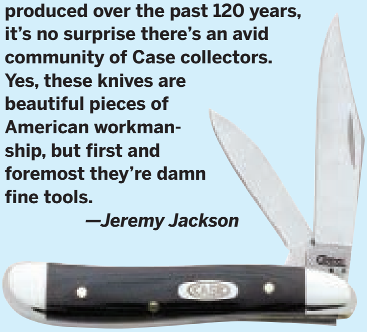
Despite the array of gee-whiz Leathermans and Swiss Army knives I own, there's one tool I carry with me all day every day: my W.R. Case and Sons Peanut pocketknife. These knives have been around since 1889, and are still handcrafted in Bradford, Pa. The ingredients list is refreshingly familiar — surgical steel blades, brass bolsters, and bone or wood handles — and the knives have a satisfying heft and always-sharp blades.

Case makes dozens of styles, from tiny to titanic, and whether you're a desk jockey or Alaskan bear hunter, there's one perfect for you. With mine, I sharpen pencils, slice salami, cut zip ties, and open boxes.

And if I ever happen to encounter my great-grandfather, we could each get out our Case pocketknives and compare them.

With thousands of different kinds produced over the past 120 years, it's no surprise there's an avid community of Case collectors. Yes, these knives are beautiful pieces of American workmanship, but first and foremost they're damn fine tools.

—Jeremy Jackson



Kumiki Wooden Puzzles

$33 nadascientific.com

The complex interlocking wooden puzzles known as kumiki have been manufactured in the Ashigarashimo District of central Japan since the late 19th century, but the traditional fastenerless joinery techniques from which their intricate designs are derived are truly ancient.

Unlike Western-style "burr" puzzles, which tend to have simple abstract shapes, kumiki are usually representative, with some of the earliest examples taking the form of classic Japanese shrines and temples.

Today, however, kumiki come in all shapes and sizes, and are commonly made to resemble animals, food items, or vehicles. This space shuttle kumiki by Tokyo's Ogawa Seiki Company is a beautiful modern example. It has 34 pieces meticulously crafted from four different woods, weighs nearly a pound, and is the size of a man's hand. It comes almost completely assembled, which was slightly disappointing to me until I realized that taking it apart was as much a puzzle — and a pleasure — as putting it back together again.

—Sean Michael Ragan

Diet Coke and Mentos Kit

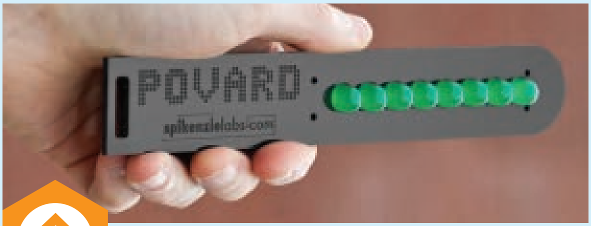
$25 **Product Code MKEPY1**

Fresh from their performance at Maker Faire, the guys at EepyBird have handcrafted replica PVC nozzles just like the ones they use themselves. Each kit contains a variety of nozzle cuts to give you the coolest, highest-shooting geysers. We'll even throw in a pack of Mentos to get you started. (Sorry, but the Diet Coke is not included.)

Compressed Air Rocket Kit

$50 **Product Code MKRS1**

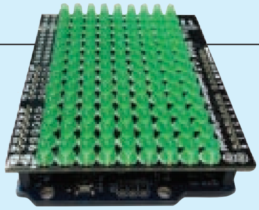
Hundreds of makers have built this launcher after reading how to do it in MAKE Volume 15. Now all the parts (including a copy of Volume 15) are available as a kit. Just add a bicycle pump, masking tape, and two 9V batteries, and you're ready to blast paper rockets hundreds of feet in the air with a few pumps. Let the summer fun begin!



Povard POV Kit

$30 **Product Code MKSKL5**

The Povard is a persistence-of-vision (POV) device that's built onto a cool laser-cut acrylic bezel. It "tricks" your eyes by flashing its LEDs at a very specific rate when you wave it through the air. The result: your brain sees a message or simple image, through the phenomenon called persistence of vision. You program the image on the Povard via an Arduino (not included, but also available in the Maker Shed).

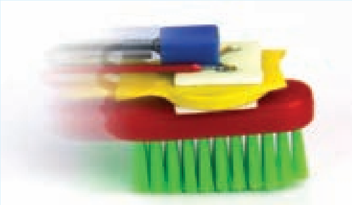


LoL Shield for Arduino

$25 **Product Code MKJR3**

Here's a charlieplexed LED matrix for the Arduino — its 126 LEDs are individually addressable, so you can use it to display anything in a 9"×14" grid. Scroll text, play games, display images or anything else.

Since this is a shield (just a board with LEDs and headers on it), you'll need an Arduino to control it. Then just download the LoL Shield library and program away!



BrushBots

$15 **Product Code MSBB**

Build your own scuttling vibrobot (or four) with a BrushBot kit; they're easy to make, fun to build, and easy to personalize. Our kit was inspired by the original BristleBot how-to from our friends at Evil Mad Scientist Laboratories. BrushBots are perfect for parties, great for groups, and super for schools.

Maker Planes

$20–$29 spinflyer.makersmarket.com

Sometimes throwing a paper airplane is just not appropriate, but never fear: Erwin Franz's elegant and playful kinetic toys will let you satisfy the urge without ticking off your office mates. He uses a miniature CNC machine to make some of the parts, and others are molded in his kitchen oven (to his wife's chagrin). The delicately balanced gliders and "paper" airplanes are mesmerizing and just plain beautiful.

—Arwen O'Reilly Griffith

Stirred, Not Shaken

$425–$449 lisa.makersmarket.com

Why, you may rightly ask, do I need perfect, glassy, 3-inch spheres of ice? Taisin, the Japanese company that first marketed these molds, would have you believe a spherical ice cube is the only truly acceptable way to chill fine whiskey. Because it has the lowest possible surface-area-to-volume ratio, spherical ice melts more slowly than ice of some other, lesser shape, and thus will minimize watering down of your fine sippable during the time it takes you to drink it.

However, the honest answer is: you don't. But I got a chance to play with one recently at Maker Faire, and it was absolutely delightful to watch the heavy, turned-aluminum molds slowly cut a rough chunk of ice into a perfect sphere over the course of about two minutes. People came from all over the fairground to stop and watch. What's more, this version, manufactured by indie Makers Market seller Lisa Lane of Carson City, Nev., will only set you back about one-quarter of the price of the fancy Japanese version.

—SMR

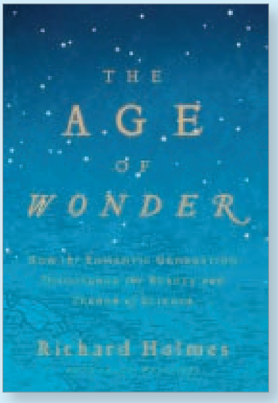
Get the Bends

$15 plusea.makersmarket.com

Toys, and robots, and musical instruments, oh my! Hannah Perner-Wilson (aka Plusea) has put together bend- and pressure-sensor kits for your inner high-tech artist.

Made from neoprene, Velostat, conductive thread, and your imagination, these sensors will make playing instruments (or stuffed animals) from across the room as easy as bending a finger. You can check out the Instructable at instructables.com/id/fabric-bend-sensor to make your own, but I admit I prefer a little hand-holding.

—AOG



The Age of Makers

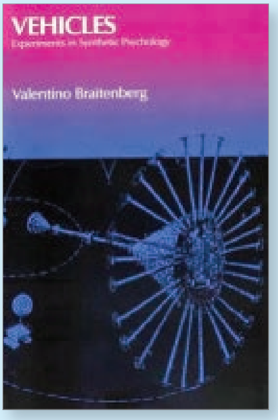
***The Age of Wonder* by Richard Holmes**
$40 Pantheon Books

Dear Makers: Please read this book. It's a wonderful history of the period of discovery and invention at the end of the 18th century that led to huge leaps forward in astronomy, chemistry, philosophy, and poetry (yup, I said poetry).

Holmes wrestles this weighty subject into a highly readable form by telling linked stories of the men and women who passionately grappled with the problems of their day. Joseph Banks, William and Caroline Herschel, and Humphry Davy rub elbows with Captain Cook and Percy Bysshe Shelley, Babbage and Darwin, Scottish explorers and Italian aeronauts. In this day and age of incredibly specialized knowledge, it's hard not to be a touch jealous at the thought that everything then seemed knowable, soon, if only you applied yourself.

Above all, Holmes shows how accessible the sciences were at the time; there were few graduate programs or peer-reviewed journals, so dabblers and tinkerers could end up creating cutting-edge microscopes, overhauling chemistry, or even running the Royal Society.

It was a time when scientists and poets saw their work as linked, when words and equations were just different ways of looking at the same problem (and in fact when the word *scientist* was invented!). This is a perfect book for any maker, or for a loved one who doesn't quite understand the drive to create something from nothing; after reading this, they will. *—AOG*



Emotional Machinery

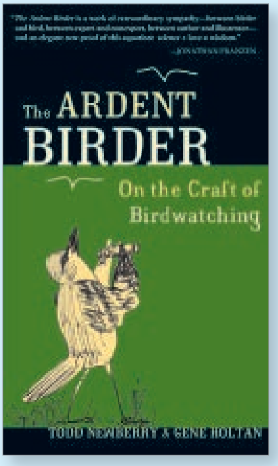
***Vehicles: Experiments in Synthetic Psychology* by Valentino Braitenberg**
$22 MIT Press

It's interesting that some of the most seminal work in bottom-up bots (those with little or no brains) was done by neurologists. Grey Walter (*profiled on page 68 of Volume 19*) was one, Valentino Braitenberg is another.

In this intriguing little 1986 volume, Braitenberg undertakes a series of thought-experiments in behavior and social interaction using simple conceptual machines (dubbed "Braitenberg Vehicles"). Each vehicle is built upon the design/logic of the previous one.

While the machines are imaginary and are designed to get us to think about our behavioral perceptions (e.g., a robot that charges a light source appears to us to be aggressive, one that "hides" under the couch seems cowardly), their basic, sense-act architecture and the thinking about machine behavior they inspired were big influences on the burgeoning behavior-based robotics "school" of the 1980s and 90s. Like Marvin Minsky's *The Society of Mind* and Douglas Hofstadter's *Gödel, Escher, Bach*, this is a book that rewards frequent reading and casual exploration.

—Gareth Branwyn



Watching Birders

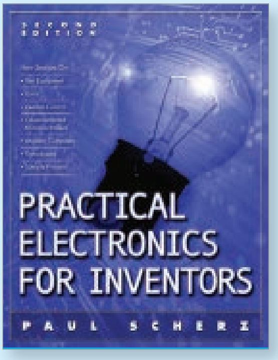
***The Ardent Birder* by Todd Newberry and Gene Holtan**
$15 **Ten Speed Press**

This charming little book talks about the craft of birding (or birdwatching), rather than bird identification techniques. In 50 short essays, author Todd Newberry shares wisdom gained from hours in the field, but this isn't a dry how-to; it's a manual that reads like a love letter to the practice of watching birds. Lively sketches and cartoons by Gene Holtan bring the book to life.

Tips include how to get "on a bird" quickly; that is, how to go from seeing a speck or movement in the trees to actually focusing on the bird with your binoculars. It's not as easy as you might think! There are also nice recommendations about meeting other birders in the field, taking notes on rarities, and various other techniques that can take your birding to the next level very quickly.

If you're a beginning birder, you'll appreciate this as your handbook to the culture of birding as you sort out terms like BVD, listers, and lifers. Advanced birders will also benefit from Newberry's mentorship, including how to be a good birding mentor, and 15 steps that every trip leader should take to heart. And if you find yourself in a disagreement over what bird your group has actually seen, you'll appreciate the essay, "On Being Doubted." An overlooked gem on the topic of how to go birding!

—Terrie Schweitzer



Induction Introduction

***Practical Electronics for Inventors, 2nd Edition* by Paul Scherz**
$40 **McGraw-Hill**

When I began my career 20 years ago, it was possible to be a successful mechanical engineer without really knowing how to push electrons. However, as time passed, I began to suspect that my understanding of engineering had a big, gaping hole in it as I ran into issues like ground loops and impedance mismatches in my data acquisition setups.

And after I discovered microcontrollers like the BASIC Stamp and the Arduino, it was quite clear that my very limited knowledge of electronics was a huge roadblock in my pursuit of fun!

Practical Electronics for Inventors bridges the gap between theory and practice. If you want to know how and why an inductor works, the background material is in Chapter 2 (the well-written, 260-page chapter on theory). Or you can jump to the detailed inductor selection guide in Chapter 3, or just skip to the chapter on filters to figure out how to design the low-pass filter, which is the reason why you started wondering about inductors in the first place.

This book deserves a place on the table right between the soldering iron and the DIY power supply!

—Daniel Sullivan

Energizer Energi To Go XP8000

$100 energizerpowerpacks.com

If your electronic gadget doesn't readily permit you to change batteries, or you simply don't want to bother with the hassle of a spare, check out this great alternative. It's an 8,000mAh rechargeable LiPo battery pack about the size of a deck of cards that weighs about as much as your smartphone.

One of the killer features of the XP8000 is that it accommodates all sorts of devices thanks to its three output ports: 5V USB, 9V–12V, and 16V–20V. There are more than a dozen plugs and charging cables, including adapters for portable DVD players and DC plugs for laptops.

The battery's power indicator also impresses. Press a button, and glowing blue bars show the charge level; plug it into its wall wart to recharge, and the bars light up automatically, allowing you to see how it's doing with a glance. In addition to the XP line, Energizer sells an SP line of solar chargers and an AP line for iPhones. *—JB*

Extech RC200 Tweezer Multimeter

$70 extech.com

The RC200 does everything you'd expect from a multimeter: measures voltage, resistance, capacitance, and continuity, checks diodes, and switches between manual and auto ranging using a stripped-down interface, basically just an LCD with a couple of buttons letting you toggle through the modes. The RC200 measures voltages up to 600V, 6nF to 60mF capacitance, and resistance ranging from 600Ω to 60MΩ. It does not measure inductance.

While the RC200's ratings aren't likely to blow anyone way, it has one outstanding feature: its tweezers. These allow you to test components — including tiny surface-mount hardware — loose or directly on the PCB, making the RC200 invaluable for tinkerers, circuit benders, and hardware hackers. A convenient adjustment wheel opens and closes the tweezers to accommodate different-sized components, or you can just squeeze them as you would any pair of tweezers.

If you don't need the tweezers, you can always swap them out for a module packing the usual test lead ports, making for a very compact standard multimeter — about 7"×1½" in size, and weighing a meager 2.3oz. *—JB*

Ubuntu Karmic Koala (v. 9.10)

Free ubuntu.com

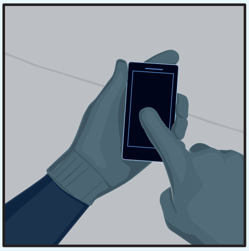
My switch to Ubuntu came from a desire to break away from proprietary software. I started with Jaunty Jackalope (version 9.04) and was a bit afraid to make the jump to the new OS, Karmic Koala (version 9.10), due to some hardware issues. Fortunately, my fears were needless. But while on the technical side everything is quite fast, Ubuntu still suffers from a plain, default GUI. Ubuntu's primary goal over the next few releases is to create their own version of an App Store, which should be completed by 10.04.

In Koala, Ubuntu users see the first step toward a fully functional app store: Ubuntu One is a free, 2GB online cloud storage service that allows Ubuntu users to sync and share files with other online users. The current, upgraded repository is nice to look at, clean when searching, and easy to install. With Lucid Lynx (version 10.04) just released in April, Koala is a great OS to utilize until Lynx establishes its base in the community.

—Eric Ponvelle

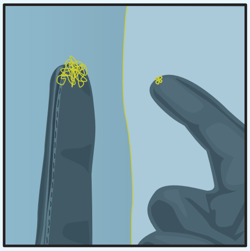
Tricks of the Trade By Tim Lillis

Gloved touchscreen control.



Have you ever tried to use your touchscreen device while wearing gloves, to no avail? Steve Hoefer at grathio.com has shared a great solution.

All you need is your gloves and a little conductive thread, available for $5 at sparkfun.com. Pick up the LilyPad Bobbin kit, or a larger supply if you like.



Now sew through the tip of the index finger, leaving lots of messy loops on the inside to ensure contact with your finger. You want the thread on the outside to be a nice little nib.

You're ready to touch that screen in all conditions! You can even do the same thing to your glove's thumb if you want to use the device's pinch and zoom functionality.

Have a trick of the trade? Send it to tricks@makezine.com.

Dremel EZ Lock System

$20 dremel.com

The Dremel EZ Lock system is a significant advance in small-tool cutting technology. While the heart of the system is a quick-release arbor (eliminating the tiny mandrel screw), its greatest improvement is the new series of cutoff wheels, brushes, buffs, sanding disks, and specialty wheels that go with it.

The new, metal-reinforced cutoff wheels have twice the life of fiberglass versions, are much less prone to breakage, and are available in thin-kerf versions, as well as specific wheels for cutting plastic, wood, laminates, and tile. And a new line of abrasive detail brushes removes rust, paint, or tarnish from a variety of materials.

My favorites are the wheels designed for cutting plastic, which are great for case modding; and I've used the diamond wheels to cleanly cut borosilicate glass (with appropriate hand and face protection). I've used these EZ Lock cutters for weeks and am still very much impressed by them. *—Christopher Singleton*

John Baichtal is a contributor to MAKE, Make: Online, and the GeekDad Blog on wired.com.

Gareth Branwyn is editor-in-chief of makezine.com.

Tim Lillis is a freelance illustrator and avid do-it-yourselfer.

Jeremy Jackson writes fiction and cookbooks in the magical land of Iowa.

Arwen O'Reilly Griffith is a staff editor of MAKE magazine.

Eric Ponvelle is a graduate of Nicholls State University in English with a concentration in technical writing.

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Daniel Sullivan is the owner of many projects that always seem to be about 85% complete.

Have you used something worth keeping in your toolbox? Let us know at toolbox@makezine.com.

Workshop

» Milwaukee's Firefly Workshop

Droid Factory

Craig Smith of South Milwaukee, Wis., is a hot tub installer during the day, an inveterate tinkerer when not on the job. He does most of his work in his crowded but well-organized basement space, which he calls the Firefly Workshop, after the fireflies that inundated it a few years ago, day and night.

The first thing a visitor might see is Smith's aluminum-and-brass "astromech" droid project. His third such robot, the droid can roll, turn its head, play sound clips and lights, and even pop out its third leg. Featured in MAKE Volume 02, Smith has been a member of the online R2 Builders Club (robotbuilders.net/r2/) since 1999. The group shares its robots at conventions, museums, science fairs, and children's hospitals.

Smith's latest project is a huge, metal-framed, walking robot inspired by artist Theo Jansen's ambulatory sculptures. It's about 60% done and Smith hopes it will be strong enough for him to ride. —*John Baichtal*

1. Project: Van de Graaff electrostatic generator ("possibly Milwaukee's biggest"). 2. Project: Steampunk pistol in custom velvet-lined box. 3. Project: Modified Fisher-Price Power Wheels bike with a metal frame, rubber tires, and a top speed of 25mph. ("Yes, I ride it.") 4. Project: Aluminum and brass R/C astromech droid. 5. Microwave cart turned painting station, with a 3-stage brush cleaning system. 6. Custom firefly nightlight. 7. Project: Scratch-built equatorial telescope mount. 8. Shopmaster drill press (shoptask.com). 9. Century 80 plug-in wire-feed welder (centurytool.net). 10. Project: C-3PO arm made from PVC pipes. 11. Project: Brass and aluminum boat horn for Smith's restored vintage Lone Star boat. 12. License plate dustpan.

Photograph by Kevin J. Miyazaki
More images: makezine.com/23/workshop

» *Like what you see? Make sure to check out MAKE's Ultimate Workshop and Tool Guide, a special edition coming to a newsstand near you this fall.*

By Donald Simanek

Fooling Around with Pulleys

MAKE readers hope that the things they make will work as intended. That doesn't always happen. Meet the fool's tackle.

» Rope and pulley systems, such as the block and tackle, have been useful since earliest times. They were among the "simple machines" described by Archimedes, and are among the first mechanical systems studied in introductory physics courses.

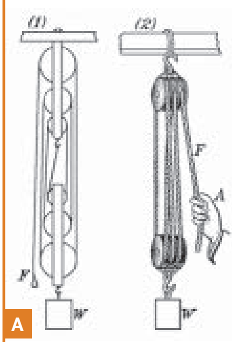
High school physics students in my day knew the block and tackle system seen in Figure A, and knew that its ideal mechanical advantage is equal to the number of rope segments supporting the load (in this case 6) which is also equal to the ratio of the distance the applied force moves compared to the distance the load moves. This assumes a perfectly efficient machine with no mechanical energy losses — the rope doesn't stretch, there's no friction, and the weight of any moving pulleys is negligible. This idealized mechanical advantage is defined by the force ratio (load weight / applied input force).

The efficiency of the ideal system (work out / work in) would equal 1, or 100%. But real pulley systems come nowhere near this ideal; their work efficiencies can range from less than 50% to more than 90%, but 80% is typical.

There's a problem with this sort of "crammed knowledge." If the student is confronted with a pulley system that is not a block and tackle, the "number of ropes suspending the load" rule is out the window.

In physics-ed circles, many of us know of the "fool's tackle" deception, shown in Figures B and C. There isn't much about it on the internet, and it seldom appears in textbooks, so I assume it's not generally known. It looks good on paper, and the naive student will conclude that its mechanical advantage is 2.

Here's the trouble: you can't construct it. Any honest attempt to build it causes its collapse. Of course, you can use deception to make constructions that appear to be fool's tackles, and can even make ones that seem to work. You can also draw an inverted



A

A block and tackle's ideal mechanical advantage is equal to the number of its rope segments.

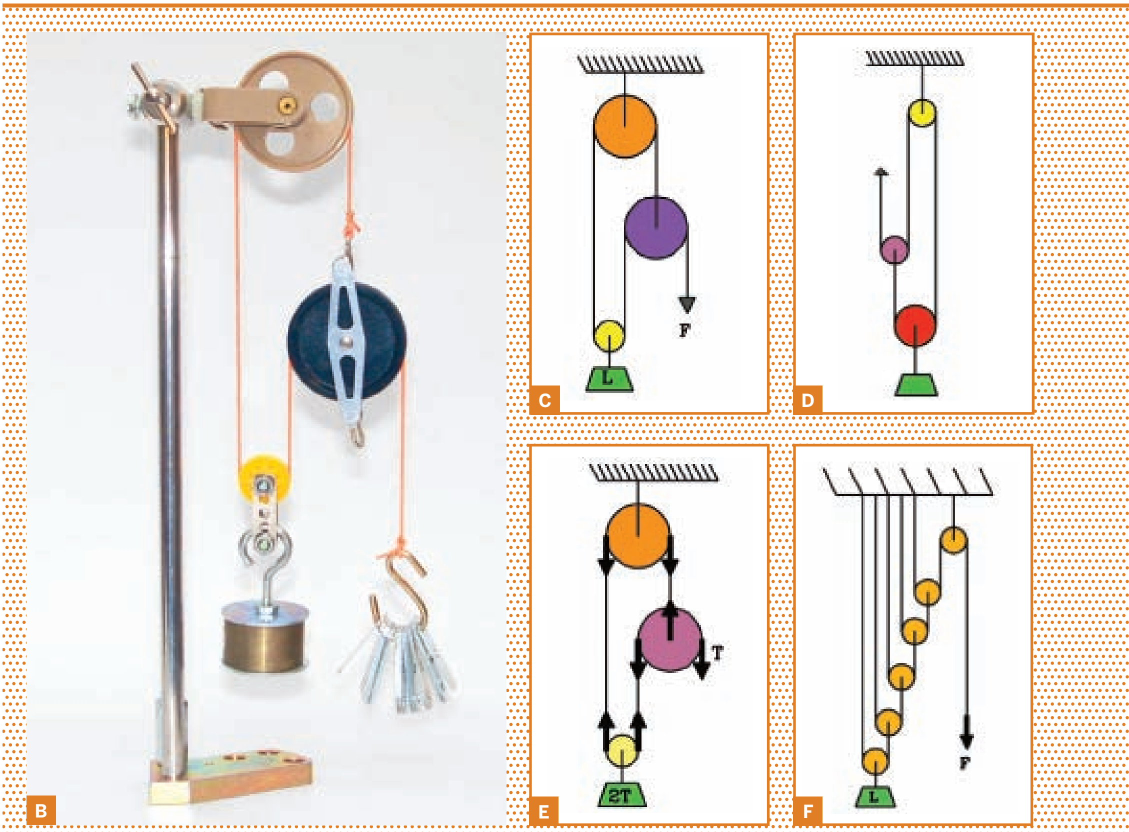
version of it that doesn't work either, as in Figure D.

Combining an impossible device with other mechanical devices, either workable or unworkable ones, is not productive either. There's a lesson in that: a plausible-looking drawing can often deceive. I see a lot of that in email stimulated by my "Unworkable Devices" web pages. I also see it in the patent literature.

This device goes a long way back. Sailors, in the days when ships had sails, were expected to understand ropes, knots, and pulleys, and be able to construct and use pulley systems. Newbie sailors were given some rope and pulleys and assigned tasks to test their skills. Sometimes this included the task of building and using one of these fool's tackles, partly as a joke, partly to see how savvy they were about machines.

We physics profs would do the same with students in elementary physics courses, and most students fell for it, some even spending half an hour trying to build the system before asking for help. I'd usually respond to these plaintive requests by saying, "Didn't we tell you to do a pencil and paper analysis of the system's performance before building it?" There were even some who reported fake data and

Illustration from *A First Course in Physics*, by Robert Andrews Millikan and Henry Gordon Gale, Revised Edition. (Ginn and Company, 1906)



PITY THE FOOL: Fig. A: (Opposite page) A typical block and tackle. Fig. B: The fool's tackle. A pulley system can't physically exist in this configuration; it collapses immediately. This one is stopped by a wedge of foam plastic between the top pulley and its frame. (Call it a "blocked tackle"?) Fig. C: The classic fool's tackle. Fig. D: An inverted fool's tackle. Fig. E: Force analysis of the fool's tackle. Fig. F: The Spanish burton.

Photograph and illustrations by Donald Simanek

analysis, hoping it wouldn't be noticed.

Some things that you can describe in words are simply not possible in nature. For example, a four-sided triangle, or a string with only one end — but these are semantic deceptions. Some impossible tasks violate the physics of the real world, such as a walking path that traverses a closed loop to return to its starting point, downhill all the way. How about constructing an equilateral triangle in a flat plane with no two angles equal? Give those tasks to someone who asserts that "anything is possible."

So how should one analyze a rope and pulley system? In the idealized (and static) case, the tension in the entire length of a rope of negligible weight is nearly constant throughout its length. Call that tension T. So the segments of a rope passing over a pulley sheave have the same tension.

In the diagram of the fool's tackle, Figure E, we see that this tension exerts forces on the pulleys as shown. But the pulley at the right experiences twice the tension acting downward as is acting upward, so that pulley cannot be in equilibrium. That pulley will fall due to the unbalanced forces. The system has an internal contradiction. It's even worse in reality due to the weight of the right-hand pulley. The system will collapse if you try to build it.

Now try your skills on the pulley system in Figure F, called the "Spanish burton." It's shown in Leonardo da Vinci's notebooks. What's the number of rope segments supporting the load? That's hard to count, because only two forces from one rope act directly on the load. The "count the ropes" rule is useless for anything other than block and tackle systems.

But the analysis of this system (or any pulley system) is easy. First assume the system is in equilibrium. Start at the right, calling the tension in the right rope F. This rope passes over the pulley second from the right, exerting an upward force $2F$ on that pulley. So, to maintain equilibrium, the rope acting downward on that pulley must have tension

2*F*. At the next pulley the downward force is 4*F*, and at the next it is 8*F*, and by the time we get to the last pulley, the downward force must be 32*F* = *L*. So the mechanical advantage is 32, and there are nowhere near that many ropes or even rope segments in the system. (There are 5 ropes and 10 segments.)

One thing seldom addressed in textbooks is how to do estimates (back-of-envelope calculations) comparing efficiency of different systems. Suppose that each pulley, moving or not, has a force due to friction, proportional to the weight its axle directly supports. Suppose also that each pulley that moves up and down has a non-negligible weight. Now what could possibly be the superiority of the Spanish burton over a block and tackle with the same ideal mechanical advantage?

The block and tackle would require 32 pulleys compared to the 6 of the Spanish burton, and the block and tackle would have 16 pulleys moving, compared to 5 of the Spanish burton (moving at different speeds, of course). But the Spanish burton has geometric problems, as well as problems with rope stretch. Figure E is misleading, because the pulley spacing, bottom to top, must be 1, 2, 4, 8, and so on, at all times. This system is seldom seen with more than 2 or 3 movable pulleys. Da Vinci took things to extremes, often drawing pictures of things that weren't practical.

I've raised some questions that you can easily answer by building such systems and testing their performance. Small pulleys can be obtained at science supply stores, or from toy construction sets. Add some stout, non-stretchy cord and some weights or small spring scales, and you can have a lot of fun learning about simple machines.

You can also devise puzzles such as "Given *N* pulleys and *N* ropes, what's the greatest mechanical advantage you could achieve using all of the pulleys? What's the greatest efficiency you can get from them?" No matter how ingenious you are, you probably won't find an unworkable system that doesn't have a fool's tackle hidden within it. (Some mathematician may be able to prove or disprove this as a theorem.)

You can buy "simple machines" educational toy kits with the necessary parts. But to get full benefit from them, children need to have some guidance and be challenged by "What if?" and "How?" questions that stimulate measurement and quantitative analysis.

PULLEY TEASER

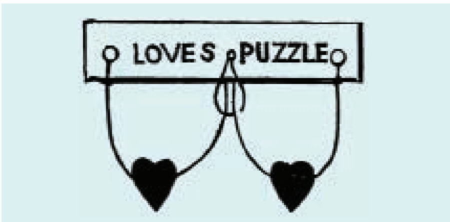
Draw as many 2-dimensional pulley systems as your inventiveness allows.

Two-dimensional systems are those where the pulleys can only move up or down, and all rope segments are parallel. Classify them as workable or unworkable. Without doing a force analysis, can you spot the common geometric feature of the unworkable ones? (Failed machine designs are always due to an attempt to violate the geometry of the universe.)

ANSWER: A movable pulley has 3 rope segments acting on it, 2 of them due to a single rope passing over the sheave. The 2 segments over the sheave exert a net force 2*T* on the pulley in the same direction, so the third rope segment must have tension 2*T* in the opposite direction, to achieve force equilibrium. Therefore that third segment cannot be part of the same rope passing over the sheave, for its tension is only *T* throughout.

CONCLUSION: An idealized pulley system is unworkable if even one movable pulley is acted upon by only one rope.

TIMELESS TEASER



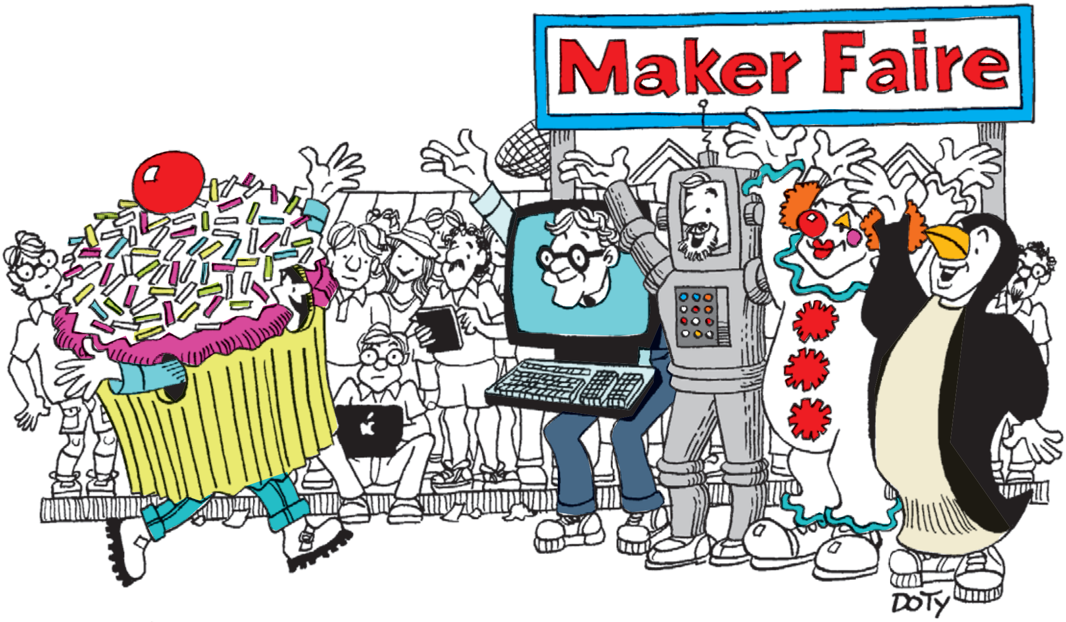
Drill 3 holes in a rectangular piece of wood. Thread 2 wooden hearts or beads onto a string. Loop and tie the cord as shown. The challenge is to get the hearts or beads onto the same loop.

ANSWER: Draw the left heart along the string through the loop in the middle until it reaches the back of the center hole, pull the loop through the hole, and pass the heart through the 2 loops that will then be formed. Then draw the string back through the hole as before, and the heart may be easily passed to its companion.

Donald Simanek is an emeritus professor of physics at Lock Haven University of Pennsylvania. He writes about science, pseudoscience, and humor at www.lhup.edu/~dsimanek.

AHA! Puzzle This By Michael H. Pryor

MAKE's favorite puzzles. (When you're ready to check your answers, visit makezine.com/23/aha.)



Gadget Brothers Reunion

A group of old college fraternity buddies from five different cities decided to reunite at Maker Faire. Each dressed up in a goofy costume and used a different mode of transportation. To pass the time on the trip, each took his favorite gadget.

» Eric took the train from Seattle.

» Steve (who wasn't dressed up as the computer) took his Droid but did not take a flight.

» The alumnus with the BlackBerry didn't ride the motorcycle and didn't leave from New York City.

» The guy with the Kindle wasn't the one who left from San Francisco.

» Larry (not dressed as the penguin) left from New York City without the iPad.

» The buddy with the Zune left from Austin (not dressed as the giant cupcake).

» Brad was dressed as the clown.

» Jimmy (without the Kindle) drove the whole way by himself.

» The five guys were: the guy dressed as a penguin, the guy from Boston, the guy dressed as a robot, the guy who had the iPad on the bus, and Eric.

Illustration by Roy Doty

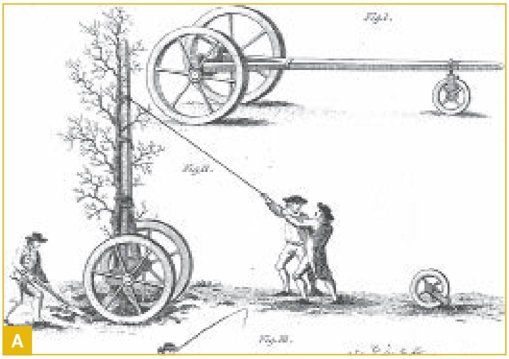
Michael Pryor is the co-founder and president of Fog Creek Software. He runs a technical interview site at techinterview.org.

Tree Moving

Transplant a big tree with a giant two-wheeled dolly.

» This method works great for moving trees that a vehicle can't get to. It's like a giant furniture mover's dolly for trees. Manual methods work OK for small trees, and when there's vehicle access the A-frame method works great (see my page on instructables.com). But I had ten biggish fruit trees to move, with no vehicle access. New methods were needed.

Or ancient ones. In England in the 1700s, Lancelot "Capability" Brown invented this tree-moving wagon to improve landscapes for the wealthy (Figure A).



A

Illustration from Samuel Hayes' *Practical Treatise on Planting and the Management of Woods and Coppices*, 1794

WARNINGS: This is big, heavy stuff. It can fall and crush heads and bodies. Ropes under tension can snap and fly a long way, causing great damage to people and property. Don't hurt your back. Trees grow much faster than a back can heal.

Get Welding

Here was my scenario: the tree-moving season is coming to an end. The fruit trees are waking up, flowering and budding. It's much better to move them when they're asleep. Like vampires.

Also, California's rainy season is coming to an end. We've had our 2 feet for the year. It might not rain for another six months. When the East Bay flats dry out, that rich, black clay soil turns to hard adobe, making the digging very difficult. There's not much time left, and I've got ten trees to move. Pressure.

I walked around the lot and grabbed a couple of wheelbarrow wheels and a lot of scrap square tubing. I did most of the welding with my spool-gun welder powered by my solar golf cart. When it got too windy, I moved indoors and finished with commercial MIG gear. Soon I had built the dolly's frame (Figure B).

The Finished Tree Dolly

I painted the frame immediately to keep the tubing from rusting again. The mast is Douglas fir, 9cm square, 3.5m long. It slides into rectangular brackets and is retained by a 15mm steel pin through the bottom bracket. The shopping cart next to it contains some giant steel hooks I made to lift the tree's root ball (Figure C).

First Use!

James in Fremont needed two trees moved. He had already trenched around this apricot tree (Figure E). The root ball is smaller than I'd like. I cut under it with a long, skinny, sharpened shovel while the dolly supported the weight of the tree. Figures D and G show a good root ball. The roots are cut cleanly so they can heal well and fight off infections.

Tip for Transport

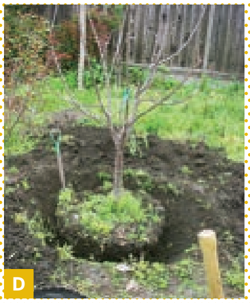
Pull on the masthead guy rope to lift the tree and tip the dolly back. It's amazing how little force it takes. Guide the tree and root ball onto a good resting spot on the dolly as you do this. Add pads and blocks under it if necessary. Don't let the dolly fall and clobber anyone. Secure the root ball to the dolly with more inner tubes (Figures F and G).

Anchor and Guy

To rig the dolly over the planting hole. I pounded the hook into the ground with a sledgehammer and tied the guy line to the hook (Figures H and I). We slipped a 2×4 under the dolly frame to keep it from

B

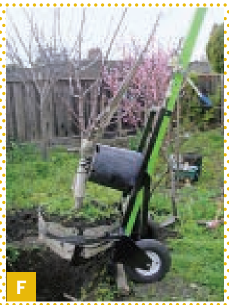
C



D

E

1. Sombrero means “shade maker” in Spanish. The inverted airfoil shape of the brim pushes it onto your head in the wind. This technology enables Mexicans to wear the biggest, shadiest hats in the world. **2. Root ball hook** is set in the ground as an anchor for the guy line to the top of the mast. **3. Kneepads.** Digging a narrow trench with a D-handle posthole spade is like paddling a canoe. The kneeling posture used by Canadian Olympic paddlers is more comfortable with kneepads. **4. Combat boots** from my little stint in the Marines. Their hard, nearly smooth soles are terrible for charging uphill, and not much good for hiking. But they are extremely good for digging holes. They just feel really good on a shovel. **5. Trunk** wrapped with carpet scraps and inner tubes. A nylon tow strap loop is tied around this padding with a lark’s head hitch. **6. Root ball** wrapped with carpet scraps and inner tubes. There are always some roots you didn’t manage to cut. When you hoist, they break the root ball apart. Wrapping with inner tubes makes the root ball strong enough that you can hoist it a little and cut the remaining roots without breaking the root ball and traumatizing the fine feeder roots. **7. Ratcheting winch or “come-along”** lifts the tree. The hoist cable goes over a pulley at the dolly’s masthead to lift the tree vertically. **8. Tow strap loop and lark’s head hitch.** The come-along attaches to this tow strap loop, which is hitched to the dolly frame with a lark’s head hitch.



F

G

H

I

Photography by Tim Anderson

falling into the hole or tipping sideways on the irregular ground. When we untied the tree, it swung to the right, so we blocked up one end of the 2×4.

Planting

James filled around the tree as I lowered it into the hole (Figure I). We leaned the dolly over the hole so we could easily rotate the suspended tree.

Dig a bigger hole than you need. When the tree is standing upright in the hole, remove the padding from the root ball. Plant the tree no deeper than the bulge at the bottom of the trunk. Mulch over the roots, water regularly, and if high winds or college students are in the area, tie guy ropes to the trunk so it doesn’t get knocked over. Happy tree moving!

Tim Anderson (mit.edu/robot) is the co-founder of Z Corp. See a hundred more of his projects at instructables.com.

DANGER! Drive a Car

By Gever Tulley with Julie Spiegler

You can make it!

Take command of 5,000 pounds of metal.

HOW-TO

Driving a car is serious business. Show that you're ready for the experience by paying attention when other people are driving.

1. Pick your location.
Find an empty parking lot or open, flat field. Fewer obstacles means fewer opportunities for collisions. Have the adult drive the car to a spot where there is nothing in front of the car for as far as possible and turn off the engine.

2. Get behind the wheel.
The adult will have to work the pedals and levers, so have them slide their seat back to make a space on their lap for you to sit. Make sure that they can still safely reach the steering wheel in case they need to take control. Review with them which of the controls you are and are not allowed to touch.

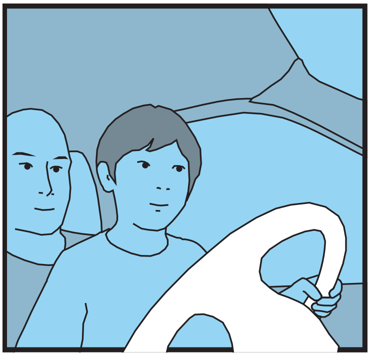
3. Prepare.
Have the adult start the car and put it in drive, but ask them to keep their foot on the brake. You are about to take control; relax and take a deep breath. When you are ready, ask the adult to remove their foot from the brake and to apply a little gas.

4. Learn to steer.
As the car rolls slowly forward, make small turns with the steering wheel so that the car weaves gently along your route. This will help you get a feel for how the car responds to the steering wheel.

5. Drive.
When you are ready, pick a point ahead where there is a streetlight, lane marking, or concrete curb, and plan to turn right or left around it. Keep planning and making turns until you can reliably turn the car when you want to, and have it go where you mean it to. If there are lane markings, try staying in your lane when you make a turn.

COLLISION

PROPERTY DAMAGE



REQUIRES
Car
Empty parking lot (private)
An adult

Duration: Short **Difficulty: Moderate**

WARNING

Keep your speed down and stay far away from any obstacles. Stop the car immediately if other cars or pedestrians enter the parking lot.

SUPPLEMENTARY DATA

It's perfectly legal for a child to steer a car as long as it's on private property.

Driving on public roads is a privilege that is granted to a person by the state when they issue a license. Unlike your constitutional rights (free speech, freedom of religion, etc.), which can never be taken away from you, the state can take your driver license away if you behave irresponsibly in a car.

Driving on a road, with other cars, has more potential for danger than any of the activities in this magazine.

Make up little driving goals and then try to do them. For example, in a parking lot with regular streetlights, you could say, "I'm going to drive in between the light poles."

Illustrations by Gever Tulley

Excerpted from *Fifty Dangerous Things (You Should Let Your Children Do)* by Gever Tulley with Julie Spiegler (fiftydangerousthings.com). Gever is the founder of Tinkering School (tinkeringschool.com), a camp where kids get to use power tools and be trusted.

REMAKING HISTORY
By William Gurstelle

Samuel Morse and the Telegraph

» Prior to Samuel F.B. Morse's invention of the electric telegraph, there was no good way to communicate information across distance at any speed greater than that of a horsed rider. Sure, there were some limited experiments, such as semaphore. Men stood on hilltops signaling with flags and noting one another's coded movements through spyglasses. This was clumsy and slow. Worse, it was incredibly expensive because it required a lot of men on a lot of hilltops to relay messages over any distance at all.

> Despite the fact that Morse had little knowledge of electricity, he plunged ahead as only a man in the throes of a serious midlife career crisis could.

In the 1820s and early 1830s, Morse was well known as an accomplished painter. In 1830, he left his home in New York for Europe, intending to refine his skills even further by studying with the masters of Italy, Switzerland, and France.

It was during this time, however, that painting began to lose its hold over the ever-restless Morse. Although he was at the peak of his artistic prowess, other ideas of how he might spend his life evidently encroached upon his thoughts. In 1832, at the age of 41, he boarded the packet boat *Sully* and cruised westward, back across the Atlantic.

Morse chanced upon a conversation with other passengers about the era's hot science topic — electromagnetism — and what he heard fascinated him. It became a turning point not only in his life but also in the future of communications technology.

Morse had boarded the ship an uninspired artist; he left it an aspiring inventor. As he disembarked, he told the ship's skipper, "Well, Captain Pell, should you ever hear of the 'telegraph' one of these days as the wonder of the world, remember the discovery was made on the good ship *Sully*."

Despite the fact that Morse had little if any knowledge of electricity, he plunged ahead as only a man in the throes of a serious midlife career crisis could. In his crude laboratory, his homemade batteries had little energy, and his elementary attempts at electromagnets produced no magnetism. He didn't even understand the role of insulation on wires.

But Morse did have two important assets: plenty of determination, and smart friends. By asking the right questions of his friend Leonard Gale, a chemistry professor at New York University, he was able to make headway, building a telegraph capable of sending messages a quarter mile. A few years later, he asked the right questions of Gale's friend Joseph Henry, perhaps the most important American scientist in the period between Franklin and Edison.

Armed with Henry's answers, Morse was able to unlock the secret of long-distance telegraphy: the *electromagnetic relay*, a switch that opens or closes a circuit based on input from another circuit. With multiple relays, electrical signals could travel any distance and arrive at a receiving station with nearly as much power as when they were transmitted.

In 1843, Morse received the then-huge sum of $30,000 from the U.S. government to construct the first long-distance telegraph line, stretching from Washington, D.C., to Baltimore along the tracks of the B&O Railroad. The wires were strung from poles and trees, insulated from the ground by crude insulators made from broken glass bottles. On May 24, 1844, the first telegraph message, "What hath God wrought," was tapped from the B&O's Mount Clare Station in Baltimore to the Capitol Building in Washington. The era of electronic, high-speed information transfer had begun.

You can make a telegraph system to communicate with friends, practice Morse code, or simply get a better appreciation for Samuel Morse and his world-changing invention. A system like the one Morse demonstrated in 1844 consists of 4 parts: the key, the sounder, the battery, and the wire (Figure A).

MATERIALS AND TOOLS

For the telegraph key:
¾"×½"×1⁄16" aluminum angle, 5¾" length
¾"×½" wood trim piece, 5¾" length
5⁄16" wood dowel, ½" length
Light coil spring, ⅜" diameter, ¾" long
1"×1" corner braces (2)
¾"×3" steel mending plate
#8 machine screw, 1¼" long, nut, washer
#8 flathead wood screws, ½" long (2)
#8 round-head screws, ½" long (2)
1×4 lumber, 7" length
Flat-shaped brass cabinet knob with machine screw

For the sounder and telegraph wire:
Magnet wire, 26-gauge, coated (50') roughly ½oz by weight. You need 45' to make the relay, and a few extra feet for your telegraph wire.
5⁄16" bolt, 2" long
12-gauge mild steel bars: 1"×12" (1) and 1"×3½" (2)
#8 wood screws, ½" long, with washers (4)
2×4 lumber, 6½" length
1×4 lumber, 12" length
2" nails or deck screws (2–4)
Battery, 9V

All-purpose glue
Variable-speed electric drill and drill bits
Screwdriver

Make the Telegraph Key

1. Glue the wood trim into the aluminum angle, with the angle's ¾" leg on the bottom and its ½" leg on the side. Let it dry. This is the key's lever or "tapper."

2. Drill a vertical hole through the lever (Figure C), centered ¼" from one end, for the knob screw (usually #8, but check your knob's threads before drilling). Then drill a horizontal 3⁄16" hole centered 2" from the same end (Figure D).

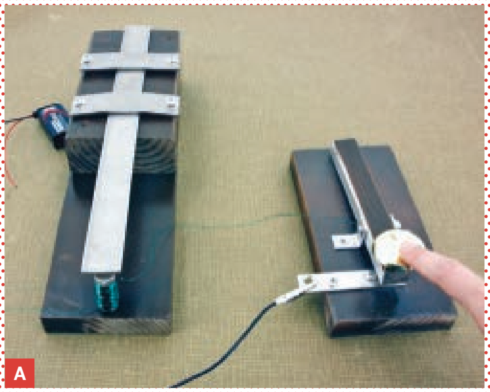
3. Drill holes on the face of the 1×4 board as shown in Figure B. This is the key's base.

4. Glue the wooden dowel into the 5⁄16" hole, so it protrudes no more than ¼". Place the spring over the dowel.

5. Attach the mending plate to the base with wood screws; this is the "anvil." Affix the corner braces to the base with wood screws (Figure E).

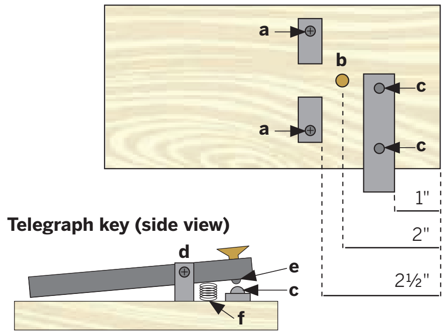
7. Mount the knob so that its screw's head is on the lever's aluminum bottom.

8. Insert the #8 machine screw through the corner braces and the horizontal hole in the lever, securing it with a nut and washer (Figure F, following page).


A

Telegraph key block (top view)

Telegraph key (side view)



a. #8×½" flathead screws
b. 5⁄16" hole, ¼" deep
c. #8 round-head screws
d. #8 machine screw
e. Machine screw to fit cabinet knob
f. Coil spring over dowel

B

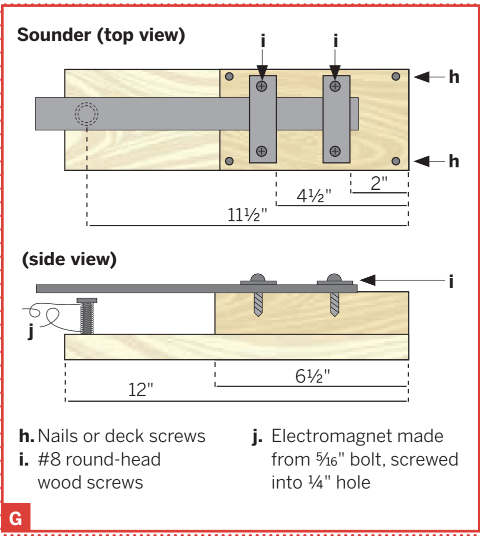

C


D

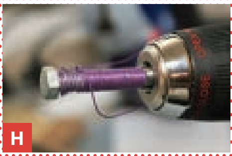

E

Photography by Sam Murphy (A) and Ed Troxell; diagrams by Katie Wilson


F



G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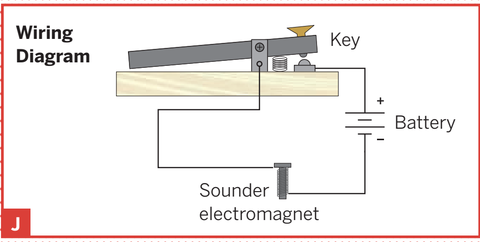

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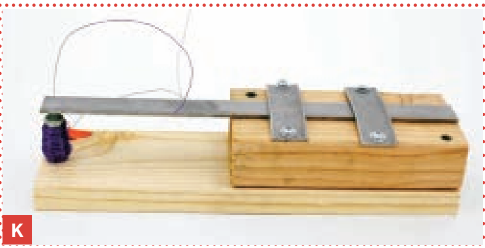
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Make the Sounder

1. Drill holes on the metal bars, the 1×4, and the 2×4 as shown in the sounder assembly diagram (Figure G). Fasten the boards together with nails or deck screws.

2. To make your electromagnet, place the 5⁄16" bolt in the chuck of the drill so the bolt's head and 1" of thread is exposed.

Leaving about 12" of wire trailing, wrap 45' of magnet wire around the threads closest to the bolt head. With a helper holding the magnet wire spool so it's free to spin, start the drill and slowly wrap the wire, using an up-and-down motion so that the wire turns are distributed as evenly as possible (Figure H). Stop winding when there's 12" left, and tie or tape it off so it doesn't unravel.

Now you've got an electromagnet with two 12" leads (Figure I).

3. Screw the electromagnet into the ¼" hole on the 1×4 base.

4. Screw the 3½" steel bars onto the 2×4, but don't tighten them completely.

5. Slip the 12" steel bar under the 3½" bars, centering it on the 2×4. Then tighten the short crossbars slightly.

Wire the Telegraph

Wire the telegraph key to the 9V battery and the sounder as shown in the wiring diagram (Figure J). This diagram shows how the telegraph key and sounder are wired for a single person (practice use).

Adjust the placement of the 12" steel bar on the sounder so it responds quickly and smoothly; it should audibly clap to the electromagnet when the telegraph key is closed. When it's well adjusted, tighten the crossbars to hold it fast.

+ See "Stone Age Telegraph" on page 42 for a story about building a telegraph using tools and materials gathered in nature.

William Gurstelle is a contributing editor of MAKE.

MAKE MONEY

Pennywhistle By Tom Parker

Sometimes it costs more to buy it than to make it from the money itself.

Photograph by Tom Parker

$10.95

Pennywhistle bought online.

$.04

Pennywhistle made from pennies.

Pennywhistles aren't expensive, and a quick search online finds plenty of sites showing how to make them out of plastic, metal, or wood. They're easy to make, too, but the devil is in the details. Adjusting one for good tone requires patience and a little trial and error.

For my pennywhistle, I wanted to fashion a universal mouthpiece or "fipple," so that I could experiment with as many different materials and proportions as possible. I made a sandwich of 3 pennies, with the center section of one removed to form an air channel or windway. I made tiny rivets of copper wire to hold these in place while I fused them together with a fourth penny drilled with a hole, using non-lead solder. Then I added a piece of scrap copper tubing with a sharp-edged hole, and a small wooden half-cylinder plug to help direct the air from the mouthpiece toward the sharp edge of the hole, known as the lip or blade. The whistle's overall tone depends on airflow over the blade.

I used a piece of bamboo for my tube, but copper or plastic pipe works, too. The fundamental note of the whistle is largely determined by the length of the tube, measured from the blade edge to the far open end. You can adjust its pitch by shortening the tube.

When you have a pitch you like, measure the length from the open end of the tube to the sharp edge of the blade, multiply that length by the ratios .85, .75, .68, .60, .52, and .45, and drill 6 finger holes whose edges are these distances from the blade.

Now tinker until it works. I may add another piece of sharp-edged penny to my copper mouthpiece so that it has its own built-in blade, but that's going to raise the overall coin count to nearly 5 cents!


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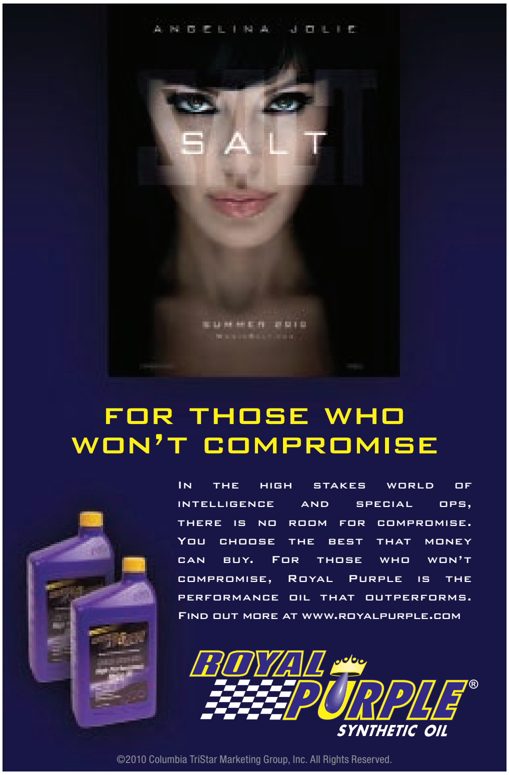
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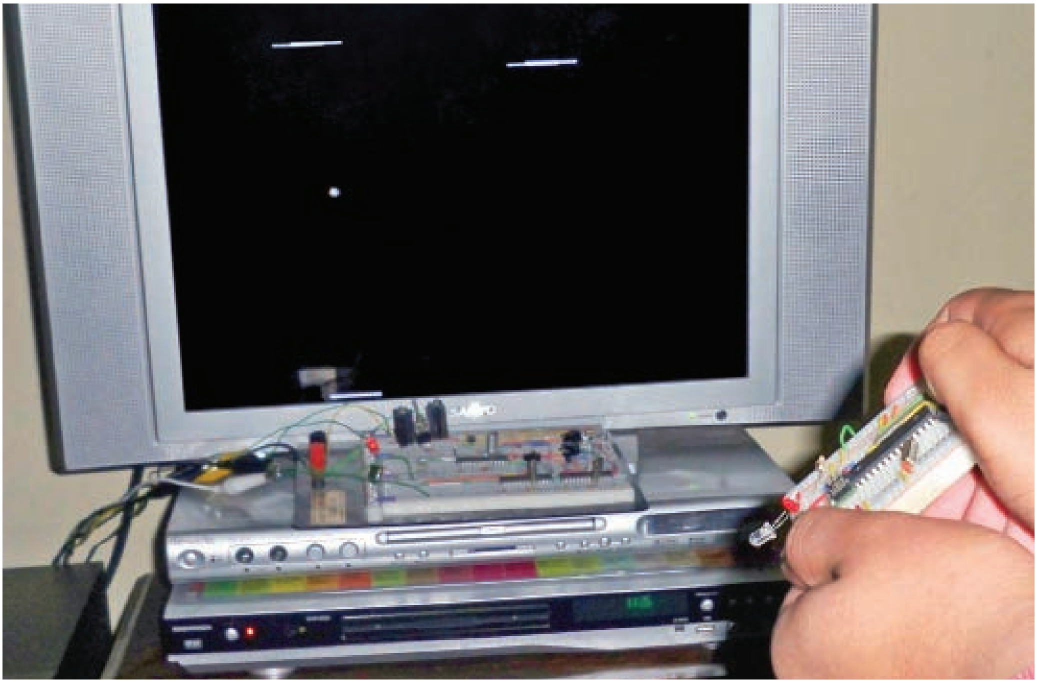
HOMEBREW

My Embedded Entertainment System

By Luis Cruz



Video games have been part of my life in Honduras since I was a kid, but it wasn't until I was 14 that my interest in game programming began.

At first I developed software primarily to learn programming, in a variety of languages. Later I decided to apply my programming knowledge to the digital-electronics world, using integrated circuits such as Atmel microcontrollers to develop my own projects. Online, I bought everything I needed to start learning electronics and microcontroller programming from NerdKits, a company founded by MIT students.

In October 2009, just one year after I started studying electronics, I decided to build my own video game system, applying everything I'd learned about microcontrollers and game programming to a single system. In spite of a lack of resources for developers in Honduras, and with limited free time as a high school student and even more limited capital, I set out to accomplish my goal.

By generating the correct waveforms with two Atmel AVR microcontrollers, I sent data for both monaural sound and monochromatic composite video to an NTSC analog television. Everything was done in the code, with the help of only a handful of resistors and capacitors.

Although sending information to a TV wasn't an easy task, I decided to take on another challenge. One day, while using my TV's remote control, I had the idea to develop my own remote control to send information wirelessly with infrared light.

My idea was to use a third AVR processor to create a motion controller for my console. This chip reads the output from a dual-axis accelerometer, whose signal changes proportionally to the game controller's movement, and then the chip drives an infrared LED on and off using pulse-width modulation, according to the controller's movement or button presses. Yet another microcontroller in the console decodes this infrared information remotely.

My project was featured in local newspapers and TV programs as the "first video game system developed in Honduras," and was selected in February as the best NerdKits project of the month.

I named my console Embedded Entertainment System, or EES. I hope my success with the EES will encourage other developers to build their own projects without fear of failing. With enough effort and perseverance, almost any goal can be accomplished.

Luis Cruz is a high school senior in Tegucigalpa, Honduras. Videos and more details about his project can be found at ees.intelsath.com.

Photograph by Luis Cruz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