INDIAN INSTITUTE OF TECHNOLOGY

ROORKEE

A SURVEY ON OPEN SOURCE COMPUTING HARDWARE

CSN-221: COMPUTER ARCHITECTURE AND MICROPROCESSORS

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1) INTRODUCTION

Open source hardware refers to hardware or the design specifications of hardware which are obtainable by purchase to the public so that the said hardware is accessible to all for study, modification, manufacture and distribution. In its spirit, open source hardware aims to make the study and production of hardware available to the public.

All open source hardware must satisfy several conditions. This includes documentation which must be packaged including the design files and should allow for modification and circulation for the same. If there is any software incorporated into the hardware, then it is required that the said software be available under an approved open source license or the interfaces must be appropriately documented such that writing code for open source software is not burdensome. The license must not hinder any firm or party from marketing the documentation as part of their product.

Open source hardware is mainly focused on things attainable for developers and most such products are relatively easy to obtain. There are many forms of open source hardware available today. This project focuses on several popular open hardware like Arduino, Raspberry Pi, Intel Galileo.

Starting from the very inception of various open source hardware, this project covers their entire evolution. Various diagrams and supplementary data has been provided such that the user is able to follow through on the theoretical conclusions. This project also gives an analysis of how various models of different open source hardware hold up against each other. It also tries to discuss upcoming and recent developments regarding the hardware.

LEARNING OUTCOMES

This paper desires to be complete in end of itself. The reader will be able to get a comprehensive and complete view of the subject.

KNOW HOW AND INSIGHT

In the entirety of this report, there is strong focus on the development and study of the hardware and how new technologies came under its fold. The reader is assured to have a concrete understanding of the discussed hardware.

PRACTICAL UNDERSTANDING

Knowledge regarding the technicalities of the discussed hardware will definitely be of help to the reader and will make the use of such technologies more handy to them.

2) RASPBERRY PI

2.1) ABOUT

Raspberry Pi is essentially a cheap single board computer that was actually aimed to increase enthusiasm regarding computing among school students in third world countries. The Raspberry pi foundation is responsible for the launch and development of the pi. It is based in Cambridge, United Kingdom.

Because of the original model's overnight fame, it sold far past its projected figures. It eventually got past its target patrons and into fields such as Automation and Robotics.

The Raspberry Pi is primitive compared to a traditional computer. But that does not imply it is partial. It is a full and complete Linux computer and satisfies all that implies with minimal power consumption.

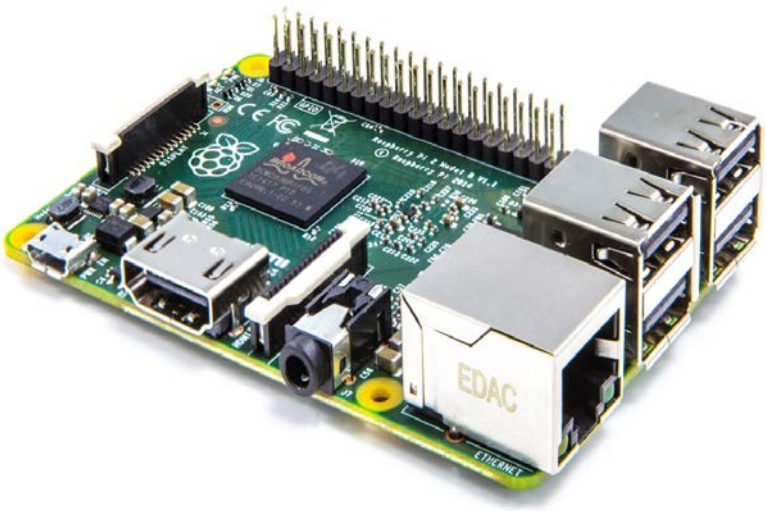


Figure 1: Raspberry Pi 2

2.2) IDEA HISTORY

Like many of the revolutionary technologies of our age, the Raspberry Pi also started in a college dorm. Eben Upton who was studying at Cambridge University along with his colleagues from their computer lab were concerned with the degrading competence and dwindling number among computer science applicants.

Merely decades later, this is no longer the case thanks to Eben Upton. From 2006, Even tried his hand at making several devices which were the previous prototypes of the Raspberry Pi. By early 2008, processors in mobiles were becoming increasingly complex and also easily affordable. It was around this time that Eben's vision began to take shape.

In mid February 2012, the Raspberry pi burst into the market. And since it has sold over four and half million units worldwide. Eben and his co-workers projected only a thousand sales.

Figure 2: Raspberry pi's logo and its founder

2.3) COMPONENTS

Aesthetically, the Raspberry Pi resembles a small motherboard. Exposed chips and open ports make it seem like it is a part of an internal board. Despite its misleading appearance, it has all the necessary hardware required to be a fully functioning computer including input-output devices and storage.

There are two extremely popular models of the device, namely Model A and Model B. The only palpable difference being the inclusion of ethernet and an additional USB port in the more lavish Model B.

ARM GPU/CPU:

Its architecture is a Broadcom BCM2835 System on a Chip (SoC). It houses a video core 4 GPU along with an ARM CPU. The CPU and GPU function as they would in a regular computer.

GPIO:

This is an acronym for general purpose input/output. These are naked connection points that permit the user to dabble with the architecture.

RCA:

The RCA jack is the default output of Raspberry Pi and is compatible with a variety of output devices.

AUDIO OUT:

This constitutes of the universal standard 3.55mm jack which allows for tethering to audio output devices.

Note: There exists no native audio in for Raspberry Pi.

LEDs:

The Raspberry Pi houses five Light emitting diodes (LEDs). These can be applied as indicators or signals by the user for the task at hand.

USBs:

A standard port for all kinds of peripheral devices, Model A has one while its costlier brother Model B has two.

Note: USB hubs can help to expand the number of devices.

HDMI:

This allows for tethering high definition displays to your Raspberry Pi.

POWER:

A 5V micro USB connector is to be attached to a compatible power stream.

SD SLOT:

An OS is crucial in booting the pi, but the pi has no onboard storage. So, the software is usually loaded in an SD card. This is available on the market but can also be downloaded online and saved to the card.

Note: Raspbian is the official recommended OS by the Raspberry pi foundation. Debian is a unique Linux based OS in that it is completely open source. A version of it runs on the pi.

ETHERNET:

This provides wired network compatibility and is only available on Model B

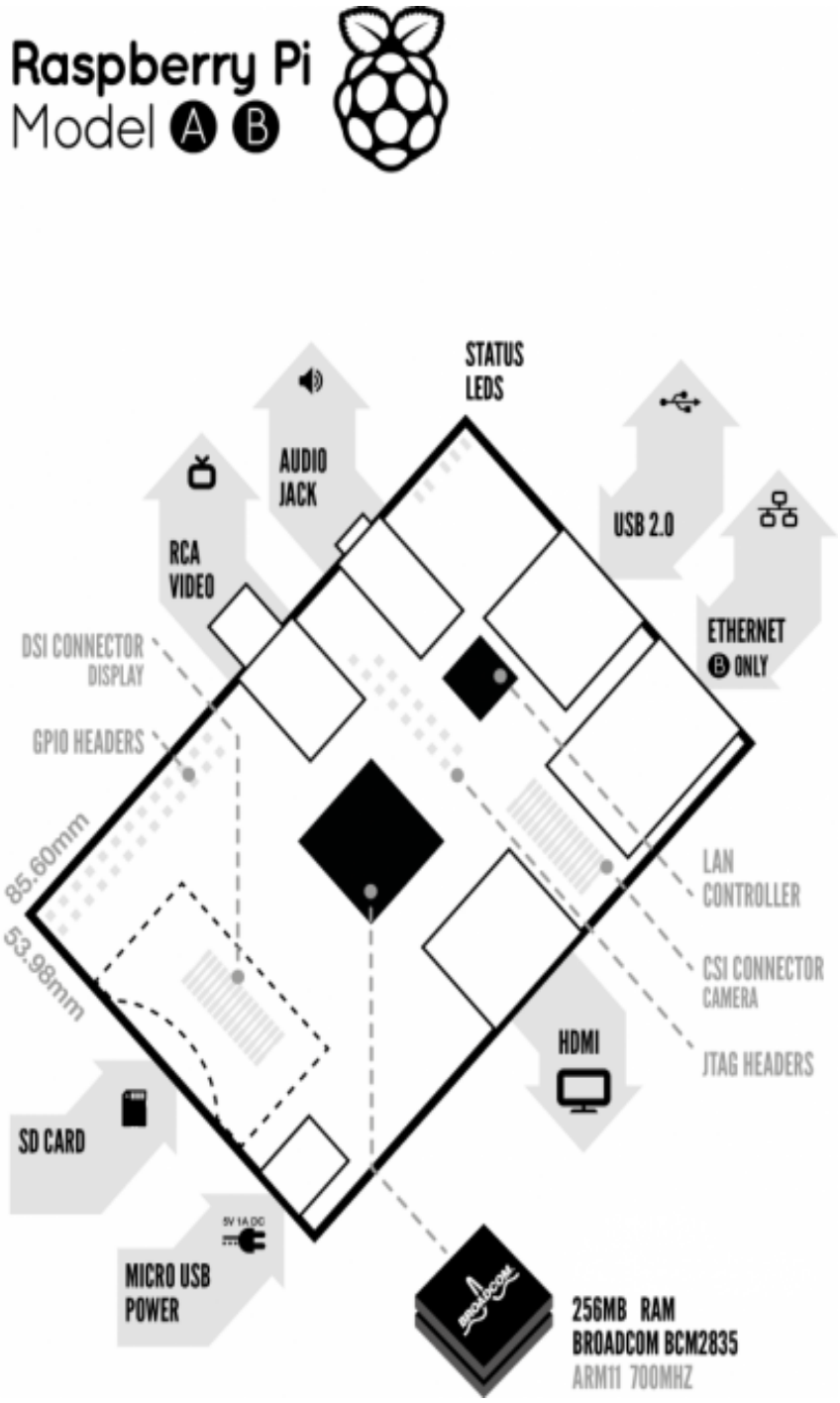


Figure 3: Broadcom processor cross-section

- SoC: Broadcom BCM2835 media processor (datasheet, BCM2835 datasheet errata, unofficial pinout, BCM2835 Register documentation - based on GPU source code) system-on-chip featuring:
  - CPU core: ARM1176JZF-S ARM11 core clocked at 700 MHz; ARM VFP. The ARM11 core implements the ARMv6 Architecture. For details on ARM instruction sets and naming conventions, see ARM architecture and List of ARM microprocessor cores.
  - GPU core: a Broadcom VideoCore IV GPU providing OpenGL ES 1.1, OpenGL ES 2.0, hardware-accelerated OpenVG 1.1, Open EGL, OpenMAX and 1080p30 H.264 high-profile decode. There are 24 GFLOPS of general purpose compute and a bunch of texture filtering and DMA infrastructure. Eben worked on the architecture team for this and the Raspberry Pi team are looking at how they can make some of the proprietary features available to application programmers
  - DSP core: There is a DSP, but there isn't currently a public API (Liz thinks the BC team are keen to make one available at some point) thread
  - 256 MiB of (Hynix MobileDDR2 or Samsung Mobile DRAM) SDRAM (or 512 MB Mobile DRAM on later boards). The RAM is physically stacked on top of the Broadcom media processor (package-on-package technology). Here is a photo of the SDRAM (left) and BCM2835 (right) ball grid arrays on JamesH's finger. You are looking at the bottom side. The BCM2835 top side has a land grid array which matches the SDRAM ball grid array. Here is a highly magnified side view of the SDRAM stacked on top of the BCM2835 stacked on top of the PCB PoP stack (you can see why its job can only be done by robots!).
- LAN9512 (Data Brief | Data Sheet) **(Model B)** providing:
  - 10/100 Mbit/s Ethernet (Auto-MDIX)[7]
  - 2x USB 2.0

- S1: Micro USB power jack (5 V - Power Only)
- S2: DSI interface. 15-pin surface mounted flat flex connector, providing two data lanes, one clock lane, 3.3 V and GND.
- S3: HDMI connector providing type A HDMI 1.3a out
- S4: Composite Video connector: RCA
- S5: MIPI CSI-2 interface. 15-pin surface mounted flat flex connector.
- S6: Audio connector: 3.5mm stereo jack (output only)
- S8: SD/MMC/SDIO memory card slot (underside)
- S7: Either 1x USB 2.0 **(Model A)** 2x USB 2.0 **(Model B)**

- P1: 26-pin (2x13) 2.54 mm header expansion, providing: see Low-level peripherals
  - 8 GPIOs at 3.3 V
  - 2-pin UART serial console, 3.3 V TTL (debug); or 2 GPIOs at 3.3 V
  - I²C interface (3.3 V); or 2 GPIOs at 3.3 V
  - SPI interface (3.3 V); or 5 GPIOs at 3.3 V
  - 3.3 V, 5 V and GND supply pins
  - ARM JTAG (if pins are reconfigured in software - on Revision1.0 boards one signal would also need to be taken from S5)
  - I²S interface (if pins are reconfigured in software, hardware hack may be required[5])
- P2: 8-pin 2.54 mm header expansion (header not fitted on Revision 2.0 boards), providing GPU JTAG (ARM11 pinout, pin 7 is nofit for locating)
- P3: 7-pin 2.54 mm header expansion (header not fitted), providing LAN9512 JTAG (pin 6 is nofit for locating)
- P4: 10/100 Mbit/s RJ45 Ethernet jack **(Model B)**
- P5: 8-pin (2x4) 2.54 mm header expansion (header not fitted), on the *bottom* of the board, providing: see Low-level peripherals **(Model B Revision 2.0 and Model A boards only)**
  - 4 GPIOs at 3.3 V
  - 3.3 V, 5 V and GND supply pins
  - Second I²C interface (3.3 V) (if pins are reconfigured in software)
  - I²S interface (if pins are reconfigured in software)
  - Handshake signals for the UART on the P1 header (if pins are reconfigured in software)
- P6: 2-pin 2.54 mm header expansion (header not fitted), providing an option to connect a hardware-reset button **(Revision 2.0 boards only)**
- TP1 and TP2: Test Points giving access to +5 V and GND respectively
- 5 Status LEDs[8][9][10][11][12]:
  - D5(Green) - SDCard Access (via GPIO16) - labelled as "OK" on Model B Rev1.0 boards and "ACT" on Model B Rev2.0 and Model A boards
  - D6(Red) - 3.3 V Power - labelled as "PWR" on all boards
  - D7(Green) - Full Duplex (LAN) **(Model B)** - labelled as "FDX" on all boards
  - D8(Green) - Link/Activity (LAN) **(Model B)** - labelled as "LNK" on all boards
  - D9(Yellow) - 10/100 Mbit/s (LAN) **(Model B)** - labelled (incorrectly) as "10M" on Model B Rev1.0 boards and "100" on Model B Rev2.0 and Model A boards

Figure 4: Components of Raspberry pi

2.4) HARDWARE EVOLUTION

Since its arrival to the public in early 2012, the hardware of the raspberry pi has undergone several gradual but nevertheless inevitable changes. The initial release consisted of two models - Model A and Model B. The immensely popular devices had a price range of $25 - $35. In mid-2014, the model A+ and B+ were announced which comprised of more GPIO's and consumed less electricity. 2015 saw the announcement of the Raspberry pi 2, with improved clock speed and more RAM. Subsequently, Raspberry pi 3 was also released.

The various parts and hardware of the Raspberry pi have kept up with the times and evolved. The progress is as follows.

2.4.1) PROCESSOR:

The first generation raspberry bi had a Broadcom BCM2835 SoC which was similar to the chips in first generation mobile computing devices.

- It had a 700 MHz ARM176JZF-S processor and a Video Core 4 GPU apart from RAM.
- It has a minor level 1(L1) cache of 16 KB along with a larger level 2(L2).
- The L2 held 128 KB and was mainly under use by the GPU.
- The RAM and the SoC were stacked one on the top of the other with only the fringes of the SoC visible.

There was a change in SoC in the second iteration of the pi. It had a Broadcom BCM2836 SoC with a 900 MHz 32-bit quad-core ARM Cortex-A7 processor. It also saw the increase of the L2 cache to 256 KB. The eventual upgrade to the Raspberry pi 2 V1.2 resulted in the earlier SoC being replaced by Broadcom BCM2837 SoC with a 1.2 GHz 64-bit quad-core ARM Cortex-A53 processor.

The Raspberry pi 3 carried over the SoC upgrade with another increase in L2 cache to 512 KB

2.4.2) PERFORMANCE:

With a clock rate of 700 MHz, the first Raspberry pi gave an actual performance of 0.041 GFLOPS (Giga FLoating point Operations Per Second). The CPU benchmark parallel to a 300 MHz Pentium II processor. The GPU had the capacity to go through 1Gpixel per second of graphic related processing. This is almost the same as 25 GFLOPS of general usage computing.

The Raspberry pi 2 had a multicore processor. It ran a quad-core Cortex-A7 CPU at 900 MHz. It had 1 GB of RAM but brought forth no changes to the GPU. In benchmarks, the second-generation Raspberry pi was seen to be almost 14 times faster than the best first-generation model, the model B+.

Another processor overhaul occurred with the third-generation Raspberry pi .It possessed a quad-core Cortex-A53 processor. The new processor was described as having almost 10 times the performance of its predecessor and held up to be 80% faster than the second.

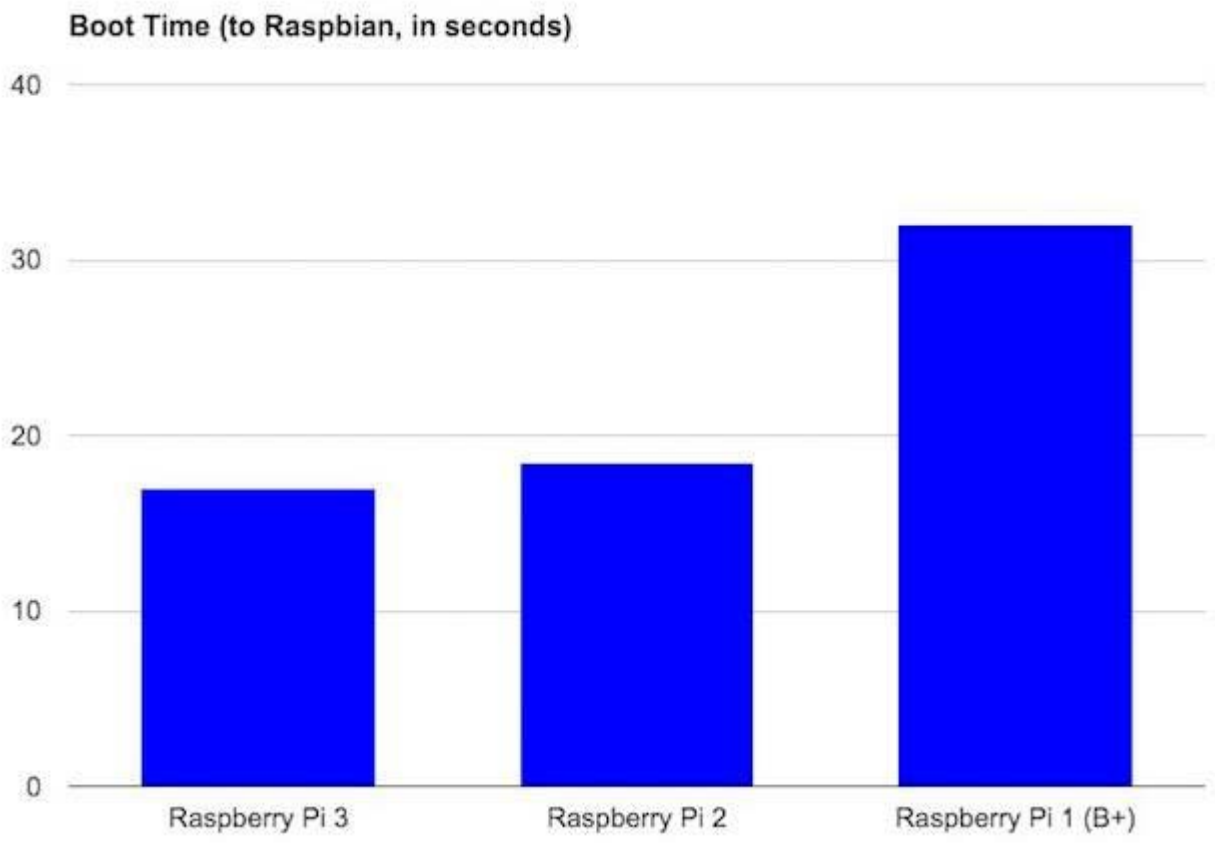


Figure 5: Boot time comparison

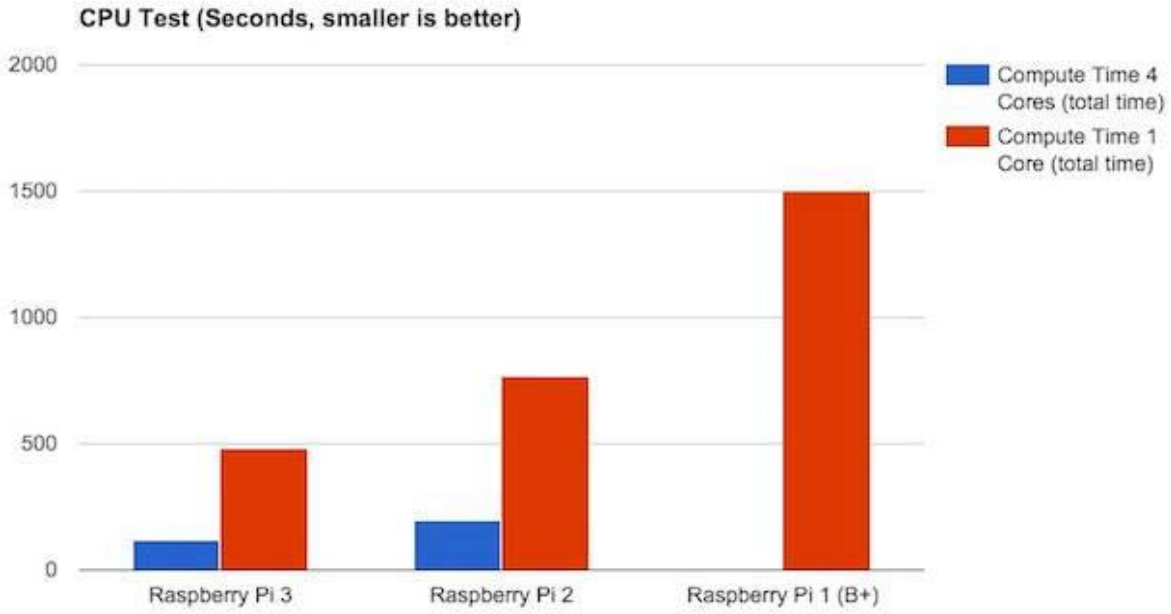


Figure 6: Compute time comparison

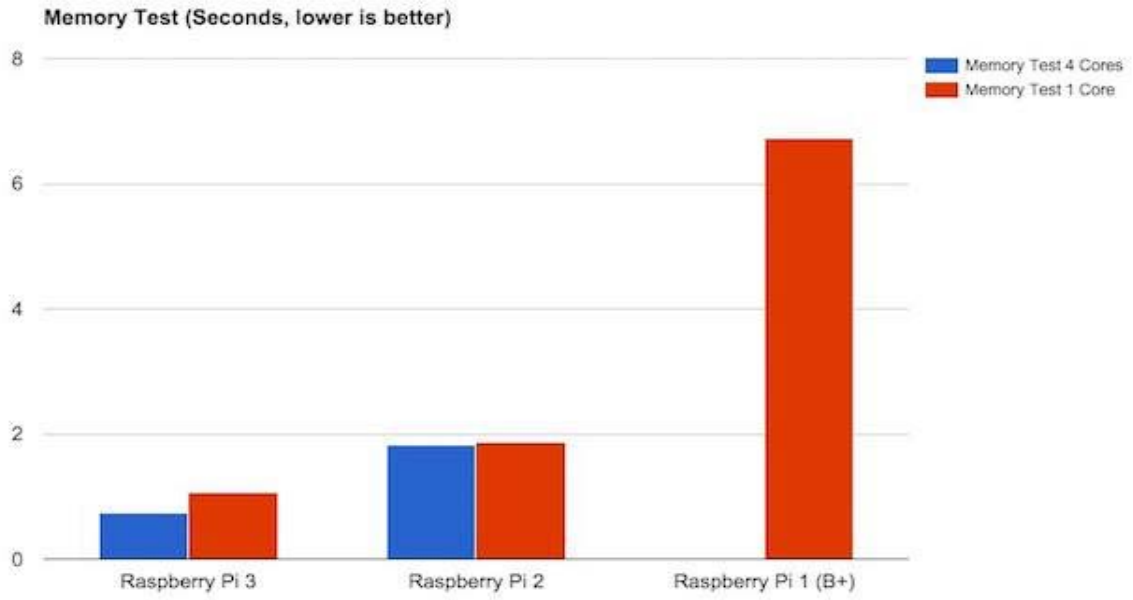


Figure 7: Memory test comparison

2.4.3) OVERCLOCKING:

It refers to the act of manually increasing a component's clock rate running it at a faster clock frequency than specified by the original manufacturer.

Soon after launch, the community figured out that most Raspberry pi devices performed admirably even under overclocking up to 800 MHz and a few even to 1000 MHz. When pushed to the limit, the Raspberry pi 2 can be overclocked up to 1500 MHz.

In the Raspbian distro, overclocking on boot is feasible with a built-in command while adhering to the conditions of the warranty. There is a built-in fail safe by which the device automatically stops the overclocking if the chip heats to high degrees of temperature (85 °C). However, it is possible to override the overclocking settings but a heat sink or similar cooling system is necessary to prevent damage to the chip. Later versions of the firmware saw several overclocked presets which when used on boot attempt to overclock the SoC without damaging the board.

Serial No.	Overclock Preset	ARM	Core clock speed	SDRAM	Overvolting
1	None	700 MHz	250 MHz	400 MHz	0
2	Modest	800 MHz	250 MHz	400 MHz	0
3	Medium	900 MHz	250 MHz*	450 MHz	2
4	High	950 MHz	250 MHz*	450 MHz	6
5	Turbo	1000 MHz	500 MHz	600 MHz*	6
6	Pi 2	1000 MHz	500 MHz	500 MHz	2
7	Pi 3	1100 MHz	550 MHz	500 MHz	6

*In *high* mode the core clock speed was lowered from 450 to 250 MHz, and in *medium* mode from 333 to 250 MHz. In the highest (*turbo*) preset the SDRAM clock was originally 500 MHz, but this was later changed to 600 MHz because 500 MHz sometimes causes SD card corruption.

Table 1: Overclocking Presets

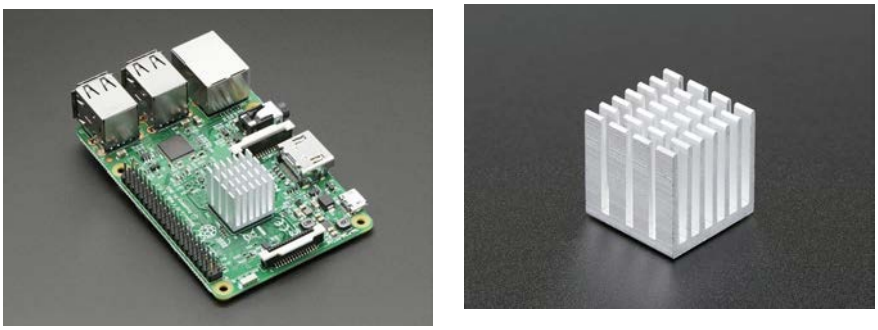


Figure 8: Heat sink

2.4.4) RAM:

The first versions of the pi had a similarly powerful CPU and GPU. It allocated 128 MB by default to each of them. For the 256 MB release it offered three different splits,

- 192 MB CPU, 64 MB GPU (1080p decoding or simple 3-D)
- 224 MB CPU, 32 MB GPU (1080p frame buffer)
- 128 MB CPU, 128 MB GPU (For heavy 3-D and video decoding)

Later versions saw various other splits but soon the Raspberry pi foundation released a newer firmware which dynamically assigned RAM to the GPU.

The Raspberry pi 2 and its successor the Raspberry pi 3 both have 1 GB RAM.

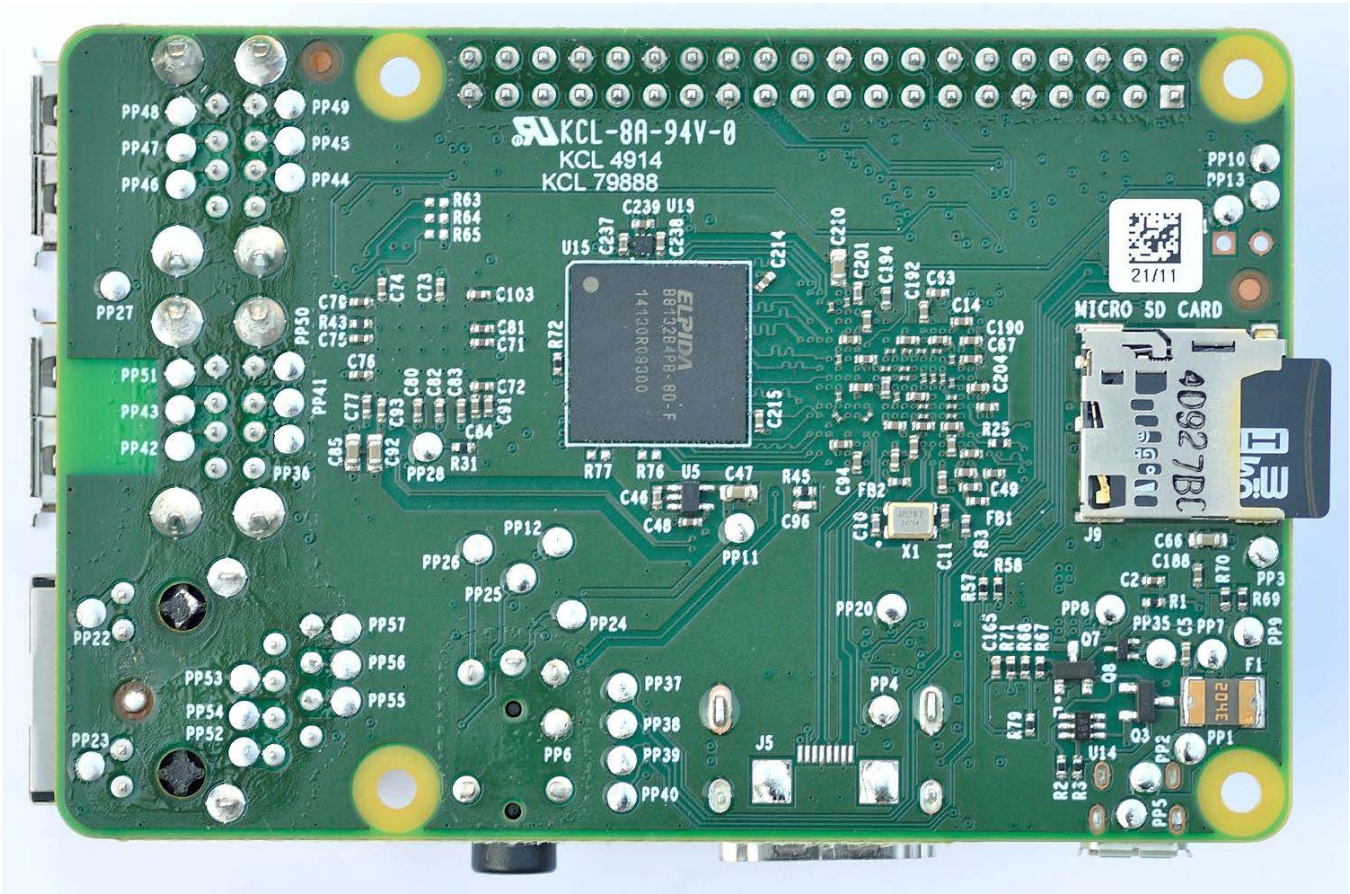


Figure 9: Underside of Raspberry Pi 2 showing the 1 GB RAM chip

2.4.5) PERIPHERAL SUPPORT:

All variants of the Raspberry pi include the standard USB port and all resulting peripherals (USB storage, USB to MIDI, keyboards) can be attached to it. It also supports several other peripherals through several pins and connectors.

2.4.6) ETHERNET:

The first versions of the pi namely, A and A+ had no Network support. The B and B+ had a built-in USB Ethernet Adapter using the SMSC LAN9514 chip. The Raspberry pi 3 is has a 2.4 GHz Wi-Fi 802.11n (150 Mbit/s) and Bluetooth 4.1(24 Mbit/s) based on Broadcom BCM43438 FullMAC chip.

Note: None of the Raspberry pi devices have a built-in clock. A shortcoming it shares with its Arduino cousins. For the sake of convenience, the device saves the time at shut down and reinstalls it on boot. Surely there exists many to this using additional hardware with the Raspberry pi interface.

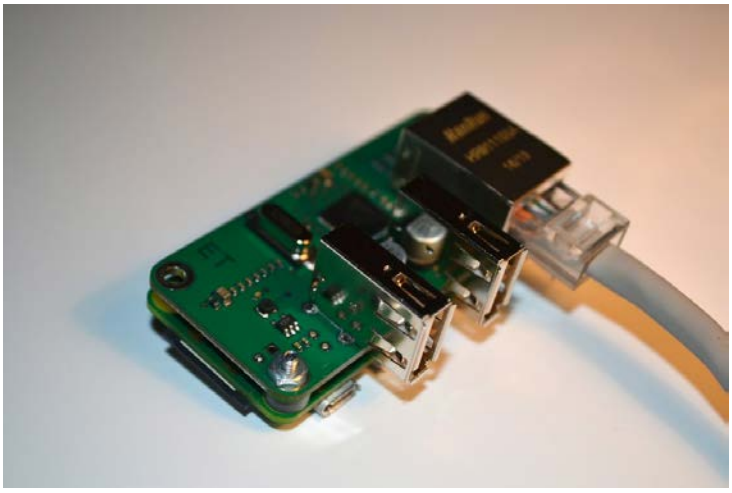


Figure 10: Raspberry Pi Ethernet

3) ARDUINO

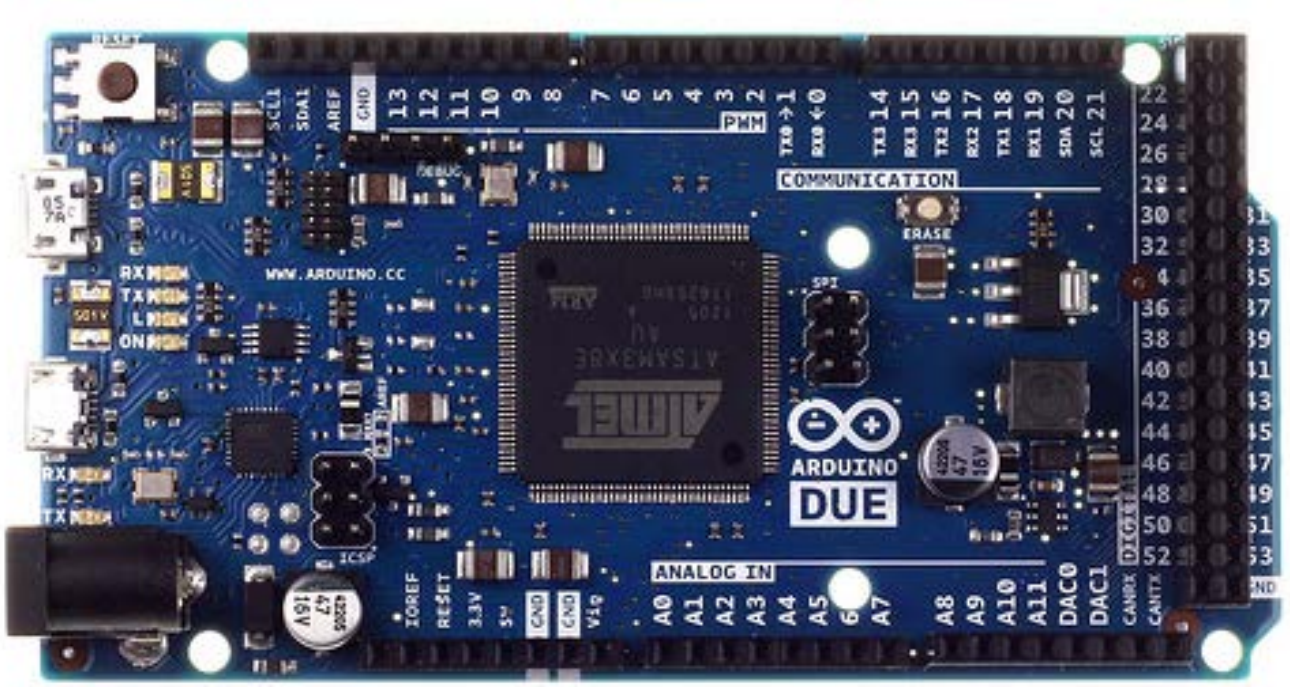


Figure 11: Arduino

3.1) ABOUT

Arduino is a kind of open source computing hardware. It basically consists of a physical unit, i.e. a piece of software, or Integrated Development Environment(IDE) and a programmable circuit board. The IDE is essentially utilized to write and afterwards upload the software or computer code to the physical board.

3.2) ARDUINO BASIC HARDWARE

There is a lot evolution in Arduino due to which there is a variation on what we said or called an Arduino. Day by Day variation in Arduino is increasing. Officially Arduino team consist of Arduino Uno and Arduino mega 2560. Arduino basically a simple small rectangular printed circuit board. Which we called as Input and Output Board.

The design for the I/O board was inspired by the Atmel AVR ATmega8. Arduino board contain a following components as serial port, expansion connectors, power supply circuitry, miscellaneous support components.

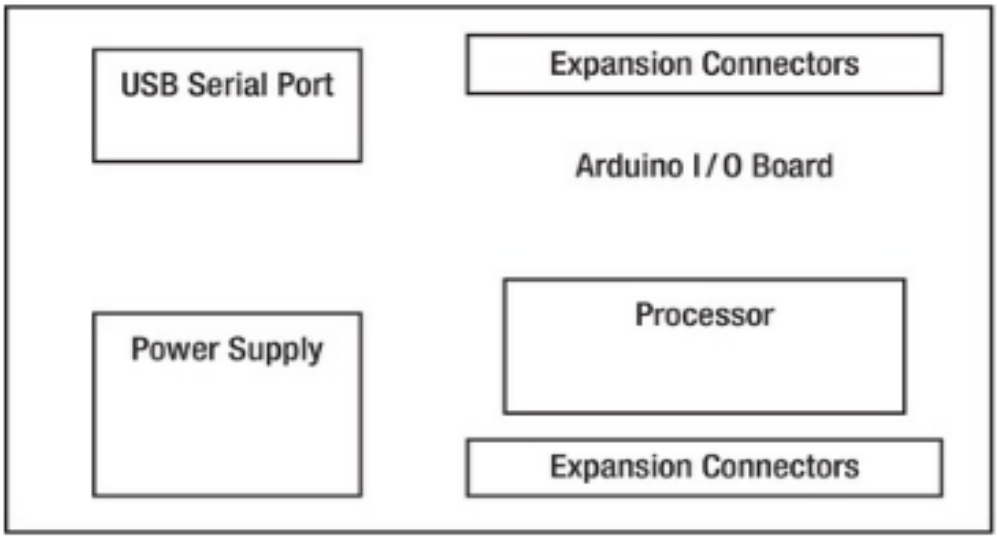


Figure 12: Input Output board block diagram

3.3) ARDUINO UNO

Arduino Uno was released in 2010. This Arduino brings a platform for doing electronics project. This device does not require a separate piece of hardware to exchange data it already contain a USB mode and Arduino integrated development environment(IDE) uses a simple version of C++. Which make it easier to program it.

It contains a Atmega processor which was upgrade twice. Originally it was the ATmega8 processor which had 8KB byte of programing memory which was upgraded to ATmega168 with 16KB byte of program memory, then further into the ATmega328 with 32KB byte of program memory, During the upgrade pin remaining compatible. The nine pin RS-232 serial connector, has a revamped interface with a virtual serial port replacing most of the circuitry.

The drawback of SMD mounted processor is that it's not easy to remove it from PCB.

Figure 13: Arduino UNO Without SMD

3.3.1) ARDUINO UNO PROCESSOR

The Atmel AVR ATmega328 is brain of Arduino Uno. It is visible as two symmetric rows of pins on either side while it on the SMD version, the processor is one half of the twin small black squares which have been soldered directly on to the PCB.

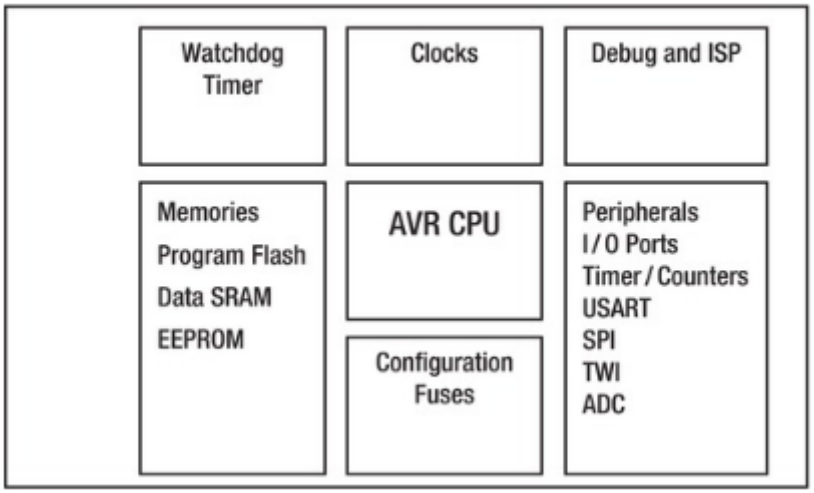


Figure 14: Block Diagram of ATmega328

This device is almost as a computer on a chip which contain CPU, Memory array, clock and peripherals in a single package.

The ATmega328 chip is formed from the original Arduino processor which has a ATmega8. It is more energy efficient than its predecessor. The device has an operation voltage range from power supply voltage from 1.8V to 5.5V while the processor has clock rate 4MHZ at low voltage and it raised to 20 MHZ when the voltage raised up to 5.5 voltage while the Arduino I/O board provides a voltage of up to 5v in order that the processor works at any clock rate up to 20MHZ.

The picoPower technology introduced a new feature in ATmega328 chip so that which reduced the power consumption and speed up the processor. After that chip are designed as P suffix as a ATmega328P.

Figure 15: Arduino UNO SMD

3.3.2) SERIAL PORT

The Function of serial port is to exchange data between device.

There is requirement of Serial port in order for relay of information between pc and Arduino. Arduino contain a pin RX and TX which to receive and transmit data or for use as Input and Output lines.

Serial communication protocols are basically many types. The serial port is also called a USART (Universal Asynchronous/Synchronous transmitter/receiver) peripheral. RS-232 mode is Asynchronous while ATmega328 chip is based on both modes Asynchronous/Synchronous.

3.3.3) EXPANSION CONNECTOR

To facilitate easier connection to the Arduino, further circuitry is added. There are four sets of expansion connector provided. The top edge of the PCB contains two connectors which are the digital pins, analog reference pin and a ground connection. TX and RX pins are also included in it.

Power and analog connectors are at the bottom edge. It also provides connection to RESET pin. Analog connectors also used as digitals I/O lines when we need which contain Six analog inputs.

DO-D13 are the 14 digital pins at the top edge of the PCB whereas A0-A5 are 6 analog pins where we can use analog pins as a digital pin.

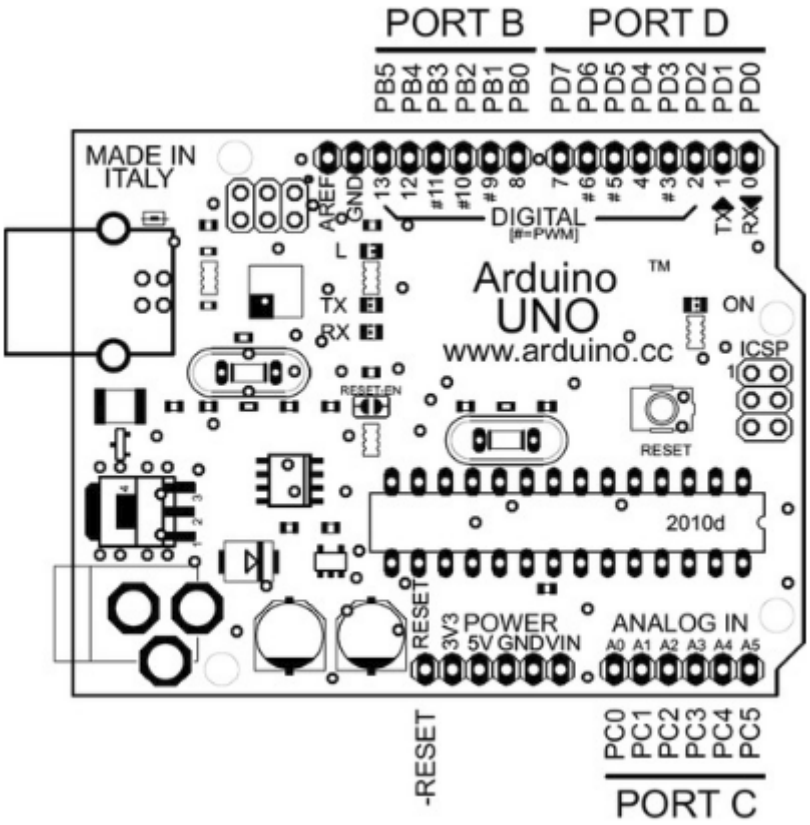


Figure 16: The I/O Board's expansion connectors facilitate additional circuitry to be easily connected.

Connector	Arduino	AVR
J1/IOL	D0/RX	PD0/RXD

J1/IOL	D1/TX	PD1/TXD
J1/IOL	D2	PD2/INT0
J1/IOL	D3/PWM	PD3/INT1/OC2B
J1/IOL	D4	PD4
J1/IOL	D5/PWM	PD5/OC0B
J1/IOL	D6/PWM	PD6/OC0A
J1/IOL	D7	PD7
J3/IOH	D8	PB0
J3/IOH	D9/PWM	PB1/OC1A
J3/IOH	D10/PWM	PB2/OC1B
J3/IOH	D11/PWM	PB3/OC2A
J3/IOH	D12	PB4
J3/IOH	D13/PWM	PB5

Table 2: Arduino I/O Board Expansion Connector Pin Names

3.4) ARDUINO SHIELDS

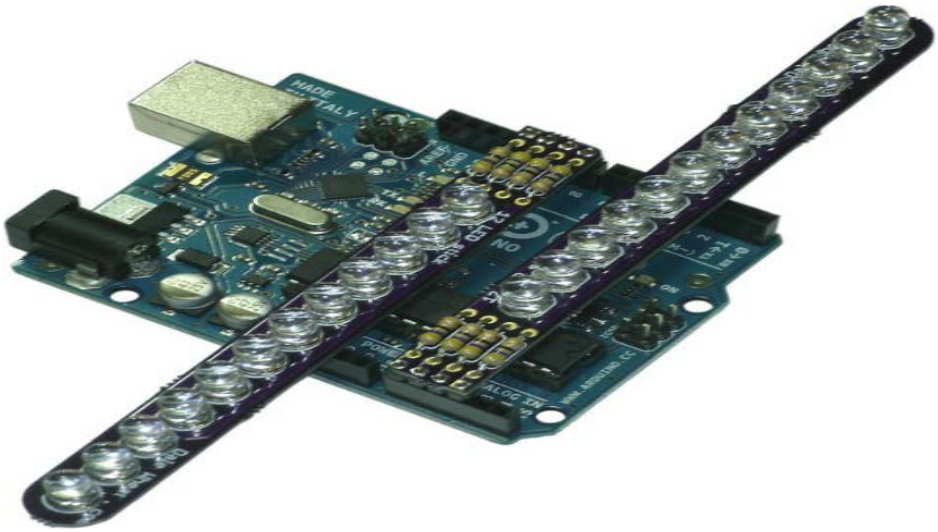
Shields refer to modular circuit board which are connected to the Arduino to provide extra functionality. Shields are also stackable and bunch of shields together form Big Mac of Arduino modules.

Shields have different structure according to its covering area on Arduino.

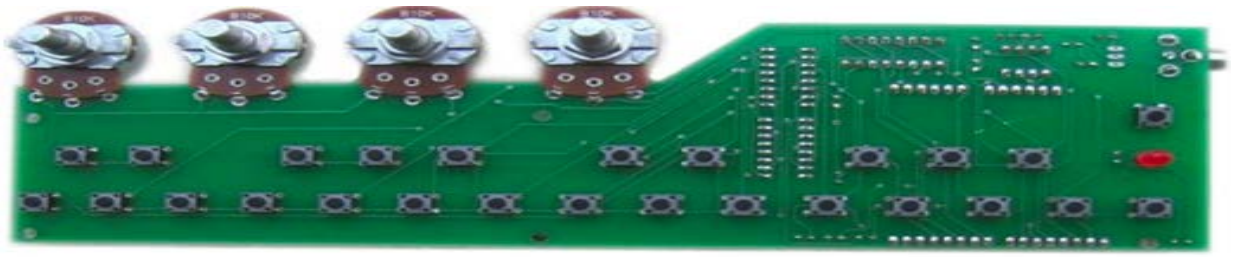
The maker shield is a cover full size of Arduino, stacking connectors allow to made a connection to all the signal from the expansion connector which also allow to add another shield on the top of it. Shields have sockets in their center to extending the functionality of Arduino by adding extra components.

Figure 17: Arduino shields

A Charlie plexing is clever wiring technique which is used for making shield space small which require some electrical connections. That is, it only uses some I/O lines which are installed in expansion connector. such as to drive a 12 LED array only need four output pins.

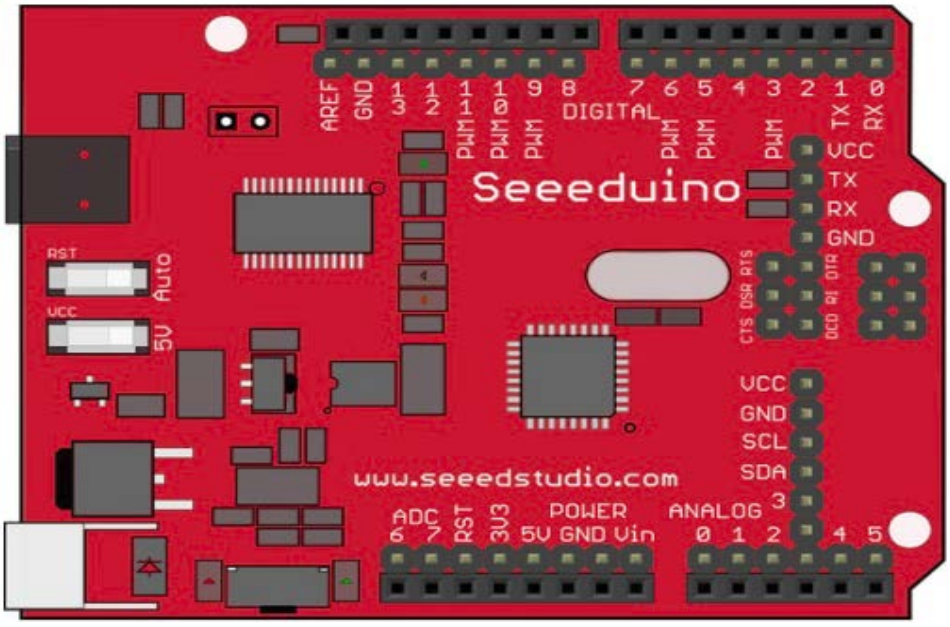


The world's largest Arduino Shield is the Critter and Guitari. The shield called as Arduino piano shield and which help in converting Arduino into a music synthesizer which contain two octave button keyboard which also provide extra user controls.



Another revolutionary shield made by Seeedstudio which is the first prototype shield. It is a powerful micro controller derived from the Arduino Mega which improve the Atmega processor to and increase the no. of pins to 70 digital I/O, analog pins to 16, and it contains 4 hardware serial ports and 14 PWM.

It also shrunk the size and made it more compatible.



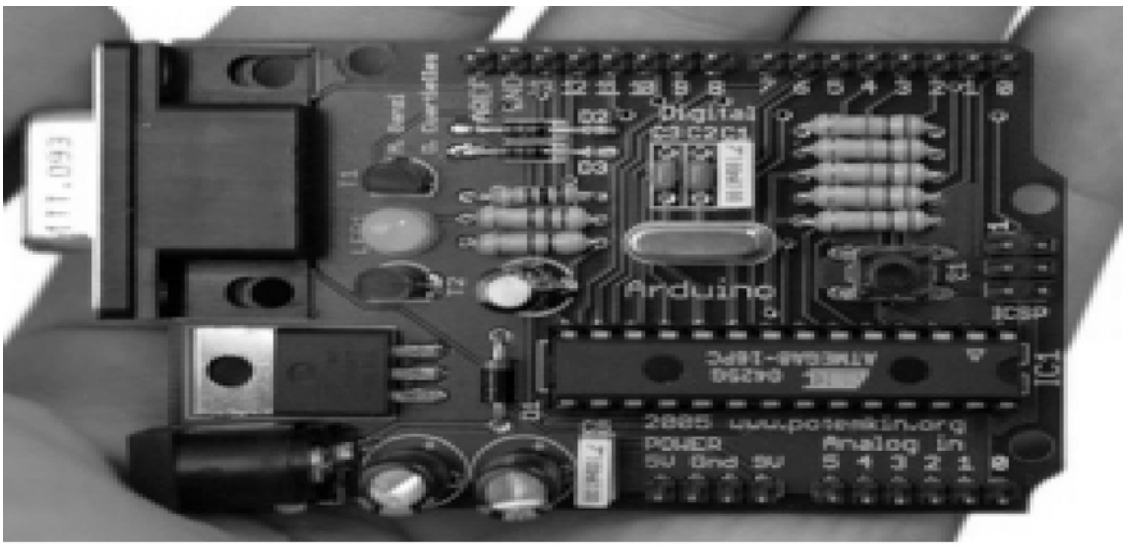
3.5) PREVIOUS HARDWARE EVOLUTION

The Arduino Uno we have today, is generated by a short evolution since it came into existence from 2005.These were designed to be easy to build from scratch. And its main goal was to provide such handy things to the students, thereby making things cheaper.

3.5.1) ARDUINO-SERIAL

Serial basically acts as a communication bridge between the Arduino board and a computer or other devices. The Leonardo version communicates via TTL (5V) serial on pins 0 (RX) and 1 (TX) using Serial1.

The Arduino Board - Serial Interface supported an ATmega8 processor in a 28-pin DIP with a maximum clock rate of 16MHz(then). Between the processor's -RESET line and ground, a reset switch was connected. When the switch was pressed, the processor rebooted into the bootloader firmware and waited a short time span for a new sketch to be sent from the controller PC. Failing this, the resident sketch was then executed. So, at that phase, the user was supposed to physically push the reset button and time the sketch-uploading correctly. Later versions successfully added auto-reset capability via the serial port, thereby removing the hassle of physically resetting the Arduino before each upload.

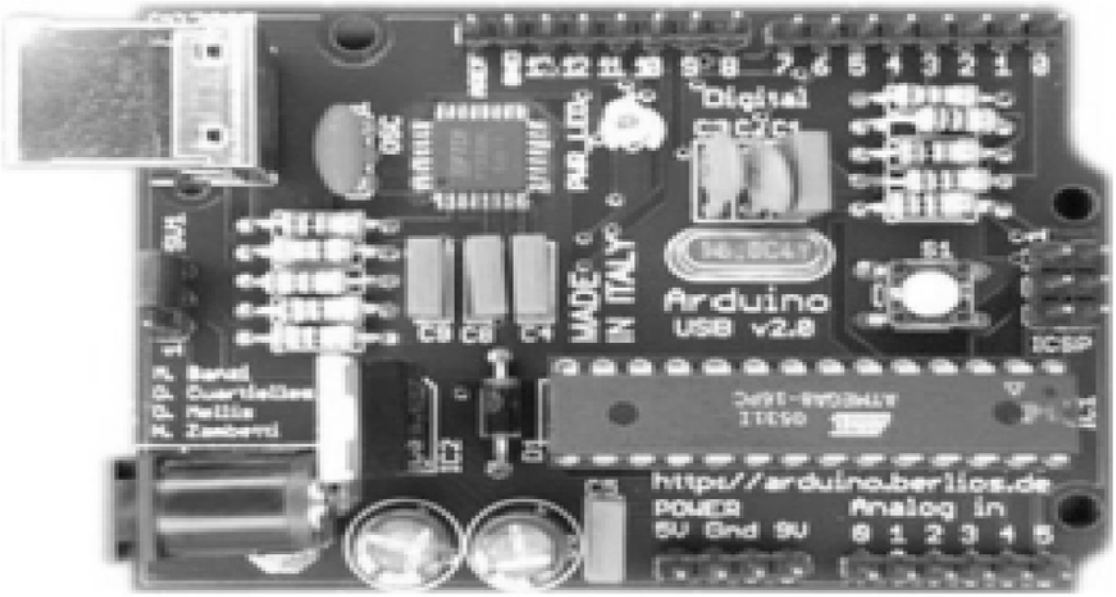


ARDUINO SERIAL

Figure 18: Arduino Serial

3.5.2) ARDUINO USB

The 9-pin RS-232 connector of Arduino I/O Board was replaced by a USB interface. With the help of USB Host library, an Arduino device can be made to act as a USB host. The devices that are attached to the USB hubs are not at all supports by the USB Host, which includes some keyboards having an internal hub.



ARDUINO USB

Figure 19: Arduino USB

3.5.3) ARDUINO EXTREME

For the expansion connectors, fewer sockets come to use by the Arduino Extreme. More surface-mounted components are now used, including LEDs.

3.5.4) ARDUINO DIECIMILA

It greatly helps by relieving the user from reaching over and pushing the reset button every time a new sketch is uploaded. It also consists of a resettable positive thermal coefficient (PTC) polyfuse in the power-supply section, which is helpful in temporary power cut off from the USB port in case too much current will be drawn. This has protected both the Arduino as well as the host PC. Technically, the application of host PC's USB hardware is to monitor current consumption and automatically shut down any excessively power-hungry devices.

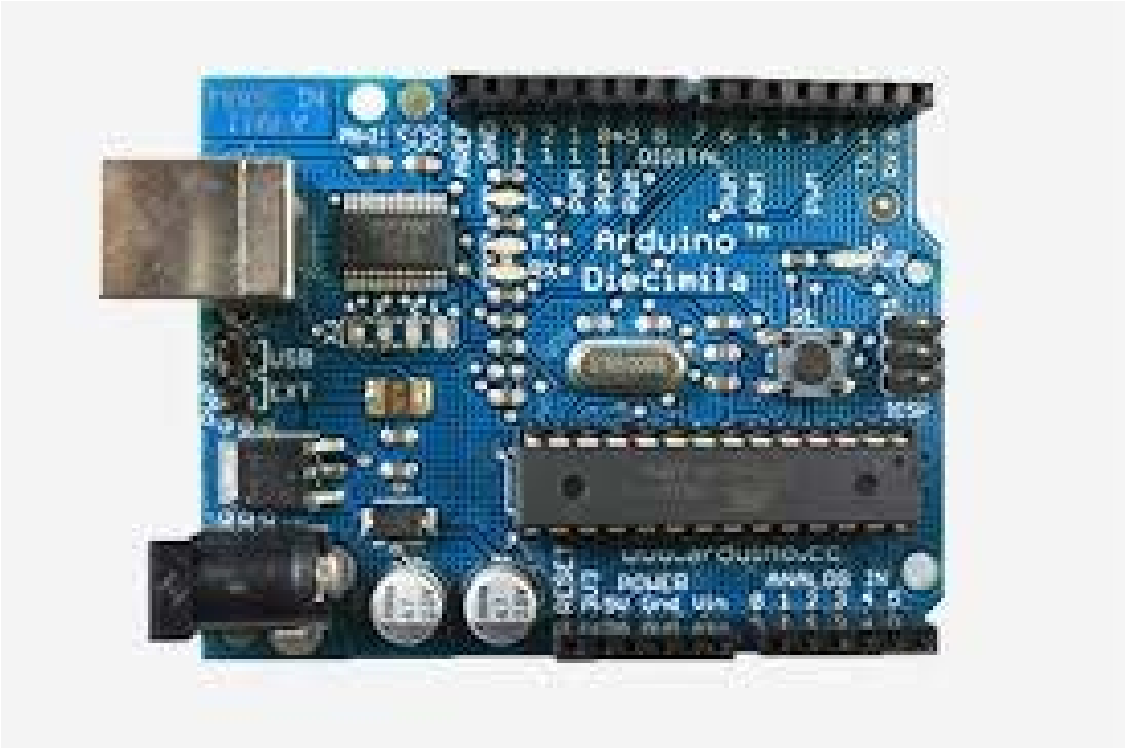


Figure 20: Arduino Diecimila

3.5.5) BREADBOARD ARDUINOS

A Breadboard Arduino is a kind of hand-crafted-Arduino, which makes things easier, negotiating the use of printed circuit board. Even no soldering work is required. A solderless breadboard is a platform in which we can build Arduino-compatible computer.

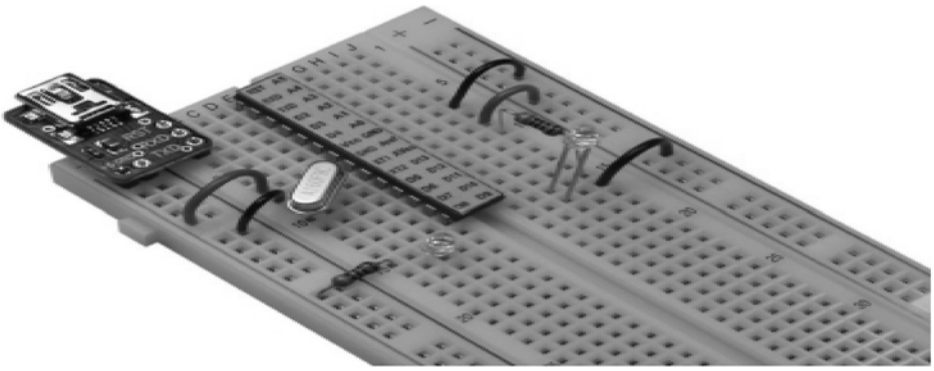


Figure 21: Arduino Breadboard

3.6) DATA ACCESS

3.6.1) PROGRAM MEMORY

The Program Memory holds the machine language instruction for the processor to execute. In device this memory is implemented as a 16-bit wide array of in-system reprogrammable flash memory. It is a self-programmable memory so that it can stored certain amount of data.

This memory also referred as a ROM (Read Only Memory). Generally, ROM was used to store or described as the non-volatile bit coding that keep it up when the power cut out.

The flash memory technology has been taken by AVR device and other semiconductor devices in order to take advantage of non-volatility and last complication in reprogrammable and less expensive.

3.6.2) DATA MEMORY

During a program execution micro-controller requires storage for a variable or to change data during program execution. This memory requirement is filled by SRAM static, random access memory. Basically, SRAM are in arrays form which can randomly accessible. This memory opposed to ram as it based on array as a static bit cell so that it doesn't required active signal to retain their contents.

3.6.3) REGISTERS

All AVR chips contain general-purpose registers. A register file is made up of 32 labelled registers from R0 to R31. Generally, registers are used for arithmetic and logical instruction of the CPU and read and write in register is done directly in register file. Advantage of having register is we doesn't need of data read or write in SRAM so that program execution become fast.

It is possible to assign 3 16-bit index pointers to data with the help of 6 special registers. The AVR Core has many useful and complex addressing modes for accessing both program memory and data memory spaces. These addressing modes are encoded into the individual machine-language instructions that are executed by the AVR Core.

3.7) MACHINE LANGUAGE INSTRUCTIONS

Generally, AVR instruction are either 16-bit or 32-bit. Most of the instruction in AVR are executed in single cycle.

Instructions are made up of four categories:

1. ARITHMETIC AND LOGIC

The arithmetic operations are add, sub, mul, etc. are performed by ALU and the operands are taken either from register file or are of constant value. After the operation, the result is written back into the register. Further logical operations are also performed by ALU.

2. A WORD ABOUT MISSING INSTRUCTIONS

In a limited instruction space to remove or prevent redundancy, complementary instruction pairs have been omitted. Example in absence of Add immediate instruction pairs have obtained by creative use of the subtract Immediate instruction.

3. BRANCH

The conditional and unconditional branch instructions allow the program to take various turns in its execution. The unconditional branch simply jumps to another program location and begins to execute at that location. Conditional branches test a particular condition and then perform the jump only if the condition proves to be true. A very concise form of the unconditional branch is the RJMP (Relative Jump) instruction

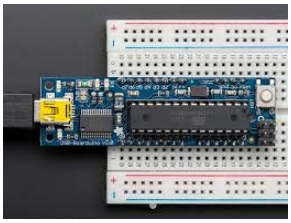
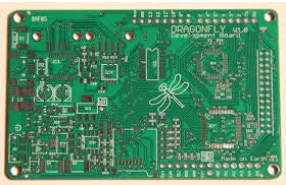
4. DATA TRANSFER

A stack refers to a commonly used LIFO (last-in, first-out) data structure, this is kept in mind while creating the architecture of the chip. A special register, the stack pointer, keeps track of what has been pushed onto and popped off of the stack. The stack itself is usually located in the SRAM section.

Moving data around inside the chip is where the data-transfer instructions come into play. Data can be moved, loaded, stored, pushed, popped, and sent in or out. Most data transfers are 8 bits, but some allow 16-bit transfers as well. The MOV (Move) instruction moves an 8-bit value from one register to another. Because the value in the original register remains unchanged, the effect is actually that of a data copy, with both source and destination registers being now equal, and the loss of the destination registers' original contents. The MOVW (Move Word) instruction performs a similar task, except that two registers are moved at once. The instruction is limited to even-numbered registers.

3.8) ARDUINO PARTS

3.8.1) Software Compatible Arduino

	Name	Description	Origin
	Boarduino DC	Design to be fit on solderless breadboard	USA
	Boarduino USB	Design to be fit on solderless breadboard	USA
	Dragonfly	Use molex type connections	USA

	Raspduino	Design to be fit on raspberry pi board	Netherland

Table 3: Software compatible Arduino

Boarduino DC

Figure 22: Boarduino DC

Since it doesn't include a USB chip in its design, so a FTDI USB 232-TTL cable FTDI friend. Also one cable used for multiple boadruinos.

It also contains a RESET, hole parts, easily to solder. It is quite advantageous due to its miniature size (Only 75mm X 20 mm).

Boadruino USB

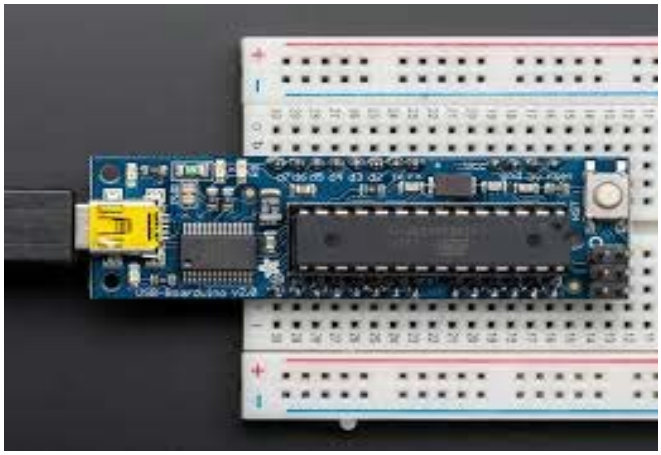


Figure 23: Boarduino USB

This version doesn’t have a dc jack, though it has USB built-in and so we can power our project. It is also having similar size as of boarduino dc and the chips are pre -programmed. It is also have reset button, USB miniB jack.

One more advantage of Boarduino USB is that 500mA fuse protects our computers USB port from over current.

Dragonfly

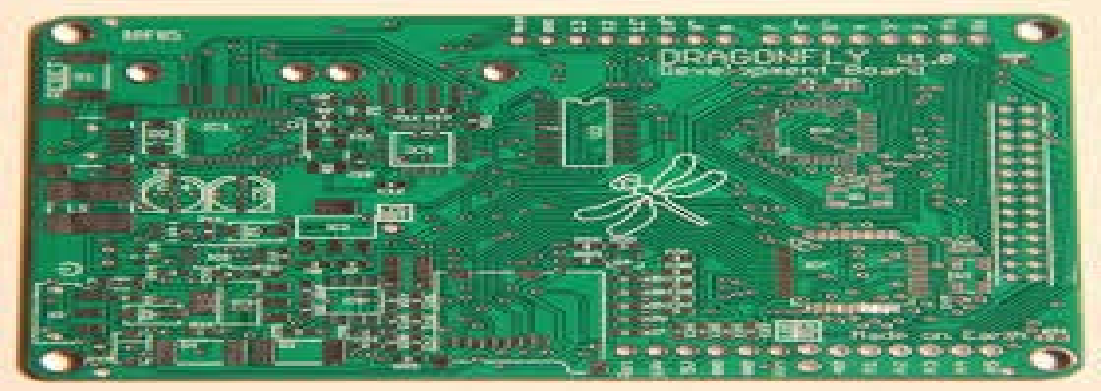


Figure 24: Dragonfly

It has four of them I2C ports. I2C has bus of speed of 400kHz. Dragonfly has I2CO on back pads, I2CO with 20 and 21 pins, I2C! on A4 and A5 pins and I2C2 has 3 and 4 pins.

Raspduino

Figure 25: Raspduino

Raspberry Pi and Raspduino can be combinedly used to make a project and once the development process it can be used single handedly. Moreover, we can add some other expansion boards (if required). Raspduino's ATmega328 can be connected directly with UART (Raspberry Pi).

3.8.2) Hardware Compatible Devices

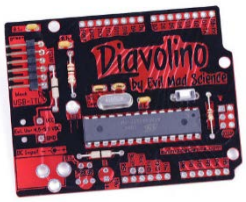
	Name	Type	Origin
	SainSmart UNO	UNO Clone	China
	SainSmart Mega2560	Mega2560 Clone	China
	Brasuino	Similar to UNO, with changes	Brazil
	Diavolino	An Arduino Layout	USA

Table 4: Hardware Compatible Devices

SainSmart UNO

Figure 26: Sainsmart UNO

It is completely use with UN0 R3. It has ATMega16U2 which use for faster rates with memory. It has SDA and SCL with AREF, also has reset pin, one of these are IOREF which allow it to shield the adaption of voltage and other is not connected. It also works with all today shields and mainly compatible with our new modern Arduinos.

SainSmart MEGA 2560

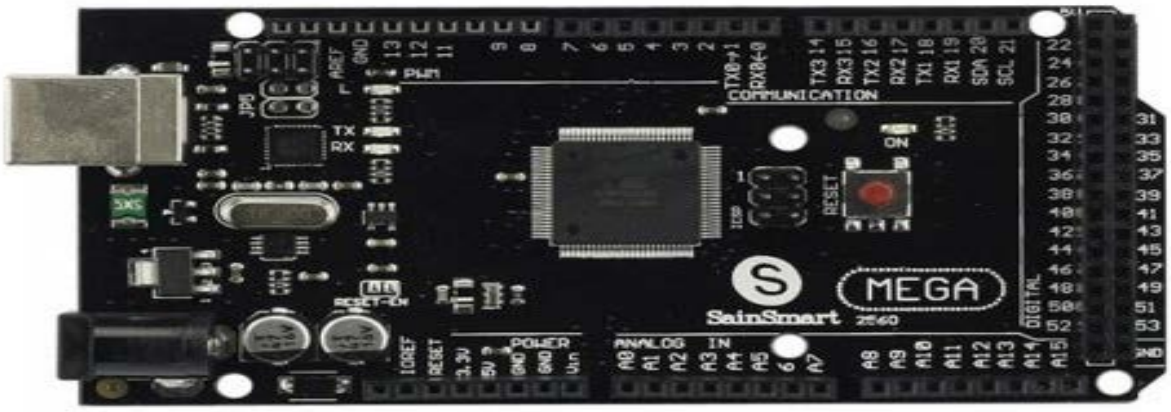


Figure 27: Sainsmart MEGA 2560

This is a microcontroller based on a ATmega2560.This one has 16 inputs, an ICSP, 54 digital I/O pins, 4 UART, 16MHz oscillator, jack, and a RESET. This one also supports microcontroller in very significant usually. Also, we can simply switch it on with AC/DC supply and it has shield support with ARDUINO Duemilanove.

Brasuino

Figure 28: Brasuino

It is made in Brazil and inspired from Arduino UNO. It has connector which has mini-USB type and USB-UART converter with mount on Atmega8U2-AU. Other features we can copy it from UNO from that it was inspired. With some features added such as reordered LED and resistance which is not interfering with pin number 13.

Divalino

Figure 29: Divalino

It is a very amusing ARDUINO which is red which is a change for ARDUINO versions. It has quite good designs which is added with TTL-cable so that it become consistent. It has microcontroller same as UNO, ATmega328P-PU. As its disadvantage, it doesn't have pre built regulator.

3.8.3) Small Form factors Arduino Boards

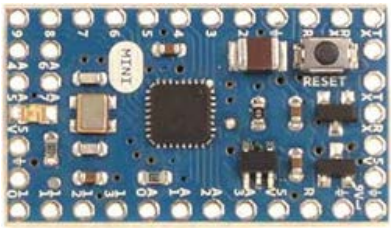
	Name	Type
	Nano	2008
	Mini	2008
	Fio	2010
	Micro	2012

Table 5: Small Form factors Arduino Boards

Nano

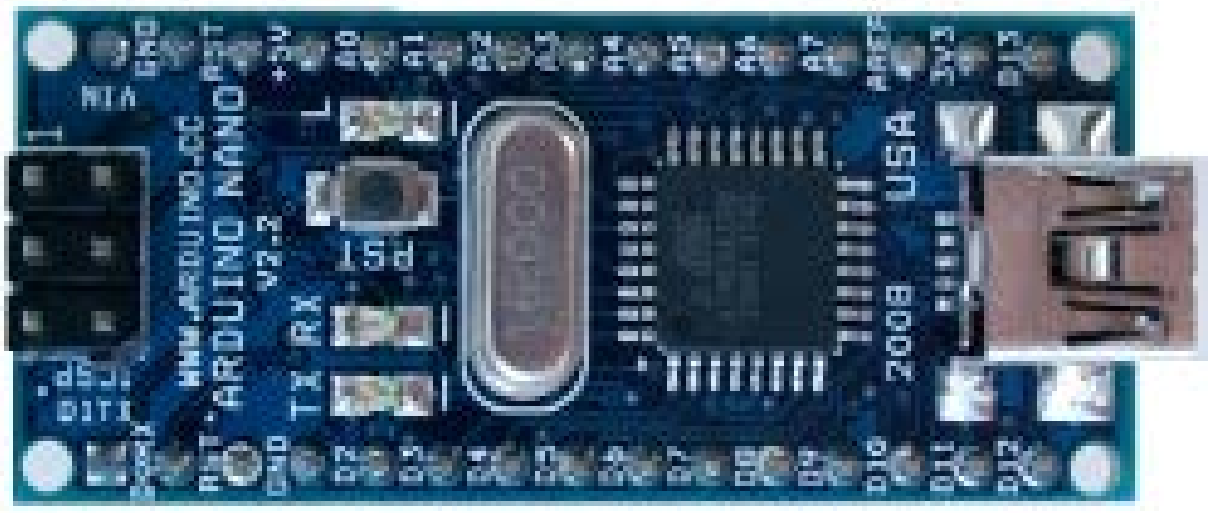


Figure 30: Nano

It is a bread board friendly board with ATMega328.Its functional is less from Duemilanove but in different aspect. It has neither dc jack nor having standard USB.

Mini

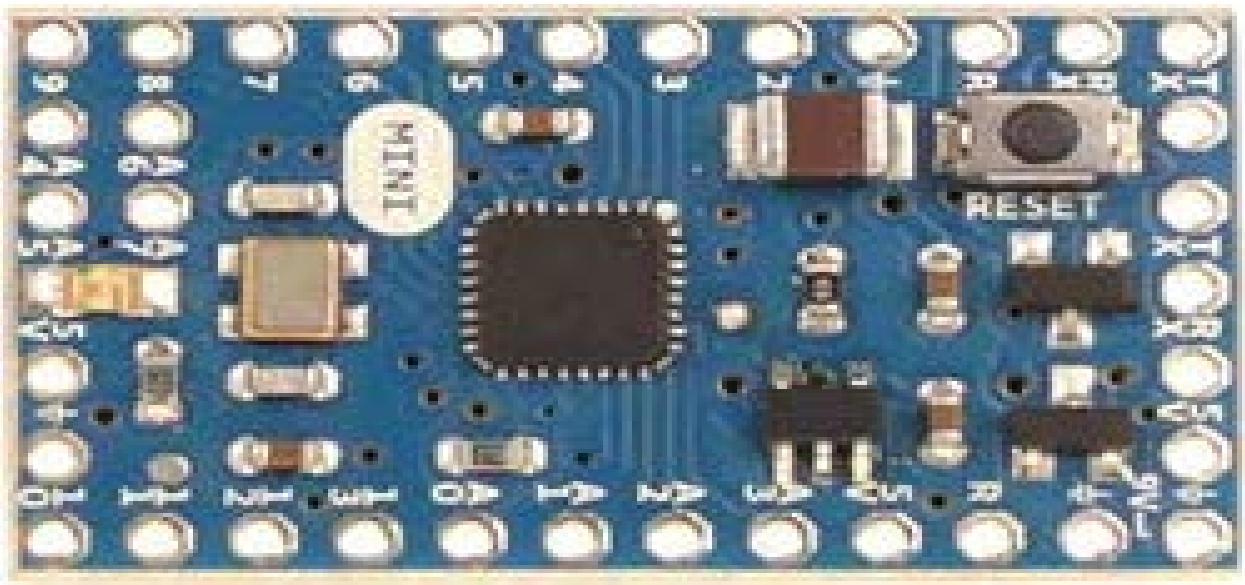


Figure 31: Mini

It has a mini microcontroller basically inspired from ATmega168 originally but changed to ATmega3218. It has 14 I/O pins, 8 signals output, 16 Hz oscillator. It can also work with many serial adapters.

Fio

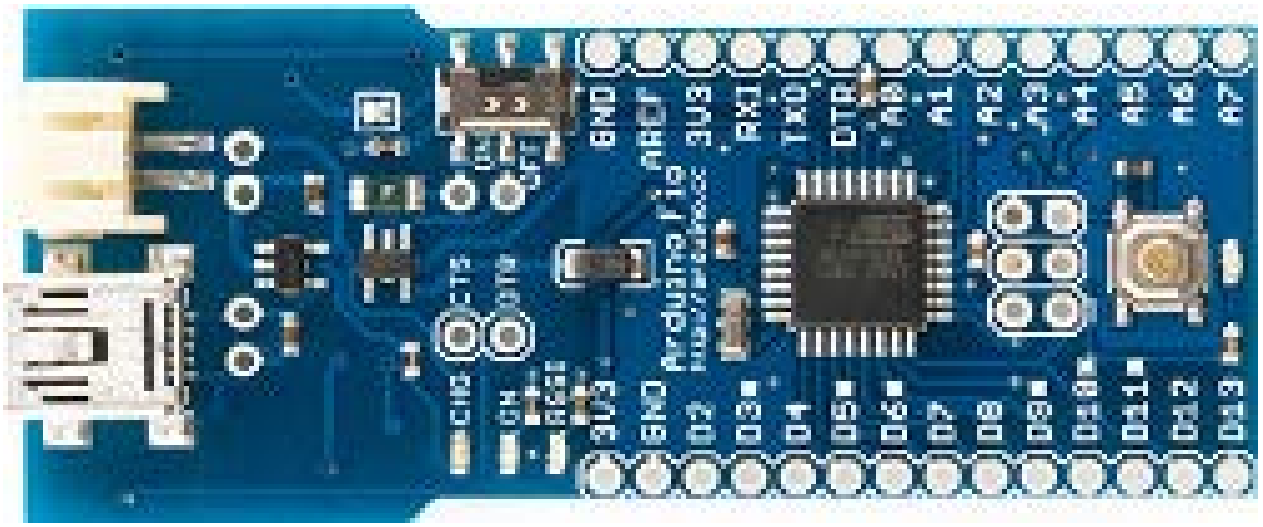


Figure 32: Fio

It has microcontroller inspired by ATmega328P. It consists of 14 I/0 pins, 8 signal, a resonate, a reset and some holes for mounting.

Micro

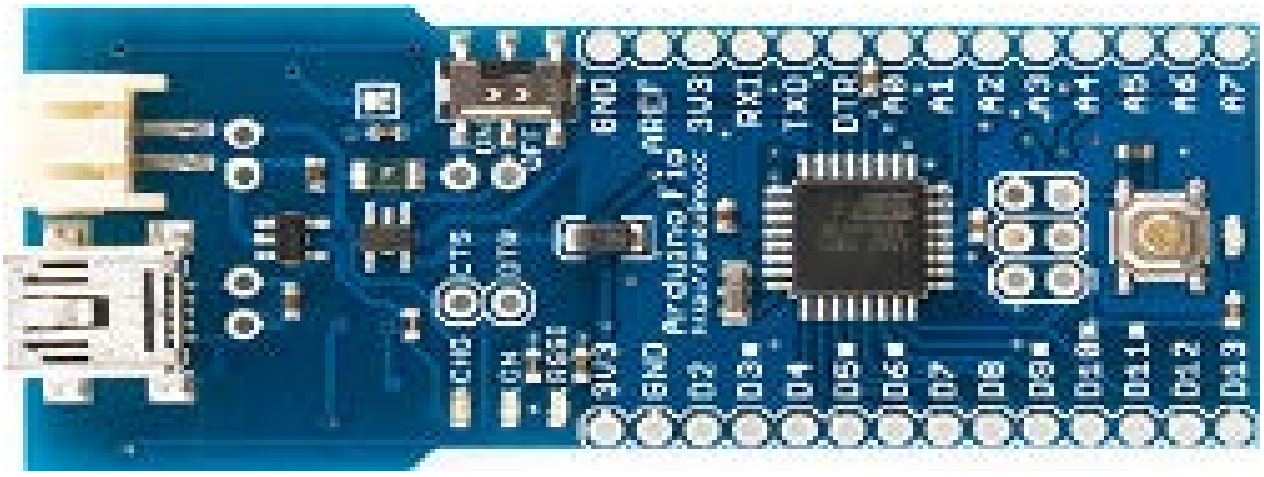


Figure 33: Micro

It has a microcontroller inspired from ATmega32U4. It is made with ADAFRUIT. It mainly consists of 20 I/0 pins, 16 MHz oscillator, USB, ICSP and a RESET.

3.8.4) Form-Factor Special Arduino Boards

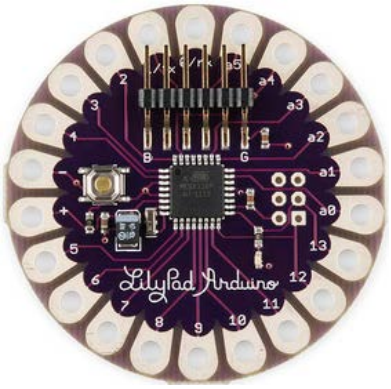
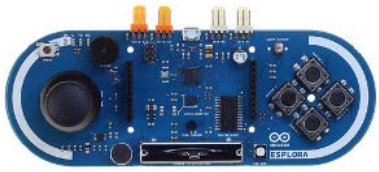
	Name	Type
	Lilypad	2007
	Esplora	2012

Table 6: Form-Factor Special Arduino Boards

LilyPad

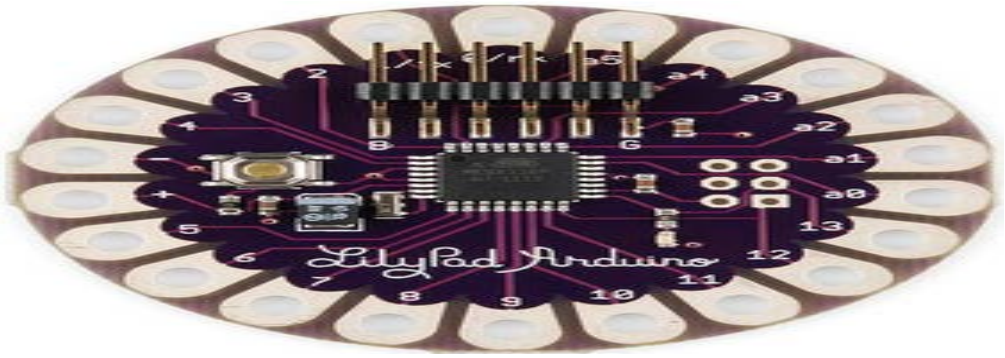


Figure 34: LilyPad

This is a microcontroller inspired from ATmega168V mix with ATmega328V. It is use for Textiles and wearable industry.

Esplora

It is mainly derivation from ARDUINO Leonardo so as its microcontroller also inspired from it. It mainly caters to the need of light and sound admirers. It has some two times capacity of input and output simultaneously.

3.9) Arduino Products Evolution

Board Name	**Year**	**Microcontroller**
Diecimila	2007	ATmega168V
LilyPad	2007	ATmega168V/ATmega328V
Nano	2008	ATmega328/ATmega168
Mini	2008	ATmega168
Mini Pro	2008	ATmega328
Duemilanove	2008	ATmega168/ATmega328
Mega	2009	ATmega1280
Fio	2010	ATmega328P
Uno	2010	ATmega328
Mega ADK	2011	ATmega2560
Leonardo	2012	ATmega324U4
Esplora	2012	ATmega32U4
Micro	2012	ATmega32U4
Yun	2013	ATmega32U4+Linino

4) INTEL GALILEO

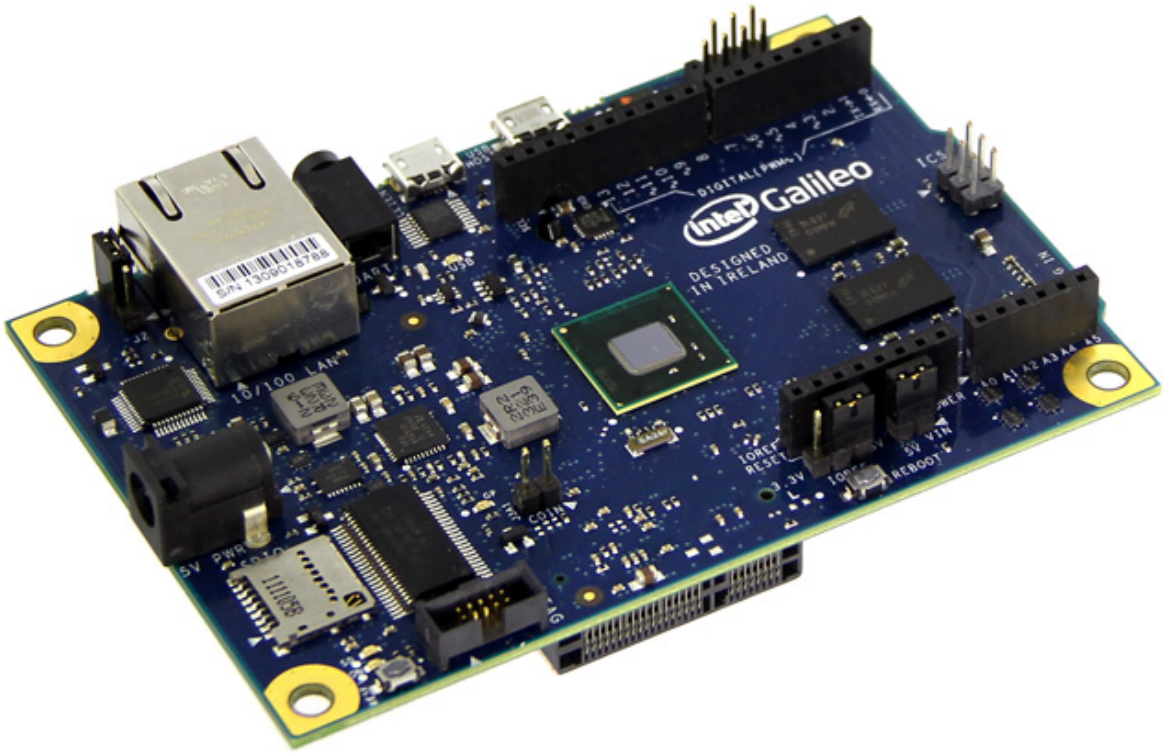


Figure 35: The Intel Galileo

4.1) ABOUT

The Intel Galileo began a line of Intel x86 architecture micro-controller boards which were also Arduino certified. It was manufactured with the intent of being put to use in the education sector. There currently exist two models of the Galileo, the Gen 1 and Gen 2.

Most of the architecture of the board is inspired by the Arduino models. It also has compatibility with 3.3V or 5V sheets. Naturally all of the Arduino IDE (Integrated Development Environment) is compatible with the board. This was one of the reasons why it was so accessible and successful in the market.

The Intel Galileo works on a Linux open source OS which is equipped with all of Arduino's libraries. This allows the board to rerun pre-existing software, these are termed sketches. Every time the board boots, a sketch runs.

4.2) IMPACT

The Intel Galileo despite containing no revolutionary improvements had a significant impact on the market and open source hardware in general. It began the collaboration of two giants in the industry, Intel and Arduino. The decision to ensure that all Arduino based code will run on the Galileo struck gold for the company.

Figure 36: Intel ® and Arduino ®

4.3) DESIGN SPECIFICATIONS

The Intel Galileo brings together pre-manufactured Arduino expansion hardware (shields) along with its IDE and libraries and its very own native technology. This makes it exceedingly accessible. For instance, the device supports programming through Windows, Mac-OS X and Linux. The device is also entirely compatible with the pre-existing Arduino line of shields.

The launch of the device coincided with the launch of the Intel Quark series which it featured. It has the Intel Quark SoC X1000. It was the company's first foray into IoT and wearable technology. The schematics were drawn up in Ireland. Quark SoC X1000 is a 32-bit, single core, single-thread, Pentium (P54C/i586) instruction set architecture (ISA)-compatible CPU. It has a clock speed of 400 MHz. The Intel Quark is considered by many to be the company's reply to ARM, the smart phone processor giant.

The Galileo has 256 MB of DDR3 RAM and 8 MB flash memory. This coupled with the 400 MHz clock rate make it over and above its Arduino siblings.

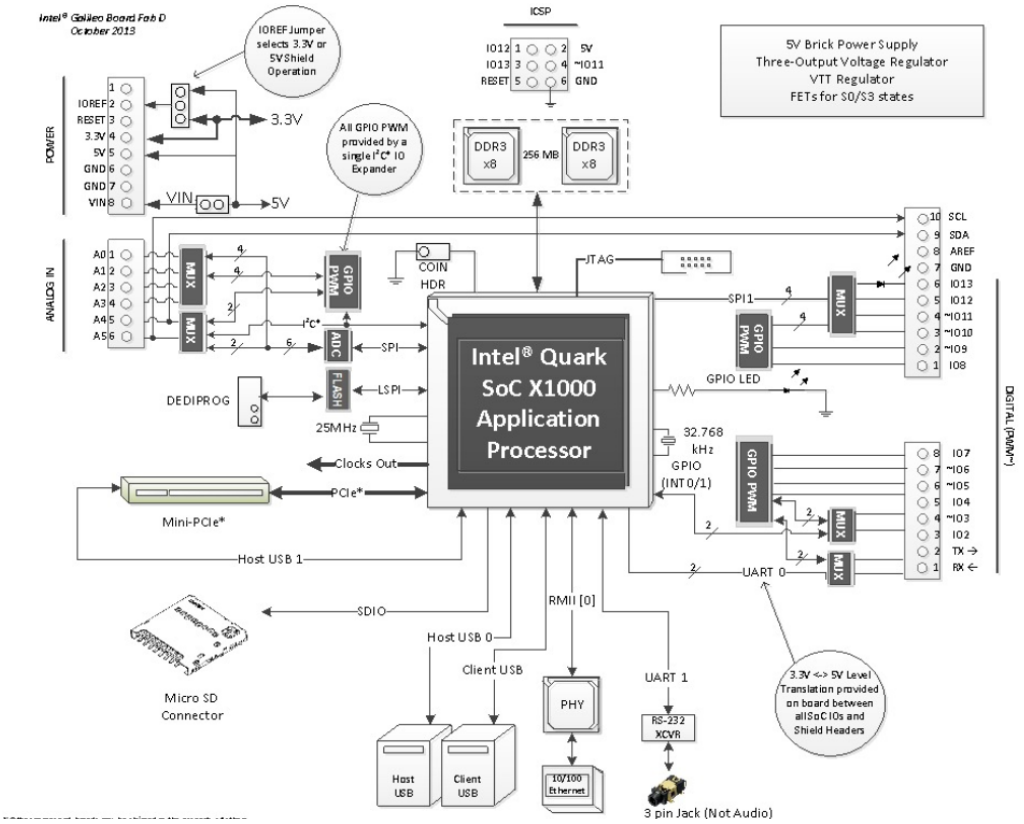


Figure 37: Intel Quark SoC X1000 Application Processor

- 400MHz 32-bit Intel® Pentium instruction set architecture (ISA)-compatible processor o 16 KBytes on-die L1 cache
  - 512 KBytes of on-die embedded SRAM
  - Simple to program: Single thread, single core, constant speed
  - ACPI compatible CPU sleep states supported
  - An integrated Real Time Clock (RTC), with an optional 3V "coin cell" battery for operation between turn on cycles.
- 10/100 Ethernet connector
- Full PCI Express® mini-card slot, with PCIe 2.0 compliant features
  - Works with half mini-PCIe cards with optional converter plate
  - Provides USB 2.0 Host Port at mini-PCIe connector
- USB 2.0 Host connector
  - Support up to 128 USB end point devices
- USB Device connector, used for programming
  - Beyond just a programming port - a fully compliant USB 2.0 Device controller
- 10-pin Standard JTAG header for debugging
- Reboot button to reboot the processor
- Reset button to reset the sketch and any attached shields
- Storage options:
  - Default - 8 MByte Legacy SPI Flash main purpose is to store the firmware (or bootloader) and the latest sketch. Between 256KByte and 512KByte is dedicated for sketch storage. The download will happen automatically from the development PC, so no action is required unless there is an upgrade that is being added to the firmware.
  - Default 512 KByte embedded SRAM, enabled by the firmware by default. No action required to use this feature.
  - Default 256 MByte DRAM, enabled by the firmware by default.
  - Optional micro SD card offers up to 32GByte of storage
  - USB storage works with any USB 2.0 compatible drive

Figure 38: Details of Intel Architecture Supported Features

Both versions of the device are compatible with the Arduino shield eco-system. Most Arduinos support shields of only a single voltage rating. However, the Galileo supports both 3.3V and 5V shields. The device also comes equipped with industry standard I/O compatibility.

With PCI express, the Galileo will support wi-fi, GSM cards and Bluetooth. This also makes the device support solid state drives.

Using the 10/100 Megabit Ethernet support will allow the device to connect to a local area network along with access to the Linux shell.

The device has Micro SD support. So, the effective storage can be incremented to 32 GB.

Despite the board being packaged with Linux, custom Windows versions can be run on both versions of the Galileo. Microsoft cut the cord to this feature in late 2015 citing outdated hardware especially clock speed.

Another distinguishing characteristic of the Galileo is that it has an inbuilt real-time clock. Many Arduino boards and the Raspberry pi do not have this feature. The real-time clock is powered by a 3V coin cell. So, it keeps accurate time without constant power supply or network connection.

There exist “jumpers” on the Galileo to change the configuration and orientation of the device. They are as follows.

- IOREF Jumper

  As we know, the Galileo supports both voltage rating shields. This is because the peripheral voltage can be set using the IOREF jumper.

- I2C Address Jumper

  Just as the IOREF is utilized to change the operational voltage, this one helps to prevent clashes by varying the I2C slave address. This helps to prevent an address clash among theI2c Slave address of the on board I/O expander and EEPROM with any external I2C slaves.

- VIN Jumper

  This jumper can be used as a 5V power source from the current supply for attached shields or peripherals.

5) PROPELLER P8X32A

5.1) INTRODUCTION

The Propeller P8X32A is a microcontroller chip. it's architecture is parallel multi-core processor of 32 bit risc which contain 8 CPU cores which called as a cogs. It was developed by R.T. Nollett.

The main purpose of designing this chip is to speed up the processing for system such as maintain low power consumption as well as at stand by mode . It's has feature of flexibility so that by maintain power of it's 8 CPU speed of process is being modify.

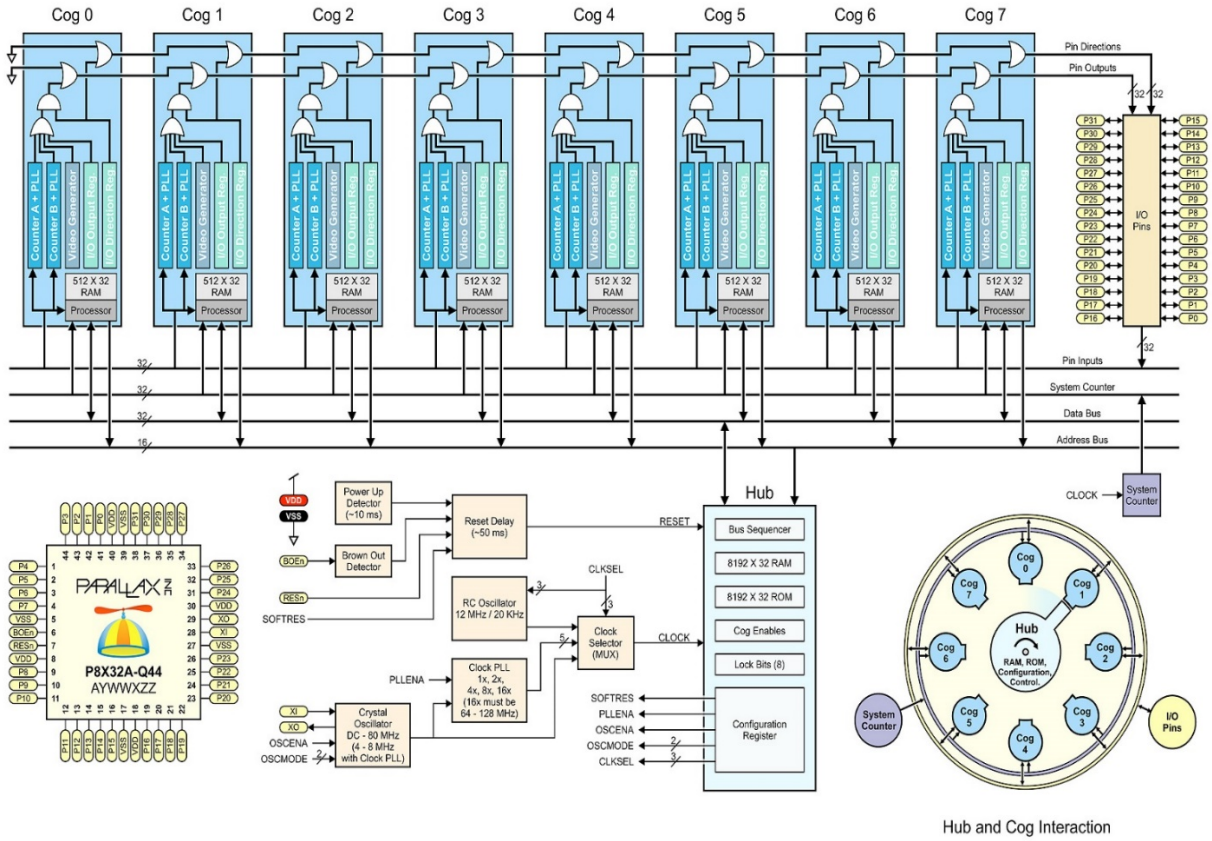


Figure 39: Propeller Chip block diagram

5.2) FEATURES OF PROPELLER

Propeller Architecture

Propeller is a processing in parallel with 8 cog each cogs is 32 bit processors all these are combined to form a micro controller.

Due to Multi-processor it maintain the run-time issues and easily resolve it and due to which there is no need of interrupts. So that the event programming for synchronous as well as asynchronous is simplify.

During a running process one cog can take 20 MIPS while whole controller take 8X20 MIPS instruction at time.

While each cog is maintain at 80MHZ while allow max 20 MIPS.

Due to all above features system capabilities increases. Due to multi-cogs it's is flexible.

Propeller Clock and wait instruction

Propeller contain two clock modes which are flexible

Which contain two internals and one external, and 1x-16x PLL which up to 80MHZ frequency of clock system.

These clock modes are switchable during code run-time. Such that frequency low and high depends on power and bandwidth sensitivity.

Due to all these modes wait instruction is strongly manage as synchronous /asynchronously.

Programming languages and resources

The propeller is programed by a two languages high level and low level. Spin is high level language that is based on object . which is used for fast development. Whereas Assembly language such as PASM is low level language which is used for fast execution .

Whereas some other language such as third party language are also support to it.

5.3) SYSTEM ORGANIZATION

SHARED RESOURCES

The system has two types of shared resources

1. Common resource
2. Mutually exclusive resource

Common resources is shared to all cogs such that it can be accessed by any cogs at a same time. Means all cogs can access same resource at same time .

Where as Mutually exclusive is a resources that are accessed by one cogs at a same time this mechanics is controlled by Hub.

CLOCK SYSTEMS

The central clock system mostly access by complete chip . This clock system has a 3 part :

1. Clock system contain a RC oscillator which act internally . which works on nearly " ~12MHZ to ~ 20KHZ "
2. Chip contain a XI input pin which works with XO pins both are function when input have high impedance.
3. Another part of the clock system is Phased locked loop(PLL) which takes as a fed by XI pin.

COG

The propeller works as parallel processor which is fast and low power consumption. This processors called as cogs. There are total 8 cogs in propeller which works independently. Each cog in Propeller contain as RAM which can store 512 word of size 32 bits. It has a advance clock system which contain two special modules and PLL system which works with XI pins. It contain a 32 input output register . All these cogs are executed parallel by a clock system.

HUB

Cog has provided a mutually-exclusive resources which is shared to one cog at a time. All this is maintain by a Hub control system. Which give a turn to each cog in a “round robin” fashion . from first cog to last cog and then back to starting cog again. All this process is executed at half of the clock system rate and above rotation process is completed in 16 clock cycles . To do all this hub system should be synchronized.

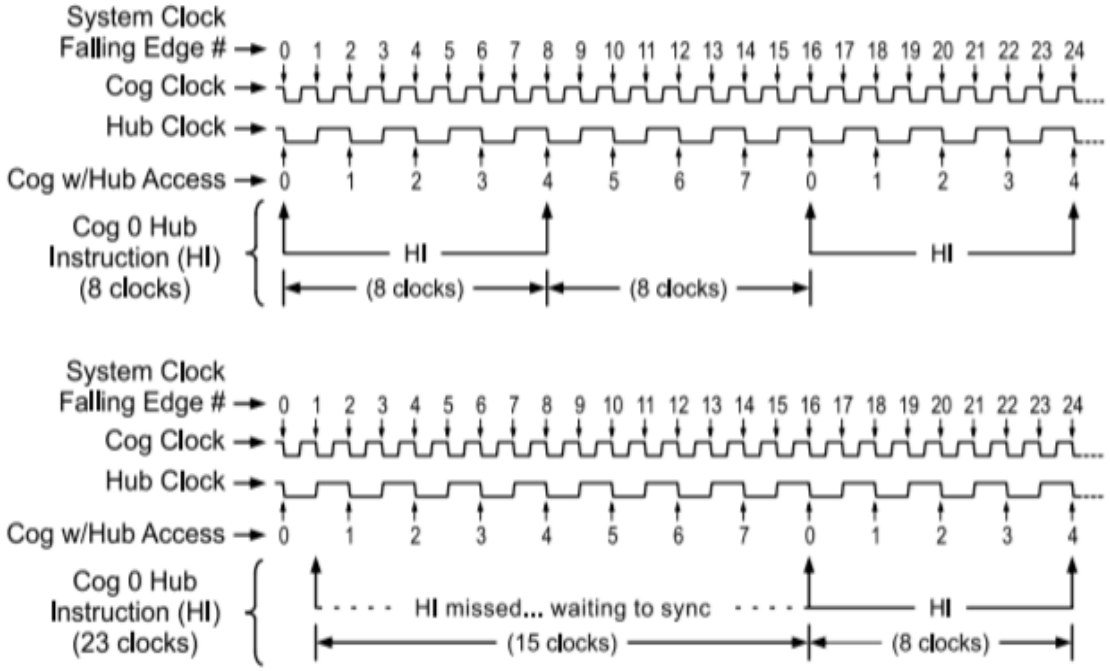


Figure 40: Clock System

PROPELLER I/O PINS

The Propeller has at 8 cog s each cogs contain 32 I/O pins , out of which 28 are called as a general purpose pins . where as input output Pins from 28 - 31 have been used for special purpose as well as general purpose . special purpose is to boot up the system . After boot up, all I/O pins are available so that any cogs can used at any time . This also have been features in cog that no two cog can access same pin at same time during run time.

Cog also contain 32 I/O direction as well as output register .which help in changing the propeller states to each pins of cog . “A cog's desired I/O directions and output states is communicated through the entire cog collective to become "Pin Directions" and "Pin Outputs."

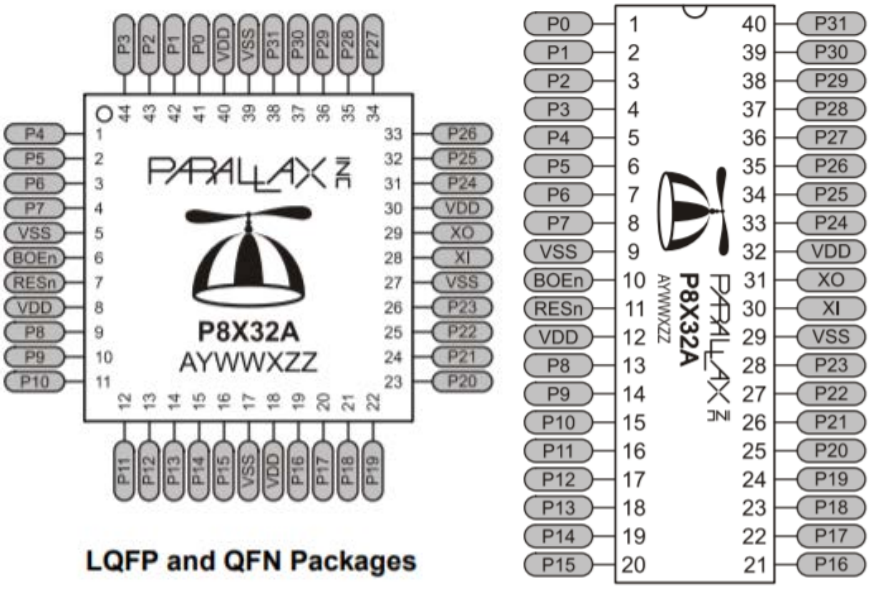


Figure 41: DIP Package Block Diagram

Table 2: Pin Descriptions		
Pin Name	**Direction**	**Description**
P0 – P31	I/O	General purpose I/O Port A. Can source/sink 40 mA each at 3.3 VDC. CMOS level logic with threshold of ≈ ½ VDD or 1.6 VDC @ 3.3 VDC. The pins shown below have a special purpose upon power-up/reset but are general purpose I/O afterwards. P28 - I2C SCL connection to optional, external EEPROM. P29 - I2C SDA connection to optional, external EEPROM. P30 - Serial Tx to host. P31 - Serial Rx from host.
VDD	---	3.3 volt power (2.7 – 3.6 VDC)
VSS	---	Ground
BOEn	I	Brown Out Enable (active low). Must be connected to either VDD or VSS. If low, RESn becomes a weak output (delivering VDD through 5 kΩ) for monitoring purposes but can still be driven low to cause reset. If high, RESn is CMOS input with Schmitt Trigger.
RESn	I/O	Reset (active low). When low, resets the Propeller chip: all cogs disabled and I/O pins floating. Propeller restarts 50 ms after RESn transitions from low to high.
XI	I	Crystal Input. Can be connected to output of crystal/oscillator pack (with XO left disconnected), or to one leg of crystal (with XO connected to other leg of crystal or resonator) depending on CLK Register settings. No external resistors or capacitors are required.
XO	O	Crystal Output. Provides feedback for an external crystal, or may be left disconnected depending on CLK Register settings. No external resistors or capacitors are required.

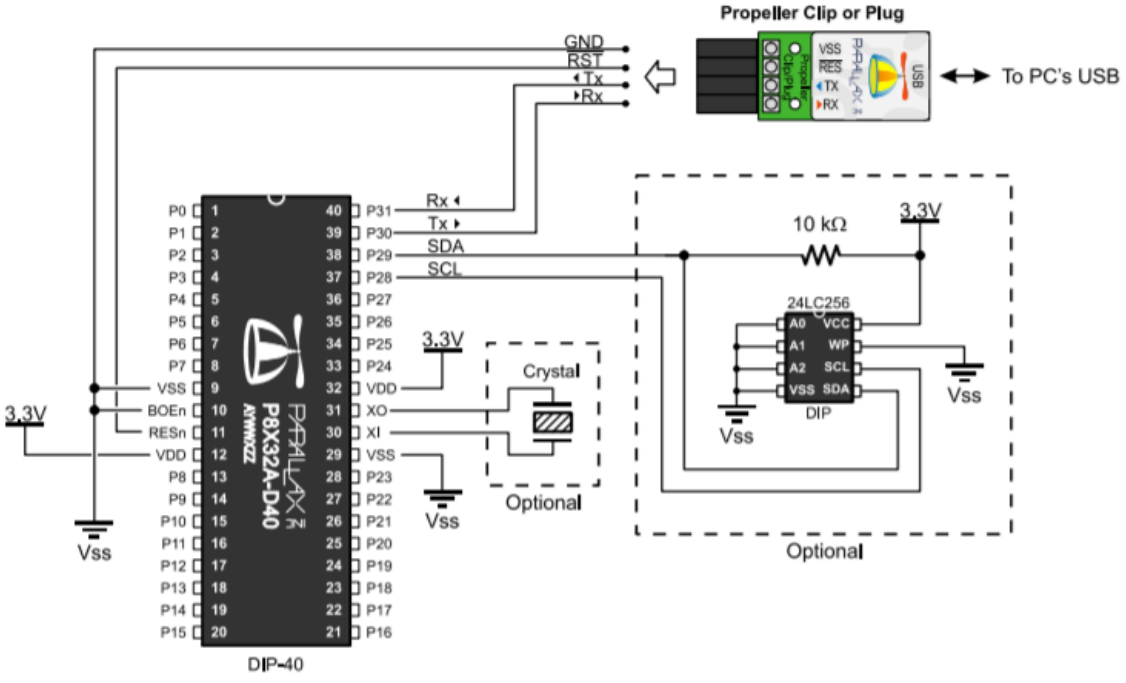
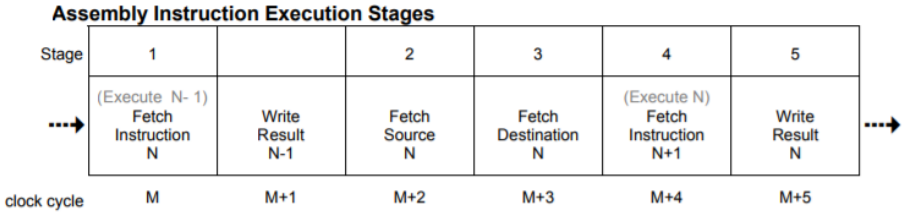


Figure 42: Pin description

INSTRUCTION EXECUTION STAGES



5.4) MEMORY ORGANIZATION

MAIN Memory

In propeller main memory is 64 kilo bytes block that can be access all cog as mutually exclusive resource through hub. Main memory block consist two sub block of 32kilo byte RAM and 32 kilobytes ROM.

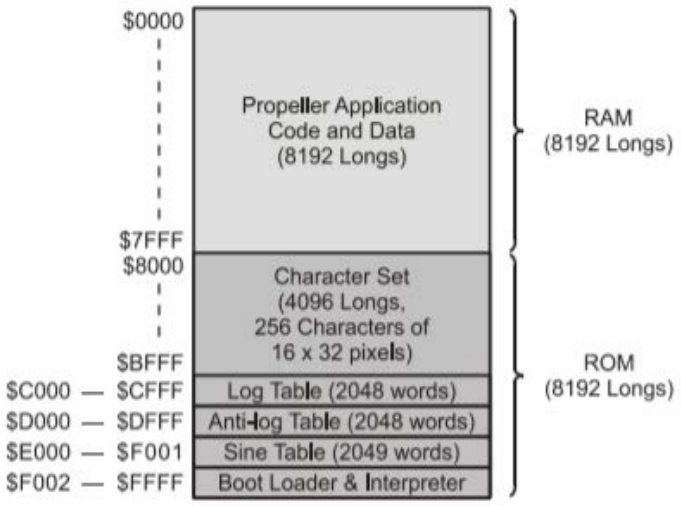


Figure 43: Propeller Main memory

RAM

RAM space is used for storing program ,variable ,stack that is used for application.

When executable program is loaded then data are written in memory from $0000 to $000F location this location is execute by bootloader and interpreter further space upto $7FFF is used for storing variable.

ROM

It is the second half portion of the main memory . it is used for storage of mathematical function and bootloader and spin interpreter.

5.5) PROPELLER APPLICATIONS

The P8X32A is particularly useful in projects that can be vastly simplified with simultaneous processing, including:

- Industrial control systems
- Sensor integration, signal processing, and data acquisition
- Handheld portable human-interface terminals
- Motor and actuator control
- User interfaces requiring NTSC, PAL, or VGA output, with PS/2 keyboard and mouse input
- Low-cost video game systems
- Industrial, educational or personal-use robotics
- Wireless video transmission (NTSC or PAL)

6) COMPARISONS

There is no doubt that both the Arduino and the Raspberry pi had significant cultural and market impact. There is no clear-cut way to compare the two devices. They can be said to be different breeds of the same litter.

The raspberry pi is a complete computer. It has its own software and the hardware required to run it. Its purpose is to serve as a small-scale computer. It can act as a server, emulate out-of-production hardware and save data.

"Raspberry Pi is like the brain. It is efficient in performing higher level processing and CPU intensive tasks."

It must be kept in mind that the Arduino is not a complete computer. It is more of a communication device, a micro-controller. It is very efficient in acting as a small controller for hardware such as LEDs, speakers and sensors. It is best put to use for primitive continual tasks.

"Arduino is like the spinal cord. It easily tethers to a huge number of peripherals and provides continuous data relay. It is best used for repetitive lengthy low-intelligence tasks."

There are several minor pros and cons to each device. The Arduino has a basic power requirement, it is not affected by power cuts and will start tasks immediately. The pi is damaged by abrupt power loss and requires boot protocols. Most of the Arduino is completely open source and needs to be installed by the user whereas the Raspberry pi comes packaged with a Linux based OS.

Most beginners start out with the Arduino as it has a lot of open source support along with the shield ecosystem. The Raspberry pi however is a more powerful device and can act as a computer despite some hiccups with real-time hardware access. Most projects or devices usually use a combination of the two devices as and when required.

Below is a table comparing two typical versions of the Arduino and the Raspberry pi.

Raspberry Pi Vs. Arduino: Comparison Table

	Arduino Uno	Raspberry Pi 2 Model B
Cost (base model)	20	39
Processor	16MHz AVR ATmega328P	900 MHz Broadcom ARM Cortex-A7
Storage	32 KB	n/a
RAM	2 KB	1 GB
I/O pins	20	17
OS	n/a	Raspbian, other varieties of Linux, Android
Languages	Arduino,	Python, C, C++, Java, Ruby
Best for	Hardware / prototyping	Software / server
Power supply	5V USB or DC jack	5V USB

Table 7: Raspberry Pi vs. Arduino Comparison table

7) CONCLUSION

a) This survey report covers most milestones and major breakthroughs since the inception of open-source hardware however it is crude to say it is comprehensive as technology is improving exponentially.

b) As previously stated above, the market leaders Arduino and Raspberry Pi serve different purposes and it is senseless to pit them against one another. The Raspberry Pi is a small but complete computer whereas the Arduino is simply a mini remote. The devices still have an avid community and are frequently put to use in DIY's and IOT projects.

c) Several successful businesses have sprung out of open-source hardware. FarmBot is an automated food production system. OSVehicle is an automation company whose products are completely open-source. They recently released TABBY EVO, an open-source platform for electric automotives. It can be used to create your own vehicle from scratch.

d) With the advent of 3D printing, the number of open-source enthusiasts has boomed in part due to the convenience of obtaining design schematics and the cost efficiency of purchasing materials.

e) Recently, a man named Lukas F. Hartmann created a completely open-sourced laptop. It utilized blobs and 3D printed models of open-source hardware as its components and it ran on open software. The community always pushes the envelope further in terms of experimentation and research.

f) The future of open-source hardware is bright. Sure, and quick progress is being made in many fields of computing and these devices will grow ever complex along with the steady arrival of cutting edge technologies.

8) REFERENCES

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