B38DF
Embedded Systems & Microcontrollers

Alexander Belyaev

Heriot-Watt University
School of Engineering & Physical Sciences
Electrical, Electronic and Computer Engineering

E-mail: a.belyaev@hw.ac.uk
Office: EM2.29

Partially based on the slides provided by Dr. Paul Record

Embedded systems are everywhere

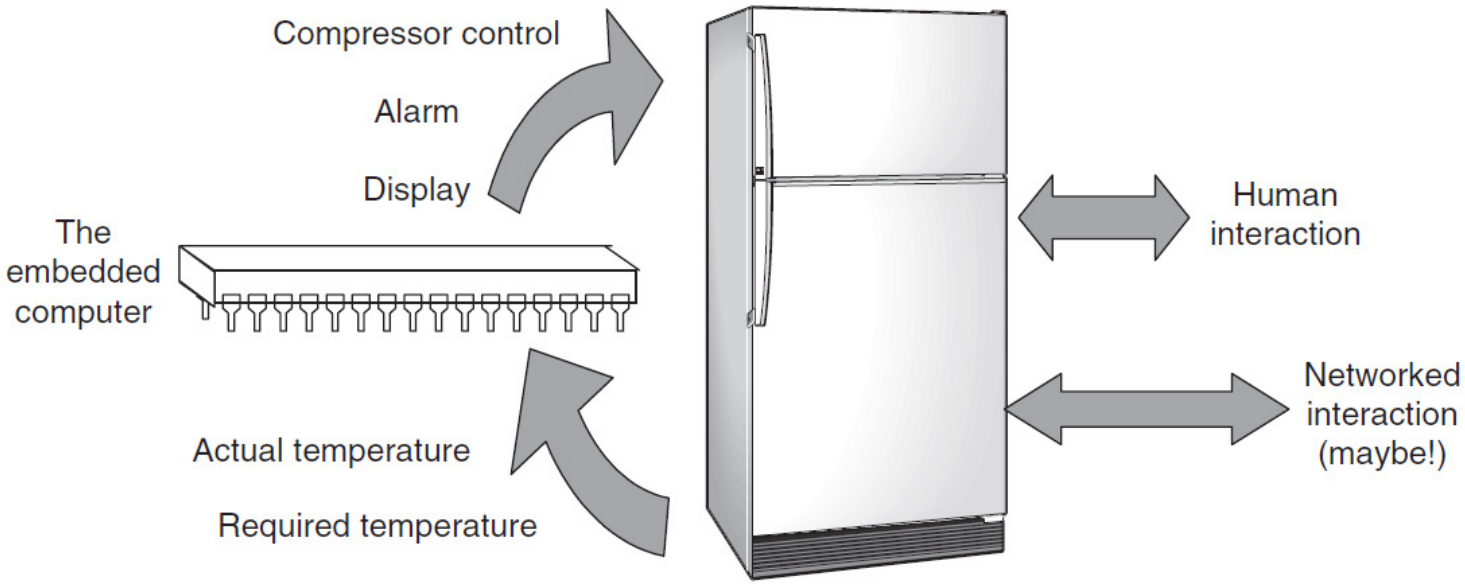
If we take any engineering product that needs control, and if a computer is incorporated within that product to undertake the control, then we have an embedded system. An embedded system can be defined as

> A system whose principal function is not computational, but which is controlled by a computer embedded within it.

These days embedded systems are everywhere, appearing in the home, office, factory, car or hospital, and many other places

Home	Office and commerce	Motor car
Washing machine	Photocopier	Door mechanism
Fridge	Checkout machine	Climate control
Burglar alarm	Printer	Brakes
Microwave	Scanner	Engine control
Central heating controller		In-car entertainment
Toys and games		

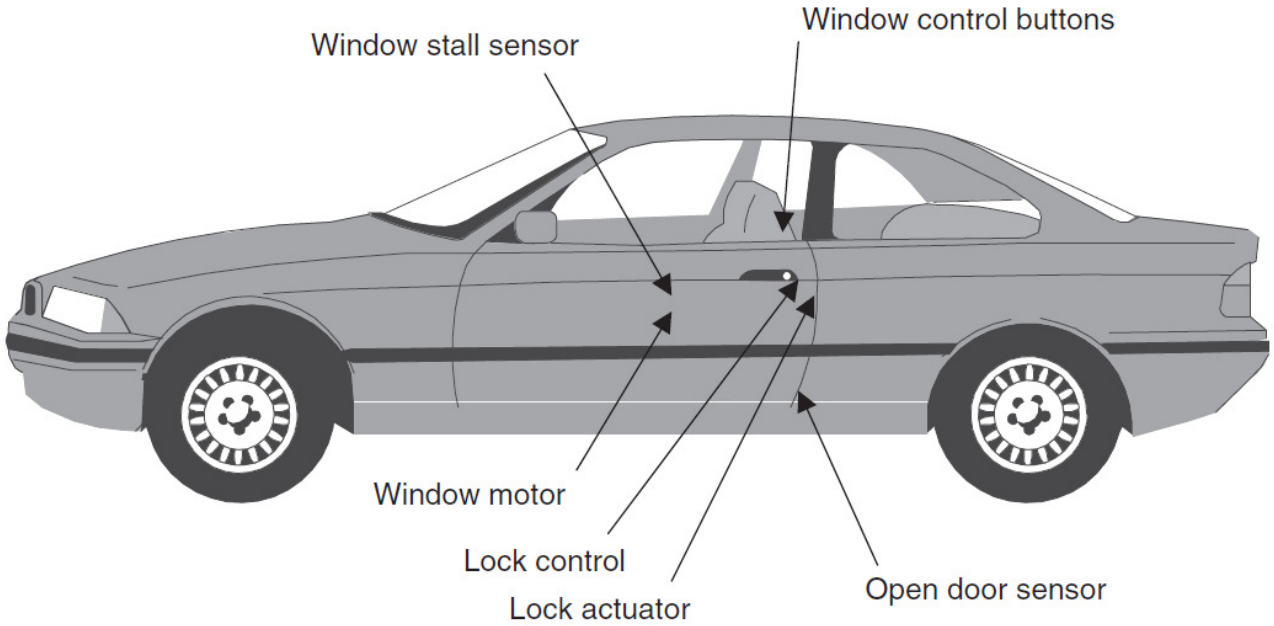
Examples of embedded systems: A refrigerator



It needs to maintain a moderately stable, low temperature within it. It does this by sensing its internal temperature and comparing that with the temperature required. It lowers the temperature by switching on a compressor. The temperature measurement requires one or more sensors, and then whatever signal conditioning and data acquisition circuitry that is needed.

Some sort of data processing is required to compare the signal representing the measured temperature to that representing the required temperature and deduce an output. Controlling the compressor requires some form of electronic interface, which accepts a low-level input control signal and then converts this to the electrical drive necessary to switch the compressor power.

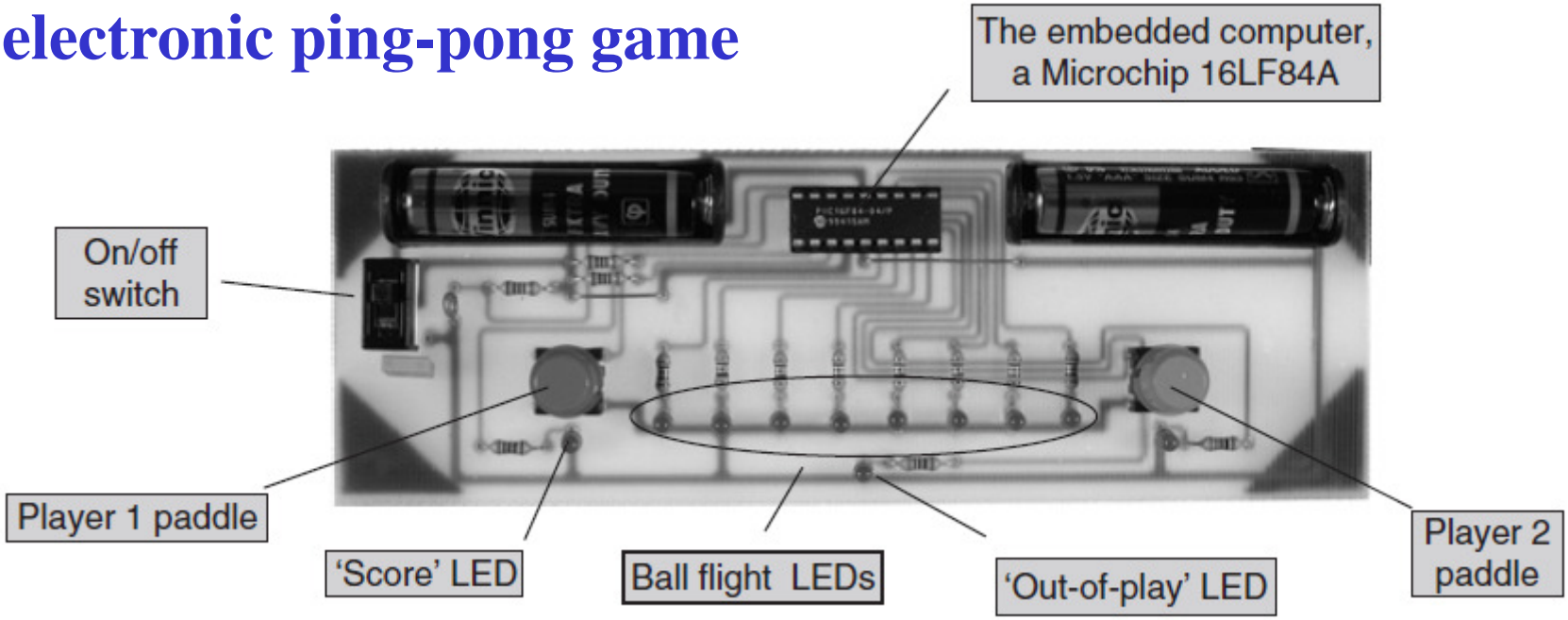
Examples of embedded systems: A car door mechanism



There are some sensors, some human interaction and a set of actuators that must respond to the requirements of the system. One set of sensors relates to the door lock and another to the window. There are two actuators, the window motor and the lock actuator.

Do we need an embedded system here? Yes, if we want to enhance functionality. Now we have the door status and actuators under electronic control, they can be integrated with the rest of the car. Central locking can be introduced or an alarm sounded if the door is not locked when the driver tries to pull away. There is therefore considerable advantage in having a network which links the actions of the door control to other functions of the car.

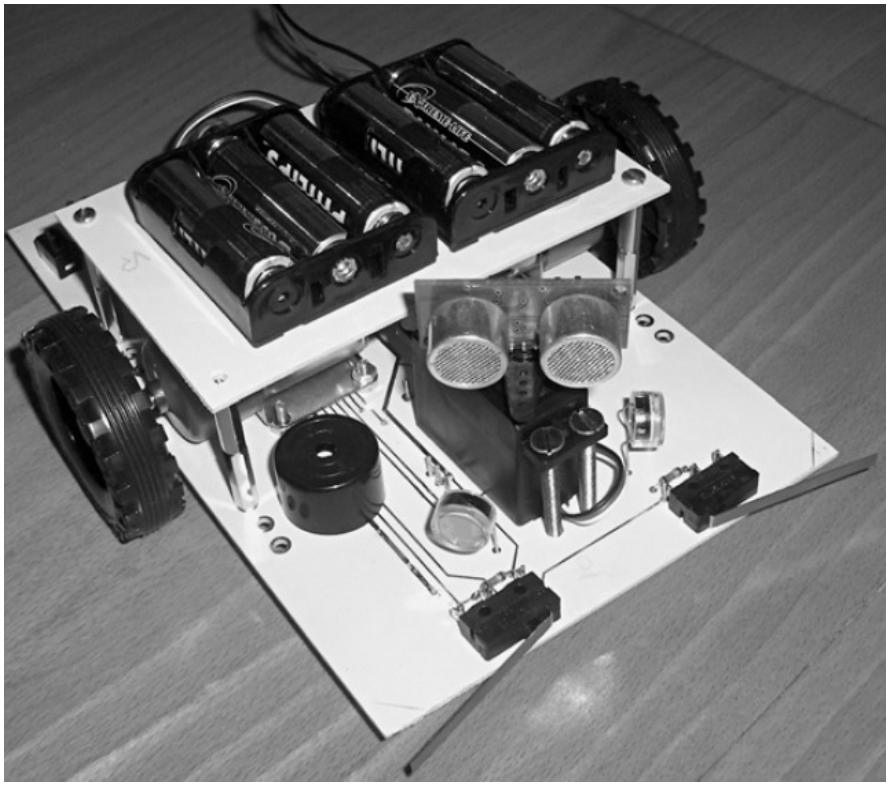
Examples of embedded systems: An electronic ping-pong game



The game is controlled by a tiny embedded computer, a microcontroller, made by a company called **Microchip**. It takes the form of an 18-pin integrated circuit (IC), and has none of the visible features that one would normally associate with a computer. Nevertheless inside that little IC there is a Central Processing Unit (CPU), a complex array of memories, and a set of timing and interface circuits. One of its memories contains a stored program, which it executes to run the game. It is able to read in as inputs the position of the switches (the player paddles) and calculate the required LED positions. It then has the output capability to actually power the LEDs to which it is connected. All of this computing action is powered from only two AAA cells.

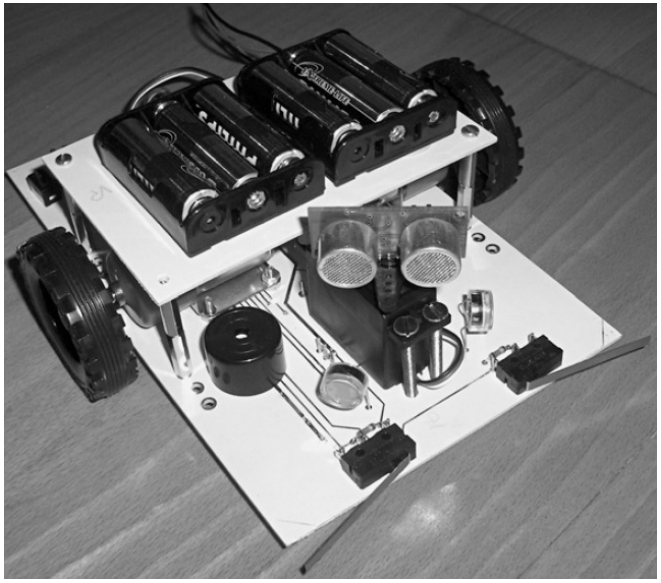
Examples of embedded systems: An autonomous guided vehicle

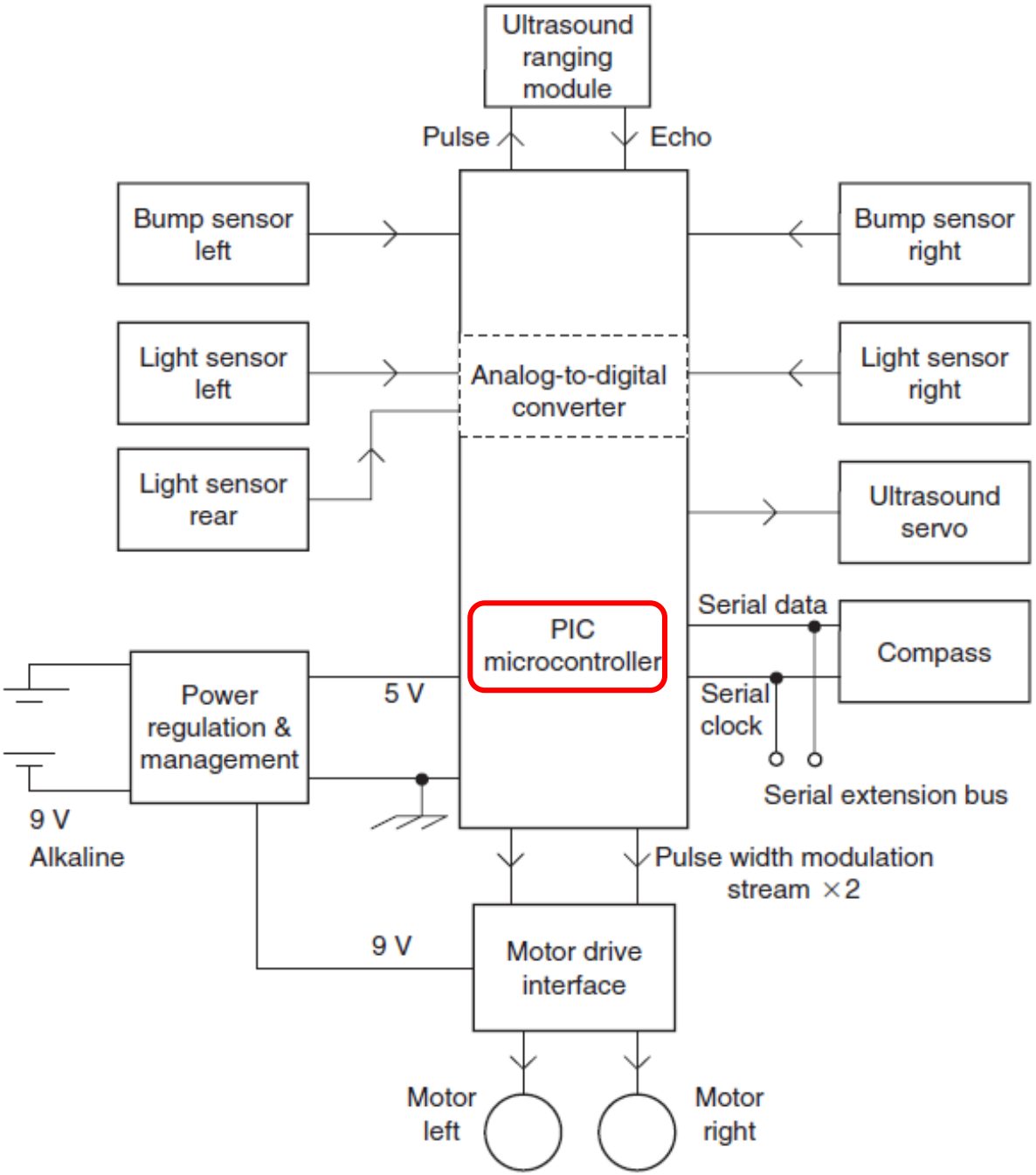
Two microswitch bump detectors sense if this vehicle hits an obstacle. An ultrasound detector, mounted on a servo actuator, is there with the aim of ensuring that the vehicle never needs to have an unexpected collision! Two light sensors on either side of the servo are used for light tracking applications – a third, not seen in the photo, is mounted at the rear.



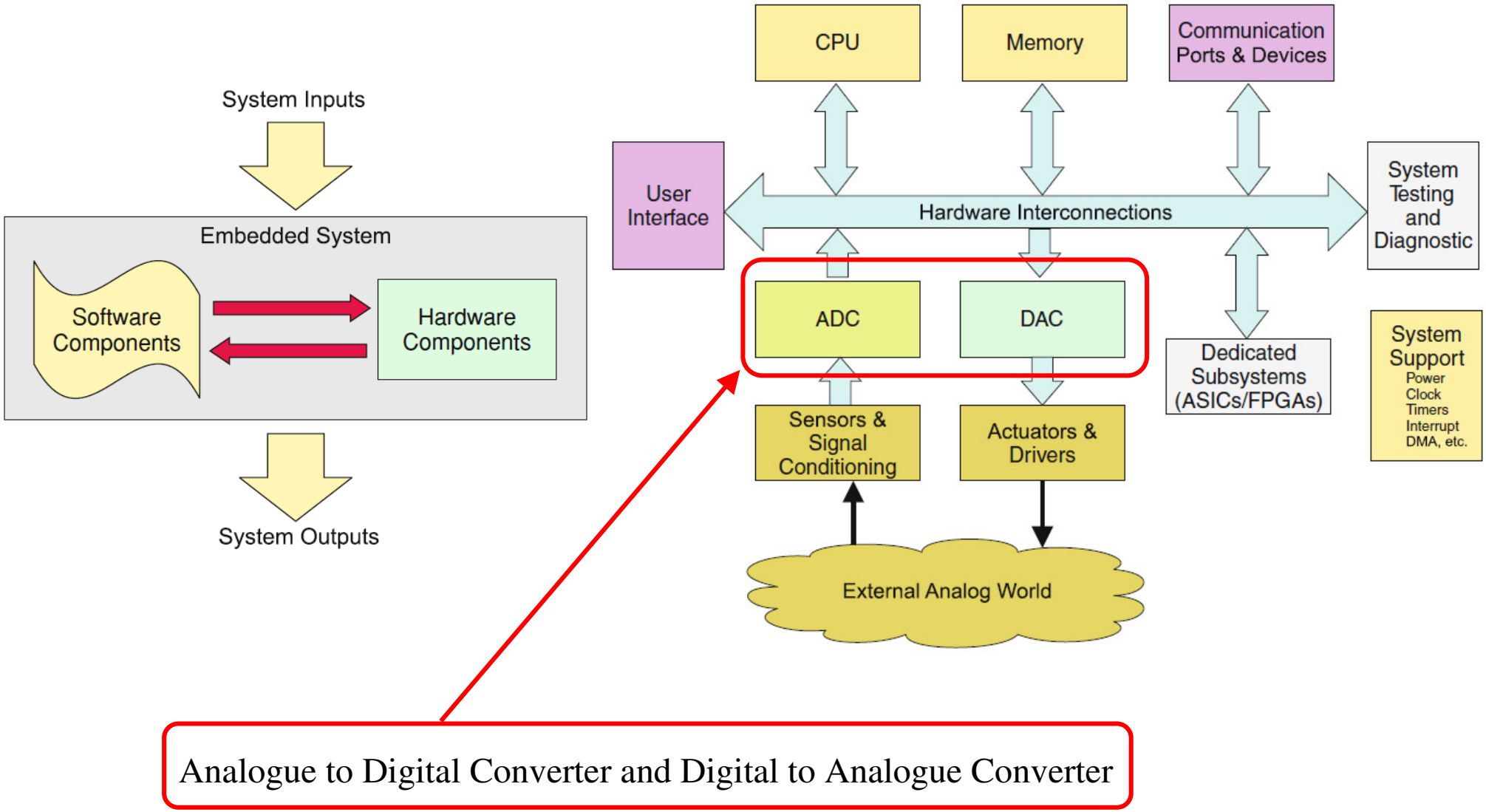
A further navigational option is a compass, so that direction can be determined from the earth's magnetic field. Locomotion is provided by two geared DC motors, while a sensor on each (again not seen in this picture) counts wheel revolutions to calculate actual distance moved. Steering is achieved by driving the wheels at different speeds. A piezo-electric sounder is included to alert a human user. It is powered from six AA Alkaline cells.

Examples of embedded systems: An autonomous guided vehicle



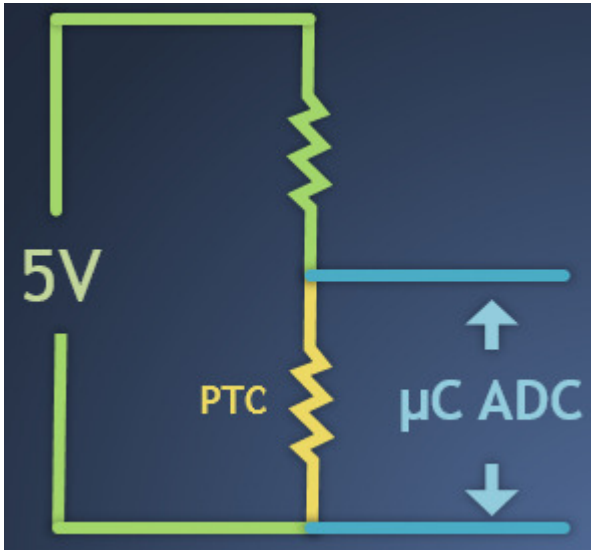


Embedded systems



Analogue to Digital Converter and Digital to Analogue Converter

A simple sensor



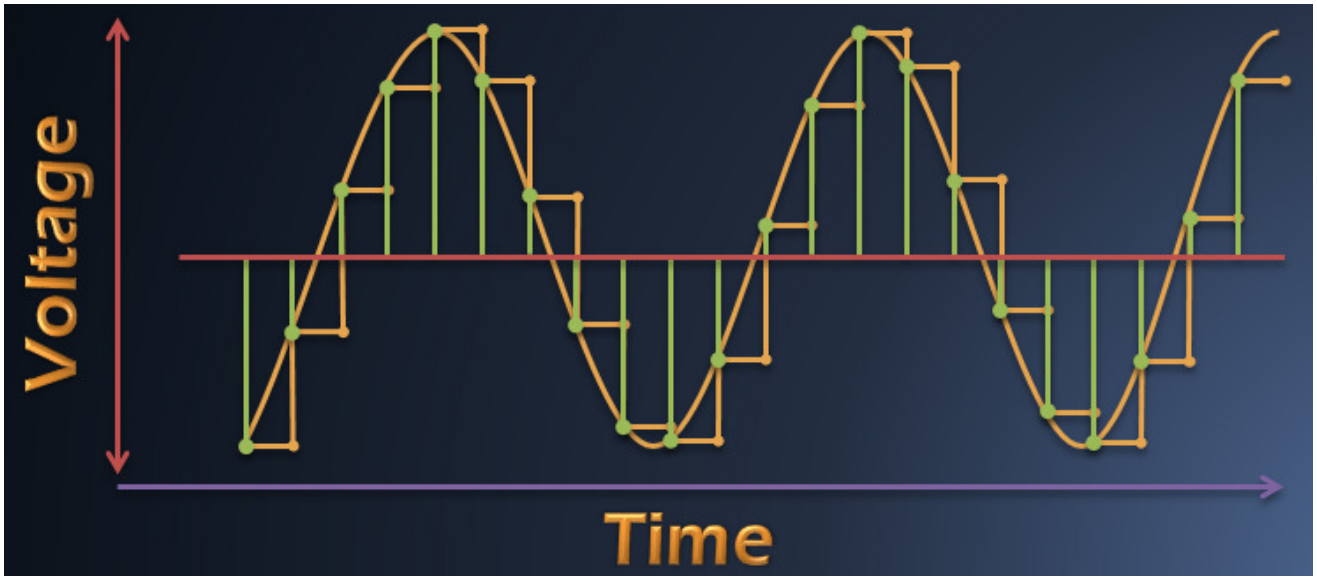
A **thermistor** is a type of resistor whose resistance is dependent on temperature, more so than in standard resistors.

With **PTC** (positive temperature coefficient) thermistors, resistance ***increases*** as temperature rises.

Analog to Digital Converter (ADC)

Just about every modern microcontroller contains an ADC(s).

- It converts analog voltages into digital values.
- These digital representations of the signal at hand can be analyzed in code, logged in memory, or used in practically any other way possible.



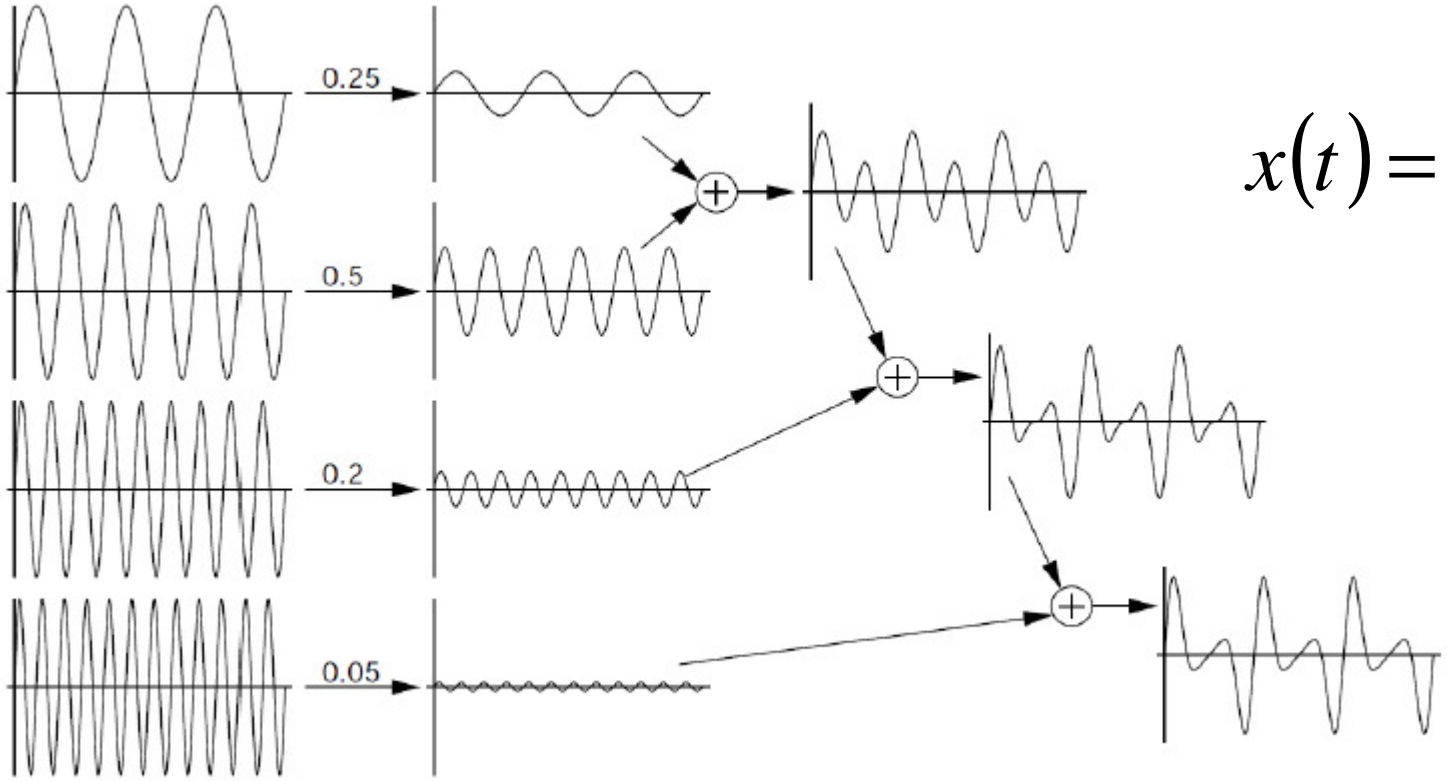
Microcontrollers have accompanying DACs.

- It does exactly the opposite function of an ADC. It takes a digital value and converts it into an pseudo-analog voltage.
- It can be used to do an enormous amount of things. One example is to synthesize a waveform. We can create an audio signal from a microcontroller.

Some Maths behind ADC (optional)

Jean Baptiste Joseph Fourier
(1768-1830)

Any periodic function can be rewritten as a weighted sum of sines and cosines of different frequencies.

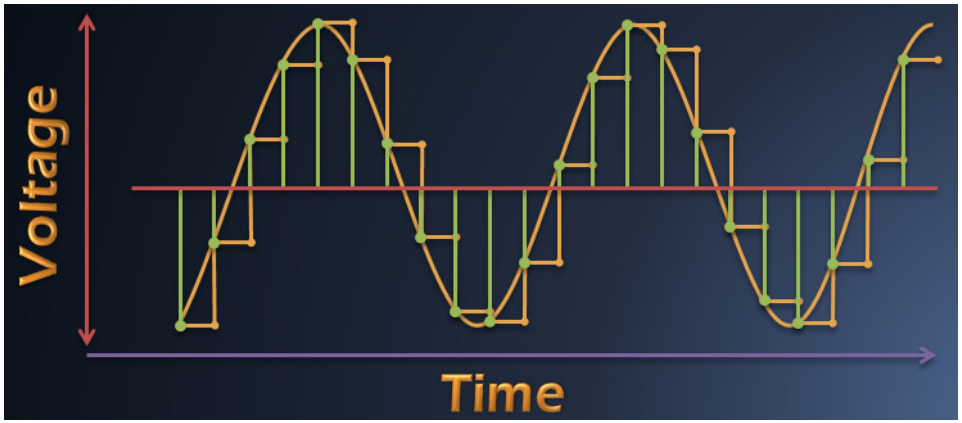


$$x(t) = \sum_{\omega} c_{\omega} e^{2\pi j \omega x}$$

Some Maths behind ADC (optional)

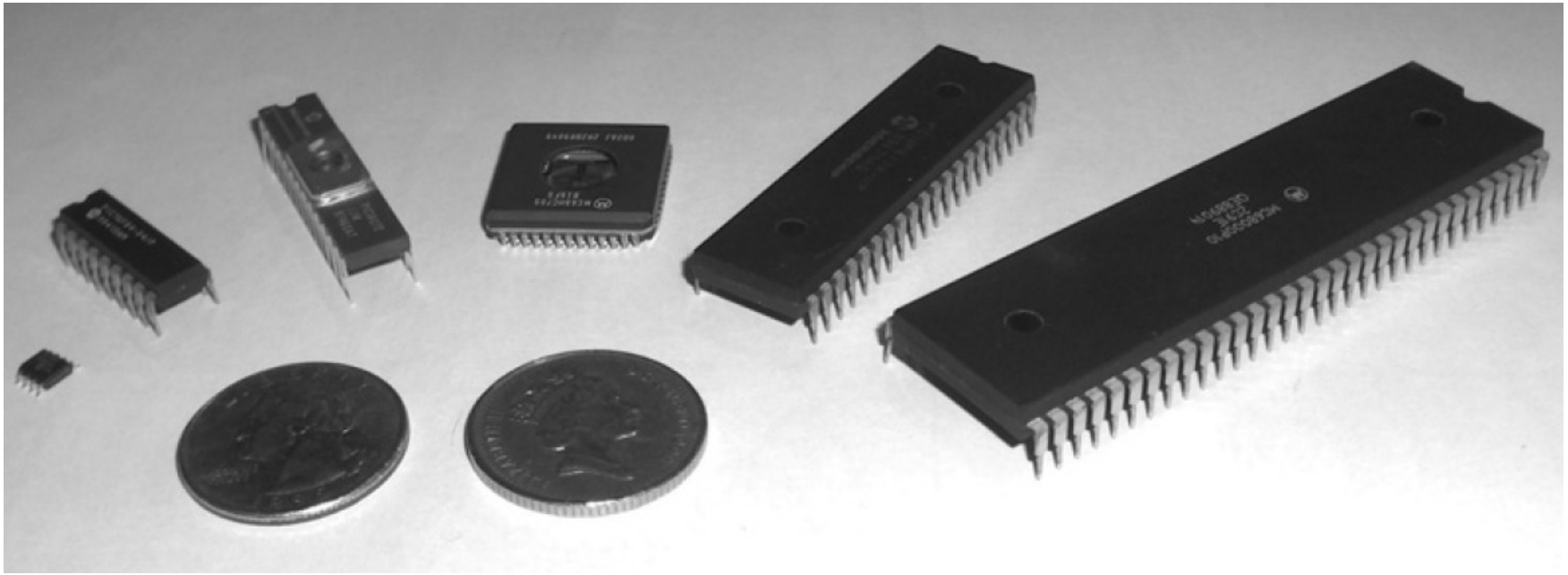
$$x(t) = \sum_{\omega} c_{\omega} e^{2\pi j \omega x} \qquad \omega = 2\pi f$$

If a signal $x(t)$ is a real-valued band-limited signal (no frequency components higher than f_M Hz), then $x(t)$ can be uniquely determined from its values $x(nT_s)$ sampled at uniform intervals T_s, where $f_s > 2f_M$



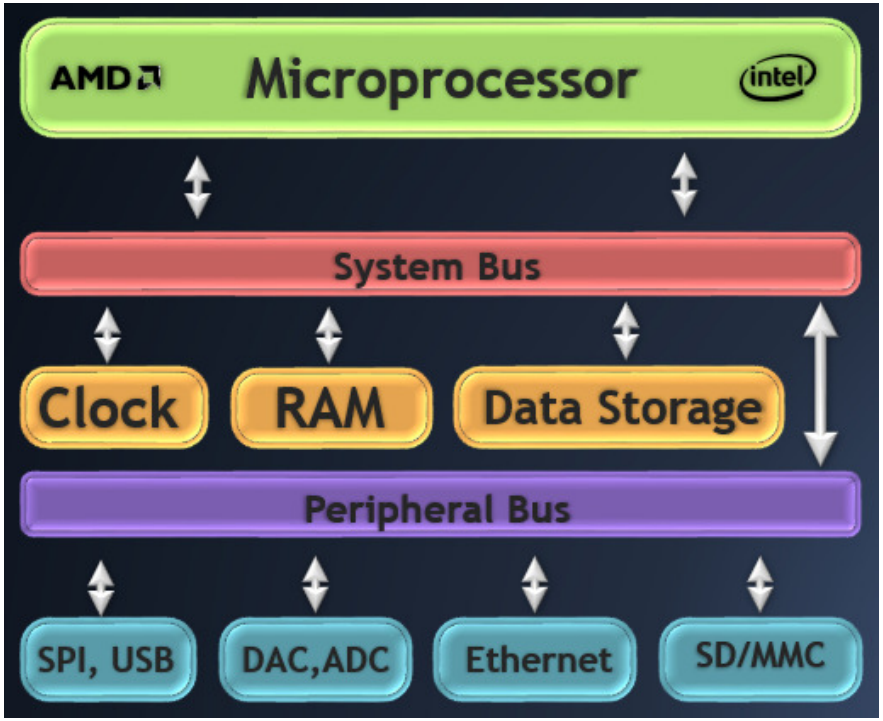
Microcontrollers

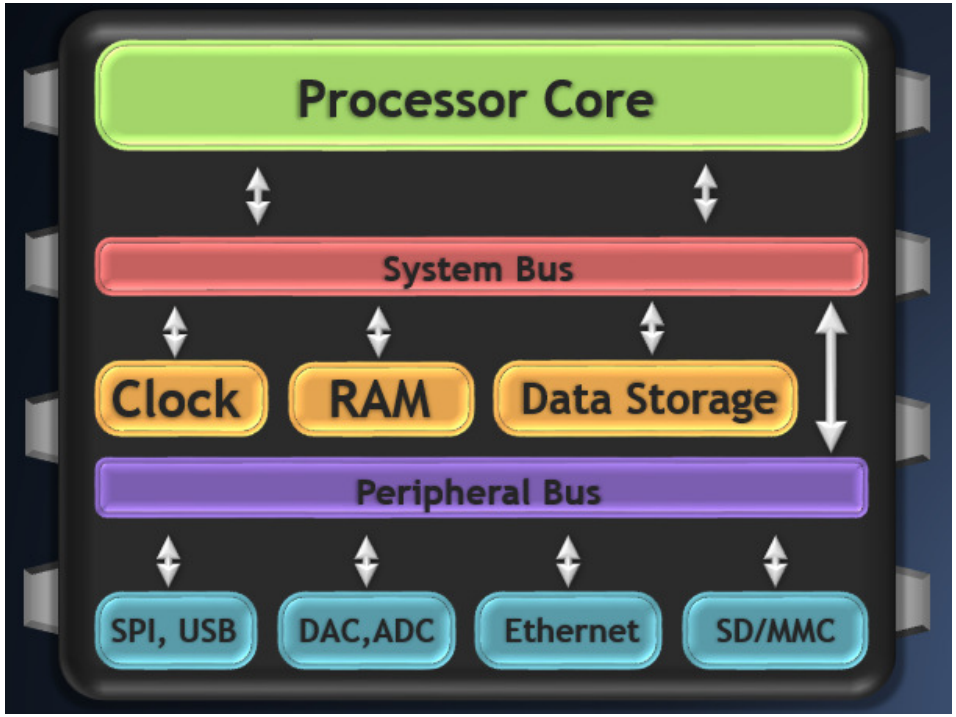
- A microcontroller is an integrated circuit that is programmed to do a specific task.
- Microcontrollers are really just “mini-computers”.



A gathering of microprocessors and microcontrollers – old and new. From left to right: PIC 12F508, PIC 16F84A, PIC 16C72, Motorola 68HC05B16, PIC 16F877, Motorola 68000.

Microprocessor vs. Microcontroller





- Microcontrollers are used for specific applications.
- They do not need to be powerful because most applications only require a clock of a few MHz and small amount of storage.
- A microcontroller needs to be programmed to be useful.
- A microcontroller is only as useful as the code written for it. If you wanted to turn on a red light when a temperature reached a certain point, the programmer would have to explicitly specify how that will happen through his code.

Microprocessor vs. Microcontroller

	Microprocessor	Microcontroller
Applications	General computing (i.e. Laptops, tablets)	Appliances, specialized devices
Speed	Very fast	Relatively slow
External Parts	Many	Few
Cost	High	Low
Energy Use	Medium to high	Very low to low
Vendors	intel AMD ARM	ATMEL ST Texas Instruments Microchip

ARM Holdings is a British semiconductor and software design company. Its primary business is in the design of ARM processors (CPUs), although it also designs software development tools. It is considered to be market dominant for processors in smartphones and tablet computers. Several recent EECE graduates became ARM engineers.

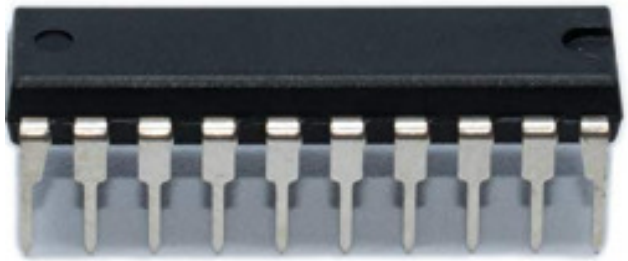
STMicroelectronics is a French-Intalian semiconductor manufacturer. ST has an office in Edinburgh and each year several our 5th year MEng students spend their industrial placement working there.

Microprocessor vs. Microcontroller

Intel 16 Core i9 7960X Unlocked CPU/Processor
by Intel

£1,390[83]

FREE Delivery
Only 1 left in stock.

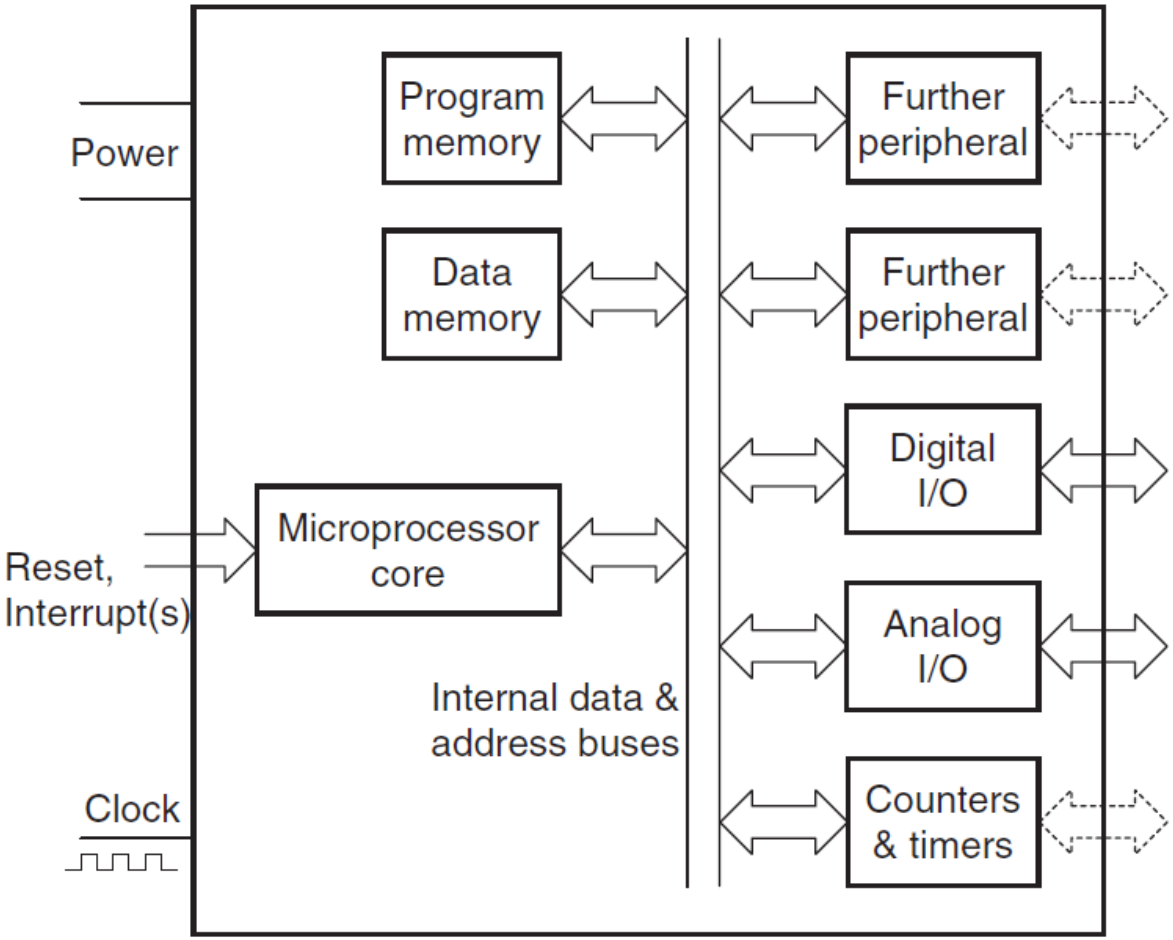


PIC16F690-I/P PIC microcontroller EEPROM256B SRAM256B 20MHz DIP20
by MICROCHIP TECHNOLOGY INC.

£4[11]

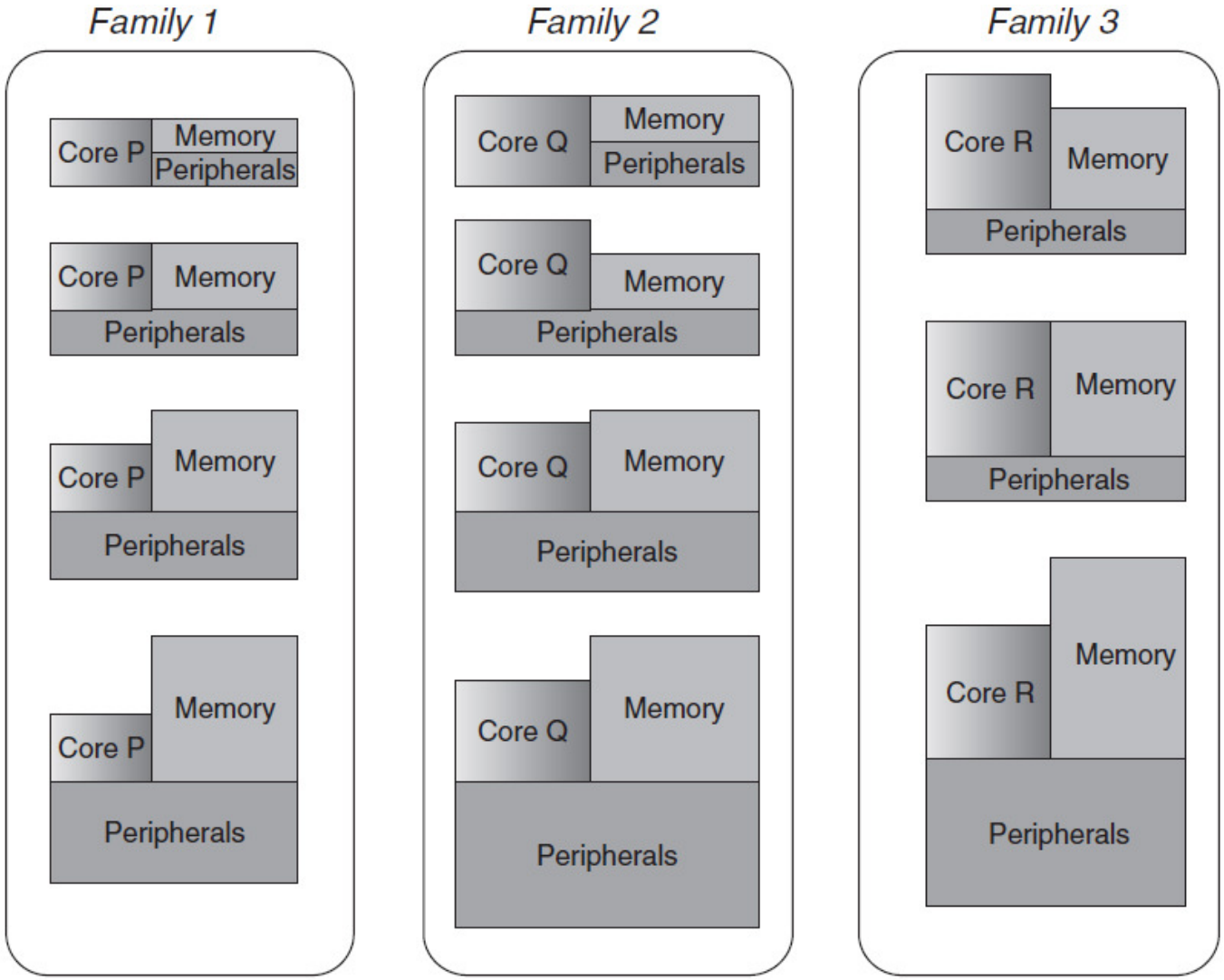
£0.60 delivery
Usually dispatched within 2 to 3 days.

Microprocessors and microcontrollers



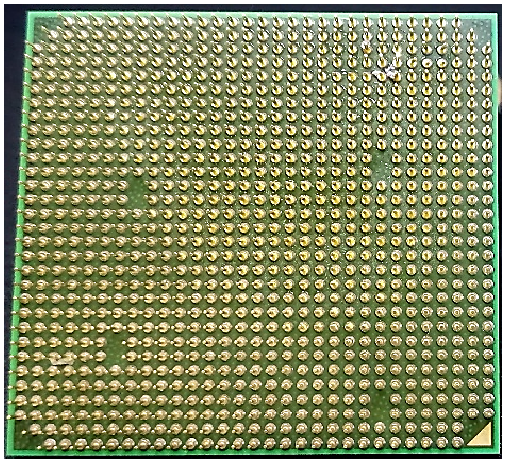
A generic microcontroller

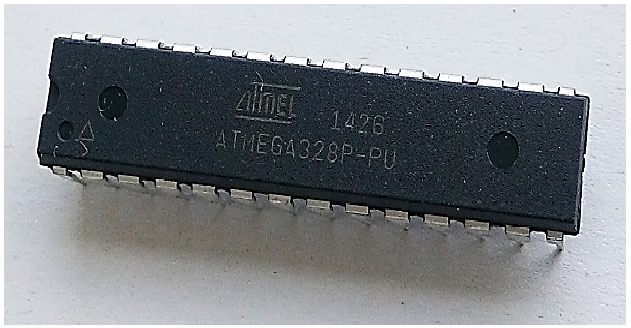
Microprocessors and microcontrollers



There are thousands of different microcontroller types in the world today, made by numerous different manufacturers. All reflect in one way or another the block diagram shown. A manufacturer builds a microcontroller *family* around a fixed microprocessor core. Different family members are created by using the *same* core, combining with it *different* combinations of peripherals and different memory sizes.

Microprocessors and Microcontrollers

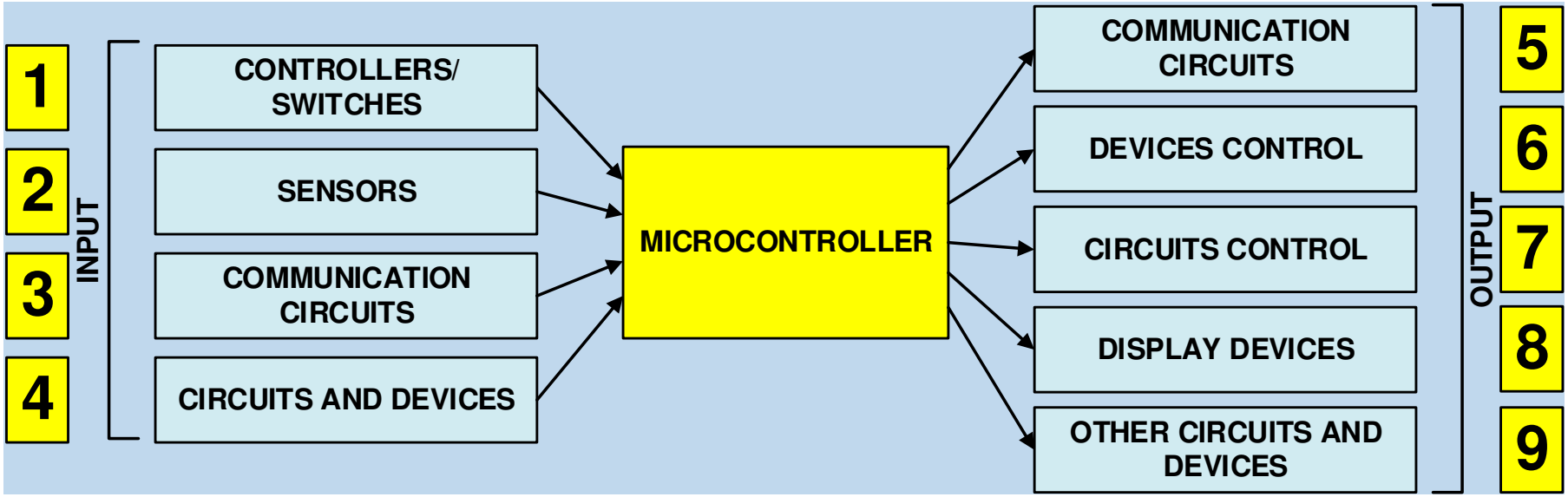




- Only a processing unit
- For general purpose systems
- High processing performance
- The heart of a computer system
- High cost
- High power consumption (as a microprocessor or as a computer system)
- High clock frequency
- Slow response to external events
- Slow system restart
- Large system physical size
- Not suitable for real time systems

- A “small computer”
- For special purpose systems
- The heart of an autonomous system
- Low cost
- Low power consumption
- Low clock frequency
- Fast response to external events
- Fast system restart
- Small physical size
- Ideal for real time systems

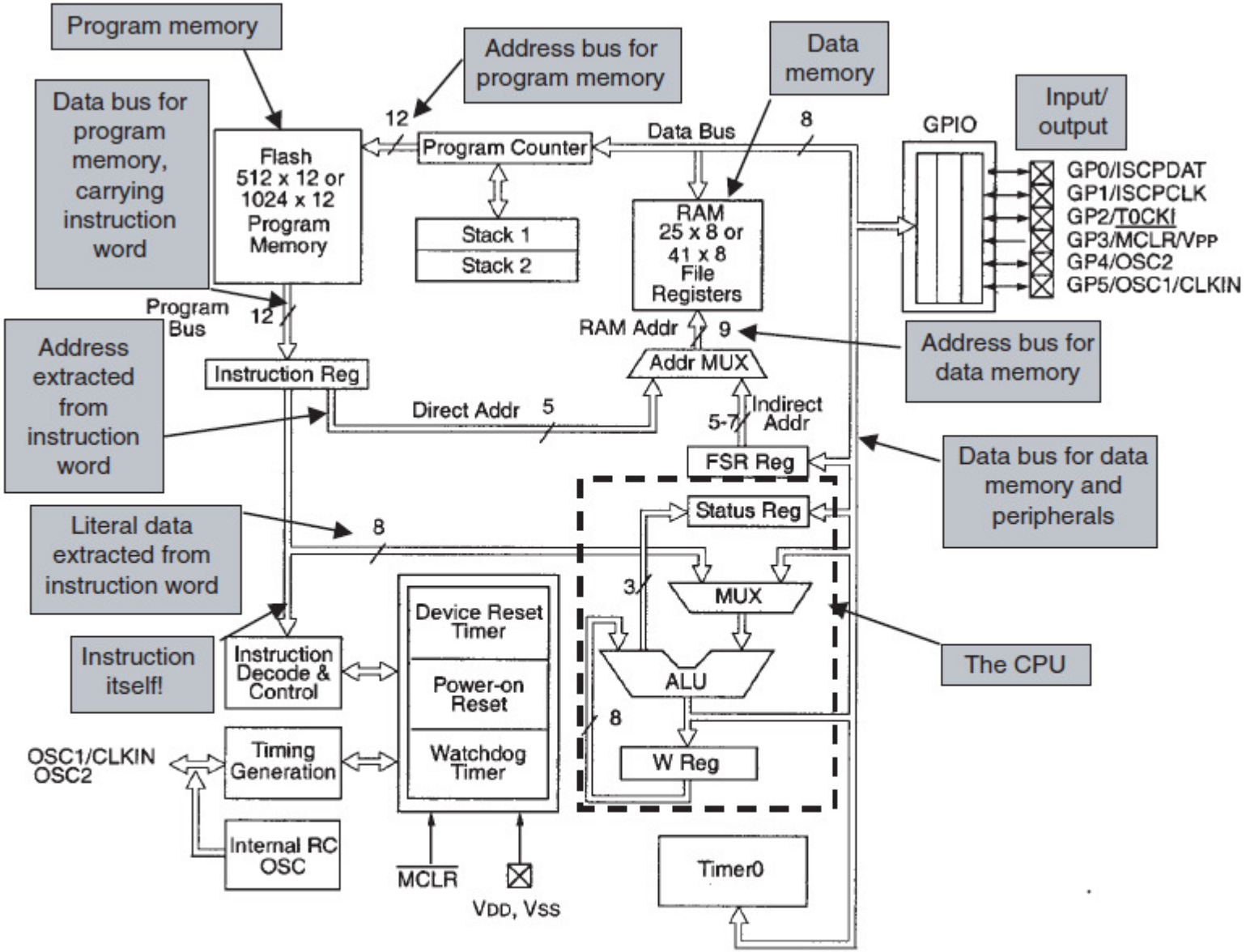
Microcontrollers



Popular microcontrollers		
Company	Internet url	Indicative model
Texas Instruments	http://www.ti.com/	MSP430F1x
Microchip	http://www.microchip.com/	PIC16F84A
Zilog	http://www.zilog.com/	S3F80P5
Freescale	http://www.freescale.com/	HC08EY
Atmel	http://www.microchip.com/	AVR ATmega328
Parallax	http://www.parallax.com/	Basic Stamp
Maxim	http://www.maximintegrated.com/	MAXQ611
Intel	-	8051

PIC Microcontroller block diagram

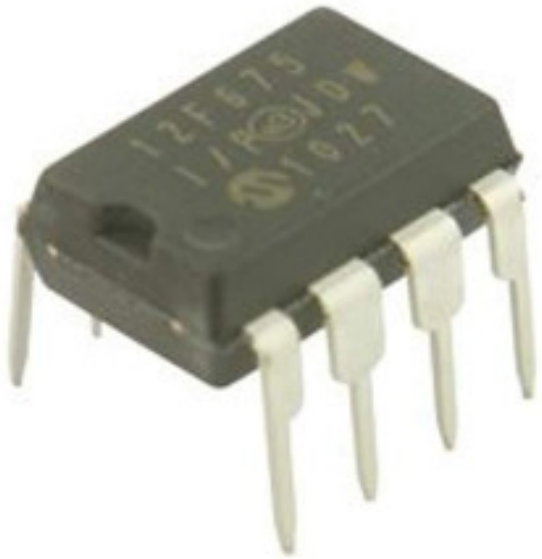
PIC12F508/509 block diagram



Key *(See also Key to Figure 1.11)*

FSR:	File Select Register	GPIO:	General-Purpose Input/Output
MUX:	Multiplexer	RC:	Resistor capacitor
W reg:	Working register		

PIC Microcontroller PIC12F508 and its development board

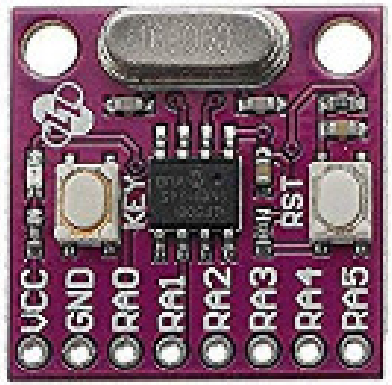


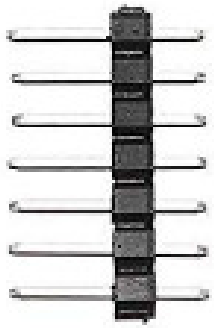
Spiratronics Microchip PIC12F508-I/P Microcontroller

by Spiratronics

£1.90

£1.99 delivery





MYAMIA 3Pcs Cjmcu-508 Pic12F508 Microcontroller Development Board

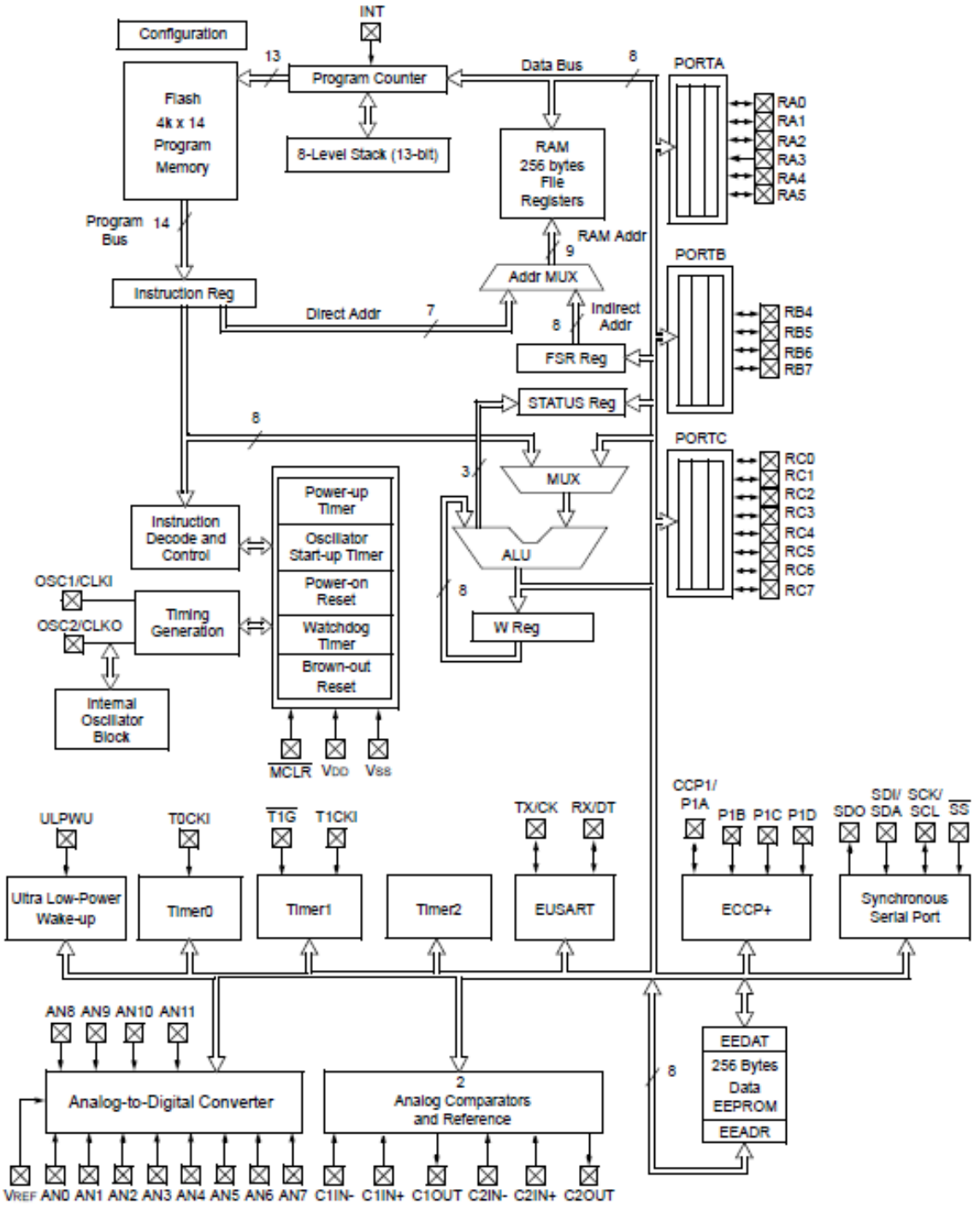
by MYAMIA

More buying choices

£10.38 (1 new offer)

Another PIC Microcontroller

PIC16F690
block diagram



Microcontroller programming

- Code is written for the microcontroller in an integrated development environment, a PC program. The code is written in a programming language. (e.g. C, BASIC or Assembly).

- The IDE debugs the code for errors, and then compiles it into binary code which the microcontroller can execute.

- A programmer (a piece of hardware, not a person) is used to transfer the code from the PC to the microcontroller. The most common type of programmer is an ICSP (in-circuit serial programmer).