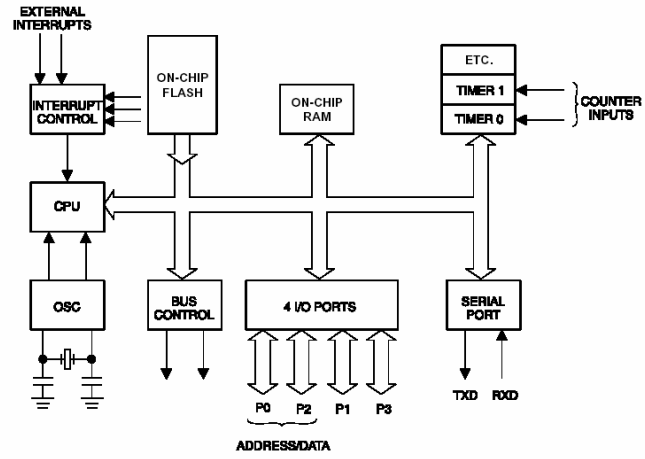
Microcontrollers

➔ a complete “Computer on a Chip”

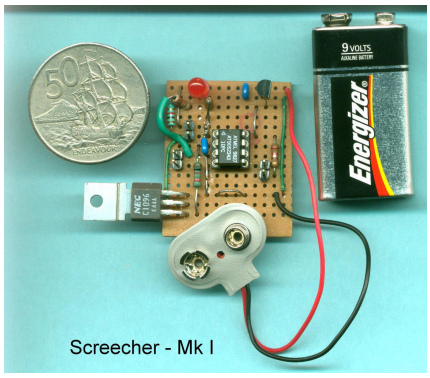
Combines in one package:

- ALU
- Memory
  - program memory
  - data memory
- I/O devices
- Clock Generation

Figure 1. Block Diagram of the AT89C core



The Screecher



The Screecher

Create a low-cost design for a battery operated box that has:

- *a button*
- *a light*
- *a very loud hooter*

When the button is pressed, the light should begin to flash, and then rapidly get faster, until it seems to be on all the time.

The hooter then sounds for two seconds, waits for four seconds, sounds for 0.4 second, waits for 15 seconds sounds for 1/10 second.

Digital Logic

Possible to design with digital logic but complex, varying flash rate would complicate the ASM

Analog Electronics

Possible, not too complex but difficult to get precise time delays, especially long ones (eg 4 & 15 seconds).

Microcontroller

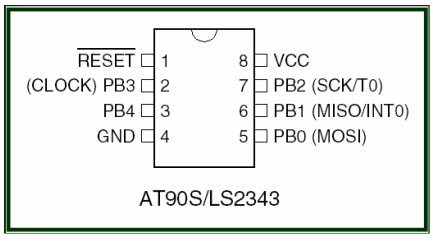
- Flexible, low cost solution
- Lowest parts count

Microcontroller Implementation

Microcontrollers are tiny computers intended to be programmed to do a single job.

Atmel AT90S2343 AVR CPU

- 5 x I/O lines
- on-chip clock
- 8 bit timer
- watchdog timer
- low power/sleep modes
- 2.7-6V supply



- 1K program memory
- 128 byte data memory
- 128 bytes EEPROM

- Fast – up to 10 millon instructions/second
- Cheap – ~ NZ$5 each in singles

From Digikey’s website – ***April 27, 2005***

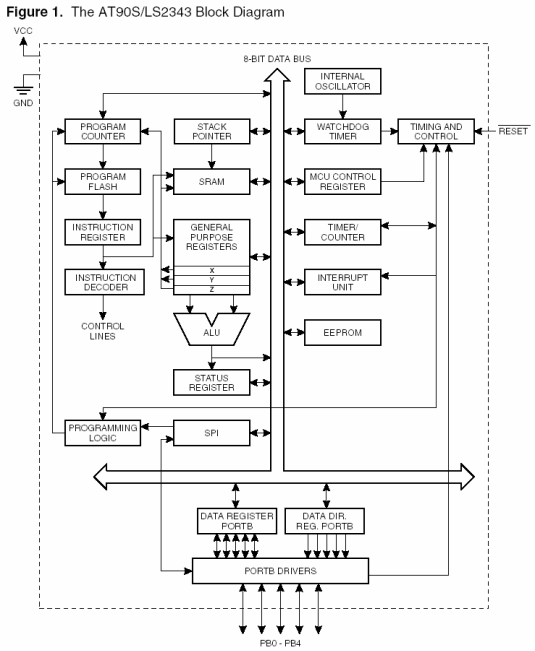
Digi-Key Part Number	AT90S2343-10PI-ND	**Quantity**	**UnitPrice**
ManufacturerPart Number	**AT90S2343-10PI**	1	**3.46**
Description	IC MCU 2K FLSH 10MHZ 8DIP	25	**2.55**
		100	**2.28**

Microcontroller – Inside vs Out

Complex internals

External connections:

- power and ground
- reset line
- 5 I/O lines



The Microcontroller Market

Quoted from *http://www.genapro.com/exsum.htm*

"The greatest number of its likely applications will be as a stand-alone microprocessor or controller in either the consumer or industrial areas:

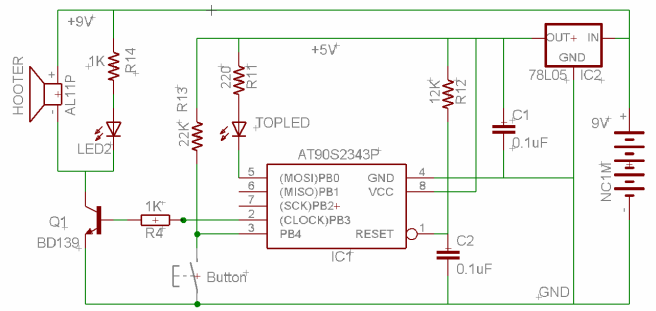
Consumer: Home energy controllers, Electronic note pads, Cellular phones, Toys, Video games, Personal computer peripherals and coprocessors

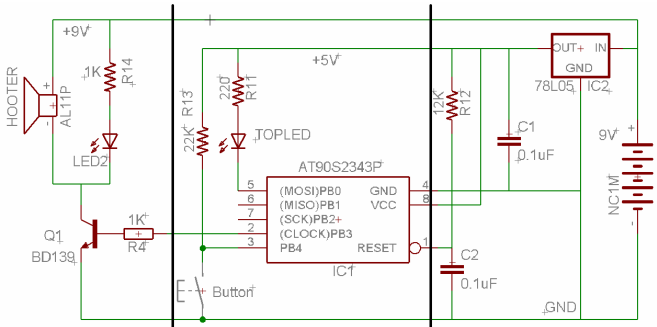
Industrial: Robotics, Process controllers, Digital Signal Processing, Wired & wireless Communications, Network & systems controller/router, Automotive controllers, Defense electronics"

Microcontroller Manufacturers

"These companies have a market share of 5% or more: Motorola, NEC, Hitachi, Texas Instruments, Intel, Mitsubishi, Lucent, and Philips".

Screecher Circuit





Hooter Amplifier (needed as 2343 can't supply enough power to turn hooter on)

Microcontroller

Power Supply & Reset

Size of Microcontroller Market

- This microcontroller market, currently worth approximately $2.5 billion, is traditionally serviced by legacy 8 and 16 bit devices, but it has seen a substantial growth in performance requirements as users demand greater flexibility, and as cost demands force the consolidation of multiple applications onto a single device.
- "The 32bit microcontroller industry blossomed in the last 5 years, quadrupling in revenues to reach $2.4 billion in 2003".
- "Over the next five years, the market will double in size again", said Tom Starnes, Research Vice President, Gartner.

source:

ElectronicsTalk Editorial Team, 20 October 2004
http://www.electronicstalk.com/news/ank/ank179.html

Example – Dishwashers

adapted from
http://www.freescale.com/webapp/sps/site/application.jsp?nodeId=023Z1Dj0TcR8bS

Home appliance controls are changing from purely mechanical to fully electronic as microcontrollers are incorporated …

Design Challenges

Cost
- appliance market is highly competitive and cost sensitive.
- high-volume market.
  => eliminating a few cents can save thousands of dollars

Flexibility - a new model can be introduced every year:
- software problems must be eliminated quickly
- requires professional development tools

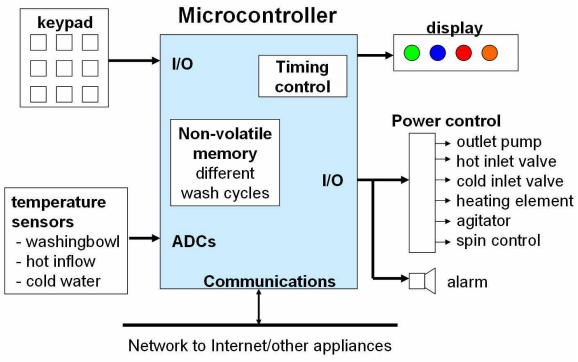
Noise - a quiet appliance is a major goal
- as consumers become busier, appliances are likely to be operating simultaneously, even during night hours when electricity is least expensive.
- minimum levels of noise and vibration are desirable.

Legislation
- energy-efficient demand from energy regulations/consumers
- designed for both water & electricity efficiency

Measurement Accuracy
For maximum efficiency, it's critical to measure:
- temperature in different interior zones of the dishwasher
- the amount of water used

Appliance Overview

Electronically controlled Washing machine



I/O - digital input/output signals

ADC - Analog to Digital Converter
Logic signals are true/false/high/low
Real-world signals (eg temperature) are continuous
➔ an ***ADC*** converts an external signal to a 8 or 10 bit number so it can be treated as a binary value

Power Control
- circuitry to convert logic signals to allow control of 230V motors, pumps …

Non-volatile Memory
- memory that doesn't forget when the power goes off

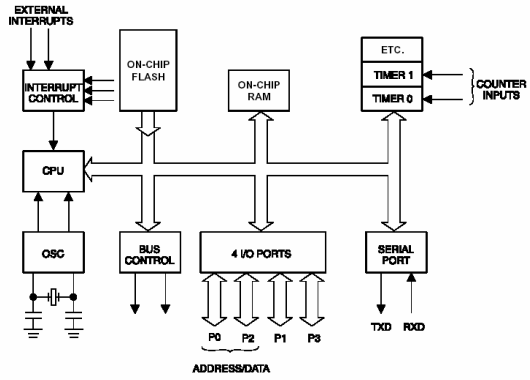
8051-Architecture - Data Sheets

"Since its 1980 introduction, the 8051 and its derivatives have shipped about two billion units world-wide (according to DataQuest), and the production rate keeps growing, with nearly 300 million units shipped in 1996 alone. Surprisingly, these sales and longevity records were achieved with essentially no changes to the core architecture or implementation, and only minor performance speed-ups."

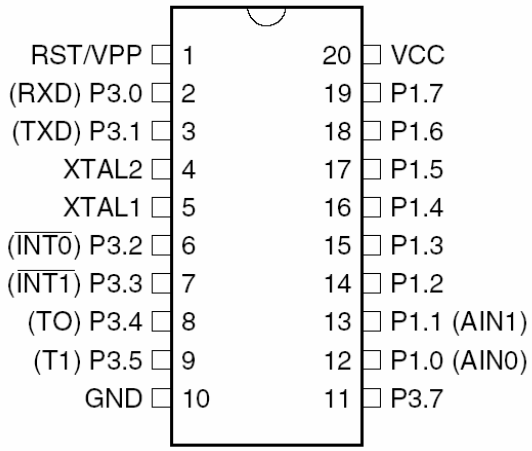
Source: Computer Systems Laboratory Colloquium - 1998
The Chip that Wouldn't Die: A 20-Year Retrospective
John Wharton - Stanford University

Atmel 8051 derivative Core

Figure 1. Block Diagram of the AT89C core



AT89C2051 – 8051 Derivative



Same "Core" – Many Variants

From: http://www.atmel.com/atmel/products/prod71.htm

"Atmel offers a broad range of microcontrollers based on the 8051 architecture. The product line includes MCS-51® in industry standard socket drop-in devices, In-System Programming capability, and small footprint 20-pin devices in ROMLESS, ROM, OTP & FLASH flavors"

Different Memory/Packages

- In-System Programmable (ISP) Flash
- Reprogrammable Flash
- Small Footprint, Reprogrammable Flash
- One-Time Programmable (OTP)
- Small Footprint, One-Time Programmable (OTP)
- ROM
- Small Footprint, ROM
- ROMless

Different Markets

The MCS-51 derivatives have features added to satisfy particular markets:

- domestic appliances
- CAN Multiplexing – "in-car" local-area-network
- MP3 Applications
- Secure and Smart Card Systems
- Data Logging

Micro Applications - The Talking Toaster

It's 3:00am. You're hungry 

…. You stumble into the kitchen. Can you really be troubled with setting the toaster's heat setting, or activating the toaster's heating coils?

Of course not! That's where the Talking Toaster comes in …. you can simply respond by speaking your reply -- no buttons to push, dials to spin, or lights to watch.

I enrolled in the CSE 477 course at the University of Washington. For my time in the class … we built a talking toaster.

The operating instructions for the toaster are quite simple:
When you want toast, ask the toaster for some toast:

You: Toast.
The toaster will then ask you what your prefer…

Toaster: How light?
Respond with either light, medium, or dark.

You: Medium.
The toaster will then lower its bread tray …

Toaster: Using setting medium. Lowering...
Toasting starts …

Toaster: Raising... done!

Adaptedfrom:http://www.the4cs.com/~corin/cse477/toaster/

Microcontroller Applications

Domestic Appliances

Microwave	CD Player
Stove	FM Tuner
Breadmaker	Fax
Toaster ?	Amplifier
TV	Air Conditioner
Video	Washing Machine
DVD player	Digital Camera
MP3 Player	Portable Phone

Computer

Main CPU – Pentium /Athlon…	Scanner
Keyboard	CD reader
Video card	DVD Writer
Hard disk	DVD drive
Modem	ADSL Router

Cellphones

Car

- Engine Control – eg: mixture, *microphone on block*
- Anti-lock braking
- Dashboard Control
- Overall control
- Entertainment (radio/CD)

This has lead to the design of a network specifically for cars – the CAN networking system.

One Vendor's Microprocessor Families

Atmel – www.atmel.com**:**

- 8051Architecture
- AT91ARM Thumb
- AVR 8-Bit RISC

Automotive Control	**Industrial Control**
Biometrics	**Military & Avionics**
Cameras	**Secure Microcontrollers**
Phones – cellphones, cordless & wall mounted	**Wireless Control**
Internet Appliances & VoIP	**Wireless Datacom**

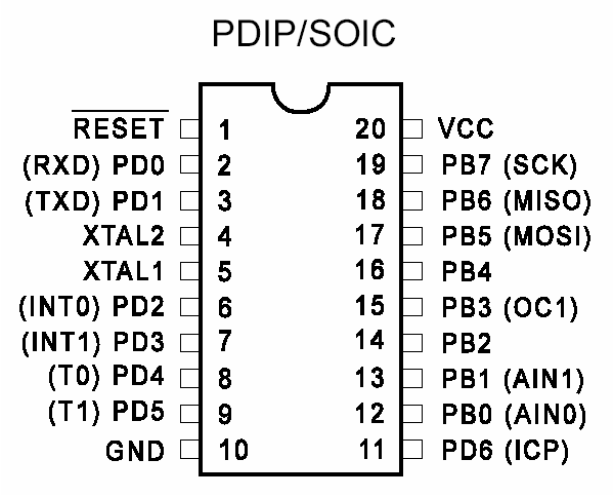
Multimedia Entertainment Equipment

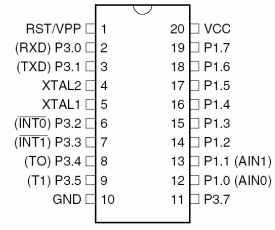
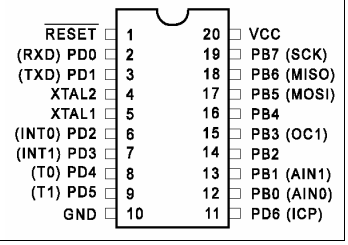
- CD & DVD players
- **DTV sets**
- Video game consoles
- **Direct Broadcast Satellite**
- ADSL / **Video gateways**
- ***Video-on-Demand* service**s
- **Digital Terrestrial TV *set top boxes***

Multimedia & Interface Technologies

- **Image sensors**
- **Bluetooth technology** / Bluetooth-enabled equipment
- **USB**
- **Firewire** IEEE 1394 – (*really fast* – like USB 2)
- Multimedia home networking for consumer electronics

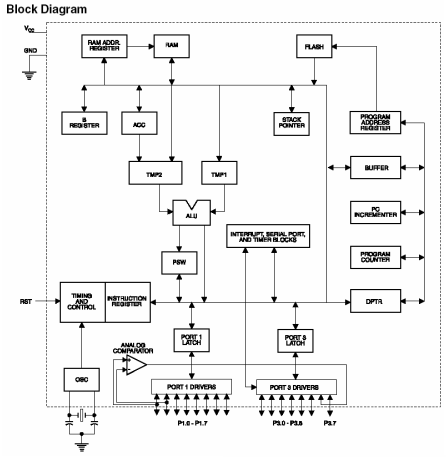
What's in a 20 Pin Package?



89C2051 – 8051 core	90S2313 – AVR Core
	

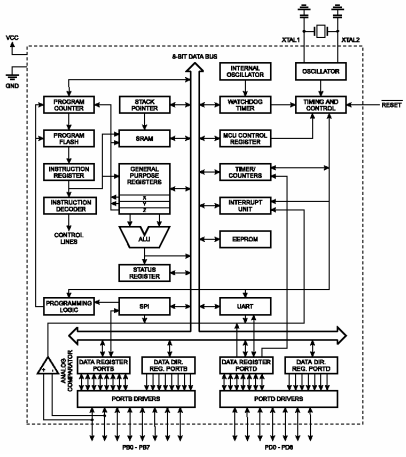
Dizzy the Robot: http://www.xs4all.nl/~sbolt/edz_sche.htm

Internal vs External View



AT98C2051

Figure 1. The AT90S2313 Block Diagram



AT90S2313

Microcontroller "On-Chip" features

Memory - Various sorts

I/O devices - lots

- Serial Ports
- Parallel Ports
- Analog I/O
- Timers & Counters
- PWM – pulse width modulator
  synthetic analog from two levels by varying the on-off ratio
- Interrupt lines direct to Pins

Support Circuitry

- On-chip Oscillator (RC, crystal, resonator)
- Watchdog timer

Memory

Microcontrollers are "fixed programmed", so need:
- non-volatile code memory (for the program)
- data memory (for variables, temporary values …)

On-chip Program Memory

- Usually quite small – from 1K instructions up
- Various technologies
  - fixed programmed by factory – cheap
  - one-time programmable
  - Flash ™ - user can reprogram (electrically)
    Limited life – typically 1000 reprogram cycles

Data Memory

- Volatile (unless has backup battery)
- 32 – 256 bytes

EEProm Memory

- *Non-volatile*
- 128-2048 bytes
- slow to read/write – need special routines
- limited life – typically 100,000 write/erase cycles

Microcontroller I/O

- Most I/O is digital – quantity being measured is voltage
- Logical 0 is close to zero volts (*Ground*)
- Logical 1 is close to Supply voltage (often +5V)

To measure any quantities, they must be converted into voltages.

Analog to Digital Conversion is possible

Eg – an 8 bit ADC will full scale of 3 volts:
- 0 volts will result in 0
- 1.5V will result in 127
- 3V will result in 255

Generally analog conversions are avoided if possible.

I/O Current Capability

AA cell 500mA for one hour (500mA-H)
- ⇨ 25mA for 20 hours
- ⇨ 1mA for 500 hours (approx 3 weeks)

I/O pin on Microcontroller can control up to 20mA (usually by connecting to ground - active LOW)

How useful is 20mA?

LED (light emitting diode)	1ma is visible 20mA is bright
Radio (depending on volume)	10-200mA
Small Motor	200mA-1000mA
Torch bulb	100mA-700mA
Hooter	150mA

Loads greater than 20mA need an Amplifier

Can use:
- a transistor
- a relay
- triac – to control 230VAC (great care is needed)

Timing

Microcontrollers can execute instructions very quickly:

- *Related to* their clock frequency
  - not necessarily the same
- Power consumption increases with clock rate

AVR Microcontrollers– one clock cycle / instruction

- 1MHz clock ==> 1 million instructions per second
- 10MHz clock==> 10MIPS

8051 family (original design) – 12 clock cycles / instr

- 12MHz clock => 1 million instructions/second (1MIP)

This is maximum rate, as some instructions take 2 or more cycles to execute.

How fast is this?

Human reaction time ~ 200mS (200 milli-seconds = 0.2s)

➔ microcontroller can execute nearly 200,000 instructions

Generating Tones

Human Hearing

20 – 20,000 cycles/second (Hertz – abbrev Hz)
felt heard only when young, (upper limit decreases with age)

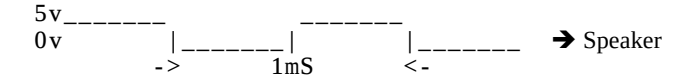
20 - 12KHz for adult

Human Hearing - Peak sensitivity ~ 1500 Hz

Speech ~ 300 – 3000 Hz

Middle C on piano = 440Hz

Tone Generator for 1000Hz – 1KHz




```
Loop
  set pin low
  wait for 500uS    // half of 1 millisecond
  set pin high
  wait for 500uS    // for r1:=count downto 0 do ;
goto Loop
```

```
; Tone Generator
; If processor is has 12MHz clock,
; each cycle takes 1us (one microsecond)


count  equ   250          ; define count=250

                          ;Time taken
Tone:  clrb  p3.7         ; 1uS      pin:=0

       mov   r1, #count   ; 1uS
stay0: djnz  r1, stay0    ; 2uS x 250

       setb  p3.7         ; 1uS      pin:= 1

       mov   r1, #count   ; 1uS      reload r1
stay1: djnz  r1, stay1    ; wait 500uS
       sjmp  Tone         ; do it again
```

- each half cycle isn't exactly 500uS but it's very close, so frequency ~ 1000Hz
- very inefficient way to generate a tone – processor is totally occupied – can't do anything else.