Control System Implementation

Hardware implementation

Electronic Control systems are also:
Members of the Mechatronic Systems

- Concurrent design (Top-down approach?)
- Mechanic compatibility
- Solve the actual task
- Separating the control system design from the mechanic "target" is a risky business

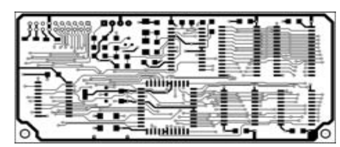
Printed Circuit Boards (PCBs) - #1

- Material requirements
  - Mech. stress
  - Electr. isolation (also at high frequency)
  - Thermal conductivity
- Materials used
  - Glass fiber dominating today
  - Ceramic materials for high thermal conductivity
  - Polymer materials for flexible PCB:s

Printed Circuit Boards (PCBs) - #2

PCB manufacturing process (simplified)

- Cupper foil attached (5-35 μm)
- Photo resistive coating
- Exposure with photo mask
- Develop pattern
- Etching



Conductive cupper pattern remains on board

Printed Circuit Boards (PCBs) - #3

- Through-plated via-holes connect the top and bottom layer
- Multilayer boards – same principle but thin layers pressed together. Then through-plated
- A lot of requirements can be met with modern PCB technology. But it's important to specify!

Electronic systems exposed to Environmental Factors

- Mechanical stress
  - Direct forces and torque can usually be avoided
  - Acceleration might be more difficult to handle
- Temperature
  - Check the classification of your components. Commercial, Industrial or (Military).
- Humidity
  - Coating , encapsuling.
- EMC

Analyzing the Control Task

- Task complexity
  - Understand the problem
  - Where is it possible to install control system parts
  - Centralized/ distributed control
- Speed requirements
  - Sensor/actuator time scheduling
  - Computational power requirements

A mutual understanding of Mechanical/Electrical design often gives the opportunity of solving a difficult problem by a minor redesign "on the other side"

Possible Solutions for the control Task

- Discrete analog circuit
- Discrete digital circuit
- ASIC (Application Specific IC)
- Programmable logic IC (PLD or FPGA)
- Computing unit (microcontroller, DSP…)

Discrete Analog Circuits - Opportunities

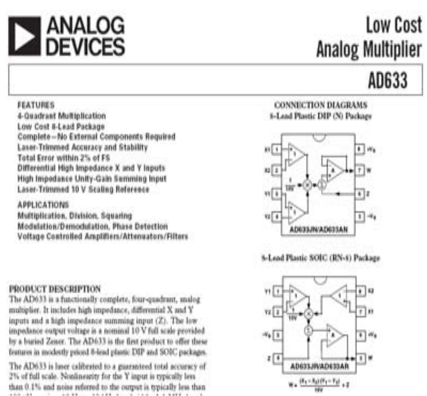
- Operational amplifiers (OP-amp)
  - Add, subtract
  - Filter
  - Derivative, integration
- Analog computation components
  - Multiplication
  - Logarithmic functions
  - Rms-detection…

Discrete Analog Circuits – Summary

+
- Continuous operation
- Fast (?!) processing of analog signals
- Cost effective

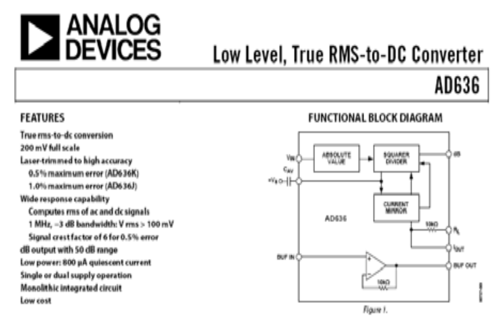
–
- Logical conditions difficult to include
- Interfacing problems
- Experienced engineer required

A multiplier for approx $9



What CPU do you need to emulate this?

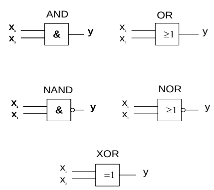
(< $6)



Discrete Digital Circuits

Gates, flip-flops, counters,registers...

- Simple logical problems
- Primary use today as support ("glue") to more advanced digital systems
- High speed applications

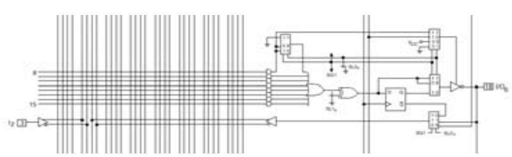


PLD - Programmable Logic Devices

- Logical function programmable. Several languages e.g. VHDL
- AND/OR -planes
- Pin mapping programmable
- Internal flip/flops makes internal state machines possible
- Comparable speed as discrete logic (often higher)

- Starts at discrete logic replacement at < 1$ cost/unit
- Large devices with several sub-blocks and interconnection matrixes

PLD structure example



GAL16V8 with a fraction of the programmable matrix and a macro cell

FPGA

Field Programmable Gate Arrays

- Larger than PLD but the borderline is not absolutely clear
- Programmable logic structures
- Several development languages e.g. VHDL
- Can include (Flash) memory, DSP
- Design supported by large libraries (IP: Intellectual Property)
- E.g. a large FPGA can very well be used to implement a microcontroller

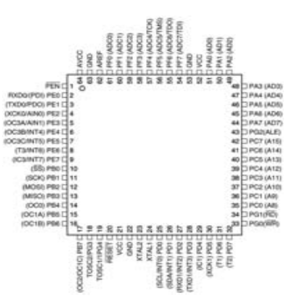
ASIC
Application Specific Integrated Circuit

- Full freedom. Analog or digital or mixed signal.
- Design supported by large libraries
  (IP: Intellectual Property)
- Design at transistor level possible
- Only used in large scale production since development costs are high. However, price per unit is low.

Microcontroller

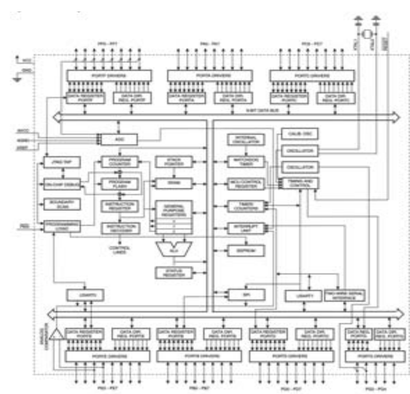
- Single chip computer. Complete system:
  - CPU
  - Memory
  - I/O devices including analog
  - Timer
- Few external components (if any)
- Low cost (< 1$ and upwards)

AVR ATmega128 - as an example



...
– Up to 16 MIPS Throughput at 16 MHz
– On-chip 2-cycle Multiplier
• Nonvolatile Program and Data Memories
– 128K Bytes of In-System Reprogrammable Flash
...
– 4K Bytes Internal SRAM
...
– Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
– Two Expanded 16-bit Timer/Counters with Separate Prescaler, Compare Mode
...
– Real Time Counter with Separate Oscillator
– Two 8-bit PWM Channels
– 6 PWM Channels with Programmable Resolution from 2 to 16 Bits
– Output Compare Modulator
– 8-channel, 10-bit ADC
8 Single-ended Channels
7 Differential Channels
2 Differential Channels with Programmable Gain at 1x, 10x, or 200x
– Dual Programmable Serial USARTs
– Master/Slave SPI Serial Interface
– Programmable Watchdog Timer with On-chip Oscillator
– On-chip Analog Comparator
...

AVR ATmega128 - overview



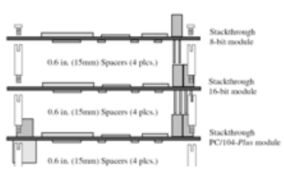
DSP
Digital Signal Processor

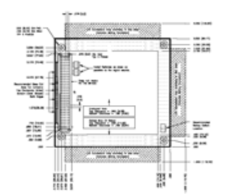
- Especially well suited architecture for signal processing (e.g. Filtering, FFT...)
- Few internal operations in each instruction gives a high execution rate
- The internal datapath can support a parallel execution at several stages.

Embedded PC

- The success of the PC architecture gives several economical advantages
- Stability problems not due to hardware
- Several standards for embedded PC exists (e.g. PC104)
- It is also possible to use an "industrial PC box" without any peripheral devices but equipped with LAN- and fieldbus-connections

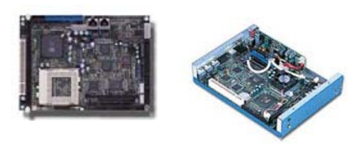
PC-104 standard for embedded PC
http://www.pc104.org





Various formats for embedded PC

Compact PCI



Free format

(PC104 host)

Industrial PC – Product Example

PLC
Programmable Logic Controller

- The fundamental industrial control system of the latest decades
- Originally only logic control but nowadays analog I/O and PID-loops
- Programming languages (IEC 61131-3)
  - Ladder Diagram (LD)
  - Function Block Diagram (FBD)
  - Instruction List (IL)
  - Structured Text (ST)
  - Sequential Function Chart (SFC)

Memory

- SRAM - Read/Write, Volatile, Static design
- DRAM - Read/Write, Volatile, Need cyclic refresh
- ROM - Read. Programmed in production
- PROM - Read, User programmable
- EPROM - Read, UV-Erasable user programmable
- EEPROM –Read, Electrically erasable
- Flash -Type of EEPROM

Rotating hard-disks are often avoided in embedded applications and replaced by disk-emulating EEPROM memories (Flash disk). Also in same housing (SSD).

Analog signals

- D/A conversion
  - Multiplying converter
  - PWM + LowPass filter (low cost solution)
- A/D-conversion
  - Successive approximation (microcontrollers)
  - Flash (fast)
  - Dual slope (high accuracy, slow)
  - Sigma/Delta

Sampling

- Sampling frequency is a critical factor
- The system has no idea what happened between the sampling instants
- Remember Nyqvist frequency: $f_N=f_s/2$

  (practically a factor 5-10 applied)
- Use filters

Galvanic Separation

When?

- Connecting to power systems
- EMC problem reduction when connecting different systems
- Grounding problem elimination

How?

- Relays
- Optocouplers (LED – phototransistor)
- Opto-fiber
- Isolation Amplifier (analog)