Embedded Systems and Microcontrollers

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Atmel Norway -- AVR Microcontroller

- Atmel Norway designs the AVR Microcontroller Family
- Predecessor: µRISC
  - Developed as a Diploma Thesis at NTH (NTNU)
  - In cooperation with Nordic VLSI
- Used as internal workhorse in several Nordic VLSI ASICs
- Processor core acquired by Atmel Corporation autumn 1995
- Atmel Norway started November 1st, 1995

What is a Microprocessor

- Definitions are fairly consistent
  - “A computer with its entire CPU contained on one integrated circuit.”
  - “A central processing unit implemented on a single chip.”
  - “A silicon chip that contains a CPU”
- Common understanding too narrow
  - Intel Pentium architectures
  - PowerPC
- Embedded Processors Account for 98% of the world’s microprocessors

What is an Embedded System?

- Definitions vary
  - “An Embedded System is any electronic product that incorporates a microprocessor”
  - “An Embedded System is a computer that is incorporated into another device, such as a car.”
- Examples
  - Cellular Phones
  - PDAs
  - Cars
  - Washing Machines
  - Battery Chargers

What is a Microcontroller?

- Processor Core
- Memories
- Digital Input/Output
- Analog Input/Output
- Peripherals
  - UART, USB
  - Timers
  - And more

Integrates a number of required components in an embedded system.

Existing microcontrollers

- Atmel AVR
- Motorola 68HC05, 68HC08, 68HC11, 68HC12
- Intel 80C51, 80C251
- Hitachi H8/300, H8/500, H8S
- Microchip PIC16, PIC17, PIC18
- ARM7, ARM7T, ARM9, ARM10
- Texas Instruments TMS370, MSP430
- Mitsubishi M16C, M32C
- And many more...
Embedded Systems usually incorporate one or several microcontrollers.

### Microcontroller Applications
- POS Terminals
- Cars
- Battery Chargers
- Cellular Phones
- Harddisks
- Keyboards, Mice, ...
- Laser Printers

### Applications in a Car
- ABS
- Anti-spin
- Instrument Panel
- Cruise Control
- Keyless entry
- Anti-Collision System

### AVR Block Diagram
- 64-pin Device (56 I/O, 8 Special Function)
- 128 Kbytes ISP Self-programmable Flash
- 4Kbytes SRAM
- 4Kbytes EEPROM
- 10-bit ADC with 8 Multiplexed Inputs
- Separate 32 kHz Oscillator with RTC
- Software Selected Clock Frequency
- UART, SPI, TWI
- Built-in Emulator support
- and more ...

### Peripheral Example: A/D converter
- ADC Control and Status Register (ADCSR)
- ADC data register (ADCH, ADCL)
- Successive approximation logic
- 10-bit DAC
- 8-channel Mux

### Peripheral Example: Digital I/O
- DDRx
- PORTx
- PINx
- Direction: INPUT
- Pull-Up: OFF (Tri-State)
Peripheral Example: Sleep controller

- Idle mode
  - CPU stopped
  - Peripherals and oscillator running
  - Typical power consumption: 10% of execution

- Power down mode
  - CPU stopped
  - Peripherals and oscillator stopped
  - Typical power consumption: 0.01% of execution

- Essential for battery powered applications

C Programming – need Extensions

- Initialization function for Hardware setup
- Special Function Register (SFR) for I/O access
- Interrupt functions
- Monitor functions for critical regions
- Routines for accessing Flash
- Intrinsic functions:
  - SFI, CLI, NOP, OPC, LPM, SLEEP, WDR
- EEPROM access routines

C Example: SFR / Intrinsic

```c
sfrb MCUCR = 0x35;
sfrb GIMSK = 0x3B;

int __low_level_init(void)
{
  GIMSK = 0xC0; /* Enable ext interrupts */
  MCUCR = 0x0F; /* Rising edge enable */
  _SEI(); /* Enable interrupts */
  return(1);
}
```

C Example: Interrupts

```c
interrupt[INT0_vect] void myInterruptHandler(void)
{
  unsigned char ucData;
  ucData = PORTB;
  if(ucData & 0x80)
    FunCall(ucData);
}
```

Developing a Microcontroller

- Specification
- Digital design and Verification
- Analog design and Verification
- Digital/analog Co-verification
- Lay-out
- Final Verification

Digital Design

- CPU, Interrupt Controller, DMA, Peripheral Functions etc.
- Developed in HDL (Verilog)
- Verification on HDL model
- Module Reuse and Improvement
- IP Modules
- HDL synthesis

Verilog Example:

```verilog
always @ (posedge clk )
begin
  // Register write
  if((adr==UCSRB_adr)&iowe) begin
    rxcie <= `DD dbus[7];
    txcie <= `DD dbus[6];
    ubrie <= `DD dbus[5];
    rxen <= `DD dbus[4];
    txen <= `DD dbus[3];
    chr9 <= `DD dbus[2];
  end
end
```
Analog Design

- Memories, ADCs, DACs, Regulators, Oscillators, PADS, etc.
- Analog modules implemented as schematic drawings
- Digital Interfaces
- IP Modules
- Process shrink (libraries) 0.35µ, 0.25µ, 0.18µ, 0.13µ

Lay Out

- The Digital Design has been synthesized to a low level representation
- The Digital Design has to be merged with the Analog Design
- The Lay Out must meet performance and size constraints

Silicon Die

- AVR Die Sales Program
  - AVR devices available in Die Form
- Micro Lead Frame Packaging
  - Low cost package technology
  - Very good noise immunity substrate connected to ground
  - Smallest standard package available
  - Near chip-scale package size; Save up to 69% of board space

New Package Options

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<th>SOIC / NSOP</th>
<th>MLF</th>
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<td>81</td>
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<td>16 x 16</td>
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Development Tools

- Complete suite of development tools needed to be made
- ANSI compliant C Compilers
- Macro-Assemblers
- Linkers/Librarianes
- Debuggers/Simulators
- RTOS
- In-Circuit Emulators
- Evaluation boards
- Programmers
- Design notes, Application notes and Reference designs

STK500 Development Board

- Supports all AVR devices
- Supports all Operating Systems
- Interfaces with AVR Studio
- Early support for new devices
**Emulators**

- Complete C and Assembly Source Code for AT904433 and ATtiny15
- Code library for SLA, NiCd, NiMh and Li-Ion Batteries
- Complete Battery Charger design based on Buck Converter
- RS-232 Port For General Use

**Battery Charger Reference Design**

**The Internet**

- Information
  - Services
    - Bank services
    - Shopping
- Remote Control
  - Smart House, Video, Alarm, Camera
- Automatic
  - Washing machine
  - Micro Wave Oven
  - Refrigerator

**Embedded Internet Toolkit**

- Complete reference design for web server
- Full TCP/IP stack
- Complete modular C-source code
- Onboard Ethernet interface