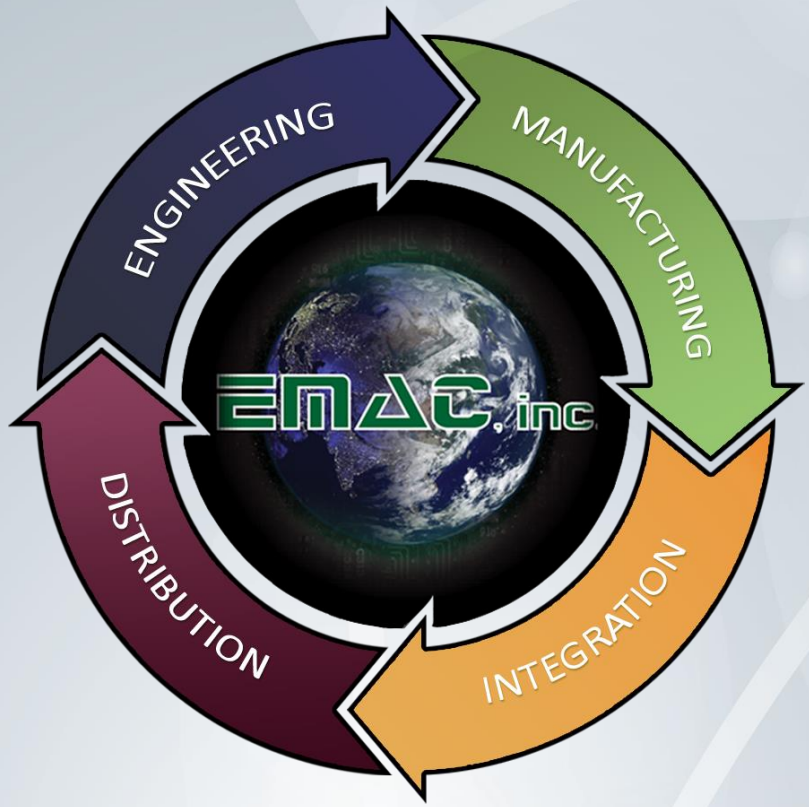
Equipment Monitor And Control



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Designing Low Power Embedded Systems

Presented by Eric Rossi
Engineering Manager
EMAC, Inc

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EMAC, Inc Overview

- Engineering Services both Software & Hardware
- Integration Services (Box Builds, Wiring Panels, etc.)
- Manufacturer of Electronic Assemblies
- Sale of Off-The Shelf SBCs, SOMs, PPCs, Servers

Low Power Overview

Embedded System designers need high reliability, but also must conform to typical design constraints of low-power, long life, and extended temperature operation.

Typical Constraints-

- **Extended Product & Battery Life (5 to 10yrs)**
- **Operating at High or Low Ambient Temperatures-**
- **Operating in Harsh Environments**
- **Seasonal Battery Charging-**
- **Safety Concerns-**
- **Cost**

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Low Power Overview

Presentation Topics & Case Studies

- Low Power Considerations (what is a low power system?)
- Power Sources
- Memories
- Peripherals
- Software
- Tools
- Microcontroller Systems
- Microprocessor Systems
- Mixed Multi-Core Systems

Low Power Considerations

- Low Power Considerations
  - Clock Frequency-
    - Dynamic External Oscillator (eg. SI5351A)
    - Crystals & Load Capacitance-
    - Internal RC Oscillators (varies over temperature)-
    - Dynamic Programmable Processor Clock
  - Regulators & System Voltage
    - Linear Regulators
    - Low-Dropout Regulator (LDO)
    - (Dynamic) Switching Regulator (efficiency)-
  - Undriven Inputs, Pullups & Voltage Dividers

Low Power Considerations (cont)

- **Low Power Considerations**
  - **Caps**
    - **Avoid Aluminum Electrolytic Caps (High Leakage)-**
    - **Leakage Current can be decreased by increasing voltage rating of the Cap**
    - **Use low ESR Caps in switching circuits (switching regulators)**
    - **Minimize the number of Caps-**
    - **Use SuperCaps for Additional Power-**

Low Power Considerations (cont)

- Power Sources
  - Battery & Charging
    - Always Low Power or just when on Battery
    - Last Gasp (SuperCap or Battery)
    - Non-Rechargeable
      - Carbon Zinc (3-5 yr shelf life; poor capacity)
      - Alkaline (5-10 yr shelf life; ok capacity)
      - Lithium (10+ yr shelf life; good capacity)

Low Power Considerations (cont)

- Power Sources
  - Battery & Charging
    - Rechargeable Battery
      - NiCad (~2 yr shelf life; Temp tolerant; 1000+ cycles; Memory)
      - Nickel Metal Hydride (~3 yr shelf life; No Memory; ~800 cycles)
      - Lithium Ion (~3 yr shelf life; ~1000 cycles)
      - Lead Acid (<1 yr shelf life; ~200 cycles; wide temp)

Low Power Considerations (cont)

- Power Sources
  - Battery & Charging
    - Smart Batteries (SMBus)
    - Protected Batteries
  - Energy Harvesting
    - Storage (Cap or Battery)
    - Types: Light, Wind, Running Water, RF, Mechanical (Kinetic), Thermal

Low Power Considerations (cont)

- Memories
  - Cache (enable or disable)
  - RAM
    - Static RAM (~5.5uW)
    - LP DDR Self Refresh
  - Flash
    - Serial NOR (~2x more power than Parallel NOR)
    - Parallel Flash - NOR (int; lower standby) & NAND (lower active)
    - Managed NAND (eMMC, Thumb Drives, etc.)
  - FRAM/MRAM (Non-Volatile Faster, Lower Power, expensive, lower capacity)

Low Power Considerations (cont)

- Peripherals
  - Serial & CAN Ports
  - Ethernet
  - USB-
  - LCDs (OLED, reflective, e-paper, transmissive)-
  - Analog
    - Analog Bias Settings (reduce bias current)
    - References
    - Analog Blocks in Micros (Comparator, A/D, D/A)
    - Analog Switch & Relays (Pick-up vs Holding)-

Low Power Considerations (cont)

- Peripherals
  - Wireless
    - LANs - Low Power Local Area Networks (6Lowpan, Thread, Zigbee, Zwave, BLE, Wi-Fi HaLow 802.11ah)
    - WANs - Low Power Wide Area Networks (LoRa [10 yr battery], LTE Cat-M1, NB-IoT, Sigfox)
    - Combo – Integrated Microcontroller & Radio
    - Radios and Battery Operation (Repeaters)

Low Power Considerations (cont)

- Peripherals
  - Global Positioning System (GPS; I2C or Serial)
    - First Fix (Searching; ~35mA)
    - Tracking (~25mA)
    - Hibernate/Sleep/Standby (No RF; microamps)
  - Autonomous Peripherals
    - Smart Sensors (event driven)
    - Smart I2C (ADT75 Temperature & H3LIS100DL Accelerometer)
    - DMA (Sleep DMA)

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Software & Tools

- Software Techniques
  - Polling Loops vs Timers (idle mode)
  - Event Reduction (increase the number of tics when scheduling threads)
  - CPU Frequency (dynamic prescaling; PLLs)
  - I/O Line contention & I/O Line Pull-Ups
  - Low Power Sleep
    - To Sleep or not to Sleep
    - Going into and Coming out of Sleep
      - Delays
      - Power Restoration
    - Interrupt Sleep-On-Exit feature

Software & Tools (cont)

- Tools
  - Energy Profilers (ULPBench)
  - Battery Life Estimator (BLE; Microchip)
  - EEVbog uCurrent Meter
  - Qoitech OTII-ARC
  - Hitex PowerScale (multi-channel but expensive)
  - Benchmarks (used for comparing processors; CoreMark & ULPmark)
  - ARM Mbed OS (supports Sleep modes)
  - MicroPython (supports Sleep modes)
  - FreeRTOS & Atollic (supports Sleep modes)
  - Linux (Xenomi, Qt, OE, Yocto, Qt Creator; ACPI)
  - Windows 10 (Battery Saver; ACPI)

Low Power Microcontrollers

- Microchip PIC
  - Sleep/Standby Modes (Microchip PIC)
    - Run Modes (Fast Run; Low Power Run – Slower Clk Source)
    - Idle Modes (CPU Halted; Int Wkup; Periphals Active)
    - Sleep Modes (CPU Halted; Int Wkup; Limited Peripheral Operation, GPIOs continue to drive)

Low Power Microcontrollers (cont)

- Microchip/Atmel AVR (Arduino)
  - Sleep/Standby Modes
    - Idle Mode (Stop CPU & Flash Clocks; Int Wkup)
    - Power-Down (Stop EXT Osc; Single Int Wkup)
    - Power-Save (Same as Power-Down but Timer/Counter 2 continues to run)
    - Standby (Same as Power-Down but CPU Clock is kept running; fast wakeup)
    - Extended Standby (Same as Power-Save but CPU Clock is kept running; fast wakeup)

Low Power Microcontrollers (cont)

- ARM – M0, M3, M4
  - Sleep/Standby Modes (Silicon Labs ARM Cortex M)
    - EM0 - Run/On
    - EM1 - Sleep (No CPU Clock)
    - EM2 - Deep Sleep (Slow Clock – 32KHz)
    - EM3 - Stop (Interrupt wakeup)
    - EM4 - Shutoff (Reset wakeup)

Low Power Microcontrollers (cont)

- General Low Power Selection Criteria
  - Minimize the number of I/O pins
  - Minimize the number of internal peripherals
  - Verify that a low-power timer is included on the MCU
  - Make sure that a DMA controller is included
  - Pay attention to Sleep Modes

Low Power Microprocessors

- **ARM**
  - ARM9 (older & slower but less leakage)
  - ARM Cortex A5
  - ARM Cortex A7
  - ARM Cortex A32

- **X86**
  - Vortex (DMP)
    - SX, DX, DX2, EX, DX3

    (~1 watt for DX; ~4 watts for a DX system)
  - Atom
  - i3

Low Power Microprocessors (cont)

- Sleep/Standby Modes (APM/ACPI)
  - Run/On
  - Idle mode (System Idle Process; Automatically enters Standby)
  - Standby (Partial Clock; Subsystems in LP mode; RAM active)
  - Slow Clock Mode (APM Sleep; Slow Clock 32khz; RAM Self Refresh)
  - Suspend (Suspend to RAM; Deep Sleep; No Clock; Long Restore Time)
  - Hibernate (Suspend to Disk; Long Restore Time)
  - Stop/ Off

Low Power Microprocessors (cont)

- Utilization of PLD or Low Power Coprocessor
  - Shared Memory & DMA
  - Buffering
  - Power Management

- Mixed Multi-Core Technology
  - TI ARM Cortex A8 & Programmable Real Time Unit (PRU) (eg. AM335x)
  - NXP ARM Cortex A & Cortex M (eg. i.MX6 SoloX)

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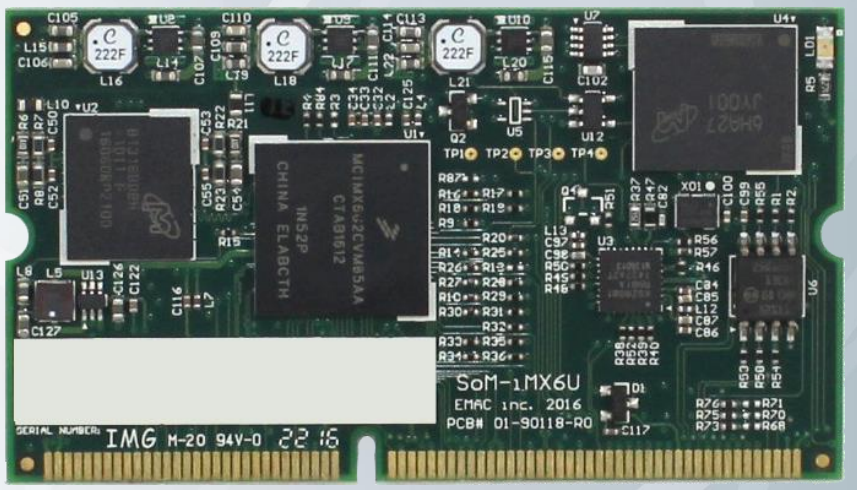
Case Study #1 (Back ->)

SoM-IMX6U System on Module

- Power Source 3.3v
- NXP i.MX 6 Ultralight ARM Cortex A7 Processor
- Dynamic Core Regulation
- ~ 2.5mA in APM Slow Clock Mode (32KHz)
- ~ 130ms to come out of sleep
- Ethernet & CAN Connectivity
- Linux OS



Case Study #2
Windows Industrial Tablet

- Power Source
  - 19.2 Vdc Laptop Power Supply
  - 2x Smart 14.4 Vdc Li Ion batteries (hot swap)
- ST Micro ARM M4 Coprocessor (power management)
- Intel E3900 Atom SMARC SOM based
- APM Power Management
- Windows 10 Embedded OS
- Wifi & Bluetooth Connectivity via PCIe Module

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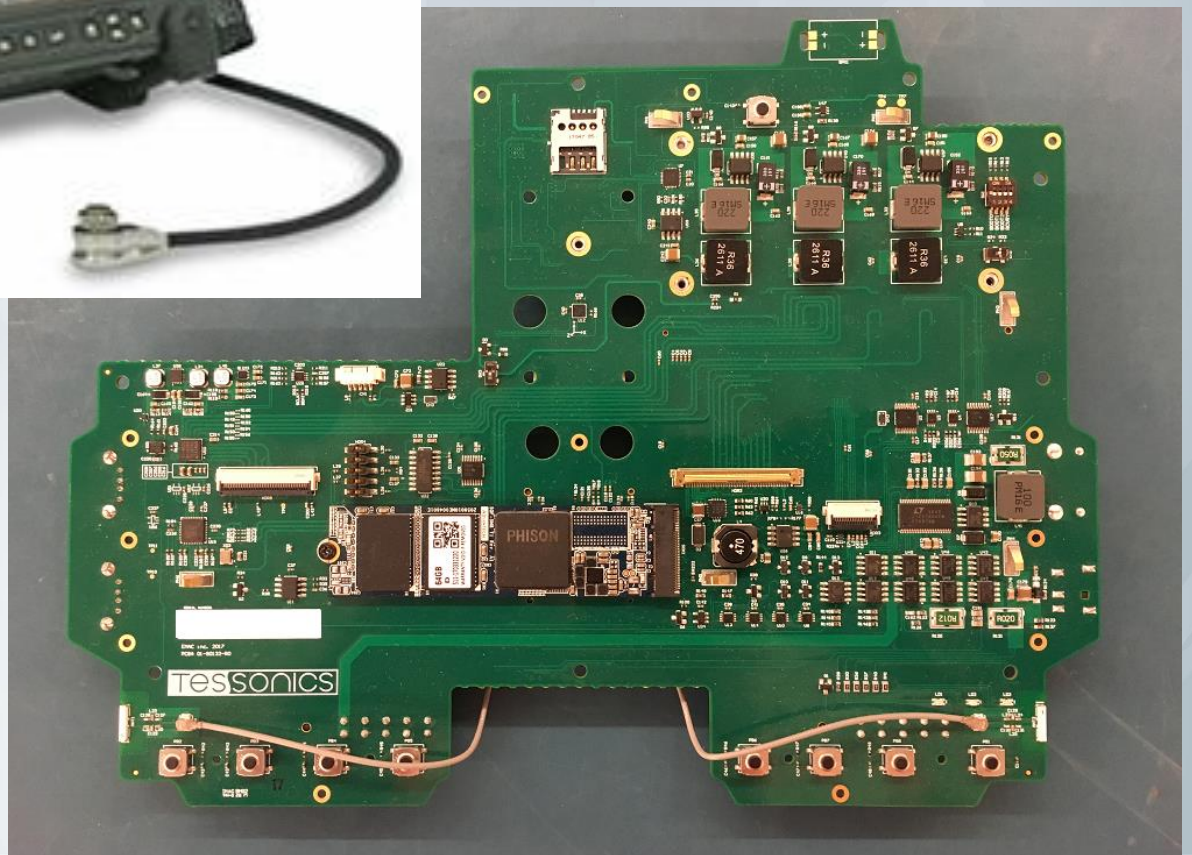
Case Study #2

(Back ->)

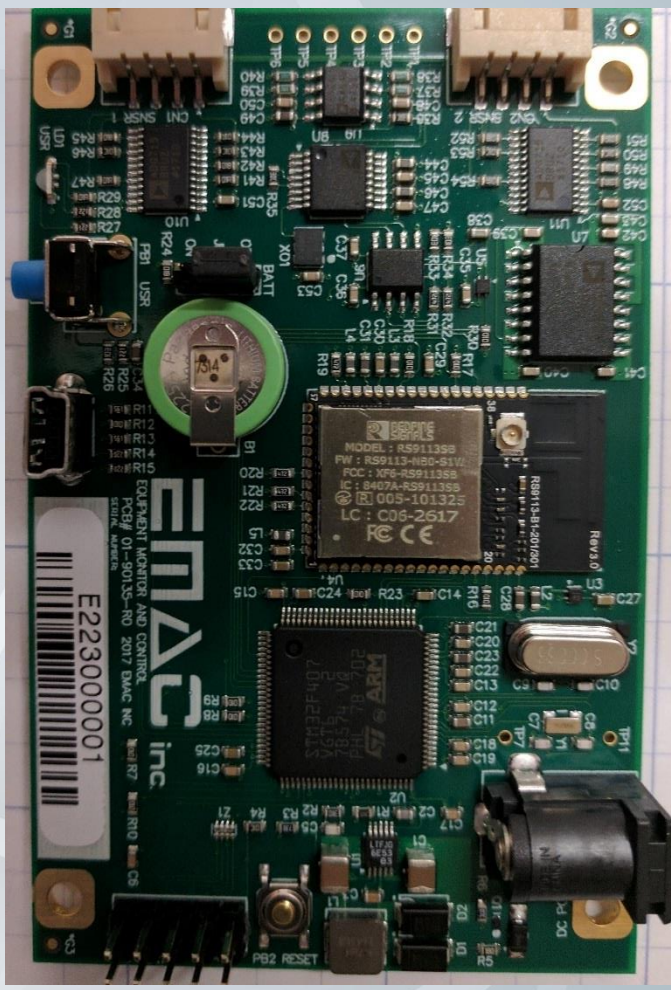


Case Study #3 (Back ->)
Wifi Communication Module

- Power Source
  - 5 Vdc Supply
- SuperCap (2.5F) for Last Gasp (~15 Seconds @ ~250mA)
- ST Micro ARM Cortex M4 Processor
- FreeRTOS OS
- Wifi Connectivity (Silicon Labs)

Case Study #4 (Back ->)
Water Purity Device

- Power Source
  - 12V Wall Power Supply
  - Non-Rechargeable Battery (6x AA Cell battery pack)
- ST Micro ARM Cortex M4 Processor
- MicroPython OS
- Wifi & Bluetooth Radios (Redpine)
- IBM Bluemix Cloud
- 3 Independent Power Modes
  - Processor, Radio, Analog Sleep



Case Study #5
Automated Camera Tracking System

- Power Source
  - 3.5 Vdc Lithium Ion Battery (x4 in parallel)
  - USB 5Vdc alternate power and charging
- Qualcomm Snapdragon 410E ARM A53 64-bit processor
- Camera Interface
- Wifi & Bluetooth Connectivity
- Android Embedded OS

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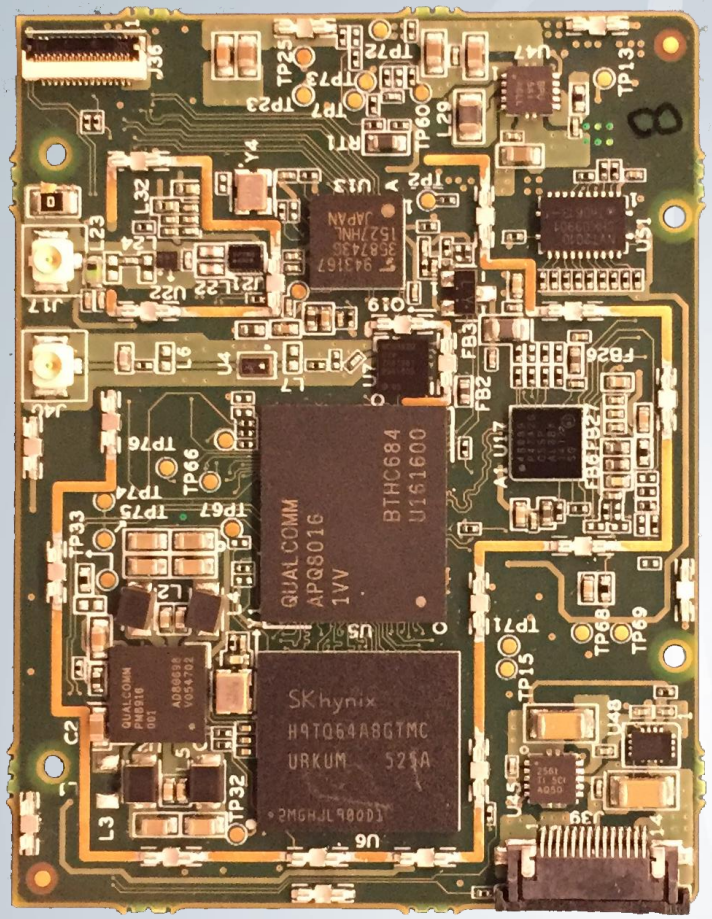
Case Study #5 (Back ->)
Automated Camera Tracking System



Case Study #6
Medical Patient Simulator

- Power Source
  - 19.2 Vdc Laptop Power Supply
  - 2x Smart 14.4 Vdc Li Ion batteries (hot swap)
  - LTC1760 Dual Smart Battery Manager
- Intel E3845 Atom COM Express SOM based
- APM Power Management
- Linux Embedded OS (EMAC OE 5.0)
- 1000 BaseT & Wifi Connectivity
- 8 Regulators (1.5v, 3.3v, 2x 5v buck, 3.3v LDO, 24v Boost, 2x 12v Boost/Buck

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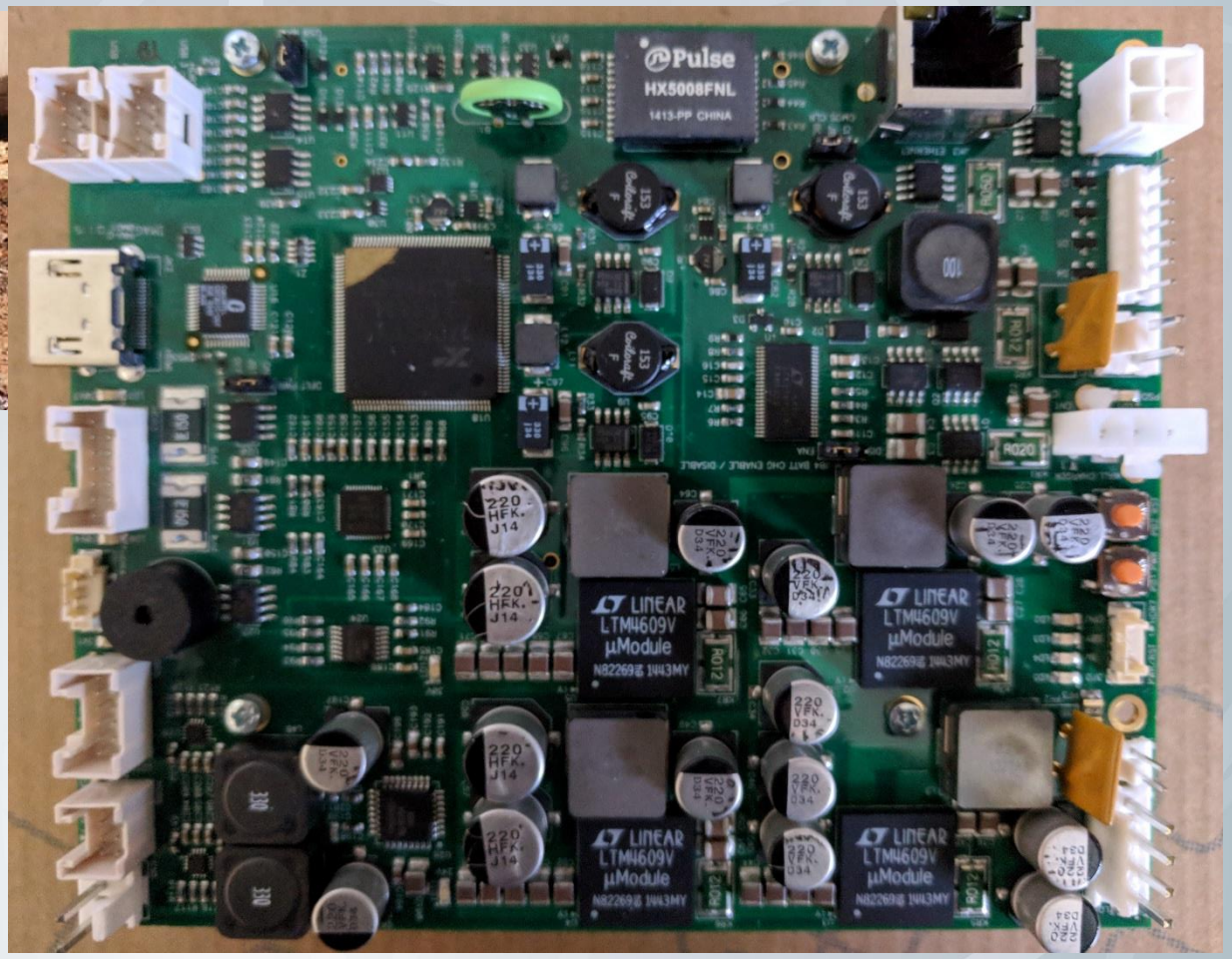
Case Study #6 (Back ->)
Medical Patient Simulator



Case Study #7 (Back ->)
Ambient Ear Buds

- Power Source
  - Rechargeable Battery 3.3v Lithium Ion (with protection)
  - 5v (USB; for power and charging)
- ST Micro M0 Power Management & Control Processor
- CSR Bluetooth Radio
- Analog Device DSP

Case Study #8
Artic Glacier Monitor

- Power Source
  - Rechargeable Battery 12v Lead Acid (Gel Cell)
  - Solar Energy Harvesting
  - ~3.2mA in Sleep
- SoM-9260 (AT91SAM9260) & SoM-IMX6U (IMX6UL)
- Microchip PIC Power Management & Watchdog Proc.
- Satellite Radio
- USB Camera
- Magnetostrictive, Accelerometer, Pressure, Temperature, Humidity Sensors
- 5 Serial Ports & CAN

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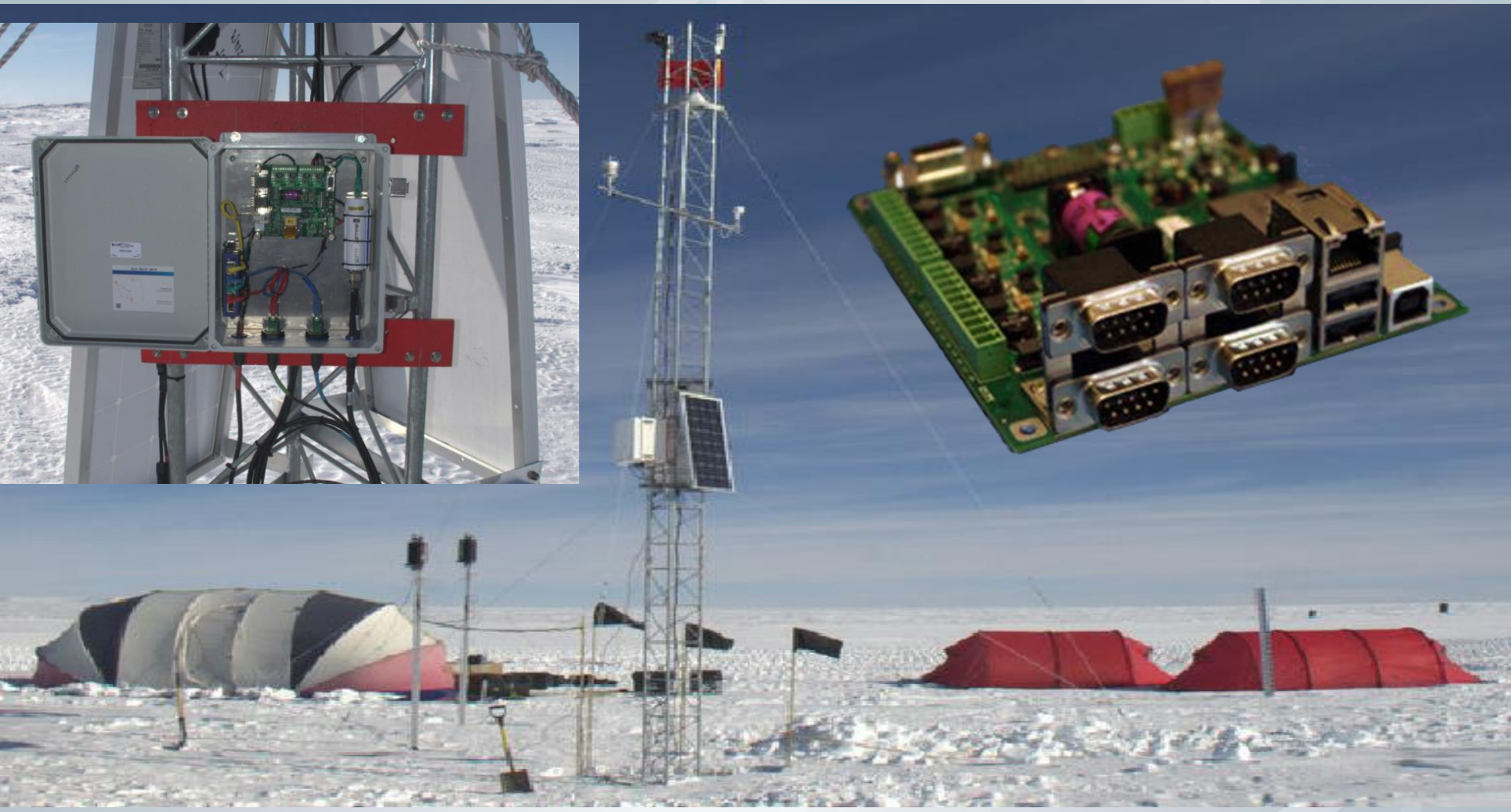
Case Study #8 (Back ->)

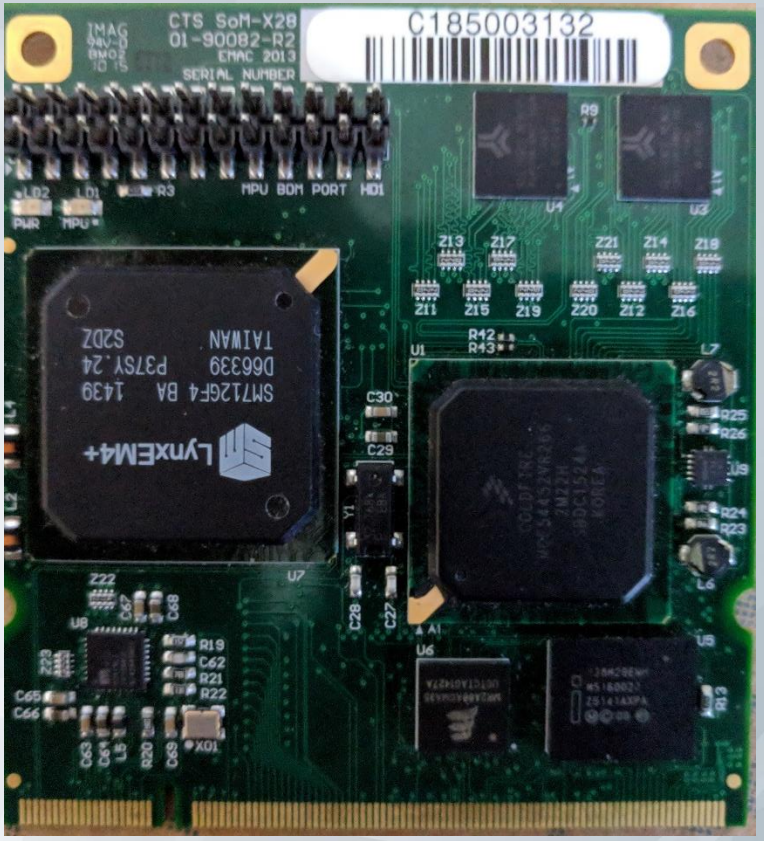
Arctic Glacier Monitor



Case Study #9 (Back ->)

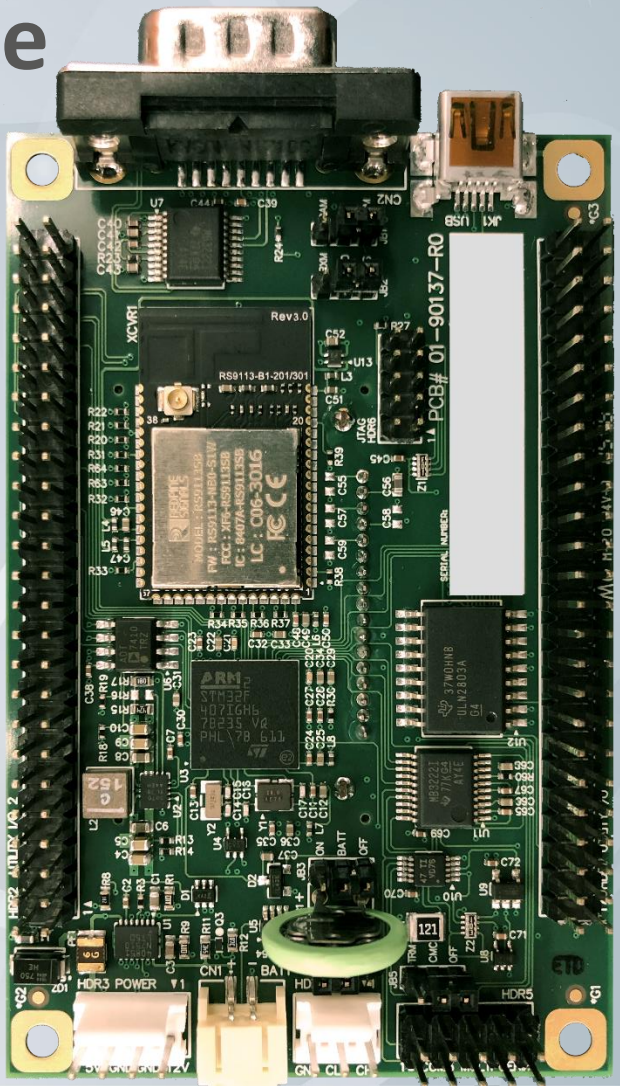
Custom System on Module (SoM)

- Power Source
  - 3.3v
- Coldfire Processor
- Lynx PCI Video Controller
- Linux OS
- MRAM (4Mb; Everspin)
- USB
- Ethernet & CAN Connectivity



Case Study #10 (Back ->)
CutiPy™ IoT Device

- Power Source
  - 5V Power Supply or USB
  - 3.8v rechargeable Li-Ion battery (LT4085 Battery Power Manager)
- ST Micro ARM Cortex M4 Processor
- MicroPython or Free RTOS OS
- Bluetooth, Zigbee, Thread & Wifi
- Graphic LCD & Pushbuttons



Case Study #11 (Back ->)
Electric Vehicle Charging Station

- Power Source
  - 5v Power Supply
- SoM-9G45 Module (AT91SAM9G45)
- Linux OS
- Cell Modem (Telit; 3g LTE)
- Wifi (Wi2Wi)
- TPM (Trusted Platform Module) Chip (high security application)

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Case Study #12 (Back ->)
Emergency Vehicle Location Device

- Power Source
  - 9v – 15v Vehicle Power Supply (Alternator)
  - 12v Vehicle Battery
- ST Micro ARM Cortex M4 Proc.
- MicroPython OS
- Cell Modem (Telit 4g LTE)
- GPS Location
- Amazon AWS Cloud

Case Study #13
Open Road Tolling (ORT) System

- Power Source
  - 12vdc Power Supply
- SoM-IMX6M ARM A9 Dual Core Module
- Linux OS with Xenomai Real Time Extensions
- 2 Ethernets with 6 Port on board Switch & CAN Connectivity
- PIC 12F635 ATX Power Management Coprocessor (~12uA in sleep; wakes up every 90 sec to reset timer)
- Replaces a Atom based solution with active cooling

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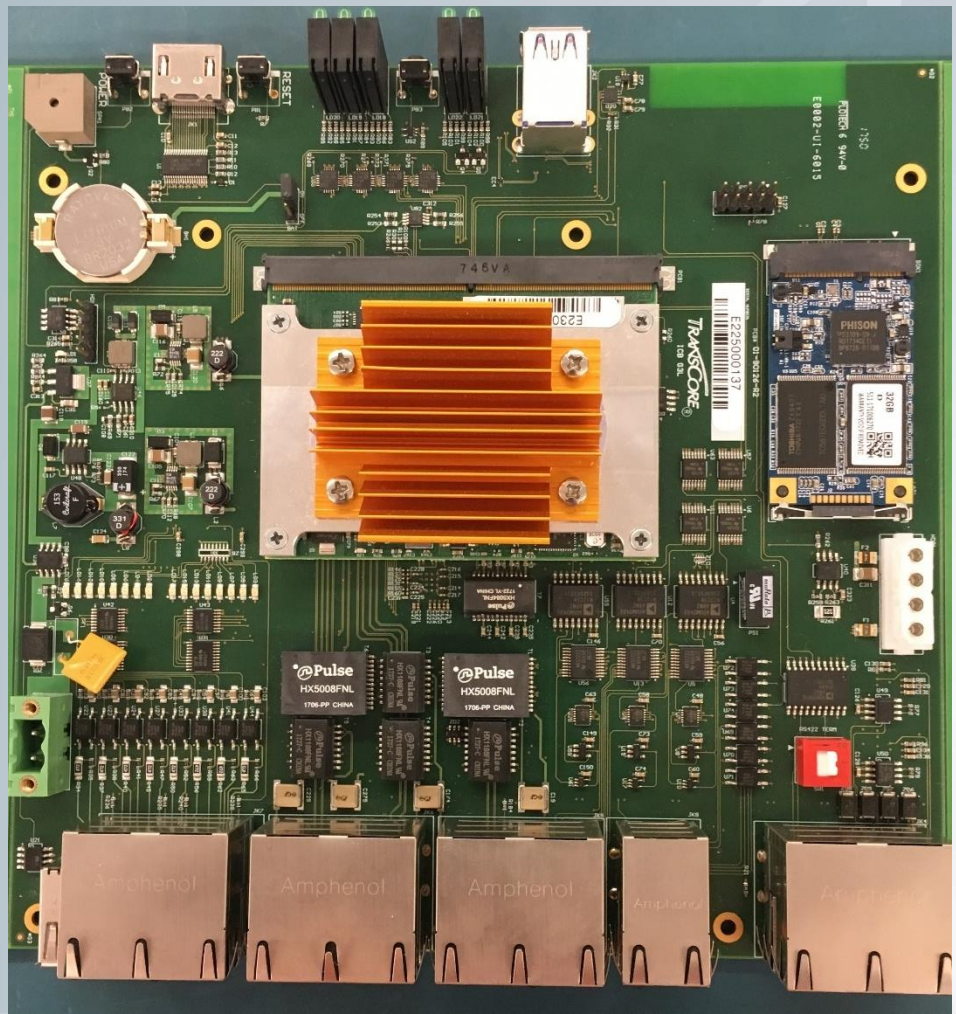
Case Study #13 (Back ->)
Open Road Tolling (ORT) System



Case Study #14 (Back ->)

Gas & Water Metering System

- Power Source
  - 12.0 vdc Power Supply
  - 12.6 vdc Lead Acid (Gel Cell) Standby Battery
- SoM-9260 ARM9 Module
- Altera PLD for Pulse Counting (< 150uA in Standby)
- Ethernet & Cell Modem Connectivity
- Over 30 days on Standby Battery
- Linux OS

Case Study #15 (Back ->)

SoM-3354 System on Module

- Power Source 3.3v
- TI AM3354/3357 ARM Cortex A9 Processor
- Programmable Real Time Unit (PRU) / Industrial Communication SubSystem (ICSS; PRU-ICSS)
  - EtherCAT
  - PROFIBUS/PROFINET RT/IRT
  - HSR/PRP
- Ethernet & CAN Connectivity
- Linux OS

Figure #1 (Back ->)

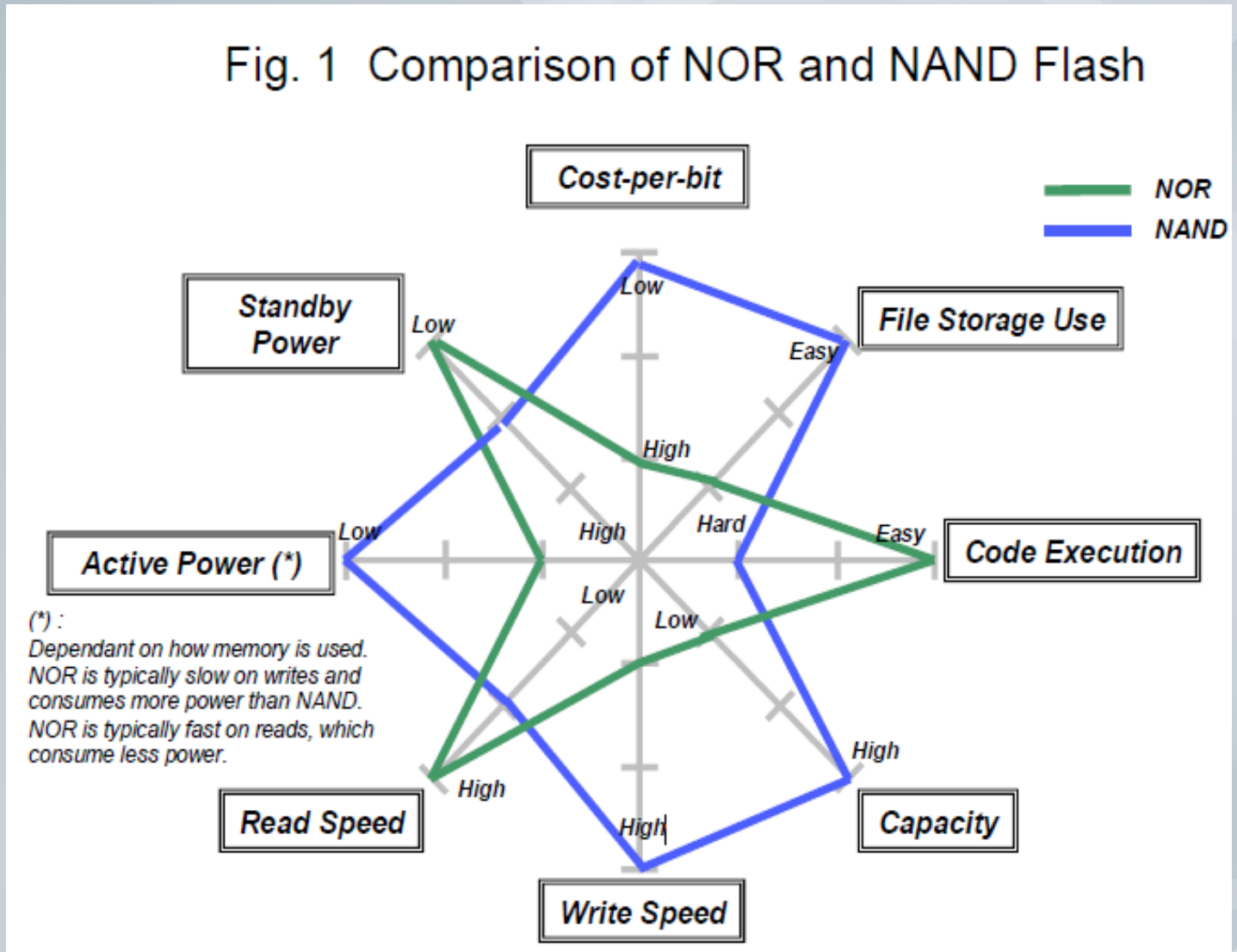


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Figure #2 (Back ->)

	Wi-Fi HaLow	Bluetooth low energy (5)	ZigBee	Thread	Sub-GHz IEEE 802.15.4
Max. data throughput	347 Mbps	2 Mbps	250 kbps	250 kbps	100 bps
Max. line-of-sight range*	N/A[1]	750 m	130 m	100 m[7]	4000 m
Power consumption	N/A[2]	Years from a coin cell	Years from a coin cell	Years from a coin cell	Years from a coin cell[8]
Mesh networking	Yes	Yes[4]	Yes	Yes	No
IP at the device node	Yes	Yes[5]	No	Yes	No
OC/mobile OS support	Yes	Yes	No	No	No
Infrastructure in place	Yes, routers[3]	Yes, mobiles[6]	No	No	No

1. Said to be greater than Bluetooth 5
2. Said to be comparable with Bluetooth 5

Figure #3 (Back ->)

Silicon Labs Energy Modes

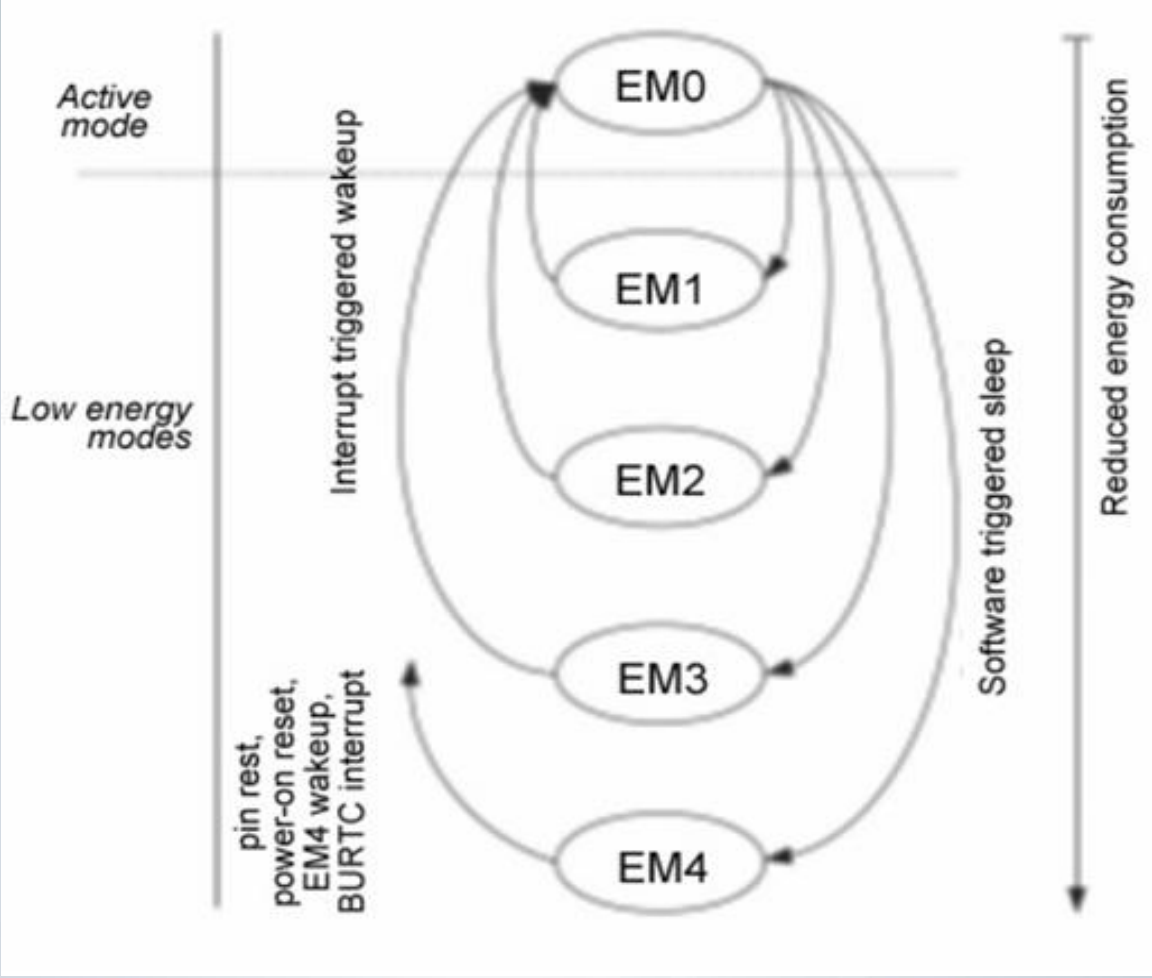
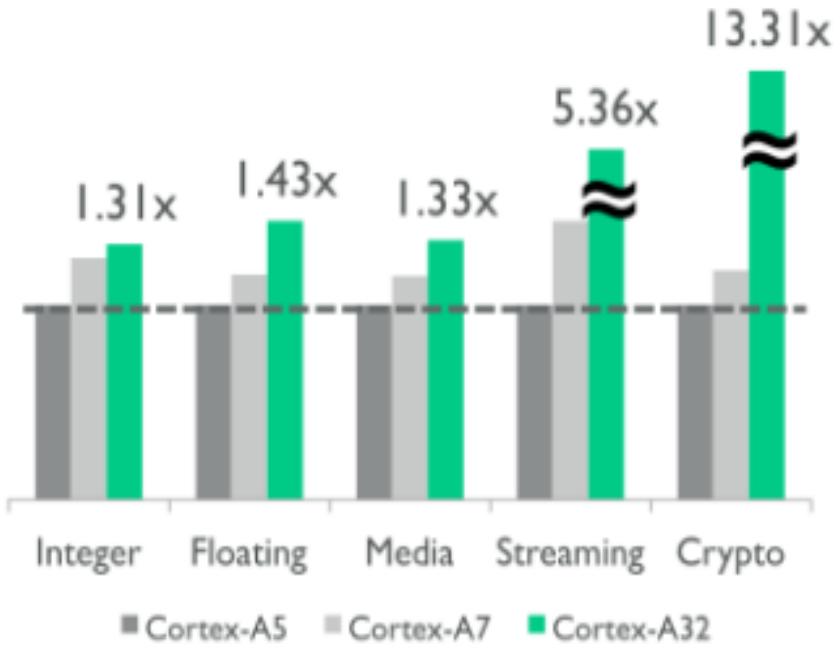


Figure #4 (Back ->)

- Higher performance than Cortex-A5 and Cortex-A7
- Same performance as Cortex-A35



Efficiency Improvement

>25% vs. Cortex-A7

>30% vs. Cortex-A5

>10% vs. Cortex-A35

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Figure #5 (Back ->)

Comparison of ARM, Atom, i7				
	Cortex A15 (no L2, 32nm)	**Cortex A9 (no L2, 40nm)**	**Atom N270 (45nm)**	**I7 960 (45nm)**
Number of Cores	2 (4 maximum)	2 (4 maximum)	1 Core, 2 HT threads	4 Cores, 8 HT threads
Frequency	1Ghz – 2.5 Ghz	800Mhz (Po) 2Ghz (Per)	1.6 Ghz	3.2 Ghz
Out-of-Order?	Yes	Yes	No	Yes
L1 cache size	32KB I/D	32KB I/D	32KB I/D	32KB I/D
L2 cache size	N/A	N/A	512KB	1MB + 8MB L3
Issue Width	4	4	2	4?
Pipeline Stages	?	8	16	14 ~ 24 (?)
Supply Voltage	?	1.05V (Per)	0.9 – 1.1625 V	0.8-1.375 V
Transistor Count	?	26,00,000?	47,000,000	731,000,000
Die size	?	4.6 mm2 (Po) 6.7 mm2 (Per)	26 mm2	263 mm2
Power Consumption	?	0.5 W (Po) 1.9 W (Per)	2.5W (TDP)	130W (TDP)