Agile Sensor Design for the Smart Grid

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Richard Newell Actel Corp.
David Brain Smartgrid Technologies Ltd.

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Agenda

- The why and what of smart grid
- GreenFire sensor – architecture and requirements
- Implementation technologies
- Design process
- Prototype system and demo

I. The Why and What of Smart Grid

What is Smart Grid?

- The Enernet, a layered energy grid akin to the Internet

  Bob Metcalf, Inventor of Ethernet, Founder of 3Com and Venture Capitalist
- Plug and play—scalable micro-generation, like a mobile phone
- The third Industrial Revolution

  John Scott, former Director of Engineering for National Grid, and Technical Director of OFGEM (UK)
- Your car becomes a small mobile power plant.

  Jeremy Rifkin, President of the Foundation on Economic Trends and advisor to several EU heads of state
- Smart grid probably offers the potential for as much engineering work in the next few decades as the Internet or the Apollo program provided across a similarly broad range of technical disciplines.

  EPRI

Sensors Everywhere

The next phase in smart grid technology is to embed sensing devices and chips throughout the system, connecting every electrical appliance. Software allows us to know how much energy is being used, at any time, anywhere on the grid.

– Jeremy Rifkin

Energy Systems Today

- Using energy today is like using a phone in the ’50s
  - Locked to a specific physical location
  - Unidirectional
  - Fixed, inflexible tariff structures
  - Limited visibility of actual usage
  - Ancient technology
- There must be a better way…
- The GreenFire system

The Virtual Energy Account

- One account which is associated with a specific home base
- Integrates all transactions across all physical locations
  - Supports micro-generation
- Security device (phone, smartcard, key fob) used to authenticate and authorize energy transactions away from home base
- Supports electric and hybrid cars, laptops, etc.

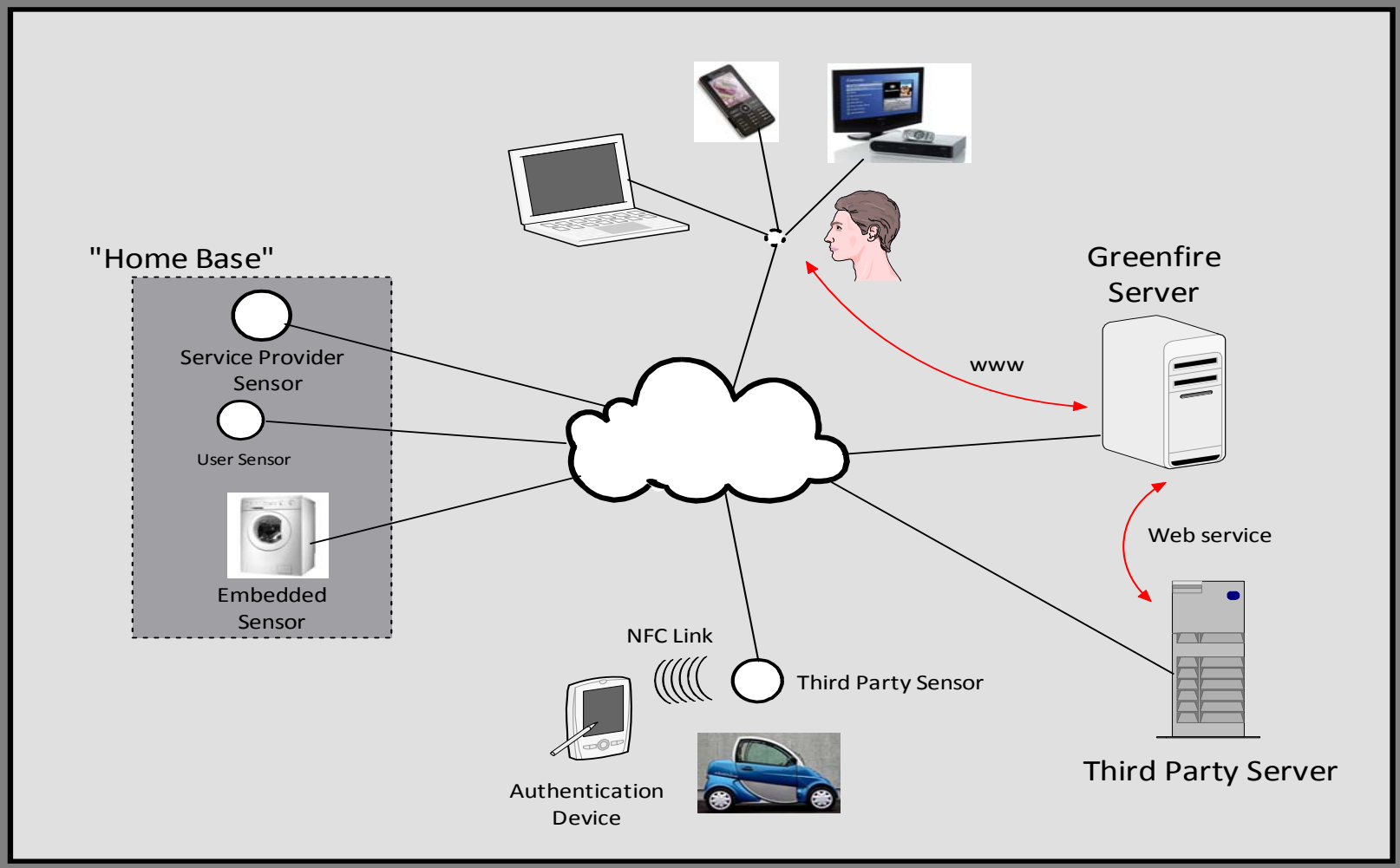
Dynamic Tariffs

- Special electricity meters are sometimes used to allow access to cheaper electricity tariffs
  - In the UK, Economy 7 white meters are used with storage heaters
  - Require special (expensive) wiring
  - Inflexible
- GreenFire sensor with actuator offers a better alternative
- Electricity distributor advertises current tariffs via server
- Each sensor registers opportunistically with server when attractive tariff becomes available
- Turns on associated appliance
- Turns off appliance when tariff is no longer available

Energy Signature

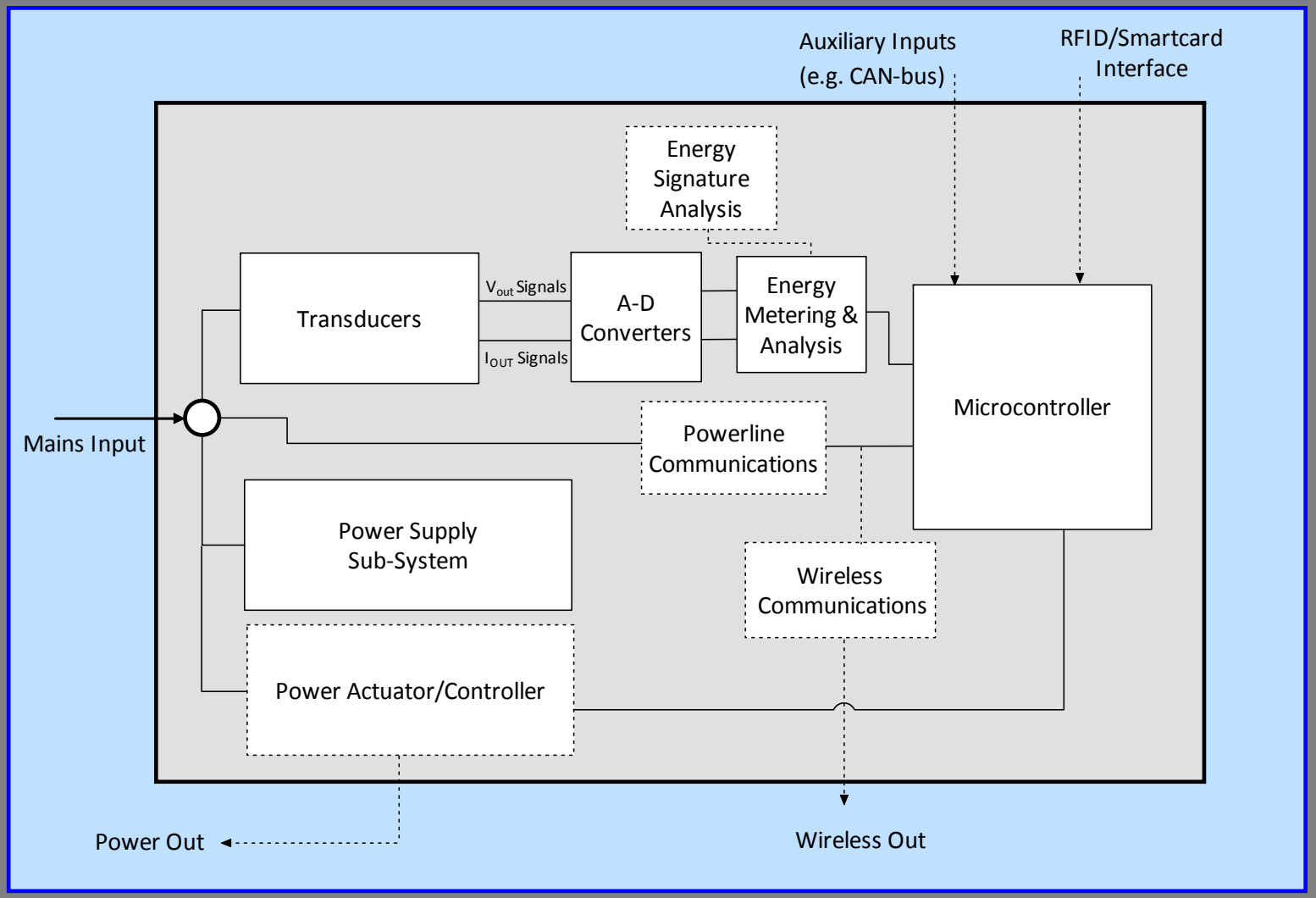
- Parameters derived from energy usage signature are used to determine if appliance is operating correctly.
- Parameters are derived from time domain and frequency domain analysis using DSP techniques.
- Manufacturers' data defines correct and incorrect operational footprints.
  - Can fault find if footprint data sufficiently rich
  - Can feed back operational data to aid in future design process
- Messaging system can also be used to send diagnostic and maintenance information from more equipment
  - OBD-II data from electric vehicles

GreenFire System Architecture



II. Sensor Architecture and Requirements

Sensor Architecture



Key Requirements: Hardware

- High integration
  - Microcontroller
  - IP communications
  - Flexible DSP
  - Flexible logic
  - Analog converter circuitry
- Low cost and low power
  - “A sensor in every socket”
- Security
  - Tamper resistance; on-chip key storage and boot code

Key Requirements: Embedded Software

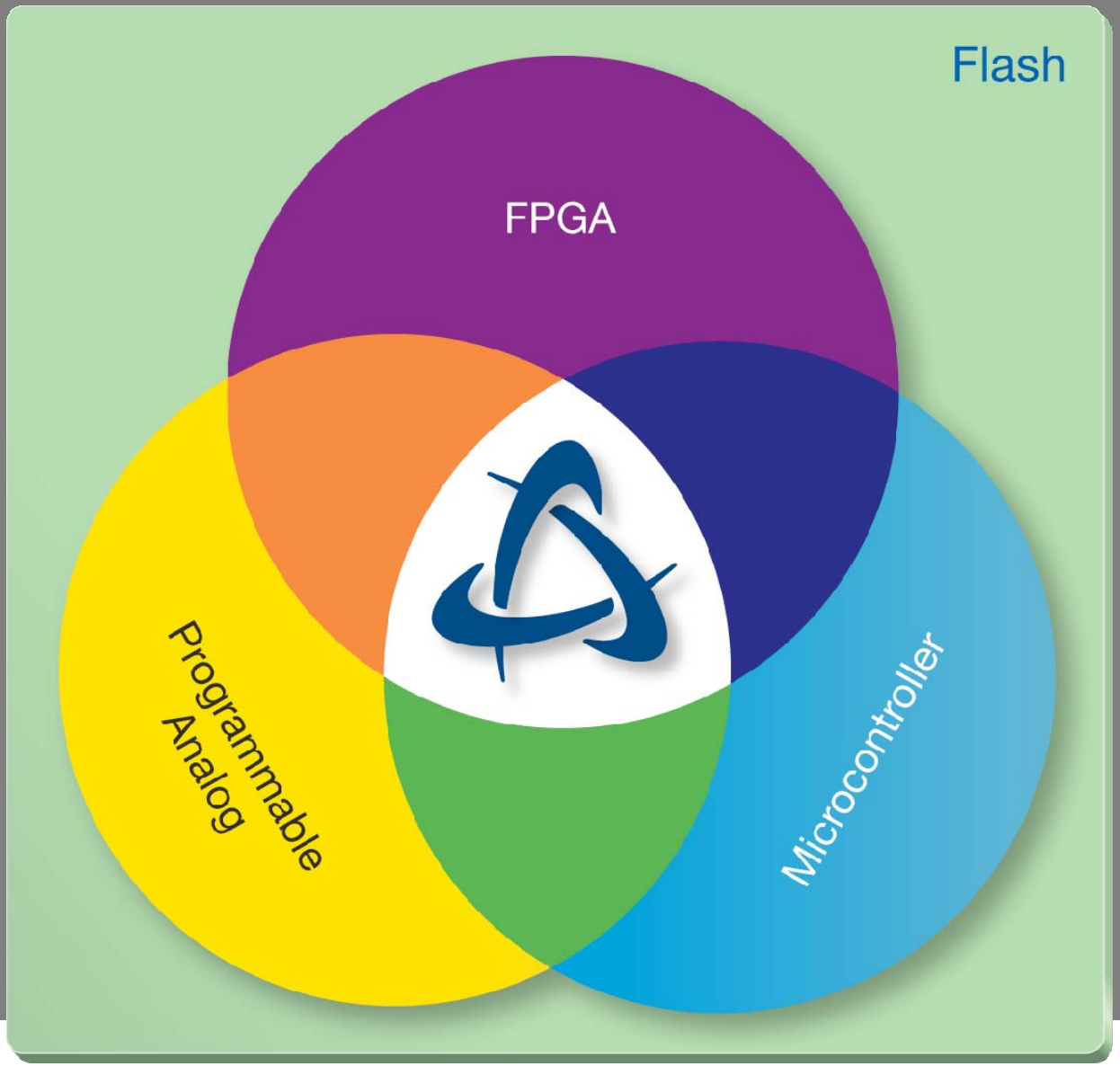
- Traditional embedded solution (C-RTOS) is too difficult
- Would like to write OO reusable code with flexible API
- Better security
- Better tool support
- Consider the mobile phone experience – J2ME, Android
- “Android for sensors”

III. Implementation Technologies

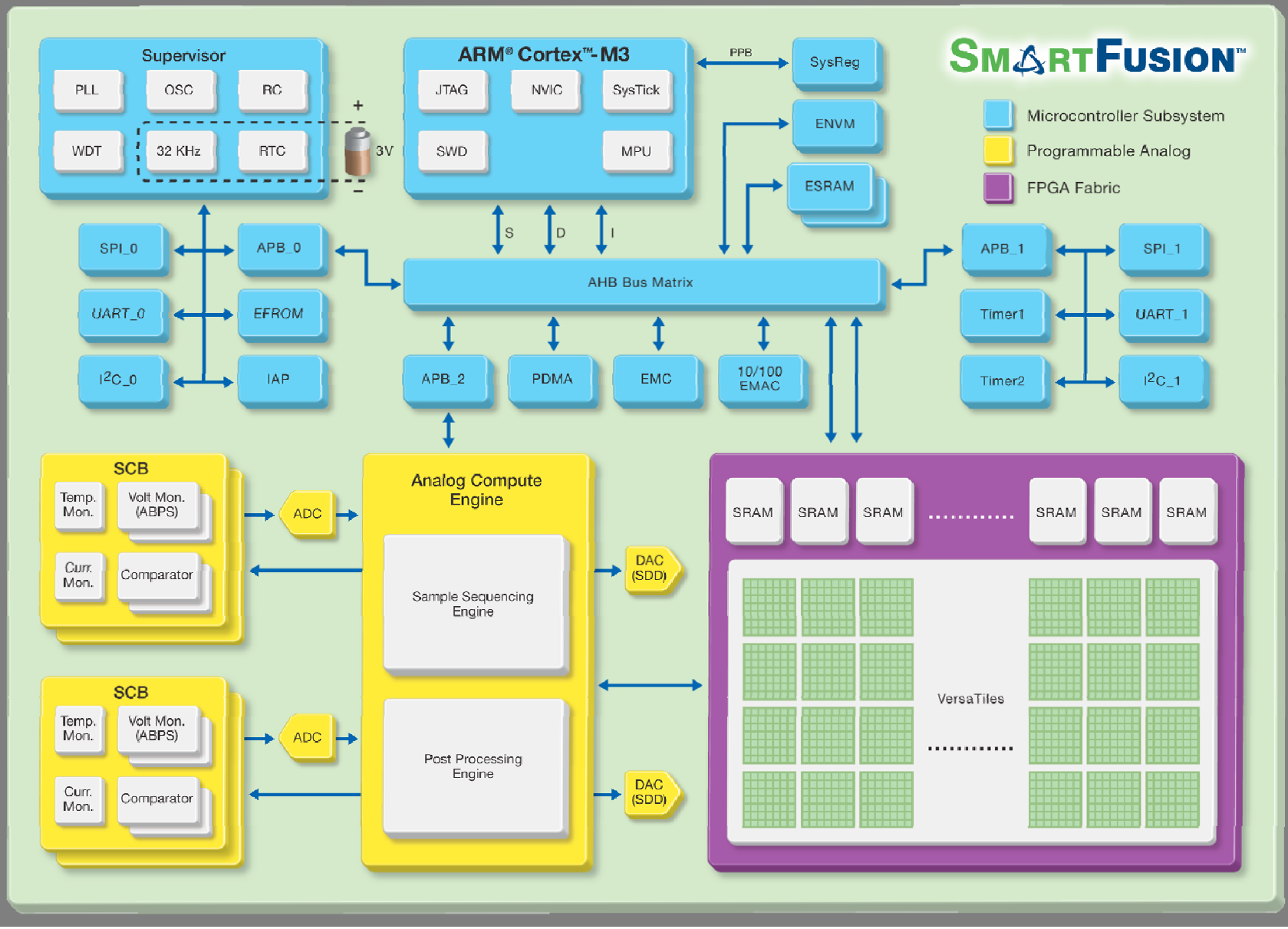
Hardware: SmartFusion™ FPGA

Highly integrated single-chip from Actel with:

- **Microcontroller**
- **FPGA fabric**
- **Programmable analog**



SmartFusion Block Diagram



Hardware Features

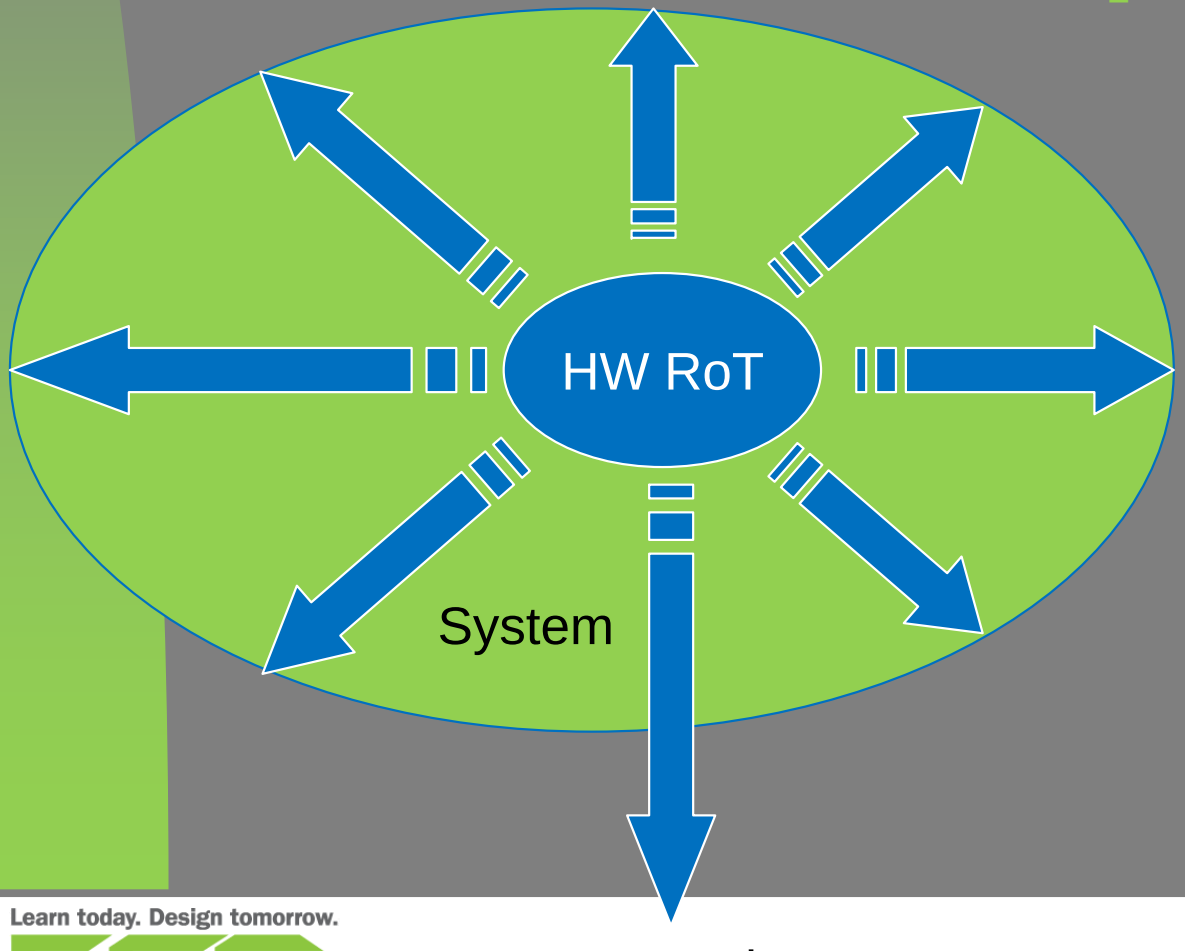
- Embedded microcontroller
  - 100 MHz ARM® Cortex®-M3
  - Power efficient
- Highly integrated
  - Standard digital peripherals, including Ethernet MAC, SPI, I^2C, UART
  - Analog converters, oscillators, etc.
  - Single-chip solution; no configuration PROM
- FPGA fabric
  - Accelerated DSP functions; misc. logic
- Hardware security
  - Tamper resistance and secure upgrades
  - On-chip eNVM for keys and boot code

Hardware Root-of-Trust

- Fielded systems need a hardware root-of-trust (RoT).
  - Software by itself is not secure.
- The hardware RoT can store keys and perform operations that extend the trust zone to cover other parts of the system.

For example:

- Execute secure boot code
- Check signatures on software stored in external memory
- Check that other boards in the system are not counterfeit
- Prevent overbuilding or cloning of systems



Software: Aplix picoJBlend™

Runs Applications written in the Java language

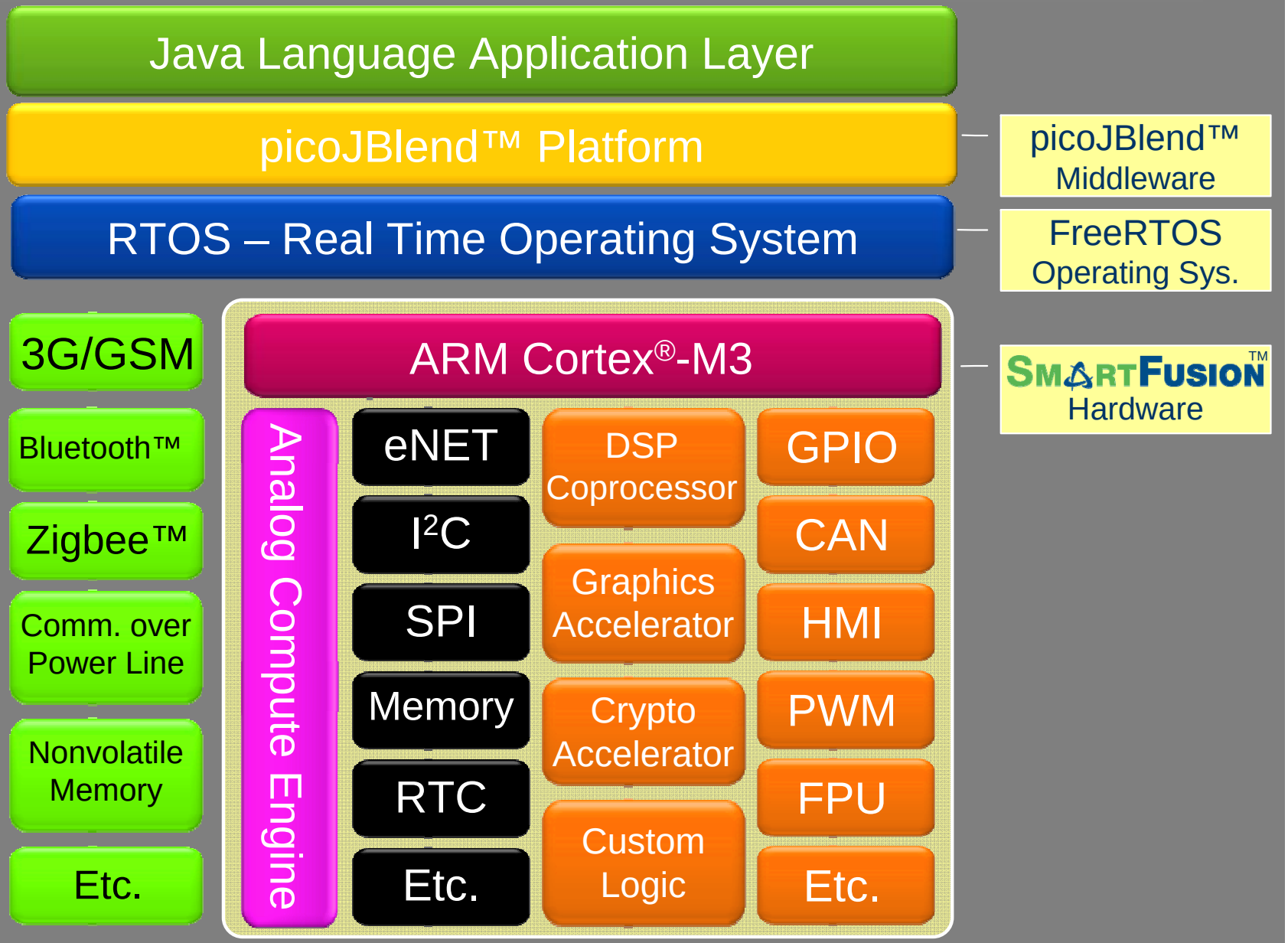
- Large (largest?) programmer base
- High productivity language
  - Object-oriented
  - Abstracts hardware, I/O streams
  - High level of design reuse
    - Portfolio of available libraries
    - Mature tools and documentation
  - Developer can concentrate on application-specific coding
- Result: faster time-to-market

Why picoJBlend? (continued)

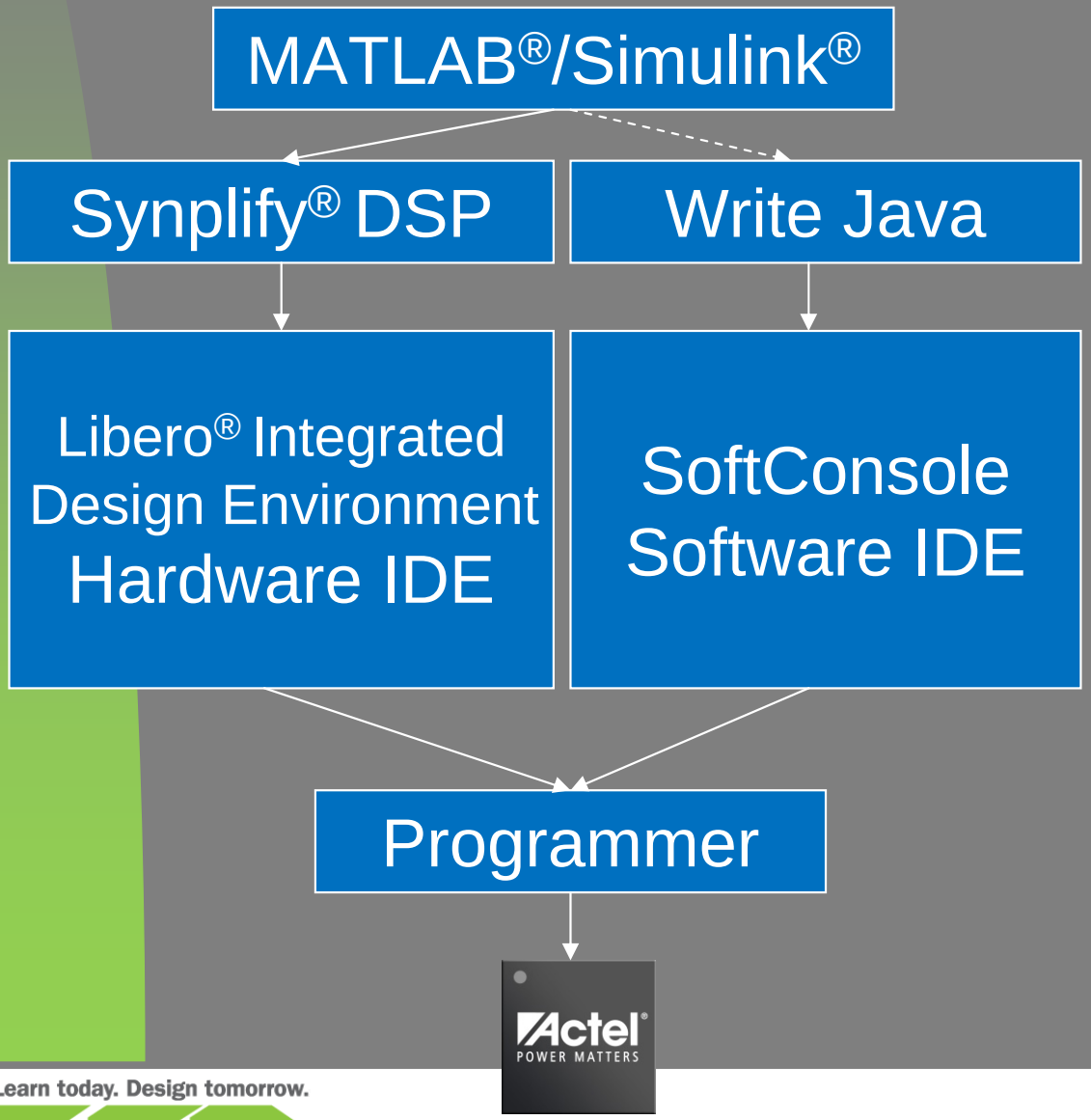
Runs Applications written in the Java language

- Secure and Safe
  - Strongly typed language
  - “Sandbox” model for application security
    - firewalls applications and network interfaces
  - Built-in memory management
    - Data encapsulation (by application)
    - Automatic garbage collection
    - No pointer violations
- Compliant with Java Card Specification

Programmer's View

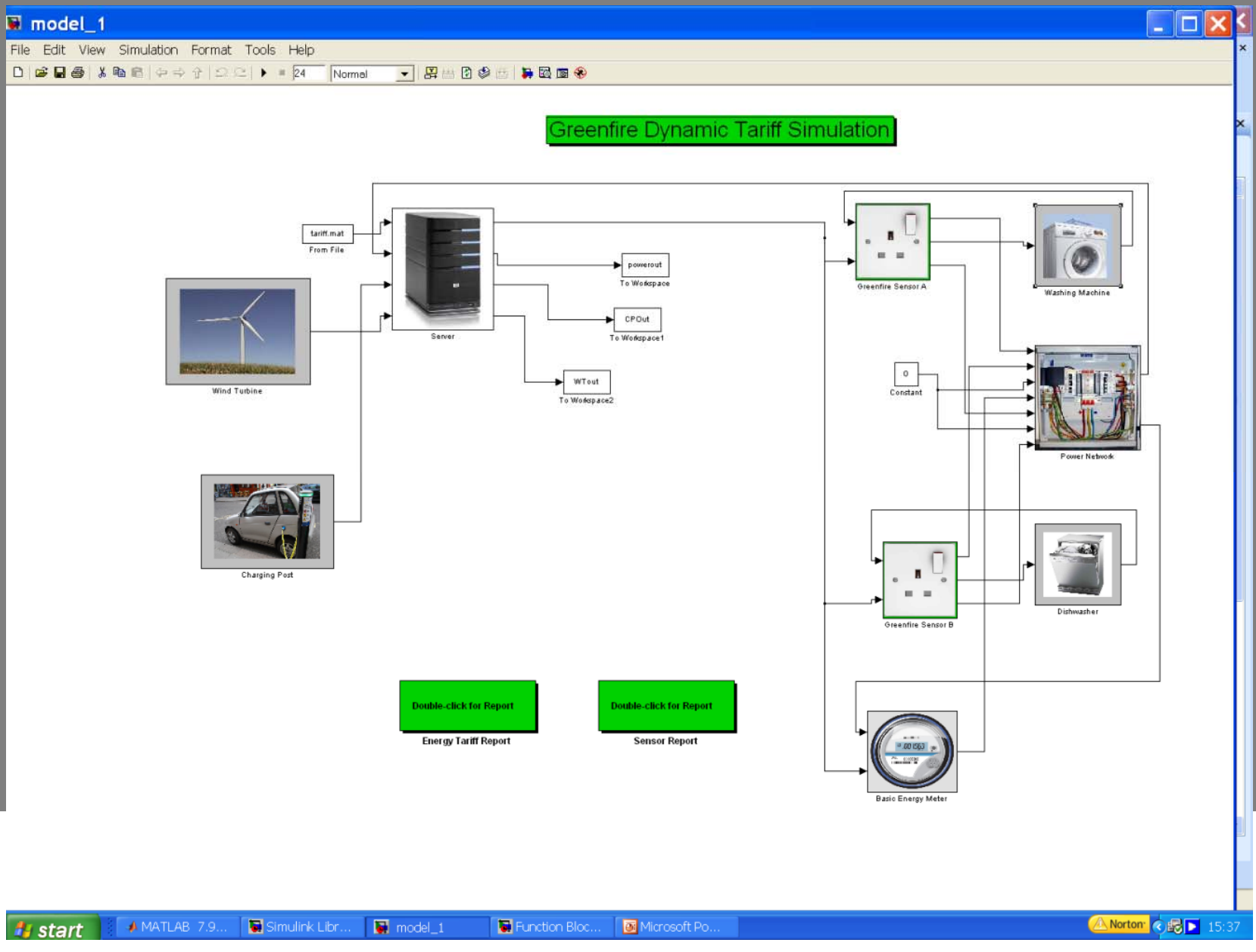


Overall Design Process

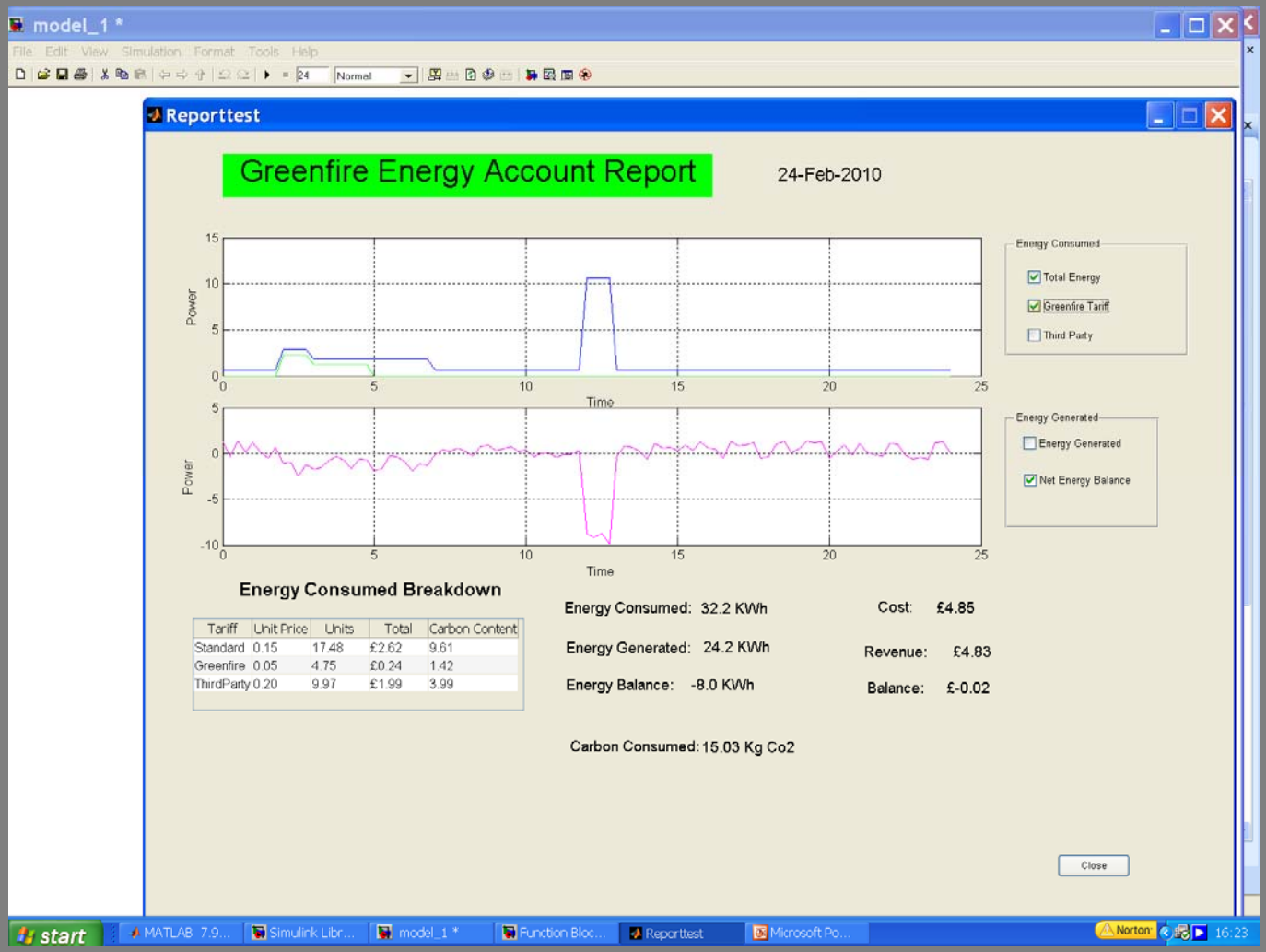


- System engineering
- Capture design
  - Write Java code
  - Auto-generate RTL
- Compile hardware and software
- Flash the device

Concept Exploration with Simulink



Simulink Report



SmartFusion Design Environment

FPGA Design Flow

Libero

SmartDesign

IP Catalog

Design Templates

Simulation

Synthesis

Layout

Timing Analysis

Power Analysis

Hdw Debug

Embedded Design Flow

Software IDE
SoftConsole, Keil, IAR

Firmware Catalog

Sample Projects

Compiler

Sim. and Debug

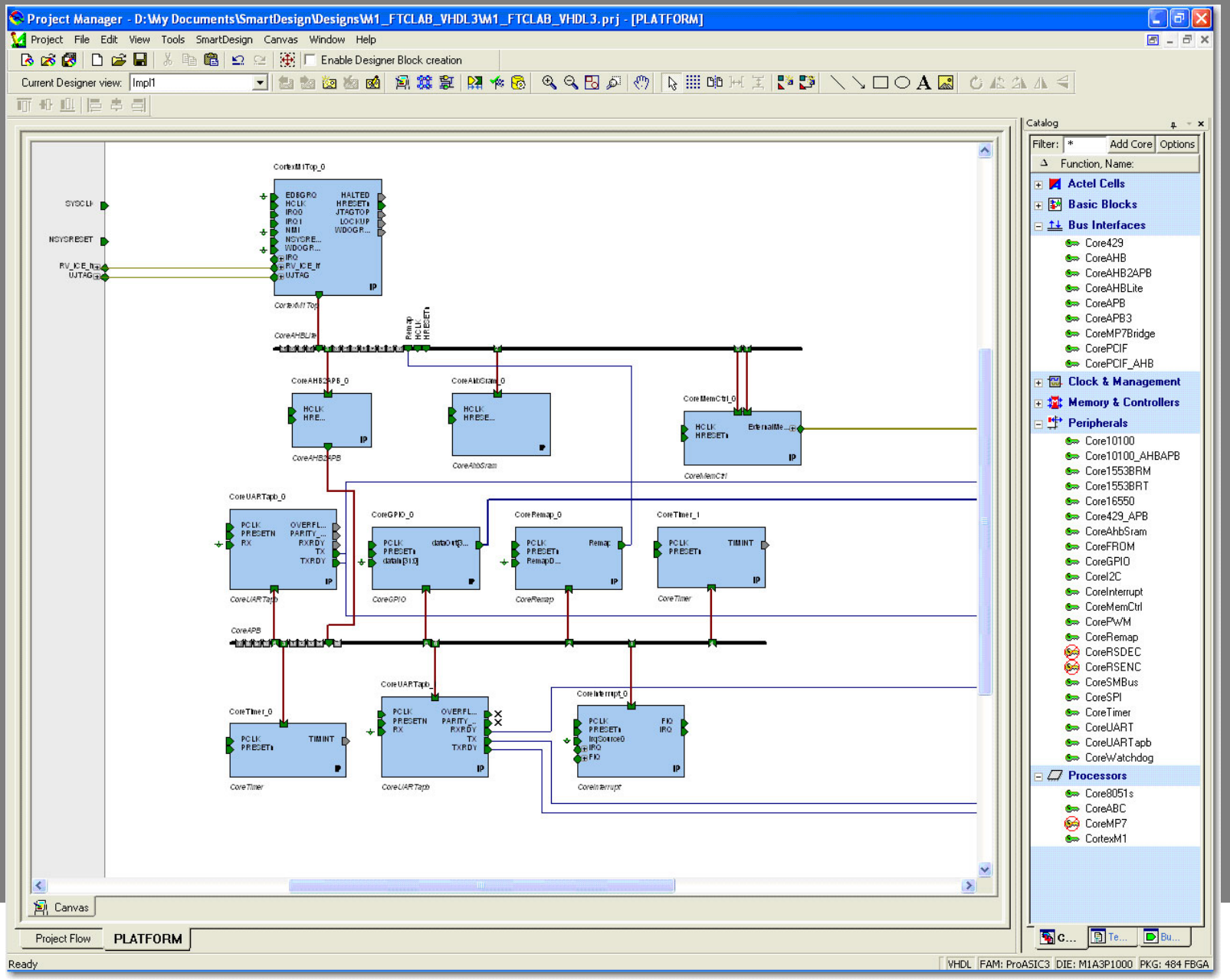
Software Program and Debug

FlashPro4

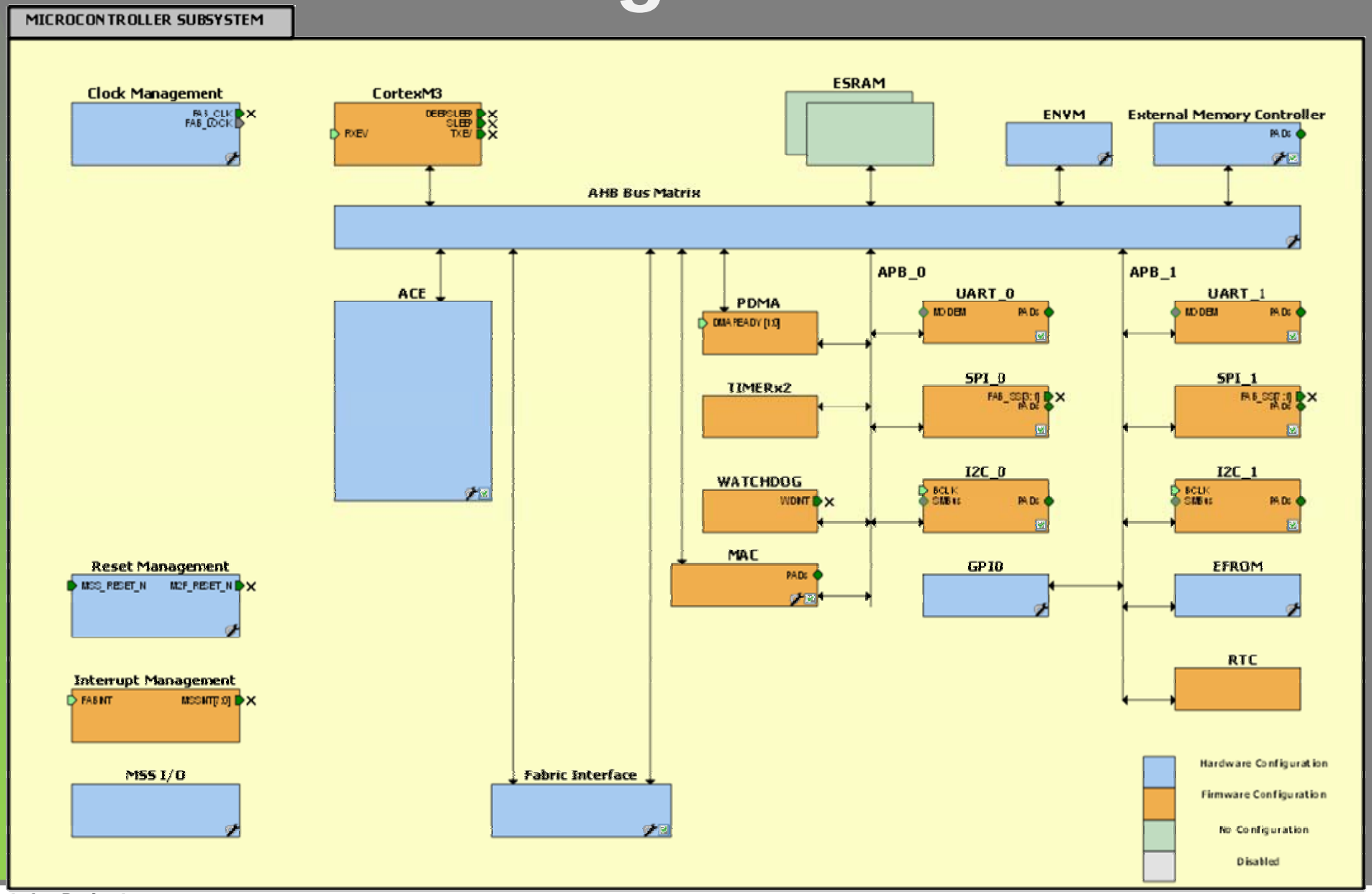
Graphical Configurator

SmartFusion Evaluation Kit
SmartFusion Development Kit

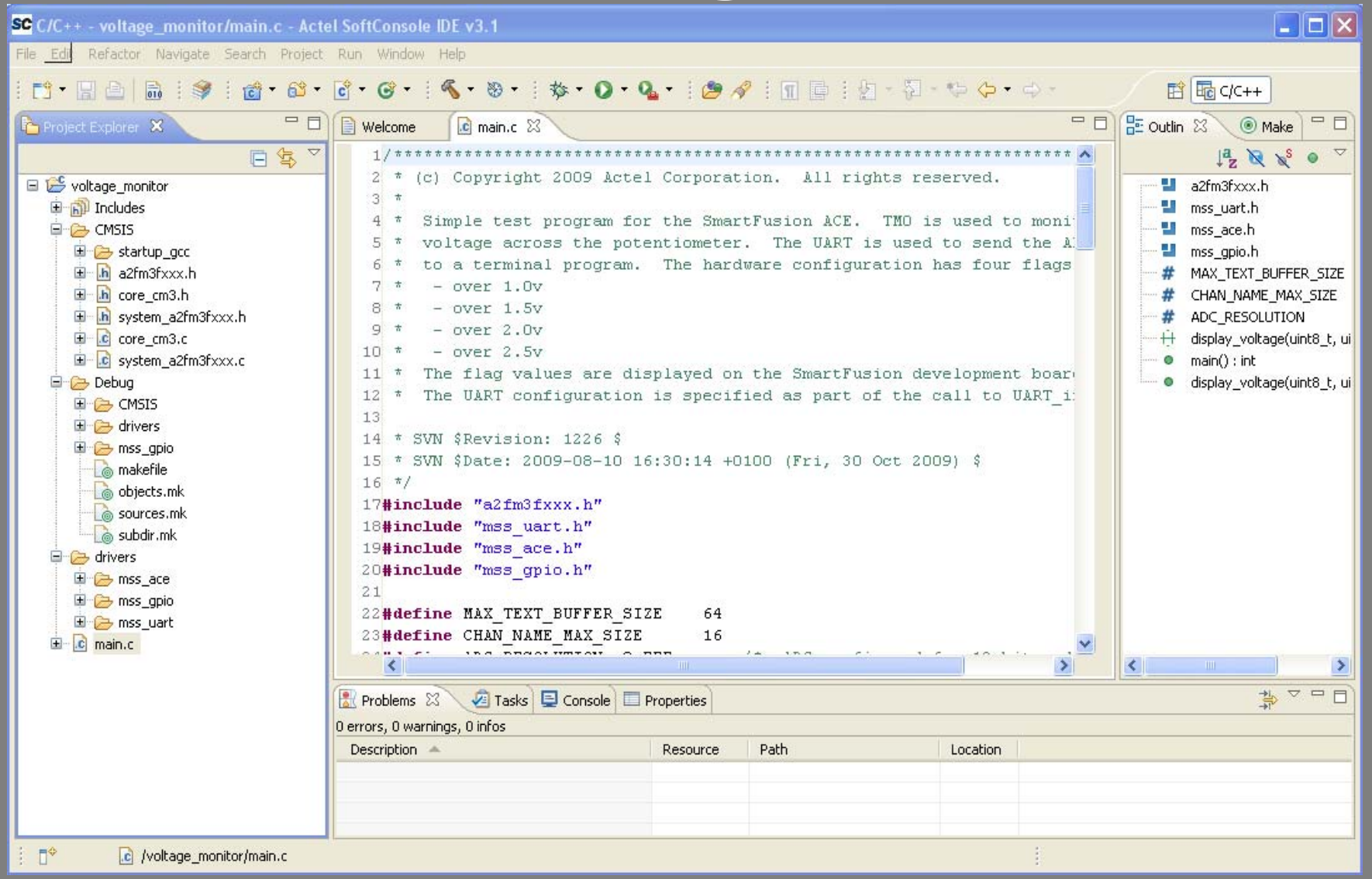
Hardware Block Assembly



Hardware Configuration Tool View



Software Design Tool View

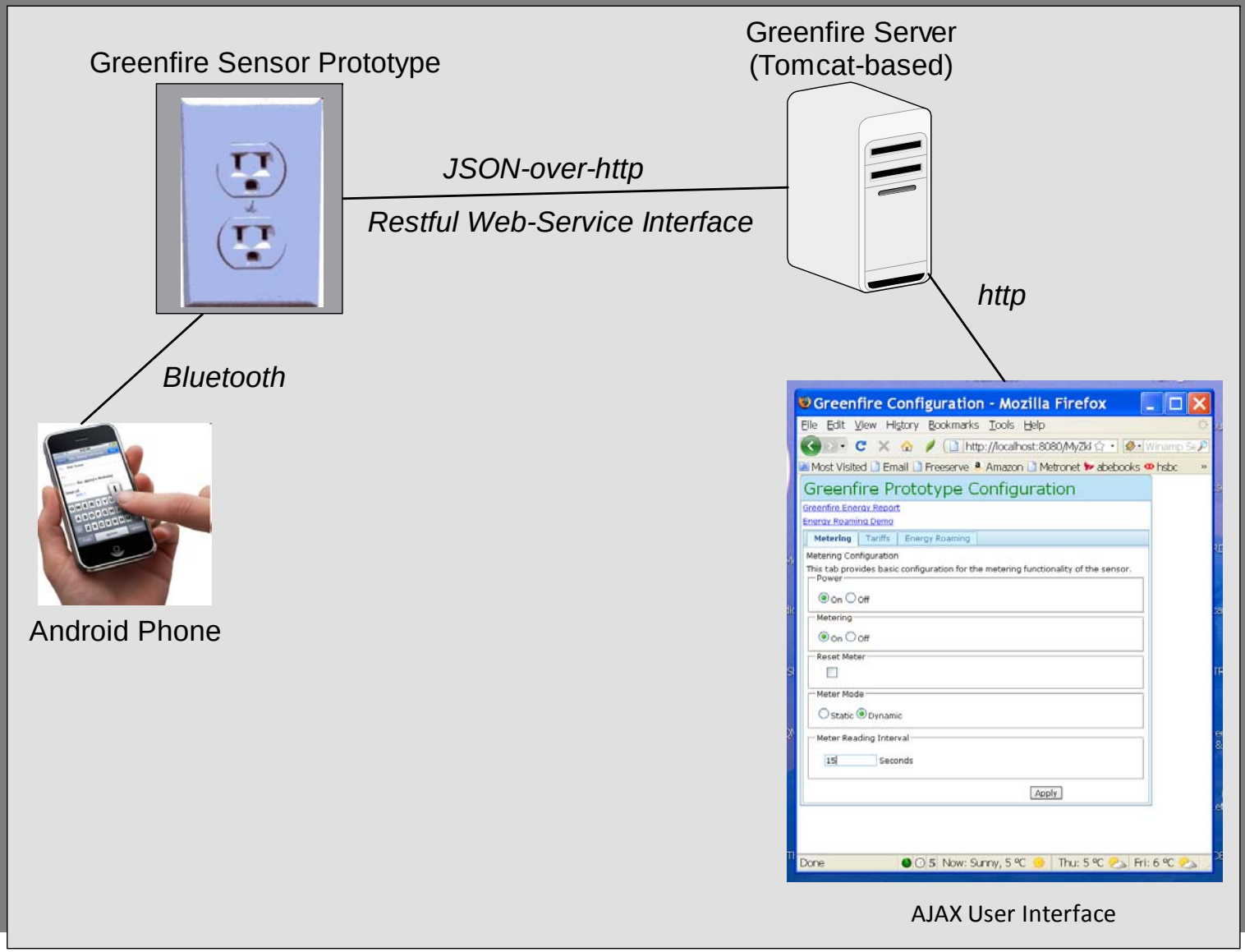


V. GreenFire Prototype

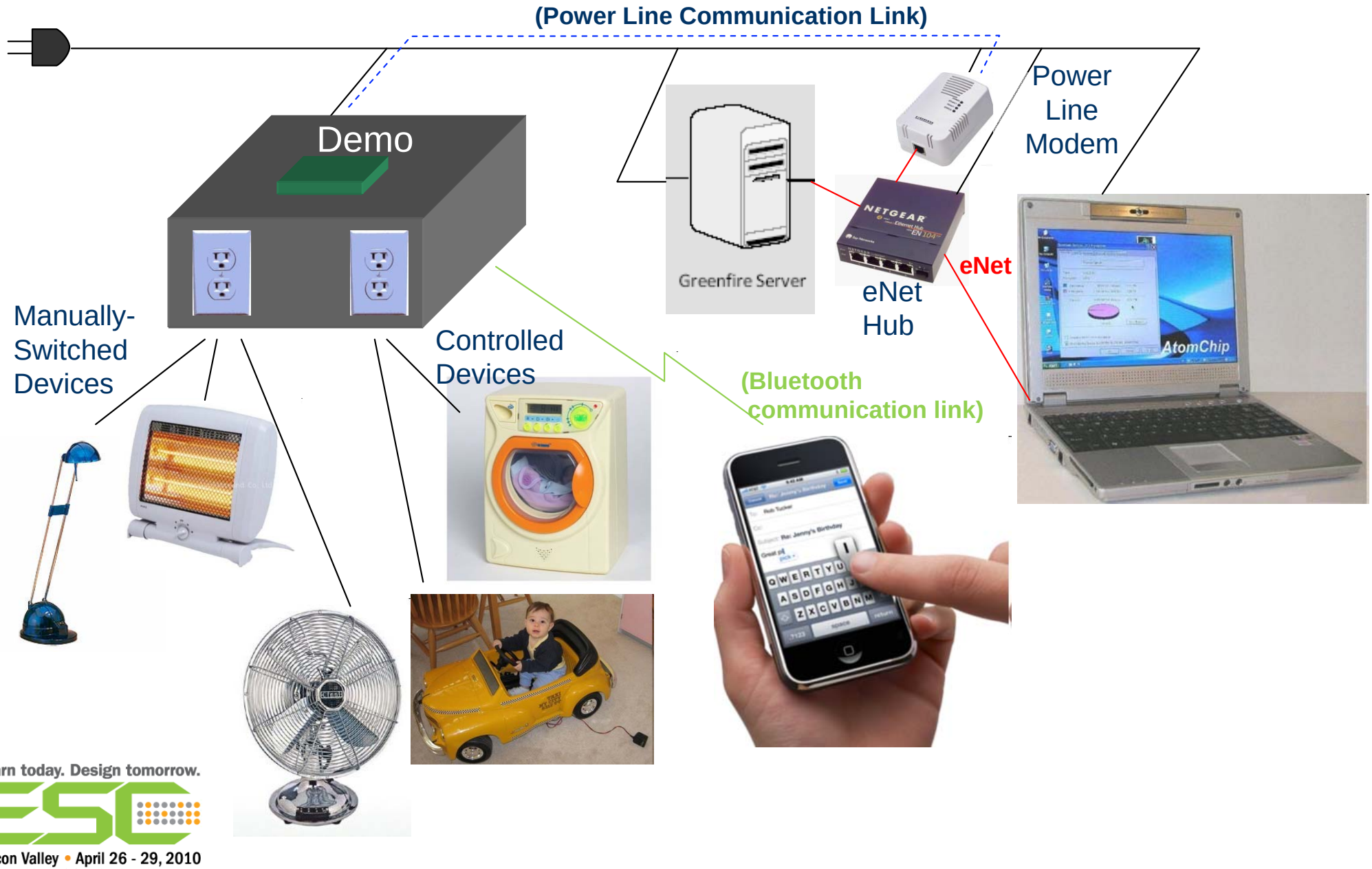
Prototype – Key Features

- Based on SmartFusion Development Kit
- Application written in Java Programming Language
- picoJBlend™ embedded middleware
- Linux server with Apache Tomcat®
- AJAX RIA user interface
- RESTful (JSON) web service interface to prototype

Prototype System Overview



GreenFire / SmartFusion / picoJBlend Prototype Hardware



Demonstration

- General sensor demo
  - Appliance control and metering
  - Demand control through dynamic prices
- Mobile energy download
  - Authorization with mobile phone
  - Integrated energy display

Next Steps

- Pre-commercial prototype
  - Reduced size and higher integration based around SmartFusion chip
  - Integral DSP for energy signature
  - Cryptographic support
  - picoJBlend API for rapid customization
- Scalable, robust server

Conclusions

- GreenFire concepts have been demonstrated
  - Mobile energy downloads
  - Dynamic tariffs
- Brings agility and mobility to energy
- The “mobile phone of the energy world”?

Questions?