Overview

- Platform-based design approach
  - small satellites in general, their comm. systems in particular
- Candidate wireless technologies
  - High-efficiency and high-linearity power amplifiers
  - Digital and mixed-signal circuits: DSPs, FPGAs, ADCs, DACs
  - Smart antennas
  - Iterative error-correction techniques
  - Cognitive radio
- Modular approach, architectural considerations
- Hardware and software development efforts
- Educational aspects
Platform-Based Design Approach

- Common set of subsystems supports multiple missions
  - different combinations/configurations yield design variants
  - product families assembled as a set of design variants
- Widely embraced by other industries
  - common examples: automobiles, consumer electronics
- Goals
  - reduce development and manufacturing cost and time
  - obtain market advantage by using variants to target different market segments
From SUVs to Small Satellites?
Platform-Based Spacecraft Design

• **Difficulties:** How small satellites differ from SUVs
  – lack of product volume
  – production lag times and rapid technological advancement may make variants obsolescent before subsequent builds
  – reliability requirements-- once on orbit, you can’t just swing by the dealer!

• **Solutions**
  – advanced manufacturing processes may make it cost effective to custom manufacture in small quantities
  – low variant lifetimes imply incorporation of latest technological advancements
  – subsystem reuse provides flight heritage
  – low-cost launch allows for replacement instead of repair
Small Satellite Platform Approach

Requirements

Model

PLATFORM DESIGN TEAM

Choose Platform Specs

Re-negotiate

Design Variants

Design

Product A

Product B

Product C

Variant A

Variant B

Variant C

Platform Design Team

Design A

Design B

Design C

Platform

Requirements

Disclaimer
Platform-Based Small-Satellite Communications Subsystems

• Modular communications subsystem design approach demonstrated successfully by AeroAstro and SSTL, among others

• Goals of this effort:
  – take modularity to a very low level
  – employ a software-defined radio for flexibility
  – exploit modularity to incorporate advanced wireless technologies developed for terrestrial applications
  – provide unique educational experiences to Utah State students both in the research lab and in the classroom

• Supported by the Space Dynamics Laboratory and the Richard and Moonyeen Anderson Wireless Research and Education Center
Candidate Wireless Technologies

- High-efficiency power amplifiers
- High-linearity power amplifiers
- Digital signal processors and field-programmable gate arrays
- Advanced signal conversion circuits
- Smart antennas
- Iterative error-correction techniques
- Cognitive radio
Power Amplifiers

• Can greatly impact peak- and orbit-averaged power consumption on small satellites
• Inefficient amplifiers complicate thermal design
• More efficient high-linearity power amplifiers
  – required for applications with high envelope dynamic range
  – leverage linearization techniques developed for CDMA handsets
  – can make bandwidth-efficient modulation possible on small sats
• High-efficiency nonlinear power amplifiers
  – nonlinear amplifiers acceptable for some applications where a constant-envelop modulation scheme is used
  – take advantage of tremendous improvements in semiconductor devices and low-loss lumped elements
  – exploit huge investment in low-voltage high-efficiency amplifiers
Digital and Mixed-Signal Circuits

• Digital signal processors and field-programmable gate arrays
  – smaller devices, reduced bias voltages, lower power consumption
  – continuously becoming more capable and power efficient on a per-operation basis

• Signal-conversion circuits pervasive in consumer electronics products
  – many specifically designed for low-power applications
  – higher sampling rates, greater precision, lower power consumption, and/or smaller packages

• Rapid evolution due to massive consumer electronics markets, including wireless industry

• Essential to develop an architecture that allows for these new components to be integrated rapidly as they emerge
Smart Antennas

- Problems addressed by smart antennas
  - small satellites can rarely afford gimbaled reflectors
  - undesirable to rely on spacecraft attitude control system for antenna pointing
  - wide-beamwidth antennas constrain link budgets, pose interference hazard to other users
- Smart antennas employ arrays of elements, signal processing in both space and time
  - provide electronic beam-steering for transmit and receive
  - useful for receive-side interference mitigation on uplink, although adaptive techniques are computationally intense
- Phased arrays are inherently modular systems
- Technology developed for next-generation terrestrial wireless systems due to billion-dollar spectrum costs
Iterative Error-Correction Techniques

- Two examples: turbo and low-density parity-check codes
- Near Shannon-bound performance possible
  - requires long block lengths, near-perfect synchronization
- Very well suited for small-satellite downlinks
  - low transmit-side (coder) implementation complexity
  - highly complex, computationally intense decoder can be implemented terrestrially
- Can typically achieve 5 to 9 dB of coding gain
  - depends on specific implementation
  - synchronization requirement limits received SNR lower bound, but receiver complexity can be exchanged for some reduction in downlink transmit power
  - iterative synchronization techniques emerging to solve this
Cognitive Radio

- Defined as the ability to adapt to changing link conditions and spectrum availability
- Major market forces pushing for optimum use of terrestrial spectrum
- Spectral congestion increasingly problematic for space-born communications, as well
- Excellent application for small-satellite downlinks:
  - use modular radio with both high-linearity and high-efficiency power amplifiers, switchable
  - use constant-envelope waveform, high-efficiency PA, and lower bit rate when limited link margin is available (e.g. near horizon)
  - use linearized PA, bandwidth-efficient modulation scheme, and higher bit rate (in same bandwidth) when link conditions allow
  - optimal use of both spectrum allocation and available power
Radio Architecture

Reference Oscillator

RF Tray 1

RF Tray 2

Buffered N:1 splitter/combiner

Optional IF up/dn-converter

AGC / Signal Conversion

Signal Processor

External Interface

External Crypto Unit

PLL

TXCO

AGC / Signal Conversion

PLL
Modularity

1) Makes more variants possible for less developmental overhead and

and

2) Minimizes the amount of redesign required to inject new technologies into existing radios
Architectural Considerations

- Allow for rapid integration of new circuit technologies
- Support a variety of signal conversion methodologies
- Provide a range of options for redundancy and fault tolerance
- Standardize interfaces and footprints as much as possible
- Allow for an additional level of modularity in the RF trays
  - customization is particularly critical here (many variants)
  - develop a wide range of reusable modules, establish heritage
Example Full-Duplex RF Tray

Legend:
- Antenna interface module (diplexer and beamforming net.)
- Power amplifier module
- LNA/RF downconverter module
- RF upconverter module
- RF tray interface module (control signal distribution, local oscillator generation, and solid state switches)
Hardware Development Effort

- Initial efforts focusing on high-efficiency PAs, modules for software-defined radio
- Starting with off-the-shelf components as placeholders, for example:
  - PC with ADC/DAC card, real-time processing
  - off-the-shelf LNAs, diplexers, oscillators (synthesizers)
- Will address interfacing, mechanical design, and EMI/EMC issues
- Do not intend to develop flight hardware in near term
  - will assemble a range of modules, build and characterize the performance of several variant radios
Software Development Effort

- Will support a wide range of modulation formats, bit rates, error-correction coding schemes
- Not undertaking effort to provide network-level functionality at this point
- Need software for both space and ground segments for hardware validation
- Intend to employ commercially-available and open-source tools where possible, such as
  - RT Linux for ground station processor
  - MathWorks / Xilinx System Generator for FPGA design simulation and implementation
  - DSP code generators
Educational Aspects

• Excellent hands-on experience for graduate and undergraduate research assistants
• Many components will translate directly into classroom examples, laboratory activities
  – electromagnetic theory, microwave engineering, and satellite communications courses, among others
  – make use of Anderson Wireless Center educational laboratory
• Software-defined radio a particularly useful tool
  – demonstrate envelope distortion in nonlinear PAs, for example
  – makes it possible reinforce communications theory with practical hardware experience, e.g. observing & measuring bit error rates
• Generate excitement, produce engineers with a better understanding of the concepts industry needs
Conclusions

• Advantages of a platform-based design
  – cost and schedule benefits
  – market advantage
  – wide range of possible variants, including those using latest wireless technologies

• Small satellites should leverage circuit and signal processing advances made by the wireless industry

• We are developing hardware and software testbeds to this end using highly modular, platform-based designs

• Significant educational impacts