All-Band All-Mode Radio for Public Safety

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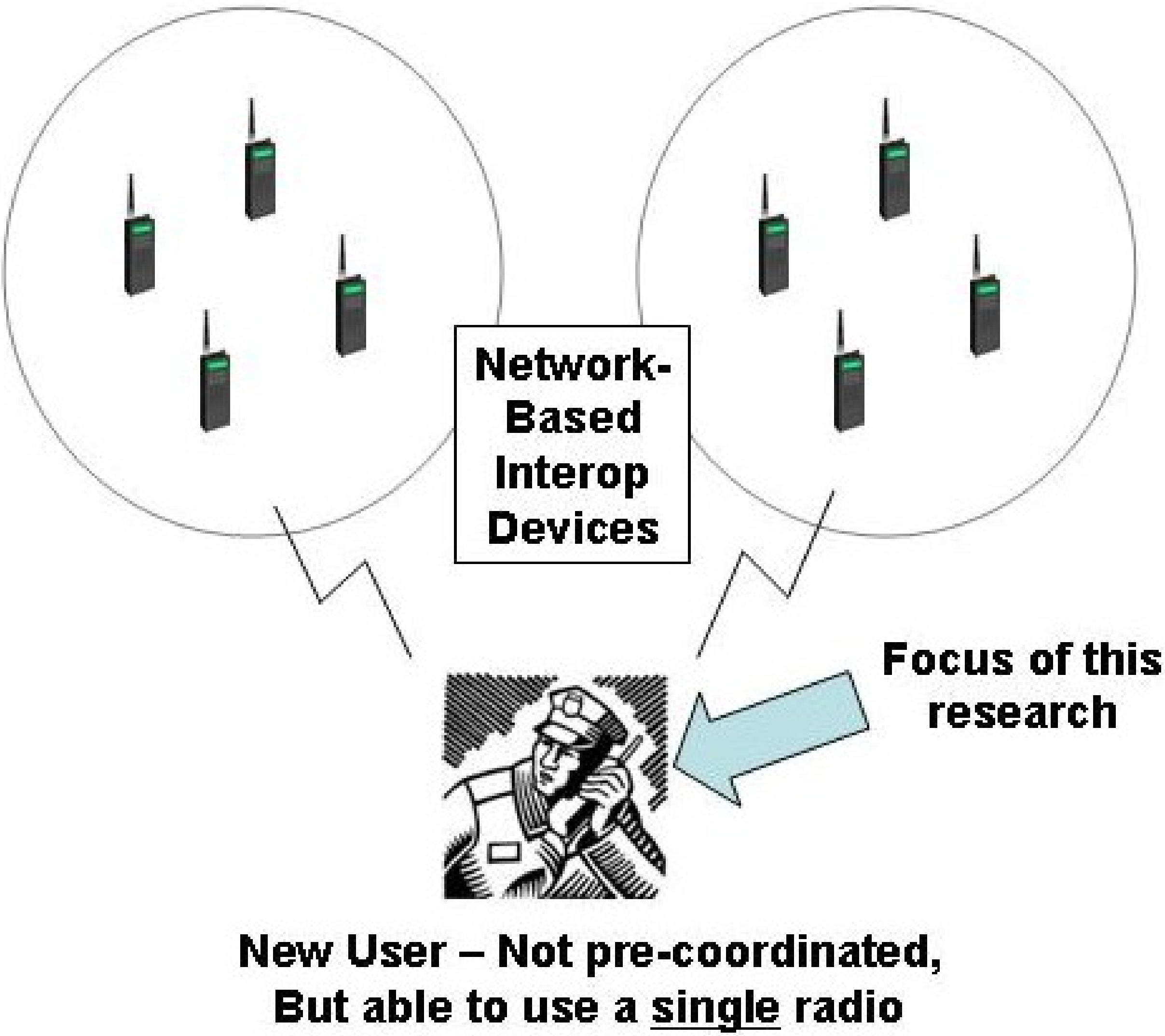
The Problem

Band	Frequency (MHz)	Mode(s)
VHF	138-174	TIA-603, P25
	220-222	Voice/Data (not TIA-603)
UHF	406-512	TIA-603, P25
700 MHz	764-776	TIA-603, TIA-902, P25, 802.16(e)
	794-806	TIA-603, TIA-902, P25, 802.16(e)
800 MHz	806-817	TIA-603, P25
	824-849	Cellular (many modes)
	851-862	TIA-603, P25
	869-894	Cellular (many modes)
PCS	1850-1990	PCS (many modes)
ISM	2400-2483	IEEE 802.11
4.9 GHz	4940-4990	IEEE 802.11, VoIP, UMTS/ TDD

+ VHF LO (25-30 MHz)

All-Band All-Mode Radio for Public Safety



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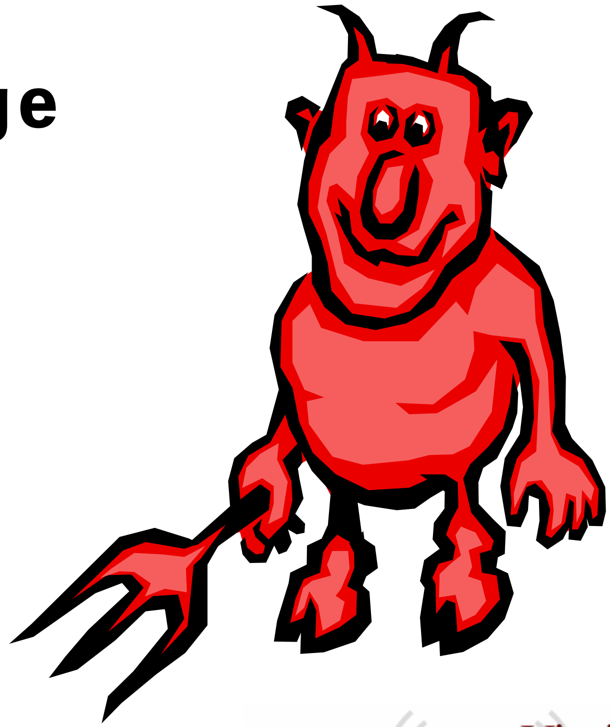
All-Band All-Mode Radio Strategy

- One-for-one replacement of existing user terminals with a low-cost all-band all-mode radio
- Begin with users most likely to benefit with small numbers of deployed radios (Chiefs; deployed Federal; local communications specialists)
- Existing systems continue to work; no additional coordination burden to local agencies
- Possibly simplified regulatory acceptance compared to other approaches

Potential Pitfalls of an All-Band / All-Mode Radio Strategy

- Bounding size, weight, power, cost
- Antennas (avoiding the "porcupine effect")
- New security issues to manage
- New operational/planning issues to manage
- Training



Objectives of this Project

- Develop a prototype radio capable of supporting all frequency bands and all protocols commonly used in U.S. public safety operations.

- Document capability / performance / cost tradeoff for various technical approaches

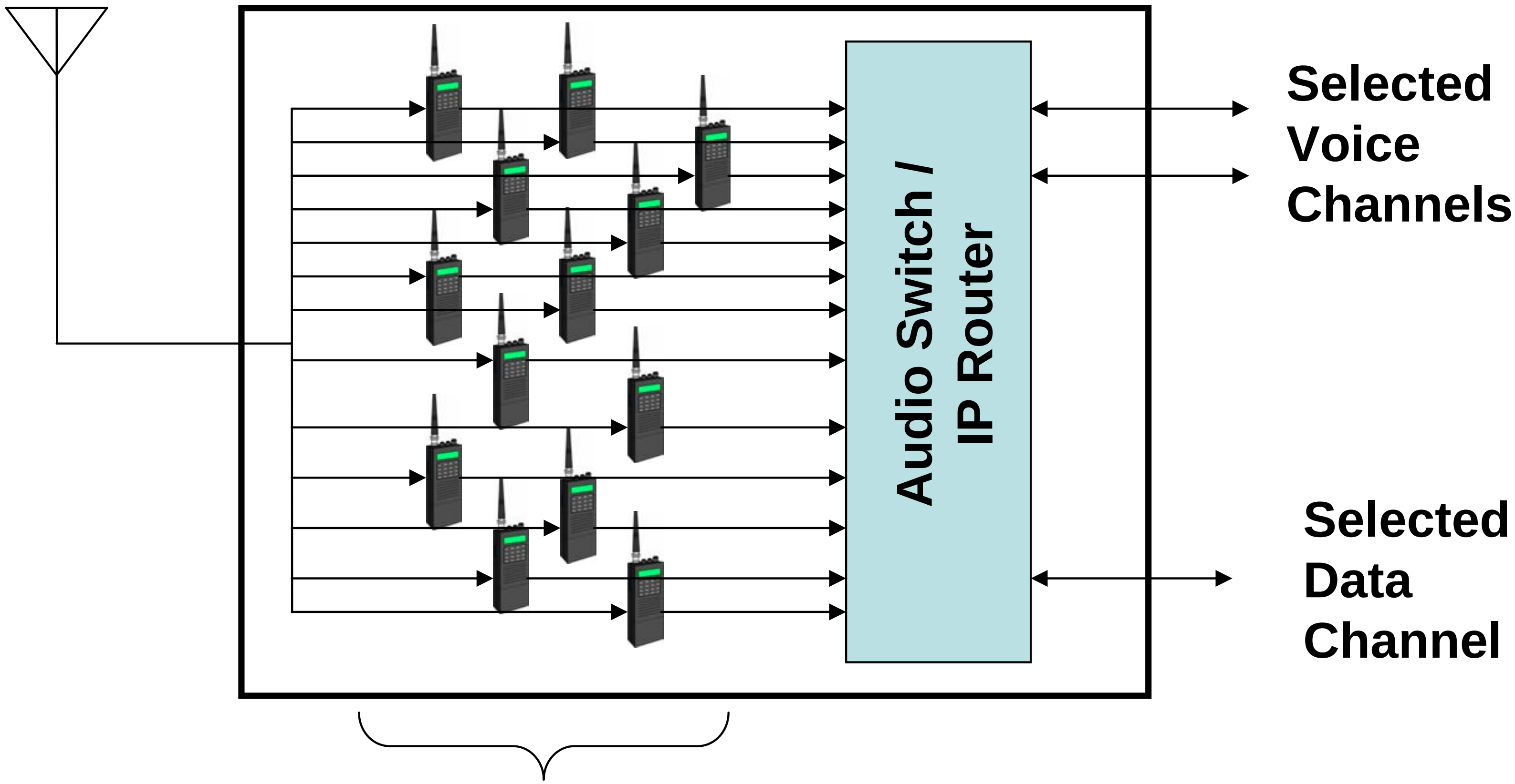
- Not specifically an SDR problem. Also not cognitive radio. But, could be enabling technology for both.

Project Schedule

- Year 1 (Started 10/05)
  - Preliminary RF, digital, and software designs
  - Not necessarily integrated or optimized for cost
- Year 2 (Started 10/06)
  - Refined RF, digital, and software designs
  - Performance/cost tradeoff
  - Fully-integrated prototype

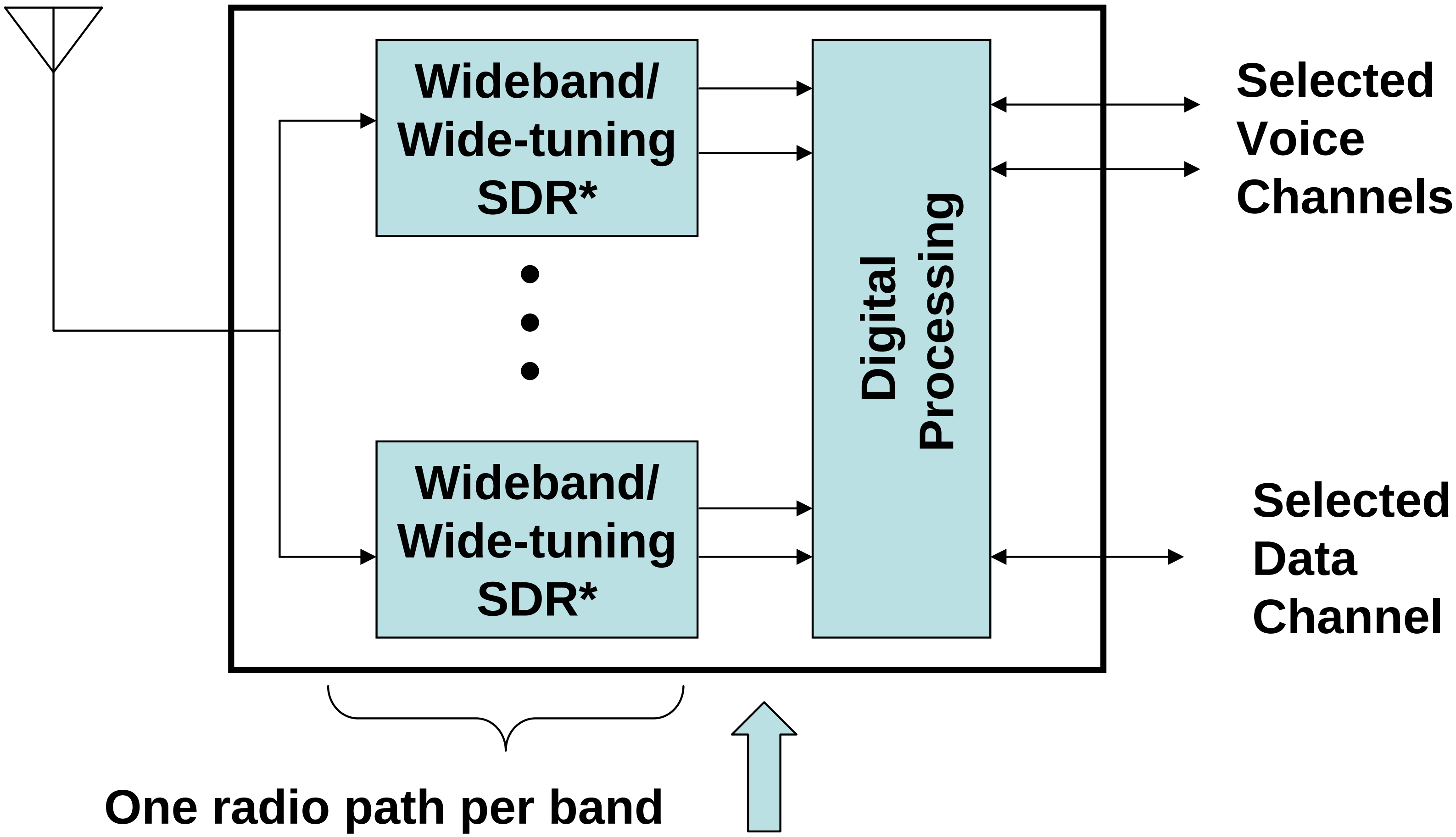
  We are here
- Year 3 (Starting 10/07)
  - Laboratory results on final/recommended design
  - Capstone demonstration

Functional View of this Radio



At least 13 bands relevant to Public Safety
x
Many channels per band
=
A lot of radios!

Closer to Practical Implementation



One radio path per band

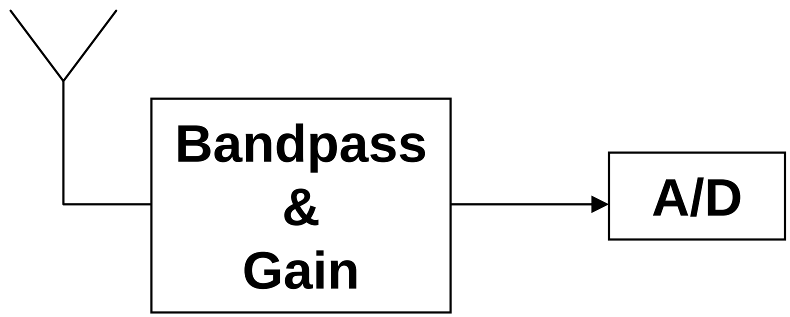
 # radio paths = Max number of expected simultaneous bands in use (2-3)

Multiple channels per band

*** SDR = Software Defined Radio**

RF Options for Wideband + Wide Tuning Range

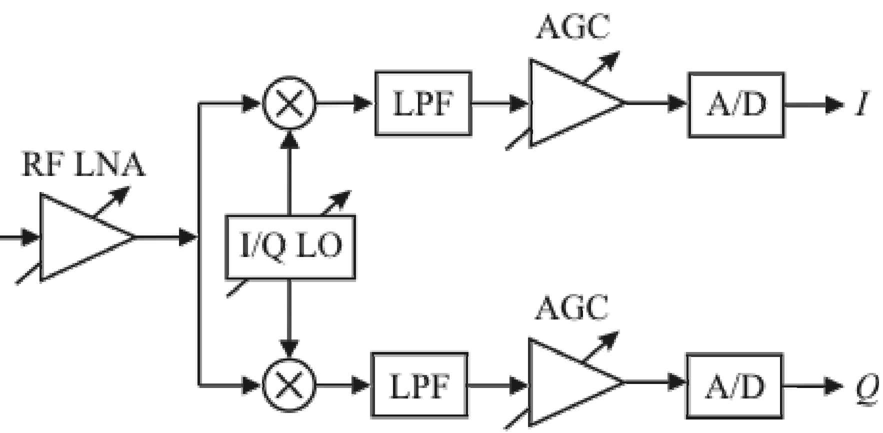
- No RF: Direct Sampling ("True SDR")
  - *Public Safety requirements: would require A/D with ENOB > 14 bits @ > 2 GSPS. Suitable part doesn't exist!*



(Showing only receive side; transmit side is analogous)

RF Options for Wideband + Wide Tuning Range

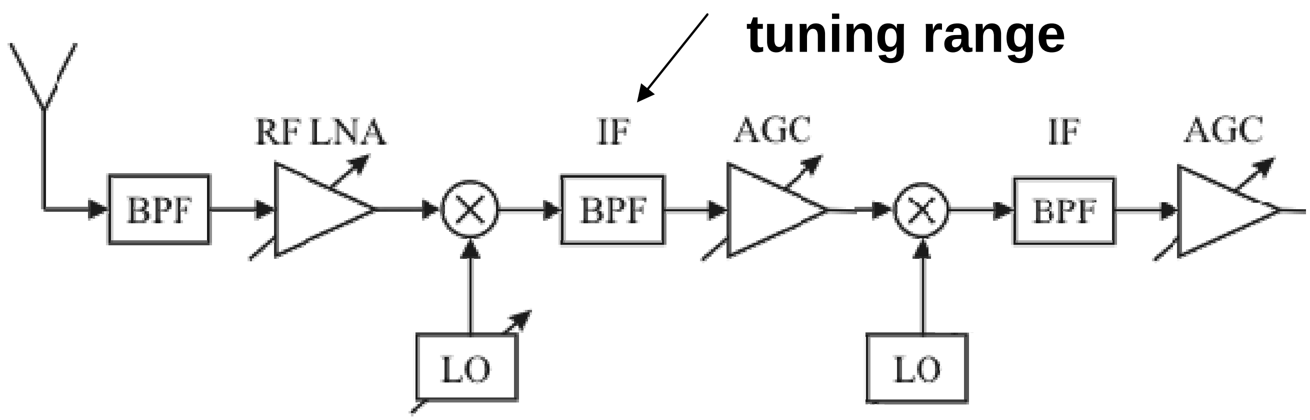
- Direct Conversion
  - *I-Q imbalance is an issue*
  - *2nd order distortion is a problem*
  - *1/f noise in band is a problem*
  - *Initial BPF needs to tune, or need filter bank*



RF Options for Wideband + Wide Tuning Range

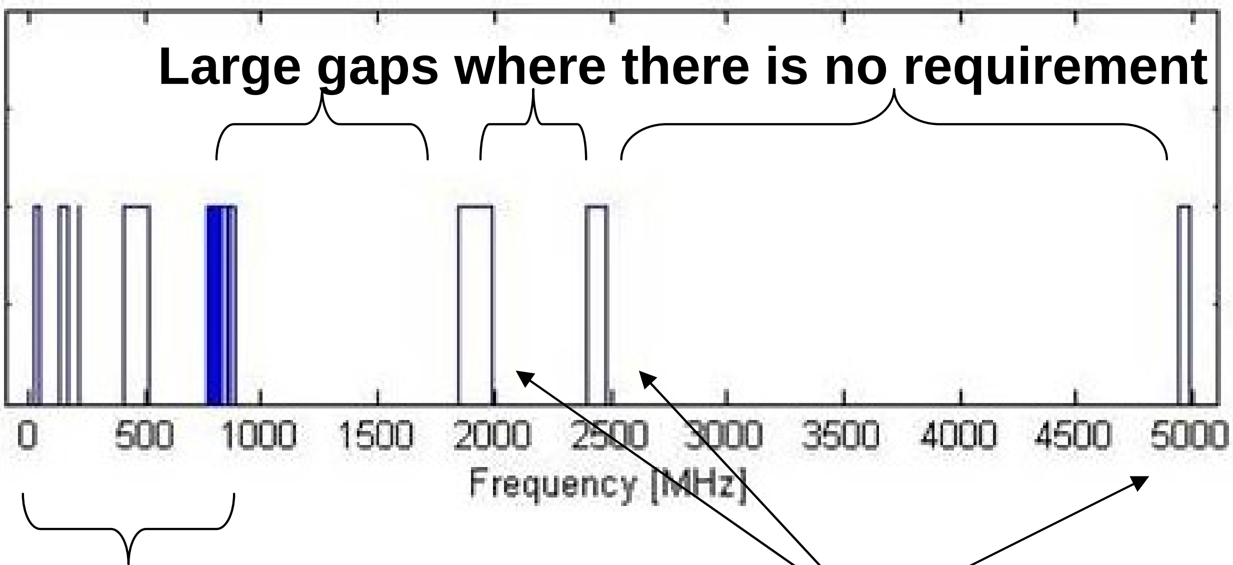
- Superheterodyne
  - *Large tuning range requires "up-down" scheme*
  - *"IF Sampling" avoids problems of direct conv.*
  - *Currently, hard to beat for best overall performance.*

Fixed, above tuning range



Digitize IF

How a Superhet Designer Views the Problem



Relatively dense use of limited range

Best to handle these separately

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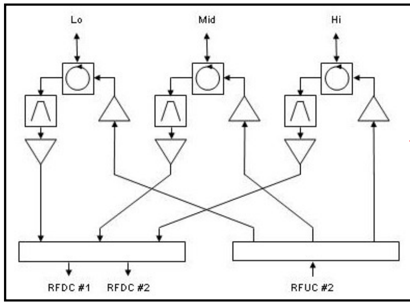
VT Superhet Strategy



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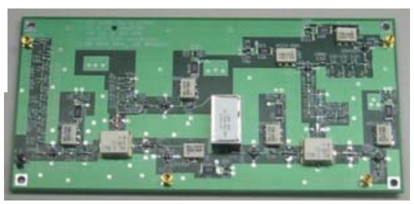
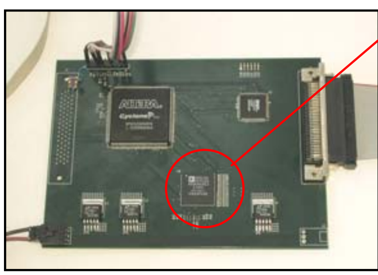
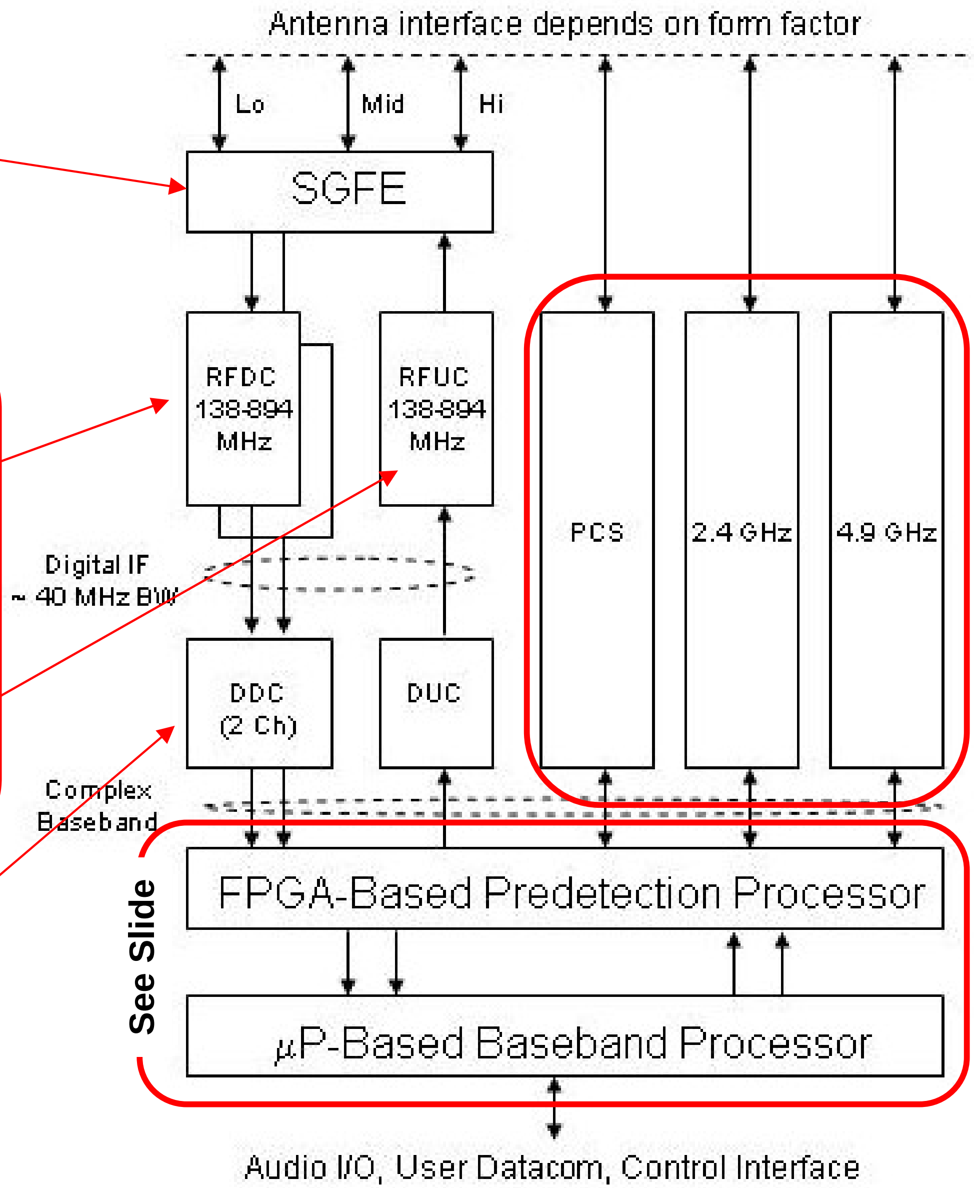


Analog Devices AD6636





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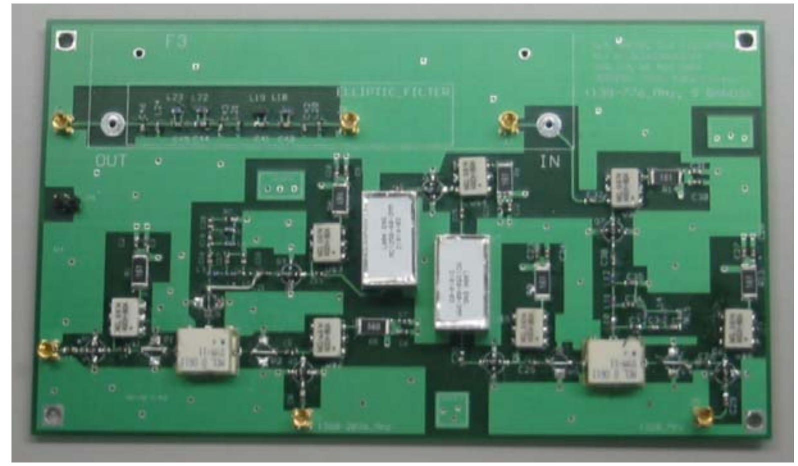
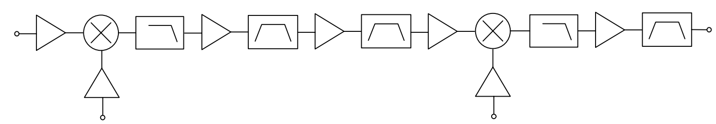
Off-the-shelf Chipsets

Strawman 138-894 MHz Frequency Converters

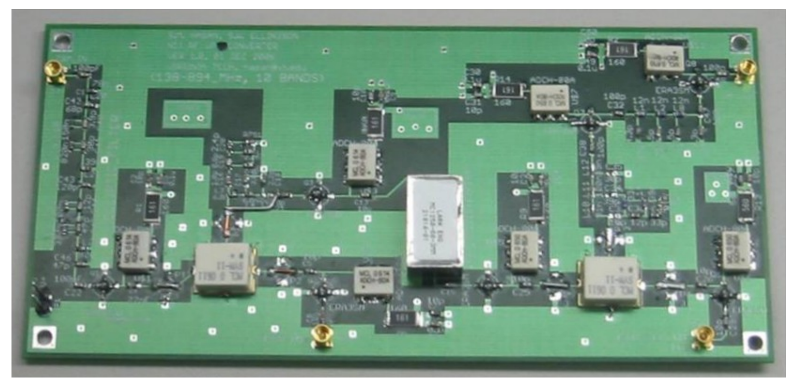
- Derivative (simplification) of existing "MCMS" design (http://www.ece.vt.edu/swe/mcms/)
- Downconverter
  - 78 MHz IF w/40 MHz BW
  - G ~ 47 dB, F ~ 4.5 dB, IIP_3 ~ -32 dBm
  - 280 mA @ 9V, 139 cm^2 (can be greatly reduced w/o redesign)
  - $185 in small quantities; Cost will increase about 25% in order to get IIP_3 where it needs to be for PS requirements (~ -10 dBm)
- Upconverter tunes 78 MHz IF to 138-894 MHz using same frequency plan





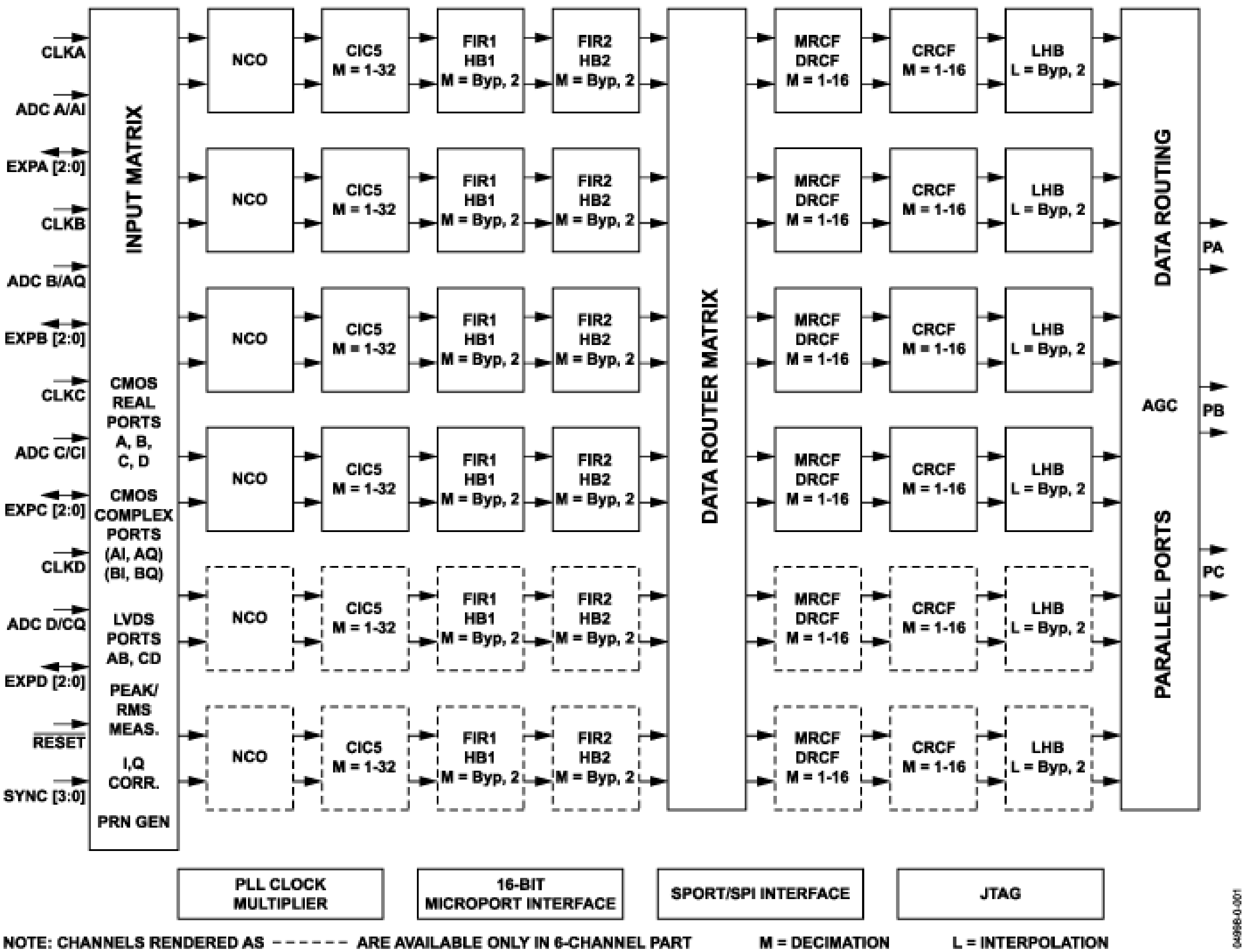
Downconverter

Upconverter

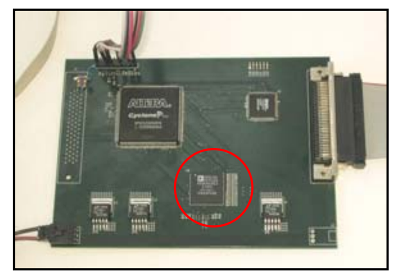


Design/Build/Test: S.M. Shajedul Hasan

Digital Downconverter



- Analog Devices AD6636 (one of many)
- 4+ channels
- Tiny!
- ~ $30/k

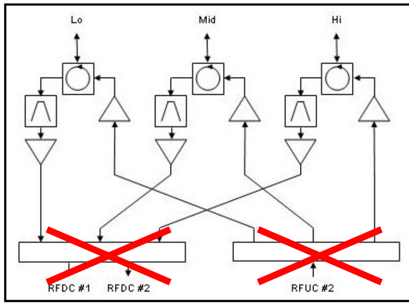


VT Evaluation Boad Design/Build/Test: Chris Anderson

Recent Developments in RF Deep Submicron CMOS Change Everything!

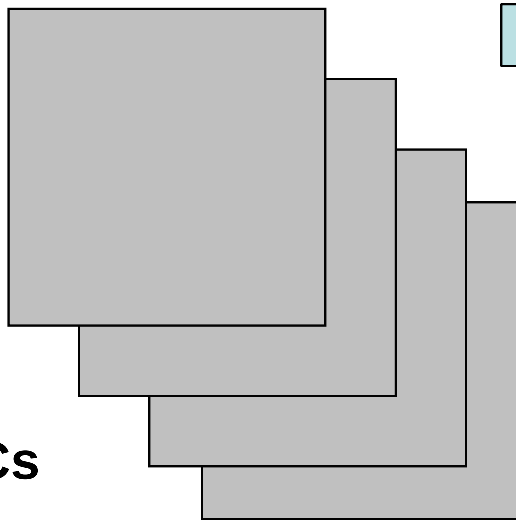
- Idea: Implement RFICs using same process used for dense, high speed digital circuitry
- Fiendishly difficult to use for RF due to process variations and poor design models.
- These problems can now be largely mitigated by:
  - Anticipating variations and revising design accordingly
  - Exploiting availability of nearby dense logic to enable radio to tweak chip as needed
- Dense: Can put many copies of an RF path on a chip
- RF and baseband can go on the same chip (if you are very careful about mitigating digital noise in the RF sections)

Use of Upcoming RFICs

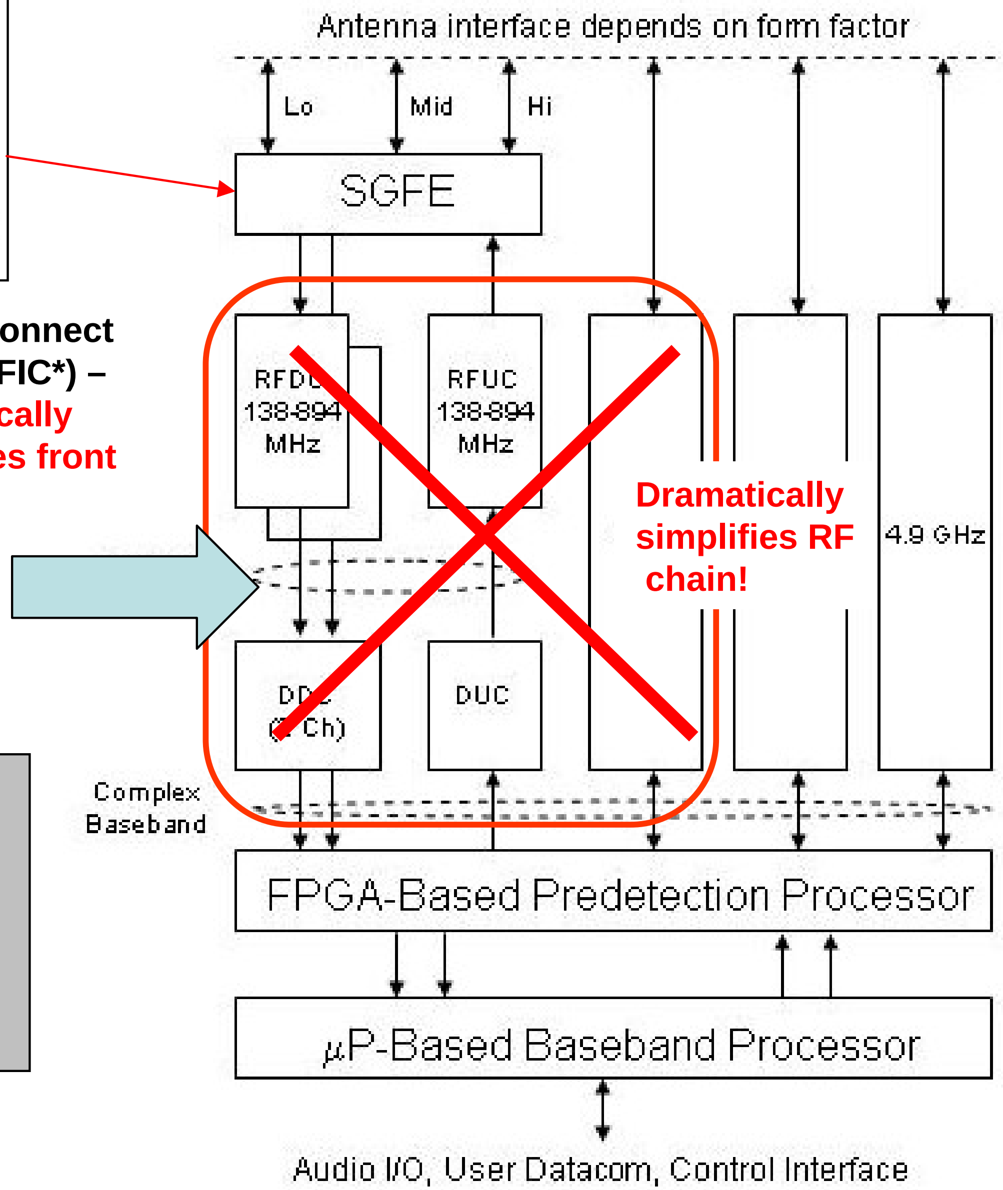


1-to-4 fan-out per band to allow simultaneous monitoring of channels in same band (Sufficient selectivity? May still need tuning filters or filter banks…)

Direct Connect (1 per RFIC*) – Dramatically simplifies front end!



2-4 SDR RFICs



New Antenna Concepts

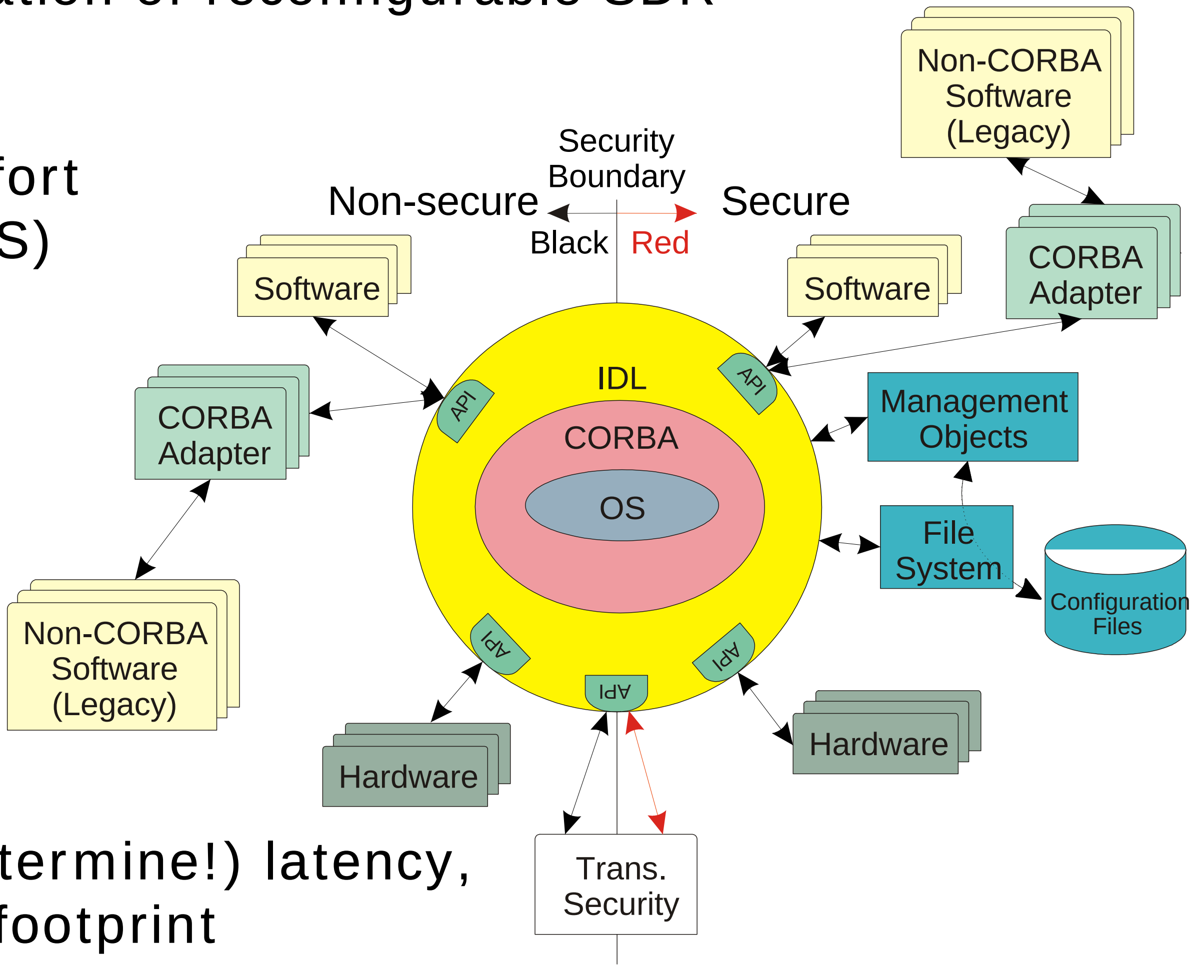
- Bending metal into new shapes will not help. We are at the physical limits.
- Reconfigurable match? Needs MEMS to be small, at the edge of being practical
- Reconfigurable antenna (antenna needs to be small; imposes limitations on transmit power)
- Deliberate F-vs.-IP_3 tradeoff (good for a few dB on RX below 400 MHz)
- Active loading (good for small antennas)
- Non-Foster Matching (tough to keep amplifiers stable…but…)

Digital Processing Philosophy

- Virtually all modern radios are "software defined" in the sense that some functionality is implemented in software
- *Modern* notion of SDR emphasizes *reconfigurability* – this requires specifically that functionality be implemented in microprocessors with large addressable memory spaces
- For an all-mode radio, this is useful primarily in that it has the *potential* to simplify the design by reducing the number of independent baseband sections – but it is not clear it is better in any other sense (cost, size, weight, power…).
- We have chosen to pursue this approach, but simultaneously strive for low cost, low power, etc.

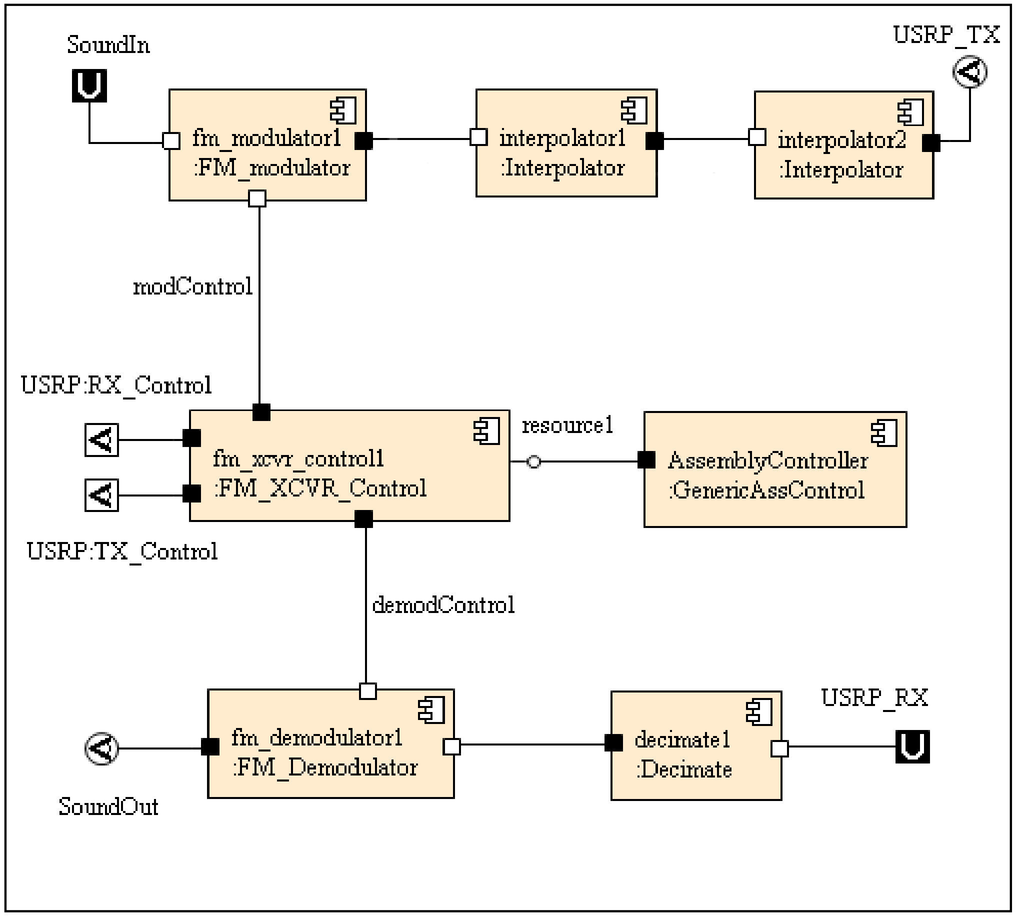
SCA Approach

- SCA = **Software Communication Architecture**. Military specification for implementation of reconfigurable SDR
- **Pros:**
  - Exists; Significant VT effort
  - Lots of momentum (JTRS)
  - Improved waveform portability
- **Cons:**
  - Intended target is general purpose μPs; difficult to accomodate FPGAs, embedded μPs, and processor cores
  - Difficult to bound (or determine!) latency, throughput, or memory footprint



SCA Implementation of the Analog FM Waveform

- Implemented on a PC by using using digital baseband input from a USRP (via USB).
- Supports monitoring of two frequencies simultaneously and allows the user to reply to transmissions on either channel.
- Demonstrated FRS-band operation at W@VT Symposium (June 06)
- Currently attempting to port this to a TI OMAP (ARM+DSP) processor and attempting to profile the implementation for throughput and memory footprint. Very difficult.
- Currently interfaces only to USRP; constrains processing and I/O options.
- Unlikely to be ready a viable solution in the timescale of this project. Work will continue with funding from other projects.

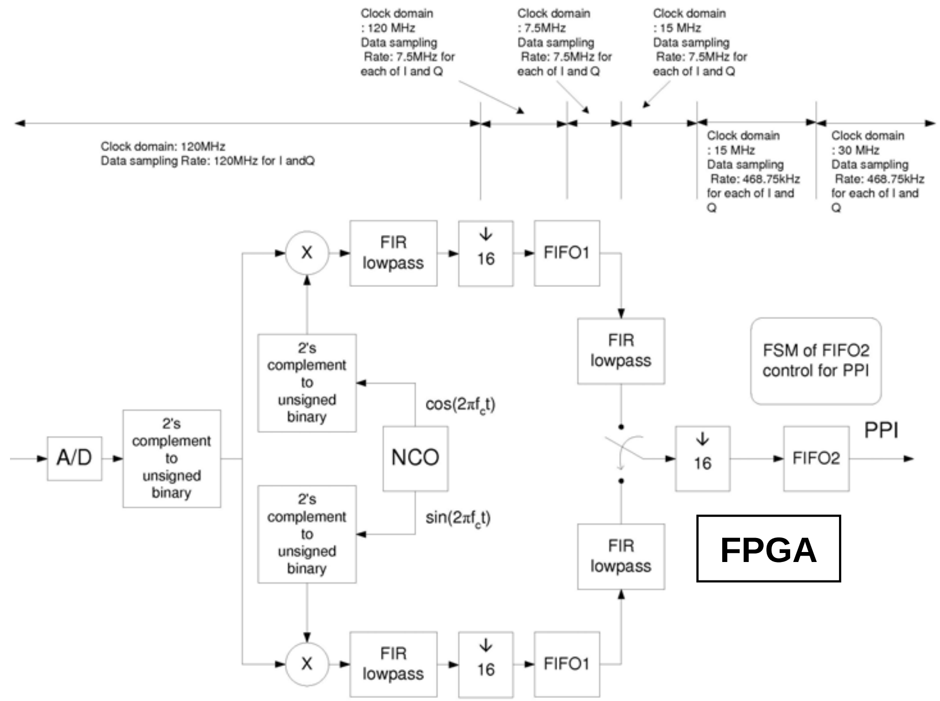


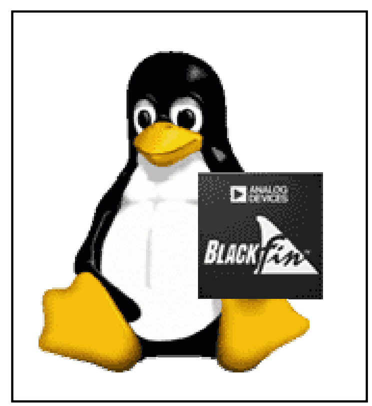
P. Balister, T. Tsou

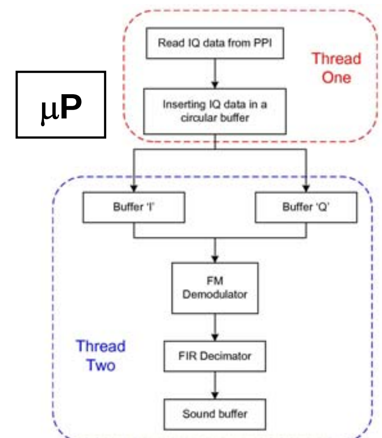
Non-SCA Implementation of Analog FM Waveform

- ***Digital IF:***
  - 12b, 120 MSPS IF sampling
  - Quadrature conversion to 468.75 kSPS with an Altera Stratix (EP1S25) FPGA
  - 17962 LEs + 171 Kbits.
- ***Baseband:***
  - 500 MHz BF537 Analog Devices Blackfin; I/O via PPI (digital video) port
  - µCLinux OS with application written in C with threads.
  - Total 42.4 MB SDRAM footprint:
    10.0 MB kernel image +
    32.3 MB dynamic OS allocation +
    0.1 MB application
  - Analog Devices AD1836A (codec) audio system
- Combined system demonstrated Fall 06

S.M. Shajedul Hasan, K.H. Lee







Concluding Remarks

- Challenges remaining:
  - **Antennas.** *Vehicles:* Not a show-stopper, but existing solutions are ugly. *Handhelds:* Needs attention, have ideas.
  - **Front End** (Duplexing/Switching). Now: Hard, not risky. MEMS promise to make this easy.
  - **Power amplifiers.** Not scary; broadband (100-2500 MHz) ~1W SiGe solutions out there.

- Technical progress documented on project website (updated ~ quarterly): http://www.ece.vt.edu/swe/chamrad/

Acknowledgements

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Philip Balister	M.S. Student
Tom Tsou	M.S. Student

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For more information:

http://www.ece.vt.edu/swe/chamrad/