All-Band All-Mode Radio
for Public Safety

Mar 28, 2007

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## The Problem

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (MHz)</th>
<th>Mode(s)</th>
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<td>TIA-603, P25</td>
</tr>
<tr>
<td></td>
<td>220-222</td>
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<tr>
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<tr>
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<td>4.9 GHz</td>
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+ VHF LO (25-30 MHz)
All-Band All-Mode Radio for Public Safety

Network-Based Interop Devices

Focus of this research

New User – Not pre-coordinated, But able to use a single radio

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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

- 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*
  - *2\textsuperscript{nd} 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.
How a Superhet Designer Views the Problem

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Large gaps where there is no requirement

Relatively dense use of limited range

Best to handle these separately
All-Band All-Mode Radio

VT Superhet Strategy

Off-the-shelf Chipsets

Antenna interface depends on form factor

Analog Devices AD6636

Audio I/O, User Datacom, Control Interface

FPGA-Based Predetection Processor

μP-Based Baseband Processor

DDC (2 Ch)

DUC

RFDC 138-894 MHz

RFUC 138-894 MHz

PCs 2.4 GHz 4.9 GHz

Digital IF ~ 40 MHz BW

Complex Baseband

See Slide

See Slide

VT Superhet Strategy

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Strawman 138-894 MHz Frequency Converters

- Derivative (simplification) of existing “MCMS” design ([http://www.ece.vt.edu/swe/mcms/](http://www.ece.vt.edu/swe/mcms/))

- Downconverter
  - 78 MHz IF w/40 MHz BW
  - $G \sim 47\, \text{dB}$, $F \sim 4.5\, \text{dB}$, $IIP_3 \sim -32\, \text{dBm}$
  - 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 ($\sim -10\, \text{dBm}$)

- Upconverter tunes 78 MHz IF to 138-894 MHz using same frequency plan

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

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

VT Evaluation Board
Design/Build/Test: Chris Anderson

NOTE: CHANNELS RENDERED AS --- --- --- ARE AVAILABLE ONLY IN 6-CHANNEL PART
M = DECIMATION
L = INTERPOLATION

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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

Dramatically simplifies RF chain!
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.-IP₃ 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 accommodate 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 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

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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

S.M. Shajedul Hasan  Ph.D. Student
Kye Hun Lee  Ph.D. Student
Jang Hoon Oh  Ph.D. Student
Kathy Wei Hurst  M.S. Student
Chris Anderson  Post Doc

Jeff Reed  Co-PI
Philip Balister  M.S. Student
Tom Tsou  M.S. Student

For more information:

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