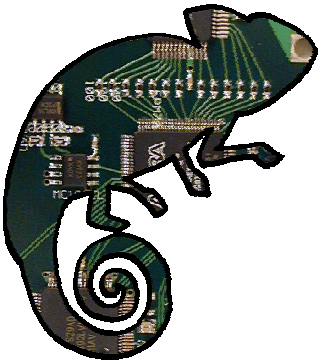

Chameleonic Radio

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The Rise of All-Band All-Mode Radio

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January 9, 2007

Bradley Dept. of Electrical & Computer Engineering
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Wireless communication is an essential component of public safety operations [1,2]. First responders have benefited from many technical advances in the wireless arena in recent years including new modes for voice and data communications, cellular and satellite communications, and wireless local area networks (WLAN). At the same time, this profusion of new technology has aggravated a looming crisis of interoperability. Incompatible equipment, rigid and fragmented spectrum allocations, and continuing reliance on proprietary and "closed" systems are some of the key problems preventing seamless communications among first responders [3].

Currently, the dominant paradigm for interoperability in public safety communications is based on network infrastructure. In this approach, disparate radio networks are integrated through the use of radios that are combined back-to-back and serve as relays. A limitation of this approach is poor support for "uncoordinated users," i.e., unanticipated users utilizing technology not supported by the network infrastructure. Classic examples include military units, state and federal agencies, and non-profit organizations acting in a support role during disaster response and other various crisis operations. However, this problem exists to some extent wherever first responders rely on cellular, WLAN, and other technologies which are too expensive or complex to be accommodated by existing network-based interoperability devices. Other solutions – including deployments of multiple sets of handsets and terminals, and loan of equipment to uncoordinated users – usually entail undesirable additional operational, training, and logistical difficulties.

At Virginia Polytechnic Institute & State University ("Virginia Tech"), we are working on an alternative to network-based interoperability: *user-based* interoperability. In this approach, existing infrastructure continues to operate without modification, but is accessed in a seamless and transparent manner by means of a single all-band all-mode radio, which is deployed to the users. Ideally, users equipped with such radios would be able to communicate in any public safety radio system, immediately and without prior technical coordination. Furthermore, all-band all-mode radios based on software defined radio (SDR) technology could eventually lead to simplification, standardization, and improved "future-proofing" of radio infrastructure.

Such technology has long been of interest to the U.S. military, which faces similar interoperability challenges and has invested considerable resources on the problem. However, military requirements differ considerably from those of the public safety community. Thus, military SDR-based multi-band / multi-mode radio technology has limited applicability to public safety applications [4].

In our research, we are taking a fresh look at the problem, taking into account the unique requirements of the public safety community, and attempting to exploit some recent and emerging technological advances in the areas of RF and digital system design. This article describes some of these technical aspects, and how they might come together to make possible the first truly all-band all-mode radios for first responders.

The Evolution of Radio Architecture

The principal challenge in the development of an economical all-band all-mode radio lies in RF design. For decades mobile radios have been based on superheterodyne architecture, in which frequency selectivity is obtained using fixed filters at intermediate frequency (IF) stages. This is hard to beat for RF performance, but becomes difficult and expensive when large tuning range is required. For an all-band public safety radio, the problem is formidable: Frequencies of interest in the U.S. include HF (25-30 MHz), VHF (30-50, 138-174, and 220-222 MHz), UHF (406-512 MHz), the 700 MHz and 800 MHz bands, cellular bands around 850 MHz and 1900 MHz, unlicensed spectrum around 2.4 GHz and 5.8 GHz, and dedicated spectrum around 4.9 GHz.

"Superhets" can accommodate multiband requirements using a "divide and conquer" strategy, in which the tuning range is divided into smaller ranges, and each is served by different IF stages which are switched in or out as necessary. In fact, this is the principle at work in many existing offerings including dual-band VHF/UHF radios and multiband receive-only radios, such as scanners. However, this approach soon faces the same problems – difficulty and cost – as the number and span of the smaller tuning ranges increase.

The natural alternative is direct conversion architecture. In the direct conversion approach, signals are mixed directly from RF to baseband in-phase and quadrature signals, and vice versa. Beginning in the mid-1990's it became possible to implement nearly-complete direct conversion receivers and transmitters capable of very large tuning range on a single integrated circuit (IC). This dramatically reduced the cost and size of a radio capable of covering a large tuning range, but left two problems unsolved: (1) inexpensive tunable filters with adequate selectivity, and (2) suitable circuitry to correct DC offset and self-mixing problems inherent in direct conversion. Until recently, these issues have cancelled out the advantages of direct conversion architecture for high performance applications.

The key to solving both problems has turned out to be the implementation of direct conversion transceivers in deep submicron complementary metal-oxide-semiconductor (CMOS) technology – the same low-cost process technology commonly used to implement modern digital circuits. Although CMOS poses considerable (and continuing) difficulties for RF chip designers, a direct conversion RF transceiver and it's associated digital processing can now be implemented on the same chip, and digital functionality can be used to augment the capabilities of the RF sections, including corrections for DC offset and self-mixing.

The remaining problem – the need for tunable front-end filtering – can now be managed in a number of ways. First, the ability to implement receivers in deep submicron CMOS has reduced cost and size sufficiently that it is possible to cost-effectively implement multiple transceivers operating in parallel, which can be directly connected to an off-chip filter bank without switches. Alternatively, RF microelectromechanical switch (RF-MEMS) technology is now becoming available. RF-MEMS provide the ability to easily switch the outputs of a fixed filter bank to one transceiver, or to switch reactive components within a single filter to implement tuning. Other approaches include increasing the linearity of the RF front end so that broader fixed analog filters can be used, and direct sampling with integrated filtering to avoid mixing altogether. Examples of the practical implementation of these concepts are now common (e.g. [5,6]), and a number of companies plan to offer single-chip products using various combinations of these techniques in the near future. The promised specifications in some cases indicate that these that may be suitable for use in a reduced complexity, low cost public safety radio.

The above technological advances are extraordinary and would not have occurred without strong market forces to motivate the work. Initially, the impetus was the demand for compact low-cost multiband cell phones; more recently however it has been the desire for high-performance single-chip digital TV tuners that has pushed the technology to its current limits [7]. Currently, there is great interest to combining mobile phone, WLAN, and digital TV functions with "personal digital assistants" (PDAs) to make "all in one" devices. Obviously, such a device would have much in common with the desired all-band / all-mode radio for public safety applications.

Challenges Remain

As previously noted, public safety requirements are distinct from those of the military and commercial markets, and so various technical challenges remain. A key issue remains performance versus cost. Generally, the specifications required for mobile radios used in public safety are more demanding than those for consumer radios, and yet must be much less expensive than military radios. Thus, it is not straightforward to adapt reference designs developed for the military or consumer markets; considerable additional design effort is required.

A particularly thorny problem is antenna integration. It is relatively simple to design and integrate antennas which perform well on two or three bands simultaneously. Antennas which perform well in receive-only applications over large bandwidths are also often possible. However, developing antennas which perform well over many bands and over large tuning ranges is a daunting task, especially for transmit operation when low voltage standing wave ratio (VSWR) must be maintained. This issue gives rise to the notorious "porcupine effect;" i.e., the need to use many antennas to support multiband communications. Reducing the number and size of antennas needed will be important if all-band radio is to see widespread use.

Other technical challenges exist, but are much more likely to be mitigated by development in other market sectors. These include compact, low-cost broadband power amplifiers, efficient power supplies and reduced power consumption so as not to degrade available talk time, and so on.

Of course, there are also non-technical challenges associated with the introduction of all-band all-mode radio. Such immensely powerful radios will require new approaches to user training and maintenance, and their widespread use gives rise to new security and operational concerns.

The SDR Connection

Many modern radios are software-defined, in the sense that much of the functionality of the radio exists in the form of software, typically implemented on a digital signal processor (DSP). The modern definition of the term "software defined radio" has come to mean something more than this, however. An SDR is now considered to be a radio whose functionality can be *changed* or *modified* in software. This is not an essential characteristic of multi-mode radios, but it is nevertheless a very useful one. The ability to redefine functionality in software means that the number of processors – hence, size, weight, and power -- is potentially reduced. The reduction is not for certain because a processor capable of SDR in the modern sense may need to be significantly more powerful and require greater amounts of memory.

Modes that should be supported by an all-band all-mode radio for public safety applications include analog FM, Project 25 voice and data, TIA-902, and various cellular and wireless LAN standards. These run the gambit from protocols which are relatively easy to implement in a modern SDR (analog FM, Project 25) to relatively difficult (cellular CDMA, IEEE 802.11b). Ironically, the latter modes are relatively easy to implement using dedicated ICs or FPGAs, as opposed to software-defined hardware. Thus, determining the baseband processing architecture that optimally supports all modes of interest is another challenge for all-mode public safety radios.

Virginia Tech Efforts

Work on all-band all-mode radio at Virgina Tech is sponsored by the U.S. Dept. of Justice's National Institute of Justice. The goal of the current effort is to develop prototype all-band all-mode radios for public safety applications. We are exploring several possible approaches in parallel, evaluating the results, and making the information available to the public safety radio community.

With respect to RF, we are developing radios based on superheterodyne as well as direct conversion architectures. This is motivated by one analysis of possible designs that suggests that the most effective approach might be to use a single high-performance superheterodyne architecture for bands below about 1 GHz, and multiple parallel direct conversion receivers or special function ICs for higher frequencies. We are also collaborating with an industry partner to develop and demonstrate an extremely capable

direct conversion RFIC design that may yield a competitive single chip solution. Another import aspect of our RF work is attempting to minimize the number of antennas needed to cover the bands of interest.

With respect to baseband processing, we are developing and evaluating both traditional "bottom up" designs based on combinations of dedicated digital up/downconverters and microprocessors, as well as a "top down" approach based on an implementation of the Software Communications Architecture (SCA) [8] for embedded DSP microcontrollers.

A project web site which described this work in additional detail is maintained at http://www.ece.vt.edu/swe/chamrad/.

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