SDR CONSIDERATIONS FOR PUBLIC SAFETY

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ABSTRACT

This paper discusses tradeoffs in designing a radio for meeting public safety requirements. In particular, the following topics are covered:

- Typical public safety requirements (including durability, environmental, features, RF specifications, radio coverage, regulatory, and standards) that tend to be key drivers for the size, weight, power consumption, and/or cost of the radio.
- Design tradeoffs for the radio, including identification of necessary SDR technology improvements for realizing higher tier SDR radio designs.

The primary focus is the handheld portable radio, which tends to be the most challenging design of the various types of radios used in a public safety system.

1. INTRODUCTION

Since the mid-1990's, Software Defined Radio (SDR) technology has been receiving considerable attention due to its potential benefits for addressing today's and future communications requirements. The public safety community shares this interest in SDR, as exemplified by the formation of Public Safety Special Interest Group (PSSIG) within the SDR Forum in 2004. A notable accomplishment of the PSSIG has been its recent publication of a report [1] that investigates SDR's potential for meeting present and future public safety requirements, including the requirements from the SAFECOM [2] and Project MESA [3] Statements of Requirements

One of the conclusions of the PSSIG report is that the major public safety radio manufacturers have already been using SDR hardware technologies in their radio designs as a result of their normal design tradeoff processes for balancing cost, size, weight, power, and performance to meet public safety requirements. The following narrative discusses the requirements that are key drivers of the radio design and some of the tradeoffs for meeting these requirements. Handheld portable designs are the primary focus, since this type of radio tends to be more challenging than larger base stations or vehicle-mounted mobile radios due to their added constraints of small size, low weight, and low battery power consumption.

2. RADIO REQUIREMENTS

2.1. Operating Modes

Most modern-day portables are capable of multimode operation, with the mode selected using a radio menu, button, or knob. Typical selectable waveforms include analog-FM, the APCO25 digital standard [4], and one or more manufacturer-proprietary protocols. Traditional waveform bandwidths have been commensurate with 12.5 or 25 kHz channel spacings, but the recent trend in some frequency bands is for much wider bandwidths to enable high-speed or broadband data capabilities. Modulations are usually variants of 2- or 4-level constant-envelope FSK for digital modes and analog-FM for analog modes, with a recent trend toward linear digital modulations due to their increased spectral efficiency. Communications of the portable may be "one to one" calls (denoted "individual" calls) or "one to many" calls (denoted "group" calls).

The frequency bands for public safety are shown in Figure 1. A communications system for a given service area has traditionally used a single frequency band of operation (however, overlays of more than one band in the same area are becoming more common). With continuing evolution into "system of systems" architectures that may span several frequency bands of operation, there is an increasing need for portables to operate in multiple user-selectable frequency bands that may be separated by one or more frequency octaves (e.g., VHF and 800 MHz).

2.2. Coverage Topologies

The coverage topology (figure 2) for a typical public safety system also influences the portable's requirements. One key driver for a public safety system design is the stringent requirement for coverage reliability (usually greater than 95% and sometimes as high as 98%), often including portable coverage within buildings with up to 30 dB (or sometimes even higher) loss. Also, traditional public safety systems, which predominantly use group calls, tend to have

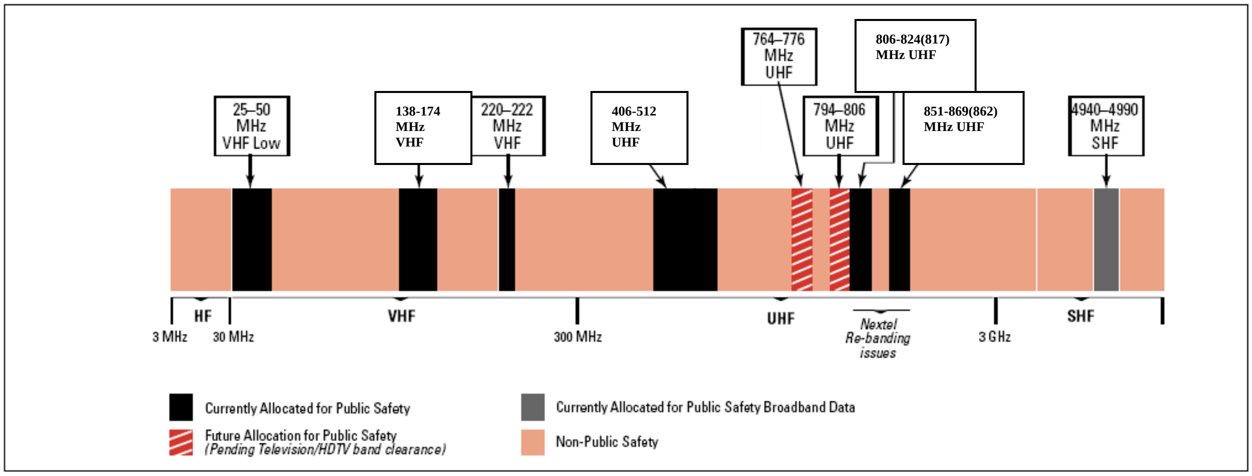

Figure 1. Public Safety Frequency Bands (Adapted from [5])

different coverage topologies than for cellular systems that use individual calls. For the common situation where there are an extremely limited number of frequency channels available for covering an area with dense user population, the topology tends toward wider tower spacings, higher towers, and higher power than for cellular systems. This accomplishes a reduction of the number of frequency channels that are simultaneously occupied for group calls over wide areas that encompass more than one site. In turn, the total number of frequency channels that are needed for the system are reduced. This coverage topology, in conjunction with the stringent reliability requirements and the need for balanced coverage to and from the portable, necessitates that the portable typically be capable of at least 3 watts of output power, placing demands on the battery technology, heat dissipation, and the internal signal isolation/shielding within the tight enclosure of the portable to mitigate PA feedback effects.

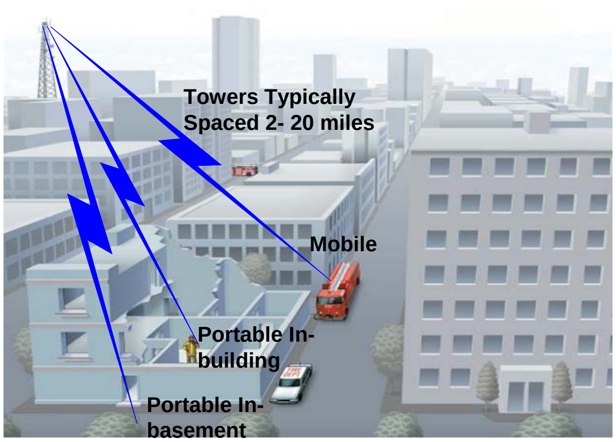

Figure 2. Typical Public Safety Radio Coverage Topology

2.3. Regulatory and Standards Requirements

The primary regulatory bodies for North America include the FCC for US state and local government users, the National Telecommunications and Information Administration (NTIA) for US Federal government users, and Industry Canada (IC). FCC regulations for private land mobile service are contained in CFR 47 [6] with Part 90 pertaining to land mobile radio systems. NTIA radio requirements, which are similar to FCC Part 90 rules, are primarily embodied in the so-called "Red Book" [7]. Industry Canada regulations [8] are quite similar to those of the FCC.

In addition, radios to be used in a hazardous environment require a Factory Mutual (FM) [9] rating of Intrinsically Safe (IS), which imparts requirements regarding arcing, sparking, circuit faults, and limits for energy storage devices (e.g., capacitors, inductors) within the circuitry of the radio. For products sold in Canada, the Canadian Standards Association (CSA) [10] closely follows the standards of FM. Products sold in Europe require a CE Mark which is based on testing the RF spectrum as well as product safety, tested to ETSI European Norm (EN) documents. In addition, the Federal Information Processing Standard (FIPS), 140-2 provides product validation to non military encryption standards.

The portable must also conform to interface, operation, RF performance, and features standards developed by bodies such as TIA and APCO, including APCO16B [11], TIA603 [12], and the comprehensive APCO25 (P25) specification [4], which consists of over 30 requirements documents. An explanation the myriad of requirements pertaining to these standards is well beyond the scope of this paper.

2.4. Radio Features Requirements

An overview of the numerous features requirements documented in the aforementioned APCO16B and P25 standards documents is contained in a previous SDR Forum publication [13] provided by this author. Also, other features are constantly evolving either as part of the evolutionary process of addressing customer expectations, gaining a competitive advantage, or explicitly in customer requests for proposals. Since there are many features, an exhaustive discussion or explanation is not possible in the limited scope of this paper. However, typical "core" features available to the radio user are shown in Table 1.

Table 1. Typical Radio Features

Fast access (<0.3 sec)	Mobile Data Terminal interface
Group calls	Over-the-air-rekeying
Individual Calls	Over-the-air-reprogramming
Encryption	Patch/SimulSelect
Emergency Declaration, Alerts, call transmission, reception/indication	Dynamic Regrouping
Scanning	PSTN interconnect
Group and Caller ID	Queuing
System Wide Calls	Transmission and message trunking
Multi-group calls (Agency/Fleet, etc)	Unit enable/disable
Data transmission and reception	Status message
Tone generation	Short message
	Call alerts

2.5. Environmental Requirements

Environmental requirements for a public safety portable include MIL-STD-810F [14], TIA-603 [12], TIA-102 [4] and the US Forest Service (USFS) Vibration Stability [15]. MIL-STD-810F testing deals mostly with pre-testing the radio under standard conditions, subjecting it to extreme environmental conditions, and then post-testing the radio under standard conditions to ensure survivability. During TIA-603 and TIA-102 testing, environmental testing of the portable is performed while the radio is operational for the most part, with the exception of a 1 meter drop test. Table 2 lists many of the typical environmental requirements.

Table 2. Typical Public Safety Environmental Requirements

STANDARD	DESCRIPTION
MIL-STD-810F	Low Pressure
	High Temperature (+60°C Operating; also storage temp)
	Low Temperature (-30°C Operating; also storage temp)
	Solar Radiation (240 Hours)
	Temperature Shock (-30°C to +60°C)
	Humidity
	Water Intrusion
	Minimum Integrity Vibration
	Blowing Rain
	Blowing Dust
	Functional/Basic Shock
	Basic Trans. Vibration
	Transit Drop
	Salt Fog
U.S. FOREST SERVICE	Vibration
TIA/EIA-603	1 Meter Drop (Shock) Allowable Degradations of Various RF Performance Requirements Versus Temperature, humidity, vibration, shock
TIA/EIA-102	Allowable Degradations of Various RF Performance Requirements Versus Temperature, humidity, vibration, shock

3. TYPICAL PORTABLE DESIGN TRADEOFFS

The design for meeting the above and many other public safety requirements is a delicate balancing act of weight, size, performance, power consumption, and cost. SDR technologies offer a significant benefit for meeting many of the radio's requirements, but, for some, it doesn't really serve a direct benefit. In general, any requirement that can be satisfied in the baseband processing of the radio benefits most from SDR due to Mohr's law advances in processing technologies.

Some examples of requirements for which SDR technologies don't really offer much benefit are as follows:

- Environmental/ruggedness requirements including those in Table 2
- Relatively high transmit output power for a handheld (at least 3 watts)
- High capacity batteries in a small form factor
- High reliability with MTBF greater than 3 years
- Low distortion, high output speaker audio
- Some of the stringent RF requirements
- High frequency stability

The costs associated with meeting these requirements thus are in essence fixed relative to SDR technology tradeoffs.

Key public safety radio design tradeoffs for which SDR technologies have a more direct influence will now be considered.

3.1. Regulatory Requirements Design Tradeoffs

Probably the most critical regulatory requirements from a radio design perspective are the stringent emission masks which the transmitted signal spectrum must not exceed. These mask requirements have a major influence on the radio's entire transmit chain, from the baseband processing which benefits from SDR technologies through the RF power amplifier and its associated circuitry which today's SDR technologies don't significantly benefit, if at all. Extreme care must be taken in employing a 3 watt PA in a small portable package so that the spectral quality of the PA output is not distorted by feedback. Also, spectral regrowth though the PA must be avoided, which requires a challenging linear PA design if the waveform is linear.

3.2. Tradeoffs to Meet Adjacent Channel Rejection Requirements

Excellent adjacent channel rejection (typically greater than 60-70 dB at 12.5 and 25 kHz frequency offsets) is a necessity for public safety to avoid disruption of life-critical communications from interference sources. Such sources can be from other nearby public safety systems, transmissions from other types of services (e.g., cellular), or even from terminals or base stations within the same system in instances where aggressive frequency reuse has to be employed in a system due to limited frequency channel availability.

This adjacent channel rejection is a key driver of dynamic range and receiver filter designs, and creates a need for receive signal A/D converters with many bits (and high spurious free dynamic range), especially if sufficiently-selective adjacent channel analog filtering is not employed ahead of the converter (e.g., in the first and more typically second IF filters) to reduce its input interference level. In the best case for an A/D converter that has somewhat aggressive analog adjacent channel filtering ahead of it, at least 12 bits are typically needed. For the other extreme that has "loose" pre-converter analog filtering with little or no adjacent channel rejection, at least 16 bit A/D converters may be required. For a portable implementation, A/D converters with this requisite dynamic range consume too much battery power to be placed in the receiver string at a point very close to the antenna to enable a high-tier SDR architecture. As such, the receive A/D converters(s) are usually placed either in a low frequency IF stage or at baseband.

3.3. Tradeoffs for Intermod Suppression and Blocking Rejection

Intermod suppression and blocking rejection (typically 80 to 100 dB) are also extremely important to avoid disruption of life-critical communications, especially from nearby strong signal emitters in the same frequency band. Like adjacent channel rejection requirements, these requirements also drive receiver dynamic range, especially in the radio's front end.

3.4. Transmit Signal Purity Tradeoffs

Examples of typical transmit signal purity requirements include the following:

- Adjacent Channel Power greater than 60 to 70 dB at 12.5 or 25 kHz offsets from the transmit center frequency
- Transmit spurious outputs better than -70 to -90 dBC;
- Digital transmit eye pattern closure less than about 5%.
- Meets the appropriate stringent FCC mask(s)
- Frequency stability of better than 0.1 part per million (ppm) for many applications

These requirements allocate to the transmit modulator, PA (and its associated RF circuitry), frequency synthesizer design, D/A converter dynamic range, and transmitter filtering. As with the A/D converter placement for the receive signal path, D/A converters in the transmit signal path with the requisite dynamic range consume too much power for placing the D/A close to the antenna; the placement is typically limited to a low frequency IF or baseband.

3.5. Tradeoffs to Enable Multiband Capability

In combination with the high dynamic range requirements discussed above, multiband capability is one of the most significant drivers of cost as well as battery power consumption. Multiband radios that are capable of covering public safety frequency bands with wide frequency separation (e.g., VHF plus 800 MHz) require multiband antennas, wider bandwidth front end amplifiers, and either high dynamic range, high speed A/D and D/A converters or replication of analog circuitry. With today's converter devices, high speed, high dynamic range usage is precluded due to battery life considerations, so the architecture for widely separated frequency bands tends to be driven to the replication of RF components for each band.

3.6. Multi-protocol, Multi-feature Tradeoffs

These are not as significant of a cost or power consumption driver as the requirements described above. For example, multiple *protocols* are much easier to implement than multiple *frequency bands.* This is because the baseband processing tends to determine the ability of the radio to support multiple protocols, and thus can take advantage of Mohr's Law growth in processing speed and density. To implement multiple bands, however, either high bandwidth, high dynamic range A/D and D/A converters would need to be placed close to the antenna, or lower speed converters can be used with replication of analog circuitry. Today, the former method suffers from excessive power consumption and cost. Furthermore, no major "breakthroughs" are anticipated at present from A/D converter technology to mitigate this problem, at least in the foreseeable future. Replication of analog circuitry has disadvantages of increased cost and size if the radio has at least, say, two widely separated frequency bands.

The gain-bandwidth product of amplifiers and the antenna at the RF front end will also need to improve greatly for efficient operation over multiple bands in one radio. For portable operation, the combination of multiple RF bands into one antenna must be accomplished in a small form factor, which traditionally has lowered the antenna's efficiency and thus reduced the battery life.

3.7. Baseband Processors Tradeoffs

A major cost/functionality and battery life tradeoff for the baseband processing is the partitioning of the high-speed baseband processing between devices such as DSPs, FPGAs, CCMs (Configurable Computing Machines), and, in some cases, ASICs. Although ASICs generally have the lowest power consumption and highest speed, they tend to have fixed functions and so lack the programmability needed for achieving SDR's advantages. Cost of ASICs in a public safety radio can be high compared to the use of ASICs in a cellular radio because the development NRE is apportioned to fewer quantities of manufactured units. FPGAs and CCMs, which are most suited to parallel processing functions and also have traditionally demanded considerable amounts of power, are more suitable for a multi-channel base station implementation than for a portable. Therefore, DSPs tend to be the "workhorse" high speed baseband processor in public safety radios, augmented with a "general purpose" host processor for accomplishing network/user interfaces and general radio control.

4. LOOKING TO THE FUTURE

Similar to the past, it is expected that the major public safety radio manufacturers such as M/A-COM will continue to incorporate the best available SDR technologies that make sense from cost, weight, size, performance, and power consumption tradeoffs for meeting the public safety customers' requirements.

It is not expected that SDR will cause a major *revolutionary* change in the way public safety radios are designed today. Instead, increasing capabilities of SDR technologies will continue to cause an *evolutionary* change in the sophistication and performance of the radio, much like it has in the past as radios have evolved from simple analog FM single mode transceivers to the degree of complexity in modern day digital radios that incorporate multiple modes in software, including the complex requirements for P25.

To keep pace with increasing capabilities of the technologies, the requirements placed on the radio will undoubtedly evolve as well. For example, the Phase 2 P25 standard that is currently being developed within the TIA committees represents increased waveform complexity relative to current generation P25 Phase 1 requirements. Also, the public safety community has been proactive in defining a vision for future requirements of the radio system; the SAFECOM SOR [2] is a good source for a vision; Figure 3 is this author's attempt to relate that vision to the future portable.

One aspect of achieving this vision is similar to the process discussed herein, i.e., continue the evolution of public safety radio designs using SDR technologies that make the most sense in regards to performance, size, weight, and power tradeoffs. In addition,

1. The public safety standards organizations, users, and technical consultants that establish the user requirements must be cognizant of SDR's cost/benefit tradeoffs in order to judiciously levy new requirements that keep pace with the evolving technology without introducing excessive cost, size, weight, or battery consumption or sacrificing any of the essential life critical requirements such as system reliability and quality of service.
2. The radio designers/manufacturers must work with those that establish the public safety radio requirements to provide feedback and education regarding these tradeoffs and cost breakpoints versus increasing capabilities.
3. The SDR technology developers need to address shortcomings in the radio front end that are discussed in this report, which includes front end RF and sampling technologies.

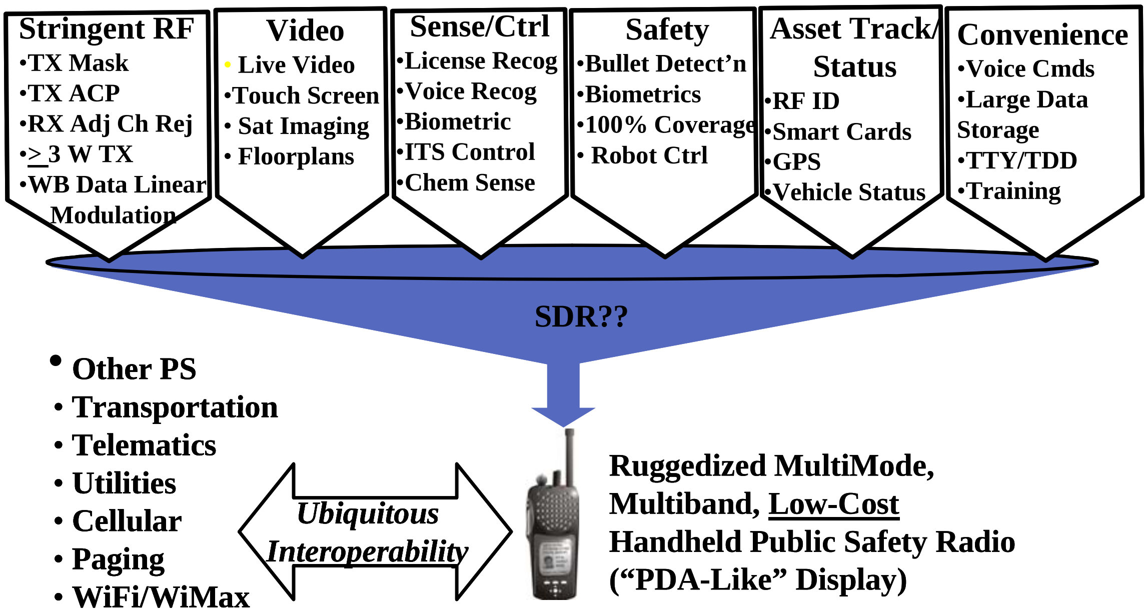

Figure 3. A Vision for the Future Public Safety Portable

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