ADVANCED COMMUNICATIONS TECHNOLOGY

U.S.C.G. Communications Interoperability Technology Assessment

Prepared for:

United States Coast Guard
Systems Directorate

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INTRODUCTION

The U.S. Coast Guard must routinely interact with other (Federal) government agencies (OGA), State and Local agencies, and various public safety organizations in the performance of its missions. In most areas of the country this is primarily local police and rescue forces, but agencies such as Customs, the Drug Enforcement Agency, and the Border Patrol may also be involved. Unfortunately the communications equipment and operating frequencies of each of these organizations are different than those used by the Coast Guard. The R&D Center was tasked with identifying communications technologies to solve this interoperability problem. This report identifies various alternatives that are either commercially available now, or will be in the near future.

REQUIREMENTS

The main interoperability requirement is to provide communications across various frequency bands. However, in many cases a simple cross-band repeater will not work because different modulations and/or channel bandwidths are used. Another problem is that different groups use different encryption methods. And finally, many public safety organizations are moving to trunked systems for better spectrum utilization. Any interoperability solution must accommodate all of these demands.

Frequency Bands

The Coast Guard has the authority to transmit on various VHF-FM Marine frequencies; generally in the range of 156–162 MHz. These are all 25 kHz (wideband) channels used as conventional, simplex, channels with Frequency Modulation (FM). The Agencies and Organizations that the Coast Guard needs to communicate with operate, in general, on other frequencies. These include the VHF bands of 153–156 MHz, 158–160 MHz, and 162–174 MHz and UHF bands at 420–470 MHz, 821–824 MHz, and 866–869 MHz. These are used as both wideband (25 kHz) and in some cases narrowband (12.5 kHz) channels. Some agencies are using trunked (as opposed to conventional) systems on their frequencies (this is most common in the UHF bands). Different modulation types are also used such as FM and C4FM.

APCO Project 25

APCO Project 25 is a joint government/industry standard setting effort to develop technical standards for the next generation communications equipment worldwide[1]. This effort is sponsored by APCO, NASTD, FED and the TIA. The four key objectives of this effort are[2] listed below. Note that objective number 2 (highlighted) is also a key Coast Guard requirement.

1. Obtain maximum radio spectrum efficiency.

2. **Allow effective, efficient and reliable intra-agency and inter-agency communications**.
3. Provide user-friendly equipment.
4. Ensure competition in system life cycle procurements.

The output of the process is a set of technical specifications that define the parameters of a Project 25 system. FTR 1024A[3] contains a list of documents that manufacturers can reference to develop equipment that meets the objective of interoperability. A general list of requirements is provided in [2]. Much of the work done by this committee is directly applicable to the Coast Guard's interoperability issues. In fact, due to the widespread acceptance of the APCO 25 standards and their adoption as Federal standards (FTR 1024A), any new Coast Guard system needs to include compatibility with APCO 25 developments.

Some of the Project 25 Technical Standards (Phase 1) are[4]:

Channel Access	FDMA
Composite Digital Rate	9600 Baud
Modulation	C4FM @ 12.5 kHz
Encryption	DES
Vocoder	IMBE

The composite signal rate of 9600 bps consists of the digital voice signal at 4400 bps, out-of-band signaling of 2400 bps, and 2800 bps of forward error correction. The channel efficiency is much improved since two Project 25 channels, which include signaling and error correction, can fit into the space required by one analog channel. Additional technical detail can be found on the APCO Project 25 web site[1].

Project 25 radios are backwards compatible; that is, they can communicate in analog mode to older analog radios as well as in digital mode to Project 25 radios. The Project 25 standards are also frequency independent, in other words, they can be used at VHF, UHF, and 800 MHz. The standards also include specifications for standard interfaces for telephone interconnect, mobile data, and voice/data encryption ,which allows for terminal equipment and software to provide these features regardless of the RF system design. The table below [4] lists many of these features.

Feature	Analog FM Systems	Project 25 Systems
Unit ID	Proprietary	**Standard**
Talk Group ID	Proprietary	**Standard**
Network ID	Proprietary	**Standard**
Emergency	Proprietary	**Standard**
Call Alert	Proprietary	**Standard Option**
Selective Call	Proprietary	**Standard Option**
Selective Inhibit	Proprietary	**Standard Option**
Status / Message	Proprietary	**Standard Option**
Radio Check	Proprietary	**Standard Option**
Interconnect	Proprietary	**Standard Option**
Mobile Data	Proprietary	**Standard Option**
Encryption	Proprietary	**Standard Option**

TECHNICAL ALTERNATIVES

Cross-band Repeaters and Multi-band Radios

Radio transceiver technologies now offer dual band or multi-band receive/transmit capability in a variety of configurations. The receive side will receive multiple channels whether VHF-VHF or UHF-UHF. Some units also offer VHF-UHF capability. Often these multi-band transceivers can be configured as crossband repeaters. A crossband repeater will receive on one band of frequencies such as VHF, then retransmit the message on another band of frequencies such as UHF. This is important if an operator needs to communicate with another agency that operates on a different frequency band.

No multi-band/repeater model has yet been identified as an off the shelf, all purpose multi-band transceiver/repeater which includes all the bands and modes the Coast Guard is interested in. However, the technology is rapidly expanding and may provide the needed functionality in the near future. The best of the current offerings are summarized below. However, the shortcoming of most of these systems is the inability to interoperate with various modulation schemes such as the C4FM called for in APCO Project 25.

ICOM

ICOM has various radios (handheld and mobile) that are multi-band, and some that are multi-mode, but nothing that is both. The IC-901A and IC-2350 are multi-band radios[5], and the IC-F1020, and IC-F30LT[6] are multi-mode radios that include narrowband channel and trunking capability.

The ICOM IC-901A, at a price of about $650, will operate within several bands of frequencies and can be programmed as a crossband repeater. In the extended bands, obtainable by removing or replacing jumpers, this handheld transceiver can operate between 138 MHz and 174 MHz, which includes the marine band. Other mobile bands in the 400 MHz to 479 MHz range are also covered. The 1240 MHz to 1300 MHz band is also covered, but the more useful 800 MHz band is not.

The ICOM IC-2350 is another handheld crossband repeater that includes the 138-174 MHz and 400-479 MHz bands. Like the IC-901A, the IC-2350 requires changing jumpers to obtain the extended frequency ranges. These radios can be preprogrammed to interoperate with up to 40 channels. Ease of use and programmability varies from model to model. Price also varies greatly with functionality, numbers of programmable channels offered, and whether handheld or base station configuration.

Ericsson

Ericsson offers a portable radio that is multi-band, VHF-UHF, but is not multi-mode. Specifically, Ericsson does not support the APCO 25 standard. The NPC-200[7] will scan 16 channels in the operating range of 146–174 MHz and 438–470 MHz. This radio operates in wideband (25 kHz channel spacing) mode only.

Daniels

Daniels Electronics, LTD offers a line of cross-band repeaters. These are rack-mount, modular systems that can be easily configured for simplex, duplex, linked, or trunked operation. Transmitter and receiver modules are available to cover the following frequency bands and modulations:

Modulation	Frequency	Channel Bandwidth
FM	30–50 MHz	**20 kHz**
FM	132–174 MHz	**12.5 / 15 / 25 / 30 kHz**
FM	300–406 MHz	**25 kHz**
FM	406–512 MHz	**12.5 / 25 kHz**
FM	806–824, 851–869 MHz	**25 kHz**
FM	928–960 MHz	**12.5 / 25 kHz**
AM	118–136 MHz	**25 kHz**

Motorola

Many of the handheld and mobile radios[8] in Motorola's extensive product line have possibilities. The most promising portables (handhelds) are the XTS 3000 Digital, MTS 2000 Analog, and the ASTRO Saber Digital radios. The most promising mobile (vehicle mount) radios are the MaxTrac Conventional, MCS 2000 Analog, and the ASTRO Spectra Digital radios. The capabilities of these radios are summarized in the tables below. The Saber and Spectra have been selected by the Coast Guard as the replacements for the MX300 and MCX1000 respectively.[9] All of these radios are available for different frequency bands, but do not support operation on more than one band.

Motorola also has several models of repeaters available; these are the GR300, GR400, and GR500.[10] All of these repeaters support VHF-UHF crossband operation as well as add-on options to provide additional functions such as selective calling, trunked repeater functionality, group calling, and advanced interconnections.

Capabilities of Selected Motorola Portable Radios

XTS 300	MTS 2000	ASTRO Saber
Digital or Analog	Analog	**Digital or Analog**
Conventional or Trunked	Conventional or Trunked	**Conventional or Trunked**
Data	Encryption	**Data**
Encryption	APCO 16 Compliant	**Encryption**
APCO 25 Capable	Software upgradeable	**APCO 25 Capable**
VHF / UHF / 800 MHz bands	VHF / UHF / 800 MHz / 900 MHz bands	**VHF / UHF / 800 MHz bands**
12.5, 25/30 kHz channel spacing	12.5, 25/30 kHz channel spacing	**12.5, 25/30 kHz channel spacing**
Software upgradeable		**Software upgradeable**

Capabilities of Selected Motorola Mobile Radios

MaxTrac	MCS 2000	ASTRO Spectra
Digital or Analog	Analog	**Digital or Analog**
Conventional or Trunked	Conventional or Trunked	**Conventional or Trunked**
Data	data	**Data**
Encryption	Encryption	**Encryption**
APCO 25 Capable	APCO 16 Compliant	**APCO 25 Capable**
VHF / UHF / 800 MHz bands	VHF / UHF / 800 MHz / 900 MHz bands	**VHF / UHF / 800 MHz bands**
12.5, 25/30 kHz channel spacing	12.5, 25/30 kHz channel spacing	**12.5, 25/30 kHz channel spacing**
Software upgradeable	Software upgradeable	**Software upgradeable**

VME-based Radios

RJO of Lanham, MD has developed a line of VME-based radios.[11] These radios have been engineered for shipboard use. They resist high impact, are drip resistant and have provisions for red/black slots to meet Tempest requirements for cryptographic equipment. These radios have been designed to replace an entire radio room by compacting all functions into one VME-based standard 19" rack. They may be either manually or remotely controlled, with high fault tolerance and swift repair turnaround times. Failed components can be repaired in minutes either by swapping cards, through software reconfiguration, or by activating spares.

The Coast Guard had reserved 26 units for purchase from the U. S. Navy contract for use afloat (High Speed Fleet Broadcast upgrade). However, this option was not picked up due to lack of funding. The concept is still of interest; however, for replacement of the present communications "high sites" in use within the NDS.

The VME box is available in a variety of sizes and slot configurations, depending upon intent. The Tempest requirement is optional. Spare radio cards may be installed and activated remotely for swift repair. The radio depends upon VME technology, modular design and software control to implement a multi-band selectable configuration between 5 kHz and 2 GHz. It is also COTS technology that is available now.

Depending upon the configuration, the VME box is available for about $11K with an additional cost of just under $15K for each VME module (receiver/exciter), times the number of bands needed. Each module is software configured to cover the required band and modulation method. A six module requirement would for example cost about $100K. While the cost of a prototype module is in the $100K range, the vendor providing the modules to RJO has agreed to provide them at the COTS price.

Software Radios[12]

Traditional radios have dedicated electronic circuitry to perform the functions of transmit, receive, filtering and so on. Software radios emulate these functions in software. It is a generic, more flexible architecture based on digital signal processing technology. Software radios employ a combination of techniques: multi-band antennas and RF conversion, wideband A/D and D/A conversion, and the implementation of IF, baseband, and bitstream processing functions in software.[13] They are currently being developed and refined for military and common-carrier applications such as cellular radio. With the introduction of digital audio broadcasting, software radio design can be applied to broadcast receivers as another solution to analog/digital multi-mode receiver technology.

Software radio uses a variety of receiver programs operating on a digital signal processor (DSP) IC hardware platform. The programs instruct the DSP chip to perform bandpass filtering, automatic gain control, frequency translation, lowpass filtering, and the

demodulation of the desired signal. The instructions for demodulating different signal types, such as AM or FM, are stored in software and applied to the received frequency accordingly.

ICOM

ICOM has a software radio receiver, the IC-PCR1000[14] that will be available in the fall of 1997. This device is a small black box that connects to a PC via the serial port. It has some impressive features including:

- Wide band coverage: 100 kHz–1.3 GHz.
- All mode operation, including CW.
- Tunable bandpass filters for VHF/UHF bands.
- Large selection of tuning steps.

However, it is a receive only device, which makes it unsuitable for NDS use.

SPEAKeasy

The SPEAKeasy multi-band/multi-mode radio (MBMMR) program[15] was started as a U.S. Air Force Rome Laboratory initiative in 1989. The initial work was done by Hazeltine Corporation under contract to the Rome Laboratories in Rome, NY.[16] This radio uses four DSP chips operating in parallel to simultaneously process four independent radio signals, whether AM, FM, frequency or phase-shift keyed. Phase I accomplishments[17] included demonstrated interoperability with the following bands and modes as well as reprogrammability and bridging functions.

HF: analog HF and HF modem

VHF: SINCGARS

UHF: ARC-164, Have Quick I and Have Quick II

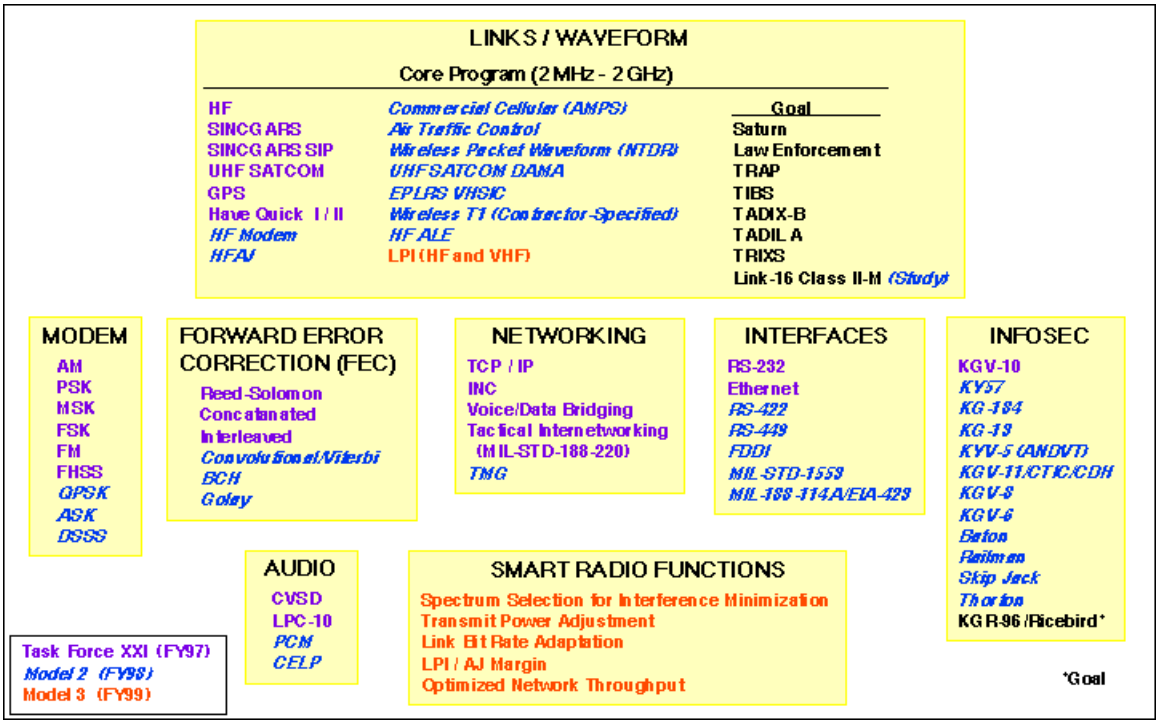
A four-year contract for Phase II of the SPEAKeasy was awarded to Motorola in June 1995. In Phase II, the goal was to move the system from the unique special purpose hardware of phase I to COTS hardware, add internetworking capabilities, data I/O functionality, and incorporate the following new modes and bands:[18]

UHF: SATCOM (25 kHz non-DAMA)

GPS

The SPEAKeasy system is designed[19] to be a standards based open system with standard module interfaces. This allows the system to be flexible and use COTS developments. The

system is intended to have a scaleable architecture that supports technology transition. SPEAKeasy waveforms and COMSEC are all programmed in software. This allows SPEAKeasy to be compatible with DoD legacy systems as well as new commercial systems.

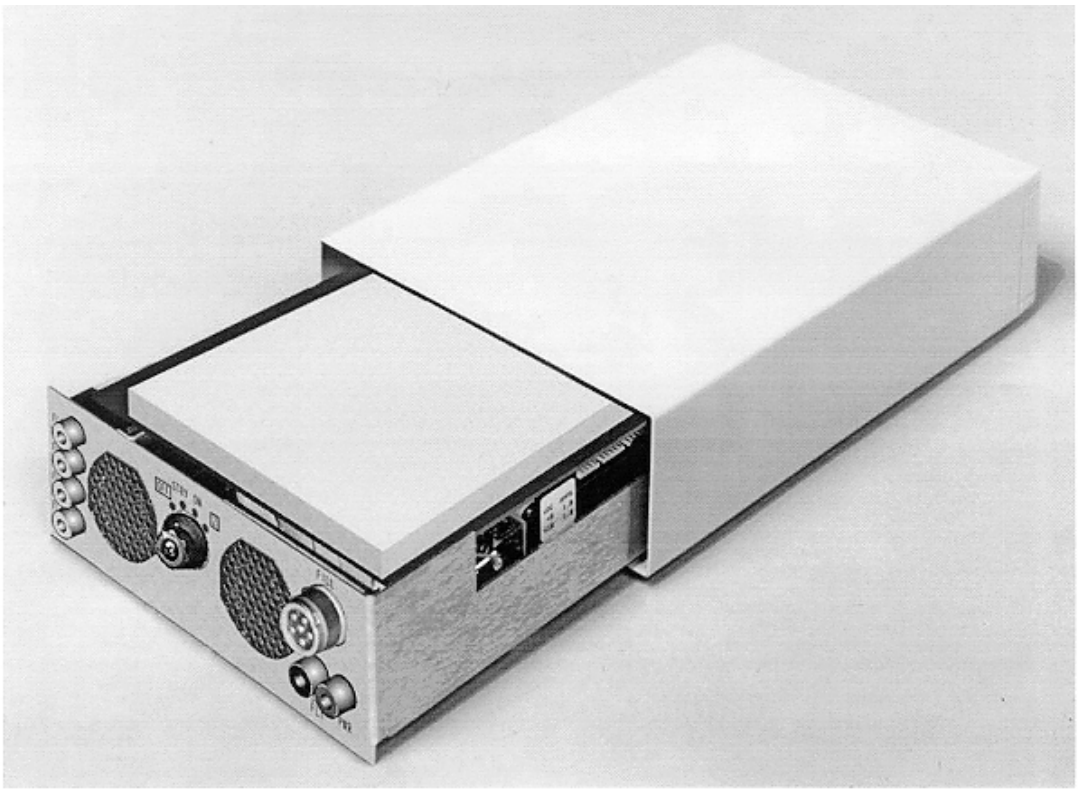


SPEAKeasy capabilities[20]

The SPEAKeasy II development phase has produced the SPEAKeasy TF-XXI-AWE model[21], which has impressive transmitting and receiving capabilities.

Hughes ACE

Hughes Aircraft Company has been developing a software radio called ACE (Advanced Communications Engine). This development has been partially sponsored by DARPA and the FAA. This system was briefed to the Coast Guard R&D Center by Hughes Aircraft in December 1996.[22] The ACE is a software radio with multi-band, multi-mode simultaneous reception capability. The system relies on Hughes' advances in A/D and D/A converters, DSPs, and wideband analog front ends. The first product has 6 simultaneous channels that can be programmed to operate anywhere in the frequency spectrum covered by the front end with a total bandwidth for all 6 channels of 30 MHz. All waveforms and modulations are defined in software allowing for the capability to communicate with virtually any radio. Since the radio can also be connected to a network, the functionality of the radio can be changed remotely over the network.



Artist's Conception of ACE Unit (6" x 8" x 2")

TECHNOLOGY DEMONSTRATION

Group Corpus Christi

Headquarters (G-opr), LCDR Kurt Nancarrow, proposed Group Corpus Christi as the location for a possible follow-on interoperability demonstration. Information on the agencies and organizations that the Group deals with was obtained from the Group Commander and Group Operations and is summarized in the table below. The common thread with all of these agencies is that the principal mode of communications is via landline and the PSTN. Even though most of the required frequencies are available, they are never used. However, the biggest difficulty noted isn't generally with the frequency assignment, it is the compatibility of encryption. In short, this Group does not appear to have a real interoperability problem and would not be a good candidate for a follow-on demonstration.

Agency	Frequency	Comms Currently Possible?	Notes
Local Police Dept.	Unknown	**Helo has the frequency available.**	Landline used from OPCEN and COMMCEN.
Highway Patrol	VHF-FM 154.950 MHz	**Freq. programmed into console.**	VHF never been used. All comms through landline.
INS / Border Patrol	VHF-FM 162.375 MHz	**Freq. programmed into console and handhelds.**	VHF never been used. All comms through landline.
Customs	VHF-FM 162.375 MHz	**Freq. programmed into console and handhelds.**	VHF never been used. All comms through landline.
Texas P&W	VHF-FM Ch 16/22	**Yes.**	Non-vessel comms on landline.
Marine Patrol	VHF-FM Ch 16	**Yes.**	
National Park Service	VHF-FM	**Freq. programmed into console and handhelds.**	VHF never been used. All comms through landline.

VME-based Demonstration

A possible interoperability technology demonstration is to set up a test of RJO's VME-based radio solution. A VME backplane and radio cards for the appropriate VHF-FM Marine, VHF-FM land mobile, and UHF frequencies could be assembled and installed at a Group high site. This would then operate as a crossband repeater to provide communications between the various organizations. The advantage of this type of solution over a fixed repeater such as those offered by Motorola or Daniels is that the system is easily configured by selecting the appropriate radio cards, it is very flexible with modifications done in software, it can have hot spares in the card cage for backup purposes, and it can provide NSA encryption using other VME cards.

The VME-based radio solution offered by RJO could be demonstrated for a reasonable cost. RJO has agreed to loan or lease the VME radio equipment to the R&D Center for a demonstration. The only costs would be for their labor and travel for system integration, meetings, and installation. A demonstration could thus be done for less than $100K. Exact

costs would depend upon the Group selected and how many frequencies would need to be covered.

Software Radio Demonstration

The future of radio communications is in the field of software radios. Although this technology is still in its infancy, some systems are available today that could be demonstrated. The SPEAKeasy program is one option; however, most of their efforts have focused on Military frequencies and modulation types. The Hughes ACE has more functionality implemented in software and is a more flexible system.

A demonstration could be done with a Hughes ACE unit at a Group high site to act as a reprogrammable crossband repeater. Different frequencies and modulation types could be programmed into the unit, and it could be connected via network back to the Group. The advantage of this type of system over a hardware solution as described above, is that the traffic is all digital (the analog signal is digitized close to the output of the antenna) and handled using DSP techniques. This allows changes in modulation, and routing to be made very easily. Also, if needed, the functionality of the unit could be reprogrammed over the network.

Hughes is interested in supporting a demonstration which could probably be done for less than $100K; although again, exact costs would depend upon the location selected and negotiations with Hughes. Teaming arrangements are also possible for this technology demonstration. The Navy is looking at incorporating ACE into their communications demonstration ship (*USS Rushmore*). Also the National Law Enforcement and Corrections Technology Center (NLECTC) in Denver is working on communications interoperability for law enforcement agencies and is interested in working with us on a demonstration.

San Diego Regional Communications System

FLEWUG and PSWN are currently sponsoring an interoperability trial in San Diego that might allow Coast Guard participation. There are actually two separate systems being put into place there. The military system is operational now, and consists of a manned communications board at the Navy Fire Department. This board is connected to other Federal agencies in the area via T1 lines. Audio is manually patched from one agency to another using these T1 lines. This system is not automatic and requires some pre-arrangement.

The local and state police and fire organizations are putting in a shared system throughout the San Diego area. This Regional Communications System (RCS) is a trunked system using VHF, 450 MHz, and 800 MHz frequencies. A SONET ring is being installed to route the trunked traffic around the area. This will be a fully automated system capable of setting up talk groups on the fly. It is scheduled to be operational in 1998. Once in operation, all of the

participants will be able to communicate amongst themselves regardless of location or frequency.

RECOMMENDATIONS

The standards created by APCO Project 25 are being adopted by many organizations throughout the United States. They have also been accepted by the ITU and published as a FTR for use by the U.S. Government. In the future, any Land Mobile radio system will be APCO 25 compliant. Therefore, the Coast Guard needs to ensure that any systems procured will meet these standards. This will enable interoperability with most other agencies and organizations.

In addition to APCO Project 25, the Coast Guard needs to keep abreast of the developments of the National Public Safety Telecommunications Council (NPSTC). The NPSTC is a group of public safety telecommunications associations that was formed 1 May 1997 to follow up on the recommendations of the Public Safety Wireless Advisory Committee (PSWAC). This council is designed to provide an exchange of information between Public Safety Agencies such as FLEWUG and APCO and the regulators (NTIA[23] and FCC[24]) as the recommendations published by PSWAC are evaluated and recommended.[25] Probably the best way to do this would be to attend the FLEWUG meetings.

This report has focused on terrestrial wireless alternatives for interoperability. Specifically not addressed are the numerous new commercial mobile satellite systems projected to be available after 1998. Some of these systems could provide interoperability solutions. These systems will be evaluated in future R&D work (Mobile Communications Infrastructure Project 9003/9250.7) starting in FY98.

All of the technology demonstrations have merit, but there is insufficient funding and personnel resources to pursue them all. The cost of participation in the San Diego effort would probably be minimal. It also offers an attractive opportunity to participate in a large-scale interoperability trial, so this option should be investigated. Since software radios are the wave of the future, this is the recommended technology to pursue. An R&D demonstration of this technology could help to push it closer to commercial availability, and use for the NDS Modernization. The VME based solution is a technology that is available now, and has very little technical risk. This system could be demonstrated, but there is less R&D value in doing so. In conclusion, I recommend that the Coast Guard pursue participation in the San Diego RCS and prepare a demonstration of software radio technology.

GLOSSARY

A/D	Analog-to-Digital
APCO	Association of Public-safety Communications Officials
C4FM	Constant-envelope 4-level FM
CW	Continuous Wave
D/A	Digital-to-Analog
DARPA	Defense Advanced Research Projects Agency
DES	Digital Encryption Standard
DSP	Digital Signal Processing
DSP	Digital Signal Processor
FCC	Federal Communications Commission
FED	U.S. Federal Government
FLEWUG	Federal Law Enforcement Wireless Users Group
FM	Frequency Modulation
FTR	Federal Telecommunications Recommendation
HF	High Frequency
IMBE	Improved Multi-Band Encoding
ITU	International Telecommunications Union
MHz	Mega Hertz
NASTD	National Association of State Telecommunications Directors
NDS	National Distress System
NPSTC	National Public Safety Telecommunications Council
NTIA	National Telecommunications & Information Administration

PSTN	Public Switched Telephone Network
PSWAC	Public Safety Wireless Advisory Committee
PSWN	Public Safety Wireless Network
RF	Radio Frequency
SINCGARS	SINgle Channel Ground and Airborne Radio System
SONET	Synchronous Optical NETwork
TIA	Telecommunications Industry Association
UHF	Ultra High Frequency
VHF	Very High Frequency
VME	Versabus Euro Module
VOCODER	VOice COder / decoDER

REFERENCES

[1] APCO International WWW site at http://www.apcointl.org/.

[2] APCO Project 25 Statement of Requirements, June 25 1997.

[3] Federal Telecommunications Recommendation 1024A-1977, April 16 1997, Project 25 Radio Equipment, Technology and Standards Division, National Communications System (NCS).

[4] APCO/NASTD/FED Project 25 presentation slides from Project 25 WWW site at http://members.aol.com/project25/index.html.

[5] Tucker Online Catalog and various e-mails copied at the following URLs: http://oak.oakland.edu/pub/hamradio/mods/icom/ic901.mod, http://www.luna.it/ftp/ham_radio/ic901.1.

[6] Detailed specifications available from http://www.icomamerica.com/new/.

[7] Detailed specifications are available at http://www.ericsson.se/US/prs/ecr5348a.htm.

[8] Complete list of portables (handheld) available at http://www.mot.com/LMPS/RNSG/portable.htm. A complete list of mobile (vehicle mounted) units available at http://www.mot.com/LMPS/RNSG/mobile.htm.

[9] Commander, USCG TISCOM letter 2880 dated 26 March 1997. “VHF-FM Replacement Radio Capabilities.”

[10] Fixed site (repeater) information can be found at http://www.mot.com/LMPS/RPG/NA/fixed/.

[11] RJO corporate glossies, and VME Technology briefing slides.

[12] Extensive background information on software radios can be found in the May 1995 issue of *IEEE Communications Magazine*. "The Software Radio Architecture," Joe Mitola, pp. 26–38. "Analog-to-Digital Converters and Their Applications in Radio Receivers," Jeffrey Wepman, pp. 39–45. "The DSP Bottleneck," Rupert Baines, pp. 46–54.

[13] "What is a Software Radio?", http://ourworld.compuserve.com/homepages/jmitola/whatisas.htm. See also "Software Radios and Digital Bits" at http://www.hamradio-online.com/1996/sep/edit0814.htm.

[14] Http://www.icomamerica.com/featured/.

[15] Http://www.rl.af.mil/Technology/Demos/SPEAKEASY/.

[16] A good background article on the SPEAKeasy radio is "SPEAKeasy: The Military Software Radio," Raymond Lackey and Donald Upmal, *IEEE Communications Magazine*, May 1995, pp. 56–61.

[17] Http://www.rl.af.mil/Technology/Demos/SPEAKEASY/phase1accom.html.

[18] Http://www.rl.af.mil/Technology/Demos/SPEAKEASY/phase2accom.html.

[19] Http://www.rl.af.mil/Technology/Demos/SPEAKEASY/ezsystem.html.

[20] Http://www.rl.af.mil/Technology/Demos/SPEAKEASY/capabilities.html.

[21] Http://www.rl.af.mil/Technology/Demos/SPEAKEASY/tfxxi.html.

[22] Hughes Advanced Communications Engine (ACE) Technology briefing slides from 19 December 1996 meeting.

[23] NTIA WWW site at http://www.ntia.doc.gov/.

[24] FCC WWW site at http://www.fcc.gov/.

[25] NTIA Public Safety Program Office, WWW site at http://pswac.ntia.doc.gov/pubsafe/.