Speakeasy: The Military Software Radio

The Speakeasy Phase II radio will use programmable processing to emulate more than 15 existing military radios. Speakeasy is a challenge, even with recent advancements in DSP technologies. The benefits, however, make the challenge highly worthwhile.

Raymond J. Lackey and Donald W. Upmal

RAYMOND J. LACKEY is a section head with Hazeltine Corporation.

DONALD W. UPMAL is the Army Project Leader on the joint service Speakeasy Multiband Multimode Radio Program.

Speakeasy is sponsored by the U.S. Air Force Rome Laboratory Contract F30602-90-C-0115.

In the past, a military radio was developed for a 30-year lifetime. It performed a single function, and was optimized for a particular field application. This was primarily caused by the slowly evolving technology and the difficulty of fitting the military user's needs into the package space available. Today, commercial applications are driving technology so that the half-life of a component is down to 19 months, that is, the time from product release to the use of its next generation replacement in new designs.

The dilemma facing the Department of Defense is: How can the military ensure communication with its latest allies and global support structure, deny interception by our current enemies, take advantage of the rapid technology changes, and control costs of military spending? Hazeltine, as the prime contractor, and TRW, as waveform software subcontractor, have faced these concerns with the Government on the Speakeasy Multiband Multimode Radio (MBMMR) Program. The Speakeasy Program is a multi-phase, tech base research and development program for the next-generation military radio, managed by Air Force Rome Laboratory (contract number F30602-90-C-0115) with triservice and ARPA funding. The Speakeasy solution is a combination of strategies, the key to which is waveform reconfigurability in modular, programmable signal processors through software implementation of waveforms and associated processing.

As Digital Signal Processors (DSPs) become faster, the Analog-to-Digital (A/D) conversion is moving closer to the antenna. The DSPs then take on additional signal processing tasks from typically analog circuits in radio implementations. The flexibility of the programmable implementation of these functions allows rapid changes to waveform modulation not possible in analog implementations. This flexibility is an advantage in the military environment where communication at different ranges and to different command levels may require different RF bands, waveform modulation types, band- width-efficient voice encoding algorithms, and encryption structures. Speakeasy Phase I proved the concept and demonstrated the capability of a military software radio.

The Speakeasy Phase II radio is planned to utilize programmable processing to emulate more than 15 existing military radios. Many radios have unique modulation forms and thus specific software modules. Other radios have modes with common waveforms, such as amplitude modulation (AM), which can use generic waveform software modules with a custom set of parameters passed as variables. The waveform software can be a standard set, a set loaded for a specific mission, or even a custom waveform designed from existing software modules for a special-operation mission. Software downloading can be accomplished either locally, by authorized user entry, or via over-the-air (OTA) data distribution.

Background

Speakeasy is a multi-phase, joint service technology program to prove the concept of a programmable waveform, multiband, multimode radio. The MBMMR modules and software will be applicable to a number of platform configurations. This will allow the smaller quantity platforms to take advantage of the mass produced modules from the greatest production base. Figure 1 illustrates the Speakeasy modular concept for implementing multiple waveform capability in common programmable modules to be used in a number of field configurations.

The MBMMR's envisioned use is on joint service platforms, could potentially perform the functions of more than ten existing radios, and should pay for itself solely from the savings accrued by the elimination of parallel maintenance and logistics tails. It is to be a modular design with a fixed, defined, open architectural interface that will allow constant upgrades as technology advances. The

0163-6804/95/$04.00 1995 © IEEE

modular design will also allow expansion for enhanced processing, including increased waveform simultaneity, fault tolerance, and survivability.

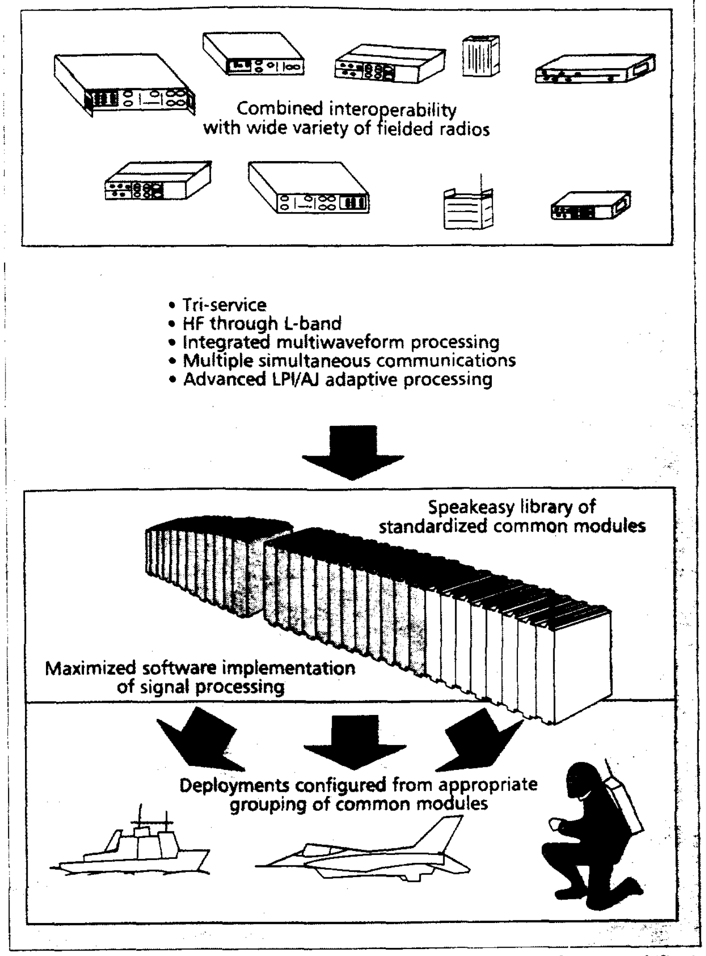
The Speakeasy-derived MBMMR will operate in bands from 2 to 2000 MHz in its basic configuration with any existing or future waveform. It has programmable digital signal processing capacity on the order of one billion 16-bit integer operations per second (OPS) and 200 million 32-bit floating-point OPS (FLOPS). This will have to be reduced to a small, lightweight package for tactical use, including the other analog circuits, RF modules, and battery. Up to four simultaneous waveforms will be active in receive or transmit. It will truly be a laptop supercomputer with antenna ports for voice and data networking.

Although every voice radio (transmit and receive unit) has a group of functions in common, there are differences that prevent interoperation between different types of units. These differences include the RF carrier frequency, modulation technique, and waveform structure. Digitally encoding the voice information further complicates the compatibility of communication systems.

Physical interaction of the RF frequency and the propagation medium also affect the applicability of a frequency band to a communication system requirement. HF signals propagate well for long distances but require large antennas, tend to have communication outages, and are difficult to use for large data bandwidths. Microwave frequencies are very good for high data rates and ECCM waveforms, but are restricted to line-of-sight situations. The typical military unit has varying communication requirements and thus has various radios for its necessary communications links.

The incompatibility of the communication equipment of even the United States' military branches was demonstrated in the Grenada conflict. The communication complexity was greatly compounded in Operation Desert Storm as a large number of allies and coalition forces performed joint operations and needed timely, efficient communication. Again, extra radios were necessary to guarantee an effective communication link.

It is evident that this proliferation of radios can become a significant logistic, as well as physical, burden to the military personnel. Speakeasy seeks to alleviate this burden by implementing the common functions in an all-digital, software-programmable, baseband signal processor, a multiband (2 to 2000 MHz) low-power RF transceiver, and interchangeable high-power RF amplifiers, and antenna subsystems. Figure 2 shows a possible futuristic manpack MBMMR, with an interchangeable RF module in back of the unit. The MBMMR will be a software radio requiring specialty hardware modules only for high power transmissions and further band extensions.



■ **Figure 1.** *The Speakeasy concept implements multiple waveform capability in interchangeable, software-programmable modules.*

■ **Figure 2.** *This futuristic MBMMR has a software-programmable baseband processing section and interchangeable RF modules.*

Approach

Flexibility is achieved by providing required processing functions in a set of processing modules. The modules are interconnected through a fault tolerant, high-speed control and data bus to maximize flexibility and reliability. This multiprocessor architecture allows the major functions to be organized in any required processing sequence dictated by the waveform structure. The Speakeasy Phase I program developed an architecture, mapped it onto a VME backplane, and developed software for the executive, a number of waveforms,

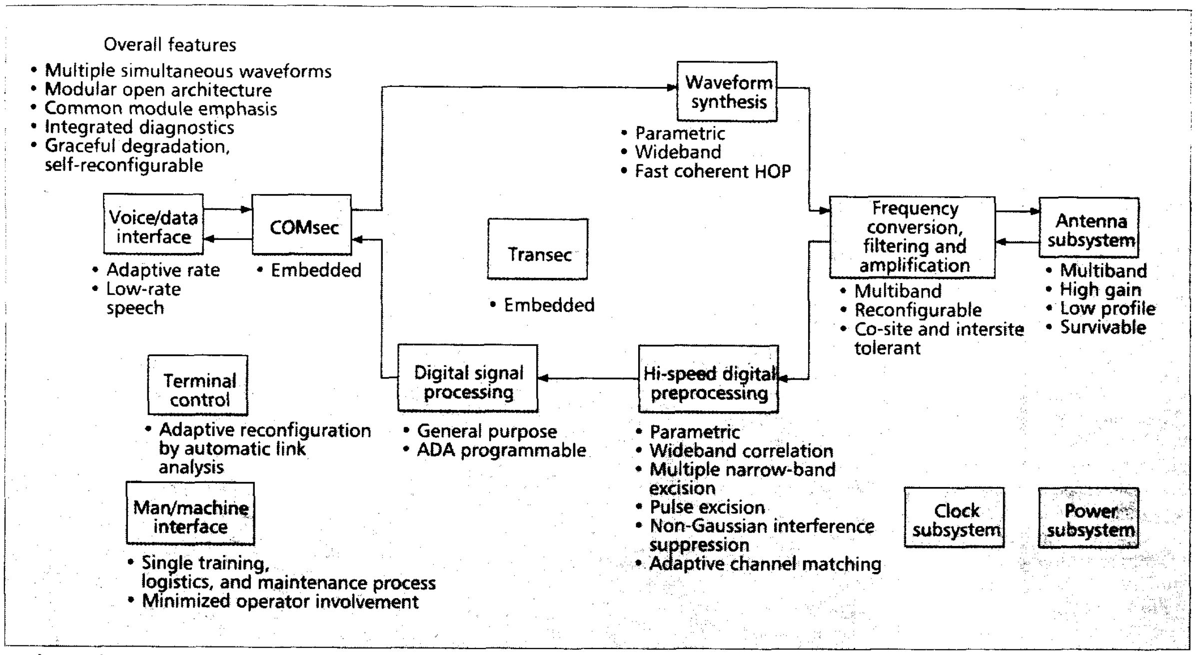


Figure 3. *The Speakeasy functional block diagram illustrates common functional processing flow of a software-based digital radio.*

and a number of INFOSEC key algorithms.

Programmable, general-purpose DSPs are used for all functions possible within the current state of the art. Application-specific processors and field programmable logic devices are used for those functions, such as the fast Fourier transform (FFT) and spread spectrum matched filters, which are too complex for efficient implementation in today's general-purpose programmable DSPs.

Packaging of the final system will be modular with open standards for both physical and electrical interface specifications. This will ensure a long service life for the radio by allowing the replacement of individual modules as technology advances, much as today's personal computers are continually upgraded. The open standards will allow contractors to repackage commercial technology and demonstrate the resulting performance improvement without major development costs or risks. The VME bus was selected for the Phase I demonstration because of the availability of commercial processor boards.

Power consumption is a major concern for the Speakeasy-derived MBMMR. Current consumer products are moving more functions to digital signal processing because of its production cost savings and enhanced performance. However, nothing in this world is free; there is a price to be paid, for example, higher power requirements. A recently introduced digital video recorder uses twice the power of its analog predecessor. Speakeasy provides enhanced performance in flexibility to emulate a large number of different radios with a wide range of modulations. The likely tradeoff, however, is higher power consumption for an individual waveform than could be achieved with a special-purpose radio designed to handle only that waveform.

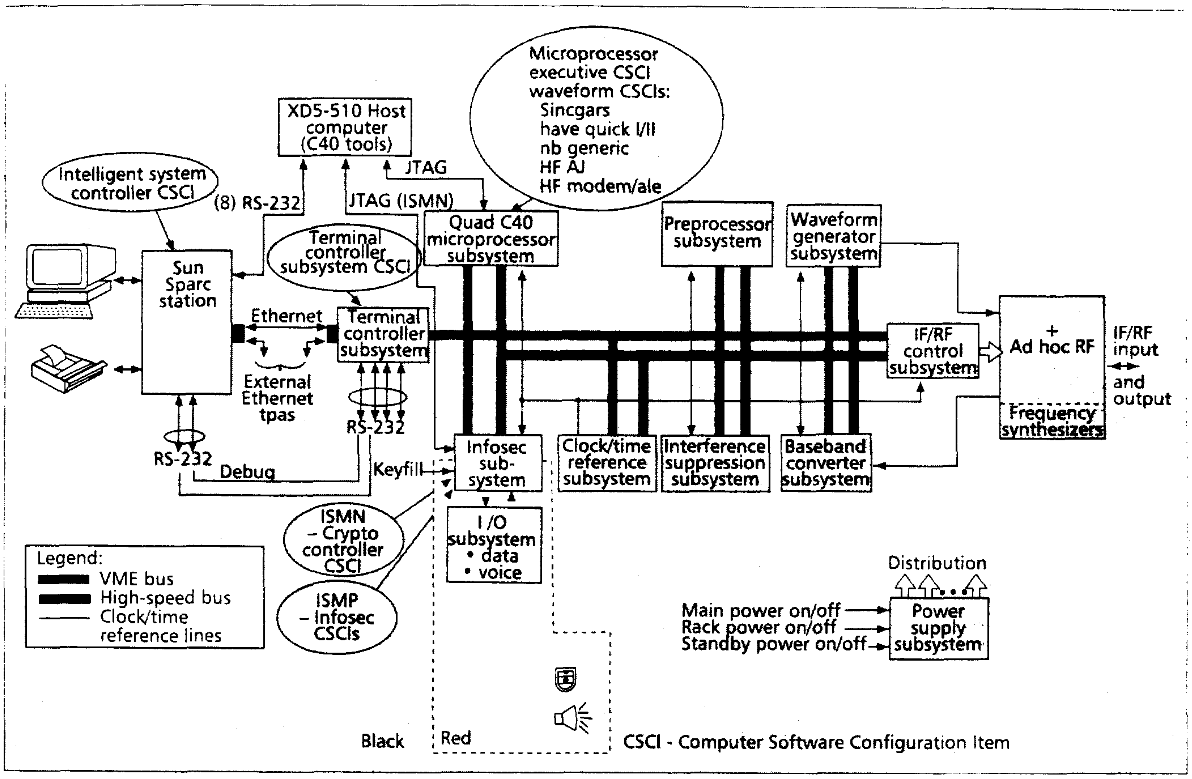
Architecture

The functional flow of processing in any radio conforms to a general standard with a few variations in methods of implementation. This functional flow also exists in the digital processing within Speakeasy, but additional algorithm options are made possible. Figure 3 is the block diagram of signal flow within the Speakeasy radio. This could be the block diagram of any radio if "digital" were removed. The addition of that same "digital," and the flexibility carried with it, makes it the block diagram of *all* radios, hence, Speakeasy.

The use of a high-speed bus to interconnect the processing elements allows an implementation block diagram to vary greatly from the functional block diagram. Figure 4 illustrates the Speakeasy Phase I block diagram. All processing is digital except the necessary analog interfaces at each end, the voice I/O with the user, and the RF signals interfacing to the antenna and atmosphere. Most of the digital processing is implemented in programmable subsystems.

The Speakeasy Phase I advanced development model hardware is based upon a VME configuration. The VME bus provides command, control, and low data rate transfers. A segmented, high-speed backplane bus was implemented to provide waveform-bandwidth data transfers. The number and types of DSP, FFT, and other modules can be adjusted to accommodate waveform types, simultaneity, fault tolerance, and unit reliability.

The DSP engine identified for Speakeasy Phase I was Texas Instrument's TMS320C40 processor. This processor is one of an evolutionary family that has wide commercial acceptance. A multichip module (MCM) with substrate measuring approximately two inches square was developed with four 'C40 processors and 5 Mbytes of memory, 1 Mbyte of local memory for each processor and 1 Mbyte of shared global memory. The photo in Fig. 5 shows the interior of this Quad-C40 MCM. The memory chips are stacked in blocks of ten



■ **Figure 4.** *The Speakeasy Phase I block diagram shows the main processing blocks and their interconnections.*

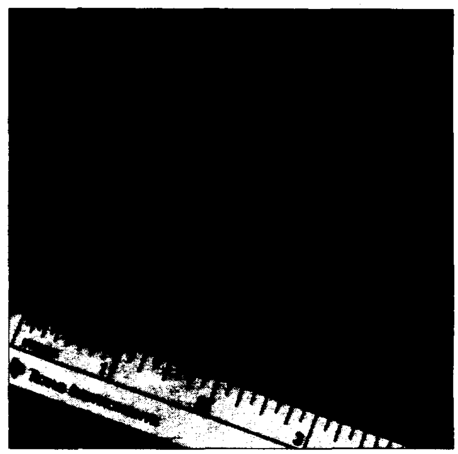
and mounted on their sides. The center chip is a programmable logic device programmed for bus arbitration and interrupt handling.

The Quad-C40 MCM is designed for clock speeds of 50 MHz, although those built under the Speakeasy Phase I program had 40 MHz devices. The performance capabilities for a 50 MHz MCM will include 200 million floating point operations per second (MFLOPS), 1100 million integer operations per second, and 300 million bytes per second I/O. All this from a module with a power consumption of less than 10 watts in today's technology.

Software

Software reprogrammability of waveform processing is the key to Speakeasy's success. Some flexibility is gained by reordering the existing processing functions. However, only limited waveform variability is achievable with the reordering of processing functions. Adding new functions will be required to develop new waveforms. The advantages conceived for Speakeasy will not be realized unless these waveforms can be added without opening the radio. Software, in programmable DSPs, is the best way to accomplish this goal.

Software lifetime is a major cost driver, more important than the platform lifetime, because of the rapid evolution of the hardware technology and the stability of the common waveforms. The higher order language of Ada was used for all waveform coding during the Speakeasy Phase I. However, interrupt service routines in the software executive had to be replaced with hand-coded assembly language modules where today's



■ **Figure 5.** *The Quad-C40 MCM provides significan t programmable signal processing in a small package.*

processor and compiled code failed to meet time constraints. Also, security-critical cryptological code in the programmable INFOSEC module was assembly language coded to meet NSA evaluation requirements.

The Speakeasy-derived MBMMR will utilize programmable processing to emulate more than 15 existing military radios. Many radios have modes with common waveforms, such as amplitude modulation (AM), which can use generic waveform software modules with a custom set of parameters passed

Waveform	RF band	Synopsis
STAJ	HF	Frequency hopping data and voice communications.
HF modem (MIL-STD-188-110A)	HF	Multirate data communications.
Automatic Link Establishment (MIL-STD-188-141A, App. A)	HF	Automatic setup and monitoring of HF links, including channel scanning, automatic answering, and link quality analysis.
PACER BOUNCE	HF	Classical analog HF communications.
SINCGARS	VHF	Frequency hopping voice and data communications.
HAVE QUICK I/II	UHF	Frequency hopping voice and data communications.

■ Table 1. *Baseline waveform compatibility.*

Waveform: Narrowband Generics

Modulation/demodulation of:

Amplitude modulation
(a) AM (DSB) with modulation from 50 Hz to 20 kHz (hopped/non-hopped)
(b) USB-SC with modulation from 50 Hz to 20 kHz (hopped/non-hopped)
(c) LSB-SC with modulation from 50 Hz to 20 kHz (hopped/non-hopped)
(d) ASK (DSB-OOK) (non-hopped)
(e) CW (non-hopped)

Frequency modulation (hopped/non-hopped)
(a) FM with modulation from 50 Hz to 20 kHz
(b) FM (FSK) with tones form 50 Hz to 10 kHz (M = 2 to 8 tones)
(c) Minimum-shift keying (MSK)
(d) CPFSK

Phase modulation
(a) MPSK (M = 2 to 8) (non-hopped)
(b) DPSK, QDPSK (hopped/non-hopped)
(c) OQPSK (non-hopped)

Phase/amplitude modulation
(a) 4, 16, 64 and 256 QAM (non-hopped)

Frequency hopping with above modulations with variable hop dwell and dead times. A predefined acquisition and frequency selection algorithm shall be used.

Data rates up to 20 kb/s (consistent with Ada execution speed)

Error deteciton and correction for digital modulations using Reed Solomon (16, 7) and (31, 15) and Convolutional K = 7, R = 1/2, T = 133, 171.

Waveform	RF Band	Synopsis
Wireless network access (WNA)	L-band	Packet data waveform
GPS	L-band	Precise position and time COTS module
Enhanced EPLRS	UHF	Position location and increased data rates
SINCGARS SIP	VHF	Increased data rates
Low probability of intercept (LPI)	—	Classified
UHF SATCOM DAMA	UHF	5 and 25 kHz DAMA
T1 Data waveform	TBD	Transmit T1 rate data
Cellular phone	Commercial	COTS module

■ Table 2. *Planned phase II waveform expansion.*

as variables. The narrowband generic waveforms identified for Speakeasy are shown in the accompanying box on this page. Other radios have unique acquisition protocols and thus specific software modules. Those waveforms in the Phase I baseline Speakeasy program requiring unique modules are shown in Table 1. Unique waveforms planned for expansion in Phase II are shown in Table 2. Physical layer functions are more easily implemented generically with increasing difficulty in the link and network layers of existing waveforms.

Emulation of an existing radio includes much more than just being able to generate a particular RF modulation. All functions of the radio, from the microphone (or data port) to the antenna, must be supported. The high-speed waveform processing at the physical layer, as well as the voice encoding at the host application layer, must also be performed in the MBMMR. The accompanying box on the next page shows the listing of I/O formats of the existing radios with which Speakeasy must be interoperable. Other levels of protocol within the 'radio' function affect interoperability. Table 3 shows the International Standards Organization (ISO) levels for one mode of one waveform to be implemented within Speakeasy Phase II. This variability, and the flexibility to meet it, is thus a major concern for the host processors and their software. More diverse ISO layers will be included as networked protocols are added. An example is the Wireless Network Access (WNA) protocol, which supports real-time, on-the-move (OTM) networking.

The waveform software can be a standard set, a set loaded for a specific mission, or even a custom waveform designed from existing software modules for a special-operation mission. Maximum flexibility is achieved if every radio holds the code for all waveforms. The storage of all of this software can become a burden. It is more conceivable to believe that the radio will be provided to the user with a waveform set common to his command segment or mission. The need for reassignment of a resource after it has been assigned must also be considered.

Maximum flexibility of the MBMMR will require software loading through a secure front panel, over-the-air download, or authorized user entry. This flexibility can also become its own problem because of the sensitivity of military communications. Managing software versions, authenticity checking of change attempts, and protecting from unauthorized snooping will be major security issues to be dealt with in the operation of a radio that has changed all of the existing paradigms.

Programmable INFOSEC

Another feature of the Speakeasy MBMMR is programmable INFOSEC, which includes both communications security (COMSEC) and transmission security (TRANSEC). COMSEC is the encryption of message data. TRANSEC is the modulation overlaid on the transmitted signal, i.e., center frequency of transmission for frequency hopping waveforms and carrier modulation such as a phase modulation for a spread spectrum coded signals. Typically, every radio has its own INFOSEC device. Speakeasy seeks to overcome this logistic nightmare by using a programmable

Baseline I/O formats
Voice
Analog
16 kb/s CVSD
2400 b/s LPC-10
4800 b/s CELP
9600 b/s MRELP
Digital data
Narrowband: 50 to 38,400 b/s
Wideband: up to 2 Mb/s

INFOSEC processor, the CrYPtographic Reduced Instruction Set (CYPRIS) processor, and software implementation of the cryptographic algorithms, in the multichannel Speakeasy INFOSEC Module (SIM), also developed in Phase I. Key management has also been implemented in software, allowing BLACK, RED, and over-the-air-rekeying (OTAR) keyfill modes. The Phase I INFOSEC module replaces five individual INFOSEC devices. Additional device capability will be added on Phase II.

ISO Layer	UHF SATCOM/DAMA - 25 kHz
3. Network	Centralized protocol Circuit and message services Pre-assigned and demand assigned services
2. Data link	Frame/slot format/deformat TDMA DAMA protocol Link quality measurement CW followed by repeated 110 I-CH (Inverted for Q-CH) and legendre framing word preamble fields Address fields and frame numbering PT and CT orderwire messages/KGV-11 CRC: 16-bit for PT or CT orderwire messages
1. Physical	FEC: Convolutional R = 1/2, K = 7 @ 75 to 4800 b/s : Convolutional R = 3/4, K = 9 @ 300 to 16 k/s Interleave/deinterleave Mod/demod: 9600 and 19200 SPS BPSK 32000 SPS DEQPSK Transmit/receive: Uplink - SHF and UHF Downlink - UHF

■ **Table 3.** *Radio emulation requires more than just waveform modulation compatibility.*

Results

The Speakeasy Phase I Advanced Development Models (ADM) were demonstrated to Government representatives in August 1994. Units were operated in links with government furnished standard radios including HAVE QUCIK, HF Modem (MIL-STD-188-110A), Automatic Link Establishment (MS-188-141A), and SINCGARS. Units also demonstrated simultaneity by simultaneously transmitting on both HAVE QUICK and SINCGARS frequency hopping nets. Bridging was demonstrated by linking two nets with different waveforms, i.e., a HAVE QUICK net was bridged to a SINCGARS net so that all users communicated, with Speakeasy acting as a bridge/gateway between the two independent nets, transparent to the users. Demonstrations included both voice and data. A computer-generated video image was transferred through speakeasy on a HF Modem waveform. Programmability was demonstrated by modifying the SINCGARS waveform on two Speakeasy units and showing operation.

Conclusion

Speakeasy is a challenge, even with recent advances in DSP technologies. The benefits, however, make the challenge highly worthwhile. Today's cooperative efforts in military engagements, as demonstrated in Desert Storm, requires flexible communication systems to interconnect with all allies. At the same time, defense budgets are being reduced and systems must last longer and cost less to maintain. Speakeasy holds the promise of being such a system. Software reprogrammability of waveform processing is the key to Speakeasy's success. This capability has been demonstrated on Speakeasy Phase I. Software lifetime is more important than the host hardware lifetime because of the rapid evolution of the hardware technology. The higher order language of Ada was used for all waveform coding during the Speakeasy Phase I development. Phase II of the Speakeasy program will be awarded in 1995 to continue the advances already made and to finalize the architecture of the objective "Military Software Radio" of the future.

Biographies

RAYMOND J. LACKEY joined Hazeltine Corporation, Greenlawn, New York, after graduation from Penn State University in 1973 with an honors degree in engineering science. He later received an M.S. in electrical engineering from Polytechnic Institute of New York. He has advanced within the Hazeltine Research Laboratory/Advanced Development Center, Adaptive Signal Processing Laboratory, where he is now a section head. His work has concentrated on high-speed digital signal processing systems, and their simulation, design, and control. He has most recently led the advanced technology insertion studies for Speakeasy Phase I.

DONALD W. UPMAL [M '80] is presently the Army Project Leader on the joint service Speakeasy Multiband Multimode Radio Program, within the U.S. Army CECOM, Space & Terrestrial Communications Directorate, Special Projects Office, Fort Monmouth, New Jersey. He has been an electronics engineer at Fort Monmouth since 1975 and the project engineer, primarily on Special Operations Forces (SOF) programs, throughout his career, including the Joint Advanced Special Operations Radio System (JASORS), the AN/TSC-99 Comm Base Station, the OA-8990 Digital Entry Device, the AN/TRC-189 Net Radio Interface System, and the AN/TSC-122 HF Multi-channel Comm System. Prior to his Government work, he was an RF design engineer at the RCA Space Center from 1970 to 1975. He has a B.S.E.E. from Fairleigh Dickinson University, and an associates degree in electronics technology from The RCA Institute. He is a member of AFCEA.