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Smart Repeater System for Communications Interoperability
During Multi-Agency Law Enforcement Operations

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ABSTRACT

A prototype "smart" repeater that provides interoperability capabilities for radio communication systems in multi-agency and multi-user scenarios is being developed by the Oak Ridge National Laboratory. The smart repeater functions as a deployable communications platform that can be dynamically reconfigured to cross-link the radios of participating federal, state, and local government agencies. This interconnection capability improves the coordination and execution of multi-agency operations, including coordinated law enforcement activities and general emergency or disaster response scenarios.

The repeater provides multiple channels of operation in the 30-50, 118-136, 138-174, and 403-512 MHz land mobile communications and aircraft bands while providing the ability to cross-connect among multiple frequencies, bands, modulation types, and encryption formats. Additionally, two telephone interconnects provide links to the fixed and cellular telephone networks. The 800- and 900-MHz bands are not supported by the prototype, but the modular design of the system accommodates future retrofits to extend frequency capabilities with minimal impact to the system. Configuration of the repeater is through a portable personal computer with a Windows-based graphical interface control screen that provides dynamic reconfiguration of network interconnections and formats.

Keywords: repeater, communications, interoperability.

1. INTRODUCTION

The Instrumentation and Controls Division of Oak Ridge National Laboratory (ORNL) is developing a smart repeater system to support the communications interoperability requirements of law enforcement and emergency response agencies. The repeater is configured as a deployable system and can serve as a communications platform to cross-link the radios of federal, state, and local government agencies who are participants in the operation. A representative scenario is illustrated Fig. 1. During a raid on a major illegal drug processing laboratory, the repeater would be deployed on a hilltop a few miles away. The repeater is programmed to interconnect the federal, state, and local government agencies participating in the operation. Other potential scenarios include on-site operations following airline crashes, natural disasters, or terrorist activities.

The smart repeater, illustrated conceptually in Fig. 2, can provide complex interoperability capabilities for multi-agency and multi-user communications. The repeater furnishes multiple channels of operation in the 30-50 megahertz (MHz) very high frequency (VHF) low band, 118-136 MHz aircraft band, 138-174 MHz VHF high band, and the 403-512 MHz ultra high frequency (UHF) radio band, while providing the ability to cross-connect between multiple frequencies, bands, modulation types, and encryption formats. The smart repeater provides rapid communications for participating federal, state, and local users during an emergency situation without requiring the large-scale acquisition of common-format radios by all participating organizations, as is presently the case

Fig. 1. Inter-agency scenario using the smart repeater.

Fig. 2. Conceptual configuration for the smart repeater.

during joint operations. The control console provides dynamic reprogramming of the repeater resources to adjust the cross-connects based on which agencies require access for any specific operation.

This paper addresses the capabilities of the smart repeater and discusses the design criteria of the system. Additional requirements pertaining to other law enforcement applications are also discussed.

2. SYSTEM CONFIGURATION

A system-level diagram of the smart repeater is presented in Fig. 3. Primary functional blocks within the system include radio receivers, radio transmitter exciters, broadband power amplifiers for the transmitters, cavity-filter transmitter combiners, a custom electronics interconnection matrix, a repeater local-controller computer, and a laptop computer control console.

The smart repeater is designed around a combination of commercial and custom hardware. Commercial hardware, or modified commercial hardware, is employed to the greatest extent possible. This approach is both cost effective and relieves constraints for equipment type approvals to meet National Telecommunications and Information Administration (NTIA) and Federal Communications Commission (FCC) requirements. The system controller, equipment electronics interfaces, and interconnection matrix are custom-designed to optimize repeater flexibility and performance.

2.1. General capabilities

The smart repeater incorporates synthesized receivers and transmitters that can be allocated and programmed in real time by the local controller. This allocation feature optimizes limited repeater resources during peak periods of loading. The system provides one full repeater channel in the VHF low band, one simplex channel in the VHF aircraft band, four full repeater channels in the VHF high band, and four full repeater channels in the UHF band. Any of these channels can be linked to one or more of the other channels.

The smart repeater operates under the control of two personal computers. A portable laptop computer with a Windows-based graphical user interface (GUI) functions as a control console. This console provides the user interface for configuring repeater channels as well as visually monitoring repeater activity and status during operation. An industrial-grade computer embedded into the repeater electronics package serves as the real-time local controller. The repeater controller receives its configuration instructions from the control console computer

Fig. 3. System-level diagram for the smart repeater.

computer and provides status information back to the console. The console computer can be linked to the smart repeater local controller by an RS-232 link, a standard telephone line, or an encoded radio link.

The major encryption standards [Digital Encryption Standard (DES), DES-XL (extended range), Digital Voice Privacy (DVP), and DVP-XL] are supported for the Motorola transmission formats. Association of the encryption format and encryption key with the specific repeater channel is managed by the local-controller computer.

As with any field-deployable system, size and weight are important considerations. The smart repeater is based on a modular design concept and provides a system that can be tailored to the requirements of each operational scenario. The modular design allows the deployment of a minimal system as the first response, with the fully-equipped repeater being activated as the operation continues. Additionally, the modular system design accommodates future retrofits to extend frequency capability to the 800- and 900-MHz bands with minimal impact to existing components of the repeater system.

The radio frequency (rf) power and coverage range is comparable with standard repeaters, providing 20-40 miles of range depending on the repeater height and the local terrain. The capability for two standard telephone interconnects (phone patches) is also provided. The smart repeater operates from standard 120-V ac power.

The modular design of the smart repeater allows the system to be packaged for ease of shipping to a deployment site. Each shipping case falls within the weight and size limits for checked baggage on domestic airline flights. Additionally, the shipping cases for all electronics subsystems serve as the equipment racks when the system is deployed. Equipment with special cooling requirements, such as the linear amplifiers, are mounted in cases that have removable front and rear covers to provide adequate air flow.

2.2. Console computer

The control console is a PC-based laptop computer operating under a Windows 95 environment. This console serves as a GUI for entering the repeater configuration information. The specific channel information including network name, frequencies, squelch tones, and encryption formats is entered through a setup screen of the console. Additionally, the setup screen allows the operator to select which networks will be interconnected.

The operational screen illustrates the full matrix of channels that have been interconnected. Status information from the local controller is also displayed on the operational screen. The console computer program checks the frequency information entered during setup to avoid specifying frequencies that are outside of the authorized bands. Once all frequencies are entered, a mathematical routine determines if any potential intermodulation products are likely to cause interference to the repeater.

The GUI program provides several additional features for control and operation of the repeater. The program provides an override function by which the operator can interrupt a lock-up condition where an incoming transmission carrier is either intentionally or unintentionally holding the repeater in a keyed condition. The status of the cross-connection matrix is monitored continuously to prevent encrypted transmissions from being routed to clear channels. Network setup files containing frequency and interconnection information can be saved, recalled, and edited for later use.

2.3. Local-controller computer

The local-controller computer is a PC-based industrial-grade computer embedded within the repeater electronics package and operating under a Microsoft DOS environment. The DOS environment is required to maintain compatibility with the radio service software (RSS) that runs on this machine. The local controller receives the radio programming information from the console computer over a 9600-baud serial communications line. This information is fed into the RSS to program each specific radio in the repeater. The RSS is operated by a scripting program that takes the operator inputs from the setup file and automatically produces the necessary keystrokes for programming the radio.

The local controller also receives the repeater cross-connection configuration information from the console computer. This configuration information is passed to the firmware logic in the interconnection matrix to establish which specific channels of the repeater become cross connected. The local controller additionally relays status information back to the control console.

2.4. Interconnection matrix

The interconnection matrix is the subsystem that electrically connects the receivers to the appropriate transmitters. Included in this interconnection network is the signal conditioning to and from the radios, the analog cross-connections for clear voice, the digital cross-connections for encrypted voice, and the radio control functions as defined by the system configuration information. Additionally, the interconnection matrix selects the connections to the appropriate radio during the programming cycle and while loading the encryption keys. A diagram depicting the functional layers of the interconnection matrix is presented in Fig. 4.

The analog matrix layer provides the audio switching for clear voice cross-connections among radios. Additionally, the analog matrix layer provides the audio interconnect between the radios and the telephone interfaces. Real-time priority lockout and override functions pertaining to clear analog audio (as determined by the programming configuration) are performed in this layer. All audio signal conditioning for connections to and from the radios and telephone interfaces is implemented as a function of the analog layer.

The digital matrix layer provides the switching functions necessary for routing the digitized audio to and from radios operating in the encrypted mode. Real-time priority lockout and override functions of digital audio (as determined by the programming configuration) are performed in this layer. Furthermore, the digital layer monitors the radio status lines from the receivers and provides the required control functions to the transmitters.

Fig. 4. Functional layers of the smart repeater interconnection matrix.

The encryption layer routes the digital data associated with the encryption modules, both during encryption key-loading and channel operation. This layer manages the hardware resources associated with the encryption and decryption processes and interconnects the networks, based upon the instructions in the programming configuration.

The radio programming layer is responsible for interconnecting the radio programming lines of a specified radio to the local controller computer during the programming process. The local controller, which is running the RSS program, downloads the appropriate programming information into the radio to configure the frequency, squelch, and encryption parameters to the unit.

2.5. Audio encryption

The Motorola versions of the DES, DES-XL, DVP, and DVP-XL algorithms are supported by the repeater. The specific information with regard to the encryption standard is entered into the control console at the time the channel is added to the repeater data base. The encryption key is then loaded into the specific repeater radios that are associated with that encrypted link. The real-time control of the encryption format and key translations is managed by the local controller computer using information sent from the console computer.

The cross-linking of encrypted signals represents one of the more difficult features of the repeater design. The commercial implementations of DES and DVP encryption algorithms introduce severe audio bandwidth limitations which contribute to marginal audio quality. Additionally, the signal-to-noise ratio of the link has a stronger effect on the audio quality when operating in the encrypted mode. Many agencies have made attempts at back-to-back linking of clear analog audio for DES or DVP systems serving two users with different keys. Because the audio of the repeater link passes through two encryption/decryption iterations and two complete iterations of analog/digital/analog conversion, these agencies have experienced marginal results. The smart repeater provides digital-level translation across encryption keys and those standards within the Motorola formats, thus removing one of the analog/digital/analog conversions and greatly improving the audio quality.

2.6. Receivers and transmitters

Because the operating frequencies and radio band requirements are generally unique to each smart repeater deployment, the rf portion of the system was designed to adapt to new scenarios with minimal hardware changes.

To accomplish this goal, the smart repeater employs frequency-synthesized portable radios as the receivers and the transmitter exciter stages. One receiver radio and one transmitter exciter radio are required for each repeater channel pair. This approach enables the entire 138-174 MHz band to be covered with a single radio and the 403-512 MHz band to be covered with two radios.

The exciter configuration for the transmitter provides a significant reduction in equipment weight and volume by eliminating the requirement for multiple mobile or base station transmitters that are pre-tuned to cover only a narrow frequency span. Instead, each synthesized exciter radio is coupled to a 100 W broadband linear amplifier that spans the entire band without retuning. Both the receiver and transmitter radios can be allocated and programmed in real time by the local controller, providing a high level of system flexibility with minimal hardware modifications.

2.7. Combining network and antennas

The transmitter linear amplifier outputs in the VHF high band and UHF band are connected to a cavity filter and isolator combining network for each band. The cavity filters increase the difficulty in system tuning and setup, but provide major performance improvements by removing spurious out-of-band rf emissions, lowering the background noise floor presented to the repeater receivers, and providing a reduction in the number of antennas and masts. A 3-dB gain antenna is provided for the transmitter signals in the VHF high and UHF bands. Each of these antennas is mounted on its own 8-m carbon-fiberglass telescopic mast.

The VHF low band and aircraft band are configured with one antenna per radio and do not employ cavity combiners. Likewise, any radio that requires real-time tuning among several operating frequencies across the band can be routed directly to a dedicated antenna. Each single-transmitter antenna will be mounted on a 3-m sectional metal mast.

All receivers except in the aircraft band share one broadband dish antenna. The receive antenna will be mounted on a 12-m carbon-fiberglass telescopic mast. The height offset between the receiver and transmitter antennas provides additional isolation of the repeater rf input and output. A specially-designed preamplifier on the receiver multicoupler supplies a low-noise front end while handling the local transmitter power without reaching saturation and thereby generating significant frequency-intermodulation products.

3. FUTURE CONSIDERATIONS

The specific features and system formats supported by the present configuration of the smart repeater were defined by a composite definition of requirements from several federal government agencies. Iterations of requirements and systems tradeoffs were performed to reduce a broad set of sometimes conflicting requirements to a manageable level that still met the general needs of the users.

The designers are aware that features such as encryption formats from additional vendors and trunking compatibility would increase the utility of the system. However, implementation of these functions would increase the complexity beyond the scope of a phase-one prototype system.

The modularity of the repeater design provides a path for an economical upgrade of features if the requirements arise. Limited compatibility with 400-MHz trunking systems is possible by using trunking-compatible radios as the receivers and transmitters. The electrical interconnectivity and programming of the radios are straightforward; however, the system timing considerations of the trunking interface impose substantial operational constraints on the users. While the 800- and 900-MHz bands are not supported by the present prototype, the modular design of the repeater accommodates future retrofits to extend frequency capabilities with minimal impact to existing portions of the system. The trunking interface constraints would likewise apply in these bands.

The Association of Public Safety Communications Officials (APCO) Project 25 addresses the technology necessary for interoperability of communications radio equipment. The APCO 25 working group is a joint public safety and federal government committee addressing the standards for implementation of digital radio, including enhanced

encryption systems. The goals of the APCO 25 committee are to establish a foundation for the next generation of digital radios, formulate a common open architecture, provide interoperability between public safety and federal agencies, and establish compatibility among equipment from multiple vendors. The smart repeater is not intended to replace APCO 25. However, this system will provide a level of interoperability among users until APCO 25 standards are finalized and the resulting equipment is placed into service by a sufficient number of users.

4. CONCLUSIONS

A prototype smart repeater system that provides interoperability capabilities for radio communication systems in multi-agency and multi-user scenarios is being developed by ORNL. This repeater functions as a programmable field-deployable communications platform that is capable of dynamic reconfiguration when cross-linking the radios of federal, state, and local government agencies. The smart repeater should markedly improve the radio communications capabilities during law enforcement or emergency disaster operations involving multiple agencies.