ASTRO 25 Conventional Systems
System Planner

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SECTION 1. INTRODUCTION

ASTRO® 25 is a completely digital system platform developed by Motorola. It takes advantage of exciting new breakthroughs in digital technology, providing the framework for capabilities previously unavailable in land mobile radio systems. ASTRO technology offers customers systems with the following features:

- Compliant to the APCO Project 25 standard
- Total digital capability
- Expanded signaling capabilities
- More efficient use of existing RF spectrum
- Expanded encryption capabilities
- Integrated voice and data

This system planner addresses conventional two-way voice and data communications systems that meet the Project 25 standard. Other System Planners address analog and VSELP ASTRO conventional system portfolios and the trunking portfolio of system solutions.

Project 25

APCO (Association of Public Safety Communications Officials,) Project 25 brings together representatives from local, state and federal government agencies. These agencies and other user organizations evaluate basic technologies in advanced land mobile radio and find solutions that best serve the needs of the public safety marketplace. The committee has encouraged the participation of numerous international public safety organizations. NASTD (National Association of State Telecommunications Directors) and the NCS (National Communications Systems), NTIA (National Telecommunications & Information Agency), and DoD (Department of Defense) are actively involved in the development of these user standards.

Why Standards

Recognizing that certain requirements are necessary for their communications systems, customers have begun developing standards that would help to make their jobs and lives easier, safer, and more economical in several ways:

1) Standards assure an effective level of system performance (endorsed by the user community) to meet the necessary communication requirements.
2) Standards provide interoperability with adjacent communications systems should it be desired and authorized by the system owners. This prevents customers from becoming a "communications island" incapable of communicating with other agencies and systems when the need arises.
3) Standards provide the opportunity for multiple proposals for original procurements and second sourcing of add-on equipment to standard systems without restricting the creativity and drive for enhanced system features.

Why Motorola Supports Standards

In general, well-conceived user-driven standards define and accelerate the market adoption of new technology. Standards give the customer confidence in investing in equipment and products that will not be obsolete in a short period of time. Standards also limit the number of technologies deployed to serve a given market. This results in economies of scale that benefit both the manufacturers (in the use of scarce development resources) and their customers (through lower-cost products resulting from higher volume).

Motorola also supports using user-driven standards because it provides an opportunity to understand and learn more from our customers so we can continue to deliver the solutions the marketplace is demanding. Because the members of user-driven standard-setting boards come out of the user community, they know their specific geographic and economic needs very well. Motorola uses this valuable information to drive the design of our future communications systems so that we can be assured that our products are meeting the needs of our customers.

Project 25 and the RF-Subsystem

Project 25 is a standard system. This means that the system defines several open interfaces. RF-Subsystem is a new concept introduced by Project 25 in TSB102. The RF-Subsystem is defined as an infrastructure, bounded by the six open Project 25 interfaces. These include the Common Air Interface, the Data Peripheral Interface, the Data Host and Network Interface, the Telephone Interconnect Interface, the Inter System Interface, and the Network Management Interface. The RF-Subsystem is any collection of site equipment, be it single station or multiple stations and single site or multiple sites. The subsystem's only requirements are that 1) its station equipment supports the Common Air Interface and 2) that it contains all necessary control logic to support call processing and the open intersystem interfaces. These become the building blocks for wide-area system construction.

Motorola's ASTRO Conventional systems provide compliance to the Common Air Interface, Data Peripheral Interface, portions of the Data Host and Network Interface, and the Telephone Interconnect Interface standards. More details on specific capabilities and features supported by the Project 25 standard ASTRO are provided in Section 2, ASTRO SYSTEM TECHNOLOGIES.

ASTRO Digital Solutions

Before entering any detailed discussion of a new technology, such as ASTRO Digital Solutions, it is crucial to first establish the bounds of that discussion. Since ASTRO Digital Solutions, as digital systems, represent an enormous shift in how we view communications systems, it may be helpful to first consider what they are NOT, before discussing what they are.

- ASTRO Digital Solutions are not simple connections of current equipment in some newly invented fashion.
- ASTRO Digital Solutions are not overlays upon current analog systems.
- ASTRO Digital Solutions are not solely "digital" systems, nor are they solely “secure” systems, nor are they solely “conventional” systems; they are not even solely “trunking” systems. In fact, they can be put into all of the existing Motorola system categories.

ASTRO Digital Solutions represent a collection of systems that requires its own tree of system categories. There will be analog only voice systems, mixed mode analog and digital ASTRO voice systems, digital only ASTRO voice systems, and integrated voice and data ASTRO systems. Mixed mode systems can support clear analog, clear ASTRO digital, and encrypted ASTRO digital signaling. Analog voice operation is not recommended on systems integrating data with voice on the same channel. These distinctions are defined further in Section 2.

The common element of ASTRO Digital Solutions is a change to the very core of a communications system: the interaction of a transmitter and a receiver in the transmission of a voice or data message. Each ASTRO system represents a complete replacement of all previous analog functional blocks in this transmission path with ASTRO equivalents. In this manner, each ASTRO system operates as a fully digital system, using digital modulation techniques, through digital networks. They will also support clear analog operation to provide a migration path from analog to digital operation and interoperation with other analog radios and systems.

Summary

This section has introduced the concept of ASTRO Digital Solutions as a natural progression from analog systems. Technological trends point toward a digital future, and ASTRO Digital Solutions represent the first step toward the future of private two-way radio systems.

But, why would we want to make such a revolutionary change from analog to digital technology?

The reasons are twofold. First, the user community has asked for this through the development of the Project 25 two-way radio communications standard. Second, is that by moving to digital communications technology, we can break barriers on system performance that are due to technical limitations of analog systems.

About This System Planner

This planner is divided into three parts. The first part (Sections 1 through 3) deal with basic ASTRO information and what capabilities the ASTRO 25 Digital Conventional Solutions offer, and then it moves into specific information about planning ASTRO Conventional voice solutions. Section 4 discusses the design of integrated voice and data ASTRO Conventional Solutions. Section 5 discusses the addition of Over-the-Air-Rekeying (OTAR) capability to an integrated voice and data system to provide improved encryption key management capability.

More specifically:

- Section 1 describes ASTRO 25 as part of an evolutionary process that will continue on.
- Section 2, System Technologies presents a discussion of the ASTRO technologies and exactly what the Project 25 ASTRO Conventional release includes.
- Section 3 provides a review of the ASTRO System Building Blocks with block diagrams along with basic system topologies.
- Section 4 provides the following information about Integrated Voice and Data solutions:

An introduction to ASTRO 25 Integrated voice and data

A brief overview of the system's data capability

Issues important in the design of a data system

ASTRO data capabilities based upon the seven essential elements of the ASTRO 25 Integrated Voice and Data System

System design, performance and migration.

- Section 5 provides a description of OTAR capability provided with the new Key Management Facility subsystem.
- Section 6 is a glossary of acronyms, terms, and phrases.
- Appendix A shows voice grade channel requirements for ASTRO applications.
- Appendix B provides Circuit Merit definitions.
- Appendix C discusses ASTRO coverage prediction.

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SECTION 2. ASTRO SYSTEM TECHNOLOGIES

Overview

This section reviews the core technologies on which the ASTRO system is based. It begins with a description of the capabilities ASTRO supports with Motorola's Project 25 ASTRO Conventional Systems release (use the ASTRO CAI options when ordering), then it reviews the Common Air Interface (CAI), one of the key interfaces of the Project 25 standard. The section then discusses the interoperable voice signaling features that ASTRO offers. These are compliant to the Project 25 standard. The section also reviews other features and capabilities of the ASTRO system and discusses in detail the ASTRO transmitter, highlighting the analog-to-digital conversion process, the IMBE vocoder, encryption techniques, modulation, signal error detection and correction, and the ASTRO receiver.

Project 25 ASTRO Conventional Platform

Project 25 ASTRO conventional solutions (using the ASTRO CAI options when ordering equipment) build upon previous releases. This is the first system release to provide compliance to the Project 25 standard in conventional systems. In addition, ASTRO also provides capabilities above and beyond the Project 25 standard. These include the capabilities that customers have already grown accustomed to in ASTRO systems.

Changes have been made to ASTRO systems in order to conform to the Project 25 Common Air Interface (CAI) standard. The Project 25-defined IMBE vocoder has replaced the VSELP vocoder. The frame format has been changed to the CAI over-the-air protocol. And Motorola has added the Project 25 DES-OFB algorithm to its encryption portfolio. DES-XL, DVP-XL, and DVI-XL encryption algorithms can also be used on these ASTRO Systems.

Traditional 25 /30 kHz bandwidths will be supported for analog interoperability. The 12.5 kHz bandwidths will be supported on analog and digital channels and for digital simulcast systems. The bandwidth emission mask will comply with U.S. FCC and NTIA regulations and with European ETSI standards.

ASTRO Conventional system offers the following Project 25 features:

- VHF, UHF, and 800 MHz frequency bands
- Digital voice
- Project 25 IMBE Vocoder
- Project 25 specified Common Air Interface (CAI) over-the-air protocol
- Project 25 embedded signaling capabilities (Network ID, Unaddressed voice call, Talking Party ID)
- Interoperable Voice Signaling Features using Project 25 digital control data (digital stat-alert signaling)

- Project 25 encryption algorithm: DES-OFB
- Project 25 12.5 kHz channel bandwidth operation
- Talkgroups on conventional channels

ASTRO Conventional system capabilities above and beyond Project 25:

- ASTRO system embedded signaling capabilities (such as encryption key info, adaptive power control, or error protection)
- Analog voice
- Analog control (MDC-1200 Stat-Alert Signaling)
- 12 kb SECURENET™ operation in subscribers only (for interoperability with existing SECURENET systems)
- Optional Motorola encryption algorithms: DES-XL, DVP-XL, DVI-XL
- Choice of 20/25/30 Channel Bandwidths
- Packet switched confirmed and unconfirmed terminal data on the same channel as voice

Conventional Systems Configurations:

- Mixed Mode (analog and/or ASTRO digital modes)
    - Talk around
    - Stand alone repeater
    - Wireline dispatch
    - Voting
    - Multicast
- ASTRO only Simulcast
- Integrated voice and data (analog operation not recommended)
    - Talk around
    - Stand alone repeater
    - Wireline dispatch
    - Voting
    - Multicast
- ASTRO only Integrated voice and data Simulcast voice with sub-site steered data

Project 25 ASTRO conventional solutions general restrictions:

- ASTRO CAI using the IMBE vocoder is not compatible with ASTRO VSELP voice operation
- 12 kb SECURENET operation is not available on an ASTRO CAI digital infrastructure
- DES-XL and DES-OFB cannot be used on the same channel.
- No base to console intercom operation.
- No local speakers at the base station.
- Simulcast configuration is ASTRO digital only. ASTRO modems or the V.24/hybrid link interface can be used for this configuration.
- CENTRACOM Gold Series consoles are required for Project 25 ASTRO interoperable voice signaling features at the console. ASTRO signaling supports continuous Unit ID, Call Alert, Status/Message (see definitions in the table that follows). Gold Series consoles are also required for conventional talkgroup operation at the console.

Data:

- Full data capability (terminal data and OTAR capability) is supported in the both the ASTRO mobile and portable radio products
- Analog traffic is not recommended on ASTRO systems that support packet data.

Specific information on ASTRO 25 Integrated Voice & Data systems is presented in Section 4. Specific information on ASTRO OTAR is presented in Section 5.

Common Air Interface

The Common Air Interface (CAI) is a major interface in the Project 25 system standard. Mobile and portable equipment from any manufacturer may be freely combined in any Project 25 system. A base line of features will be guaranteed from any system to work through any manufacturer's radio. ASTRO provides the following interoperable voice signaling features which are compliant to the Project 25 Standard and which will work with any non-Motorola r radio offering these features if they are also compliant to Project 25. Project 25 has requirements that a manufacturer must meet in order to call his product offering Project 25. The following mandatory features are now offered in our ASTRO Digital Conventional Systems. These features are available when used in the ASTRO digital mode.

Mandatory Project 25 capabilities

These capabilities are mandatory for compliance to Project 25.

FEATURE	BENEFIT
Network Access Code	Provides a simple means for the radio units to address radio networks or (Network Identifier) specific stations, depending on the radio system configuration.
Unaddressed Voice Call	Allows open communications in a conventional system.
Talking Party Identification	The Unit ID of a transmitting unit is embedded in the digital signaling (PTT-ID or Unit ID) on every transmission.

Interoperable voice signaling features

Interoperable voice signaling features are categorized as standard options within the Project 25 standard. These capabilities, when offered by other compliant manufacturer's radios, will work on any configurable portable or mobile in a Project 25 system. Items categorized as standard options within the Project 25 standard are not required for a system to be considered Project 25 compliant. However, if a manufacturer chooses to offer a standard option, it must conform to the requirements the standard dictates.

Project 25 capabilities that are Standard Options for Compliance:

These are also called Interoperable Voice Signaling Features.

FEATURE	**BENEFIT**
Individual Voice Call	A two-way voice call between a user and another individual user (Selective Call)
Group Voice Call	Allows users to separate voice communications into individual talkgroups on a radio channel. Each Group Voice Call is addressed to a specific group of users. The user group can be optionally displayed on the receiving radios.
Channel Wide Group Call	This is a special type of Group Voice Call that allows a user to transmit a message to all talk groups on the channel simultaneously
Channel Monitor	Allows the ability to monitor all the traffic on the channel
Call Alerting (call alert)	Allows a dispatcher or another radio to selectively alert another individual unit that the caller is trying to contact him.
Emergency Alarm	A non-voice message sent by a portable or mobile to notify a console operator of an emergency condition.
Emergency Call	After the emergency button is pressed, subsequent PTT will contain an emergency indicator along with the Unit ID until the operator takes one of several actions to cancel the emergency condition.
Radio Check	Allows a console operator to verify if a desired target radio is turned on and functioning and within the range of the system.
Selective Radio Inhibit/Enable	When a radio is lost or stolen, your communications system is still protected because a console operator can send a message out over the air that will disable that radio. Even though the radio is disabled, the console can still request voice, data and stat-alert signaling messages from a disabled radio.
Radio Unit Monitor	In an emergency situation, it is important to keep tabs on what's (Remote

FEATURE	BENEFIT
	Monitor)happening in the field. The ability to remotely key the transmitter of an individual portable helps the console operator keep in touch with live circumstances so that help can be given in an effective, efficient manner.
Status Update	A user's status can be updated from a list of pre-determined messages. The user may transmit the radio's status when desired, or the radio's current status can be transmitted in response to a Status Request from a console.
Status Request	Allows the console operator to request and retrieve the status of an individual user when needed.
Message Update	A user can send a short, predefined message to the console when desired.
Scan	Provides scanning on channels where a mobile or portable unit locks onto any channel in a predetermined list when it detects: a) a digital signal, or b) a digital signal with the proper network ID. Capability includes auto scan (mode strapped) and talk back scan (the ability to talk back on the channel being scanned). Provides mixed analog and digital scanning for analog and digital voice.
Scan for Data	Provides scanning with the inclusion of one data channel in the scan list. In progress data calls are completed before the unit will switch to detected activity on a voice channel. Data channel can be designated as priority or non-priority similar to voice channels. A priority data channel, when active, overrides voice priority sampling. (The radio will not leave the data channel to sample priority voice channels while a data call is active.)
Telephone Interconnect	Calls between a telephone network user and the radio system's users can be made. It may be initiated from either the radio system side or the telephone network side. This is especially useful for users who need to operate over a large geographic area or for supervisors that need to dispatch to an entire group from any telephone.
Voice Encryption using DES-OFB	This service provides the ability to encrypt digital voice transmissions using the DES-OFB, Project 25 specified algorithm.
Packet Switch Confirmed Delivery	A connectionless two-way data service between radio-network access points providing a Data service which maximizes the utilization of network resources for information transfers which are of a short burst nature. Error correction/protection services are provided by the radio network. Confirmation of delivery is provided. Network resources are allocated on a shared basis among multiple calls or connections.
Packet Switch Unconfirmed Delivery	A two-way data service between radio-network access points offering Data delivery of unconfirmed packets. Error correction and detection services are provided by the network. Service is connectionless. Network resources are allocated on a shared basis among multiple calls or connections.

Above and beyond Project 25 compliance

In addition to Project 25 specific features and capabilities, each RF-Subsystem manufacturer may augment the basic feature set to include new features which may only be supported on that manufacturer's mobiles and portables to provide added value. The following features are available with stat/alert signaling when used in the analog mode (definitions match those given above):

- PTT ID
- Selective Call
- Call Alert
- Emergency Alarm
- Emergency Call
- Radio Check
- Selective Radio Inhibit/Enable
- Remote Monitor
- Status Update
- Message Update
- Status Request

The following additional features are offered on ASTRO systems:

FEATURE	**BENEFIT**
Dual Priority Channel Scan	This service provides the ability of a mobile or portable to scan one first-priority channel, one second-priority channel, and multiple non-priority channels.
Repeater Talkaround Operation	Direct mode for mobiles and portables. Allows radios to talk directly to one another without the use of RF infrastructure.
Voice Encryption	The ability to encrypt digital voice transmissions using DES-XL, DES-OFB, DVP-XL, or DVI-XL algorithms.
Telephone Interconnect	Calls between a telephone network user and the radio system's users can be made in the analog mode. It may be initiated from either the radio system side or the telephone network side. This is especially useful for users who need to operate over a large geographic area or for supervisors that need to dispatch to an entire group from any telephone.

The ASTRO Transmitter

A functional block diagram of the ASTRO transmitter is shown in Figure 2.1.

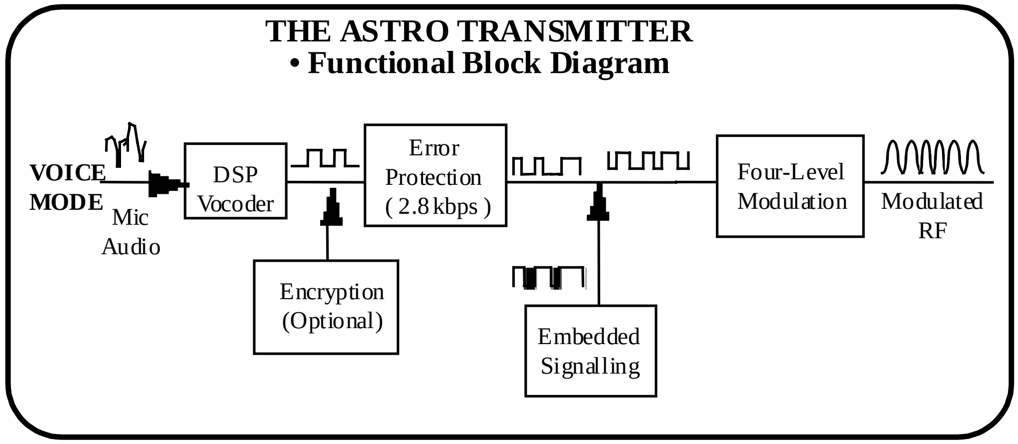

Figure 2.1 The ASTRO Transmitter

The new ASTRO system alternative is to transmit all information—whether it be voice, data, or signaling—in a digital form. This means that any analog signal in an ASTRO system is transformed into a digital signal (a binary data stream of 1's and 0's, or bits) before any processing of it takes place. ASTRO radios then transmit combinations of voice, data, and signaling over an RF channel at a rate of 9.6 kilobits per second (Kbps). By so processing all signals in a digital form, the transmission scheme can be designed specifically to provide optimum performance on digital signals. Let's look at the ASTRO transmitter stage by stage, to see the technology selected to provide such optimum performance.

STAGE 1: Voice processing

The first step in the digital process of an ASTRO radio is the conversion of analog voice to a digital form. Such conversion is not new to most of us, although we may not realize it. Long distance telephone calls are processed with digitally converted voice, and SECURENET systems have been using digitally converted voice since the 1970's. Many different analog-to-digital (A/D) signal conversion methods have been developed over the years.

Techniques used by phone companies provide high-quality voice reproduction, but they require an extremely large amount of digital information (64 Kbps) to represent voice. However, these techniques have not been applied to radio systems because they could not provide audio quality acceptable for all voice communications within the band width constraint of a land mobile radio channel.

SECURENET systems are an example of a digital technology that is limited by this constraint. SECURENET systems use an A/D conversion method called CVSD (Continuously Variable Slope Delta [Modulation]). CVSD was initially designed to operate at a data rate of at least 30 Kbps. However, to fit the constraints of radio channel bandwidths of 25 or 30 kHz, the technique is required to operate at a lower data rate (12 Kbps). As a result of this less-than-optimum data rate, there is a noticeable degradation of recovered audio quality. Some users tolerated such degradation because they required the system security that SECURENET provided.

What is a Vocoder?

A primary objective of ASTRO systems is to provide audio quality comparable to that of today's clear analog systems, not only in 25/30 kHz land mobile radio channels, but also in 12.5 kHz channels. The trick is to get the lower data rate onto the radio channel. The first step in converting the audio to digital is the function of the VOCODER. A vocoder (short for voice coder-decoder) is a voice digitization technique that creates a digital representation of the sounds generated by the human voice. Vocoders themselves are not new, but their application to radio systems is. This is because the technology required to perform the complex algorithms of speech processing only recently has advanced to the stage that allows it to be implemented in portable and mobile radios. This new high-capacity signal processor, the Digital Signal Processor, or DSP, provides the necessary power to perform high level functions within compact packages.

If digital technology is the gateway to a new level of system performance, then the DSP is the gate itself. The DSP is the heart of the design of the ASTRO radio. Utilizing the power of the DSP, ASTRO systems now allow customers to obtain all of the benefits that digital systems can provide.

Close-Up on Vocoder techniques

In the past, most A/D converters have been designed solely to generate a set of data values that track the actual flow of an analog signal, no matter its source. However, since an analog signal changes values instantaneously, this approach can never produce an entirely accurate representation. In an ideal world, the data rate could be increased at will to obtain a near-perfect digital representation. In actuality, however, a problem exists in that the bandwidth required to transmit a digital signal is proportional to its data rate, and a real world communications channel must conform to a defined spectrum allocation. In the case of the private two-way radio communications system, this translates into the limitation that such an A/D converter can only be as effective as allowed by the band width constraint of the land mobile radio channel.

Close-Up on IMBE™

One of the major factors contributing to the success of the Improved Multi-Band Excitation™(IMBE) speech coders is that they use a fundamentally different technology than standard speech coders. The technology is the outgrowth of work begun at the Massachusetts Institute of Technology in the early 1980's. The goal of the work was to develop a robust speech model that would outperform the linear prediction speech model in traditional speech coders. This work resulted in the Multi-Band Excitation (MBE) speech model, which provides a unique speech-coding framework resulting in a number of advantages over linear prediction based speech coders.

The IMBE speech compression algorithms are the performance leaders for low-bit-rate speech compression systems. MBE-base technology provides superior speech quality. In addition, the speech coder has been designed for robustness in both background noise and channel errors.

Based on IMBE's high speech quality and robustness to errors, it has become the international standard for a number of communication systems. The IMBE system is currently the standard for several global satellite-based mobile communication services, including several Inmarsat and OPTUS services. The IMBE speech coder has successfully been in use commercially since the late 1980's. The IMBE speech coder, therefore, has been selected the vocoder of choice by Project 25.

The MBE coder divides each segment of speech into distinct frequency bands and makes a voiced/unvoiced (V/UV) decision for each frequency band. This allows the excitation signal for a particular speech segment to be a mixture of periodic (voiced) and noise-like (unvoiced) energy. This added degree of freedom in the modeling of the excitation signal allows the MBE speech model to generate higher quality speech than conventional speech models.

The inherent problem with most linear prediction speech coders is that the linear prediction model does not yield high quality speech (or robustness to background noise) without the addition of a prediction residual. The prediction residual can be viewed as an error signal that corrects for inaccuracies in the linear prediction model. Elimination of this residual results in a harsh, mechanical quality in the speech. Consequently, all high quality linear predictive speech coders transmit a residual. The primary difference between these systems is the manner in which they accomplish this task. Linear Predictive Coding (LPC) at rates below 8 Kbps/sec divide the residual into small pieces or vectors and then search through a code book to find the code vector which is the closest match. Searching through a reasonable sized code book is a computationally complex task. IMBE does not require the use of code books, consequently, requiring fewer computations than most other vocoders.

The IMBE speech coder does not have these problems because it is not based upon linear prediction. Instead, it uses the Multi-Band Excitation speech model to produce high quality speech without the need for a residual signal. They maintain speech intelligibility and naturalness compared with other vocoders.

In summary, the IMBE speech coder is superior to many other vocoders. Its primary advantage is superior speech quality at low data rates. It is less complex and can be implemented in a cost-effective manner.

STAGE 2: Encryption

Digital encryption is a technology found by many to be indispensable. It is often vital that messages not be heard by unauthorized parties. In some cases, such protection is the difference between life and death. The same IC-based digital encryption algorithms used in SECURENET systems are used in ASTRO systems. (Remember, the digital ASTRO 9.6 Kbps signal by itself is not encrypted. Any ASTRO radio can process a non-encrypted ASTRO signal. As digital standards evolve, it is quite likely that commercial scanners will be developed that will also follow the standard). Project 25 defines the encryption algorithm and has chosen the standard mode of operation as Output Feedback (OFB). OFB basically defines how information is transformed from plain text to cipher text. OFB minimizes the error propagation in going from plain text to cipher text. For more detailed information refer to Project 25 DES Encryption Protocol Standard TIA/EIA 102.AAAA. (Motorola also offers the following additional algorithms to choose from DES-XL, DVP-XL and DVI-XL).

Encryption enhancements

ASTRO digital technology offers several enhancements previously unavailable in encrypted voice radio systems. First, there is no range degradation in the encrypted mode, regardless of the algorithm employed. Second, there is no additional truncation at the beginning of an encrypted message, since encryption synchronization information is buried in embedded signaling (to be discussed later). This advantage is illustrated in Figure 2.2.

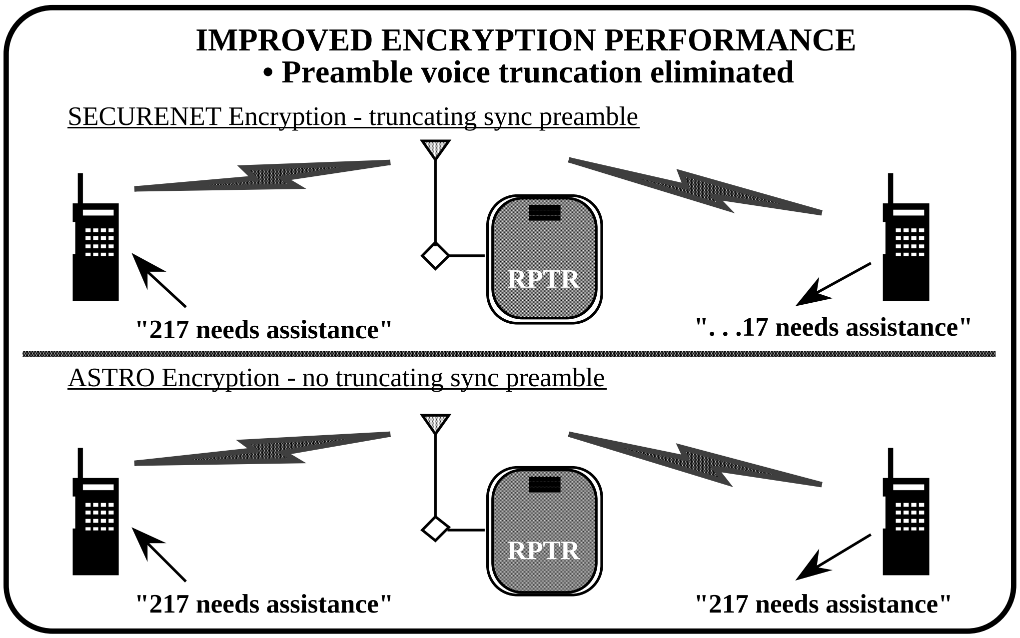

Figure 2.2 Improved Encryption Performance

Multiple algorithm

The third enhanced encryption feature provided by ASTRO is the ability to house multiple algorithms within a single radio (i.e. two of Motorola's standard IC-based algorithms), for further secure communications interoperability and partitioning capability, as illustrated in Figure 2.3.

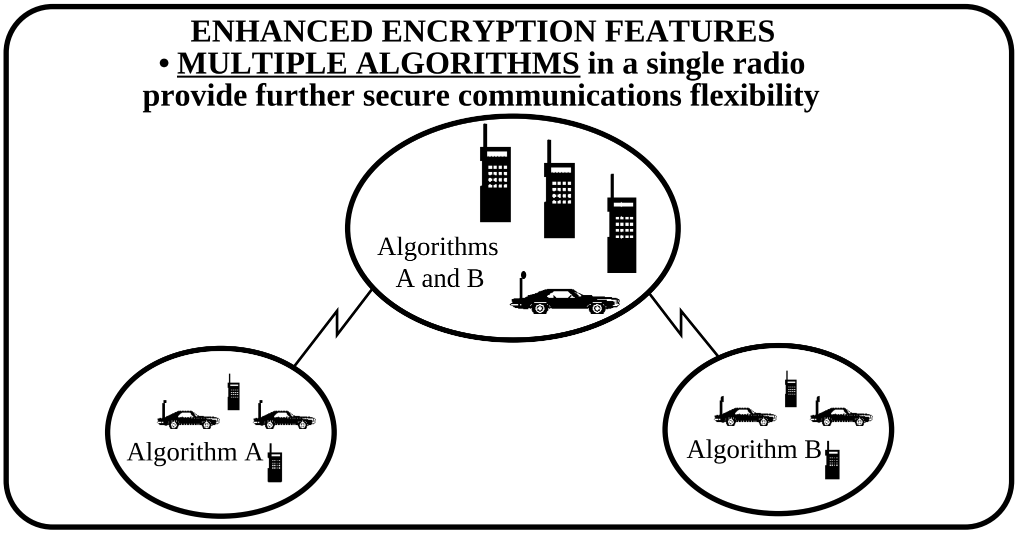

Figure 2.3 Multiple Encryption Algorithms

Multikey

Figure 2.4 illustrates the fourth enhancement, the ability to store up to 16 encryption keys in the ASTRO subscriber units. These keys can additionally be distributed between the multiple algorithms as necessary.

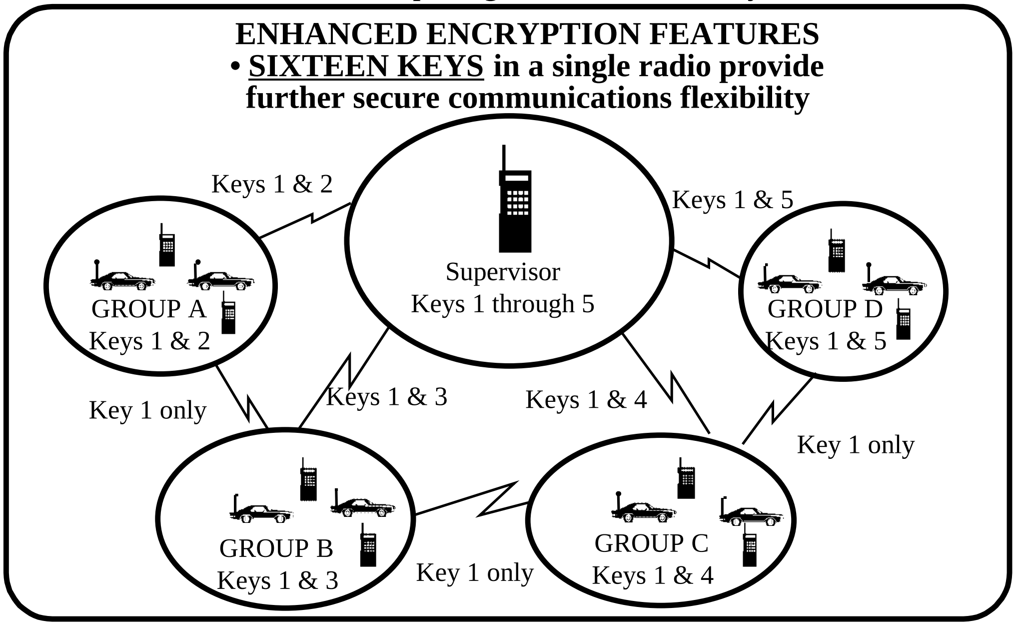

Figure 2.4 Multikey Operation

STAGE 3: Error protection

In an ideal world, an RF channel would simply carry signals from place to place, without altering them. Unfortunately, the real RF channel inevitably encounters interfering (noise) signals. Such noise mixes with a transmitted signal and distorts its shape. If the transmitted signal is an analog signal, the noise effect can directly result in audio quality degradation at the receiver. This is illustrated in figure 2.5.

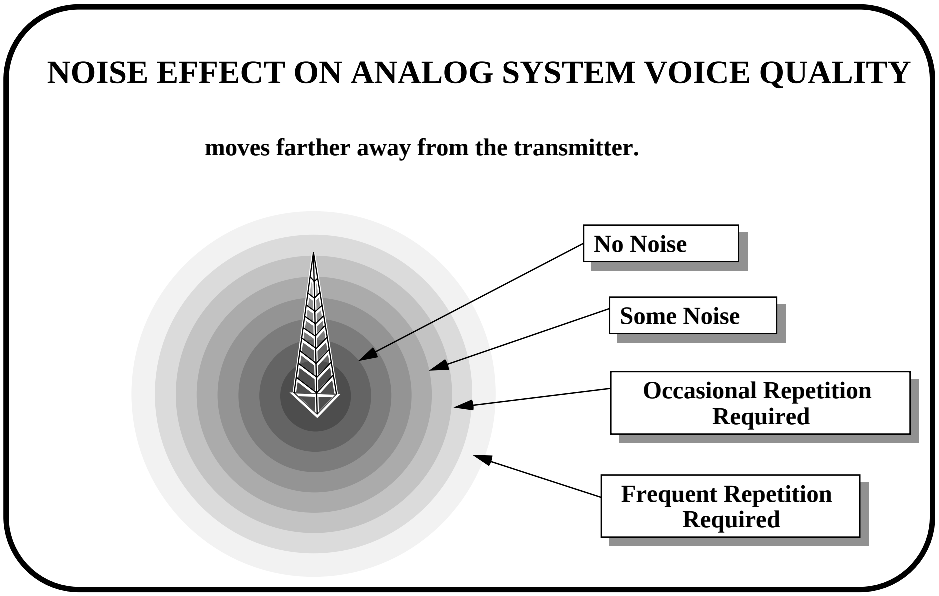

Figure 2.5 Effect of Noise in an Analog System

Error protection and digital audio quality

Since it is impossible for a receiver to have the information needed to fully restore an analog signal, it can do nothing but send the distorted version of the signal to the speaker. If the transmitted signal is a digital signal, the noise effect can create errors in the data that would also result in degradation of audio quality. ASTRO systems, however, can manipulate the IMBE voice data to protect it from such errors.

The redundancy introduced in the digital signal through the addition of the error correction bits allows an ASTRO receiver to detect where errors have occurred during a digital transmission. The receiver can then correct those mistakes, as long as the number of errors does not exceed the code's error correction capabilities. If the radio finds that too many of the incoming bits have been corrupted, it is smart enough to realize that it cannot fix the problem, and instead uses portions of prior correct information to predict how the missing piece might have appeared. An estimate of the piece is created and inserted in the hole.

It is not necessary to protect 100% of the digital voice (which would require a significant increase in the data rate) in order to achieve sufficient error protection. ASTRO systems have been designed to protect voice messages from an RF channel bit error rate (or BER) of up to 10% and still be able to provide usable audio to the user.

It is this error protection that allows an ASTRO system to provide the kind of consistent audio quality throughout its coverage area that a comparable analog system could never offer. In the ASTRO system, however, the audio quality remains at a high level because the error protection effectively minimizes the noise effect, as illustrated in figure 2.6.

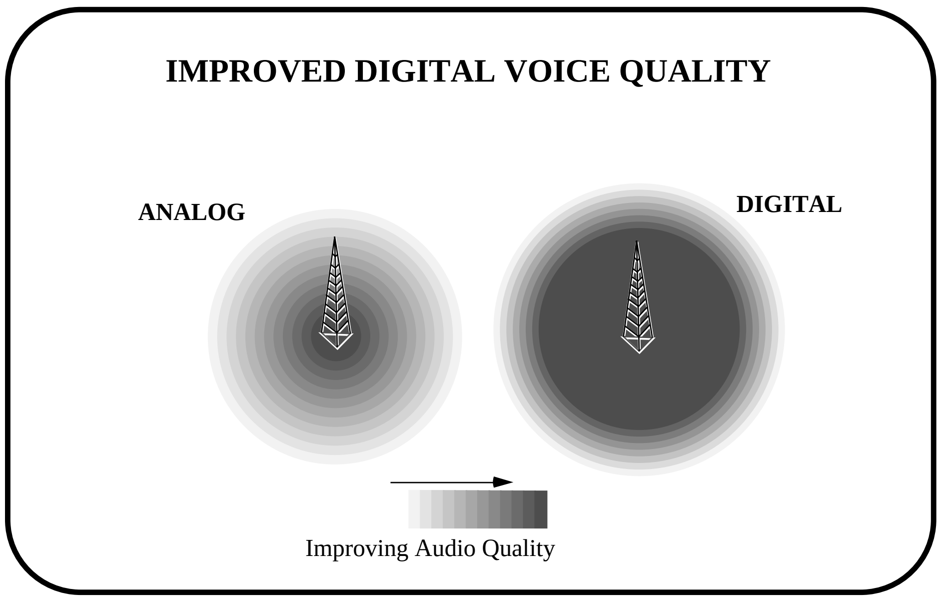

Figure 2.6 ASTRO Digital Audio Performance

Figure 2.7 graphically illustrates the relationship of delivered system audio quality, comparing good to poor audio quality with strong to weak signal strength. Note that, in very strong signal areas, the analog signal, because there is no processing, may sound slightly better than the digital audio signal. Note also that digital signals do not increase the size of the coverage of the system, but rather improve the quality of the audio throughout much of the coverage area.

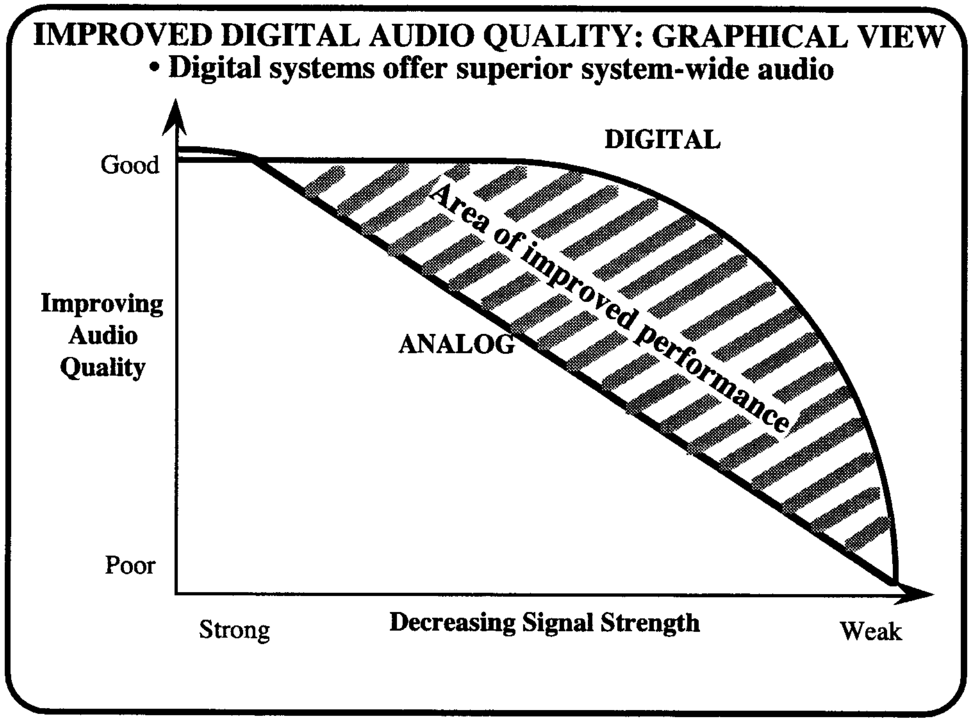

Figure 2.7 ASTRO Digital Audio Performance

STAGE 4: Embedded signaling

In the earliest private two-way radio communications systems, the only type of information that was transmitted from place to place was a voice message. But it was not long before the system user would demand more. One by one, new feature requirements became part of a system user's set of expectations about how the system should perform. And whether it be the ability to know the identity of a transmitting radio or the ability to protect voice messages with digital encryption, most of these features have necessitated that signaling or control information share a system's RF channels with voice information. In fact, today it would be difficult to find a radio system that did not pass some type of information along with voice. Some popular examples include:

- Coded squelch control signals, such as PL for selective repeater access.
- Radio unit identification codes, for selective calling and ID indication.
- Digital encryption synchronization data, for successful voice security.
- Digital encryption key variable identification codes.
- Emergency notification signals, for immediate alerting to a volatile situation.

Analog signaling

In current analog systems, there are two ways to send this information:
(1) Sub-audible continuous signaling:
Signaling and control information is transmitted simultaneously with voice. The information is sent as tones or as low speed data; in either case it is kept within the sub-audible frequency range to avoid interfering with the concurrent voice transmission.

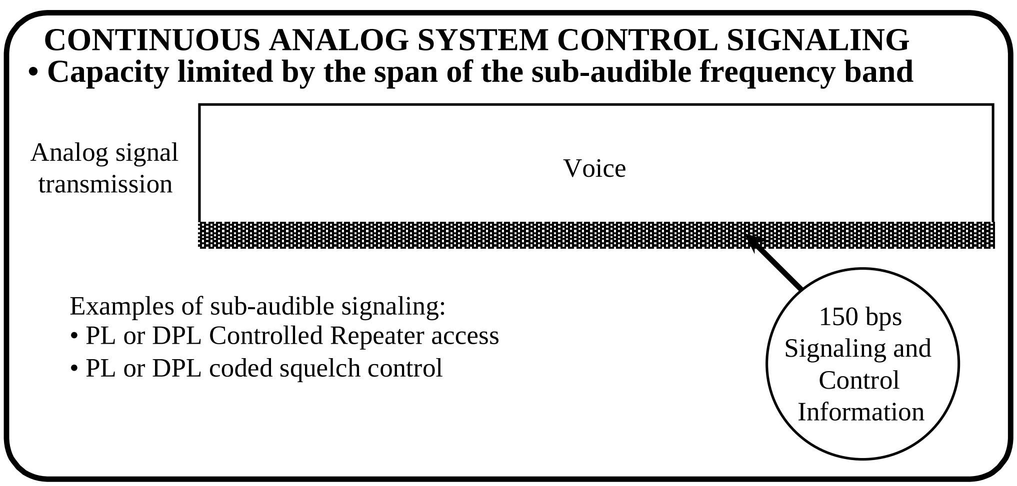

Figure 2.8 Sub-Audible Analog Signaling

(2) Preamble signaling:
A burst of signaling and control information is sent prior to a voice message. Again, the information is sent either as tones or as low speed data.

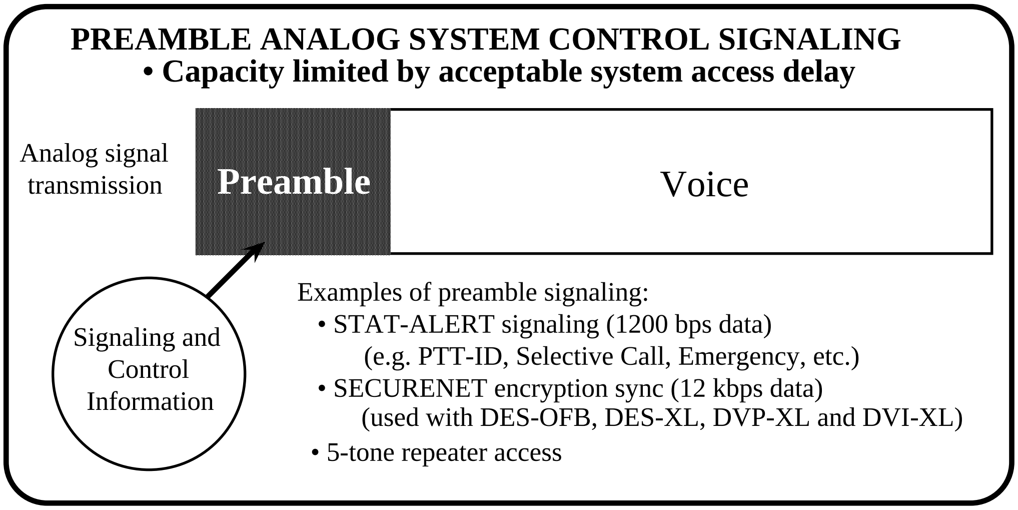

Figure 2.9 Preamble Analog Signaling

While these two signaling schemes have been quite effective in allowing the transfer of important information, they have also been quite limited in what they could accomplish without a serious trade-off of some other fundamental aspect of system operation. In the former case, signaling must compete with voice for channel bandwidth. Sub-audible signaling, with its spectrum required to extend no higher in than the bottom edge of the audible frequency band, is severely limited in signaling capacity. The selection of tones is restricted within this band, and low speed signaling is transmitted at 150 bps. In the latter case, signaling must compete with voice for channel access time. While more information can be transmitted using preamble signaling than with sub-audible signaling, voice transmission cannot start until the signaling is completed. Thus, because it is possible for a radio user to start talking before the radio is ready to transmit voice, the beginning of a voice message could be lost. Preamble length must therefore be kept to a minimum.

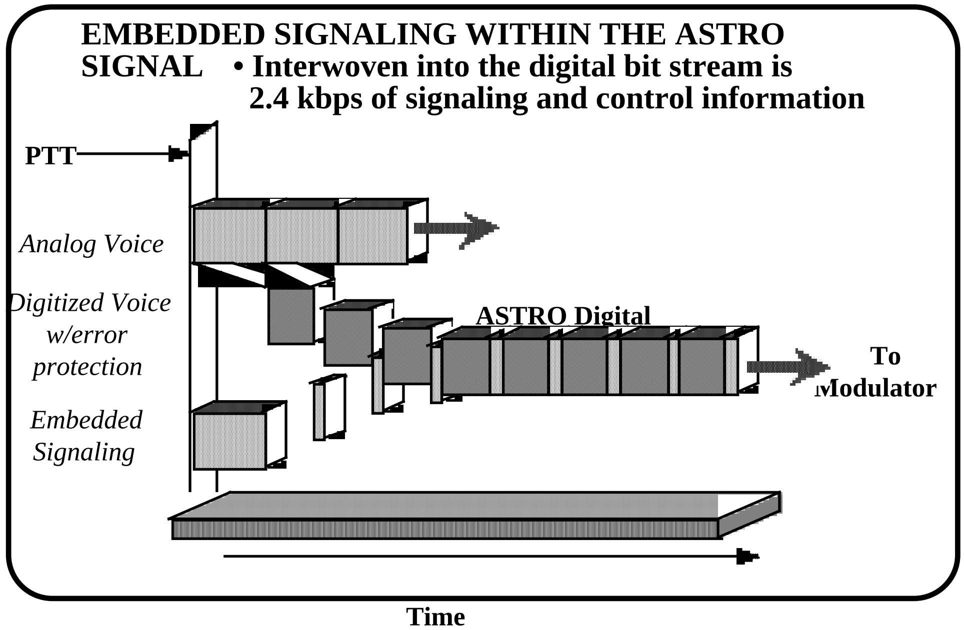

Figure 2.10 Voice and Embedded Signaling

Illustrated in Figures 2.9 and 2.10, embedded signaling represents the capture of the positive elements of sub-audible and preamble signaling, without their negative elements. It allows ASTRO systems to have a signaling capacity on the level of a preamble signaling system and be able to pass such signaling throughout a voice message (as could have only been achieved in a sub-audible signaling system). Because of this high-capacity continuous signaling, ASTRO can give complete information to radios in two very important scenarios:

- Late entry (when a radio begins to monitor the channel in the middle of a transmission).
- Re-entry (when a radio loses the ability to monitor a transmission and then regains it).

Embedded Digital Signaling Features

An ASTRO radio continuously repeats embedded signaling information throughout a voice transmission until such time as the state of the radio changes. This allows receiving ASTRO radios to obtain the information at any time. In combining the benefits of both sub-audible and preamble signaling, ASTRO systems can perform the same signaling functions that have been performed in analog systems but more rapidly and more reliably. They can also perform new features never before implemented. (see "Project 25 ASTRO conventional release" in this section for more information):

- Network Identifier (Network ID): a universal ID shared by all system radios for access to the system infrastructure (analogous to coded squelch).
- Source Unit and Destination Unit ID's: field radio ID’s that can be used for a transmitting radio ID display or for selective calling. Note that the ID is transmitted continuously with voice (and optionally displayed), whereas in preamble signaling it could only be sent once and potentially be missed. This is illustrated in Figure 2.11.

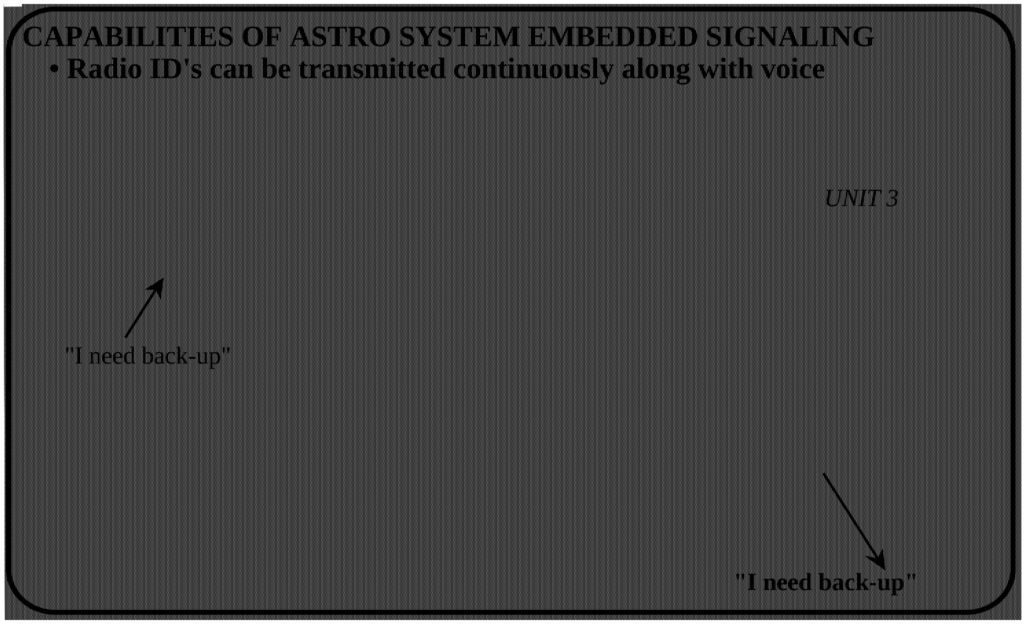

Figure 2.11 Numeric ID Display

- Talkgroup ID: an ID that can be used to signify a grouping of radios and for sending and receiving selective group calls.
- Encryption Sync: data that is used to maintain the successful synchronization of the encryptor of a transmitting radio and the decryptor of a receiving radio during secure operation (if the radios are equipped for secure operation).
- Emergency: an immediate alert to the console operator that a radio user is in the midst of a volatile situation.
- Key ID: in an ASTRO Multikey system, an ID that is used to inform a receiving radio of which encryption key variable must be used for successful decryption of the voice message, and allows selective secure calling.
- Adaptive power control feed back information: measures of the radio environment used to adapt a portable's transmit power level.
- Error Protection: extra bits inserted to provide the signaling information with protection from interfering noise signals. Just as in the case of voice information, the signaling information is important enough to merit the addition of error protection.

Stand Alone Signaling

Stand-alone signaling is available for ASTRO Conventional Solutions. It complies with TSBK (Trunked Signaling Blocks) as developed under Project 25 trunking. Capabilities that ASTRO offers using Project 25 TSBK's include call alerting, radio check, selective radio inhibit/enable, radio unit monitor, status update, status request and message update. Please see "Project 25 ASTRO conventional release" in this section for definition information on these capabilities.

Conventional Talkgroup Operation On Portables And Mobiles

Radio channels are often extremely busy. Users may be divided into individual work groups. Many work groups may share the same channel. But, perhaps the work groups don't have the need to regularly communicate with each other. With ASTRO Conventional talkgroup operation, radios can be assigned to a given talk group. Under normal operation, they will only communicate with members of the same talk group. When the need arises, a user can make a call to a different talk group. Or, when necessary, a Channel Wide Call can be used. A Channel Wide Call is a call that will be heard by all ASTRO subscribers listening to the channel regardless of talk group selection.

Conventional Talk Group Operation radio features

Talkgroup-Selective Squelch:
A talkgroup can be strapped to a radio mode so the radio will use that talkgroup when it transmits. The radio will only unmute on the strapped talkgroup.

Talkgroup Normal Squelch:
A talkgroup can be strapped to a radio mode so the radio will use that talkgroup when it transmits. The radio will unmute on any talkgroup.

Talkgroup Select Menu:
This menu allows the user to select a particular talkgroup for transmit operation from a pre-assigned list of talkgroups.

Channel Wide Talkgroup :
The channel wide talkgroup can be strapped to a radio mode or can be selected from the talkgroup select menu. All radios on the channel will unmute to a call that is addressed with the channel wide talk group.
Talkgroup operation can be disabled in the radio's RSS. If talkgroup operation is disabled, all transmitted calls will use the default talkgroup. The default talkgroup allows transmission to all users on the channel and reception of audio from all users on the channel. In this case, talkgroups will not be used as qualifiers for received calls.

Talkgroup hang time

The talkgroup hang time is initiated in a radio once the reception of a channel wide call ends. While the hang time is active, the radio will respond with a channel wide call instead of responding with its own strapped or selected talkgroup. This feature is used as a means to temporarily merge talkgroups on the channel.

Conventional talkgroups and secure multikey operation

When talkgroup operation is used with multikey encryption, then encryption keys will be strapped to talkgroups. Key selection is not allowed for talkgroup operation. A talkgroup will not be allowed to use more than one encryption key, since that would subdivide the talkgroup. If talkgroup operation is disabled in the radio's RSS, secure operation will work as it normally does without key group segmentation.

Formatting talkgroups in radio service software (RSS)

Four independent lists of 16 Talkgroups can be programmed into the radio through the use of Radio Service Software (RSS). To format talkgroups in the RSS begin with a list of desired talkgroups. A talkgroup list can be used on one channel, or several channels. If the talkgroup is secure, then key number must be assigned to be slaved to that talkgroup. The name of the talkgroup and key should then be entered into a talkgroup list. The talkgroup Select Menu uses this list to determine the valid combination of talkgroup and key.

Next, enable talkgroup operation for the mode. Assign a talkgroup list to the mode. Select a talkgroup from the assigned talkgroup list for use on the mode.. If the mode is talkgroup selectable for PTT operation, specify this in the mode so the talkgroup select menu can be accessed on that mode. Finally, choose either selective squelch or normal squelch for receive operation in the mode.

ASTRO conventional talkgroups at the console

Conventional talkgroup operation with a control center requires a CENTRACOM Gold Series console. For information on Conventional talkgroup operation in the CENTRACOM Gold Series console, please see Section Three of this system planner.

STAGE 5: Four level digital modulation

Available frequencies are rare and treasured commodities. The RF spectrum has been saturated in nearly every corner of the globe by the frequency demand of communications system customers. Expectation of difficulty in obtaining frequencies has become a key consideration when designing private two-way radio communications systems. Today's system architect often finds that a system design ideal to meeting a customer's communications needs cannot be implemented because an insufficient number of frequencies are available. This is a problem with two possible solutions:

- Have more spectrum allotted for private radio system users.
- Make more efficient use of the spectrum that is available by allowing multiple access to an RF channel.

The first solution, however, is solely under the control of local regulatory agencies and its ability to find such spectrum to grant. Depending on this event to occur is not the ideal solution to present frequency shortages. For this reason, Motorola has explored the only other alternative. By taking Frequency Division Multiple Access technology one step further than it has progressed today, ASTRO systems achieve its enhanced voice, signaling, and data capabilities in narrowband channels. ASTRO systems allow multiple access of a current FDMA 25/30 kHz channel by dividing it in half and granting each half to a different radio user group, as ASTRO channels require a channel spacing of only 12.5/15 kHz.

The key to reducing the transmission bandwidth required to pass a digital signal is to reduce the transmission data rate. ASTRO systems incorporate two technologies in order to maintain a desirable voice information rate while keeping to a transmission rate low enough to pass within a 12.5/15 kHz channel. The first of these technologies has already been discussed. Recall that in utilizing an IMBE vocoder, the ASTRO transmitter can effectively represent voice messages with only 4.4 Kbps of digital information.

The second technology is called Four Level Digital Modulation, and it once again represents a manner in which an ASTRO system exercises its control as a digital system. The process of four level digital modulation can simply be considered a manipulation of binary 9.6 Kbps signals to reduce their required transmission rate. Specifically, through a method called four level C4FM (Compatible 4-Level FM, a form of four-level frequency shift keying compatible with QPSK). An ASTRO transmitter combines each pair of bits into a single symbol (or baud) and can transmit those symbols at a rate half of that of the input bit rate of 9.6 Kbps, or 4.8 kilobaud per second. The process is labeled "four level" because the symbol set required to represent all possible bit pairs must include four symbols (a quaternary set).

Close-Up Four level modulation

Prior to the development of ASTRO systems, modulation has been implemented in land mobile radio systems in one of two analog forms:

- Amplitude Modulation (AM)
- Frequency Modulation (FM)

Most Motorola radios have used the latter, in which a person's voice message is used to modify (modulate) the frequency of an RF carrier (an oscillating wave, or sinusoid). Thus, the RF signal "carries" a representation of the actual voice message.

ASTRO systems actually use a digital form of analog FM. Once voice or data has been processed to form a 9.6 Kbps binary data stream, the modulator uses the bits to shift the frequency of an RF carrier between discrete values. This process, called Compatible 4-Level FM (C4FM), allows a considerable amount of information to be placed on an RF carrier without using a wide band width. ASTRO systems use this C4FM scheme, meaning that the RF carrier will be shifted among four frequency values. This allows an ASTRO radio to send two bits of information by doing only one thing -- shifting a carrier frequency -- and hence send twice as much information in a given amount of time.

Specifically, the process works as follows:

(1) A digital input signal arrives as a binary data stream. For example, it could appear as 10111001000110 . . .

(2) Two bits at a time are sequentially removed from the data stream. For the example above, this would appear as 10 -11 - 10 - 01 - 00 - 01 - 10 . . .

(3) As the two bits are removed from the data stream, there are four different possibilities. The bits could be 00, 01, 10, or 11.

(4) For each possibility, the digital modulator is prepared to shift the RF carrier frequency. Each shift then represents two bits. ASTRO systems use the following scheme:

- Bits 01 --> Shift to center frequency + 1.8 kHz
- Bits 00 --> Shift to center frequency + 0.6 kHz
- Bits 10 --> Shift to center frequency - 0.6 kHz
- Bits 11 --> Shift to center frequency - 1.8 kHz

(5) At a receiver, the shifts in the RF carrier are detected. For each shift, the receiver recovers the two bits that were transmitted and the digital message is reconstructed exactly.

The ASTRO receiver

Figure 2.12 is a block diagram of the ASTRO receiver.

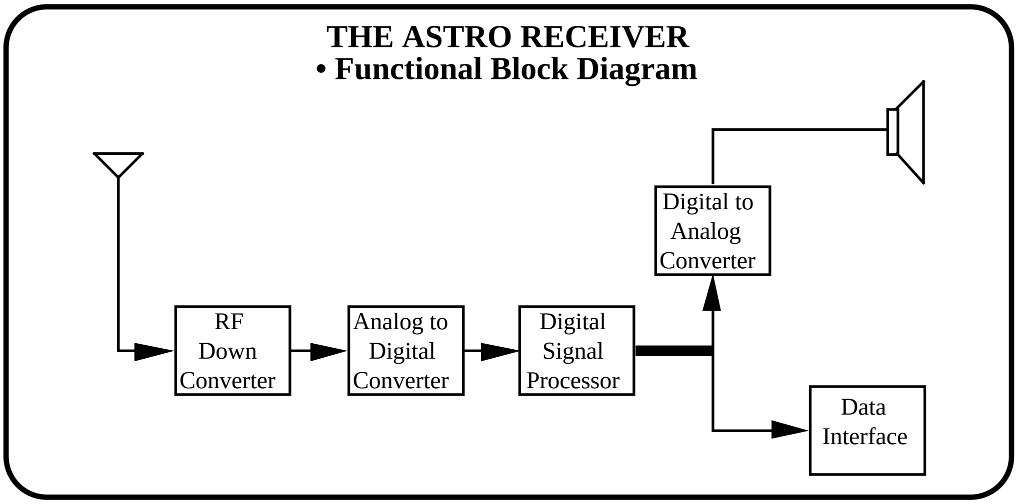

Figure 2.12 ASTRO Receiver

The ASTRO receiver DSP

The receiver performs, in reverse, the same functions performed by the transmitter. But there is one other key digital functional block in the receiver that is worth discussing. In looking at Figure 2.12, it should become apparent that a large portion of what makes up a current analog FM receiver is not present in an ASTRO receiver. This is because a Digital Signal Processor (DSP) performs many of the receiver functions single-handedly. It is also the key to the radio's ability to switch between its voice and data modes.
The receiver DSP allows the use of software to control the parameters that define how an ASTRO radio will operate. This flexibility is key to the backward compatibility of an ASTRO radio:

- It allows the switching of a radio's receiver bandwidth between 25/30 kHz and 12.5/15 kHz channels.
- It allows switching of a radio between SECURENET and ASTRO encrypted voice operation.
- It allows switching of a radio between analog and ASTRO unencrypted voice operation.
- It allows switching of a radio between ASTRO encrypted voice operation and ASTRO unencrypted voice operation.

All of this switching can be programmed into an ASTRO radio through the Radio Service Software (RSS) and will then occur automatically as a radio user moves between modes.

NOTE: More information about ASTRO system backward compatibility and migration can be found in later sections and in the ASTRO Migration Planner.

Summary

This section has touched on the basic technologies that make ASTRO systems the revolution in communications that they are. It has examined the tools that ASTRO systems use to provide optimum performance as digital systems. And it has reviewed how ASTRO systems will comply with Project 25 standards. Reviewing those capabilities and tools once again:

Summary of the Project 25 ASTRO Conventional release

- Details on exactly what is included in this system release including detail on Project 25 compliance.
- Project 25 Common Air Interface mandatory requirements and standard options
- CAI is a major interface in the Project 25 system standard. A baseline of features will be guaranteed from any system to work through any manufacturer's radio.

Project 25 Interoperable voice signaling features

- ASTRO offers many Project 25 specified features that can be used with radios from any manufacturer that provide compliance to these capabilities in their radios.

Additional ASTRO capabilities

- ASTRO goes above and beyond Project 25 with additional capabilities needed by users.

Voice Coder, or “Vocoder”:

- Project 25 vocoder has been implemented in ASTRO systems. IMBE technology means high quality audio in 12.5 kHz channels.

Encryption

- ASTRO encryption provides message security without compromising system performance. The new digital platform also offers several encryption feature enhancements.

Error Protection

- Error protection allows digital radios to reconstruct high-quality audio even if interference has disrupted the signal. ASTRO radio users will hear fewer noise bursts and other distortion, annoyances that are typical of analog systems as the radio user moves farther away from a transmitter site.

Digital Signaling

- ASTRO systems deliver advanced signaling features, with improved system reliability.

Subscriber and console talkgroup operation segmented communications capabilities.

Four Level Digital Modulation

- Efficient digital modulation contributes to the reduced spectrum requirements that make narrowband operation of ASTRO systems possible.

Automatic Receiver Mode Switching

DSP digital receivers allow the radio user to easily move between a wide variety of system types and services. This is key to the migration flexibility of ASTRO systems.

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SECTION 3: VOICE SYSTEMS

Overview

This section describes the elements for building an ASTRO system. As mentioned in the introduction, not every possible system configuration is covered. The basic conventional systems topologies - talk around, stand-alone repeaters, dispatch, voting/multicast, and voting/simulcast systems - are the subject of this section. The first part of this section reviews the components of a system that are unique to ASTRO. The second part describes the basic topologies. For specific product information and specifications, see the individual product planners. Ancillary items such as antennas, transmission lines, and coverage predictions are the responsibility of the field personnel, as in any system design.

Voice System Components

ASTRO Field Radios

As mentioned in the previous section, the availability of the Digital Signal Processor (DSP) has allowed two-way communications technology as advanced as the ASTRO transmitter and the ASTRO receiver to be integrated into a package as small as a portable or mobile radio.

ASTRO Portable Radios

Two ASTRO portable products are: the ASTRO digital SABER™ and the ASTRO digital XTS 3000™.

The ASTRO SABER portable is available in three models:

- The ASTRO Digital SABER I model with no LCD display, no keypad, and 16 programmable modes.
- The ASTRO Digital SABER II model with a 2-line/14-character LCD display, a limited function 3 x 2 keypad, and 255 programmable modes.
- The ASTRO Digital SABER III model with a 2-line/14-character LCD display, a 3 x 6 keypad, and 255 programmable modes.

The ASTRO Digital XTS 3000 is available in two models:

(1) The ASTRO XTS 3000 Model I with no LCD display, no keypad, illuminated 16-position rotary frequency knob; and 16/48 programmable modes.

(2) The ASTRO XTS 3000 Model III, with a 3-line/12-character backlit display, full alphanumeric 3 x 6 keypad and 255 programmable modes.

Figure 3.1 shows the family of ASTRO portables.

Figure 3.1 ASTRO Digital Portables

ASTRO Digital SABER Portable Features

The **ASTRO Digital SABER** series is a versatile radio platform that has many capabilities. In addition to the on/off switch, volume control, monitor button, and mode selector switches, ASTRO Digital Sabers include:

- a clear/coded toggle switch
- a low battery indicator (SABER II and III)
- the ability to lock and/or mute the keypad (SABER II and III)

The SABER II and III, have six blue function buttons. These keys work with "soft" function labels on the display to provide easier radio operation and extra flexibility in managing new ASTRO features.

ASTRO SABER Frequency and Power

The **ASTRO Digital SABER** series is available in the VHF, UHF, and 800 MHz frequency bands. Power levels and band splits are shown in Table 3.1:

ASTRO Digital SABER Model Availability		
BAND	**FREQUENCY RANGE**	**TRANSMITTER OUTPUT POWER**
VHF	136 - 174 MHz	1 to 5 Watts
UHF	403 - 470 MHz	1 to 4 Watts
UHF	450 - 512 MHz	1 to 4 Watts
800 MHz	806 -870 MHz	3 Watts

Table 3.1 ASTRO Digital SABER Portable Basic Models

ASTRO Digital XTS 3000 Portable Features

XTS 3000 is the result of market research which solicited customer inputs and requirements to help determine the most desirable XTS 3000 form and function attributes. Specifically, the introduction of XTS 3000 provides a portable redesign that is intended to meet these stated customer needs and desires for comprehensive capability – but within a smaller package! As a result, the XTS 3000 provides the feature / function capabilities of the ASTRO Saber within an "MTS 2000 size" subscriber unit.

In addition, this marketing research was the basis for the strategy that ensured the XTS 3000 be redesigned for communality of use with some MTS 2000 accessories. Communality of accessories includes such items as Surveillance Earpieces, Headset Accessories, Ear Microphone Systems, Radio Interface Modules, Remote Speaker Microphones, Single Unit Chargers and Antennas.

Excluded items to this communality include such items as select Carry Cases and Straps, Vehicular Adapter, Public Safety Microphones and Multi-Unit Chargers.

ASTRO XTS 3000 Frequency and Power

The **ASTRO Digital XTS 3000** series is available in the VHF, UHF, and 800 MHz frequency bands. Power levels and band splits are shown in Table 3.2:

ASTRO Digital XTS 3000 Model Availability		
BAND	**FREQUENCY RANGE**	**TRANSMITTER OUTPUT POWER**
VHF	136 - 174 MHz	1 to 5 Watts
UHF	403 - 470 MHz	1 to 4 Watts
UHF	450 - 520 MHz	1 to 4 Watts
800 MHz	806 -870 MHz	3 Watts

Table 3.2 ASTRO Digital XTS 3000 Portable Basic Models

ASTRO SPECTRA Radios

The ASTRO mobile is available in five packages:

- **ASTRO SPECTRA W3** - A Hand Held Control Head configuration- alphanumeric LCD dot matrix display; 3 x 6 keypad, including three programmable soft keys for quick access of features, scrolling through preprogrammed lists and unlimited keypad entry of phone numbers, radio IDs, etc.
- **ASTRO SPECTRA W4** - A vacuum fluorescent display; rotary channel and volume switches; Zone/Mode capability; remote and dash mount configurations.
- **ASTRO SPECTRA W5** - A vacuum fluorescent display; electronic channel and volume rocker switches; Zone/Mode capability; remote and dash mount configurations.
- **ASTRO SPECTRA W7** - A vacuum fluorescent display; electronic channel and volume switches; 3 x 4 numeric keypad for unlimited keypad entry of phone numbers, radio IDs, etc.; Zone/Mode capability; remote and dash mount configurations.
- **ASTRO Digital SPECTRA W9** - A vacuum fluorescent display; electronic channel and volume switches; 3 x 4 numeric keypad for unlimited keypad entry of phone numbers, radio IDs, etc.; Zone/Mode capability; remote mount configuration only.

The **ASTRO Digital SPECTRA** series is a versatile radio platform that has many capabilities. In addition to the on/off switch, volume control, monitor button, and mode selector switches, the ASTRO Digital SPECTRA includes:

- a clear/coded toggle switch,
- a display brightness adjust
- an ability to lock and/or mute the keypad.

ASTRO SPECTRA radios can be connected to a mobile data terminal or laptop computer to allow data messages to be transmitted or received over the RF. Please refer to Section 12 for more information on ASTRO SPECTRA data operation.

Figure 3.2 shows some of the ASTRO mobiles.

Figure 3.2 ASTRO Digital SPECTRA

ASTRO SPECTRA Frequency and Power

The **ASTRO Digital SPECTRA** is available in the VHF, UHF, and 800 MHz frequency bands. Any of the ASTRO Digital SPECTRA packages can be ordered to operate in various frequency sub-bands and at various output power levels.

ASTRO Digital SPECTRA Model Availability

BAND	FREQUENCY RANGE	TRANSMITTER OUTPUT POWER
VHF	136 - 162 MHz	10 to 25 Watts 25 to 50 Watts 50 to 110 Watts
	146 - 174 MHz	10 to 25 Watts 25 to 50 Watts 50 to 110 Watts
UHF	403 - 433 MHz	20 to 40 Watts 50 to 110 Watts
	438 - 470 MHz	10 to 25 Watts
	450 - 482 MHz	20 to 40 Watts 50 to 110 Watts
	482 - 512 MHz	20 to 40 Watts 50 and 78 Watts
800 MHz	806 - 870 MHz	35 Watts (30 Watts in talkaround)

Table 3.3 ASTRO Digital SPECTRA Frequency Availability

ASTRO Mobile Choices

It should be noted that the selection of a package and an output power level for an ASTRO Digital SPECTRA can require some restrictions on the mounting configuration of the radio. These are similar to those for the analog SPECTRA:

- The W3 package can only be ordered as remote mount.
- The W4 package can be ordered as either dash mount or remote mount.
- The W5 package can be ordered as either dash mount or remote mount.
- The W7 package can be ordered as either dash mount or remote mount.
- The W9 package can only be ordered as remote mount.
- All high power (70 - 100 W) radios are configured as remote mount only.

BACKWARD Compatibility

The ASTRO Digital SABER, ASTRO Digital XTS 3000 and the ASTRO Digital SPECTRA can be ordered with a conventional system or a trunked

of ASTRO Field Radios

Digital SPECTRA can be ordered with a conventional system or a trunked system (SMARTNET or SmartZone) software package. In addition, the radios can be programmed to be backwards compatible and can support many current analog system features, illustrated in Figure 3.3, which include:

- Analog communications on a 12.5/20/25/30 kHz channel (as standard),
- Private-Line (PL) and Digital Private-Line (DPL) coded squelch control (as standard),
- STAT-ALERT advanced conventional signaling (as standard),
- SECURENET™ 12 Kbps digital encryption on a 25/30 kHz channel for interoperability with SECURENET systems (as an option), and
- Advanced SECURENET Multikey and Over-the-Air-Rekeying (OTAR) features on a 25/30 kHz channel using MDC1200 protocol (as an option).
- Note that use of analog capability is not recommended for systems using integrated data (see Section 4 of this system planner for more information).

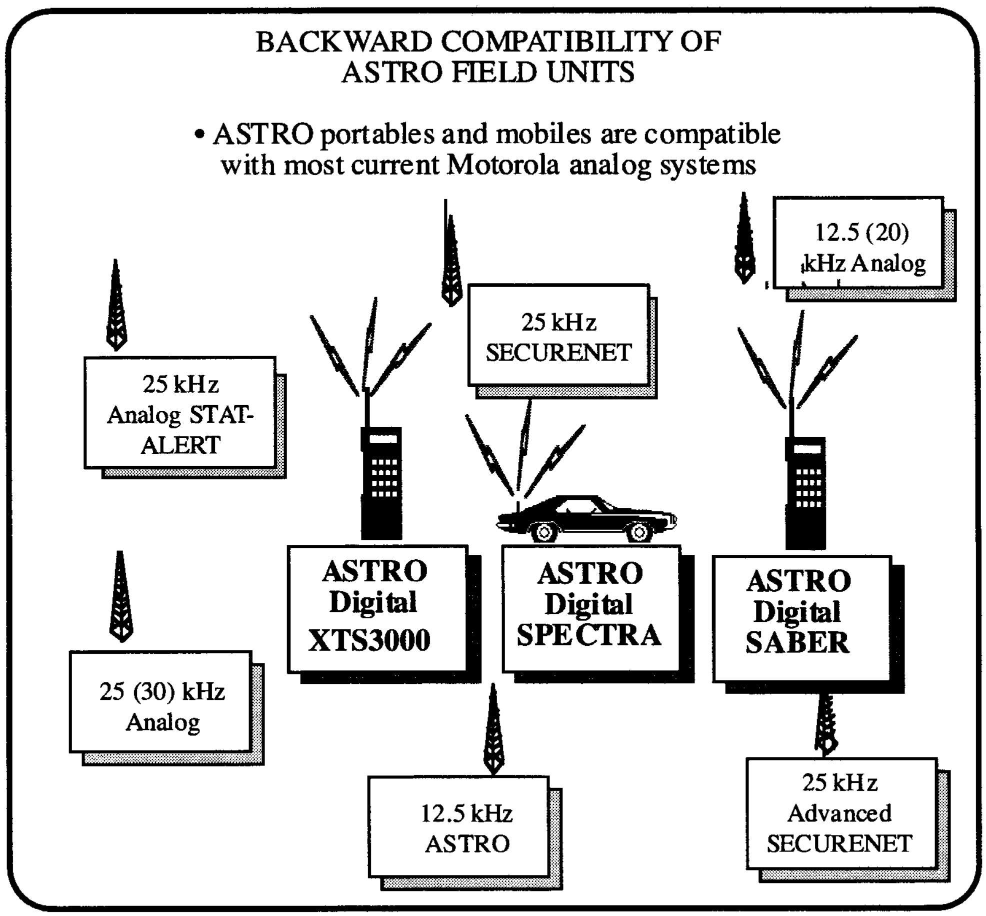

Figure 3.3 Subscriber Interoperability

Field Unit Modes and Programming

Both mobiles and portables are field programmable with existing IBM-compatible hardware (IBM 386 minimum recommended) and the appropriate Radio Service Software (RSS) and interconnect cables. When the radio mode is programmed, one of four operations is programmed. This achieves the desired interoperation of ASTRO field units with various system types. These four types of operation are summarized in Table 3.4.

PROGRAMMABLE OPERATION OF ASTRO FIELD UNITS

• Four types of operation allow interoperability with different systems

TYPE OF OPERATION	TRANSMISSION FORMAT		RECEIVE CAPABILITY	CHANNEL BANDWIDTH REQUIRED
	Clear Mode	Coded Mode		
ALL DIGITAL	Unencrypted ASTRO Signals (12.5 kHz)	Encrypted ASTRO Signals (12.5 kHz)	Auto receive of encrypted and unencrypted ASTRO Signals (each 12.5 kHz)	12.5 kHz
MIXED NARROW BAND	Analog Signals (12.5 kHz)	Encrypted ASTRO Signals (12.5 kHz)	Auto receive of analog signals (12.5 kHz) and encrypted ASTRO signals (12.5 kHz)	12.5 kHz
MIGRATION MODE	Analog Signals (25 kHz)	Encrypted ASTRO Signals (12.5 kHz)	Auto receive of analog signals (25 kHz) and encrypted ASTRO signals (12.5 kHz)	25 kHz
FULLY BACKWARD COMPATIBLE	Analog Signals (25 kHz)	SECURENET Digitally-Encrypted Signals (25 kHz)	Auto receive of analog signals (25 kHz) and SECURENET signals (25 kHz)	25 kHz

Table 3.4 Infrastructure Interoperability

Each type of operation includes an encrypted transmission format and an unencrypted transmission format. The radio user selects the transmission format in which he or she wants to send a message by adjusting the position of the clear/coded toggle switch. Note that this switch only controls the transmit mode; the switch has no bearing on the receive portion of the radio. The radio user will automatically receive any inbound message sent in either one of the transmission formats designated for the selected mode.

For more information on ASTRO portable radios, see Study Guide R8-1-415 and for more information on ASTRO SPECTRA mobile radios, see Product Planner R4-1-96B.

ASTRO Consolette

The ASTRO Digital CONSOLETTE radios (Figure 3.4) represent Motorola's first fully digital two-way desktop station for the Land Mobile environment. These desktop stations incorporate microprocessor technology and other advanced digital technologies to deliver unparalleled functionality and flexibility.

The ASTRO digital consolette utilizes an ASTRO mobile radio capable of ASTRO Conventional, SMARTNET or SmartZone trunking with basic transmit/receiver operation in the ASTRO digital and analog modes. The ASTRO digital consolette will use the same RF hardware and chassis used by the analog Spectra Desktop Station.

Figure 3.4 ASTRO Digital Consolette

ASTRO Consolette Frequency and Power

The ASTRO Digital CONSOLETTE is available in the VHF, UHF, and 800 MHz frequency bands. Power levels and band splits are shown in Table 3.5.

ASTRO Digital CONSOLETTE Availability		
BAND	**FREQUENCY RANGE**	**TRANSMITTER OUTPUT POWER**
VHF	136 - 162 MHz 146 - 174 MHz	25 to 50 Watts
UHF	403 - 433 MHz 450 - 482 MHz 482 - 512 MHz	20 to 40 Watts
800 MHz	806 - 870 MHz	35 Watts (30 Watts in talkaround)

Table 3.5 ASTRO Digital CONSOLETTE Frequency Availability

The ASTRO Digital CONSOLETTE is available in two packages: the Local Control Package and the Digital Remote Control Package.

The ASTRO Consolette is partially based on the existing analog Spectra Desktop product. An ASTRO SPECTRA (low power) is integrated with a power supply, control panel and appropriate display housed in the analog Spectra station housing. Connection to external desksets and accessories will be via two DB-25 connectors on the back panel of the main housing. For all power ranges, the ASTRO Consolette will be capable of a 20% duty cycle.

The Local Control package provides and ASTRO SPECTRA radio modified to operate as a control station integrated with a power supply. Transmit audio will be provided from a standard desk microphone (paddle mic). The Local Control version differentiates itself by showing the control head through the plastic housing. Operations are the same as the W7 ASTRO SPECTRA mobile radio. The front panel assembly consists of the W7 control head, speaker, Power-On LED, optional VU meter/clock, and optional encryption key variable loader Hiroshe connector. All Consolette features are accessible from the control panel at the front.
The Digital Remote Control package provides full feature control operation from a DGT9000A or DD2000 digital control deskset communicating with the Consolette via a rear panel DB-25 connector. The local control head on the Remote control Consolette is removed and is replaced by a front panel. No local speaker will be provided. Power-On LED and optional encryption key variable loader Hiroshe connector, located on the Consolette (not the digital

remote deskset-DGT9000A), are available as well.

Digital control provides full control operation from a remote digital control deskset over a four wire line. The four wire configuration will be used for separate transmit/receive audio and data paths. Transmit and receive audio will be carried on one pair, and the serial communications data will be carried on the other pair.

An Digital Remote Adapter, serving as a junction box, will be required to interface between the control station and the remote control digital deskset. This is due to the fact that the DGT9000A does not support extended local control operation. As many as sic DGT9000A/DD2000 desksets can be interfaced to the Consolette.

For more information on the ASTRO Digital CONSOLETTE, see Product Planner R4-26-9.

ASTRO Infrastructure

For ASTRO system infrastructure design flexibility, a diverse set of ASTRO infrastructure devices has been developed.

ASTRO Stations

ASTRO can be configured for either base station or repeater operation. There are two versions of the ASTRO station, QUANTAR for the VHF, UHF and 800 MHz bands and QUANTRO for the high power stations in the VHF, UHF and 800 MHz bands. Both versions are ASTRO-transparent; no digital voice or data processing takes place in either. However, digital signal error correction is performed on all received ASTRO digital signals.

Station Design

The QUANTAR and QUANTRO stations (Figure 3.5) have been designed in accordance with customer input. Some features that these products include are:

Modular design: All major circuits of the ASTRO stations are modular in design. The receiver, control card and wire line board, and exciter board are in the main chassis. The power supply and power amplifier in the QUANTAR station is internal to the chassis; in the QUANTRO station, it is rack-mounted outside the main chassis in either the cabinet or on the rack mount.

- Power Supply: The QUANTAR station ships standard with a switching power supply, which has the ability to operate over a wide range of voltages (90-280 VAC) and frequencies (47-63 Hz) without any modifications or jumper changes. The QUANTRO station uses a ferro resonant power supply which operates at a voltage of 110 AC and a frequency of 60 Hz. Options are available to substitute a multi-voltage (90-140/180-280 VAC, 60 Hz) or 50 Hz power supply if desired.
- Enhanced diagnostics capability: Both stations have been designed with the Field Replaceable Unit (FRU) concept in mind, to ease the burden of servicing and maintenance. A variety of tests and alarms are available to aid in the failure detection process.
- Simpler installation and handling: Station modules are easy to install and remove, and require a minimum of cabling between them.
- NOTE: Local microphone/speaker capability is not available at the station.
- Also, no base to console intercom operation is available at the station.

NOTE: For more information on the QUANTAR and QUANTRO stations, please see Product Planner/Ordering Guide RO-2-66D and the QUANTAR/QUANTRO FLASHport Ordering Guide RO-4-444C

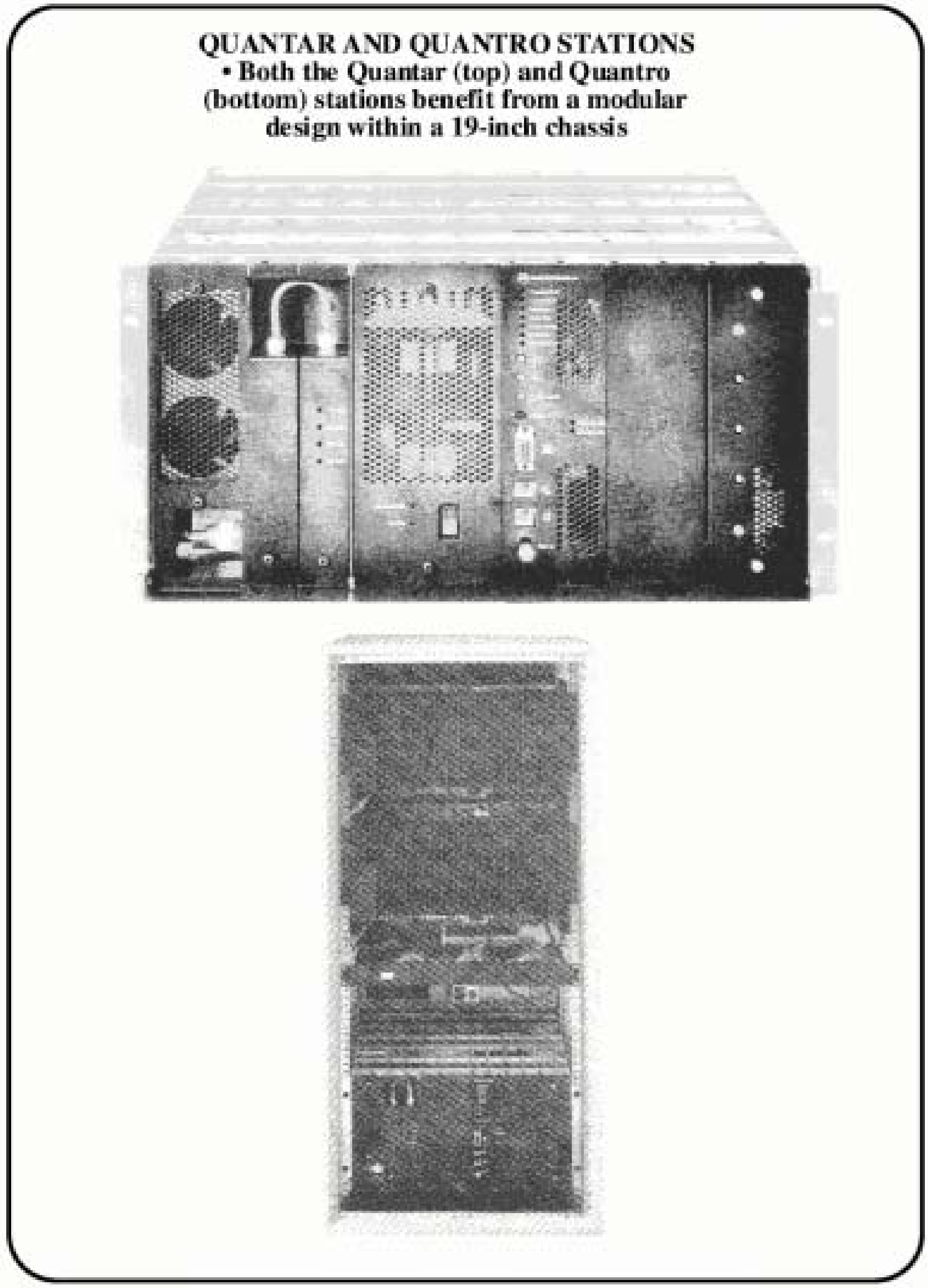

Figure 3.5 QUANTAR and QUANTRO Stations

ASTRO Satellite Receivers

The features of the **ASTRO Satellite Receivers** (Figure 3.6) are almost identical to those of the ASTRO stations. The ASTRO-TAC Receiver is targeted for the mid tier ASTRO customer. In the ASTRO-TAC Receiver a V.24 wireline interface (hybrid link operation) is standard. The 9.6 Kbps ASTRO modem is optional. The QUANTAR Satellite Receiver is targeted for the high-tier ASTRO customer requiring wildcard capability. In the QUANTAR Satellite Receiver both the V.24 wireline interface (hybrid link operation) and the 9.6 Kbps ASTRO modem are options, but one or the other must be ordered for ASTRO operation. The ASTRO-TAC Receiver is 2 rack units and the QUANTAR Satellite Receiver is 5 rack units. For more information on the ASTRO receivers, please see the QUANTAR/ASTRO-TAC Receiver Product Planner R4-2-96A.

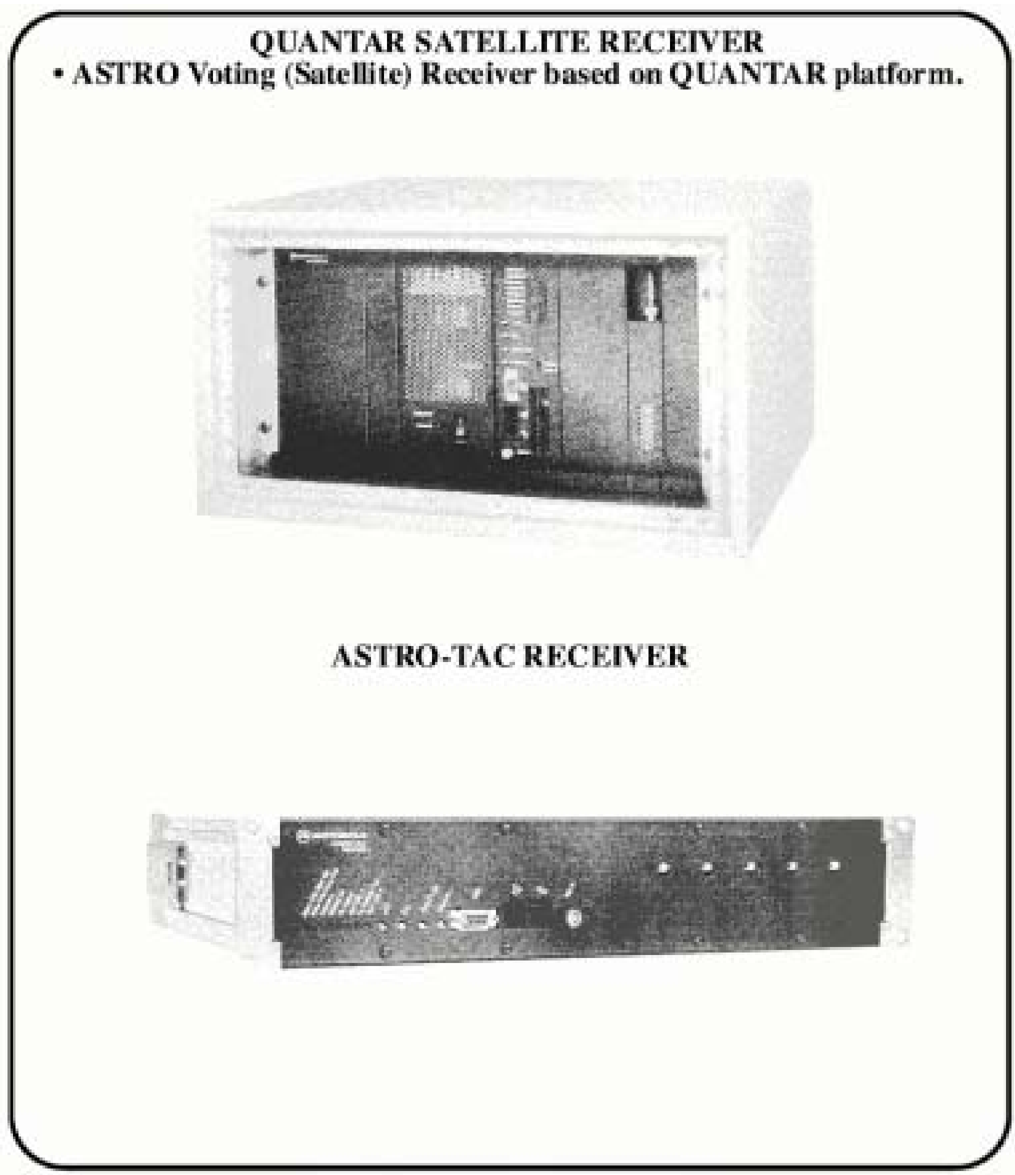

Figure 3.6 ASTRO Receivers

ASTRO Infrastructure Backward Compatibility

As standard, the ASTRO stations are configured for conventional system operation. In addition, similar to the field units, the stations are backward compatible and can support many current analog system features:

- Analog communications on 12.5/20/25/30 kHz channels (as standard),
- Private-Line (PL) and Digital Private-Line (DPL) coded squelch control (as standard),
- STAT-ALERT advanced conventional signaling (as standard)

Similar to the field units, there are three types of operation that the stations can be set for:

- MIXED MODE: Automatic receive of 12.5 kHz ASTRO encrypted and unencrypted signals, as well as 12.5 kHz analog signals.
- MIGRATION MODE: Automatic receive of 12.5 kHz ASTRO encrypted and unencrypted signals, as well as 25 kHz analog signals. The channel band width required is therefore 25 kHz.
- FULLY BACKWARD COMPATIBLE MODE: Automatic receive of 25 kHz analog signals and 25 kHz SECURENET signals. The channel band width required is hence 25 kHz.

NOTE: ASTRO infrastructure is not capable of being programmed for both ASTRO and SECURENET mode. Stations must be programmed for either ASTRO or SECURENET, but not both.

In any of the four cases, if the station is configured to act as a repeater, signals are repeated in the same format in which they are received.
The ASTRO station offers significant flexibility by supporting backward-compatibility with analog and SECURENET systems. Refer to the ASTRO Migration Planner for more detailed migration information. The station and satellite receiver support the fully backward-compatible mode in conjunction with a SECURENET Digitac and CIU. The ASTRO comparator and the DIU will not support 12 Kbps SECURENET operation.

The above alternatives are depicted in figure 3.7.

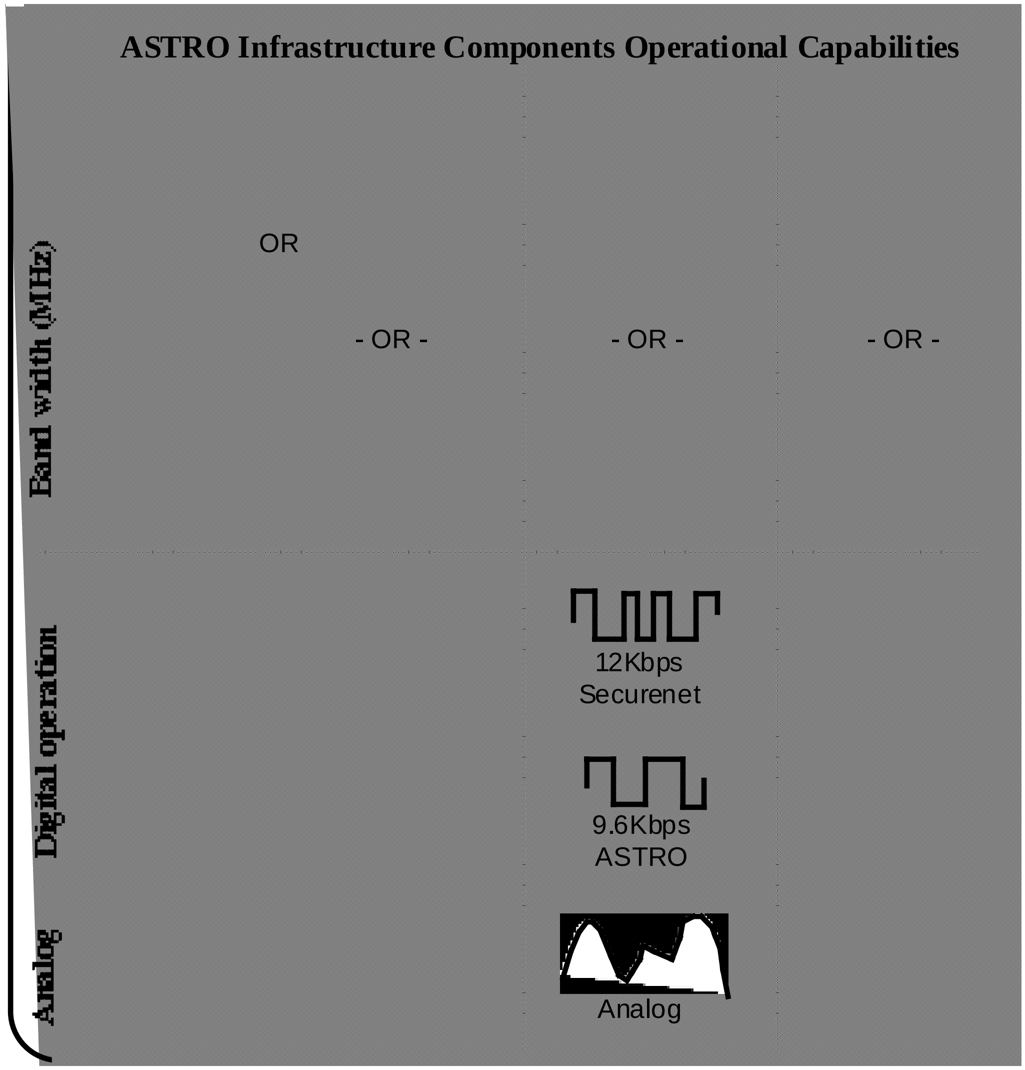

Figure 3.7 ASTRO Backward-Compatibility

The ASTRO Comparator

To improve coverage in many wide area systems, multiple satellite receivers are added to cover "dead spots" created by buildings, foliage, valleys, or hills. To insure that the best "audio" from these satellite receivers is processed, a comparator compares and selects the best signal to be passed onto the desired recipients. This process is known as receiver voting. Radio systems that employ this technology are often referred to as Total Area Coverage (TAC) systems.

The ASTRO-TAC 3000™ Comparator is a state-of-the-art digital voting comparator for use with Project 25 systems. It is compatible with Motorola stations and receivers designed to meet the Project 25 Common Air Interface (CAI) standard. The ASTRO-TAC 3000 is NOT a replacement for the ASTRO-TAC™ comparator. The ASTRO-TAC 3000 Comparator is designed for systems with IMBE (CAI) vocoding; the ASTRO-TAC Comparator is designed for VSELP based systems. The voting of analog signals can be supported in conventional voting configurations, but only in a Project 25 designed system. It is NOT compatible with existing analog stations or satellite receivers utilizing status tone or 12 Kbps SECURENET systems. Encryption is supported (transparently), but only in the 9.6 Kbps ASTRO format.

In an ASTRO-TAC 3000 Comparator Voting System, receivers are connected via telephone lines or microwave links to the ASTRO-TAC 3000 Comparator. The comparator communicates with surrounding ASTRO infrastructure elements such as base stations/repeaters, satellite receivers, and dispatch consoles (with a Digital Interface Unit (DIU)) via a Wireline Interface Board (WIB). In general, the WIB processes and routes all wireline audio signals between the comparator and the external equipment.

In conventional systems, V.24, hybrid, and modem link interfaces are supported. Each ASTRO-TAC 3000 Comparator CAN be configured to accommodate both V.24/hybrid boards and ASTRO 9.6 Kbps wireline modems in a single ASTRO-TAC 3000 Comparator. The ASTRO-TAC 3000 Comparator is capable of supporting from two (2) to sixteen (16) synchronous serial input/output ports in a conventional system. Each Wireline board has 2 I/O ports and requires either one or two ASTRO modems (depending if only one or both of the ports will be active) or one V.24/hybrid board.

The ASTRO-TAC 3000™ Expansion Comparator can support up to two (2) synchronous serial Digital Interface Unit (DIU) input/output ports and up to 64 synchronous serial base station input/output ports. The ASTRO-TAC 3000™ Expansion Comparator utilizes the primary chassis for Digital Interface Units connection while each secondary chassis hold up to sixteen (16) input/output ports (8 wireline boards) each. The ASTRO-TAC 3000™ Expansion Comparator supports digital only operation. In addition, only V.24 digital only link interfaces will be supported. The Remote Comparator Display (RCD), stand-alone software program, only supports remote comparator status, control display, and operation. The software program resides on a DOS based PC. Monitor and Control Network (MCN) supplied by CTI Products Inc. and will not be supported for the expanded comparator.

For more information on ASTRO-TAC 3000™ Comparator and Expansion Comparator, please refer to the Product Planner and Ordering Guide R4-26-6A.

Figure 3.8 ASTRO Comparator

ASTRO Digital Interface Unit

All ASTRO digital systems require a **Digital Interface Unit (DIU)** to convert voice to a digital format. Current analog system tone remote console products can also be interfaced to an ASTRO radio infrastructure by way of a DIU. The DIU is a stand alone device connected between a control console (with one or more operators) and an ASTRO station or ASTRO-TAC 3000 Comparator. It may be rack mounted or cabinet mounted. The DIU performs five key functions for the console operator(s):

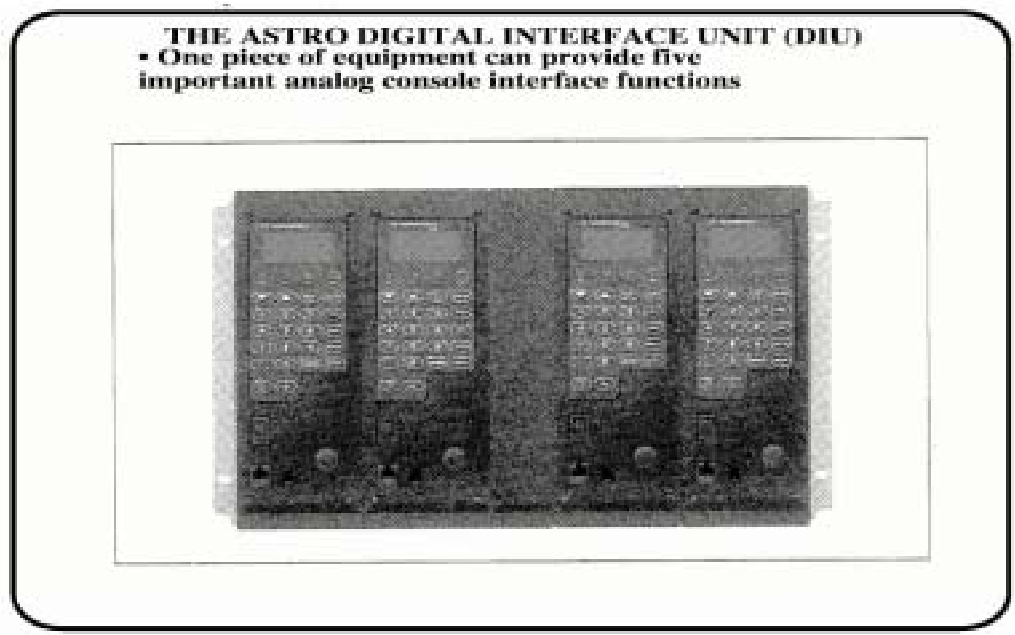

Figure 3.9 ASTRO Digital Interface Unit (Rack Mounted)

(1) It contains the IMBE circuitry used to perform the analog-to-digital (A/D) signal conversion of outbound voice messages and the digital-to-analog (D/A) signal conversion of inbound voice messages.
(2) (2) It generates ASTRO station keying command sequences. Any sequences sent by the console are converted to digital commands and then inserted in the ASTRO signal's embedded signaling.
(3) (3) It provides encryption/decryption functions for the console operator.
(4) It routes ASTRO embedded signaling information to a separate port, so that the appropriate console hardware or external device can access it for decoding (only in a CENTRACOM GOLD Series console).
(5) (5) It provides the interface to the telephone interconnect device (MRTI-2000). The MRTI2000 converts ASTRO signaling and voice to analog DTMF tones and voice for telephone interconnect calls.

GPS Site Reference for ASTRO Only Simulcast

The equipment used to synchronize an ASTRO simulcast system is the GPS disciplined time frequency standard. The standard is modular structured and provides buffered 5 MHz outputs and 1 PPS signals on the rear back panel. All models include a GPS Receiver with antenna and connecting cable. Several models also include a back-up crystal and automatic switch over.

Control Centers

Project 25 System with an ASTRO Gold Series Console

The picture below shows a typical Project 25 ASTRO system connected to a CENTRACOM Gold Series Console:

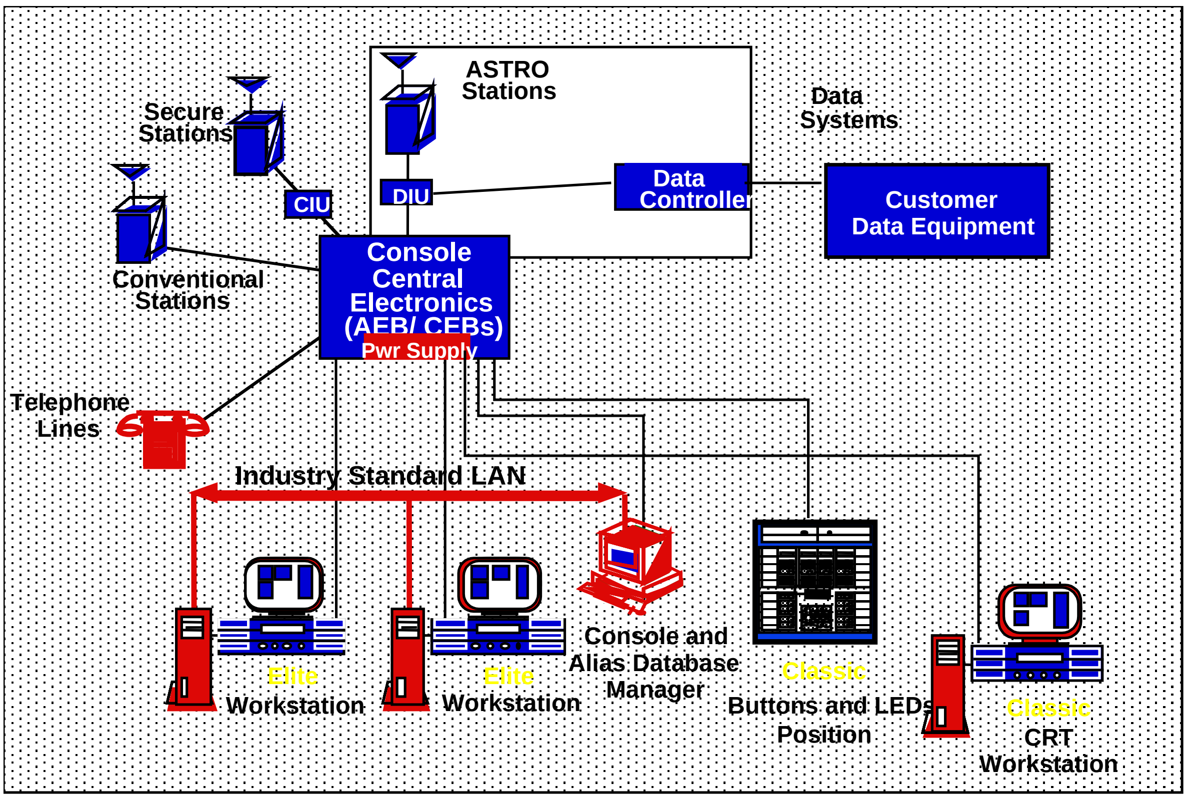

Figure 3.10 CENTRACOM Gold Series Console

Conventional ASTRO APCO Project 25 Feature Matrix

Table 3.6 shows what features that can be used on operator positions using Project 25 ASTRO Conventional Channels.

Feature	Classic Buttons and LEDs	Classic CRT	Elite GUI
Push To Talk ID	Y	Y	Y
Emergency Alarm/Call	Y	Y	Y
Enter ID	Y	Y	Y
Radio Check	Y	Y	Y
Status Request	Y	Y	Y
Selective Radio Inhibit	Y	Y	Y
Remote Monitor	Y	Y	Y
Individual Voice Alert	Y	Y	Y
Individual/Group Call Alert	Y	Y	Y
Repeater Access Code	N	N	N
Dual Mode	Y	Y	Y
Triple Mode	Y	N	Y
Receive Qualifier Control	Y	N	Y
Single Conventional Talkgroup	Y	Y	Y
Multiple Conventional Talkgroups	Y	Y	N
Channel Wide Call	Y	Y	Y
Alias Database Manager	Y	Y	Y
Console Database Manager	Y	Y	Y
Field Prom Programmer	N	N	N
Carrier Operated Relay	N*	N*	N*
High Speed Mute	N*	N*	N*
Take Over Relay	N*	N*	N*

**Not compatible with Digital Keying.*

Table 3.6 Features Available on Different Operator Position Types

New Console Feature Overview

The CENTRACOM Gold Series contains easy to use features available on the Classic Buttons and LEDs and Classic CRT operator positions:

- Integrated Voice and Data using Project 25 Common Air Interface (CAI)
- Digital Keying
- ASTRO Conventional Talkgroups
- Channel-wide Call
- Receive Talkgroup Indication
- ASTRO Conventional Talkgroups with Encryption
- Individual Multi-select of Talkgroups

Integrated Voice and Data using Project 25 Common Air Interface (CAI

In a Project 25 ASTRO Conventional System the CENTRACOM Gold Series can be used in conjunction with a data controller on the same channel. This provides integrated voice and data capability on the same resource, in turn saving valuable frequency resources.

CENTRACOM Gold Series Digital Keying

The CENTRACOM Gold Series console uses Digital Keying to control a base station in a Project 25 ASTRO system. Both the console and data controller connect to the Digital Interface Unit (DIU). Digital Keying provides faster system access time than Tone Remote Control (TRC). In ASTRO systems without a data controller, digital keying is required for faster keying and to allow for future feature enhancements.

ASTRO Conventional Talkgroups on Classic Operator Positions

ASTRO conventional talkgroups allow users of a channel to become segmented into groups. This allows a dispatcher to control the radio system more efficiently, providing easier communication between users in functional groups. The Classic Buttons and LEDs and the Classic CRT operator positions allow a maximum of 16 talkgroups on each channel.

There are two available button options on the Classic Buttons and LEDs operator positions: single and dual talkgroup switches (see Figure 3.11). The single talkgroup buttons require a single button press to access talkgroups. Single talkgroup buttons are typically used on systems that require few talkgroups per channel or on operator positions where space is not a limitation. Dual talkgroup buttons work in a toggle fashion. For example, if the dispatcher wants to transmit on Talkgroup 2 (see Figure 3.11), then the dispatcher will push the button twice to get to the bottom mode. Dual talkgroup buttons should be used on Classic Buttons and LEDs systems where button space is limited. Single and Dual talkgroup buttons can be mixed together on the same Channel Control Module.

X41 Single Talkgroup Button **X45 Dual Talkgroup Button**

Figure 3.11 Button options on classic Buttons and LEDs Operator Positions

Single and dual talkgroup buttons should be ordered as custom label buttons. The X41 and the X45 options will have to be programmed in the field.
Each talkgroup display on the Classic CRT consumes one line of text in a channel control window. Each line of text for a talkgroup has an "on" condition and an "off" condition. An 8-character text name can be programmed on the Classic CRT representing a talkgroup.

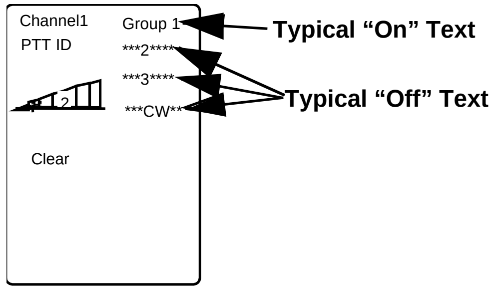

Figure 3.12 Classic CRT Channel Control Window

The illustration in Figure 3.12 shows a classic CRT with 4 talkgroups. The selected talkgroup is displayed with the "On" text is "Group 1". The unselected talkgroups are shown by the "Off text" or "***#****". If the dispatcher desires to transmit on a talkgroup other than 1, then they would select the proper talkgroup by changing the state of one of the "Off" text to the "On" text. The below illustration shows the new Channel-wide talkgroup selected.

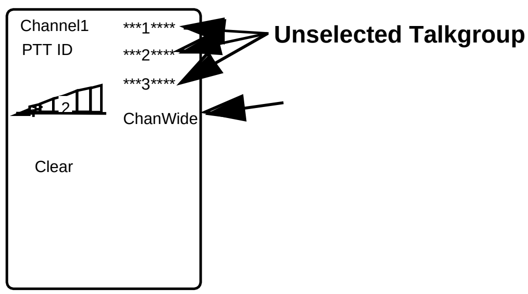

Figure 3.13 Classic CRT Channel Control Window

Channel-Wide Call

The channel wide call feature allows the dispatcher to contact every properly programmed ASTRO user on the channel. The channel-wide call consumes a talkgroup button. If this feature is used, the maximum number of talkgroups per channel is 15. When a dispatcher makes an outbound channel wide call, all radios in the ASTRO mode will hear the dispatcher's audio. This feature is sometimes referred to as the “system-wide call”.

Receive Talkgroup Indication

On channels using multiple ASTRO conventional talkgroups, unmatched talkgroups are indicated by a blinking LED on the Classic Buttons and LEDs operator interface (Figure 3.14). The unmatched condition occurs when the selected outbound conventional talkgroup indication is different from the current inbound received talkgroup. If the received talkgroup is the same as the selected transmit talkgroup then only the received call and busy LEDs will activate (Not shown). The received talkgroup indication will last for the duration of the call.

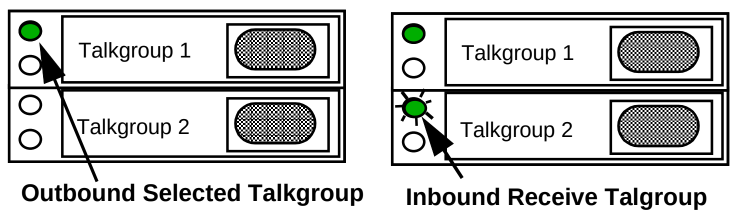

Figure 3.14 Talkgroup indication on Classic Buttons and LEDs Console Interface

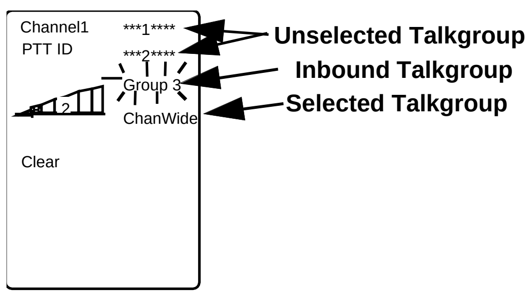

Figure 3.15 Classic CRT Channel Control Window

An outbound talkgroup selection is indicated on the Classic CRT by displaying the "ontext". If a talkgroup is not selected it will display the "offtext". When an inbound unmatched call is received the proper received talkgroup will blink the "Ontext" condition for the duration of the call. Figure 3.15 shows that the selected talkgroup is "ChanWide" and the Inbound talkgroup is "Group 3". If the dispatcher wanted to respond to only Group 3, the Blinking Group 3 text would have to be selected, then transmission would be possible.

ASTRO Conventional Talkgroups with Encryption

In ASTRO Conventional systems requiring secure talkgroups, each talkgroup must have a single dedicated key. This configuration is known as key strapping. Strapping an encryption key to the ASTRO conventional talkgroup provides security for all confidential communications within that talkgroup. Each talkgroup can have a unique encryption key, allowing security between talkgroups on a conventional channel. The console will send a dedicated encryption key for individual calls such as voice alert. This designated individual key should be the same across all portables on the channel.

When secure communication is desired and the dispatcher would like to use the channel wide feature, all subscribers should be programmed with the same key linked to the channel wide ID. This will ensure that the dispatchers channel wide transmission will be heard by all of the ASTRO subscribers on the channel regardless of the currently selected talkgroup or mode (coded/clear indication) on the subscriber.

Individual Multi-select of Talkgroups

The CENTRACOM Gold Series allows individual talkgroups to be combined into multi-selects. A multi-select, or an All Points Bulletin (APB), is an outbound radio transmission from a dispatcher to all field units simultaneously on multiple channels. This allows the dispatcher to transmit important messages on multiple systems and multiple channels all at once, which saves critical response time. When using ASTRO conventional talkgroups on a channel, only one talkgroup can be added to a multi-select transmission for each channel. For example, if the console is programmed with three talkgroups on a channel, Talkgroup 1, Talkgroup 2, and Talkgroup 3, the dispatcher could select Talkgroup 2 into the multi-select and transmit to Talkgroup 2. Talkgroup 1 and Talkgroup 3 would not hear the outbound dispatcher's radio transmission. If it is desired to reach all ASTRO radio users in a multi-select, then the system-wide talkgroup should be programmed and used as the multi-select talkgroup.

When the multi-select is opened into edit mode, the current selected talkgroup will be displayed and be used as the multi-selected talkgroup. In the multi-select edit mode, talkgroups can be changed and stored in memory. When the multi-select is closed, the multi-selected talkgroups will remain stored in multi-select memory and the talkgroup selection will revert to the previously selected talkgroup (talkgroup that was selected before the multi-select was opened).

Partitioned Channel vs. Non-partitioned Channel

There are two ways to configure a channel on the CENTRACOM Gold Series console in a Project 25 ASTRO Conventional system: partitioned or non-partitioned. Partitioned channels allow the use of conventional talkgroups, channel-wide call, receive talkgroup indications and allow easy segmentation of users on a single channel. Non-partitioned channels work the same way as previous ASTRO systems. Dispatch calls on non-partitioned channels are not addressed to any particular group of users. Outbound calls on non-partitioned ASTRO channels (unaddressed calls) will be received by all subscribers on that channel. The only way to segment users on non-partitioned channels is to use encryption. Up to 8 encryption keys can be used on non-partitioned channels. Non-partitioned channels do not indicate the cross key (inbound key is different than outbound selected key), where on partitioned channels cross talkgroup indication will be indicated for unmatched talkgroups. (Refer to talkgroup receive section.) Non-partitioned channels work similarly to previous versions of ASTRO on the operator positions and it is possible to place inbound and outbound individual calls. Table 3.7 shows the features associated with partitioned and non-partitioned channels:

Partitioned Channel Features	Non-Partitioned Channel Features
Up to 16 keys (one per Talkgroup)	8 keys Maximum
Talkgroups (16 maximum)	Auto-Key
Receive Talkgroup Indication	Momentary Key Override
Channel-wide Call	Auto-Momentary Key Override
Inbound/Outbound Individual Call	Inbound/Outbound Individual Call

Table 3.7 Features of Partitioned Versus Non-Partitioned Channels

When systems are configured for partitioned channels on the console (Using conventional talkgroups), all audio is heard by the dispatcher position independent of which talkgroup is selected.

Elite with Conventional Talkgroups

The Elite Graphical User Interface (GUI) can support a single talkgroup on partitioned channels. This talkgroup is programmed initially by the Console Database Manager. Each Elite operator position programmed with the Project 25 ASTRO conventional channel can only transmit to its default talkgroup and will hear all audio from all talkgroups on the channel.

Using the Console Database Manager each Elite operator position can be programmed to have the channel-wide talkgroup as the default so the operator can respond to all ASTRO users on the channel. On Elite there is no inbound indication of which talkgroup on a partitioned channel is active. The Elite Graphical User Interface can address different talkgroups than the default talkgroup by using the Voice Selective Call feature.

Using Assignable Channels and ASTRO Conventional Talkgroups

On Classic Buttons and LEDs and Classic CRT positions, it is possible to have an Assignable channel with a mismatched number of talkgroups when the channel is assigned. For example, if the physical Digital Channel Control Module (DCCM) has five talkgroup buttons and a channel with eight talkgroups is assigned, three talkgroups cannot be accessed. To ensure proper design when using assignable channels, always program the maximum number of buttons to correspond with the maximum number of talkgroups on all assignable modules. Also, if an operator assigns a channel that has five talkgroups to an assignable channel that has eight buttons, three buttons will not be active. An audible beep will occur if the inactive buttons are depressed.

Patching Channels With Conventional Talkgroups

When a partitioned ASTRO channel using conventional talkgroups is patched together, the channel will automatically revert to the channel-wide mode. When outbound patch audio (audio coming from another channel and/or dispatcher) is active, it will be broadcast on the ASTRO channel using the channel wide ID. This means that all ASTRO units will hear the patch audio from the other channels. When partitioned channels are in a patch, current talkgroup selection will be maintained so that if the operator performs a general transmit or instant transmit on the partitioned channel, the console will send a system-wide call to the selected talkgroup on that channel. Only patch transmits will use the channel-wide talkgroup.

In some system configurations inbound ASTRO units may not be heard by other ASTRO units on the Conventional Channel but will be patched to other channels. This condition occurs if there are non-repeater ASTRO systems using talkgroups or on ASTRO systems where the portables are programmed for selective squelch. For example, if Channel A (ASTRO partitioned repeater) is patched to Channel B (Analog VHF Repeater) and Talkgroup 1 keys up on Channel A, then the console will hear the audio, as well as the radios on Channel B. Other radios listening to Channel A on different talkgroups not listening to Talkgroup 1 (programmed with selective squelch) will not hear the inbound audio (See above illustration). If a portable on the Analog VHF system wants to respond to Talkgroup 1 they will be heard at the console and by all talkgroups on Channel A because all patch audio is going out in a channel wide talkgroup mode.

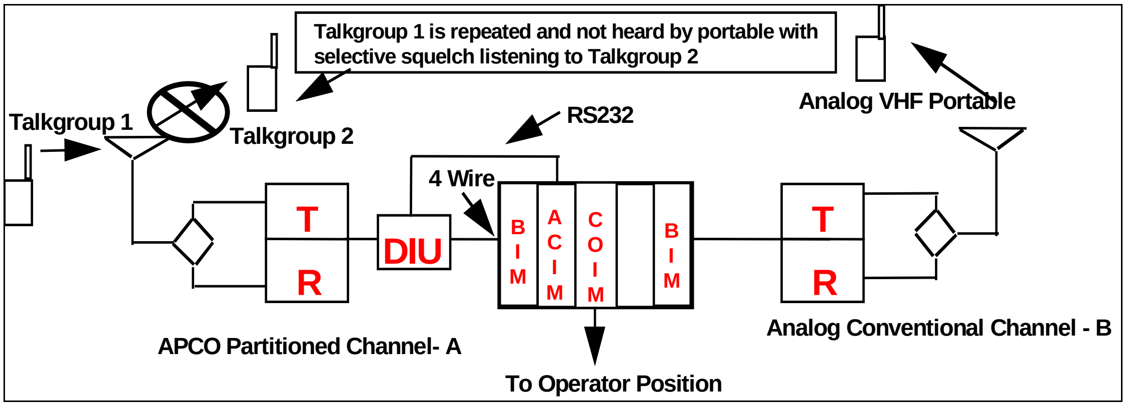

Figure 3.16 Channel Partitioning

Classic Buttons and LEDs Using Dual Talkgroup Buttons

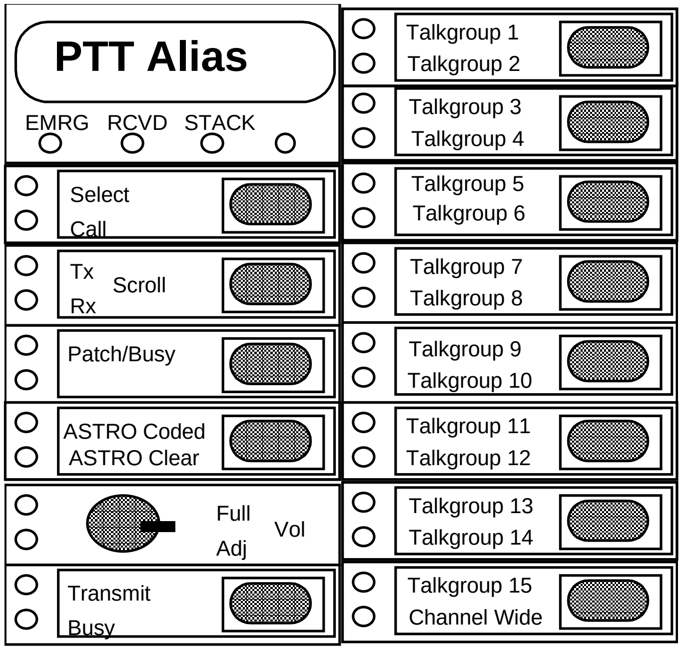

Figure 3.17 Digital Channel Control Module using Dual Talkgroup Buttons

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Classic Buttons and LEDs Using Single Talkgroup Buttons

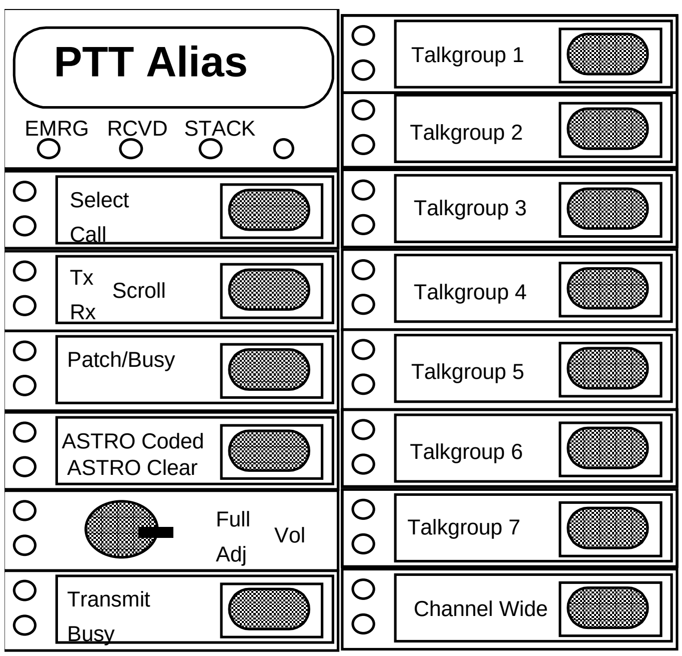

Figure 3.18 Digital Channel Control Module using Single Talkgroup Buttons

Ordering and Configuration Information	All talkgroup buttons should be obtained by ordering custom label buttons through the Console Design Advisor (CDA). All talkgroup buttons will have to be linked to a talkgroup ID list in the field. The talkgroup ID list will have 16 spaces for IDs; one of them can be the channel-wide ID.
Channel Hardware	All new Gold Series Systems using the ASTRO Conventional channels require a B1825 ASTRO VSELP/ASTRO CAI channel hardware package. All ASTRO channels will be configured for digital keying from the factory.
ASTRO CAI Software License	All channels in the CENTRACOM GOLD series system require an X393 ASTRO CAI Conventional Channel Software License. The X393 option should be ordered as a sub-item to the B1827 Gold Series License Manager. For ASTRO SmartZone Trunking Systems using IMBE, order the X285 SmartZone ASTRO VSELP and ASTRO CAI Console Software License as a sub-item to the B1827 Gold Series License Manager. One X285 License is required per SmartZone system.
Migration Field Issues	ASTRO Signaling using the IMBE vocoder is only supported in the CENTRACOM Gold Series Console. Simple voice communications without signaling is available on the CENTRACOM Series II Plus, CENTRACOM Series II and on other consoles (Figure 3.19). For details on how to migrate from the CENTRACOM Series II or Series II Plus to the Gold Series order the R4-13-9 Gold Series Migration planner.

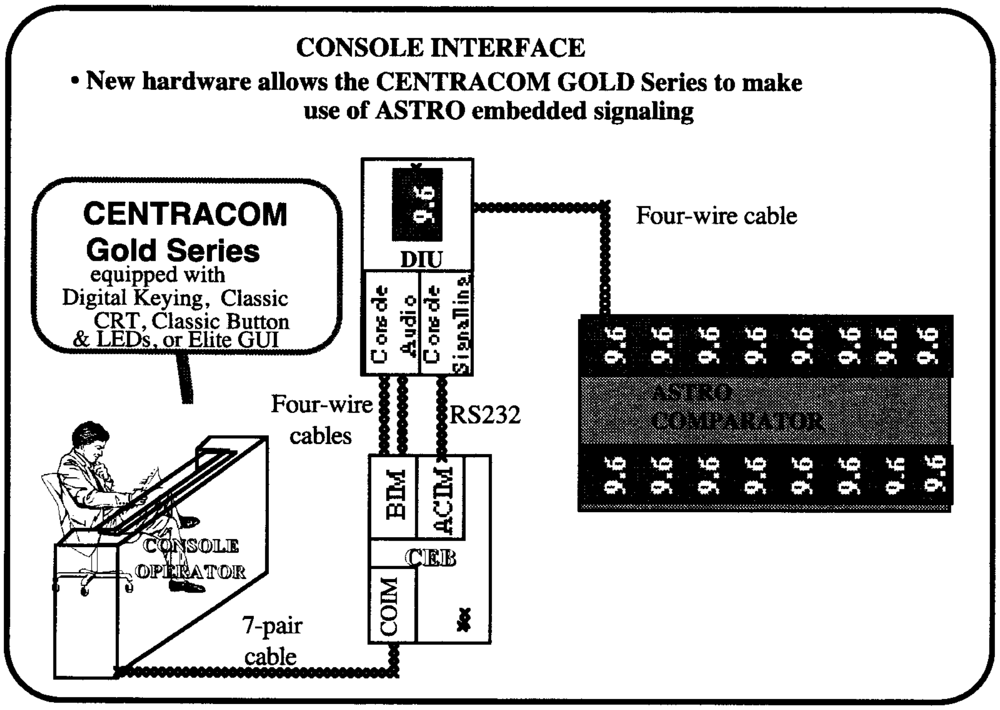

Figure 3.19 ASTRO / Console Interface

ASTRO Control Equipment For Talk And Listen Operation Only

A Project 25 ASTRO Conventional system requires the use of a CENTRACOM Gold Series console for control operation. If a customer does not wish to upgrade an existing older model console, only talk and listen and basic console operations will be available at the console. In multi-channel systems, one DIU is needed for each ASTRO-equipped channel. In a CENTRACOM Series II installation, only one DIU is needed for each station to be controlled, no matter how many operator positions are in use.

Since the DIU can convert Tone Remote Control (TRC) sequences into ASTRO station signaling commands, the following analog console products can support inbound and outbound ASTRO voice operation as well as basic console operations:

- T5600 Series and Command Series desk top consoles.
- CENTRACOM Series II (6809 based) or Series II Plus (68000 based) console equipped with TRC and K874AA Positive Mode Control Switch.

Any standard format tone remote control console (non-positive mode control consoles will have a limited control command set).

ASTRO Encryption Support Devices

An ASTRO system can be ordered to support digital encryption, the highest level of security available for a private two-way radio communications system. Similar in technology to digital encryption, ASTRO digital encryption also allows the system user to define unique key variables and selectively control the set of recipients of important messages. ASTRO provides multiple encryption algorithms to choose from including DES-XL, DES-OFB, DVP-XL, and DVI-XL. Project 25 DES-OFB allows interoperability with Project 25 radios supplied by different manufacturers.
To enable such operation, ASTRO encryption support devices are available.

ASTRO Key Variable Loaders

The encryption key variables to be used in a secure ASTRO system can be distributed to field units, DIUs and RNCs through the use of a hand-held device called a **Key Variable Loader** (Figure 3.20).

Figure 3.20 ASTRO KVL3000

KVL 3000 Capabilities

The KVL 3000 supports both Advanced SECURENET™ (ASN) operation and ASTRO 25 operation.

For ASN operation, the KVL 3000 offers the following features:

- Up to 1024 encryption keys (traffic and shadow combined)
- Supports multiple encryption algorithms

DES (CFB, XL and OFB)

DVP

DVP-XL

DVI-XL

- Supports dual algorithms (DES and one other)
- Supports multiple encryption protocols

12 Kbps SECURENET

9.6 Kbps Secure ASTRO™ (VSELP vocoder)

9.6 Kbps Secure ASTRO 25™ (IMBE vocoder)

- Supports multiple encryption standards:

FIPS46-2

FIPS 81

FIPS 140-1 Level 1

- Supports software upgrades via PCMCIA card slot and FLASHport™ technology

For ASTRO 25 operation, the KVL 3000 offers the following features:

- Supports multiple encryption algorithms

DES (XL and OFB)

DVP-XL

DVI-XL

- Supports the following encryption protocol
  9.6 Kbps Secure ASTRO 25™ (IMBE vocoder)
- Supports multiple encryption standards:

FIPS46-2

FIPS 81

FIPS 140-1 Level 1

- Supports software upgrades via PCMCIA card slot and FLASHport™ technology
- Supports transfer of keys to/from a Key Management Facility (KMF) using “Store and Forward” feature.

Refer to Section 5 for more detail about the KVL 3000 and its role in encryption key management.

ASTRO Product Inter-Connections

No design of a radio communications system can be complete if it consists solely of the selection of products. In fact, determining how to connect products together as a system can often be more complex than deciding what products to include in the system. The design of an ASTRO system is no exception. Therefore, to complete a "library" of ASTRO system building blocks, a discussion of the available product interconnection alternatives is needed.

Four different types of link connections can be utilized: internal ASTRO 9.6 Kbps modems, external CCITT V.32 modems, digital multiplex with sub-rate data cards, or hybrid links (analog without modem; V.24 for digital). When using external modems or digital multiplex, the V.24 link interface option is required in all infrastructure boxes within the system, i.e. comparator, stations/receivers and DIU.

When using external modems or digital multiplex, the link to the co-located station must go through the same kind of links as the remote sites, i.e. you must use back to back modems (or back to back multiplex). The reason for this is the time delay difference through the modems compared to the direct V.24 cable connection. The ASTRO-TAC 3000 is sensitive to the time delays in the receive path and can not deal with signal delay differences larger than 100 ms.

The V.24 termination requires an external modem or multiplex. The external modem must be set up for 9.6 Kbps synchronous operation and must provide an error rate not greater than 0.000001.

Local Wire Line (Twisted Pair Cable)

For equipment that is co-located (comparator-and-station or comparator-and-DIU,) and a cable run of no greater than 50 feet (RS-232C), V.24 may be used.

Hybrid Link Operation

For mixed analog/ASTRO systems, hybrid links may be used. A hybrid link consists of two paths, each having a 4-wire termination. The first path is an analog path; the second is the digital path. The digital path will require external V.32 modems.

When modems (other than the external V.32 external modems) are required; they are installed as daughter boards on an I/O port of an ASTRO station, an ASTRO Satellite Receiver, an ASTRO Comparator, or a Digital Interface Unit (DIU). Two items to note on the modems:

- The modems provide balanced 600 ohm terminations.
- They require a four-wire circuit between them, regardless of whether the audio flow between them is one-way or two-way.

Mixed Link Operation

Mixed link operation is allowed. A system design can have V.24, hybrid-links, and external V.32 modems existing in the same system.

Leased Telephone Lines

If two ASTRO products are not co-located, there are several interconnection alternatives from which a customer can choose, the first of which is leased telephone lines. The scenario is similar to the same case in an analog system. However, what is true in the implementation of the local wire lines in an ASTRO system is true of leased telephone lines in an ASTRO system as well. If 9.6 Kbps ASTRO signals are to pass down a narrow-band wireline path, modems are required. The same modems as those described above can be used.

To assure the proper operation of the 9.6 Kbps modems, the leased telephone lines are four-wire connections and meet a set of specifications on the order of those for AT&T Service Type 5 or Type 3002 lines, as listed in Appendix A.

Phone line performance varies between the various local common carrier (phone company) service providers. Appendix A cites several specifications which U.S. service providers guarantee as minimum specifications. Typical operation is often far superior to these specifications. However, at times, actual performance may be worse than these guaranteed specifications. In this case, the service provider will likely remedy these faults as soon as they are identified. To assure proper operation, D1 conditioning with a 28 dB signal to C-message noise level can be ordered. Most of the 3002 or Type 5 ordered lines will have greater than 24 dB. This is a recommended system design caution based on previous systems already installed.

When using phone lines to interconnect ASTRO equipment, it is highly recommended that the above guidelines be followed. In addition, lines should be subjected to a simple series of tests as published in the product installation manuals to ensure proper modem performance and the timely assessment of any further corrective action required by the service provider.

Refer to Table A.1 in Appendix A for minimum telephone line specifications for ASTRO applications.

Analog Microwave Links

Another method of interconnecting equipment within an ASTRO system (as in an analog system) is via an analog microwave link. Because such a link is a narrowband path just like a leased telephone line, the same rules apply:

- Modems are required at each end if 9.6 Kbps ASTRO signals are to cross the analog microwave link.
- The interface to the analog microwave link at each end must be four-wire.
- The analog microwave multiplex channel must meet a set of specifications on the order of those for AT&T Service Type 5 or Type 3002 lines. Normally, a properly loaded base band easily meets the minimum modem requirements.

Digital Microwave Links

Outputs from the ASTRO infrastructure equipment will be via the ASTRO 9.6 Kbps modems. Direct digital microwave interfaces for ASTRO infrastructure devices are available as the V.24 link interface. This interface provides an ASTRO only, 9.6 Kbps, RS-232 connection to a DSU or data card in a multiplex which is the interface to the digital microwave system. The V.24 link interface is an option to the QUANTAR/QUANTRO stations/receivers, ASTRO-TAC 3000™ and DIU. Use a four wire card if hybrid link operation is desired.

ASTRO Product Inter-Connections Backwards Compatibility

As mentioned, the list of accessories needed to support an RF channel in an ASTRO system is no different than the list for an RF channel in an analog system. In fact, an accessory used to support an RF channel in an ASTRO system can be the same accessory that would be used to support an analogous RF channel in an analog system. This is true of antennas, transmission lines, multi-couplers, combiners, duplexers, pre-amplifiers, and external power amplifiers.

The ASTRO modems are also backward compatible, as they are capable of passing analog signals as well as ASTRO digital signals. The modems default to digital operation but automatically are bypassed upon detecting an analog signal.

The only special considerations required are with respect to the narrow channel size and the interchannel separations which may be observed as users move from 25 or 30 kHz systems to 12.5 kHz systems.

Summary ASTRO digital technology provides new system benefits and enhanced system design flexibility through the availability of a complete family of ASTRO products:

- ASTRO Digital SABER: A fully digital portable radio available in three different models to allow a customer to choose their desired level of radio complexity.
- ASTRO Digital XTS-3000: A fully digital portable radio available in two different models designed directly from customer research.
- ASTRO Digital SPECTRA: A fully digital mobile radio that can be physically configured as per a customer's application.
- ASTRO Digital CONSOLETTE: A fully digital two-way desktop station incorporating microprocessor and other advanced digital technologies
- ASTRO QUANTAR and QUANTRO Stations: Fully digital stations completely modular in design for ease of installation and maintenance.
- ASTRO Satellite Receivers: Two fully digital receivers are offered to meet the needs of the mid-tier and high-tier ASTRO customer requirements. Both are modular in design for ease of installation and maintenance.
- ASTRO-TAC 3000 Comparator: A fully digital signal voter which can vote both on ASTRO signals and on analog signals.
- Digital Interface Unit (DIU): Digital keying capability for more efficient operations and tone remote control options that allow current analog system console technology to interface to ASTRO radio infrastructures.
- CENTRACOM Gold Series console: Console that allows ASTRO signaling, digital keying and conventional talkgroup capability.
- ASTRO-Capable Encryption Key Variable Loader (KVL 3000) a hand-held device used to manage the distribution of encryption key variables in a secure ASTRO system.

ASTRO systems configured with the equipment listed above allow customers to reap the following ASTRO system benefits:

- Digital Audio Quality: By incorporating error protection bits into the transmitted ASTRO signal, an ASTRO system can maintain reliable, consistent audio quality throughout much of the system coverage area. Error detection and correction performed by the repeater furnishes enhanced system performance by removing interference before repeating the signal.
- Enhanced Signaling: By embedding 2.4 Kbps of signaling and control information within an ASTRO voice signal, the ASTRO system can provide signaling capacity greater than any analog system, without the loss of audio and without the audible “squawks” that are common to analog system signaling schemes.
- Improved Spectral Efficiency: An ASTRO system requires a bandwidth of only 12.5/15 kHz per channel, potentially doubling the number of frequencies available for channel assignment.
- Enhanced Encryption Capabilities: An ASTRO system provides improved encryption capabilities, including multiple algorithms, up to 16 keys per subscriber unit, and the elimination of preamble voice truncation, all on 12.5 kHz channels. ASTRO also provides a choice from multiple encryption algorithms including the Project 25 DES-OFB.
- Backward Compatibility: ASTRO products can be programmed to transmit and receive analog signals, allowing them to interoperate with analog radios and analog systems. ASTRO stations/repeaters can be programmed for analog/ <u>or</u> analog/ASTRO operation. ASTRO station/repeaters <u>cannot</u> be programmed for <u>and</u> ASTRO simultaneously. ASTRO field radios can also be equipped and programmed to transmit and receive 25 kHz signals. However, it should be noted that other ASTRO system benefits are lost when ASTRO products operate in analog modes.
- FLASHport: ASTRO products support FLASHport upgrades, a capability that allows adding software and/or hardware to support future feature development.
- ID Display: An optional feature, the ASTRO display portable or mobile can display the numeric ID of a received ASTRO transmission.
- Subscriber unit numeric display on associated DCCM at console
- Dispatcher access to ASTRO embedded signaling

Voice System Topologies

Talk Around Voice Systems

System application

The primary element in the design of any private two-way radio communications system is the networking of a fleet of field radios (portable and mobile radios). In most circumstances, the radio system customer will know: how many system users will require a field radio, which system users will need to communicate with each other, and where system users will need to transmit and receive from when communicating with other system users.

This information becomes the basis in determining the extent of the required system coverage area.

If, within this coverage area, any system user can directly communicate with all of the other system users they are required to -- relying solely on the output power of the transmitter in their portable or mobile radio -- the system need be no more complex than a Talkaround system.

Simply put, a Talkaround system is one in which no infrastructure is required to successfully network all the system's field radios. All field radios are within range of each other at all times, and all are to be party to each and every transmission. A single frequency is assigned to all field radios to serve as a half-duplex channel.

Figure 3.21 illustrates a typical talkaround system.

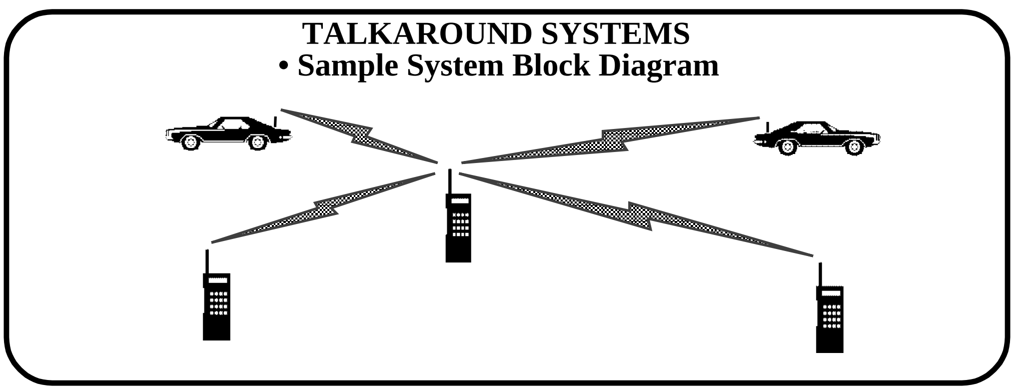

Figure 3.21 Talk Around System

Stand Alone Voice Repeater Systems

System application

Direct RF communication—relying solely on the transmitter output power of a portable or mobile radio—is not always enough to successfully network a fleet of field radios throughout a system coverage area. When a customer requires coverage over a large area or in a building, an infrastructure must be added to complete the network.

In many of these cases, the simple insertion of a full-duplex stand alone repeater in the transmission path can extend the talk-out range of the field radios sufficiently, with a minimum of additional cost. Such a repeater is transparent to field radio communications; it does nothing to modify a transmission other than to clean it up, amplify it, and pass it on.

ASTRO repeaters offer additional flexibility. Users with multiple agencies (such as plants with Transportation, Materials Handling, and Security departments, or police departments with Patrol and Detective Divisions) can share a common repeater in a digital mode, encrypted or unencrypted, without being forced to listen to communications that do not pertain to their particular organizational activities. Each subscriber can be assigned to a specific talkgroup while maintaining an individual ID number.

System example close-up: ASTRO operation

Figure 3.22 is block diagram of a Stand Alone Repeater system with multiple talkgroups.

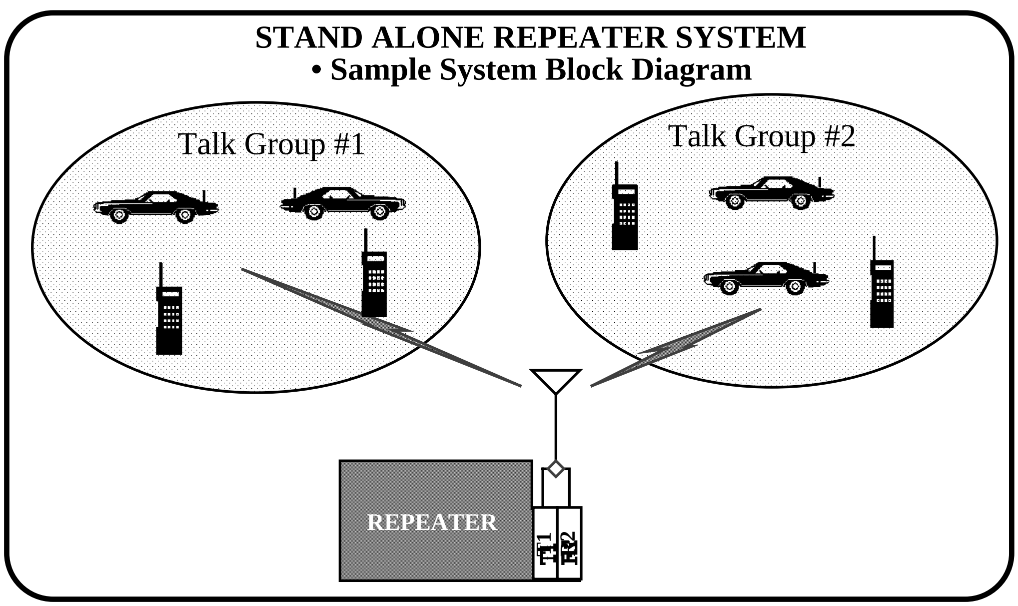

Figure 3.22 Stand Alone Repeater System

In the example shown in Figure 3.22, Talkgroups 1 and 2 are segmented in their normal operations. They share a common repeater, but since each talkgroup shares a unique "talkgroup ID", they do not listen to unintended communications. Of course, all subscribers have the capability to monitor their channel before transmitting. If the talkgroups have a requirement to communicate, the radios can have the other's talkgroup programmed on one of the operating modes of the portable or mobile unit.

The standalone repeaters operate transparently on the properly formatted ASTRO signals. They do not modify signals in any way, other than to refresh them and perform error correction on them (using the embedded error protection bits) before sending an amplified version of them out over the air.

NOTE: ASTRO QUANTAR/QUANTRO repeaters must be equipped with the EPIC control board to fully support all ASTRO mode Advanced Conventional call types.

This system configuration also supports telephone interconnect. The MRTI2000 telephone interface requires an analog interface. Since this system is capable or digital or mixed mode operation, a DIU must be incorporated. The DIU is the analog/digital and digital/analog converter in the infrastructure. To support telephone interconnect, the repeater must have an ASTRO modem (for either ASTRO only or mixed mode), a hybrid link consisting of a V.24 and separate analog interface (4-wire termination on each), or V.24 (for ASTRO mode only) interface to communicate with the same type of link interface in the DIU. The DIU connects to the MRTI2000 completing the connection to the PSTN.

Dispatcher Voice Systems

System application

Dispatchers are used when centralized monitoring and/or control points are needed. In such cases, one or more console positions are present in the system, and are usually given priority in accessing the system's RF channels.

Design alternatives

The overall shape of a Dispatch system depends on a customer's requirement for information flow. In general, there are three scenarios for the customer to choose from (per RF channel):

(1) CONSOLE AS SUBSCRIBER: The console communicates with field radios via a single-frequency, simplex base station. The console appears to the fleet of field radios as just another subscriber. Again, in this scenario the console does not maintain priority access to the channel. The RF channel works just like a talk around channel, except that a dispatcher can fully participate in radio conversations.

(2) CONSOLE AS HUB: The console communicates with field radios via a two-frequency, full-duplex base station. Any transmission from a field radio goes solely to the console; all messages received by a field radio come solely from the console. The dispatcher is therefore at the hub of all

operations—in total control—and maintains priority access to the RF channel.

(3) CONSOLE AS SUPERVISOR: On a two-frequency, full-duplex repeater channel, the console communicates with field radios via that repeater. Field radio transmissions are both routed to the console and in-cabinet repeated to other field radios. The console maintains priority access to the RF channel, and can interrupt a field radio transmission in progress as required.

A dispatch console system may also include the capability to monitor other radio channels without being able to talk on those channels. For example, a police dispatcher might monitor a fire department channel.

The dispatch system configurations also support telephone interconnect. Both analog mode and ASTRO digital mode interconnect calls are supported. The DIU provides the MRTI telephone device interface.

Console operator positions are normally placed at locations where they can be most conveniently manned on a regular basis. Such a location might be an organization’s headquarters or home office. RF infrastructure devices such as base stations, repeaters, and satellite receivers are normally placed at locations that provide optimum system talk-in and talk-out coverage (such as a mountaintop, a rural site, etc.). What this means is that in most circumstances a console must be able to control RF equipment remotely. In such cases, leased telephone lines or microwave links can be used to link the console and RF equipment sites.

For those cases when the console can be co-located with the RF equipment, local wire line (e.g. twisted pair cable) can be used.

ASTRO Dispatch Operation

Figure 3.23 shows a block diagram of a multiple channel Dispatcher system.

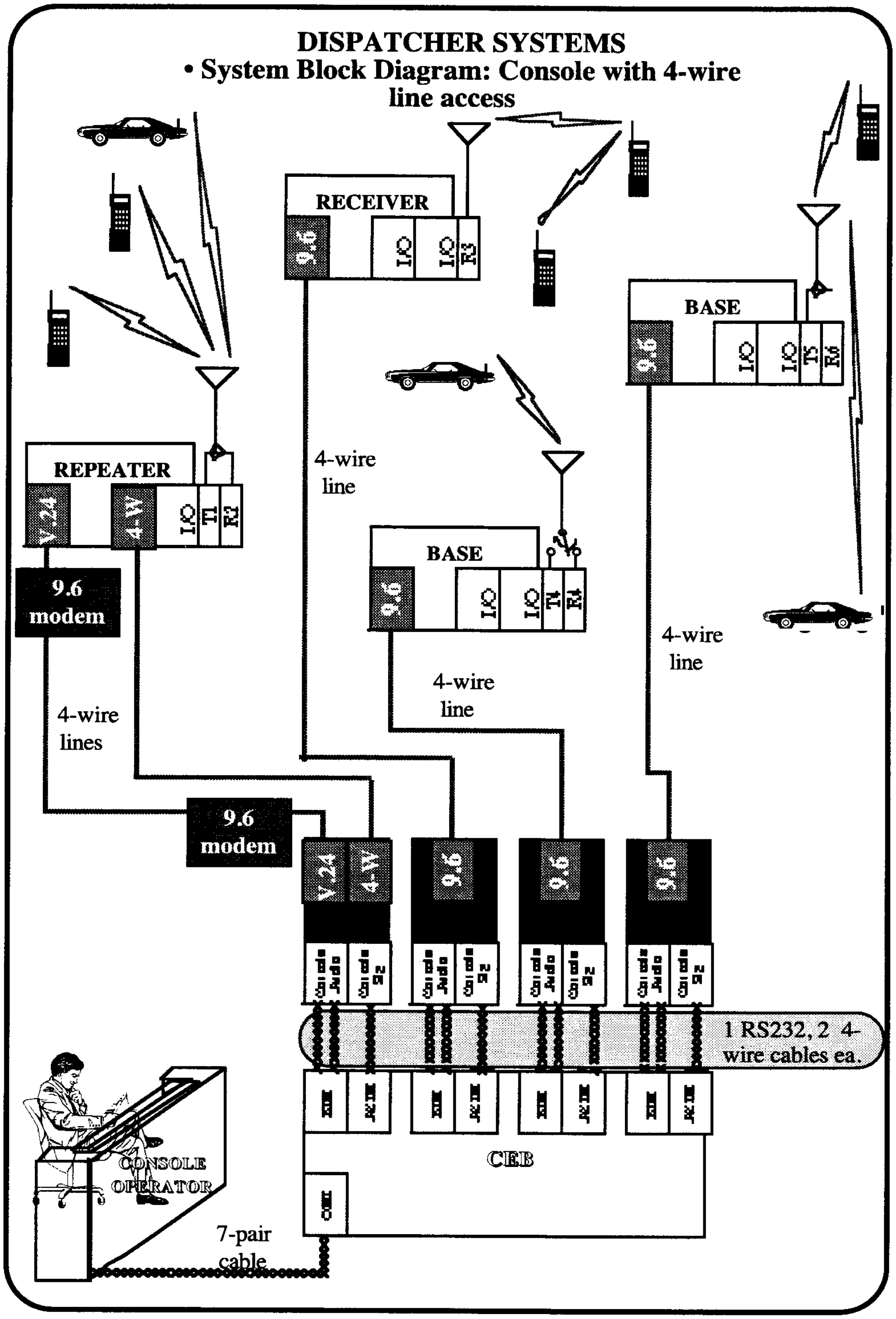

Figure 3.23 Typical Dispatch System

Each of the four console interface scenarios are depicted in Figure 3.23. For simplicity, the fleet of field radios in this example consists merely of five portable radios and three mobile radios. From left to right:

- On the first channel, the dispatcher is in a CONSOLE AS SUPERVISOR configuration. It can monitor the half-duplex communications amongst the three field radios on the repeater channel, and has priority access if and when it wants to participate in the conversation.
- On the second channel, the dispatcher is in a CONSOLE AS MONITOR configuration. It can monitor the half-duplex communications between the two field radios on the talk around channel (T3R3), but cannot participate.
- On the third channel, the dispatcher is in a CONSOLE AS SUBSCRIBER configuration. It can have a conversation with the field radio on the talk around channel (T4R4), just as if the console was itself another field radio.
- On the fourth channel, the dispatcher is in a CONSOLE AS HUB configuration. It is the only link between the two field radios on the channel, since it is the only receiver that will pick up transmissions from, and the only transmitter that can send transmissions to, either field radio.
- On each channel, the RF equipment is remote from the console and is linked to the console site via leased telephone lines.

The key elements in the design of this system are as follows:

- Proper selection of RF infrastructure devices: For ASTRO operation all of the standalone repeaters are either the QUANTAR or QUANTRO ASTRO station.
- Proper selection of field radios: To transmit and receive ASTRO signals, all of the subscriber units are ASTRO Digital SABERs, ASTRO Digital XTS 3000's or ASTRO Digital SPECTRAs. The customer selects the correct mix of ASTRO products to meet the unique requirements of his system.
- The console voice and control interface: A Digital Interface Unit (DIU) is allocated for each of the channels to perform IMBE A/D and D/A signal conversion for voice messages and to translate console sequences into ASTRO station digital commands.
- Modems to pass high speed digital signals on wire lines: High speed ASTRO signals cannot pass down narrowband wire line paths without modification. In order to pass ASTRO signals on the 4 kHz leased telephone lines used to link the console site with the 4 RF sites, 9.6 Kbps modems are required both in the stations and in the DIUs. For ASTRO digital only operation V.24 link interfaces may be used in the stations and DIUs.
- V.24 link interface: The V.24 termination requires an external modem or multiplex. The external modem must be set up for 9.6 Kbps synchronous operation and must provide an error rate not greater than 0.000001. The only certified modems are UDS V.3225 modems.
- Hybrid links: Hybrid link operation is possible where analog voice does not use a modem and digital voice is sent via a V.24 termination.

- Proper operation of telephone lines: To guarantee the proper operation of the 9.6 Kbps modems, the leased telephone lines are four-wire connections and meet a set of specifications on the order of those for AT&T Service Type 5 or Type 3002 lines.
- Embedded signaling to console: To make use of ASTRO embedded signaling features, a CENTRACOM Series II Plus is required. The console is equipped with a DCCM and an ASTRO Mode Switch for the channel. The console's Central Electronics Bank (CEB) is also equipped with an ASTRO Console Interface Module (ACIM) for each of the 4 channels so that embedded signaling information can be received from the DIUs. To simplify the technology needed to transfer embedded signaling information between the DIUs and the console, the DIUs are co-located with the CEB.

Wide Area Voice Systems

System application

Most communications systems will include equipment that transmits at various power levels (Table 3.6)

Radio Type	Transmission Level
Portable	2 to 5 Watts
Mobile	25 to 100 Watts
Fixed stations	6 to 350 Watts

Table 3.8 Transmission Ranges by Device Type

Similar "dead spots" could be caused by a densely wooded area, a deep valley, or an inconveniently located hill -- in short, by any environmental factor that can adversely effect RF propagation. But perhaps the most significant cause of system "dead spots" is the inevitable unequal range of radios with varying transmitter output power levels.

The solution to the problem of system "dead spots" is a wide area system. Since their primary application is to eliminate these "holes" in a system coverage area, wide area systems are also often called Total Area Coverage (TAC) systems.

Design alternatives

The one element that is common to all wide area (voting and Simulcast) systems is the same element from which they get their name: an infrastructure device called a signal voter, or comparator.

This comparator is normally located at a central site in the system, and is linked to some number of repeaters and/or satellite receiver sites that are strategically placed to balance coverage throughout the system coverage area -- removing the “dead spots” that would otherwise be present.

All repeaters and satellite receivers operate on the same receive frequency; it is expected that field radios will simultaneously hit multiple sites (to varying degrees) on each of their transmissions. The signals received at each site are routed back to the comparator, which compares them and picks the best one to pass on to the desired recipients.

A repeat path through the system is required, but there is also a dispatcher that must be able to monitor all transmissions while maintaining priority access to the channel. Voted audio is routed both back to the repeaters for re-transmission to the field radios and on to the dispatcher console. The dispatcher can access all of the system repeaters via the comparator, and can interrupt a field radio transmission in progress as required.

Console operator positions are normally placed at locations where they can be most conveniently manned on a regular basis. Such a location might be an organization's headquarters or home office. This is often the same site where the comparator can be located, and in this case a local wireline can be used to interconnect the comparator and DIU. If the comparator and DIU are equipped with ASTRO modems, 4-wire twisted pairs can be used; if the comparator and DIU are equipped with V.24 interface ports, then a data cable must be used; if the comparator and DIU are equipped with the hybrid link interface option, both a 4-wire twisted pair cable and a data cable must be used.

Repeaters and Satellite Receivers

Repeaters and satellite receivers typically are strategically located to balance system coverage and will almost always be remote from the comparator. The equipment interconnects based on equipment port type is discussed below:

ASTRO MODEM

If the repeater and satellite receivers are equipped with ASTRO modems, 4-wire leased lines or 4-wire channel bank cards (either analog microwave, digital microwave or optical fiber connections) can be used to interconnect the RF equipment to the comparator or DIU.

V.24

If the repeater and satellite receivers are equipped with V.24 interface ports, external V.32 synchronous, leased line capable modems, connected to 4-wire leased lines or 4-wire channel bank cards (either analog microwave, digital microwave or optical fiber connections), can be used to interconnect the RF equipment to the comparator or DIU. A data cable must be used to connect the V.24 port of the RF equipment to the V.32 modem.

V.24

If the repeater and satellite receivers are equipped with external interface ports, external Digital Service Units (DSU) equipped with 9600 bps, synchronous capability can be used to interconnect the RD equipment to the comparator or DIU. A data cable must be used to connect the V.24 port of the RF equipment to the DSU. DSUs can be standalone units that can connect up to leased digital circuits, or to a card that plugs directly into a channel bank.

HYBRID LINK

If the comparator and DIU are equipped with the hybrid link interface option, both a 4-wire audio and a 9600 bps data connection must be used. Combinations of 4-wire leased lines or 4-wire channel bank cards (either analog microwave, digital microwave or optical fiber connections) can be used to interconnect the analog audio signal of the RF equipment to the comparator or DIU. Interconnections for the 9600 bps data as discussed above in the V.24 paragraphs must be used for the data connection of the hybrid link.

If the comparator must be remote from the console/DIU site, the comparator must be treated as if it were remoted RF equipment. The comparator would have the same transport interface constraints as outlined above for the repeater and satellite receivers.

Voting system operation

The ASTRO-TAC 3000™ Comparator is the key to system operation. All signals received at any of the receiver sites are routed to the comparator, which selects the best signal to pass on.

The ASTRO-TAC 3000 Comparator features a state-of-the-art digital voting methodology: Frame Diversity Reception. The ASTRO-TAC 3000 Comparator votes on 20 msec segments of each signal based upon certain digital signal parameters. As the comparator receives the various signals, it looks at each of the 20 msec data frames and compares the bit error rate (BER) and error correction coding (ECC). The comparator then selects the data frame or signal with the lowest BER and ECC and resends it. By utilizing the best pieces (data frames) of each input signal, the result is often a better output signal than any one signal being received at the comparator.

Other solutions to increase coverage particularly in high density environments such as major metropolitan areas, are Simulcast and Multicast. Simulcast is similar to a voting system since it has multiple receivers on a given frequency, but it also has multiple transmitters on a single frequency. It provides enhanced wide area coverage through the simultaneous transmission of identical RF signals from multiple sites in a single system. In order for the transmitter signals to be launched at precisely the same time from all transmitters, Global Positioning Satellite (GPS) site reference receivers are required to time synchronize all repeaters and the comparator. The outbound signal from the comparator includes the launch time when the stations should transmit that signal. Simulcast combines state-of-the-art technologies yielding superior results in audio quality, site overlap performance, and specifications.

Multicast operates similar to simulcast except that the transmitters are on different frequencies and GPS technologies are not employed.

This system configuration also supports telephone interconnect. Both analog mode and ASTRO digital mode interconnect calls are supported. Since the MRTI2000 telephone interconnect device requires an analog interface, a DIU must be incorporated. In most of the scenarios above there will already be a DIU as the analog/digital conversion point of the system for the console which is an analog device. The DIU also connects to the MRTI2000 completing the connection to the PSTN.

System example close-up: ASTRO voting operation

Figure 3.24 is a block diagram of a voting system with a comparator co-located with a console, and four wire lines to the RF sites. For simplicity, the fleet of field radios in this example consists merely of seven portable radios and four mobile radios. One repeater and three satellite receivers are required for total area coverage.

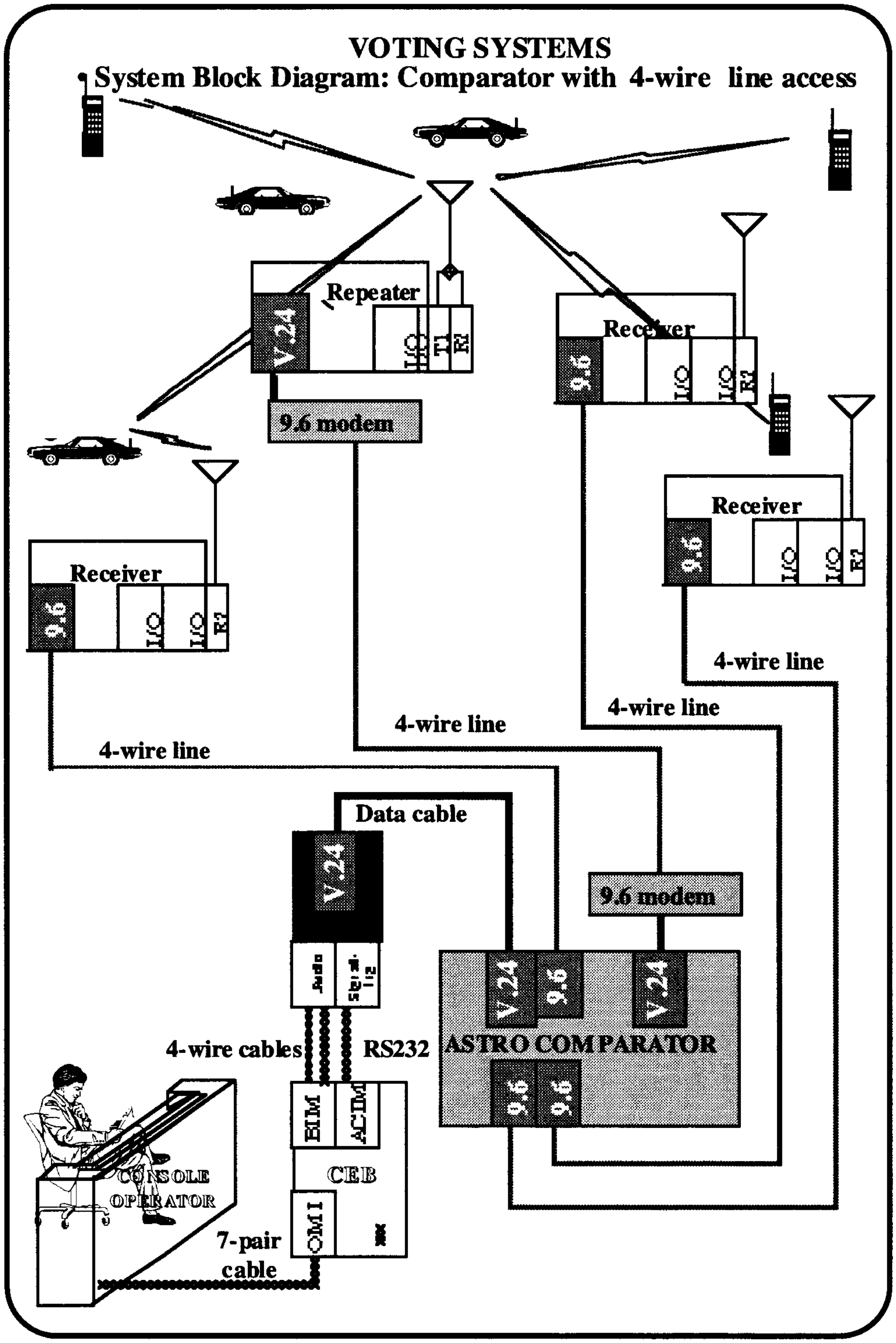

Figure 3.24 ASTRO Voting System

ASTRO only Simulcast

There are two primary reasons simulcast is used in land-mobile radio. The first is to improve coverage in a given area where exceptional path loss is encountered, such as is with high reliability in-building coverage in a city. The second reason for using simulcast is to extend the area of system level coverage to that greater than is available from a single site.

To provide high levels of audio quality, simulcast systems must provide highly matched and accurately timed signals to be transmitted from the various simulcast transmitter sites. The system uses precise (absolute) time information, which is obtained through the use of the Global Positioning System (GPS). The GPS signals are received continuously by special receivers that recover time information. This information is used in the ASTRO system to synchronize the various simulcast transmitters. The GPS based simulcast system greatly reduces the complexity of the equipment required to meet the timing criteria, and speeds installation as well.

With the ASTRO conventional simulcast system, telephone lines can be used to distribute signals and still obtain high quality simulcast. This is because the ASTRO simulcast system is immune to frequency response and delay variation in the distribution network. These impairments are mitigated by using digital distribution paths and timing standards to control path frequency response and delay.

All simulcast functionality is built into the comparator and base station. A GPS time/frequency source is required at each site to provide precise time and frequency reference information. The equipment used to synchronize an ASTRO simulcast system is the GPS disciplined time frequency standard. The standard is modular structured and provides buffered 5 MHz outputs and 1 pulse per second (PPS) signal on the rear back panel. All models include a GPS Receiver with antenna and connecting cable. Several models also include a back-up crystal and automatic switch over.

System example close-up: ASTRO only Simulcast operation

This system release supports multiple transmitters, from two (2) to fifteen (15), transmitting the same signal on the same RF frequency such that their coverage areas overlap. The number of transmitters can be up to sixteen (16) when no DIU is connected to the system. A maximum of one DIU can be connected to each ASTRO-TAC 3000™ Comparator.

The simulcast system supports ASTRO (digital) operation only (no analog simulcast operation). Simulcast operation supports both digital wide pulse (25 kHz) and digital narrow pulse (12.5 kHz) operation.

The ASTRO only Simulcast system configuration supports all ASTRO voice and ASTRO signaling capabilities supported by standalone and voting configurations unless otherwise specified.

This system configuration also supports telephone interconnect. Only ASTRO mode interconnect calls are supported. Since the MRTI2000 telephone interconnect device requires an analog interface, a DIU must be incorporated.

In most of the scenarios above there will already be a DIU as the analog/digital conversion point of the system for the console which is an analog device. The DIU connects to the MRTI2000 completing the connection to the PSTN.

The ASTRO simulcast system transmits 9.6 Kbps of information over the wireline. Three different types of link connections can be utilized: internal ASTRO modems, external CCITT V.32 modems or digital multiplex with sub-rate data cards. When using external modems or digital multiplex, the V.24 interface must be used on all boxes within the system, i.e. comparator, base stations and DIU. Mixed configuration, ASTRO modems and V.24 interface is allowed on the ASTRO-TAC 3000.

When using external modems or digital multiplex, the link to the co-located station must go through the same kind of links as the remote sites. Use back to back modems (or back to back multiplex). The reason for this is the time delay difference through the modems compared to the direct V.24 cable connection. The ASTRO-TAC 3000 is sensitive to the time delays in the receive path and can not deal with signal delay differences larger than 100 ms.

Figure 3.25 is a block diagram of an ASTRO only simulcast system with a comparator co-located with a console, four wire lines to the RF sites and using ASTRO modems or V.24 for link interfaces. For simplicity, the fleet of field radios in this example consists merely of seven portable radios and four mobile radios. Four repeaters are shown for total area simulcast coverage. Figure 3.26 is a block diagram of an ASTRO only simulcast system using the V.24 link interface and external modems.

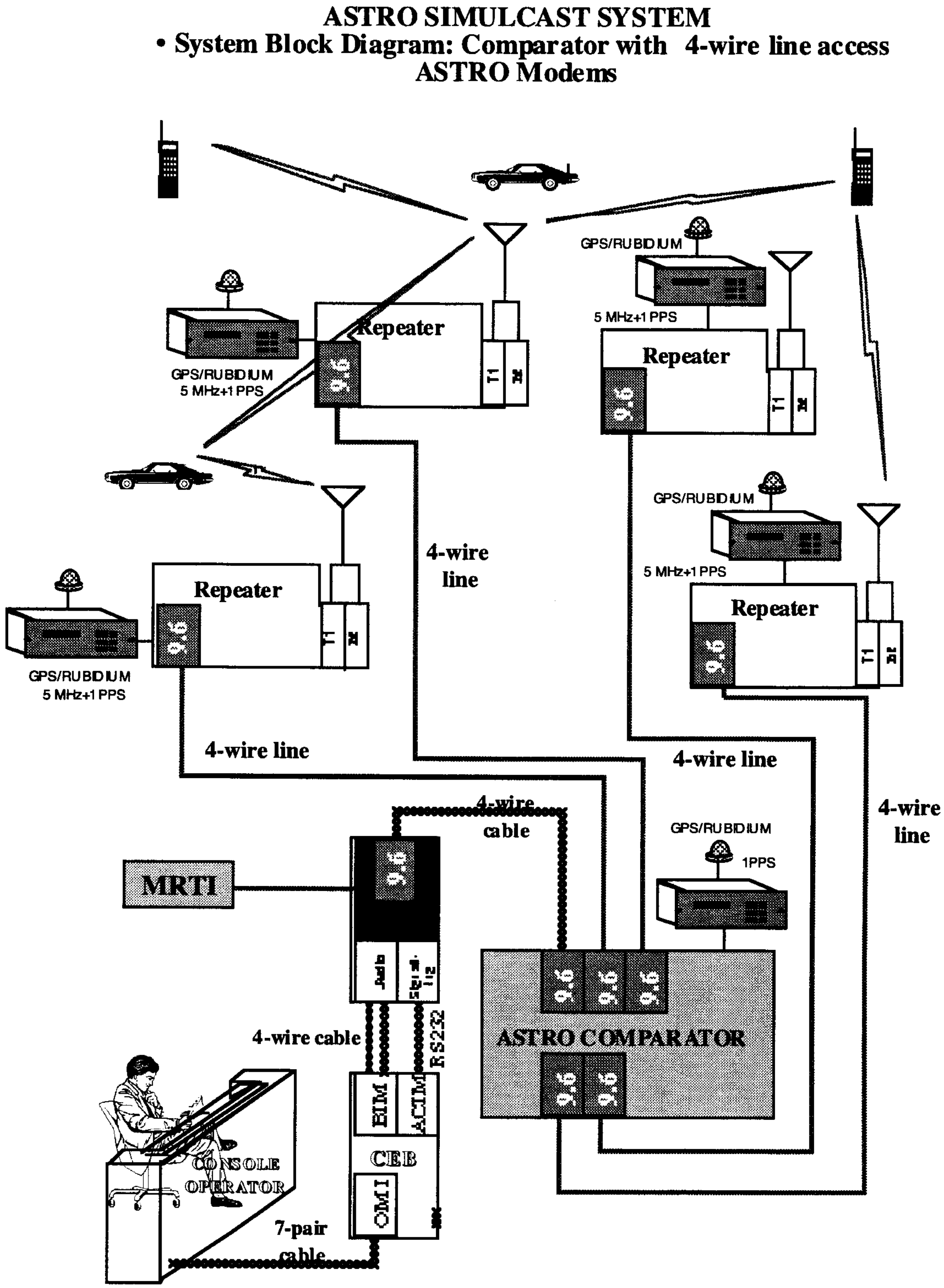

Figure 3.25 ASTRO only Simulcast system with internal ASTRO modems

ASTRO SIMULCAST SYSTEM
• System Block Diagram: Comparator with 4-wire line access External Modems

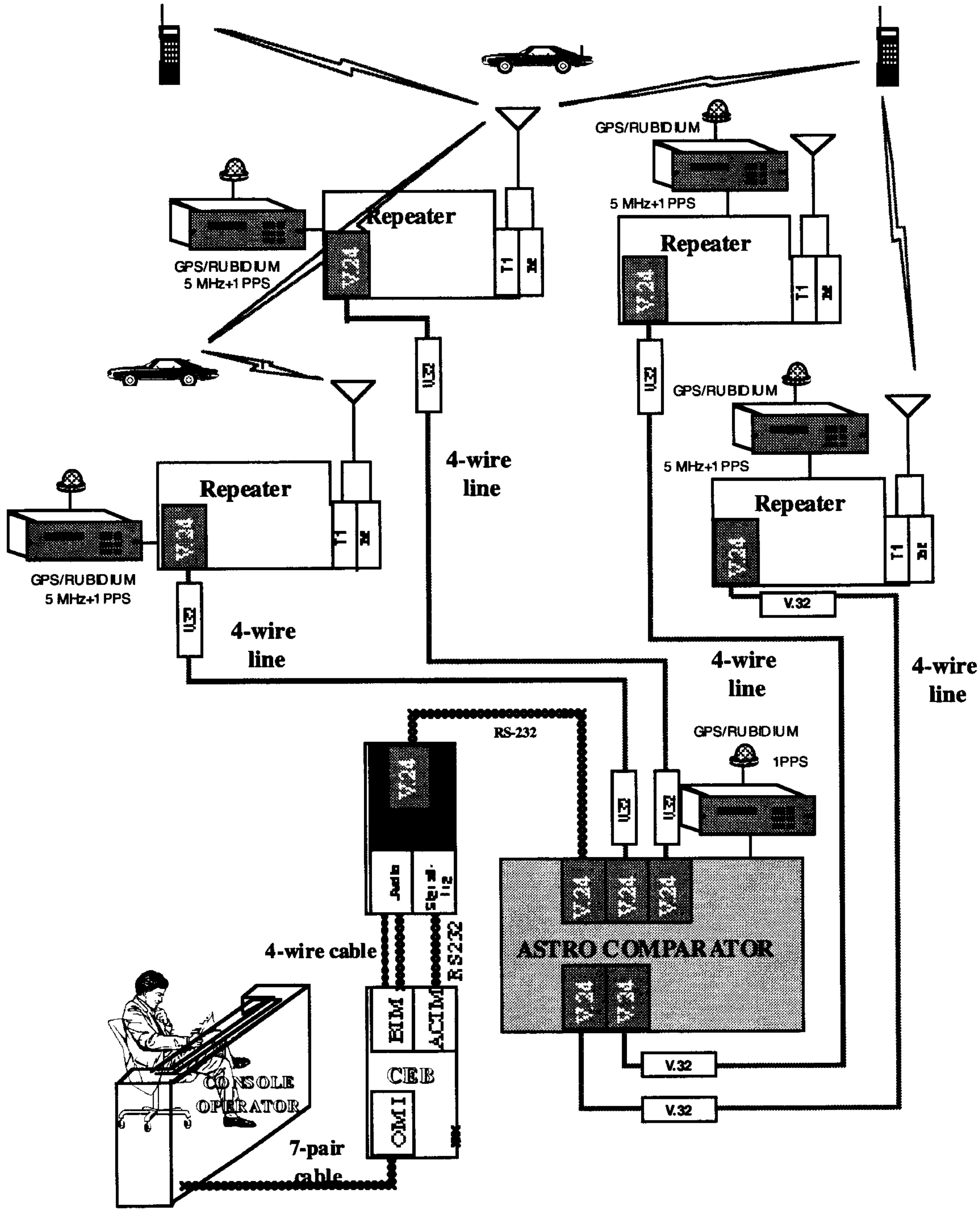

Figure 3.26 ASTRO only Simulcast system with V.24 link interface and external modems

Key Elements

The key elements in the pre-sale design of a wide area system are as follows:

Proper selection of RF infrastructure devices: To transparently pass ASTRO signals, all of the standalone repeaters are either the QUANTAR or QUANTRO ASTRO station. The satellite receivers must either be the QUANTAR Satellite Receiver or the ASTRO-TAC Receiver.

Proper selection and equipping of the comparator: To vote on ASTRO signals, the comparator is an ASTRO-TAC 3000 Comparator. One wire line card must be ordered for every two I/O ports required to connect the console and all of the RF sites. In ASTRO only simulcast systems a GPS time/frequency source is required at each site to provide precise time and frequency reference information to the station/repeaters and ASTRO-TAC 3000 Comparator.

NOTE: If the system were a multi-channel system, a separate comparator would be required for each channel.

Proper selection of field radios: To transmit and receive ASTRO signals, all of the subscriber units are ASTRO Digital SABERs, ASTRO Digital XTS 3000's or ASTRO Digital SPECTRAs. The customer selects the appropriate mix of ASTRO products to meet the unique requirements of his system.

The console voice and control interface: A Digital Interface Unit (DIU) is allocated to perform IMBE A/D and D/A signal conversion for voice messages and to translate console sequences into ASTRO station digital commands.

NOTE: If the system were a multi-channel system, a separate DIU would be required for each channel.

Modems to pass high speed digital signals on wirelines: High speed ASTRO signals cannot pass down narrowband wire line paths without modification. In order to pass ASTRO signals on the 4 kHz leased telephone lines and local wirelines used in this system, 9.6 Kbps modems are required in the stations, in the comparator, and in the DIU. For ASTRO digital only operation V.24 link interfaces may be used in the stations and DIUs. When using external modems or digital multiplex, the link between the comparator and the co-located station must go through the same kind of links as the remote sites, i.e. you must use back to back modems (or back to back multiplex). The reason for this is the time delay difference through the modems compared to the direct V.24 cable connection. The ASTRO-TAC 3000 is sensitive to the time delays in the receive path and can not deal with signal delay differences larger than 100 ms.

The V.24 termination requires an external modem or multiplex. The external modem must be set up for 9.6 Kbps synchronous operation and must provide an error rate not greater than 0.000001. The only certified modems are UDS V.3225 modems.

The console embedded signaling interface: To make use of ASTRO embedded signaling features, the selected console is a CENTRACOM Gold Series.

To simplify the technology needed to transfer embedded signaling information between the DIU and the console, the DIU is co-located with the CEB.

SECTION 3. INTEGRATED VOICE & DATA SYSTEMS

This section assists Motorola field personnel in understanding and implementing ASTRO 25 Conventional Integrated Voice and Data systems. These sections discuss available ASTRO data operation, the products and system configurations, and the interactions between data and voice on a radio channel. ASTRO voice operation is discussed only to the extent necessary to explain related data concepts and data/voice interactions.

Organization

This chapter is organized into the following sections:

Overview

Features

Capabilities

Requirements

Components

Topologies

Overview

This section overviews the ASTRO 25 Integrated Voice and Data system and includes a presentation of the seven essential elements of this ASTRO system solution.

This section focuses on ASTRO data topics, and includes information about ASTRO voice operation when necessary to clarify the integrated operation of data and voice.

ASTRO 25 Integrated System

The ASTRO 25 Integrated Voice and Data System (Figure 4.1) enables data messages to be exchanged between mobile data terminals and a central computer using radio frequency (RF) or wireless communications. The data messages share radio channel time with voice messages.

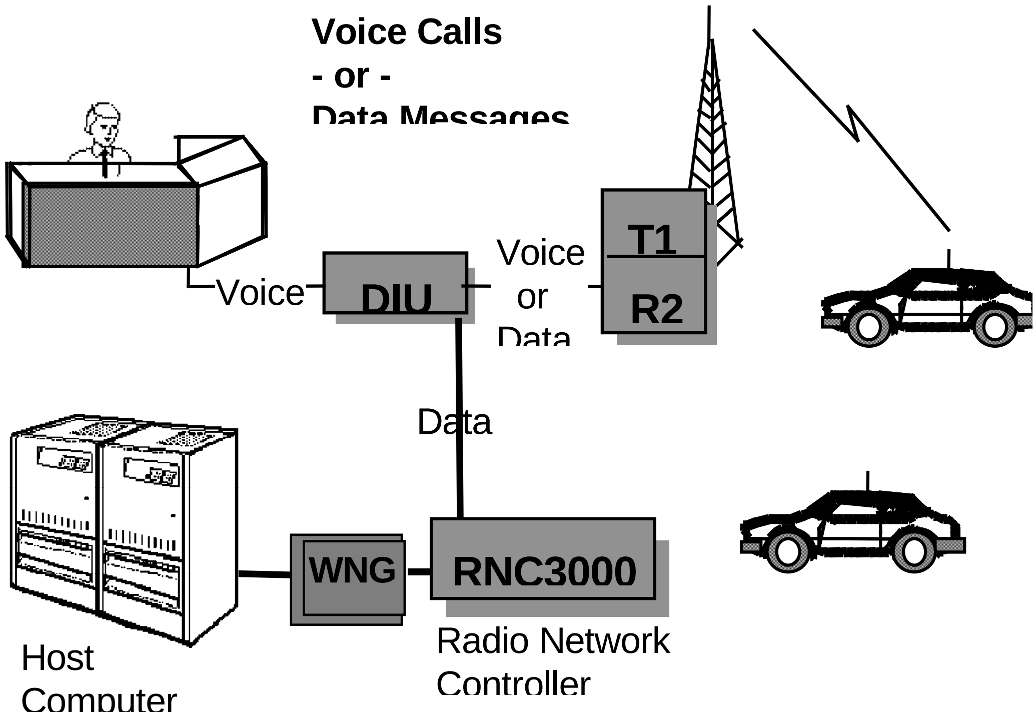

Figure 4.1 Single Site ASTRO 25 Integrated Voice and Data System

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Project 25 Data Interfaces and Protocols

APCO Project 25 specifications have been written to cover both packet and circuit data systems, data communications between radio terminals and fixed networks, and from radio terminal to radio terminal either directly or through a repeater. The ASTRO Conventional Integrated Voice and Data System provides packet data, radio terminal to fixed network (FNE) and FNE to radio terminal only communications.

The Project 25 specification for the Air Interface is called the "Um" interface or Common Air Interface (CAI). The "Ed" interface is the Project 25 specification for the RNC to Host interface or more generally for what the "RF System Gateway" must provide to a fixed data network. The "A" interface is the Project 25 specification for the Mobile radio to Terminal. Anything labeled CAI data or Um, Ed, or A interface compliant must comply with the relevant Project 25 specification. All specifications for the Project 25 "open" interfaces must be published, public information so that multiple vendors can bid on "open" specifications. This includes physical media, transmission and recovery technologies, software protocols, and data formats.

In this System Planner the A, Um and Ed interfaces (Project 25 open interfaces) will be referred to as the terminal, air and host interfaces, respectively. All other interfaces will use Motorola proprietary protocols.

Why Integrated Voice and Data

Data communications provides a means of extending an organization's wireline computer system and its associated data files to people in the field. Data communications can provide unique applications that include:

Database inquiry and update
Data entry
Status reporting
Messaging
Computer-aided dispatch
Report writing

The ASTRO 25 system provides an RF pipe or "bearer service" for the data application; it does not provide the application itself. Most customers utilize third party developers to provide applications software for the host and mobile terminal ends of the system. Motorola offers a wide variety of application support through our RadioWare Software Alliance Partner Program. A description of the possible applications listed above is shown below in order to give you a better idea of how customers may choose to utilize their ASTRO Voice and Data System.

Database Inquiry and Update

One of the key capabilities of an integrated voice and data system is database inquiry and update. Field personnel can directly access centralized computer files in order to obtain information without involving the dispatcher. Specific examples of database inquiry and update include:

- A police officer can check license plates and possible criminal records at a traffic stop, making his or her job faster, easier and safer.
- Service personnel can check customer and product databases to determine if a product is under warranty and whether or not necessary parts are available. After completing the service, databases can be updated from the field to reflect the work performed and any charges incurred.

Data Entry

Using an integrated voice and data system allows field personnel to enter data directly into a main computer system. Field personnel can create or update information directly through the mobile or portable data terminal. This reduces delays typically associated with office paperwork and eliminates the need for duplicate data entry, resulting in reduced paperwork for everyone, and improved accuracy since there are fewer opportunities for data entry and transcription errors.

Status Reporting

Status reporting applications reduce the need for typical status updates such as "en route", or "message acknowledged". Such status updates are simplified through the user of standard keys on the mobile data terminal. Sending the status update with the touch of a single key takes a fraction of the time it takes to send a voice transmission. Some examples of status reporting applications include:

- A police officer can respond to a call simply by pressing an "en route" status key on the mobile terminal. This allows a faster response time to an emergency situation.
- Field service personnel can inform the dispatcher that they are at a customer location by pressing an "at site" status key on the mobile terminal.

In addition to making it easier and faster for field personnel to provide status information to the dispatcher, an automatic display of field unit status allows dispatchers and supervisors to keep track of in-service units. This simplifies selecting units for assignment.

Messaging Applications

Messaging applications provide the capability of entering a free form text message into the computer system or data terminal and then sending the messages at the touch of a key. Sending the message takes a fraction of the time it takes to send the same message by voice.

Other advantages of using a messaging applications rather than voice include:

- All of the details of the message are transmitted accurately.
- The display of the message on the data terminal or console reduces the possibility of a misunderstood message.
- Messages are also stored on the data terminal; they can be recalled at a later time to check the information.
- Messages can be received and stored while the user is away from the mobile.
- Messages can be sent to multiple field personnel at the same time with the assurance that they will all receive the same message.

Computer-aided Dispatch (CAD

A Computer-Aided Dispatch (CAD) application is greatly enhanced when combines with mobile data communications. Because the mobile data terminals can be interfaced with the CAD system, the effectiveness of the CAD system is maximized to allow fast, efficient, accurate, and private dispatching.

For example:

- In a public safety system, this means that dispatcher workload and stress can be significantly reduced. Due to the streamlined dispatch process, departments can handle an increase in the number of requests for aid with the same number of dispatch positions.
- In an industrial, transportation, or field service environment, all service calls are immediately transferred to the dispatch computer where they are sorted according to type and priority. The system recommends which unit is the most suitable for the assignment, allowing the dispatcher to make the final decision.
- The dispatcher in CAD applications is assisted by computer screens showing the status of the service personnel and the work in progress. At the touch of a key, the work order is instantly dispatched to the appropriate field person's mobile or portable data terminal.

Report Writing

Report writing applications allow users to complete certain reports directly on data terminal and send them immediately to the host computer. Information obtained in these applications is more accurate due to reduced handling and transcription of the reports. The clerical effort in obtaining the information is also minimized. For example:

- In a public safety environment, records management is more efficient because the computer files are updated as soon as the field person transmits the report.
- In an industrial environment, field personnel receive job assignments in an electronic format. When the job is done, the field person enters a job completion report directly into the data terminal.

Easy-to-use, fill-in-the-blank forms can be custom designed for each application. Once completed by the data terminal user, the reports are transmitted to the host computer system when the relevant files are immediately updated.

Seven Essential Elements of Integrated Voice and Data

Seven elements used to identify issues that impact ASTRO data system design as shown in Figure 4.2.

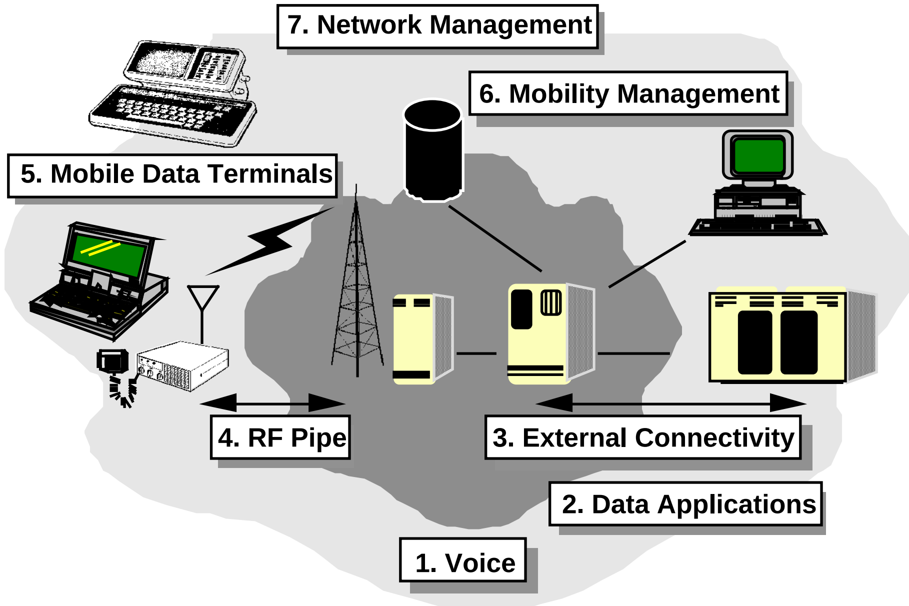


Figure 4.2: Seven Essential Elements of ASTRO 25 Integrated Voice and Data

1. **Voice Communications** - the ASTRO system provides voice dispatch and unit-to-unit voice communications service.
2. **Data Applications** - the ASTRO system enables the use of data communications applications that are separately available or may be developed through the Motorola RadioWare organization or by third party developers.
3. **External Connectivity** - the ASTRO system provides a link between itself and a customer's host computer system where the data application resides.
4. **RF Pipe** - the ASTRO system includes the communications characteristics of the radio channel, the two-way radio system equipment that interfaces to the channel and to the radio system's interconnecting media.
5. **Mobile Data Terminals** - the ASTRO mobile radio provides a hardware and software interface for mobile data terminals.
6. **Mobility Management** – allows the system to maintain a record of the location (by fixed station site) of each mobile unit, efficiently directing host-initiated data messages.
7. **Network Management** - assists in monitoring and maintaining system service by providing statistics on data radio system usage.

Integrated Voice and Data (IV&D) Features

ASTRO Features and the Seven Essential Elements

Table 4.1 lists ASTRO 25 Integrated Voice & Data features organized with respect to the seven essential elements model.

Essential Elements	**ASTRO 25 Integrated Voice and Data System Features**
Voice	Supports voice traffic; provides a method for contention management between voice and data traffic
Data Applications	• *Can be developed by RadioWare, Alliance Program Partners, or Customers* Database Inquiry Messaging Status Update Report Writing • Interoperable Voice Signaling Features D*eveloper's Tools* MagicPipe™ Wireless CommStack API software and documentation for mobile terminals; host interface documentation for application development.
External Connectivity	• IP (Internet Protocol) bearer service: supports end-to-end connectivity to IP-based applications in the mobile terminals and on the wireline network, • Subscriber : RS-232 with SLIP driver interface • Terminal: MagicPipe™ CommStack API • Host End : IP over Ethernet • (Optional) FLM (Formatted Logical Messaging support for legacy host application support. This option is not compatible with the IP bearer service.
RF Pipe	*Topology*: • Single Site • Multiple Single Site • Voted, Single Transmitter, Multiple Receiver • Simulcast/Sub-Site Steered – Simulcasted voice with site steered data *Infrastructure Products*: • RNC3000 Radio Network Controller • Wireless Network Gateway (WNG) • ASTRO Digital Interface Unit (DIU) • ASTRO-TAC 3000 Comparator • QUANTAR/QUANTRO Stations (ASTRO Repeater Configuration)
Subscriber Radios, Terminal Devices	*Subscriber Products*: • ASTRO Spectra Mobile • MW-520 Mobile Workstation • Forté™ Wireless Commpad • Ruggedized, Third-Party Laptop Computers
Mobility Management	Intra-system manual mobility
Network Management	Basic Statistics Management from RNC3000 console

Table 4.1 - Feature Summary based on the Seven Essential Elements

IV&D System Capabilities

This section provides additional detail on the capabilities of the ASTRO 25 Integrated Voice and Data system using the seven essential elements model.

Key Concepts	Digital voice and data on the same ASTRO channels -Cost effective infrastructure -One mobile radio does both voice and data Mobile subscriber units -ASTRO Spectra mobiles with integrated modems -Voice has priority over data Data coverage comparable to voice -Trellis coding -Selective ARQ Digital Sense Multiple Access (DSMA) technology -"Busy bits" avoid collisions between voice and data and between data messages. They tell the system that the channel is in use
System Features	• Integrated Voice and Data • Full duplex infrastructure operation • Digital Project 25 Common Air Interface (CAI) data formats • Radio to fixed network (Host) data configuration • Project 25 End-to-end IP (Internet Protocol) Service • ASTRO FLM (Formatted Logical Messaging) to Host • Connectivity • Manual mobility • Conventional data alongside trunking • Voice has priority over data • Applications Developer's Tools
Subscriber	• Data Mode Delete (for channel scan) • **SLIP** interface on ASTRO SPECTRA mobile
Products	**Infrastructure** • ASTRO QUANTAR/QUANTRO Repeater Stations • RNC3000 Radio Network Controller • Wireless Network Gateway (WNG) • ASTRO DIU (Digital Interface Unit) • ASTRO-TAC 3000 Comparator • CENTRACOM Gold Series console **Subscriber** • ASTRO Spectra Mobile • MW-520 Mobile Workstation • Forté™ Wireless Commpad • Ruggedized, Third-Party Laptop Computers
Frequency Band	• VHF, UHF, 806, 821 MHz bands. • 12.5/20/25/30 kHz Channel bandwidths
Topology	• Single Site • Multiple Single Site • Voted - Single Transmitter, Multiple Receiver • Multicast • Simulcast/Sub-Site Steered - Simulcasted voice with site steered data

Table 4.2 - ASTRO IV&D Capabilities Summary

Element 1 - Voice

The purpose in discussing voice traffic in the data section of the systems planner is to ensure that all elements of voice radio system usage are identified, and their compatibility with, and affect on, ASTRO data operation are also identified. The most important of these elements is ***contention*** for the radio channel between voice and data messages.

The greater load on a radio system's message handling capacity will occur on a system's talk-in frequency. ASTRO 25 Integrated Voice and Data systems are required to use full duplex base stations for every fixed site base station unit, primarily to allow messages to be processed on the outbound station frequency and on the inbound station frequency simultaneously.

The concept used in contention management in an ASTRO 25 Integrated Voice and Data system is that ASTRO voice traffic is granted priority over data traffic. Two scenarios can be described to illustrate this principle:

- The mobile unit will delay a data transmission if it detects DSMA "busy bits" on the outbound transmitter frequency indicating that the inbound frequency is in use, by an ASTRO digital signal – either voice, or data. DSMA will be explained later in this subsection.
- The mobile unit will delay a data transmission if it senses a squelch open condition resulting from the outbound frequency's use of analog voice or analog signaling

S-DSMA (Slotted Digital Sense Multiple Access) is a technique that uses certain bits from the ASTRO digital signal protocol to provide an indication on the outbound frequency of the inbound frequency's status - either the inbound frequency is receiving a message (i.e. is "busy" - hence the term "busy bits") or the inbound frequency is idle:

- If the inbound transmissions from a mobile unit are ASTRO digital voice the outbound station frequency will repeat the voice transmission, and set the busy bits to indicate that the inbound channel is occupied.
- If the inbound transmission is ASTRO data, the station will transmit an "information idle" digital signal with the busy bits set to indicate that the inbound channel is occupied.

A mobile radio unit will not delay an inbound voice transmission in either analog or digital mode unless the mobile voice PTT occurs *while* that mobile is transmitting a data packet. Should that happen, the mobile will finish the packet transmission first.

Similarly, from the fixed end of the system, the ASTRO DIU will delay data messages outbound from the host if it is occupied with voice traffic from the console. Console outbound voice messages will also preempt outbound data messages, once the data packet in process has been sent.

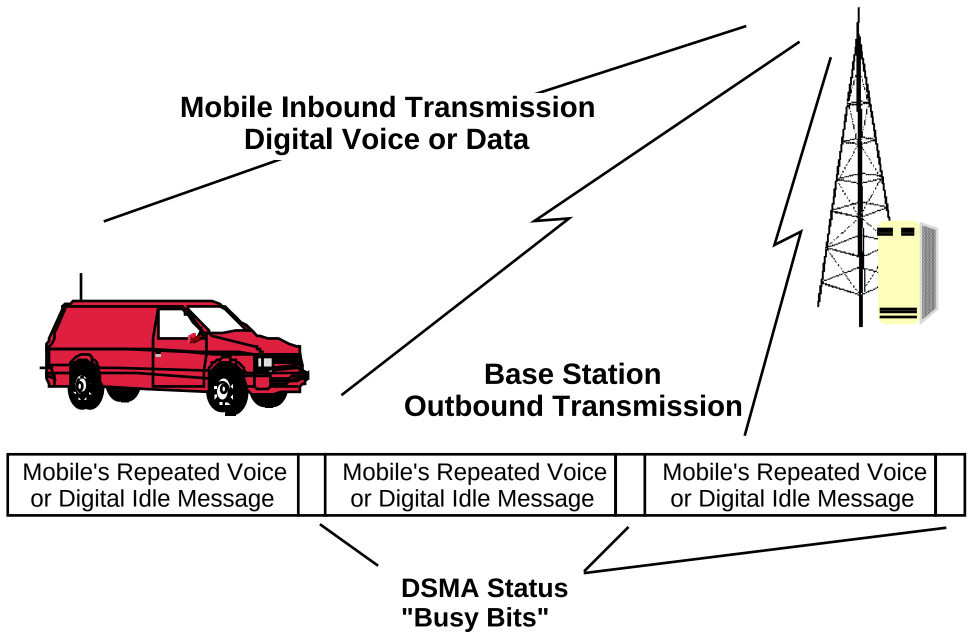


Figure 4.3 - Digital Sense Multiple Access ("Busy Bits") Operation

Busy bits are inserted into the outbound channel and read by listening ASTRO mobiles at defined times within the ASTRO frames (Figure 4.3). The mobile units use the busy bit information to discipline their access to the inbound frequency for sending data messages. Since the busy bits occur at predetermined times within the ASTRO digital signal frame, they can be used as an efficient tool for channel access management control.

Analog message traffic does not provide as effective a channel access management situation as does digital message traffic. Analog traffic (voice, tones, MDC-1200 signaling, etc.) on a repeater station's outbound frequency may not be heard by mobile units, and since those mobiles can use only squelch status to discipline access to the radio channel, the incidence of message collisions may be quite high.

It is recommended that any *ASTRO 25 Integrated* Voice and Data system use ASTRO digital transmissions only, as digital transmissions provide the most effective channel access management operation.

Element 2 - Data Applications

This subsection discusses ASTRO data applications capability, developer's tools, and Motorola's RadioWare organization.

ASTRO Application Capability

The ASTRO system is designed to support the majority of packet data applications typical for two-way radio use, but is also intended for customers operating voice and data using the same mobile radio and infrastructure. Some of the common applications which are suited for the ASTRO system are described below. Applications for *ASTRO 25 Integrated* Voice and Data systems can be sourced through Motorola RadioWare™ or third party developers.

Computer-aided dispatch: (CAD) is a common host application function. It involves the ranking, formatting and delivery of information required by field personnel to performing specific tasks. A dispatch typically includes event, address, and information for a specific individual, or groups of individuals in the field.

Database Inquiry and Update: Database inquiry is a field-initiated request for information held in one or more centralized databases. Database update is the entry of new or modified information into a database held within one or more host computer systems.

Status Reporting: Status reporting is a field initiated notification of the user’s status to a host application. This typically involves the communication of indexed (canned) messages that have been assigned special meanings for the terminal user and host application. Common examples of status messages are:

- Enroute Assigned
- On-site Available

NOTE: This operation can potentially mix two different status/message reporting systems. Status messages that originate from the mobile data terminal application are sent to the host computer/CAD system, and are not sent to the voice dispatch console operator. Likewise, status messages originated from the radio (ASTRO voice frame messages) go to the console and cannot be sent to the host computer/CAD system.

User-to-User Messaging: The ASTRO system allows separate mobile users to exchange data messages with each other by sending the messages intended for each other through the fixed infrastructure network and using a host application to perform the message routing, similar to electronic mail. Direct mobile-to-mobile data messaging without any infrastructure interaction is not supported in ASTRO 25 Integrated Voice and Data systems.

RadioWare

RadioWare is Motorola's private market software application and service business that provides wireless system customer driven solutions. By aligning with premier software suppliers, RadioWare can offer software tools and applications integrated into software solutions that complement Motorola two-way radio communications systems.

RadioWare software solutions may include externally developed software applications provided by alliance partners, or internally developed solutions such as WaveSoft™ Fire. RadioWare may also provide software tools to provide a seamless interface between radio communication systems and data applications solutions, or integration services to support other phases of project implementation.

Application Development Environment

Customers usually employ third party developers to write applications to run on radio/data systems. The following applications development documentation and tools are needed to support that applications development:

Host Application Programmers Guide - This document describes the interface between the WNG (or the RNC3000 in FLM-based systems) and the customer's host computer network, and is used in developing host-side interfaces to RF network.

MagicPipe™ Wireless CommStack - This developer's tool kit includes the interface specifications required by developers to design communications applications for mobile computers on either IP or FLM-based systems..

Emergency Data Operations

Since voice takes priority in the system, emergency data messages generated by a data terminal are not recommended in ASTRO systems. ASTRO users should rely on mobile radio-originated ASTRO voice mode signaling to notify a dispatcher of an emergency condition.

Element 3 - External Connectivity

This subsection describes both the physical and logical connections used at the "ends" of the ASTRO 25 Integrated Voice and Data system, that is, between a radio and its connected data terminal, and the Wireless Network Gateway (WNG) connected to the customer's host computer network.

Radio Physical Connection

A Motorola Data Terminal or laptop computer must use a special cable to be connected to an ASTRO digital radio. The appropriate cable can be purchased with the radio as part of a data-ready option, or separately as an aftermarket kit.

Radio Logical Connection - MagicPipe™ Wireless CommStack

MagicPipe™ Wireless CommStack (MWCS) software runs on a computer operating with Windows™ operating system that is connected to an ASTRO radio. MWCS handles the communications management tasks between the radio and the data terminal that supports mobile data applications. MWCS also provides application developers with an industry standard programming interface (WinSock™) that frees them from having to know lower layer protocol details.

Every data terminal connected to an ASTRO radio requires a license for MWCS software. MWCS is available as a separate line item for installation into laptop computers used in mobile data applications.

Application developers can purchase a tool kit that includes the documentation and software tools necessary to integrate MWCS software into their applications.

Radio Control Protocol (RCP) Messaging

Radio Control Protocol (RCP) messages support control communications between the ASTRO radios and the Data Terminal. There are basic RCP messages and Enhanced RCP messages. Basic RCP messages comply with Project 25 RCP requirements. Basic RCP is standard for ASTRO voice and data and is required to support Rx/Tx (Receive/ Transmit) of the following type of message information.

- Get Information
- Information Response
- Unknown Command
- Radio Power Up
- Radio Not Registered
- Data Service Available/Not Available

Enhanced RCP is a purchased option or is available as a FLASHport upgrade. MWCS is required to enable Enhanced RCP features for customers and application providers. Enhanced RCP messages support unique, expanded Motorola functionality as follows.

- RF Acknowledgment Received
- Enable/Disable RF Ack Received
- Generic Successful Response (to Enable/Disable message)

Host Computer Physical Connection

In an IP-based system, the Wireless Network Gateway connects directly to the customer's wireline Local Area Network (LAN) using a 10 Base T Ethernet connection.

For FLM-based systems, the host computer must interface directly with the RNC3000 using an Ethernet, X.25 or asynchronous connection. The physical interface will vary depending upon the particular link protocol selected. See the RNC3000 Host Applications Programmer's Manual for more information about connection to an FLM-based host.

Host Computer Logical Connection

For ASTRO data, the ASTRO 25 Integrated Voice and Data system uses the standard's Internet Protocol (IP). The WNG acts as the IP router for both inbound and outbound data messages. It holds the database of mobile terminals authorized to use the system. And it links mobile terminal IP addresses and mobile CAI (common air interface) addresses

For FLM-based systems, a host computer must connect directly to the RNC3000 and be knowledgeable of the specialized FLM protocol. In this configuration, the WNG is not used. The ASTRO system's use of FLM is similar to its use in RD-LAP systems. Existing applications written for RD-LAP can be modified to run on ASTRO 25 Integrated Voice and Data systems. Note, however, that FLM is *not recommended* for **new** ASTRO 25 Integrated voice and data systems. FLM is not a Project 25 compliant interface, nor is it as flexible as an IP interface in routing or servicing connections to more than one host. See the RNC3000 Host Applications Programmer's Manual for more information about connection to an FLM-based host.

Element 4 - ASTRO RF-PIPE

This subsection focuses on the system configurations which support integrated voice and data and the infrastructure components required in the ASTRO conventional system.

System Configurations Supporting Data

The radio system configurations supporting ASTRO 25 Integrated Voice and Data include single site systems, multiple single site systems, receiver voting systems, multicast systems, and simulcast systems. Combinations of these site configurations can be networked to a single RNC3000 to provide wide area integrated voice and data coverage.

In each of these configurations, the radio system base stations are configured for full duplex operation - voice messages may be in-cabinet repeated, and sent down the wireline path to the DIU and dispatch console. Data messages are not in-cabinet repeated, but are sent down the same path to the DIU, from which they are passed on to the RNC3000, and then to their host destination.

ASTRO Voice systems integrating data must use repeaters with wireline control or voting/simulcast configurations with repeater and wireline control.

The stations operate full duplex on the wireline. This allows separate data calls to occur simultaneously on the inbound and outbound frequencies. Data call management will be discussed further in a section on the RNC3000 Radio Network Controller.

IP Implementation Across Interfaces

FLM is a Motorola protocol for sending and receiving data messages and providing control of the RF network via customer host computers. Aside from the use of FLM, previous versions of ASTRO were almost fully Project 25 compliant. The only missing factor was the ability to send end-to-end Internet Protocol (IP) datagrams. The ASTRO 25 Integrated Voice and Data system now offers the IP connectivity at the radio-to-terminal and RNC-to-host interfaces. IP is added to the RNC-Host interface by the addition of the Wireless Network Gateway (WNG). WNG provides an Ethernet connection to IP networks. FLM is still used in this configuration as a link layer protocol between the RNC and the WNG. All external interfaces use IP messaging . The system flow across interfaces follows.

- The WNG routes IP messages from the wireline network to the RF system.
- The WNG maps the Layer 3 address of the mobile terminal destination to the Layer 2 address of the terminal’s mobile radio.
- The WNG uses the FLM protocol to transfer the data message to the RNC3000.
- The RNC translates FLM packets/command information into ASTRO

protocol and sends them to the DIU

- The DIU forwards ASTRO Infrastructure Signaling (AIS) Infrastructure Control Word (ICW) to the base station
- The Base station removes AIS / ICW and transmits CAI formatted message
- The target radio receives CAI formatted message and translates to IP/UDP packets
- Radio sends IP/UDP packets to terminal
- Terminal responds in IP/UDP. Supports RCP/ICMP messaging (the counterpart to FLM at RNC – Host interface).

ASTRO 25 Integrated Data Requirements

This section focuses on the issues important in analyzing and understanding customer data system requirements. The seven essential elements model is used to identify issues which impact ASTRO data system design.

Element 1 - Voice

Integrating voice and data on the same channel brings several efficiencies. These include:

- Use of one RF channel for both voice and data
- Use of one system infrastructure for both voice and data
- Use of one subscriber to send and retrieve both voice and data messages over the air

Integrating voice and data on the same channel also brings several points to consider. These include the following:

- Traffic loading
- Customer application requirements
- Contention of voice and data

Lightly loaded voice channels represent an excellent opportunity for a successful integration of voice and data on a single channel. Customers with very busy voice channels may choose to utilize data and voice on separate channels. ASTRO still would afford the ability to use only one system of mobiles.

The data portion of this planner will deal only with analog and ASTRO digital voice. While ASTRO mobile and portable radios retain capability for 12 kb SECURENET operation, SECURENET is not supported in an infrastructure providing Integrated Voice and Data operation.

Element 2 - Applications

Understanding the customer's applications requirements are key to determining if an ASTRO 25 Integrated Voice and Data solution is appropriate.

The ASTRO system provides a RF pipe or "bearer" for the data application; it does not provide the application itself. Most customers utilize third party developers to provide applications software for the host and mobile terminal ends of the system. Motorola offers a wide variety of application support through our RadioWare Software Alliance Partner Program.

Table 4.3 lists data applications typical of private market system users. Most of these applications require relatively short data exchanges between host and mobile terminal.

Public Safety **(Police, Fire, EMS)** CAD (Computer Aided Dispatch) Incident Reporting/Dispatch Multi-Agency Message Switches License Plate Inquiry Drivers License Vehicle Identification Numbers Wants & Warrants Stolen Articles Parking Violations & Fines (Scofflaws)	**Utility** **(Electric, Gas, Telephone)** Field Service Work Order Dispatching Trouble Management Data Collection CIS (Customer Information Systems) Database Inquiry
Courier Service Dispatch Routing Pickup & Delivery Package Status Database Inquiry Record Management	**Federal Government** Hazardous Materials Law Enforcement Encryption Logistics Warehousing Distribution

Table 4.3 - Data Applications Summary

Element 3 - External Connectivity

This subsection discusses connection of the radio system to the customer's host computer system.

Host Connectivity Requirements

The customer’s host connectivity requirements determine compatibility with the network infrastructure, or the need for additions or modifications to the host equipment. To analyze the requirements, the host computer platform model and its interface capabilities must be known.

For an ASTRO 25 Integrated Voice and Data system, the Wireless Network Gateway (WNG) provides the physical interface between the RF network and the host computer network . The WNG supports a single 10 Base T Ethernet link to the wireline system. To the wireline network, the WNG acts like an IP router that will forward IP traffic to and from mobile computers on the RF network.

The physical (wired) distance between host and WNG as well as the interconnecting means must also be considered. The network connections should impose no performance limitations on the radio/data system.

Host Application Requirements

The host application is the customer specific program that runs on the host computer. The host application is the source of all messages sent to mobile terminals and determines how all mobile terminal initiated messages are processed. More than one application and/or host can use the same RF data system, particularly if all hosts communicate using IP-based messaging. In situations where access to multiple host computers is necessary over a variety of different protocol links, a customer may require a message switch.

Host application functional requirements are determined by working with the customer. A needs analysis is usually performed by the application vendor through direct observation, operator interviews, and interface with the customer's information systems staff. Each transaction to and from mobile terminals is outlined as a series of steps. At each step, the developer determines how the information is either added to, acted upon, or archived. Messaging requirements (length, content, and anticipated load, etc.) should fall out from this phase of systems analysis. Data message lengths and loading can then factor into analyses of both host processing and RF system capabilities.

Host Capacity Requirements

After messaging requirements are determined, it is important to assess their impact on the host computer. An analysis of the present use of the host processor can indicate if the host can support the additional load introduced by RF system users. The host must also support radio system application(s) in *real time*.

The host may also be supporting applications other than the RF data system. The impact of these other applications on the RF data system also should be assessed. For new host platforms, the total system user load must be considered in determining host capacity requirements.

The customer’s system analyst and host applications vendor should provide this analysis with assistance from Motorola's Advanced Products Team.

Element 4 - RF-Pipe

This subsection discusses the interaction of data system and radio system characteristics in determining system performance.

System Performance

System performance depends on efficient message delivery from the host application, the transaction response time, and the amount of voice traffic on the radio channel.

Host Message Lengths

Data message length is a key factor in response time in a two-way radio system. While applications for wireline terminals may be written without regard to message lengths, messages that exceed a specified length must be broken into smaller *packets* before they are transmitted over a radio channel in an ASTRO system. The payload (user data) limits for the ASTRO Internet Protocol (IP) (or Format Logical Messaging (FLM)) protocol data packets are 484 bytes outbound from host, and 456 bytes inbound from the mobile terminal.

Staying under the radio/data system's maximum message length may require application program modifications. However, experience gained in other radio/data applications indicates that both host and mobile originated messages are typically shorter than these limits.

Terminal Packet Data Transmission Flow and Addressing

Terminal data packets flow over several different interfaces within an ASTRO Conventional Integrated Voice and Data System. They flow on the interface between the terminal and the radio. They flow on the Air Interface between the radio and the stations. They flow on the ASTRO wireline interface between the station and the DIU. They flow on the ASTRO wireline interface between the DIU and the RNC. And they flow on the interface between the RNC and the WNG, and the WNG and the host computer network.

Digital voice and signaling are independent capabilities that co-exist on the same channels and wireline paths with ASTRO terminal packet data.

Inbound terminal data or mobile to Fixed Network (FNE) is delivered in either unconfirmed or confirmed (ACK required) packets. Outbound terminal data or FNE to radio / radio to FNE to radio, is also delivered in either unconfirmed or confirmed (ACK required) packets. Confirmed packets that are not acknowledged (ACK) will be repeated up to an RSS programmable number of times. The default in the RSS is three repeats.

Outbound terminal data packets contain addresses that are used for delivery to the correct target mobile computer. Addressing is done both at a Layer 3 (IP network and terminal device) level, and at a Layer 2 (RF network and radio/radio group level).

All radios in a system have a single IP address. Each mobile computer connected to a radio has a unique IP address. The single IP address for the radio is used to carry control information between it and the connected mobile computer. The computer's unique IP address identifies it as a unique message source or receiver in the network. Radios have one unique Logical Link ID (LLID) address for selective data delivery. This is a CAI Layer 2 address. Radios can also have up to eight group LLID addresses for group data delivery. These are CAI Layer 2 addresses.

Inbound terminal data packets are delivered to the RNC through Layer 2 CAI addressing and routing through the RF system. The RNC forwards the packets to the WNG, which routes them according to their IP address.

For an FLM-based system, the RNC forwards the packets directly to the FLM host rather than through a WNG.

Transaction Response Time

A "transaction" is the combination of a message transmission and its subsequent acknowledgment by the recipient of the message. Total transaction "response time" during average and peak system usage is important to both customer and applications developer.

Inbound transaction time is measured from the time the mobile initiates a "SEND" command until the RF infrastructure acknowledges the message. Outbound transaction time is measured from the time the WNG routes the IP datagram to the RF network until the mobile computer receives and acknowledges the message.

NOTE: These time measurements do ***not*** include application processing times; data application issues should be left to their developers. Motorola's focus is on performance of the two-way radio system that supports the customer's application. Two-way radio performance for data communications is discussed in later parts of this system planner section.

Customer Use of the System

Use of the system is determined by interviews with the customer and application programmers. The following factors should be considered:

- The functions of host applications
- The user transaction associated with each function
- Voice activity on the channel during peak and non-peak hours
- How often each transaction is performed by system users
- The frequency, number, and size of data messages to be delivered in each transaction.
- Users per square mile or "user density"

Number of Mobile Terminal Users

The number of mobile terminals must not exceed the registration capacity of the RNC3000. Since not all registered terminals are active at a given time, an estimate of the maximum number of active terminals must be made and combined with messaging requirements to determine the message throughput capacity required of the RF data system. The RNC3000 operator's manual provides further information.

Number of Voice Users

An estimation of voice activity during normal and peak hours must also be made in order to predict throughput performance. The ASTRO 25 Integrated Voice and Data system grants priority to voice traffic in situations where there is an identifiable and controllable contention situation. Data throughput will therefore be reduced by voice loading on the radio channel.

RF Coverage Requirements

A customer's radio system coverage requirements determine the selection and configuration of network infrastructure products. The ASTRO 25 Integrated Voice and Data system provides reliable data communications throughout the same areas where the system provides readily usable (i.e. Circuit Merit 3 or better) voice communications. However, there is a tradeoff between the desired RF coverage area for data, and the data throughput of the system. Extending the range of a system's operation will require more data message retries to successfully complete transactions, thus lowering throughput

Element 5 - Subscriber Radios and Terminal Devices

Customers may use the Motorola MW-520 Mobile Workstation, the Forté Wireless Commpad or selected third-party laptop computers. Either requires both radio system operating software as well as applications software. Both the usage environment and the customer's budget will determine this choice. Personalized laptop computers with sufficient capability to run mobile data applications are available. Contact the Motorola Advanced Product Team for the current status of Motorola approved third party computers.

ASTRO 25 Integrated Voice and Data operation is available on both the ASTRO Digital mobile and portable radio products.

Element 6 - Mobility Management

The ASTRO 25 Integrated Voice and Data system offers manual roaming between different radio sites. The RNC3000 Controller maintains a record of each terminal affiliated with it. If the radio system uses multiple base station sites, each site will have a separate I/O from the RNC3000. The RNC3000 will keep track of each mobile unit, and its I/O port "affiliation." The radio user must manually switch channels when roaming from the coverage of one site into another. Once the user has switched channels, the radio automatically affiliates with the RNC3000 using the new site.

Roaming among multiple RNCs is not supported in the ASTRO 25 Integrated Voice and Data system.
Voice and data systems using more than one repeater to cover broader geographic areas must deal with a mobile moving from the coverage area of one repeater to another. In voice–only conventional systems, users become accustomed to switching channels at appropriate locations. Data operation requires a stored record of radio locations in order to allow the host to reach a radio, either with acknowledgments, or host-initiated messages. Accordingly, any radio must *register* with an RNC3000 controller before it can send and receive data messages. Roaming is the term used to describe the movement of a radio from the coverage area of one site into that of another.

Registration Registration is a method to inform the fixed network when a data capable radio enters and exits a data capable mode of operation. The radio must first complete a registration process before data messages can be exchanged between terminal and host. Registration has no impact on voice operation.

A radio registers when the radio powers up in a data capable mode, changes modes into a data capable mode, completes a terminal connection, exits from a channel scan mode, exits the external keyloading mode (encryption operation), or exits the radio lock or terminal connection mode. A radio de-registers when it is powered-down, inhibited, placed in test mode, keyloaded, is channel scanning, or leaves a data capable mode.

A radio that is configured for data is always in data-disabled state (for terminal data messages only) until it executes a Registration Procedure and gets a Registration Response (Accepted) for the "Registration host". The WNG performs all registration tasks and becomes the "Registration Host" for the system. A database of radio ID's authorized for data must be entered and maintained on the WNG. This database will be used to accept or deny requests for registration sent inbound from radio/terminals.

The RNC 3000 also maintains a database of currently registered radios and the sites that they are affiliated with. The RNC also performs the Visited Location Register function in the ASTRO network. The WNG provides the Home Location Register functionality.

In FLM systems, the RNC 3000 performs the registration tasks and the customer's host acts as the "Registration Host". The customer's host must also provide the Home Location Register functionality.

Intra-RNC3000 Roaming Conventional two-way radio system users are accustomed to changing modes or channels when they move from the coverage area of one repeater to other.

To maintain continuity of the system's data operation, users must change operating mode or channel when they enter the coverage area of a different repeater. The mode change causes the radio to register again with the RNC3000, thus notifying it of the new location of the radio.

Inter-RNC3000 Roaming Roaming between different RNC3000s is not supported in the ASTRO 25 Integrated Voice and Data system.

Element 7 - Network Management

The ASTRO 25 Integrated Voice and Data system offers basic statistics viewing capability and configuration management through the RNC3000 or Wireless Network Gateway consoles (consoles are VT 100 terminals required for configuration and management of each of these components)..

Basic data system statistics and configuration management capability are offered via the RNC3000 console connection option to the RNC3000 Controller. The RNC3000 Host Application Programmer's Manual and Operations Manual provide additional details.

IV&D System Components

This subsection describes the unique infrastructure and subscriber products required to add data capability to an ASTRO two-way radio system. It also discusses any changes needed to the voice radio system components when adding data messaging.

Infrastructure Components

This subsection describes the unique infrastructure required to add data capability to an ASTRO system.

Wireless Network Gateway and RNC3000

The Wireless Network Gateway acts as an IP router between a host Local Area Network (LAN) and the ASTRO radio system. This gateway will allow, through the Project 25 IP, computer hosts and networks to interface with ASTRO systems.

The Wireless Network Gateway uses the IBM AIX® operating system running on a powerful Motorola RISC-based hardware platform.

The RNC3000 software runs on the embedded pSOS operating system. The Radio Network Controller XR12 hardware is based on a VME architecture using a Motorola 68030-based control processor, hard disk drive, and a configurable number of 68030-based I/O processors. It routes data messages and manages message traffic over the ASTRO radio system. The Radio Network Controller XR12 is available in a 12-slot chassis. The 12-slot chassis is expandable up to 64 QUANTAR base station links.

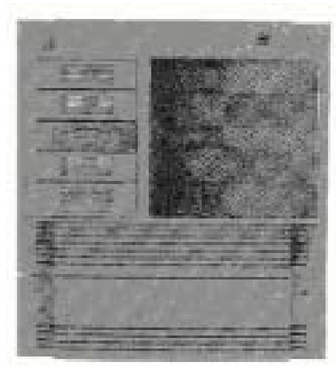


Figure 4.4 - RNC3000 Radio Network Controller

The RNC3000 (Figure 4.4) provides the following features:

Message Routing

The Wireless Network Gateway manages the routing of messages to and from the RF network. It uses Layer 3 IP addresses to route messages to the appropriate destination mobile terminals or wireline host computers.

The RNC3000 is responsible for managing messages between the WNG and radios. In an FLM system the RNC3000 manages messages between the customer's host computer and radios.

Outbound Message Routing

In the outbound direction (from the host computer to the mobile data terminal), the Wireless Network Gateway and the RNC3000 control transmission of outbound data messages through the ASTRO radio system. Outbound terminal data packets contain addresses that are used for delivery to the correct target radio. Addressing is done both at a Layer 3 (IP network and terminal device) level, and at a Layer 2 (RF network and radio/radio group level.

All radios in a system have a single IP address. Each terminal connected to a radio has a unique IP address. The single IP address for the radio is used to carry control information between it and the terminal it's connected to. The terminal's unique IP address identified it as a unique message source or receiver in the network.

Radios have one unique Logical Link ID (LLID) address for selective data delivery. This is a CAI Layer 2 address. Radios can also have up to 8 group

LLID addresses for group data delivery. These are CAI Layer 2 addresses. Group messages are always sent unconfirmed.

Individual outbound data messages can be either confirmed or unconfirmed. If the message is sent unconfirmed, the RNC3000 sends the message one time to the mobile terminal. No retries occur. If the user data message is sent confirmed, the RNC3000 requires an ACK from the radio acknowledging receipt of the message. If no ACK is received within four seconds, the RNC3000 will retry the data message up to a configurable number of times.

Inbound Message Routing

An Inbound terminal data or radio to Fixed Network (FNE) message is delivered in either unconfirmed or confirmed (ACK required) packets. Confirmed packets that are not acknowledged (ACK) will be repeated up to an RSS programmable number of times. The default in the RSS is three repeats.

Inbound terminal data packets are delivered to the RNC through Layer 2 CAI addressing and routing through the RF system. The RNC forwards the packets to the WNG, which in turn, routes them according to their IP address.

For an FLM system, the RNC forwards the packets directly to the FLM host.

The RNC3000 will return an acknowledgment message to the radio. If an acknowledgment is not received when required, the message will be retransmitted by the radio up to an RSS-configurable number of times. If delivery is unsuccessful**,** the terminal will notify the application program that the message was unsuccessful.

When a new mobile terminal registers, the registration host handles that registration.

Configuration and System Management

The RNC3000 is fully configurable through the RNC3000 console. The system operator can monitor limited system alarms and statistics from the RNC3000 console.

Subscriber Unit Management

The RNC3000 will add a mobile terminal into its database in response to a mobile terminal registration request and upon receiving an FLM registration acceptance message from the host. The RNC3000 will delete a mobile terminal from its database upon an RNC3000 console command, or an FLM registration host command.

Distance Between DIU and RNC	The DIU and the RNC3000 Data Controller must be co-located in an ASTRO 25 Integrated Voice and Data system. The connection is RS-232, and is subject to those same length restrictions.
Site Expansion Capability	The RNC3000 can support one station site or can be expanded to serve up to 64 sites.

Wireless Network Gateway (WNG

The Wireless Network Gateway (WNG) is a software platform designed to link wireline data networks to Motorola radio frequency (RF) networks The WNG provides Project 25 standard Internet Protocol (IP) routing between the end user's wireline network and the wireless subsystem. It provides the following services to wireless users:

- User registration
- Radio user authorization
- Unit-to-unit messaging
- Group messaging
- Outbound message queuing

The WNG also provides detailed statistics and alarm information to monitor operation and loading to support audit, diagnostic, and optimization activities that can be viewed directly via the Gateway.

The WNG utilizes the IBM AIX® operating system running on a powerful Motorola RISC-based hardware platform. This hardware and software combination supports up to 100,000 messages per hour and up to 12,000 register users.

DIU

The DIU, as a network element, performs hub-type switching functions. It switches inbound packet streams to one or more of these devices:

- a Console ACIM
- a RNC3000
- a Comparator Status / Control Module

As a hub it generates data packets to inform all attached network elements of the busy and in-use status of the outbound wire path to the RF network that they share.

The DIU's primary purpose is to act as the analog voice interface to the console and MRTI2000. The DIU performs conversion from analog to digital voice and digital to analog voice. As the server to these analog devices, the DIU must manage the flow of information between the packet network and the analog channels.

DIU and RNC3000 System Connections

The DIU provides the interface to the RNC3000 and through it, the host computer data connection to the ASTRO 25 system. The data interface to the RNC3000 requires a new communications board in the DIU and a new "W" adapter cable. The "W" adapter provides only the breakout connections - full length cabling must be supplied as part of the install. Newly-manufactured DIUs will include this communications board and the adapter cable. An upgrade kit is available for fielded DIUs.

The DIU provides a junction point for both voice and data signals in the system (Figure 4.5). For a system using mixed-mode voice operation (supporting both analog and ASTRO digital voice) the DIU provides 600 • 4-wire termination's for a dispatch console and for a QUANTAR station.

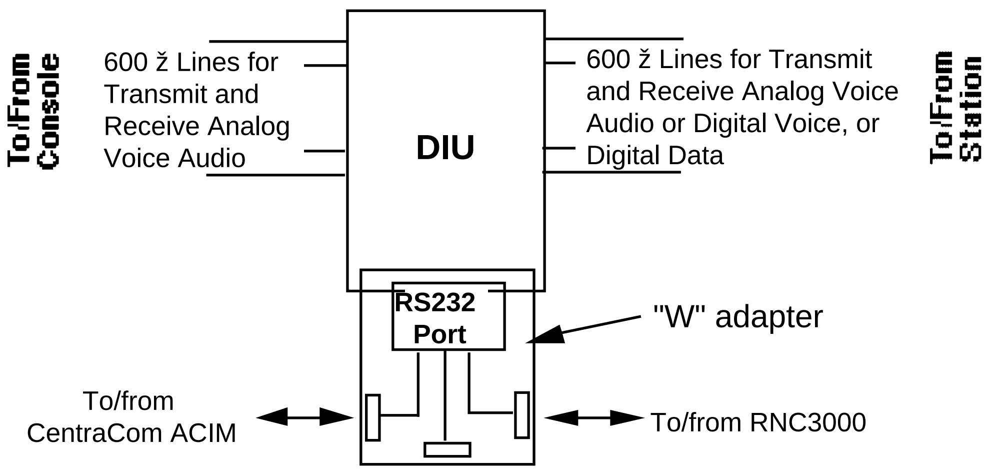


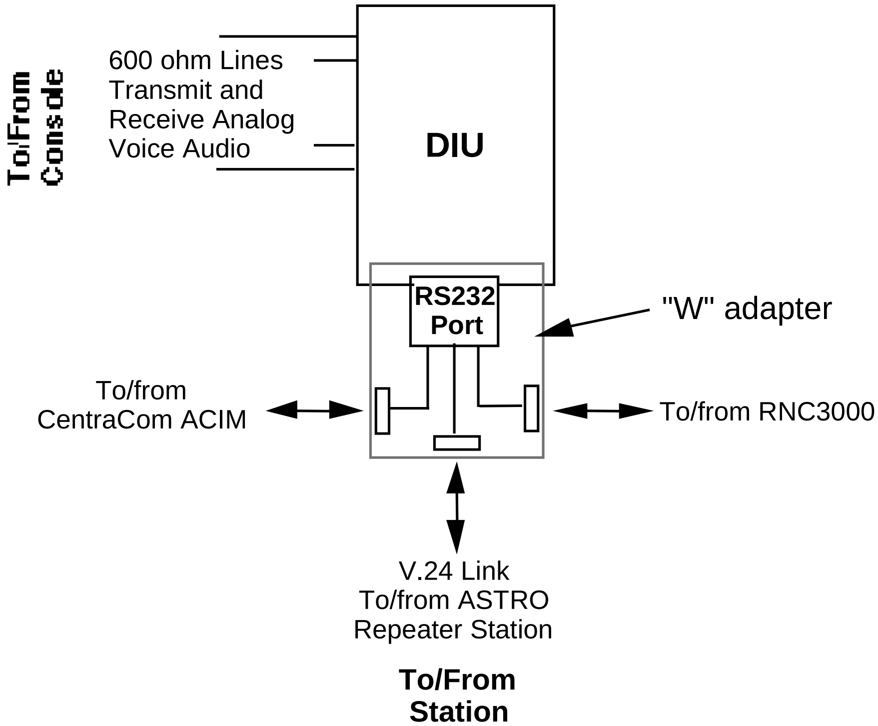
Figure 4.5 - Integrated Voice and Data Connection

The "W" adapter provides three connection port terminations to the DIU for other devices. All ASTRO 25 Integrated Voice and Data systems use the port to the RNC3000.

A variety of remote control console equipment may be used. The minimum requirement is for tone remote control signaling to control voice traffic through the DIU, gain priority over data messages, and control (via the DIU) the full duplex station.

CENTRACOM Gold Series consoles with the ACIM (ASTRO Console Interface Module) may use the ACIM link to recover embedded information from ASTRO radio transmissions (Unit ID, Emergency call, etc.) CENTRACOM Gold may also use the ACIM link to send digital commands to the DIU, eliminating the need for tone remote control. See Network Interface Cards below for more information.

If the system has been configured for digital voice and data operation only, the 600 Ohm connections to the station are not required, and the V.24 link may be used instead (Figure 4.6).



4.6 - V.24 Digital Voice Only Connection

NOTE: Only one form of connection to an ASTRO station can be used - either the 600 ohm wireline connection or the V.24 digital only connection.

Base Stations/ Receivers

Base stations and receivers are gateways between the ASTRO wireline and the ASTRO RF network. This gateway functionality is done in addition to their normal radio transmitter/ receiver functions. As gateways, base stations monitor data being transported on both RF and wire backbones and recognize data that is addressed to themselves as a gateway. They take data off one backbone, repackage it appropriately for the other backbone, and transmit it to the appropriate address.

In order to add data capability to a new QUANTAR/QUANTRO station, the ASTRO Conventional Operation Option and the Repeater Operation Option are required. Data capability is not provided on simplex base stations.

To add data capability to an existing QUANTAR/QUANTRO station, both a hardware upgrade and a software upgrade may required. The station upgrade will include a replacement controller board (unless the station is equipped with the EPIC board already), a modified eight wire wireline board, as well as a firmware changeout.

ASTROTAC 3000

To improve coverage in many wide area systems, multiple satellite receivers are added to cover "dead spots" created by buildings, foliage, valleys or hills. To insure that the best signal from these satellite receivers is processed, a comparator compares and selects the best signal to be passed onto the desired recipients. This process is known as receiver voting. Radio systems that employ this technology are often referred to as Total Area Coverage (TAC) systems.

For data within an integrated voice and data system, the ASTROTAC 3000 comparator combines the functions of routing and selection. Its voting function among multiple inbound receivers causes it to select one of several inputs on the basis of receiver bit error rate and provide that selected signal to the DIU.

The comparator assists in an outbound routing function in that it will provide a signal sent to it by the DIU to all its output ports. The signal will have already been flagged with an address of the specific "gateway" (i.e. base station) that is to route the packet further.

The ASTROTAC 3000 comparator is designed for systems with IMBE (CAI) vocoding; the ASTROTAC comparator is designed for VSELP based systems. An ASTROTAC comparator can be upgraded to an ASTROTAC 3000.

In conventional systems, V.24, hybrid, and modem link interfaces are supported. Each ASTROTAC 3000 comparator can be configured to accommodate both V.24/hybrid boards and ASTRO 9.6 Kbps wireline modems in a single ASTROTAC 3000 comparator. The ASTROTAC 3000 comparator is capable of supporting from 2 to 16 synchronous serial input/output ports in a conventional system. Each Wireline board has two I/O ports and requires either one or two ASTRO modems (depending if only one or both of the ports will be active) or one V.24/hybrid board.

Network Interface Cards

The Console ACIM is compliant with the relevant subset of ASTRO wireline protocol requirements to interface the digital network to the analog console system. It will assemble/ disassemble the packets going to and from the network that are required to support console signaling and carry message payloads.

Effectively, any other device, MRTI2000, Comparator Status/ Control module, etc. must have at least this level of interface into the network, supported through the DIU.

Digital Network Links

All ASTRO infrastructure signaling (AIS) is digital, packet data. V.24 protocol over a point to point, full duplex, serial, digital connection provides the simplest and fastest local or remote links to carry AIS data packets.

Analog Network Links

ASTRO modems to analog links are used if the wireline link path is shared with analog voice or signaling for backward compatibility or for some reason, analog only telephone service is chosen for the link. When ASTRO modems are used, the digital packet data must be modulated into modem tones for transmission over the analog wireline links.

All of these network elements process packet data. Typically packet handling is based on the header information in each packet. Packets may contain voice packets, terminal data packets, end-to-end message packets, and/or control signaling information.

Subscriber Radio and Terminal Devices

This subsection describes radios, mobile data terminals, feature interactions between terminal and radio, and requirements for laptop computers to be used in an ASTRO data system.

Radios

Any ASTRO radio can be used for integrated voice and data operation in a conventional system. In addition, an ASTRO Conventional Data System can be implemented in parallel with an ASTRO Trunking System for data alongside trunking. This allows the user to share the same radio when both systems operate within the frequency band of the radio.

The radio requires a specific option to enable data operation. This option can be ordered either factory-installed with new units or as an after market upgrade through FLASHport. If ordered as a FLASHport upgrade, a cable must also be ordered separately. Note that some high power mobile models may require a hardware change. The radio unit interfaces to a Motorola MW-520 Mobile Workstation, a Motorola Forté Wireless Commpad or a third-party laptop computer via the radio's RS-232 (or serial) port and a data cable with a DB9 pin connector to the terminal/laptop.

Channel Scan; Other Mobile Features

Scan operation for all voice formats (ASTRO/Analog) and voice related signaling is unchanged from previous versions of ASTRO radios, *except* as noted in this subsection concerning channel scan, and the following subsection discussing other radio features.

Release 3.1 now supports scan with data. One channel from any scan list can be chosen to be the Designated Data Channel. During scan operation in that particular radio mode, only that channel will be capable of data operation. The designated data channel can be assigned as either priority or non-priority. If assigned as a priority channel, the radio treats the channel the same as a priority voice channel. When a data message is detected, the radio switches to the data channel to receive the message.

While receiving a message on a scan data channel, the radio suspends voice priority sampling. The radio will not leave the data channel to briefly sample priority scan voice channels until the current message transfer is completed. Assigning the designated data channel as a priority scan channel can help ensure that all data messages are received. When a scan data channel is set as non-priority, there is an equal chance of missing a data message as there is in missing a non-priority scan voice channel.

Feature Interaction Summary between Radio and Terminal

Table 4.4 shows how data operation interacts, or is affected by other radio features or operating modes. If any of the features in the first column are activated, then the voice and data interactions will be handled as described in the table:

	Active Feature in ASTRO Mobile	**Notification to the Terminal by the Mobile**	**Data Transmitted from Terminal to Mobile**	**Data Received from the Infrastructure by the Mobile**
Group A	Radio Inhibit Radio Lock Test Mode	When the feature is active, radio will notify the terminal software that "Data Service is not available"	Any data packet received by the Radio from the terminal will be *Discarded and **no** response will be sent to the terminal.*	Any data packet received by the Radio from the network will be *Discarded*
Group B	Emergency Key Erase Status Message Selective Call Phone Call Alert	When the feature is active, Radio will notify the terminal software that "Data Service is not available"	Any data packet received by the Radio from the terminal will be *Discarded and terminal will be notified that the network is unreachable*	Any data packet received by the Radio from the network will be *sent to the terminal*
Group C	Scan (cannot be enabled while Radio is in data mode)	When the feature is active, **no** notification is sent to the terminal.	Scan is suspended and application data will be transmitted. Scan must be manually re-enabled.	Radio is not capable of receiving application data while it is scanning.
Group D	External Keyloading (SECURENET or ASTRO Encrypted)	When the feature is active, Radio will notify the terminal software that "Data Service is not available"	Any data packet received by the Radio from the terminal will be *Discarded and terminal will be notified that the network is unreachable*	Any data packet received by the Radio from the network will be *Discarded*

Table 4.4 - Feature Interaction between Terminal and Radio

Radio Modems

The ASTRO 25 radio, when ordered with the data option, contains the modem required for communications with the data terminal. **No external modem is required.**

Mobile Data Terminals

This subsection describes Mobile Data Terminals available for operation on an ASTRO 25 Integrated Voice and Data System.

Mobile Workstation 520

The Mobile Workstation 520 (MW520) offers users the power of a desktop computer with the flexibility required in the mobile environment. It has a 120 MHz Pentium processor, large VGA display, and up to 32MB RAM. MW520's compact three-piece design offers flexibility in vehicle mounting without sacrificing the traditional ruggedness of one-piece MDTs. It is durable enough to withstand harsh environmental conditions and to consistently deliver the performance required. The backlit display controls and uplit keyboard provide increased visibility.

The MW520 includes full peripheral connectivity. With two external serial ports, two Type II/one Type III PCMCIA slots and enhanced parallel port, the Workstation is capable of being connected to CD-ROM drives, GPS receivers, bar-code readers and magnetic card readers.

The MW520 is a full-featured computer running Microsoft Windows 3.11 or Windows 95. It supports existing software applications, including Motorola's ASTRO-DTA messaging application and PoliceWorks. Applications can be developed for the MW520 using standard Windows development tools. These applications can make use of the supplementary function keys just below the display screen. These keys can provide quick access to critical functions in applications.

General specifications for the MW520:

LCD

- Monochrome VGA, 9.4" diagonal
- 640 x 480 Resolution
- 64 Gray Levels
- Transflective

Mass Storage

- Hard Disk: 810MB or larger (Opt)
- Flash Disk: 10MB (Std) or 20MB (Opt)

Communications/Expansion

- Serial = 2 with 16550 UART support
- Parallel = 1 with ECP/EPP support
- Video = Analog VGA
- PC Card Slots = Two Type II or One Type III

Physical Size

- Processor: 2.65” x 7” x 8.5”
- Display: 10.3” x 11” x 1.3”
- Keyboard: 2” x 12” x 8”

FORTE™ Wireless Commpad

The FORTE Wireless Commpad (Figure 4.7) is Motorola's portable data terminal product that can be combined with its separately available Vehicle Docking Station for use in ASTRO systems. Since the FORTE Commpad relies on the SPECTRA mobile radio for communications, the ASTRO version of the FORTE Commpad comes without an internal radio modem. When placed in the Vehicle Docking Station, the FORTE Commpad will connect to the ASTRO SPECTRA mobile radio via the serial port interface port available on the Vehicle Docking Station. When removed from the Vehicle Docking Station and SPECTRA mobile, the FORTE Commpad will not be connected or have access to the ASTRO system.

Figure 4.7 - FORTE Wireless Commpad

The MagicPipe™ Wireless CommStack for ASTRO *must* be ordered as an option with the FORTE Wireless Commpad for use in ASTRO FLM systems.

Laptop Computers

A computer used with the ASTRO data capable radio must meet the following requirements - an IBM/compatible unit running Windows operating system with minimum 16MB RAM and an RS-232 serial port. 2 MB hard drive storage is also required. The MagicPipe™ Wireless CommStack must also be ordered and installed on the laptop for ASTRO FLM systems and is recommended for IP systems. Please contact the Advanced Product Team for the current status of Motorola approved third party computers.

IV&D Topologies

Single Site IP Systems

Figure 4.8 shows a single site integrated voice and data system. It provides Radio to Fixed Network Equipment (FNE) Integrated Data (non-repeated) and Digital Voice (repeated) communications service using the Project 25 IP protocol. The ASTRO 25 system does not support direct repeated data messaging.

The ASTRO data controller (RNC 3000) must be connected to the DIU. This requires a cable to connect DIU and RNC; also the DIU must contain (or be upgraded for) a new version COMM board.

The ASTRO data capable radio requires an option to enable data operation, and a special cable to connect the laptop/mobile terminal to the radio.

The DIU is co-located with the RNC3000, and is connected to it through an RS-232 (V.24) port.

The RNC3000 is connected via Ethernet to the WNG. The WNG is then connected to the host network via Ethernet. For FLM systems, the WNG is not used. The RNC3000 is connected directly to the Host Computer instead.

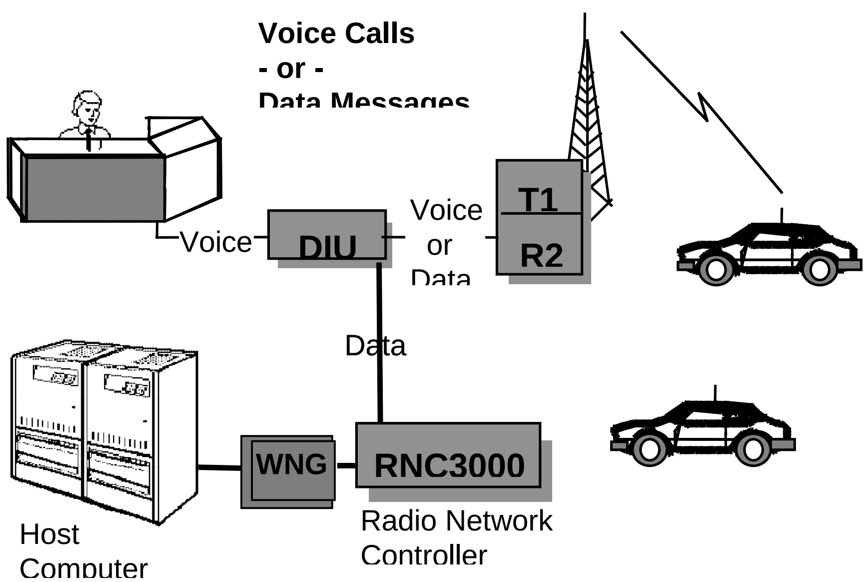


Figure 4.8 - Single Site IP Configuration

Multiple Single Site Systems

Since the Radio Network Controller (RNC3000) can support up to 64 sites, a multi-site multi-channel system can be created by connecting multiple DIU-repeater sets on different RF frequencies to one RNC (Figure 4.9). The system requires multiple repeater channels, or sufficient geographic separation to mitigate site-to-site interference. Mobile data users are required to *manually* change their radio channel when moving from the coverage area of one site (and channel) to another.

If a customer migrates into this configuration from an ASTRO single site configuration, they can reuse the existing RNC3000. If the customer originally purchased the RNC3000 with a single site capability, it may be upgraded to support multiple sites.

The RNC3000 is connected via Ethernet to the WNG. The WNG is then connected to the host network via Ethernet. For FLM systems, the WNG is not used. The RNC3000 is connected directly to the Host Computer instead.

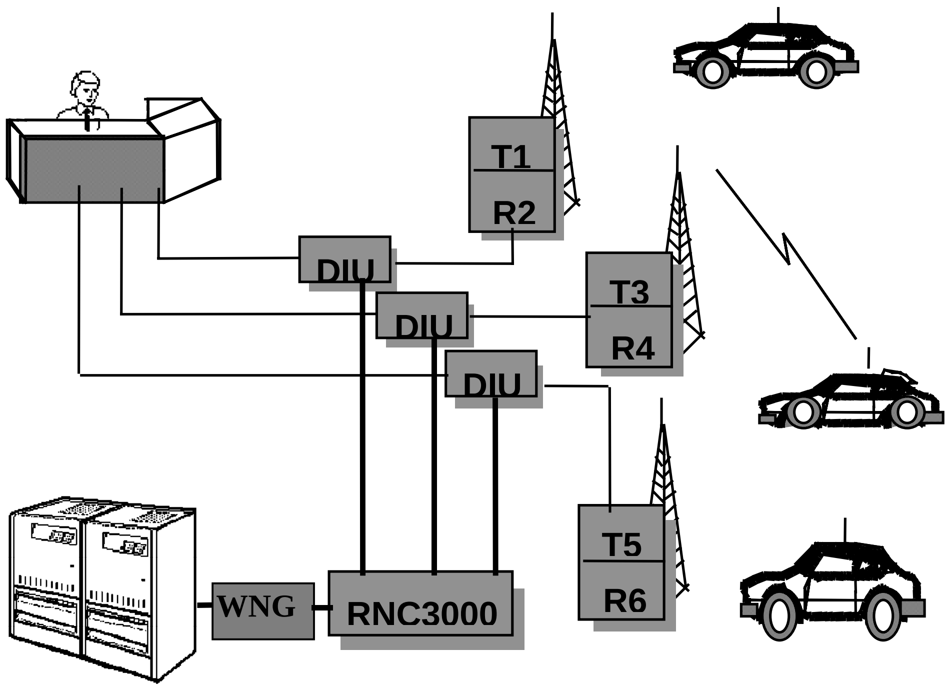


Figure 4.9 - Multiple Single Site Configuration

Receiver Voting Systems

Figure 4.10 shows a receiver voting system. This configuration offers Radio to Fixed Network Equipment (FNE) Integrated Data (non-repeated) and Digital Voice (repeated) communications service. This system topology is used when a single receiver does not provide sufficient inbound coverage for mobile transmissions but a single transmitter does provide sufficient outbound coverage. All receiver signals meet at the comparator, and the comparator selects the best quality signal to forward to the DIU.

This system will provide voice communications to the console, and can provided voice voting repeater operation as well. Data messages are not repeated - the comparator selects the best received data message signal and forwards it to the DIU. The DIU then passes that signal to the RNC3000.

The equipment added to support data traffic is the same as for single site systems - mobile terminals with connecting cables and software, and the RNC3000 controller connected to the DIU. (An ASTRO-TAC 3000 comparator is needed for voting operation). The RNC3000 is connected via Ethernet to the WNG. The WNG is then connected to the host network via Ethernet. For FLM systems, the WNG is not used. The RNC3000 is connected directly to the Host Computer instead.

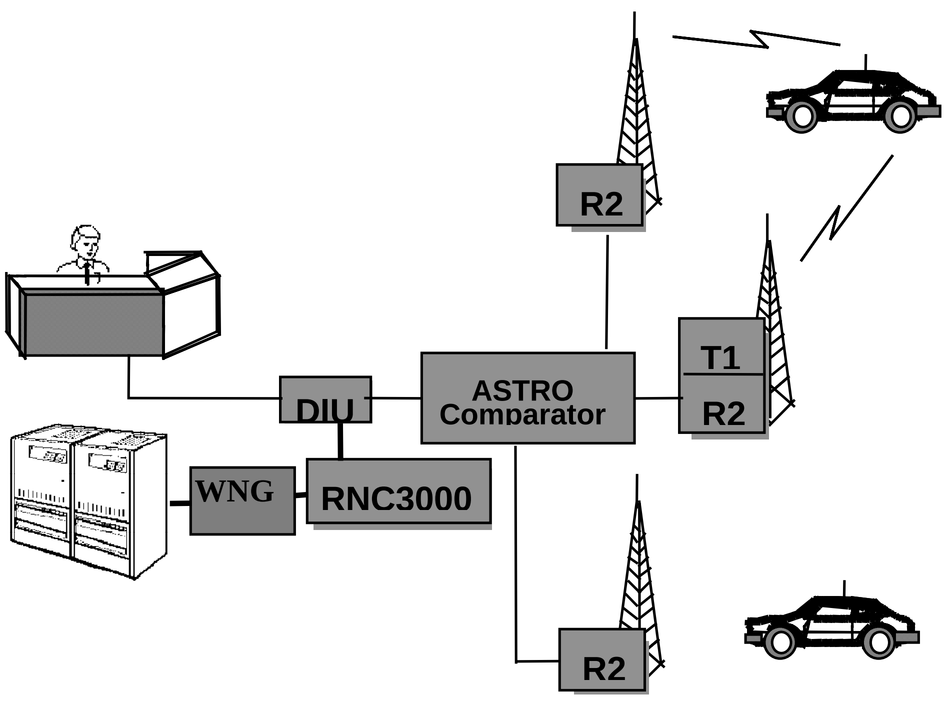


Figure 4.10 - Receiver Voting System Configuration

Multicast Wide Area Voting Systems

Multicast systems (Figure 4.11) provide a wide area broadcast service by transmitting the same signal over a number of transmitters, each on a different frequency. Multicasting provides the transmitter coverage advantages of simulcast yet avoids simulcast's requirement for synchronization of the fixed station transmitters. It provides a simple means of obtaining wide area voice coverage: Radios can use a common talk-in frequency, and broadcast their voice calls throughout a much larger region than is attainable with a single transmitter site.

Mobile users in a multicast system must rely on their knowledge of the territory in which they operate to know which transmitter (and frequency) to listen to for the best signal. Even so, multicasting has proven to be a viable method for providing wide area transmit coverage for many customers.

The RNC3000 is connected via Ethernet to the WNG. The WNG is then connected to the host network via Ethernet. For FLM systems, the WNG is not used. The RNC3000 is connected directly to the Host Computer instead.

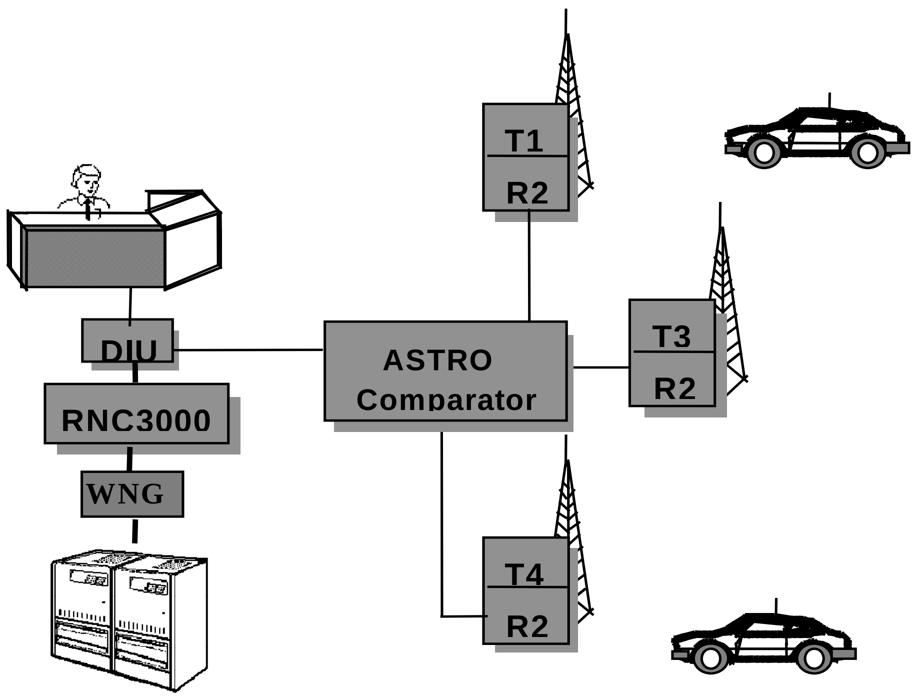


Figure 4.11 - Multicast System Configuration

Data messages originated at a mobile terminal are routed through the receivers that "hear" them, and the comparator selects the best signal. That signal is passed to the DIU, then on to the RNC3000. Acknowledgments of inbound messages, as well as all host-originated outbound messages are broadcast over all the system's transmitters.

Simulcast

Figure 4.12 shows the simulcast system configuration supported in the ASTRO 25 system. This configuration offers Radio to Fixed Network Equipment (FNE)

Integrated Data (non-repeated) and Digital Voice (repeated) service. The simulcast system topology is used to provide wide area transmitter and receiver coverage. The ASTRO 25 simulcast system simulcasts digital voice only - it does not permit use of analog voice, nor are data messages simulcasted. The system responds to inbound mobile data messages by steering acknowledgments to the transmitter associated with the voted receiver for the inbound message. This is called data site steering.

The RNC3000 is connected via Ethernet to the WNG. The WNG is then connected to the host network via Ethernet. For FLM systems, the WNG is not used. The RNC3000 is connected directly to the Host Computer instead.

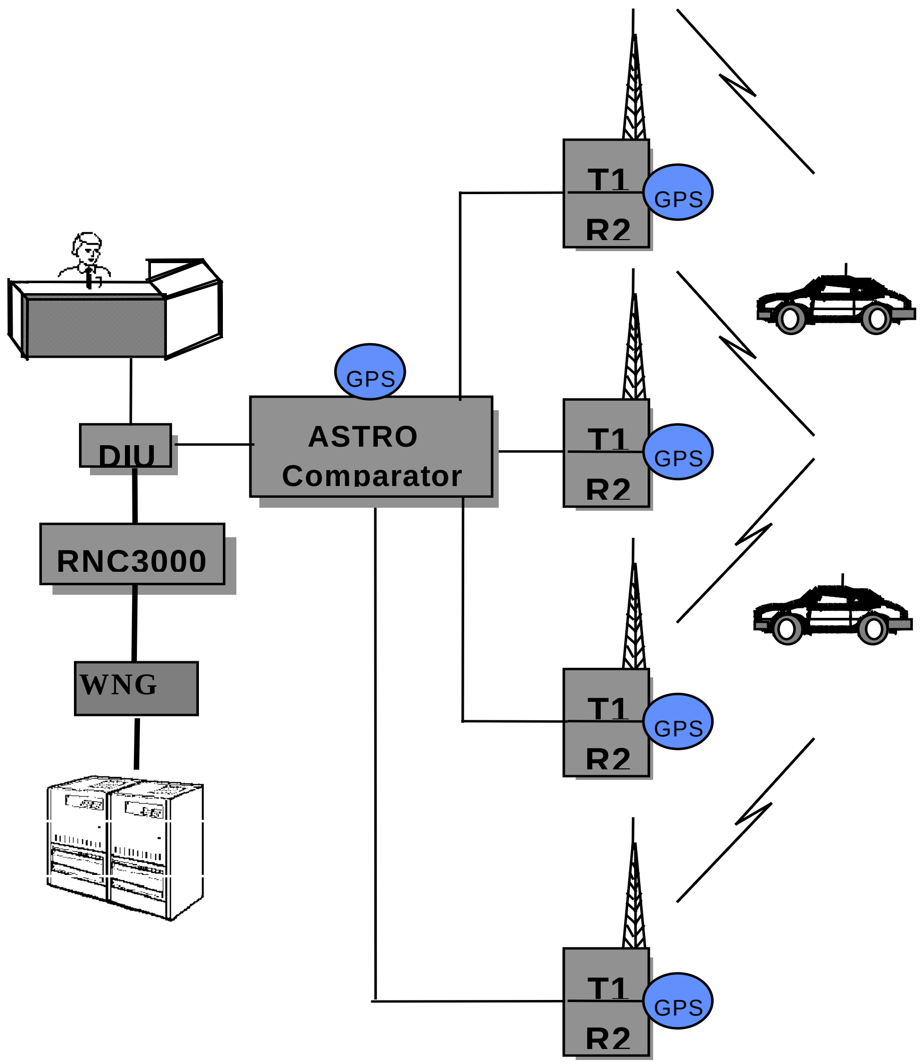


Figure 4.12 - Simulcast Configuration

Data Site Steering

A wide area voice and data ASTRO simulcast system will site steer data transmissions to mobile data terminals. When a mobile transmits a data message, each station receiver within range of that transmission routes it to the comparator. The comparator votes among the signals it receives, and routes the address of the station from which it received the best message signal, along with the message, to the DIU and then to the RNC3000 Controller. The RNC forwards the message to the WNG (or directly to the computer host in an FLM system). The RNC also adds that station address to the outbound acknowledgment and forwards it through the DIU to the comparator. The comparator sends the acknowledgment to all stations. Only the station to which the acknowledgment has been addressed transmits it. Host-originated outbound messages depend on the registration information held in the RNC3000 to determine the correct site to use.

If the RNC3000 does not have a station address to use in reaching a radio, it uses a simulcast "radio finder" mechanism to reach the target mobile.

Radio Finder

Radio Finder is used when normal message delivery of a confirmed data message to a registered radio is unsuccessful. The RNC3000 attempts to reach the radio by addressing the data message with a *broadcast* address. Use of the broadcast address causes the system to simulcast the message. If the transmission solicits a response from the mobile, the last known transmitter site address for that mobile is updated and the subsite to subsite radio finder mode is be exited. If radio finder solicits no response from the radio, then the radio is considered unreachable from the outbound message. No attempt is made to search for the radio on a different site.

Combination Configurations

The ASTRO 25 Integrated Voice and Data system can be designed to support a combination of single-site, wide area voting and simulcast configurations connected to a single RNC3000. The system's ability to track the site registration of the radios in the system is the same as described in the Multiple Single Site configuration. The mobile user must switch to the channel in use in the current coverage area. Switching causes the radio to register with a new site or sub-system.

Figure 4.13 shows two simulcast sites in a combination configuration.

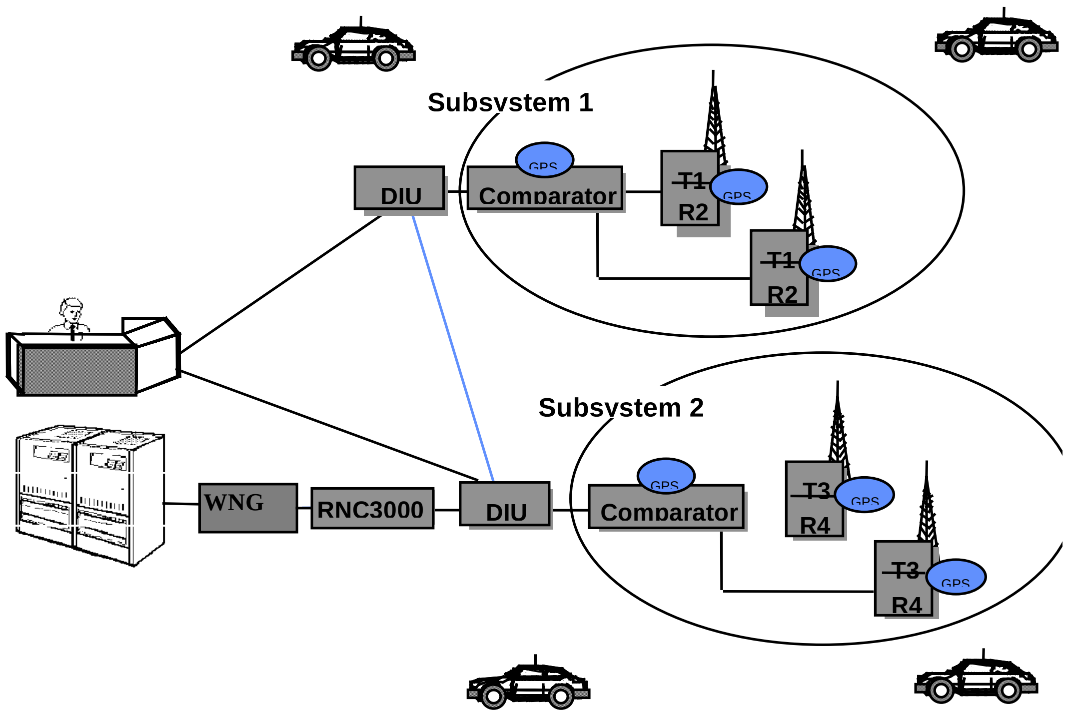


Figure 4.13 - Combination Configuration

IV&D System Performance Guidelines

This subsection of the planner discusses the performance of the ASTRO 25 Integrated Voice and Data two-way radio system. The system may be used to transport analog voice, digital voice, and digital data. The contention between these three types of signals is one of the factors affecting system performance.

The ASTRO 25 Integrated Voice and Data system is best suited for customers with moderate messaging requirements. Its data throughput capacity, in the absence of voice, compares favorably with Motorola dedicated radio data systems. However, adding voice into channel loading reduces data capacity.

The ASTRO 25 Integrated Voice and Data system can provide an excellent system solution for many customers. The system design balances RF coverage, data message throughput and delivery time, and voice contention.

The guidelines provided in this section will aid in initially determining if the performance offered by ASTRO 25 Integrated Voice and Data matches specific customer needs. The guidelines will also help system engineers in optimizing designs to meet specific performance requirements. Performance specifications and load modeling tools are not provided in this system planner.

Supported Operating Modes (Analog or Digital)

In an ASTRO 25 Integrated Voice and Data system, voice communications modes may be configured as user-selectable, meaning that either analog voice or ASTRO digital voice may be transmitted on the radio channel. ASTRO data will always be in digital mode. Mixed analog and digital operation requires ASTRO 9.6 kb modems or V.24/hybrid links for each wireline link between stations and DIUs.

Alternately, the system may be configured for digital operation only, and V.24 links used between all fixed infrastructure products.

These configurations are identical to those in ASTRO 25 voice-only systems. Contention between analog voice and digital data has been discussed in earlier sections of this planner. While analog voice operation is not prohibited in the ASTRO equipment, it is not recommended: It does not provide as efficient a method for managing voice/data contention on a radio channel.

Interaction Between Voice and Data

The ASTRO 25 Integrated Voice and Data system grants voice messages priority over data messages whenever the two contend for use of a channel. There are a number of contention scenarios involving each system component that originates and/or handles both voice and data messages:

Data Capable Radio
A radio prioritizes voice transmissions over data transmissions; however, it will allow a data transmission-in-progress to complete sending a packet that it has already started to transmit before switching to voice transmission.

Base Station
The station operates full duplex. It grants priority to voice signals received via transmit wireline input from the DIU. These messages will interrupt any repeated voice traffic. Data messages are not repeated, and may be sent down the receive wireline while the station is transmitting other traffic.

When the station is transmitting an outbound data message, it will allow transmission of the current data packet to be completed even though a voice message may have been received during the transmission of the data message.

DIU
The DIU grants priority to console-originated voice traffic, but will allow a data transmission-in-progress to complete a current packet before seizing priority. If the DIU is receiving a data message, and the console starts a transmission, the passage of the received data to the RNC3000 will be unaffected.

There is some potential in each of these voice-interrupting-data scenarios for truncation of the initial portion of a voice message. A packet containing 500 bytes of user data is transmitted in approximately 700 msec. That is the maximum truncation expected. Since many packets will not be that long, and the voice PTT interrupts all not occur at packet start, most truncations will be less than that.

System RF Coverage - "Balancing

"Balance" refers to the differences between a radio system's "talk-in" coverage (from radio to base) and its "talk-out" coverage (from base to radio.) Two-way systems frequently exhibit a talk-out *advantage*; a system base station will usually have greater transmit power, or at least a more favorable (and fixed) antenna location.

Maintaining a system talk-out advantage is important in a two-way radio data system. Data messages passed from host to mobile terminal are normally longer than those passed from mobile terminal to host. Longer messages have a slightly lower probability of successful delivery, and designing RF coverage to favor system talk-out will better balance talk-out and talk-in message reliability.

System RF Coverage Simulation and Testing Methods

System RF coverage performance for both ASTRO 25 voice and data will be referenced to voice coverage contours.

System RF coverage can be simulated with MOZAIK^{sm}. This program requires a number of input parameters and yields several output parameters. The input parameters include the range of service area, land use, land cover data, terrain data, site data, system model used, plus performance specifications for base station and mobile equipment. The output parameters are base site height above average terrain (HAAT), equivalent area reliability, effective radiated power of base and mobile, effective static sensitivity of base and mobile and the effective noise floor of the base and mobile environments. The input parameters are provided by the Motorola Coverage Standards Manual, field engineering experience, or the appropriate product group. The most used product of MOZAIK is a coverage map that is scaled and drawn for customer-specific proposals.

Coverage Acceptance Test Plans (ATP) are designed and implemented with the FACTWare^{sm} hardware and software tool. FACTWare aids in calculating a statistically required number of test grids for evaluating a customer’s system. FACTWare is then taken into the field to perform the coverage test. Voice coverage testing uses Received Signal Strength Indication (RSSI) for analog systems and Bit Error Rate (BER) with a V.52 test pattern for digital systems. A customer may also require that subjective tests be performed using voice calls over the radio.

Voice Parameters for Coverage Simulation

Radio performance specifications are part of the data needed for system coverage simulations. ASTRO radio equipment catalog sheets specify static receiver sensitivity performance using RF input levels (µv or dBm) required to yield 12 dB SINAD and 20 dB quieting for analog FM. Sometimes a corresponding sensitivity value for digital voice is given. But if no value is given, the accepted practice is to use the analog 12 dB SINAD sensitivity as equivalent to a 5% static bit error rate for digital.

This value is also the standard bit error rate level for C4FM modulation according to TIA/EIA TSB102.CAAA, the TIA measurement document for radios compliant with the Project-25 specifications. This level will deliver approximately Circuit Merit 2 audio quality for analog and digital modulation. Since 12 dB SINAD is a static measurement, faded Circuit Merit 3 and 4 system designs will require additional average signal levels to provide acceptable voice performance with fading.

A system design for digital audio must account for Rayleigh fading effects just as in analog. Mean Opinion Score (MOS) tests are used to determine audio quality levels expressed in Deliver Audio Quality (DAQ) in static conditions and in fading at various Doppler frequencies. When defining the system coverage, the field engineer must select the acceptable DAQ value, estimate the equivalent BER in fading and note the required signal strength to achieve this BER. The resulting DAQ value depends on the BER, signal level and the fading speed (mobile velocity).

Target Bit Error Rates

The target BER for a given DAQ is influenced by the equipment configuration and the environment. The field engineer must consider the following parameters:

System Frequency Band	Channel Bandwidth
High Band (132-174 MHz)	25.0 kHz
UHF Band (400-512 MHz)	12.5 kHz
800 Band (806-869 MHz)	
Radio's velocity (Doppler Frequency)	Vocoder
Average (45 mph)	VSELP
Fast (60 mph)	IMBE (Project 25)
Slow (3 mph)	
Receiver IF Configuration	
Wide (11.2 kHz) (Simulcast)	
CEPT (7.8 kHz) (European)	
Narrow (5.76 kHz) (Project 25)	

Data Performance Parameters - Guidelines and Tradeoffs

An ASTRO 25 Integrated Voice and Data system design balances data communications parameters - throughput and delivery time - against RF coverage, and the amount of voice traffic expected on the channel.

Throughput is the rate at which information flows through the system. While voice throughput is usually specified in "calls per hour", data throughput is specified in "messages per hour."

Delivery time for data messages is the length of a full message sequence including the inbound data message and outbound acknowledgment. or, an outbound data message and its inbound acknowledgment. Also included in delivery time are the retries that either host and mobile will make if messages are not acknowledged as having been completely received from the initial transmission.

Guidelines and Tradeoffs

There are definite tradeoff decisions to be made in a system design. A system designer concerned primarily with data performance will optimize throughput and delivery time parameters. He will avoid or minimize the use of voice on the channel, and he will ensure that the RF coverage in the customer's desired operating area *exceeds* that required for a faded CM3 voice design.

Alternately, if coverage area and continuity of voice service are more important, the system's throughput will decrease and its delivery time may increase. For instance, data messaging along a CM3 (or less) voice contour will increase the number of retries required to support a high rate (for example 95%) of successful message deliveries. A lightly loaded system may tolerate this added activity easily. However, the delivery performance of a system that is loaded closer to its limits will degrade and may fail to satisfy the customer during peak usage periods if significant numbers of messages require retries due to data block errors induced by RF conditions.

Customer Traffic Profiles

Both voice and data traffic profiles are needed to design an integrated voice and data system. A voice traffic profile includes call rates and call durations. For data, the profile includes average message lengths and peak message rates.

Traffic profiles will change throughout the day - at the start of a shift, or due to other operational routines, or at the end of a shift, for example. The system design and the customer's performance expectations must account for changing profiles.
A load model or messaging profile describing the customer's data messaging plans is a critical step in determining the suitability of an ASTRO data solution. This profile lists each type of message and its approximate length in user-accessible bytes (i.e. not including headers or error mitigation added by the transmission protocol.) It also lists the number of times per hour per mobile terminal that such a message will be generated. This profile can then be used to calculate the total message load, and compare it to a "safe" channel utilization.

Both the voice call rate and data message rate per channel are significant. The procedure in the last paragraph is typical of message loading calculations used in dedicated data systems. Anticipated voice loading must also be used to *derate* the data messaging capacity to set reasonable performance expectations.

Data Coverage The ASTRO 25 Integrated Voice and Data system can provide RF system coverage for data messaging that is comparable to voice message coverage where a single fixed station site is considered (i.e. one mobile transmitter and one station transmitter involved in either a voice or data message exchange.) The comparison is made at a CM3 voice contour - not a system fringe area.

The message management techniques used in the ASTRO data system play a significant part in attaining this performance. Reliable messaging at a CM3 voice contour requires that both message acknowledgments and retransmissions of missed portions of messages be used.

Radio operators manage voice message traffic all the time; they respond to, or acknowledge messages. If they think they missed a message, they will ask that part or all of it be repeated. Acknowledgment and repetition are proven ways of dealing with the variables in performance encountered on a two-way radio channel The **ASTRO 25 Integrated** Voice and Data system has automated much of that process for data messaging.

Most data messages are exchanged using a confirmed service. Confirmed service requires that the receiving entity acknowledge messages sent to it. If reception was successful, the message sequence ends with the acknowledgment. If the reception was initially unsuccessful, the receiving entity will still acknowledge the message, but will also request that the portions of the message that it missed be repeated. This technique, called Selective Automatic Retransmission Request, or SARQ, helps ensure the reliable delivery of messages, while making the best possible use of air time on the radio system.

Retries are built into the messaging reliability plan and coverage performance plans. If a customer's throughput and delivery time requirements dictate that the majority of his messages be completed upon initiation, or no later than the first retry, then his RF coverage area for effective data operation will not be as great as that for voice operation.

Message delivery success depends upon the use of confirmed message service and the selective retransmission of corrupted data blocks. Longer messages. predictably, cannot be sent as reliably as short ones. Furthermore, the system will operate more optimally inside the voice coverage contour area where automatic data retries are minimized. Inviting additional retries by operating the data system outside the contour will cause additional collisions between voice and data messages as well as lost data messages - both the data system's throughput and its delivery time will degrade.

NOTE: Unconfirmed service sends a message only once; if the receiving entity can't recover the message accurately, it discards it. For example, messages sent to multiple units use unconfirmed service. Most messages are sent with confirmed service.

System Integrated voice and data operation on a radio channel has been modeled

Message Throughput

through computer simulation. These performance models predict the message throughput on a radio channel that is used for both ASTRO digital voice and ASTRO data. The models do not include the use of analog voice on the same channel as data.

The models permit the evaluation of many message loading scenarios. They provide insight into the relationship between the level of voice traffic and the level of data traffic that may be put through a radio channel. They explore the relationship of message lengths to system message capacity, and also predict the throughput impact of numerous data message retries.

These simulations establish the guidelines for specifying expected throughput for an ASTRO 25 Integrated Voice and Data system. Actual system performance has been shown to closely track the throughput predictions, given comparable message loading conditions. Successful throughput specification of an integrated voice and data system will require as much care in developing a customer traffic profile as is normally used in developing RF coverage expectations. The subsections that follow will provide the guidelines needed to develop throughput information.

Voice Message Throughput

Voice calls per hour and data messages per hour are the two measures of usage for radio channel time. Either can be approximated and plotted on a graph with one axis for voice calls, and the other for data messages (Figure 4.14).

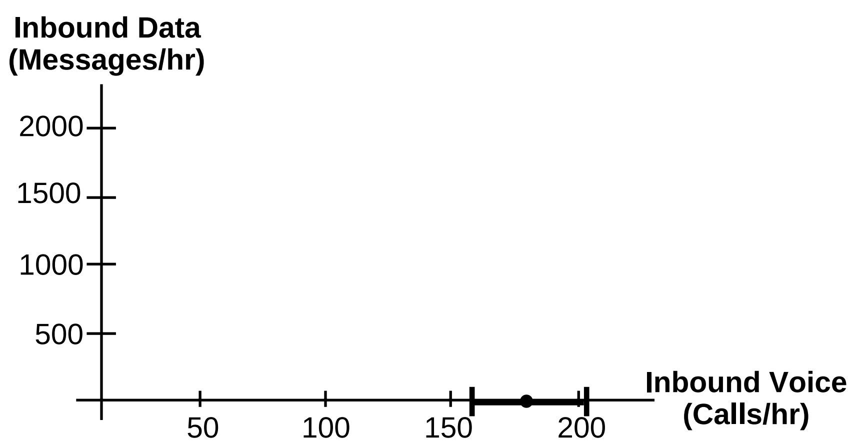


Figure 4.14 - System Voice Call Loading Inbound - Mobile to Station

The effects of contention and the resultant throughput can be shown on this graph. This example assumes that an average voice exchange will consume approximately 10 seconds of air time - half of that mobile-originated; the other half dispatch originated. The maximum voice loading available on the inbound frequency can be plotted as an x-axis point at 180 inbound calls/hr, and variance allowed for in the establishment of the maximum voice loading. Not all voice calls will be delivered, either. Some will be lost in contention for the channel, and the operators will have to transmit their call again. When dispatch is using his half of the 10 seconds for each call, the inbound channel is assumed to be unavailable. Note that this also assumes no data traffic.

Data Message Loading

Data loading can be estimated also, using a condition of data traffic only (i.e. no voice) on the radio channel. Experience gained through analyzing usage of dedicated mobile data systems indicates that typical user message sizes range from 50-200 bytes. Longer messages can and do occur, but are generally less frequent.

Those average message lengths result in message transmission times for ASTRO data of 100-300 msec after adding data transmission overhead. Message transmission times are a small part of the total required data message transaction time, however. Nearly all messages are acknowledged; others will require selective retransmission of portions of messages that were initially negatively acknowledged. Messages may collide with one another, in spite of the access discipline provided by DSMA "busy bits," and this will lead to additional retries. A reasonable range of inbound data message capacity, supported by simulation modeling and test data, is indicated on the graph below. The capacity shown is user-accessible capacity, existing in addition to that required to service acknowledgments and automatic retries.

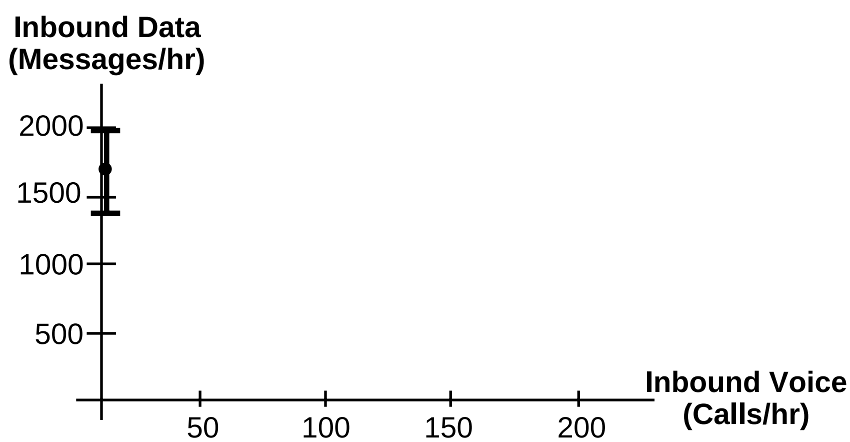


Figure 4.15 - System Data Message Loading Inbound - Mobile to Station

The total data message throughput over the channel, including outbound messages, will be at least twice that shown on this graph. The inbound acceptance rate is a useful measure of the system's capacity, indicating how many terminals the system can service, given knowledge of the message service they will require.

NOTE: Data throughput in Figure 4.15 is shown with no voice on the channel.

This graph is indicative of the maximum data message capacity of the ASTRO 25 Integrated system.

Ranges shown along both axes indicate that customer messaging requirements may vary from those used in this system planner, and the system's data communications capability will vary also. The next subsection will integrate voice and data, plus discuss the impact of other data messaging parameters.

Integrated Voice and Data

Voice activity reduces the data messaging capacity on a radio channel. Voice messages are granted priority over data messages, A mobile sending voice can transmit on top of a mobile sending data, while a mobile will not send a data message until it senses that the inbound channel is clear by reading the busy bit status. Voice priority will increase the amount of time needed to complete data transactions.

The Figure 4.16 illustrates the capacity tradeoff between voice and data on the same channel. The three curves plotted show relationships between inbound and outbound user message profiles and system capacity.

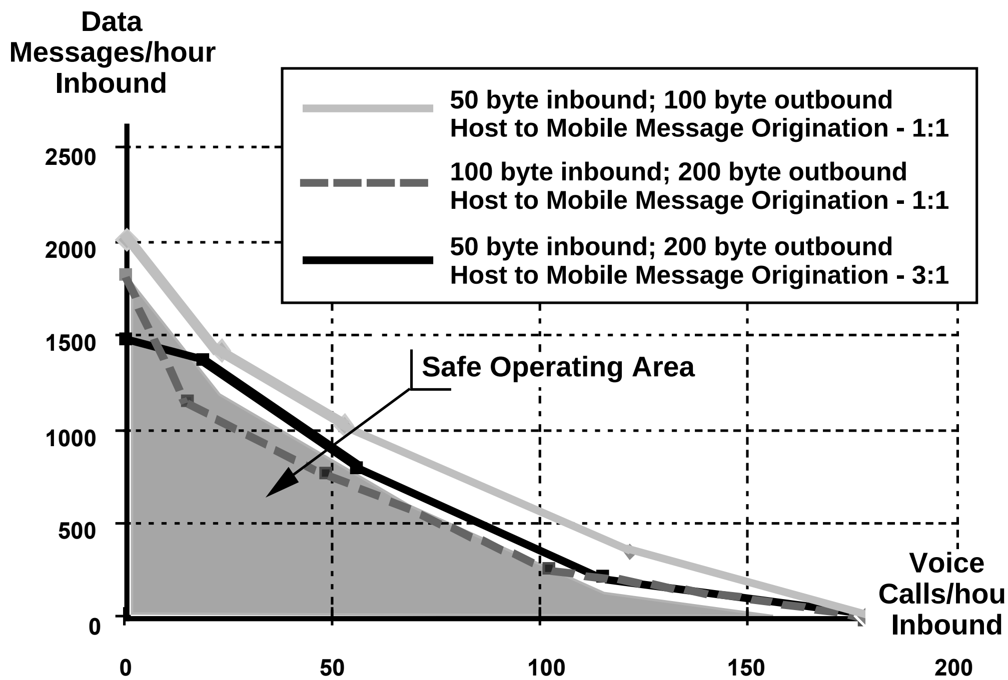


Figure 4.16 - Expected Message Capacity – Integrated Voice and Data on a Single Site System

Voice loading determines data capacity. Since voice messages take priority over data messages, the proper way to interpret this graph is to move horizontally along the voice call axis, read upward, then across to determine a corresponding data message capacity. Notice that light levels of voice loading have an *immediate* effect on data capacity. The shaded area is the "safe" expectation area - operating a channel outside these limits risks frequent incomplete data message transactions.

Remember that the operating area shown in Figure 4.16 is expressed in terms of inbound (mobile-originated) messages only, but includes various outbound message scenarios as shown in the inset legend. A system's total message capacity will be at least twice that of the inbound channel.

NOTE 1: Figure 4.16 should be used only in an initial evaluation of the potential of ASTRO 25 Integrated Voice and Data to satisfy a customer's requirement, once that customer's data message load profile has been determined.

NOTE 2: these load relationships apply only when digital voice is used. This is a good place to again emphasize that the use of analog voice in an integrated voice and data system is not recommended. Analog voice usage will reduce data throughput much more quickly than will digital voice.

If analog voice is used, a mobile unit has only squelch status (i.e. the PL, DPL) for determining if the inbound channel is available for a data message. A console keying the transmitter in analog will "busy" out a mobile from sending a data message, even though the inbound frequency may not be in use. Had the console keyed in digital, the busy bits set in the station could have marked the inbound frequency as "open." Similarly, in voice repeat mode, that station's transmitter is often held keyed after the inbound signal has stopped (dropout delay). In analog, dropout delay time is lost for data transmission. In digital, the dropout delay period can mark the inbound frequency available. Each of these scenarios can represent several seconds lost for data transmission.

The parameters of the data messages themselves will have some effect on throughput. The curves shown in gray-line, and in dashed-line in Figure 4.16 illustrate this. There are slight, though consistent reductions in throughput as message lengths increase. Even though the graph depicts only inbound message load, both mobile-originated and host-originated messages are included in a 1:1 ratio, making the total throughput capacity of the system twice that shown on the graph.

The black-line curve depicts system capacity where the host originates three times the messages that the terminals originate. The inbound available load is reduced, even with no voice load, due to the larger number of inbound acknowledgments that will be passed through the system in response to all the outbound messages. Even so, the total message capacity (inbound plus outbound) under that loading scenario is nearly 6000 messages per hour if no voice is used.

Performance Summary

RF System Coverage

System requirements for data communications that emphasize coverage area must concede lower throughput and longer *delivery* time for data messages, as additional retries will be required, or messages may be missed altogether when using data in areas with CM3 or lower voice coverage.

Data Message Throughput and Delivery Time

ASTRO 25 Integrated Voice and Data provides a medium capacity data communications system. The system smoothly blends voice and data operation together, but favors voice operation by prioritizing voice over data messages. A system requirement that emphasizes data throughput and delivery time must minimize voice usage. The ASTRO system's capability to be used either for data or voice makes it an especially attractive offering to customers.

Load Modeling

Data message load models for customer-specific applications must be developed for an ASTRO system just as is done for dedicated RD-LAP or MDC4800 systems. The load model, in conjunction with the customer's voice calling plan, will indicate how the customer's radio channels can be effectively used.

SECTION 4. OVER THE AIR REKEYING

Overview

Standards in ASTRO 25 OTAR

Underlying major improvements to the ASTRO 25 system is the focus on standards. This section briefly explains some of the most important aspects of these standards.

Difference between APCO 25 and ASTRO 25 standards.

The **Project 25 standard** is the creation of the Association of Public Safety Communications Officials (APCO) whereby representatives of federal, state and local government agencies have evaluated basic technologies in advanced land mobile radio to find solutions that best serve the needs of the public safety marketplace. Many international public safety organizations have been included in the development of these user-driven standards, such as the National Association of State Telecommunications Directors (NASTD), National Communications Systems (NCS), National Telecommunications & Information Agency (NTIA) and the Department of Defense (DoD).

Project 25 itself includes 6 standard interfaces: Common Air Interface, RF Subsystem, Data Port Interface, Inter-System Interface, Interconnect Interface, and Network Management Interface. **ASTRO 25** is Motorola's digital system designed in compliance with that standard.

ASTRO 25 is designed with the following benefits:

- Improved spectrum efficient narrow band operation assures the efficient use of radio channels without giving up necessary capabilities.
- Direct Interoperability for reliable communications between work groups. This helps eliminate isolated islands of incompatible communications.
- Smooth migration from analog to digital systems.
- Digital unit-to-unit communications without using repeaters or other infrastructure.

Difference between ASN and ASTRO 25.

Motorola's Advanced SECURENET (ASN) system employed a more limited version of key management using the Key Management Controller and an earlier version of the Key Variable Loader. ASN, an advanced version of the SECURENET, offered multiple key functionality as well as some Over-the-Air-Rekeying(OTAR). For this reason, ASN OTAR and ASTRO 25 OTAR will be distinguished whenever possible. In the rare instance where Over-the-Air-Rekeying is referred to as a generic feature, the term OTAR will be used alone.

NOTE: Since many customers considering a KMF will have ASN systems already in place, they may want to know about interoperability between the two key management systems. Directions for moving keys between a KMC and a KMF are covered generally in the KMF user documentation set, and in detail in the KVL3000 Operations manual.

Processes

Centralized Key Management

Centralized key management amounts to applying encryption keys to talk groups from a central database using graphical controls.

Key Distribution

Once associations between radios have been created within the KMF, the keys corresponding to each CKR need to be loaded into the Universal Crypto Modules (UCM) within each radio. This key distribution process must be executed using the KVL3000 before OTAR is possible.

Over-the-Air-Rekeying(OTAR)

ASTRO 25 OTAR is accomplished using the KMF to formulate and send Key Management Messages (KMMs) through the Local Area Network (LAN) to the Wireless Network Gateway (WNG) and ultimately to the subscriber units. The KMMs used by the ASTRO 25 OTAR system are a superset of the OTAR messages standardized by APCO Project 25. The process of moving keys through the RF interface is described fully in the KMF user documentation.

What the KMF Provides

Combining centralized key management with standards-based OTAR can enable effective planning, implementation and execution of powerful and flexible security doctrine for a diverse set of user requirements.

Components

System (logical) Components

The KMF system includes the following components:
KMF Server: The KMF Server maintains the database of Keys, Subscribers, CKRs as well as system Operator and Administrator users. In tandem with up to 5 attached encryption modules (EMCs), the KMF Server also encrypts and routes all Key Management Messages (KMMs).
KMF Client: The KMF Client provides the main user interface in the KMF System. Aside from limited remote control of the KMF Server, the client allows users to perform management of keys, subscriber units, KVLs, CKRs, operator and administrator user accounts, OTAR commands, OTAR Event Display and KMF Online Help.
Wireless Network Gateway: The Wireless Network Gateway (WNG) serves as the interface between the RF network and the Local Area Network.
Radio Network Controller: The Radio Network Controller (RNC) helps the WNG perform mobility management for subscribers in an ASTRO 25 system.

Software Components

KMF Client Application: The KMF Client application runs on a Pentium machine with NT Workstation. The application will not boot if it is not able to logon successfully to a KMF Server
KMF Server Application: The KMF Server application runs on a Pentium machine with NT Server.

Hardware components

The hardware required to implement OTAR functionality in an ASTRO 25 system is described here briefly.

Windows Machines

At least 2 standard Pentium machines are required for the KMF – one configured to be a Server, the other as a Client. The specifications for these machines are clearly stated in the KMF Installation and Configuration booklet.

KVL3000

Motorola's Key Variable Loader (KVL3000) The KVL3000 serves 4 main functions within the ASTRO 25 system:

Key Fill Device: The KVL's primary function is to serve as a key fill device for all of Motorola's secure communications equipment – that is, subscriber radios, DIUs, RNCs, KMF EMCs, and other KVL3000s.

Configuration Tool: The KVL also serves as a configuration tool that can be used to set and view various parameters within Motorola's secure communications equipment. This role of the KVL is used during the initialization of a secure system, programming sessions of secure modules (KVL & UCM), and maintenance activities done at a service shop.

Mini-Key Management Tool: The KVL can be used as a portable key management device when used in a non-OTAR/non-KMF system.

Store and Forward Tool: When used a KMF, the KVL3000 can be used to store Key Management Messages (KMMs) from a KMF and forward those message to other Motorola Secure Communications Equipment.

WNG: Motorola's Wireless Network Gateway

The WNG is required as part of the Integrated Voice and Data network. It provides verification and authorization functions that register secure devices so that they may request and receive OTAR services. The WNG also provides IP routing and IP to CAI address resolution functions for data applications.

RNC: Motorola's Radio Network Controller

The RNC is required as part of the Integrated Voice and Data network. Together with the WNG, the RNC registers all field units to receive Integrated Voice and Data applications, such as OTAR or data terminal communications. It also tracks the port/base station affiliation for each subscriber device to properly direct outbound host messages in a multi-channel system. Finally, the RNC provides the translation between the CAI and wireline interfaces of the ASTRO radio system and the FLM over IP interface of the WNG and application host environment.

Features

General Features

Correct implementation of a KMF subsystem in an ASTRO 25 system can provide strong, flexible encryption for voice and data. In addition to helping track subscriber units and moving encryption keys efficiently, the KMF includes several advanced security features:

Mark unit as Compromised

From the KMF Client, an operator can mark a unit as Compromised. When a unit is designated Compromised, the unit will receive no further OTAR messages, but may receive inhibit or Zeroize messages.

Secure Inhibit/Enable

A KMF operator can send an encrypted command to inhibit a subscriber radio, making the radio unable to communicate. The enable command reverses this state.

Zeroize

A KMF Operator can send this message to a radio that needs to be excluded from all secured communications. When the subscriber unit receives this message, all encryption keys are deleted from the unit, and it is permanently disable in KMF.

Locked out

When a radio has been locked out using the KMF, any rekey request will be denied and will result in a “no service” message from the KMF.

Local or Remote KVL Connection

The KVL3000 can connect to the KMF via RS-232 port. The KVL’s optional PCMCIA modem adapter can also be used to connect with the KMF from a remote site.

Key Management Database

The KMF client automates the process of managing a database of keys, units and CKRs on the KMF Server. This database can be backed up on network drives, removable media and other servers to provide disaster recovery,

Graphical User Interface

The KMF application allows complicated relationships between subscriber radios and encryption keys to be managed easily by relatively unsophisticated users. The KMF makes use of elements common to many other Windows programs, enabling encryption schemes to be imposed and maintained over a large number of subscriber units with relative ease and efficiency.

Common Off The Shelf hardware

KMF Application Runs on Common-Off-The-Shelf (COTS) hardware, meaning that customers may purchase client and server machines according to the specifications outlined in the KMF user documentation and install the KMF applications on these machines if they choose to do so.

Key Management Features

Key Management

Key Management enables encryption to be imposed over conventional talk groups controlled by Radio Service Software (RSS). Key material can easily be created, inventoried and archived.

CKR Management

Encryption is systematized using Common Key Reference (CKR) groups. CKRs provide a construct by which encryption keys can be efficiently distributed among a configurable list of users.

Unit Management

The KMF allows all subscriber units to be tracked and inventoried via OTAR.

Keyset Management

The KMF application provides an operator with two Keysets to perform rekeying operations. Only one Keyset can be active in the system at a time, and an operator is able to rename and activate either keyset as necessary. This feature enables an operator to perform rekeying operations without interrupting communications.

OTAR Features

Subscriber and DIU Clear Hello

The KMF operator can send a message to any subscriber radio or DIU to confirm that unit is on the system.

Subscriber and DIU Encrypted Hello

The KMF operator can send a message to any subscriber radio or DIU to confirm that unit is on the system with functioning encryption.

Subscriber and DIU Inhibit/Enable

The KMF client can be used to select any subscriber radio or DIU and completely disable any communications using the Inhibit command. This command is reversible using the Enable command.

Subscriber and DIU Zeroize

The KMF client can be used to select any subscriber radio or DIU and permanently erase all encryption keys using the Zeroize command. This command is not reversible using any command. A zeroized radio must be reentered in the WNG database.

Subscriber and DIU Full Update

The entire set of encryption keys assigned to a radio or DIU can be sent via OTAR using the Full Unit Update command.

Subscriber and DIU Optimized Update

Any new encryption keys assigned to a radio or DIU can be sent via OTAR using the Optimized Unit Update command.

Subscriber CKR Group Update

Any new encryption keys assigned to a CKR group can be sent via OTAR using the Group Update command.

Subscriber Keyset Changeover

The Keyset Changeover command activates the formerly "Inactive" keyset and delivers any changes to keyset names to all subscriber units in the system.

Polling

The Polling Feature allows the KMF to track each unit in the system with minimal user intervention, while conserving system resources. When this feature is invoked, the KMF application sends short messages to any unit that has not yet responded to a group OTAR command. Each receiving unit transmits all pending acknowledgements to the KMF, thereby updating the status of the unit.

Subscriber, DIU, and RNC Store & Forward

The KVL can be loaded with pre-addressed messages from the KMF such that the KVL operator's job is greatly simplified. The acknowledgements are likewise stored on the KVL and uploaded to the KMF following the load, so the KMF interface can show accurate encryption status for each unit.

Retry Opportunities

The KMF can intelligently re-try updates to units through the Retry Opportunity mechanisms as follows: When a unit with update messages pending registers with the ASTRO data system, the KMF receives an alert and retries the messages until the message reaches the intended unit.

Management Features

KMF User Account Management

Using the KMF client, users with administrator permissions can create or delete KMF user accounts. Accounts with operator-only privileges are allowed to perform key management and OTAR operations, while administrator permission is required to perform administrative functions at the KMF Server, such as backing up and restoring the database or activating a standby server. The KMF provides password protected Login/Logout capabilities at KMF Client and KMF Server Manager. The KMF also provides administration capabilities for user accounts including new account creation, password protection controls, and privileged assignments. The KMF supports two levels of service for user accounts, these being Operator and Administration. An Operator has access only to key management and OTAR functions; where as, an Administrator has access to those functions plus database administration, user account management, and KMF network administration functions.

Network Element Management

Connections to networked parts of the ASTRO 3.1 data system, such as WNGs and RNCs are managed using the KMF interface.

Encryption Management

All key management and OTAR operations depend on the KMF Server's ability to perform encryption in real time, and this encryption is performed by the EMC module(s) connected to the server. Therefore, EMC status can be viewed from both the client and server interfaces. Only the server interface allows the operator to control the loading of master encryption keys into the EMC.

Key Kettle Management

The KMF allows encryption keys to be stored two different ways in the KMF system: with or without Key ID numbers. Encryption keys stored in the KMF without KIDs show up in a Key Kettle – one per algorithm. Keys are then added to the KMF database from the Kettle, at which point, the key disappears from the Kettle, a KID is assigned to it, and it shows up inside the Keys list. When the number of keys in a Kettle reaches 10, the KMF issues a Key Kettle Low warning, prompting the user to add more keys to the Kettle. Keys are added to the Kettle in three ways: Keyboard entry, in which the key data is typed in via the KMF Client terminal keyboard; KVL, in which keys are loaded from the KVL (these keys are associated with KIDs in the KVL, but the KIDs are ignored when the keys are loaded into the Kettle); and EMC, in which the EMC is used to generate new key material and load it into the Kettle.

KMF System Parameter Management

Some advanced features, such as Retry Opportunities and Auto-Key-Loss-Key Rekeying, can be turned on and off using the System Parameters tab in the KMF Client.

GUI Interface Features

OTAR Event Display

KMF Operators can view the progress of OTAR commands using the OTAR Event Display, which uses colorful icons to indicate the progress, success or failure of OTAR commands.

Event Logging to Database

The KMF system automatically logs all significant events to a flat file on the KMF Server which is then archived every 24 hours.

KMF Instrument Panel

The KMF Client Toolbar can be expanded to reveal the status of encryption modules and other system elements on which OTAR operations depend, giving the operator a simple visual indication of system readiness.

KMF Server Manager

The KMF Server Manager is the interface used to control basic operations of the KMF Server, as well as administrative functions such as database backup, redundancy management and encryption management.

Capabilities

KMF system capability can be roughly quantified by the number of transactions (OTAR message segments) per hour that can be processed with no noticeable delays, and without impact on overall data network traffic. OTAR throughput for a given system is difficult to quantify for the following reasons:

- **Traffic pattern does not resemble communications traffic.** OTAR is a system service rather than a communications service, therefore the system traffic it generates depends more on administration than on user patterns.
- **RF Channel allocation for OTAR traffic depends on system setup.** If OTAR services share an RF channel with other data or voice traffic, availability and capacity of resources are obviously harder to determine.
- **System Topologies are variable.** OTAR services can be applied over a variety of RF system topologies, which may influence the time required for OTAR message delivery and confirmation.

The following factors can be used to guide a determination of the number of KMF Servers to employ for a given system:

Number of Subscriber Units

Currently, the recommended maximum number of secure units per server is on the order of 10,000. The KMF maintains database records for each unit it services, and as database size increases, KMF response time for some operations can also increase. Although OTAR operations are not substantially impacted by database sizes within this range, some database-intensive operations such as viewing a CKR to Unit assignment table will be impacted, eventually reaching a point that users might find unacceptable. Assigning more than a few hundred units to a given CKR will tend to aggravate this aspect of performance and should be avoided when possible.

RF Channel Traffic

The following estimates have been provided for the sake of planning only: They are not to be relied upon as hard limits or specifications.

Importantly, if a single RF channel is to be shared between OTAR message and voice traffic, throughput will be nearly impossible to predict. It is therefore recommended that at least initially, planners allocate RF channels for OTAR traffic only wherever possible.

In either case, usage should be planned on a per-radio-channel basis, using the customer's best working assumption defining how OTAR will be used, coupled with basic guidelines on OTAR/data message capacity on a typical radio channel.

The following guidelines use individually addressed, confirmed service messages as a basis for estimation. These messages, Full Unit Update (FUU) and Rekey Request (RR), are the most traffic-intensive of all operations performed by the KMF, and therefore should serve as a kind of "worst case scenario" when attempting to estimate network impact.

- A typical radio channel will support approximately 500 individual rekeying operations/hour (RRs and/or FUUs) *if* the channel is 100% available for

OTAR traffic, (not shared with voice or another data application), and the transactions originate at a distributed rate instead of all in one burst.

Figure 5.1 illustrates the impact of voice call traffic on OTAR message capacity for a given RF channel.

> **NOTE:** It is unlikely that a customer would put 500 voice users on a conventional channel. They also may not have channels available for OTAR-exclusive use. Ratings like this are meaningful only in describing a channel's capacity under a short-term high traffic load. That is, a channel may occasionally be stressed at a 500 transaction/hr *rate* for a short time if a number of users initiate RRs or the KMF initiates a series of FUUs. In either case the KMF "negotiates" delivery with the radio channel. The targets also negotiate delivery of their responses over the radio channel.

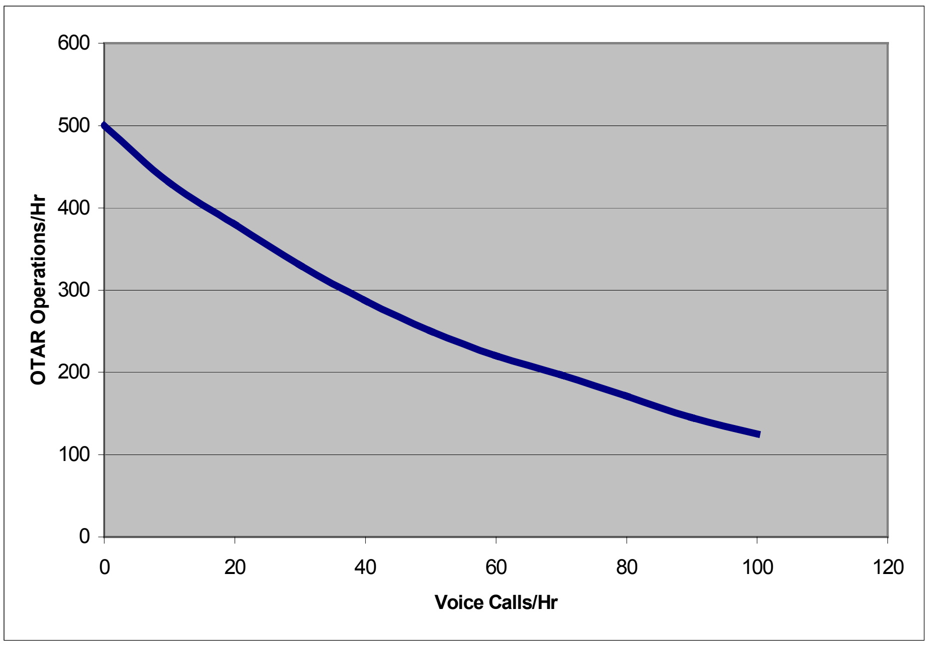


Figure 5.1 Radio Channel Capacity Estimate

Time to Rekey—any one subscriber unit

The total time required to rekey an individual unit is composed of the following components, which are repeated for each message segment: KMF process time + possible hold-off time (due to voice or other data on the channel) + RF delivery time. An individual unit rekey typically requires 3 message segments. KMF process time is typically 3 to 5 seconds per message segment. Possible hold-off time depends on channel loading and is less than 1 second per segment for an idle channel.

Due to the use of confirmed messaging, RF delivery time depends on coverage performance and is typically 2 to 5 seconds per segment in strong signal contours. Taken together, these components create a typical rekey time on the order of 15 to 25 seconds on an idle channel in strong signal conditions. Update time = 3 segments * (5s KMF process + 1s holdoff + 3s RF) = 20s.

Time to Rekey—groups of subscriber units via CKR Update

The total time required to rekey a CKR group is composed of the following components, which are repeated for each message segment: KMF process time + possible hold-off time per site + RF delivery time per site. A CKR update requires one message segment for each organization that shares the CKR, or alternatively, one segment for each "map" that includes the CKR. KMF process time is typically 3 to 5 seconds per message segment. Possible hold-off time depends on channel loading and is less than 1 second per segment for an idle channel; however, the group message is broadcast to all sites in a serial fashion, so the hold-off time is cumulative for each site in the system.

Due to the use of unconfirmed messaging, RF delivery time depends on message length and is typically less than 2 seconds; again, the group message is broadcast to all sites in a serial fashion, so the RF delivery time is cumulative for each site in the system.

Taken together, these components would create an approximate CKR Update time on the order of 60 seconds for a CKR shared by 3 small organizations on a 5-site system where all sites are idle. Update time = 3 segments * (5 seconds KMF process + 5*(1 second "hold-off" + 2 seconds RF per site)) = 60 seconds.

Number of KMF Clients

Each KMF Server can support up to 10 KMF Clients. Although the KMF does not strictly enforce this limitation, instead permitting up to 16 logons, - it has been determined that a single KMF server should support no more than 10 simultaneous logons. A simple method of implementing such a limit would be to enable no more than 10 user accounts per KMF Server. This would work because the KMF Server does prevent more than one simultaneous logon per user account.

Number of Main Servers per Standby Server

The KMF System allows for the designation of a KMF server to be installed as Standby server for one or more Main servers.

The mechanism for designating Standby servers involves placing a backup of the database on the Standby server's hard drive – one for each Main server to be backed up. There is no hard limit to the number of Main servers that can be backed up on one Standby, but the Backup databases of each Main server must be able to fit on the hard drive of the Standby server.

Two other logistical factors limit what can be accomplished using Standby servers:

- First, when a Main server goes down, the Standby server must be manually switched to function as a Main server – the switchover does not happen automatically in KMF release 1.0.
- Second, once the Standby server is switched to functioning in place of a Main server that is off line, any other "Main" backup databases previously stored on that Standby server are not available, nor is the former Standby server available for backing up any other Mains.

Requirements for ASTRO 25 OTAR

ASTRO System Requirements

Integrated Voice & Data

Because ASTRO 25 OTAR relies on data communication between radios and the Local Area Network, Integrated Voice and Data (IVD) is required. An ASTRO system configured for Voice-Only may have ASTRO 25 OTAR added, but only by first adding the necessary IVD components first.

Network Requirements

System Requirements

A Local Area Network running TCP/IP over at least 10-megabit Ethernet is also required for ASTRO 25 OTAR.

Components

System Elements

Required System Elements

In order for ASTRO 25 OTAR to be implemented, the following elements must be in place and visible to each other on the Local Area Network:

- KMF Server
- KMF Client
- KVL3000

Topologies

Client-Server

1 Server, up to 10 clients

For the 3.1 release, the following KMF subsystem topology is approved (Figure 5.2):

- One Main KMF Server
- One Standby KMF Server (optional – recommended)
- One to ten KMF Clients

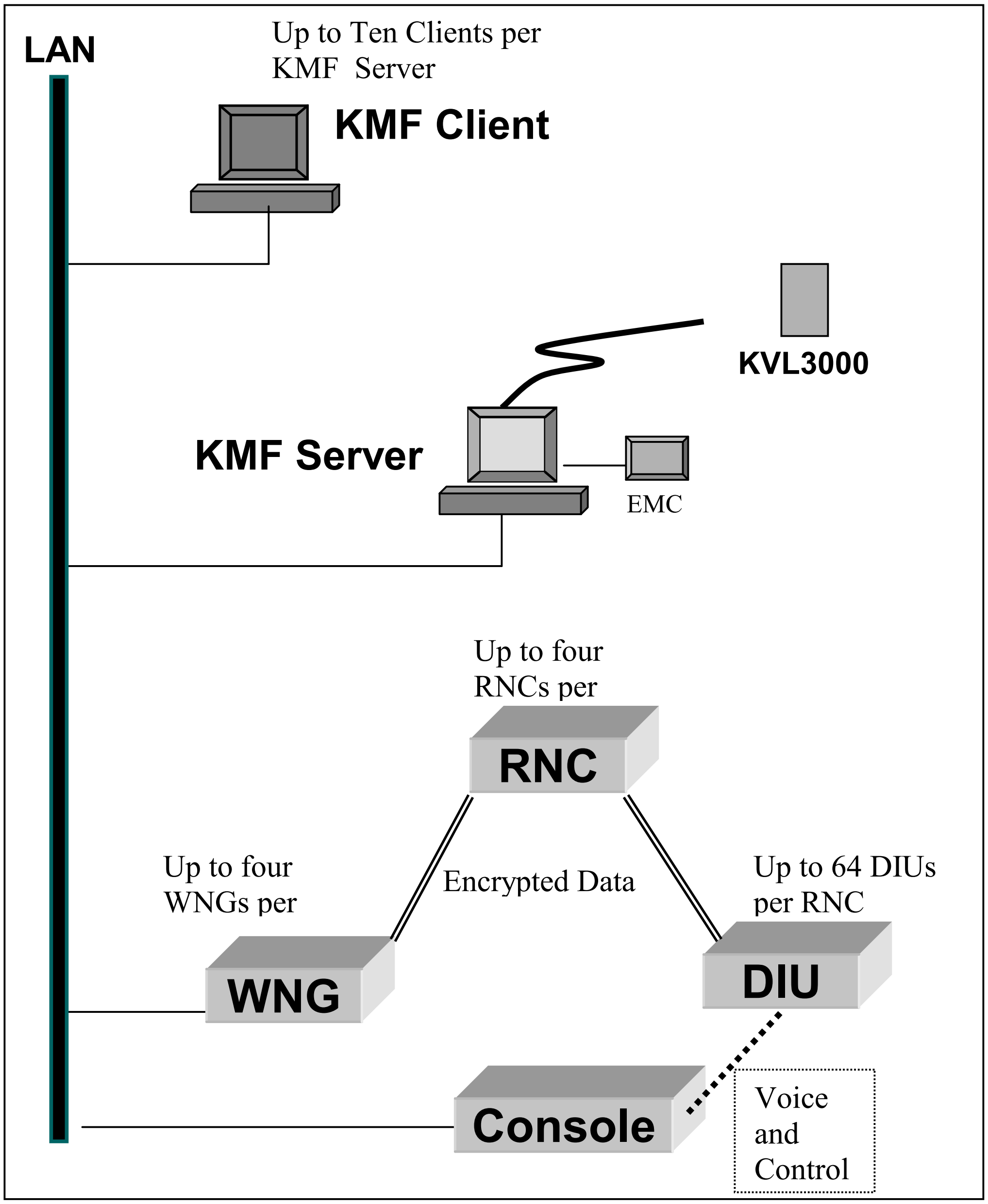


Figure 5.2 KMF Subsystem Topology for Release 3.1

Design Considerations

Planning a KMF subsystem

General Considerations

The following section explains what factors influence KMF System Planning.

Number of Servers

Number of Users

If your system has more than 10,000 subscribers, consider installing two KMF Main Servers and at least one Standby.

Number of Standby Servers

If you are uncertain how to decide whether to recommend a Standby KMF server in a given system, find out if the customer is willing to do without OTAR for as long as a week in the event of a KMF machine failure. There are clear advantages to having a Standby server designated and in place: an instance of the KMF database already stored on the Standby machine, the KMF Server application already installed, the KMF client application cannot run without a KMF Server up and running.

Number of Clients

The number of KMF Client applications needed will depend on several factors. The logistics of network, fleet map, configuration of other system elements should be taken into account. Additionally, keep in mind the difference in capability between KMF Client and KMF Server applications: In short, the Server must be started and stopped using the Server Manager application – these crucial operations cannot be performed using the KMF Client application. Conversely, no key management operations can be performed using the KMF Server Manager. For this reason, a KMF Client is required co-located with the Server.
Ultimately, customer preference will guide the selection of the number and location of the remaining KMF Clients.

TERMS AND PHRASES

Access Method	The ability and means necessary to store data, retrieve data, or communicate with a system. FDMA, TDMA, and CDMA are examples.
ACIM	ASTRO Console Interface Module (CENTRACOM Series II)
Algorithm	A finite set of well defined rules for the solution of a problem in a finite number of steps.
Analog	A signal that can vary continuously over a given range, such as voice.
APCO	Association of Public Safety Communication Officers
ASTRO	MOTOROLA Trademark for Land Mobile Radio Sector's FDMA digital radio system.
Backward Compatibility	Ability of new units to operate within an "old" system infrastructure or to directly intercommunicate with an "old" unit.
Bandwidth	The amount of spectrum, expressed in kilohertz, occupied by information sent on a single communications channel.
BER	Bit Error Rate
BIM	Base Interface Module (CENTRACOM Series II)
Bit	Acronym for binary digit.
Bit Error Rate (BER) Threshold	The level at which the bit error rate exceeds the error correction capability and communication fails in a digital system.
Bit Rate	In a bit stream, the number of bits occurring per unit of time, usually expressed as bits per second or "bps".
C4FM	4-ary FM transmitter which uses QPSK-C modulation to work with a compatible receiver.
CAD	Computer Aided Dispatch
CAI	Common Air Interface
Carrier Squelch	A radio receive mode of operation that unmutes the receiver only in the presence of a received signal.
CATP	Coverage Acceptance Test Procedure
CCITT	International Telephone and Telegraphic Consultative Committee
CEB	Central Electronics Bank (CENTRACOM Series II)
Channel	A single unidirectional or bi-directional path for transmitting or receiving, or both, of electrical or electromagnetic signals.
Channel Rate	The data rate at which information is transmitted through the channel. An example is, "9.6 kilobits per second."

Channel Spacing	Typically measured in kHz from the center of one channel to the center of the next adjacent channel. May or may not be identical to bandwidth.
Circuit Switching	A method of communicating in which a dedicated communications path is established between two devices. Unlike packet switching, digital data are sent as a continuous stream of bits.
CM	Circuit Merit - defines delivered audio quality
CODEC	A COder-DECoder device (analog to digital voice conversion).
COIM	Console Operator Interface Module
Counter Addressing	A synchronizing method used by Motorola in the DVP-XL and DES-XL encryption processes.
DCCM	Display Channel Control Module (CENTRACOM Series II Plus) CCM with an 8 digit, 5x7 dot matrix display and various LED enunciators, for displaying data such as unit ID.
De-key	Turn the transmitter off.
DES	Data Encryption Standard
DES-OFB	Data Encryption Standard - Output Feedback
Digital	A way of representing information using ones and zeros. In an RF environment, the signal can only vary discretely over a given known range.
DIU	Digital Interface Unit (ASTRO)
DPL	Digital Private-Line
DRC	Digital Remote Control
DSMA	Digital Sense Multiple Access ("Busy Bits")
DSP	Digital Signal Processor - A specialized digital microprocessor designed to perform complex functions on analog signals digitizing the voice and sending the results on.
Dual Mode Equipment	Equipment which will transmit and receive information using either the Project 25 standard digital signals or current analog standard signals without modification or interfacing circuits.
DVP	Digital Voice Protection
E & M	A logic signaling arrangement that uses separate leads, called respectively the "E" lead logging input and the "M" lead logic output, for signaling and supervisory purposes over voice circuits usually in microwave applications.
ECC	Error Correction Coding
Embedded Signaling	Digital signaling information which is transmitted simultaneously with voice. It includes such functions as Unit and Talk group ID, site access, and encryption sync information.
Encryption	A coding of plain text (or clear voice) into unintelligible forms for secure transmissions.
EPIC	Enhanced Performance Intelligent Controller

Error correction	Digital coding technique for detecting and correcting information transmission errors.
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access, an access method of improving spectrum efficiency that divides a communication channel into two or more individual channels.
Field Radio	Portable and mobile radios, could also include control stations.
FLASHport	With Motorola FLASHport capable equipment, software can be upgraded by simply "flashing" in the new software via a PC. New PROMs or other hardware are not required.
FLM	Formatted Logical Messaging
FNE	Fixed Network Equipment. That equipment making up the fixed infrastructure of a system.
Format	In a data transmission, the arrangement of contiguous bits or frame sequences which make a group, word, message, or language.
FRU	Field Replaceable Unit
FSK	Frequency Shift Keying
GUI	Graphical User Interface
HLGT	High Level Guard Tone
ICW	Infrastructure Control Word
IMBE	Improved Multi Band Excitation voice coding technique developed by DVSI, Project 25 standard
Inband Signaling	Signaling that uses frequencies or time slots within the bandwidth of the information channel.
Index name	Textual name of the index. Defaults are Index 1 and Index 2.
Internet	A collection of packet-switched and broadcast networks that are connected together via gateways
IP	Internet Protocol
Kbps	Kilobits, or Thousand(s) of Bits Per Second
Key	The parameter defining an encryption code or method.
Key algorithm ID	Identifies the algorithm or encryption type that a key should be used with.
Key data	The actual key variable as entered into the KVL.
Key Index	Key indexing separates the keys into two sets. Selecting Index 1 selects the first set and selecting Index 2 selects the second set. While Index 1 is selected, this feature allows the keys in Index 2 to be changed without interrupting secure communications on Index 1 keys. When all of the radios Index 2 keys have changed, the radios should select index 2 for voice use. Then index 1 keys can be changed for the next encryption period. This feature allows continuous secure communications while keys are changed in the system

Key ID	A 16 bit identifier for the key. Entered into the KVL after the key data is entered.
Key name	Textual name of the key as appears in the RSS screen, the key select menu, or on the display in the event of receiving a call, or optionally, TMSS change to Secure, mode change, or transmitting. Default name in RSS is "Hardware KEY 1". Older radios use "KEY 1" as the default.
Key number	The number of the key as specified in RSS. The key number ranges from 1 to 16 without key indexing and ranges from 1 to 8 with key indexing
Key Physical ID (PID)	The physical location in memory where the key is stored. Same as key slot.
Key slot	The physical location in memory where the key is stored. Same as Key Physical ID (PID)
Key Tag	The parameter defining one of several encryption codes or methods.
KVL	Key Variable Loader (SECURENET)
LC	Link Control
LCD	Liquid Crystal Display
LDU	Logical Data Unit
Linear Amplifier	A radio final amplifier in which the output is linearly proportional to the input. Usually a class A amplifier.
LLGT	Low Level Guard Tone
LPC	Linear Predictive Coding
Modem	Modulator/Demodulator.
Modulation	A controlled variation of any property of a carrier wave for the purpose of transferring information.
MRTI	Motorola Radio Telephone Interconnect
Multikey	An advanced SECURENET feature, this encryption feature allows a single ASTRO radio to be equipped with up to sixteen (16) different encryption keys.
Multiple Algorithm	An ASTRO feature which allows for two Motorola hardware-based algorithms to reside in a single radio unit. This feature supports Interoperability and migration.
NASTD	National Association for State Telecommunications Directors
NCS	National Communications Systems group
NIST	National Institute of Standards and Technology
NTIA	National Telecommunications and Information Administration
PA	Power Amplifier
Packet Switching	A method of transmitting messages through a communication network, in which long messages are subdivided into short packets before transmission. Usually, packet switching is more efficient and rapid than circuit switching.

PL	Private-Line
PPS	Pulse per second
PROJECT 25	APCO created Project 25 Committee, whose purpose is to create a digital standard for Public Safety users. Representatives include members of APCO, NASTD. and the U.S. Federal Government.
Protocol	A set of unique rules specifying a sequence of actions necessary to perform a communications function.
PS	Power Supply
PTT	Push-To-Talk
QPSK	Abbreviation for Quadrature Phase Shift Keying modulation technique; PSK using four phase states.
QPSK - C Family	A form of digital modulation which can use a C4FM FM transmitter or a CQPSK AM transmitter with a CFDD compatible receiver. This modulation method is a blend of 4-level FSK and $\pi/4$ DQPSK, which allows operation using either a transmitter with a frequency modulator using a class C power amplifier or a transmitter with an AM modulator using a linear class AB power amplifier. The CFDD compatible receiver is used for either transmitter.
RAC	Repeater Access Code
RD-LAP	Radio Data Link Access Procedure
RF	Radio Frequency
RHT	Receiver Hang Time
RNC	Radio Network Controller
RNG	Radio Network Gateway
RS-232	An asynchronous, serial, data transmission standard that defines the required sequence, timing, and hardware interface.
RSS	Radio Service Software
SECURENET	Motorola's 12 Kbps voice encryption system.
Software	A set of instructions that tells the computer what to do.
Squelch	A radio circuit that eliminates noise from the speaker when no transmitted signal is present.
STAT-ALERT	Motorola's analog system which allows enhanced signaling capabilities with voice communications.
Subscriber Unit	A mobile or portable radio unit used in a radio system.
System	Any organized assembly of resources and procedures united and regulated by interaction or interdependence to accomplish a set of specific functions.

THT Transmit Hang Time

TRC Tone Remote Control

TSBK Trunked Signaling Blocks

TX Motorola form based messaging application.

UHF Ultra High Frequency

V.24 CCITT definitions for interchange circuits between data terminal equipment (DTE) and data communications equipment (DCE)

VHF Very High Frequency

Vocoder VOice COder-decoDER, a type of voice coder. Usually consists of a speech analyzer and a speech synthesizer which convert analog speech into digital signals for transmission and digital signals back into artificial speech sounds for reception.

APPENDIX A: Voice Grade Channel Requirements

Table A.1 lists Voice Grade Channel Requirements for ASTRO Applications

Parameter	Type 3002	Service Type 5	M1020
Insertion Loss	16 dB	0 to 16 dB (Depends on Network Interface)	
Loss Variation at 1000 Hz			
Long-Term	+/- 4 dB	+/- 4 dB	+/- 4 dB
Short-Term	+/- 3 dB		+/- 4 dB
Modem Tolerance			
Bandwidth	2700 Hz (300 - 3000 Hz)	2700 Hz (300 - 3000 Hz)	
Frequency Response (Ref.: 1000 Hz)			
400 - 2800 Hz		loss, -2 to +10 dB	
500 - 2500 Hz	loss, -2 to +8 dB	loss, -2 to +8 dB	
300 - 3000 Hz	loss, -2 to +12 dB	loss, -2 to +12 dB	
Delay Distortion	1750 microseconds @800 - 2600 Hz	1750 microseconds @800 - 2600 Hz	1500 microseconds @600-2600
Maximum Average Input Signal Level	0 dBm at Network Interface	0 dBm at Network Interface	
Maximum Test Tone Level	0 dBm at Network Interface	0 dBm at Network Interface	
Signal to C-Message Noise Level	>24 dB	>24 dB	
Frequency Shift	+/- 5 Hz	+/- 3 Hz	+/- 5 Hz
Phase Jitter	Less than 10 degrees	Less than 10 degrees (20 - 300 Hz)	Less than 10 degrees

Table A.1: Voice Grade Channel Requirements for ASTRO Applications

APPENDIX B: Circuit Merit Definitions

Circuit merit is a widely used measure of audio quality for analog radios. National Engineering Services Coverage Standards gives the following definitions for analog voice under static conditions (Table B.1).

Circuit Merit Figure	Grade of Performance	SINAD	Approximate Receiver Quieting
1	Unusable, Speech present but unreadable	Below 8 dB	0 to 6 dB
2	Readable with difficulty. Requires frequent repetition.	8 to 16 dB Average = 12 dB	14 dB
3	Readable with only a few syllables missing. Requires occasional repetition.	14 to 22 dB Average = 17 dB	20 dB
4	Perfectly readable but with noticeable noise.	20 to 30 dB Average = 25 dB	30 dB
5	Perfectly readable, negligible noise.	Above 30 dB	40 dB

Table B.1: Analog Voice Circuit Merit Definitions

Receiver sensitivity is often given in terms of the 12 dB SINAD point, which is equivalent to circuit merit 2. It has been assumed that IMBE under strong signal achieves CM-4.4.

APPENDIX C: ASTRO Coverage Prediction

ASTRO Digital Voice Sensitivity

The ASTRO equipment data sheets will give you the radio static performance, such as 12 dB SINAD and 20 dBQ sensitivity for analog FM, but not all data sheets will give you the digital sensitivity value.

In the case of digital radios, the equipment sensitivity is given as 5% static BER (Bit Error Rate) level. This level is the standard bit error rate for C4FM modulation according to TIA/EIA TSB102.CAAA, which is the TIA measurements document for APCO 25 type radios.

This level will deliver approximately the audio quality of Circuit Merit 2 for analog and digital modulation.

System Design for Circuit Merit (CM)

When an ASTRO radio is used in the analog mode, the same rules for the coverage calculation will apply as for other analog equipment. For the ASTRO operational modes, new system design parameters must be defined.

Similar to analog systems, the digital system design has to account for the Rayleigh fading, therefore, a new parameter has been defined, the fading sensitivity. Rayleigh is no longer being considered a reliability factor, but rather part of the sensitivity for the faded case.

Mean Opinion Score (MOS) tests have been used to determine delivered audio quality levels expressed in CM in the static environment and the faded environment for various Doppler frequencies. (See Appendix II for Circuit Merit Definitions).

The delivered CM2 audio quality is normally not good enough for public safety users. Motorola designs the system coverage for CM3, some customers may even ask for CM4 design.

Preliminary design goals for ASTRO systems have been set at CM3 for static and faded environments.

When defining the system coverage, the systems engineer must select the minimal acceptable Circuit of Merit value, estimate the equivalent BER in fading, and note the required signal strength to achieve this BER. The resulting CM depends on the BER, signal level and the fading speed.

ASTRO BER Coverage Prediction

The target BER for a given Circuit Merit is influenced by the equipment configuration and the environment. As a result, the design engineer has to consider the following parameters:

Frequency Band
Radio Speed (Doppler Frequency)
Equipment Configuration
Modulation Bandwidth
Vocoder

The above parameters can be further categorized as:

- Frequency Band
  - High Band (132 - 174 MHz)
  - UHF (400 - 512 MHz)
  - 850 (806 -869 MHz)
- Radio's Speed (Doppler Frequency)
  - Average (70 km/h)
  - Fast (Highway) (100 km/h)
  - Slow (Walking) (5 km/h)
- Configuration
  - Wide IF (11.2 kHz)
  - CEPT IF (7.8 kHz)
  - Narrow IF (5.76 kHz)
- Modulation Bandwidth (C4FM)
  - 25.0 kHz
  - 12.5 kHz
- Vocoder
  - IMBE (3.0 release)

Receiver IF Filter Bandwidth

The ASTRO stations and subscribers have three different IF bandwidths, 11.5kHz, 7.8kHz and 5.76kHz. The station can make use of one of the three bandwidths at any given time. The subscriber can be programmed to use two of the three bandwidths. This capability is needed when the subscriber must listen to some 12.5kHz channels and some 25kHz channels. The 11.5kHz bandwidth is used in systems that used 25kHz channels and +/-5kHz analog FM deviation. A narrow ASTRO modulation can also use this bandwidth. The 7.8kHz bandwidth has been used in European systems and at 900MHz systems. The 5.76kHz bandwidth is a new, very narrow IF bandwidth. This bandwidth was developed to be used in systems where the channel bandwidth allocation is 12.5kHZ and where these 12.5kHz bandwidth channels can be assigned every 12.5kHz in the frequency spectrum.

Coverage Acceptance Test Plan (CATP) Issues

In analog systems, we use the average power level to indicate pass or fail. This does not allow for using a lower noise figure to help pass a CATP. By using BER, the receiver's actual noise figure will establish the performance.

It is anticipated that we will still use the RSSI (power measurement) in addition to BER. Therefore, the receiver should be attenuated to achieve the specification sheet performance for BER, and the RSSI calibration table should be adjusted to reflect the actual power that an unattenuated radio would receive.

Delay Spread Curves for Mosaic

Coverage calculations for digital simulcast systems have traditionally relied on two-source capture models. Such models specify the required signal ratio between two simulcasting sources necessary to achieve some level of performance (for example 1% BER), as a function of differential signal delay. Developing such a capture model for three or more simulcast sources is not very practical, because of the large number of different signal ratios and delay combinations that must be considered.

A more desirable model would be truly based on multiple interferers, rather than on two source approximations. One way to achieve this, is to view the received signal as a single transmission undergoing multiple delay spread. The relative signal strengths and delays would then correspond to the so-called power delay profile of the aggregate signal. The rms value of the aggregated signal is weighted by their respective power levels.

Each ASTRO simulcast system design should be verified with the Motorola Mosaic coverage calculation program.

Narrow/Wide Pulse Design

Narrow pulse refers to 12.5 kHz modulation into a receiver with any of the IF bandwidth configurations. Wide pulse is a special wideband modulation into the wider IF configuration. Wide pulse is intended for simulcast designs. Wide pulse modulation effectively spreads the digital symbols thereby allowing greater site to site separation than permitted with narrow pulse.

ASTRO was designed to utilize the 12.5 kHz channel spacing. The signal filtering allows a reception of two simulcast signals with equal strengths with 38 μs of delay for Circuit Merit 3 audio quality level. The system is using normal 12.5 kHz channel spacing with 5.76 kHz IF bandwidth.

To improve the system performance with signals with larger delays, the wide IF, different transmitter splatter filtering, and higher deviation can be used. This is possible only in a 25 kHz channel spacing configuration.

In addition, site separation degrades as the number of simulcast transmitters increases. This happens because more transmitters make more opportunities for log normal signal strength variation to allow at least one other distant transmitter to come in strong enough to interfere with the nearby transmitter.

The Wide Pulse operation requires 25 kHz channel spacing. If the customer desires a future migration to 12.5 kHz spacing, then a Narrow Pulse simulcast should be designed from the beginning.

NOTE: Subscriber receives in wide-pulse; transmits narrow pulse. Parameters for wide and narrow pulse are set up through radio RSS.