What is APCO Project 25?

Version 1.1

Contents

In 1989, APCO (the Association of Public Safety Communications Officials International), together with other US governmental organizations, set up the steering committee 'Project 25' and gave it the task of selecting appropriate standards for digital public safety mobile radio communications.

This steering committee had the following objectives for its work:

1. Provide enhanced functionality with equipment and capabilities focused on public safety needs.
2. Improve radio spectrum efficiency
3. Ensure competition in system life cycle procurement
4. Allow effective, efficient and reliable intra-agency and interagency communications

The detailed work of producing standards documents was delegated to the Telecommunications Industry Association (TIA). The result to date is a set of over 30 documents, beginning with a System and Standards Definition that was released in November 1995. This document presented a standard system design and identified a number of interfaces that are to be standardized.

The APCO Project 25 Standards

The result of the steering committee's work is a set of standards known as APCO Project 25 (alternatively APCO 25 or P25). APCO Project 25 is the only standard approved by the US Department of Homeland Security that can demonstrate the degree of interoperability required to qualify for US Federal funding. APCO Project 25 is also gaining favor in other countries.

Some of the earliest TIA decisions related to the CAI (common air interface). The committee opted for the following technologies:

- FDMA (frequency division multiple access). This simply means that the spectrum is divided up into channels, each of which occupies its own share of bandwidth. By contrast, other technologies give multiple access by using timeslots (e.g. TDMA) or separate codes (e.g. CDMA).
- 12.5 kHz channel spacing. This is twice as efficient as traditional analog wideband channels, which generally use 25 kHz.
- C4FM (compatible 4-level FM) modulation scheme. This enables 9600 bits per second to be transmitted on the 12.5 kHz channel
- IMBE (improved multi-band excitation) vocoding. This enables speech to be represented digitally using a bandwidth of only 4.4 kbps.

Many of the technologies used in Project 25 are proprietary, but the steering committee decided that it would only include a technology if the owners of intellectual property rights agreed to license it to other participating manufacturers at no cost (for mandatory features) or under "fair, reasonable and non-discriminatory terms."

The standards do not impose a rigid uniformity. Manufacturers can choose to offer conventional or trunked, voice, data, or both, encryption options or clear only, and so on. A feature can be mandatory (all compliant product must support it), standard (not essential but if offered, it must conform to the definition), or optional. For example, the various data services are standard features: equipment is

not required to support them, but if it does, the implementation must follow the standard.

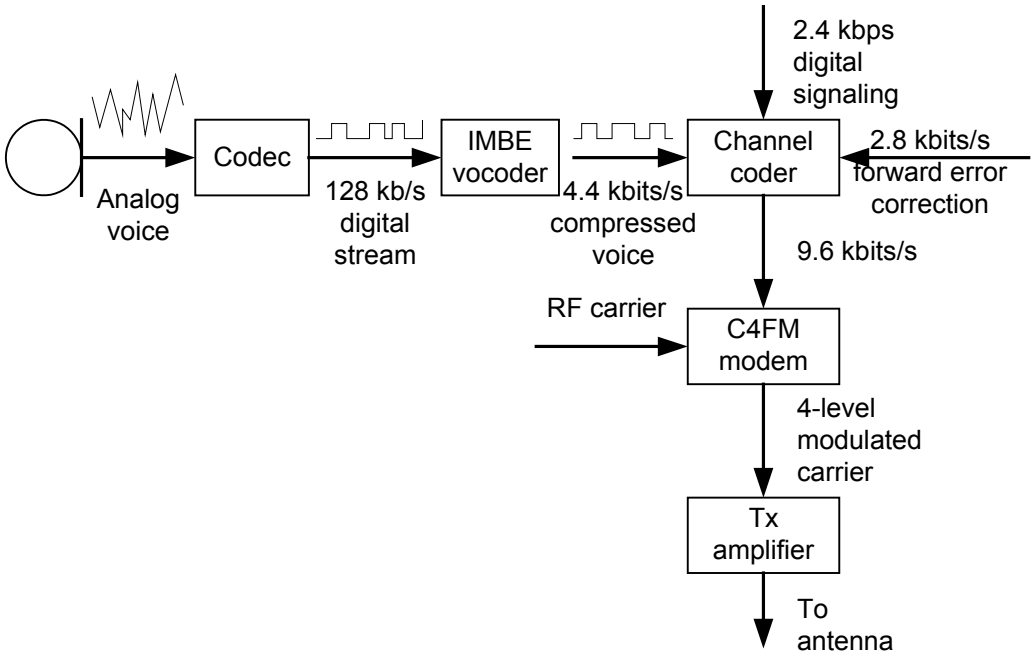
The APCO Project 25 standards will continue to evolve. What we currently have is P25 Phase 1. Already Phase 2 is being planned, which will for example use 6.75 kHz channel spacing and require different modulation scheme(s).

Advantages of APCO Project 25

- There are no unreasonable intellectual property barriers to P25. P25 is an open standard and manufacturers can easily license patented technologies. Users will have a good choice of suppliers.
- P25 is a digital standard and offers the option of encryption.
- P25 lets you start with analog and transition gradually to digital. You don't need to throw away all your existing equipment. P25 equipment must be able to talk to existing conventional radios in analog mode.
- There is no need to obtain a clean new block of RF spectrum. Existing 25 kHz channels can still be used by analog radios and divided into two 12.5 kHz digital channels as needed.
- P25 uses proven technology. While for example FDMA is not the newest technology, it is well understood and very reliable.

Theory of Operation

P25-compliant radios can operate in digital or analog mode. The figure below and the accompanying step-by-step description show the operation in digital mode:



1. The microphone converts speech into an analog electrical signal.
2. The codec samples that signal and produces a stream of digital information. This information is coded at 128 kbits/s.
3. The vocoder (voice encoder) compresses this digital information, using algorithms especially designed for voice. For P25, the vocoder uses IMBE (improved multiband excitation). This reduces the bit rate to 4.4 kbits/s
4. To protect the voice signal from errors caused by fading and interference, encoded bits are added to the voice information. This is known as forward error correction (FEC) and enables receivers to correct such errors, as long as there aren't too many of them. It adds 2.8 kbits/s to the bit stream.
5. Signaling information is interwoven with the voice signal, adding a further 2.4 kbits/s. (This signaling doesn't just appear at the beginning of the voice stream; it is interwoven with it, so that users can still join a call, even if they missed the beginning.) Header and terminator data units are added to the start and end of the voice stream to complete the data frame.

A P25 modem modulates the carrier with this digital data, using the C4FM modulation scheme. Receiving a P25 signal proceeds as the reverse of the above. The radio demodulates the signal, corrects any errors, and extracts the signaling. The vocoder and the codec then reconstruct the analog voice signal from the digital data.

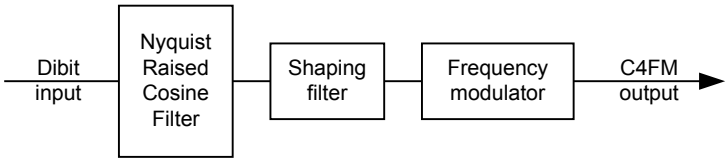
C4FM Modulation

While analog FM modulates the frequency of transmission using the voice waveform, digital transmissions must transmit a stream of zeros and ones and these must be encoded in some way on the carrier wave. The APCO P25 Phase 1 standard mandates the C4FM modulation scheme. This scheme handles the data at 9.6 kbits/s, which means that receivers must be able to detect a set of two bits about every 200 microseconds.

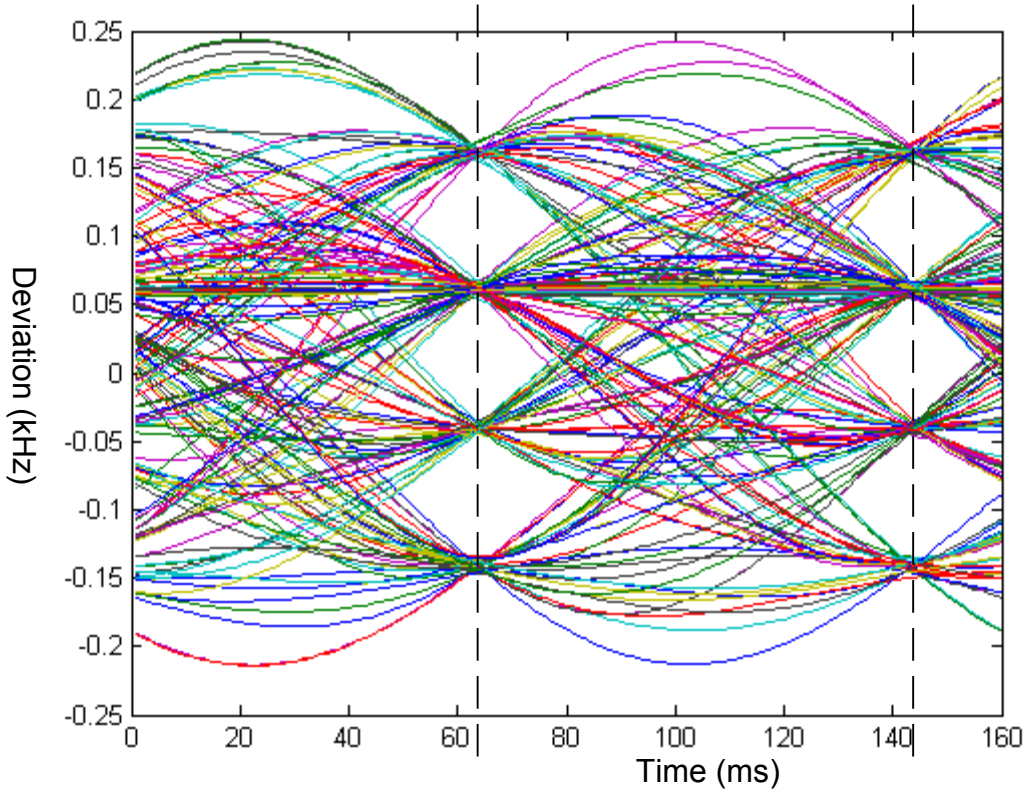
In the C4FM modulation scheme, each set of two bits (dibit) is represented as a fixed deviation from the transmit frequency:

Information	**Frequency deviation**
01	+1.8 kHz
00	+0.6 kHz
10	-0.6 kHz
11	-1.8 kHz

The RF output of digital C4FM, like that of analog FM, has a constant amplitude. Two filters are used to prepare the digital signal for input into the modulator. The Nyquist filter aims to minimize interference between symbols and the shaping filter helps to make the signal immune to noise on the channel (to improve performance, rather like the pre-and de-emphasis on analog FM transmissions).



The result is a waveform that makes a smooth transition between dibits, as shown in the following eye diagram.



When the transmitter is functioning properly, the deviation at the moment of measurement is very close to the nominal value for the pair of bits. The receiver can decode the bits with a high degree of accuracy.

Dual Mode

P25-compliant radios must be able to operate in both analog and digital mode. This means that they are backwards compatible with conventional analog FM radios. A P25 user can select an analog talk group and converse with others who have legacy analog equipment.

Services

The APCO Project standards define the following services.

Feature	Definition	Conventional	Trunking
Affiliation	Affiliation allows the operator of a subscriber unit to change from one talk group to another.	Not Available	Standard Option
Announcement Group Call	Announcement Group Call is a special talk group call that allows a user to address several different talk groups simultaneously.	Not Available	Standard Option
Broadcast Voice Call	Broadcast Voice Call provides one-way voice calls from an originating user to one or more other users. The target user group may be a subset of all of the system users or it may be all of the system users.	Not Available	Mandatory
Busy Queuing	When all available channels are busy, requests for service are placed in a "busy queue", with assignment to the next available channel made based on the priority level of the waiting call(s) and order of request.	Not Available	Standard Option
Call Alert	Call Alert is an individual selective calling feature that allows a dispatcher or another subscriber to selectively alert another individual unit that the caller is trying to contact him.	Standard Option	Standard Option
Call Interrupt	Call interrupt allows a dispatcher to interrupt a call enabled by the system by directing the call to the individual with the proper priority.	Not Available	Standard Option
Call Restriction	Call restriction is a service that limits the services a subscriber may receive from a system. Restriction may be controlled by the subscriber unit or by the system.	Not Available	Standard Option
Call Routing	Call routing allows the system to process a call in a resource-efficient manner.	Not Available	Standard Option
Continuous Assignment Updating	Talk group activity is constantly reported on the control channel, such that it assures that a radio just coming into the system will be immediately assigned to the appropriate voice channel if the talk group it is set to is active.	Not Available	Standard Option
Discreet Listening	Discreet listening allows a user to listen to or block calls based on specific signaling criteria.	Standard Option	Standard Option
Encryption	Encryption allows for the protection of voice and data within a Project 25 system.	Standard Option	Standard Option
Group Voice Call	Radios assigned a given talk group are provided with talk group call and will, under normal operation, only communicate with members of the same talk group. Special cases of Talk Group Calls include Announcement Group Calls, Broadcast Voice Calls, and System Call.	Standard Option	Mandatory
Individual Voice Call	A dispatcher or subscriber unit may selectively call another unit to carry on a private conversation.	Standard Option	Mandatory
Interconnect	Properly equipped and authorized subscribers can initiate and receive calls from telephone network.	Standard Option	Standard Option

Feature	Definition	Conventional	Trunking
Message	This feature allows a subscriber operator to send preprogrammed messages to a dispatcher	Standard Option	Standard Option
Misdirected Radio Protection	If the radio accidentally locks onto the wrong voice channel it will be pushed back to the control channel to wait for the next call. This keeps radios from mistakenly participating in the conversations of other talk groups.	Not Available	Mandatory
Multiple Algorithms	Multiple algorithms allow interoperability with standard encryption algorithms.	Standard Option	Standard Option
Multiple Key Encryption	Multiple Key Encryption is an encryption attribute in which a minimum of eight (8) key variable can be made available for communications within a given system.	Standard Option	Standard Option
Over The Air Rekeying (OTAR)	OTAR allows for adding, changing, deleting, and managing the encryption keys of radio units over the air.	Standard Option	Standard Option
Priority Call	Individual users and groups of users may be assigned different priority levels.	Not Available	Standard Option
Preemptive Priority Call	A preemptive priority call is a call that will always be granted resources, even if it means the system must disconnect a lower priority call already in progress.	Not Available	Standard Option
Radio Check	Check allows a system user to verify if a desired target radio is (l) turned on and functioning and (2) within range of the system.	Standard Option	Standard Option
Radio Unit Disable	Radio Unit Disable allows a dispatcher to send a signal to the target radio that renders the radio totally inoperable.	Standard Option	Standard Option
Radio Unit Enable	Radio Unit Enable allows the dispatcher to send a signal to the target radio that revives a subscriber unit that was previously disabled	Standard Option	Standard Option
Radio Unit Monitoring	Radio unit monitoring is a feature by which a dispatcher may remotely cause a selected subscriber to transmit without the subscriber operator's intervention, and without causing an audible or visual indication at the subscriber unit that it is transmitting.	Standard Option	Standard Option
Registration	Registration provides a means of restricting service access to only valid subscriber units.	Not Available	Mandatory
Roaming	Roaming allows a subscriber unit to move from the coverage of one site (or system) to another site (or system).	Standard Option	Standard Option
Silent Emergency	Silent Emergency allows a subscriber operator to trigger a call without using the push-to-talk switch, for example with a push button switch.	Standard Option	Standard Option
Status Request	Status Request allows a user of the system to determine the status of another user of the system. This feature is initiated at a system control point.	Standard Option	Standard Option
Status	Status allows a subscriber operator to send a preprogrammed status updates to the dispatcher.	Standard Option	Standard Option
System Call	System Call is a specific example of a Broadcast	Not Available	Standard

Feature	Definition	Conventional	Trunking
	Call that allows a system dispatch operator to make a high priority call to all users of the system.		Option
Talking Party Identification	The unit ID of a transmitting unit is embedded in the digital signaling on every transmission.	Standard Option	Standard Option
Unaddressed Voice Call	Unaddressed Voice Call provides two way voice calls from any user to an indefinite collection of one or more users. All parties within the coverage of the Unaddressed Voice Call can hear each other.	Mandatory	Not Available

Data Communications

APCO Project 25 radio systems can optionally support data services. The standard envisages two main categories of data services: circuit-switched and packet-switched. In addition, it defines three different configurations for those data services: radio to radio, radio to radio via repeater, and radio to fixed network equipment. To be Project 25 compliant, a data system must support one or more service/configuration combinations.

In APCO Project 25, data services can run on the same equipment as voice. A system does not need to have dedicated data channels.

Circuit-switched data

In this data service, the radio behaves like a modem. A data terminal (DTE) device can be attached to the radio and communicates with it using the AT command set specified by the TIA/EIA-602 standard.

Packet-switched data

This data service is IP-based. A data terminal device communicates with the radio via SLIP or PPP and can pass IP packets to fixed network equipment or to other radios directly or via the infrastructure.

The raw data rate is 9.6 kbits/s. The actual data throughput for unconfirmed data is up to 7.2 kbits/s, once the overheads of forward error correction, header, and status bits are subtracted. If the data is confirmed, the radio must also periodically wait for acknowledgement and selectively re-transmit, resulting in data rates of up to 4.8 kbits/s.

Low speed data

APCO P25 also supports low speed data (around 80 bits/s) which is embedded in the voice stream. A protocol standard for this has yet to be developed, but at least one manufacturer has used low speed data to transmit GPS positioning information.

Digital Signaling

The P25 CAI defines signaling information that is sent over the air along with voice. Because transmissions are digital, it is easy to add extra information such as the destination talkgroup and caller ID.

Receiver Squelch

Analog conventional radios can send subaudible signaling to enable radio and base station receivers to discriminate between incoming calls. A receiver only unmutes to the calls intended for it. P25 radios can do the same in analog mode, but in digital mode, they use a digital equivalent. The P25 standards define two items of information that can be used to discriminate between calls. The first item is the Network Access Code (NAC), and the second is a talkgroup ID or an individual ID. The NAC must be present but a talkgroup or individual ID is optional. Radios can be programmed to unmute only when an incoming call contains correct values for both items.

Network Access Code

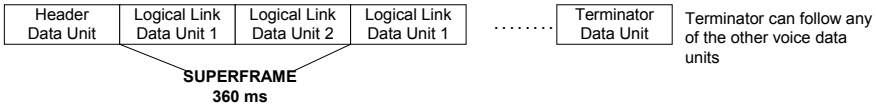
The NAC is a 3-digit hexadecimal number. It can be used as a means of selectively accessing the base station infrastructure. An NAC can specify a particular base station/repeater or a particular network. It then functions as a base station or network address. If the network is a TaitNet digital network, the NAC can specify a channel group within the network. When the NAC is used in this way, radios and the base station are all programmed with the same receive and transmit NAC. This prevents receivers unmuting to signals from other sources. Different channels can be given different NACs, so that users can access different base stations or networks using the same frequency pair simply by changing channel.

Alternatively, the NAC can be used to distinguish particular groups of users. It then functions as a talkgroup ID. Each group of radios is given a particular NAC (generally the same one for transmitting and receiving). The base station infrastructure is configured so that it receives any NAC and retransmits the NAC that it received. Special NAC values make this possible: 0xF7E tells the base station receiver to unmute when a digital signal with any NAC is detected. 0xF7F does the same, but also tells the base station to use the NAC of the received signal when retransmitting.

Structure of P25 Speech Frames

An over (part of a conversation that begins when the user presses PTT and ends when he/she releases it) starts with a Header Data unit, continues with a series of 'logical link data units' (LDU) that carry the digital speech, and ends with a Terminator Data unit.

There are two types of LDU: LDU1 and LDU2. The two together are referred to as a superframe.



The Header data unit contains:

- Frame synchronization information
- Network Identifier (NID), containing the Network Access Code and the Data Unit Identifier (indicates what type of data follows).
- the ID of the talk group that the caller belongs to
- encryption information (not used by the TB9100 in the first release)

- Manufacturer's ID (not used, enables systems to implement special features specific to one manufacturer)

LDUs (both LDU1s and LDU2s) contain:

- frame synchronization
- NID
- 9 voice codewords (IMBE frames)
- status symbols, which indicate whether the channel is busy, idle, or unknown

The terminator data unit contains frame synchronization and the Network ID. It signifies the end of the message.

Interoperability

Improving interoperability is one of the aims of Project 25. Interoperability is 'the ability of public safety personnel to communicate by radio with users from other agencies or departments.'

Public safety agencies need to interoperate in the following ways:

Day-to-Day interoperability involves coordination during routine public safety operations, for example:

- Firefighters from various departments join forces to battle a structural fire
- Neighboring law enforcement agencies must work together during a vehicular pursuit.

Mutual-Aid interoperability involves a joint and immediate response to a catastrophic accident or natural disaster and requires tactical communications among numerous groups of public safety personnel. For example:

- Airplane crashes
- Bombings
- Forest fires
- Earthquakes

Task Force interoperability involves local, state, and federal agencies coming together for an extended period of time to address an ongoing public safety concern. Task forces lead the extended recovery operations for major disasters, provide security for major events, and conduct operations in prolonged criminal investigations.

Levels of Interoperability

Radio systems offer different levels of interoperability. Task forces need a high level, while a lower level suffices for routine public safety operations. SAFECOM, a US Federal organization concerned with interoperability issues for radio communications systems, has endorsed an analysis (originally proposed by Motorola), which defines six levels of interoperability. The following table summarizes these levels, from the highest (shared systems) to the lowest (swap radios).

Interoperability Level	Description	Comment
Level 6 *Standards-based Shared Systems*	One large shared system with common or coordinated administration.	Long-term solution. Currently only possible using proprietary technology. Very expensive.
Level 5 *System-specific Roaming*	Use compatible radios and pre-arranged roaming agreements and authorizations.	Supports a full range of features. Wide area.
Level 4 *Gateway (Console patch)*	Dedicated hardware temporarily connects two incompatible systems together via 4-wire audio or RF links.	Requires time and effort to set up on the fly. Radio can't leave home system.
Level 3 *Mutual Aid Channels*	A Mutual Aid repeater system has been set up. Users manually switch to a mutual aid channel when they want to communicate with users from another agency.	Requires planning and radio programming. Disconnects radio from home system.
Level 2 *Talkaround/Direct Mode*	Users from different agencies select a channel that bypasses their repeater systems. The users communicate directly with each other.	Simple short-term solution. Limited range.
Level 1 *Swap Radios*	One agency supplies some of its own radios to another agency.	Simple short-term solution. Requires cross-training on radios.

To meet the goal of Level 6 interoperability, the P25 standards are being expanded to include a standard for interconnecting different radio systems. The proposed Inter RF Sub-system Interface (ISSI) will tie together radio systems that presently must rely on vendor proprietary solutions to inter-work. Although this standard is expected soon, today's situation is that P25 systems from different vendors cannot interoperate without the assistance of a proprietary solution.

Crossband Interoperability

While interoperability is one of several drivers for APCO Project 25, the standard does not mandate a specific frequency band (although 700 MHz is planned for future interoperability). As subscriber units are generally only capable of operating on a single band of frequencies, the need for crossband capabilities may arise. For example:

- Two or more agencies wish to pool some of their infrastructure resources but for various reasons must operate on different bands (already purchased radios,

not enough channels available in either band). Generally each agency talks amongst itself but sometimes talks to the others.

- A system is built in one area and another system is built in neighboring area on a different band. Sometimes users from the neighboring system must visit. The visitors are likely to need to talk to both the visited system's regular users and their home system's dispatcher. In this case there is a primary band used by the regular users and secondary band(s) used by visitors.

When the FCC opened the 821-824/866-869 MHz spectrum to Public Safety use in the 1980s, it also established the National Public Safety Planning Advisory Committee (NPSPAC), to recommend rules for assigning and using the new spectrum.

NPSPAC recommended (and the FCC adopted) five Interoperability channels: one calling channel, and four tactical channels. In negotiating the border interface zones with Canada and Mexico, these five pairs were also adopted by those countries for Public Safety interoperability use. The channels, therefore, are known as I-CALL (866.0125), and I-TAC 1 thru 4 (866.5125, 867.0125, 867.5125, and 868.0125 respectively).

In the Fourth Report & Order (January 2001), the FCC adopted Project 25 Phase I as the voice standard for communications on the 700 MHz band interoperability channels, which are channels specifically set to allow different public safety entities to communicate with one another.

The 700 MHz band covers 764-776 and 794-806 MHz, and the interoperability channels may occupy up to 2.4 MHz of this. When a plan for these interoperability channels is available, it is desirable that they are supported in a cross-band repeater configuration.

Summary: APCO P25 and Interoperability

While the chief barriers to achieving interoperability are organizational and procedural, Project 25 is able to overcome some technical barriers.

- Project 25 radios must be dual mode. This means that they can communicate with legacy analog FM radios. If one agency has a Project 25 system and another has an analog FM system, they can interoperate by talking on an analog FM channel. This can be done in direct mode (repeater talkaround) or by setting up Mutual Aid channels.
- Project 25 requires manufacturers to ensure backwards compatibility with their own legacy equipment.
- Purchasers of P25 radios can have confidence that their equipment is interoperable with P25 equipment from other manufacturers.
- Radio services are implemented in a defined way. If they are mandatory, P25 radios must support them. If they are standard, they are optional, but if provided, they must be implemented as the TIA standards define them.
- Trunked P25 radios can roam to other networks and still operate (roaming agreements, authorizations, and radio programming are necessary for this)
- P25 envisages a standard interface between RF subsystems. When this interface is defined and manufacturers implement it, it will be possible to link networks together with a common or coordinated administration.

Further Reading

Both of the following standard textbooks summarize APCO project 25:

Boucher, N (2000) *Trunked Radio and Enhanced PMR Radio Handbook* John Wiley

Singer, E (1994) *Land Mobile Radio Systems* 2nd Edition Prentice Hall

The UK-based Radiocommunications Agency has produced a digital project report, looking at different kinds of digital professional mobile radio:

Radiocommunications agency (2002) *PMR Technology Appendix*. Available from www.ofcom.org.uk/static/archive/ra/topics/pbr/digital/digitalreport/pmrtechappdx-v1.pdf

The standards themselves are available from the TIA (www.tiaonline.org). The following gives a general overview:

TIA (1995) *TSB102-A APCO Project 25 System and Standards Definition*

The APCO, P25 interest group, and TIA websites provide news and information:

www.apcointl.org

www.project25.org

www.tiaonline.org/standards/project_25/index.cfm

Among other manufacturers, Motorola has an overview of Project 25:

http://www.motorola.com/cgiss/LA/products/systems/english/apco25overview.htm

