

# The Firefighter's Guide to Open Standard P25 Communications.

2013 Edition: Includes Introduction to  
other Digital Radio Standards.

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## INTRODUCTION TO P25

As yesterday's radio communications networks age and struggle to support new services demanded by today's ever-changing public safety environment, firefighters find themselves needing to make decisions regarding their communications network sooner than expected. The decision is not only vital to the safety and productivity of today's workforce, it's a decision that must be far reaching enough to satisfy future needs over a 15-20 year useful life of the network infrastructure.

What makes P25 so special? Firstly, it was designed by public safety users in conjunction with radio manufacturers to provide real-world mission critical communications. It provides reliable and clear communications over a wide area.

As an open standard it offers true interoperability which guarantees that users of this technology will always be able to talk to each other. It also guarantees a competitive market in which manufacturers strive to improve quality and cost-effectiveness of their products. Finally, the success of the standard can be judged by the fact that not only have P25 systems been deployed by public safety agencies globally, but that the standard has matched the needs of other industries such as power utilities and transport systems.

The discussions that follow will examine what is necessary in today's public safety communication. Then we take an in-depth look at P25 technology features and benefits and how they affect your department. Next we look at how P25 can meet the narrowbanding frequency challenge set by regulators who are responding to the communication needs of public safety in the face of a critical shortage of radio spectrum. Public Safety agencies not only have a choice of vendors, but a choice of technology. This paper will also introduce new digital mobile radio technologies that are seen as a viable choice for public safety agencies. Finally, we give an evaluation of your present system and an analysis tool to begin the process of moving your communications towards the evolving standards.

**Voice and data communications need to be seamlessly available from one end of the jurisdiction to the other.**



## KEY ELEMENTS FOR A FIRE DEPARTMENT'S COMMUNICATIONS SYSTEM

Below are the most important elements firefighters need in their communications:

- ▶ Reliability
- ▶ Clarity
- ▶ Good coverage
- ▶ Appropriate call services
- ▶ Privacy
- ▶ Interoperability
- ▶ Data

### **Reliability**

Unlike cell phone or home computer users accessing a public network, public safety officers cannot tolerate dropped calls or outages of any kind.

### **Clarity**

Urgent communications between officers and agencies need to be clear. Instructions misunderstood due to noisy backgrounds or distorted speech places officers in danger.

### **Good coverage**

An officer who can stay in touch with his agency is never alone. In contrast, an officer who loses contact is isolated and vulnerable. Availability of service at the very edge of an department's jurisdiction or inside a building is achieved through networks engineered for good coverage.

### **Appropriate call services**

Different agencies have different requirements for how their staff communicates. For some, an all-informed broadcast service is enough. Fire Officers, on the other hand, rely on being able to make unit to unit calls inside a fire scene. Many agencies organize their personnel into groups and require the ability to make group calls. The demands of command and control across multiple groups and multiple emergencies create the need to send special emergency calls and to prioritize other calls in various ways. In short, call services must match your agency's operational requirements.

### **Privacy**

Increasingly, fire departments are protecting their communications from eavesdropping by installing encryption technologies. Encryption ensures that only the intended parties can understand a received call, which to anyone else sounds like noise. Unwanted listeners – whether hostile or friendly - are therefore cut out of the communications network, leaving agencies to manage incidents more effectively.

### **Interoperability**

Now more than ever, agencies cooperate and consequently must communicate with each other. For agencies replacing aging analog equipment, the US government will supply federal funding on the condition that the replacement technology is probably interoperable.

### **Data**

Once considered a "nice to have", data has assumed a greater role as agencies rely on their communications systems to pass text messages, status updates, information about vehicle positions, incident locations and details from public safety databases, etc.

## THE P25 STANDARD AND ITS BENEFITS FOR FIRE DEPARTMENTS

P25 started life in 1989 as APCO project 25. APCO is the Association of Public Safety Communications Officials, a user organization representing police, fire, emergency medical and other public safety agencies. Among the various projects they initiated was project number 25 to define a digital radio technology for public safety users. The broad goals of this project were to:

- ▶ get the best possible use out of radio spectrum,
- ▶ allow effective and efficient communication within a public safety agency and between agencies,
- ▶ ensure that a competitive market would exist in which different manufacturers could participate, and
- ▶ create a technical platform for equipment that was easy to use.

With the active participation of radio vendors, the result of this initiative has been a dynamic and expanding suite of standards, driven by user needs, in tune with the rapidly evolving digital technologies of modern computer networks and voice over IP. This set of standards is administered by the TIA (Telecommunications Industry Association) as TIA 102, the official name for the P25 standards.

### P25 IS AN OPEN STANDARD

P25 is a truly 'open' standard and is not proprietary to a single manufacturer. This means that competition is possible between manufacturers not only when a new system is purchased but over the lifetime of the system (e.g. each time new subscriber units are purchased). The P25 standards define conventional, trunked and simulcast systems.

#### What are the mandatory requirements of the P25 Standard?

There is clear definition on P25 functionality, and in order for a manufacturer to claim P25 compatibility they must meet certain minimum functional criteria. At a minimum, to ensure interoperability between different manufacturers equipment, a P25 radio must meet two mandatory P25 Standard interface components:

- ▶ The Common Air Interface (CAI) that defines the digital radio transmissions which are at the heart of P25.
- ▶ The Improved Multi-Band Excitation (IMBE) or Advanced Multi-Band Excitation (AMBE) vocoder that converts voice to digital.

**Officers in the field depend on clear, available, noise-free communications.**



**What are the standard options in the P25 Standard?**

There is also a range of defined ‘standard options’, which a manufacturer may choose to add to their product. However, if included, the option must operate as defined by the P25 standards. This ensures interoperability between different manufacturers who choose to include these features. For example, the various data services and encryption are standard features; equipment is not required to support them, but if it does, the implementation must follow the standard.

**What are the manufacturers’ options in the P25 Standard?**

Beyond what is mandated and the range of standard options, there is a third category of features, which may be unique or proprietary to a manufacturer. These are known as manufacturers’ options. This means that although many manufacturers make P25-compliant equipment, not all P25 systems are created equal. Individual manufacturers are free to incorporate additional features and functionality into their products. Proprietary encryption technologies or proprietary schemes for interconnecting radio networks can be useful or add value at a lower cost, but also create an interoperability barrier since they generally cannot be used with other vendor’s equipment.

**INTEROPERABILITY FOR FIRE DEPARTMENTS AND SPECIAL TASK FORCES**

Interoperability is one of the major objectives of P25. Interoperability is the ability of public safety personnel to communicate by radio with users from other agencies or departments. Interoperability with analog radio equipment also provides a migration path to digital.

**Six Levels of Interoperability in Radio Communication Systems**

Radio systems offer different levels of interoperability. Task forces need a high level, while a lower level suffices for routine public safety operations. SAFECOM ([www.safecomprogram.gov](http://www.safecomprogram.gov)), a US Federal organization concerned with interoperability issues for radio communications systems, has endorsed an analysis which defines six levels of interoperability. The table on the next page summarizes these levels, from the highest (shared systems) to the lowest (swap radios).

**Different agencies and departments need to be able to talk to one another.**



**LEVELS OF INTEROPERABILITY FOR RADIO COMMUNICATION SYSTEMS** (as endorsed by SAFECOM)

INTEROPERABILITY	DESCRIPTION	COMMENT
<b>LEVEL 6</b> <b>Standards-based Shared Systems</b>	One large shared system with common or coordinated administration	Long-term solution. Currently only possible using proprietary technology. Very expensive.
<b>LEVEL 5</b> <b>System-specific Roaming</b>	Use compatible radios and prearranged roaming agreements and authorizations.	Supports a full range of features. Wide area.
<b>LEVEL 4</b> <b>Gateway (Console Patch)</b>	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.
<b>LEVEL 3</b> <b>Mutual Aid Channels</b>	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.
<b>LEVEL 2</b> <b>Talkaround/Direct Mode</b>	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.
<b>LEVEL 1</b> <b>Swap Radios</b>	One agency supplies some of its own radios to another agency.	Simplest short-term solution. Requires cross-training on radios.

Fire departments need to inter-operate in the following ways:

▶ **Gradual migration to digital**

It is not always possible (financially or logistically) to upgrade an entire radio fleet at one time. It is often necessary for the new radios being installed to operate with the existing radios until all can be replaced over a period of time. Only when all the radios have been installed and/or issued can the transition to P25 be completed.

▶ **Day-to-day interoperability**

Involves coordination during routine public safety operations, for example: 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:

- ▶ Aircraft crashes
- ▶ Terrorist incidents
- ▶ Wide area wild fires
- ▶ Earthquakes/hurricanes.

▶ **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.

## **COMPLIANCE TO THE P25 STANDARD**

A basic requirement for Phase 1 P25 digital radio equipment is backwards compatibility with standard analog FM radios. This supports an orderly migration into mixed analog and digital systems, enabling users to gradually trade out radios and infrastructure equipment.

Agencies can invest in the latest P25 technology and operate it initially in analog mode with the assurance that there is a clear migration path to the future.

### **The P25 Common Air Interface (CAI)**

Some of the earliest and most fundamental TIA decisions relate to the CAI standard. This interface standard specifies the type and content of signals transmitted by P25 compliant radios. A P25 radio using the CAI should be able to communicate with any other P25 radio using the CAI, regardless of manufacturer. The CAI also defines the 'to' and 'from' addresses, encryption, trunking and conventional control messages. The coverage that can be achieved by P25 is equivalent to that of analog equipment (the industry benchmark), but without sacrificing audio quality. The design of the CAI was carefully engineered to ensure that public safety users could get the benefits of superior digital clarity without needing to reach into their pockets to fund significantly more radio sites to match the coverage they already had with analog equipment.

### **System-level interoperability**

To meet the goal of achieving the highest level of interoperability (Level 6), the P25 standards have been expanded to include a standard for interconnecting different radio systems. The Inter RF Subsystem Interface (ISSI), which has been available since 2009, ties together radio systems regardless of vendor or frequency band. Previously, public safety agencies were forced to rely on vendors to connect two radio networks.

### **The P25 Compliance Assessment Program (CAP)**

The P25 CAP is a US Government-sponsored program that establishes a process for ensuring that equipment complies with P25 standards and is capable of interoperating across manufacturers. CAP certification is likely to become mandatory for any vendor intending to sell digital radio equipment as 'P25 compliant'. It is the only guarantee that exists for P25 interoperability.

Tait Communications' TELTEST has been officially recognized by the US Government as one of eight P25 CAP recognized laboratories, which also include laboratories maintained by Motorola Inc, Harris Corp., and EF Johnson Technologies. P25 compliant declared equipment is qualified as such if it:

- ▶ has been tested at a P25 CAP recognized laboratory,
- ▶ has been determined by the supplier to be compliant with all current requirements of the P25 CAP,
- ▶ possesses a Supplier's Declaration of Compliance (SDoC) and,
- ▶ has a Summary Test Report (STR) that has been reviewed by the P25 CAP Laboratory Program Manager.

Typically, equipment is independently tested for P25 compliance at three separate laboratories with the consequence that competing vendors will test each other's equipment and thereby keep the process honest. Each manufacturer's declaration of compliance can be viewed on a government website, the Responder Knowledge Base, at <https://www.rkb.us/>

### **Radio frequency use with P25**

P25 can be used on a wide range of VHF, UHF and 800MHz frequencies, allowing existing analog channels to be upgraded gradually to P25 digital channels. A new block of spectrum does not need to be purchased. P25 channels are designed to be more spectrally efficient than traditional analog wideband channels. In a crowded RF environment, converting to P25 will allow more radio channels to operate in the same amount of RF spectrum.

In order to improve the efficiency of radio spectrum use, P25 has been rolled out in two phases:

#### ▶ P25 Phase 1

12.5 kHz channel spacing is twice as efficient as traditional analog wideband channels, which generally use 25 kHz. Phase 1 P25-compliant systems are backwards compatible and interoperable with legacy analog conventional FM systems. Thus old analog portable and mobile radios can work alongside new digital radios until such time as the old radios are replaced.

#### ▶ P25 Phase 2

Phase 2 is the next version of P25 and is twice as spectrally efficient as Phase 1. It can fit two voice or data streams into a 12.5 kHz channel where Phase 1 allows only one. To achieve this, a new CAI needed to be designed, but modern P25 radios will support the Phase 1 CAI as well. As part of the standard, Phase 2 P25-compliant systems are backwards compatible and completely interoperable with P25 Phase 1 systems.

### **P25 IMPROVES AUDIO QUALITY**

For the end user, one of the key benefits of a change from analog to P25 digital radio technology is the improvement in audio quality. An analog signal will gradually weaken and become harder to use as the distance from the site is increased. The user will experience increased amounts of ‘hiss and crackle’ until finally the received audio is completely lost in noise.

Digital P25 systems use a component called a vocoder to convert voice information into digital data. During the digitization process, the background noise, typically present in analog systems, is reduced. The vocoder uses artificial intelligence techniques to recognize and enhance voice, but suppresses wind or machine roar, music, and anything that it sees as ‘non-voice’. The result is that crystal-clear audio quality is maintained by the built-in error correction right to the edge of the coverage area. Fringe areas that were difficult to operate in under the analog system will become loud and clear under a P25 system.

### **P25 INCREASES THE PRIVACY OF YOUR COMMUNICATIONS**

P25 technology not only increases the range of secure transmissions it adds a new level of flexibility. There are various methods of encrypting an analog signal. However, in general, the more advanced the encryption - the more rapidly the coverage will deteriorate.

P25 transmissions may be protected by digital encryption. Because the vocoder produces a digital bit stream, it is relatively easy to encrypt. One major benefit of this type of encryption is that it does not affect speech intelligibility nor does it affect the system’s usable range. Both of these advantages are major improvements over encryption that was used in analog systems.

The P25 standards specify the use of the Data Encryption Standard (DES) algorithm with a 56 bit key and the Advanced Encryption Standard (AES) algorithm with a 128 or 256 bit key. Failure to insist on using P25-standard encryption - either DES or AES - could jeopardize the safety of firefighters at an assignment where multiple agencies are required to interoperate. Federal grants require that features such as encryption, meet standards of interoperability and are quality tested against the CAP.

To start the process, both the transmitting and the receiving devices must have an encryption key inserted. This is done using a keyloader, which typically looks like a PDA or barcode reader. The P25 standard prescribes how a keyloader should work. Essentially the encryption key is similar to a door key. It has a specific pattern that the encryption and decryption of a transmission will follow. Most P25 subscriber equipment is optionally available with multiple keys. That is, a unit could use one key for one group of users and a separate key for another group of users.

P25 also includes a standardized Over-the-air Rekeying (OTAR) function. OTAR is a way to greatly increase the utility of encryption systems by allowing transfer of encryption keys via radio. This remote rekey ability means that subscriber units no longer have to be physically touched in order to install a new or replacement key. OTAR can be done from a Key Management Facility (KMF).

The P25 standards use the United States federal government classifications for encryption:

- ▶ **Type I**  
used for classified national government communications
- ▶ **Type II**  
used for unclassified national security related communications
- ▶ **Type III**  
used for unclassified but sensitive government communications
- ▶ **Type IV**  
used for commercial or other communications (e.g. exportable).

#### **P25 INCREASES CONTROL OVER YOUR INFORMATION**

Because P25 transmissions are digital, it is easy to add extra information such as the destination ID (individual or talkgroup) and the caller ID. The P25 CAI defines signaling information that is sent over the air along with voice. This information allows a wide range of services to be offered. These services include different types of calls (unit-to-unit calls, group calls, emergency calls etc.) but also the ability to prioritize calls, to authenticate users, to temporarily disable and re-enable particular radios over the air, and so on.

#### **Identifying Users and Talkgroups**

Every subscriber unit on a P25 system has a Unit ID. Individual subscriber units are numbered in the range 1 to 9999999. The Unit ID's should be programmed into the subscriber units using a national, corporate or agency wide unit identification scheme.

In addition to individual Unit IDs, P25 systems also use talkgroups. A talkgroup is a group of radios that are required to operate together. The agency can decide exactly how it wants group radios according to its communications needs. For example, one agency might set up talkgroups based on regions, another might choose to set up talkgroups based on organizational units (e.g. motorcycle unit, SWAT team, foot patrol, commanders-only etc).

#### **P25 NETWORKS ARE CUSTOMIZABLE**

The design of a radio communications network is determined by such factors as how big an area is to be covered, cost, availability, and most important, the communications objectives of an agency. Unlike some other network technologies, P25 does not limit an agency from designing and operating a system built specifically to its unique needs. Systems can be designed which are trunked, conventional, simulcast, or even a combination of all three. Voice and data services are supported as standard. P25 networks can be built with digital links - similar to wide-area computer networks - or can be specially wired together in the manner of traditional analog radio systems.

**Physical radios do not need to be handled to change encryption. This can be done remotely from a Key Management Facility (KMF).**



Tait P25 Key Fill Device

## **DIGITAL CONNECTIVITY IS NOW EASIER AND MORE COST-EFFECTIVE**

Over the past couple of decades Tait has been involved in what magazines and technology pundits have dubbed ‘the digital convergence revolution’. This refers to a sharing of technologies that were hitherto completely separate. Voice on one network and data on another. The practical outcomes of this revolution have not only been visible to consumers in the form of smart phones, digital media players, WiFi hotspot networking, and internet telephones. It has also been felt in professional communications, especially in public safety. The modern digital radio network shares much in common with a computer network. A P25 digital hand portable is, like a smart phone, largely a computer, and a modern laptop is now also a communications device.

This convergence of technologies has been driven mainly by standards, used to develop the Internet, that prescribe how digital data is organized, stored, and transmitted. The networking standards underlying digital convergence are commonly referred to as ‘Internet Protocols’ or IP standards. A P25 radio converts voice into digital data packets and sends these packets through a network using the same standards that govern the transmission of computer data through an office LAN or the Internet.

There are two principal advantages to converging technologies:

### **1. Easier, more flexible connectivity**

If it is possible to ‘connect anything with anything’ using a common, shared networking approach, then specialized, proprietary hardware is no longer required. For instance, to attach a console, or a PABX, or data gateway to a radio network. Designing a whole communications system that ties together radios, cellular, consoles, mobile data terminals thereby becomes not merely feasible; it becomes standard. It is therefore easier to grow and add capabilities to such a network.

### **2. Cost reduction**

With the use of open standards and the removal of the need to design expensive special connection hardware, there are fewer boxes, less cabling, and less physical space required to deploy a digital radio network. A P25 IP-based network can use the same off-the-shelf equipment (e.g. switches, routers) that offices use to create a local area network. There are also fewer points of failure and lower maintenance costs incurred. Moreover, open standard connectivity enables equipment from different companies to be combined, and as a result, allows public safety agencies to make budget choices that, until now, were not possible.

For P25 users, the benefits of digital connectivity are a present reality, not a science fiction future. The flexibility and cost saving advantages can be achieved with today’s P25 equipment for small agencies as well as for larger county-wide or statewide systems.

## **P25 OFFERS FLEXIBILITY IN OPERATIONAL DESIGN**

P25 enjoys an almost unique capability in its ability to operate as a conventional, trunked, or simulcast system. As public safety agencies have already discovered, it is fairly straightforward from an engineering point of view to convert a P25 conventional network to trunking, while retaining the investment in the original network. Simulcast operation can be added to all or part of an existing trunked or conventional P25 system. Each mode of operation has its own strengths and tradeoffs which can be summarized as follows.

### **P25 Conventional Operation**

In a conventional system each group of users is permanently allocated a particular communications channel which they can select on a radio using a selector knob or button. After manually selecting the appropriate channel for talking to a given group, a user simply presses the push-to-talk (PTT) button on the radio or microphone to begin talking. A scanning operation alerts the called parties to the incoming call on that channel. It is a simple, fast, and reliable mode of operation. It is also the simplest, most cost-effective network solution.

The chief disadvantage of this simple solution is that it does not use communications channels particularly efficiently. It can happen, especially if there are more than four channels on a radio site, that one of the channels becomes overloaded (and callers must wait), while the other channels are underused. This is similar to a bank in which the teller tasked with handling personal checks is overloaded, while the teller reserved for handling business checks is idle.

In a conventional system there is no indication that a channel is busy (other than discovering that a call cannot be made), nor when it becomes free. A radio user can only try again at random.

**P25 allows dispatch to have more control over defining talkgroups, prioritizing messages and integrating data.**



### **P25 Trunked Operation**

If an agency has more than four channels at a site, it can use trunking to spread the load more evenly. The basic idea of trunking is to use a computer (a ‘trunking controller’) to control use of the communications channels. This is much like a bank opening up all of its tellers to handle any sort of transaction and then using one of its officers to direct each customer in a queue to the next available teller. The computer takes the role of this officer and, via its own reserved communications channel (called the ‘control channel’) which is in contact with both queued radio callers and with all the other communications channels, can direct the next caller to the next free channel. It can even alert a queued caller when a channel is freed up. In this way, an agency can get the best possible use out of all of its communications channels.

There are other advantages of trunking which arise from the presence of a controller. Radio users can be authenticated to see if they are allowed on a site. Group calls are more efficient because the only sites that participate are those where the radios are active (i.e. have ‘registered’). Priority calls are possible because the controller can promote prospective callers to the head of the queue. And for connected radio networks, a radio user can roam from one network to another while still communicating with his home dispatcher or his group.

The network intelligence associated with trunking is not without costs, however:

- ▶ it is a more complicated and more expensive design,
- ▶ it introduces another point of failure namely, the trunking controller,
- ▶ it uses an extra communications channel/frequency to support the control channel,
- ▶ it adds extra time to set up a call - conventional calls don’t have this overhead,
- ▶ the radios behave slightly different versus operation in a conventional system.

These costs need to be balanced against the powerful gains provided by trunking, such as:

- ▶ more users can be supported with the same frequencies because the channels are used more efficiently with idle time automatically minimized,
- ▶ calls can be queued, so no caller is left guessing when communication is possible,
- ▶ controlled access of end user devices to the network,
- ▶ calls can be prioritized, and
- ▶ there is a wide-area multi-network capability comparable to cellular networks (which, in most respects, are consumer-grade trunked radio systems).

### **P25 Simulcast Operation**

When an agency must communicate over a large geographical region but has only one or a few frequencies at its disposal, then simulcast operation is an ideal solution. The idea is to use its few frequencies to create an all-informed broadcast-style network. To simplify matters, imagine a single frequency system that operates county-wide. A radio user on a P25 conventional simulcast can move anywhere within the coverage of the radio network and still stay in touch. There is no need to do anything special, such as manually selecting a channel, since all of the radio transmitters are working on the same frequency. This has the roaming advantage of trunking, but is simpler and faster since it does not have the overheads of trunking setup or scanning. It can even have a side benefit in providing better coverage inside buildings where the radio user is in the reach of two different transmitters.

Analog radio system users have been running wide area public safety simulcast networks for many years. P25 digital gives them a familiar type of communications environment, but with superior digital clarity and extra services (such as encryption, or the ability to disable stolen or lost radios). The technically difficult challenge of simulcast, whether analog or digital, is how to manage interference for a radio user who is in an overlap zone, where his radio can receive the same call coming from two different transmitters. Since the call from a nearer site can arrive sooner, it can interfere with the same call arriving just slightly later from a more distant site. Careful control of the frequency and timing of transmitters using extra equipment can virtually eliminate interference.

While highly economic and less complex than P25 trunking, digital simulcast comes with some additional costs and limitations over P25 conventional systems:

- ▶ more equipment is needed to make it work well,
- ▶ the network design and configuration is critical to reduce or eliminate overlap zones and to achieve the expected coverage,
- ▶ finally, P25 digital simulcast loses one advantage of P25 conventional namely, the ability to interoperate with analog conventional - P25 simulcast is all-digital.

But it also picks up an unusual advantage elsewhere. With P25 it is possible to simulcast trunked digital channels as well as conventional digital. This ability to combine different operational modes is another aspect of the design flexibility inherent in P25 technology. While public safety users generally design networks that use a single P25 operational mode, whether it be conventional or trunked or conventional simulcast, a few organizations have found reasons to deploy mixed systems that combine all three modes. Accommodating requirements such as these is an indication of the freedom of design that is possible with P25.

For a summary of the advantages and limitations of the three P25 operational modes refer to the table on the next page.

**Natural disasters are a prime case for the ability of different agencies to seamlessly communicate with one another.**



FEATURES	CONVENTIONAL	TRUNKED	CONVENTIONAL SIMULCAST	TRUNKED SIMULCAST
<b>Network Access</b>	Uncontrolled. Radios must only have the right access code number programmed into them.	Controlled. Radios must have the right access code number programmed into them & be known to the network.	Uncontrolled. Radios must only have the right access code number programmed into them.	Controlled. Radios must have the right access code number programmed into them & be known to the network.
<b>Dual (analog/digital P25) Mode</b>	Yes	Yes	No	No
<b>Channel Efficiency</b>	More efficient if less than 4 channels	More efficient if more than 4 channels	More efficient if less than 4 channels	More efficient if more than 4 channels
<b>Spectrum Efficiency</b>	Low	Medium. But higher channel efficiency means fewer channels required.	High	High
<b>Call Setup Time</b>	Fastest. Begin talking immediately	Medium. Network check & call set up. Then wait for go-ahead beeps.	Fast. Slightly longer than conventional.	Medium +. Slightly longer than trunking.
<b>Roaming</b>	Can be designed to allow radios to move around network but not seamlessly.	Near seamless	Seamless	Seamless
<b>Queuing</b>	No	Yes	No	Yes
<b>Cost</b>	Lowest	Higher	Medium	Higher

### Choose conventional

If you want the fastest, most cost-effective network and can support all of your teams with 4 channels or less. Choose conventional if you don't mind the limitations of occasional congestion on some channels while others go idle, as well as little access control.

### Choose trunked

If you need more than 4 channels and must use all of them to the maximum, you need greater access control and high availability (fallbacks in case of equipment failure), and greater operational flexibility. Choose trunked if you don't mind the cost of additional controller equipment, licenses, and the need to set aside one channel as a control channel, as well as the longer call setup time incurred.

## OPEN DIGITAL RADIO STANDARDS

GSM cellphone technology, APCO P25 in United States public safety, TETRA in Europe and DMR worldwide are examples of successful digital standards. Successful standards bring real advantages. When vendors work to agreed standards, those managing radio systems have a choice of supplier which can bring down prices, and improve quality. Customers are not at risk of being unable to source products for replacement or expansion through the demise of a sole supplier.

To properly qualify, a standard needs to be non-proprietary, so not under the control of one vendor. It should be defined and controlled by an independent body with a proper process for resolving conflict between interested parties. Some standards only define the air interface, while others cover line interfaces as well.

Equipment designed and produced to a standard by one vendor should be interoperable with equipment from another vendor. However, there is often room for differences of interpretation of a standard, and vendors can add proprietary features not covered by the standard itself. It is wise to look for standardized interoperability test procedures or results from certified interoperability laboratories.

The advent of digital radio has increased the importance of standards. With conventional analog FM, interoperability for basic features is inherent. However digital equipment cannot interoperate unless the same protocols are used. For example, if different vocoders are used, speech cannot be understood; if different control signaling is used, users cannot communicate call setup information.

### Digital radio standards developments

In 2000, there were only two non-proprietary open digital PMR or LMR standards; TETRA and APCO P25. TETRA (TErrestrial TRunked Radio) was developed by the European Telecommunications Standards Institute for large, national networks run by government agencies for public safety organizations and others. APCO P25 was designed primarily for public safety users. While TETRA originated in Europe and APCO P25 in the United States, both standards have been widely adopted outside their area of origin.

In 2005, European Telecommunications Standards Institute (ETSI) published the DMR (Digital Mobile Radio) standard with three tiers for business and professional systems with low complexity and low cost. ETSI has since defined dPMR (digital Private Mobile Radio), an FDMA variant for DMR Tier 1, which now provides equivalent FDMA standards for Tier 2 and Tier 3.

**Firefighters face the daunting task of deciding whether to improve or replace existing communications systems in order to meet FCC mandates.**



## DIGITAL MOBILE RADIO (DMR)

DMR now provides a full set of air interface standards covering voice and data services, and conformance tests. Current developments will add interfaces, encryption and application protocols to the standard.

DMR provides a low-complexity digital standard to replace analog radio. DMR is promoted as a data and voice standard that can operate in 6.25kHz channel equivalence mode.

- ▶ Tier 1 is aimed at applications such as sport, family vacations and commercial enterprises such as retail. It is license-free and permits up to 500mW transmit power output. Operation is peer-to-peer, so it requires no repeaters.
- ▶ Tier 2 is digital conventional. It achieves 6.25kHz channel equivalence through 2-slot TDMA on an existing 12.5kHz narrowband FM channel. Designed for easy migration of analog to digital, the output spectrum must fit in to the existing 12.5kHz narrowband FM channels used by legacy analog systems.

The choice of modulation scheme and associated symbol rate are critical. 4FSK modulation is used with an associated symbol rate of 4800symbols/sec. Each symbol carries 2 bits of data, so the equivalent data rate is 9600bits/sec. Both the downlink (base station to terminal) and uplink (terminal to base station) use this modulation.

- ▶ Tier 3 DMR Trunked is a digital replacement for MPT 1327, aimed at applications that will benefit from trunking efficiency. These include organizations responsible for critical infrastructure, such as utilities, transportation, oil, and gas.

## dPMR

Digital Private Mobile Radio (dPMR) is an ETSI standard developed after DMR, and using FDMA to divide the 12.5kHz channel into two 6.25kHz sub-channels. The implications of this are covered later in the **Key Comparisons of the Standards** section. Just as there are three tiers of DMR, there are three modes of dPMR. Mode 1 is peer-to-peer, Mode 2 is conventional (repeaters and infrastructure), Mode 3 has managed sites, each with a beacon channel (dPMR terminology for trunking with control channels). However, dPMR is only offered outside the United States. In the United States its main supporters, Icom and Kenwood, have developed NXDN as their own protocols, which are based on dPMR but incompatible with it. Early 2012 (at IWCE) they announced NXDN will become an open standard.

**DMR Tier 1 - commercial enterprises such as retail**

**DMR Tier 2 - digital conventional**

**DMR Tier 3 - digital trunked replacement for MPT 1327**

**“dPMR is an ETSI standard developed after DMR and uses FDMA technology”**

## KEY COMPARISONS OF THE STANDARDS – WHAT DOES IT ALL MEAN IN PRACTICE?

We have worked through digital modulation methods, multiple access schemes, and the main open digital radio standards that exist. All this is necessary background, **but what does it mean in practice?** What performance differences would the end user experience when using one radio standard versus another? Perhaps the best way to illustrate this is to compare some key standards, and show the implications of the different modulation methods, symbol rates, and multiple access schemes that were chosen.

### Assessment Criteria for standard comparisons

First, let us define the following assessment criteria against which to benchmark the performance resulting from the following standards:

- ▶ Spectral efficiency
- ▶ Ease of migration from existing analog systems
- ▶ Coverage
- ▶ Choice of frequency bands

Using these assessment criteria, we will first compare DMR to dPMR.

### DMR versus dPMR comparison

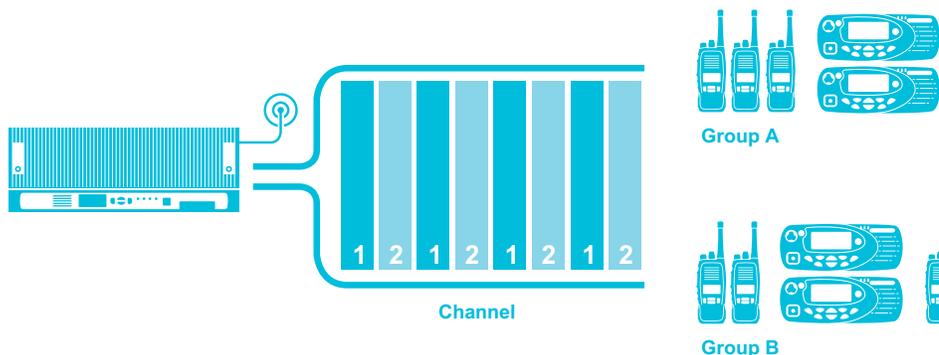
The open digital radio standards section reveals that the major difference between DMR and dPMR is the choice of multiple access scheme. DMR uses 2-slot TDMA to achieve two communication paths per 12.5kHz channel, whereas dPMR uses FDMA to divide the 12.5kHz channel in to two 6.25kHz sub-channels.

Therefore, the comparison of these two systems very much comes down to understanding the relative advantages and disadvantages of TDMA versus FDMA.

In theory there appears to be little difference. In Spectral Efficiency terms, both achieve 6.25kHz channel equivalence. Coverage-wise, the modulation methods and symbol rates mean coverage would be almost identical to existing narrowband FM systems in both cases. While the resulting radio signals do look quite different (DMR appears similar to narrowband FM, whereas the dPMR signal appears as two individual signals each with 6.25kHz bandwidth), both fit within existing 12.5kHz narrowband FM channels. So the choice of frequency bands may be made according to the application and terrain to be covered.

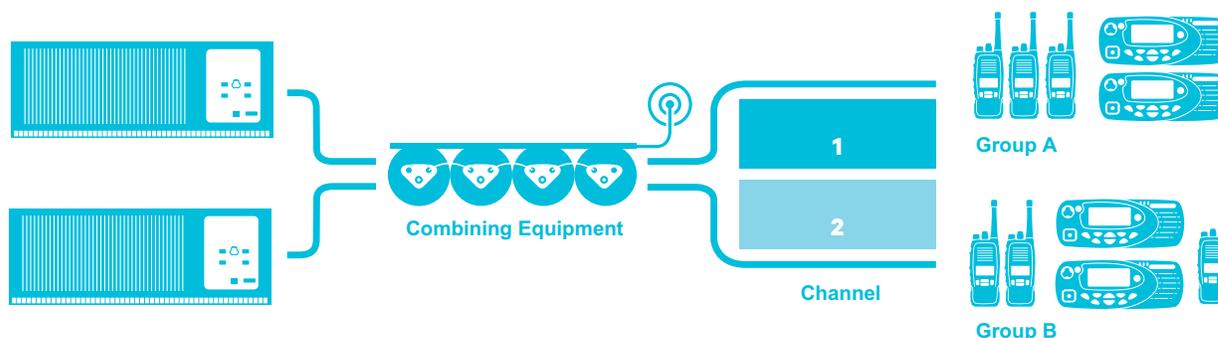
### Ease of migration from existing analog systems

The obvious difference is the ease of migration from analog systems. With DMR, because the TDMA slots are operating on the same frequency, the resulting infrastructure is much the same as for a narrowband FM system, effectively reducing the cost of system infrastructure. In effect, you only need one repeater, one antenna and a simple duplexer, as shown in the diagram below.



**TDMA**  
TDMA DMR system representation

Contrast this with infrastructure for an FDMA dPMR system. As both 6.25kHz sub-channels must operate simultaneously, two repeaters (one for each 6.25kHz sub-channel) are required, plus expensive combining equipment for multiple frequencies to share the single base station/repeater antenna, as shown below.



**FDMA**  
FDMA dPMR system representation

FDMA infrastructure costs are considerably higher than for 2-slot TDMA DMR. In addition, the losses of the extra combiners may require additional RF Power Amplifiers to maintain the transmitted power level and therefore coverage.

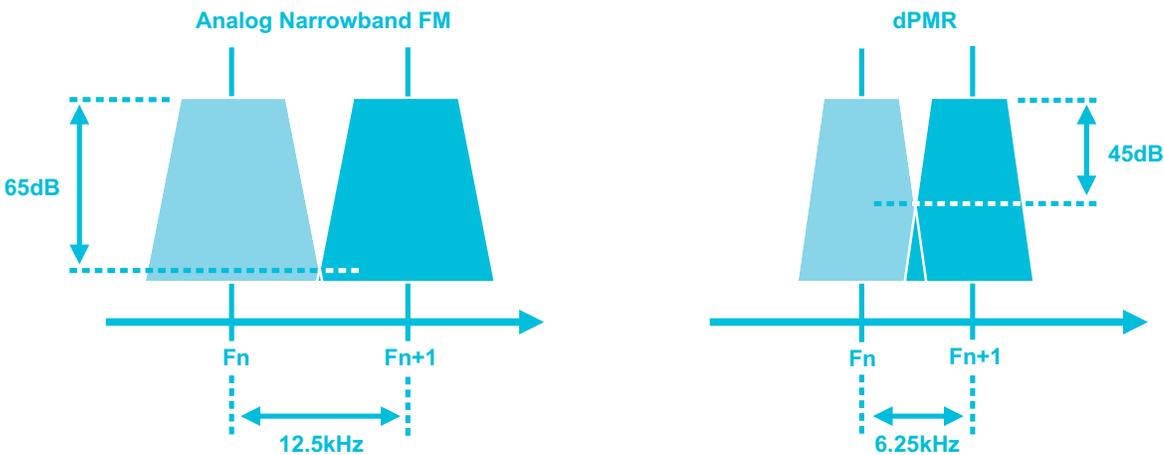
To summarize, 2-slot TDMA DMR makes efficient use of expensive infrastructure and simplifies migration. Compared to FDMA, 2-slot TDMA allows you to achieve 6.25kHz efficiency while reducing investment in repeaters and combining equipment. Much of the combining equipment used in the previous analog FM system can be re-used by a new DMR network.

This is the obvious advantage of a TDMA system such as DMR, over an equivalent FDMA counterpart like dPMR. However, if we look beneath the surface, other differences appear that have consequences in terms of other assessment criteria.

### Spectral efficiency

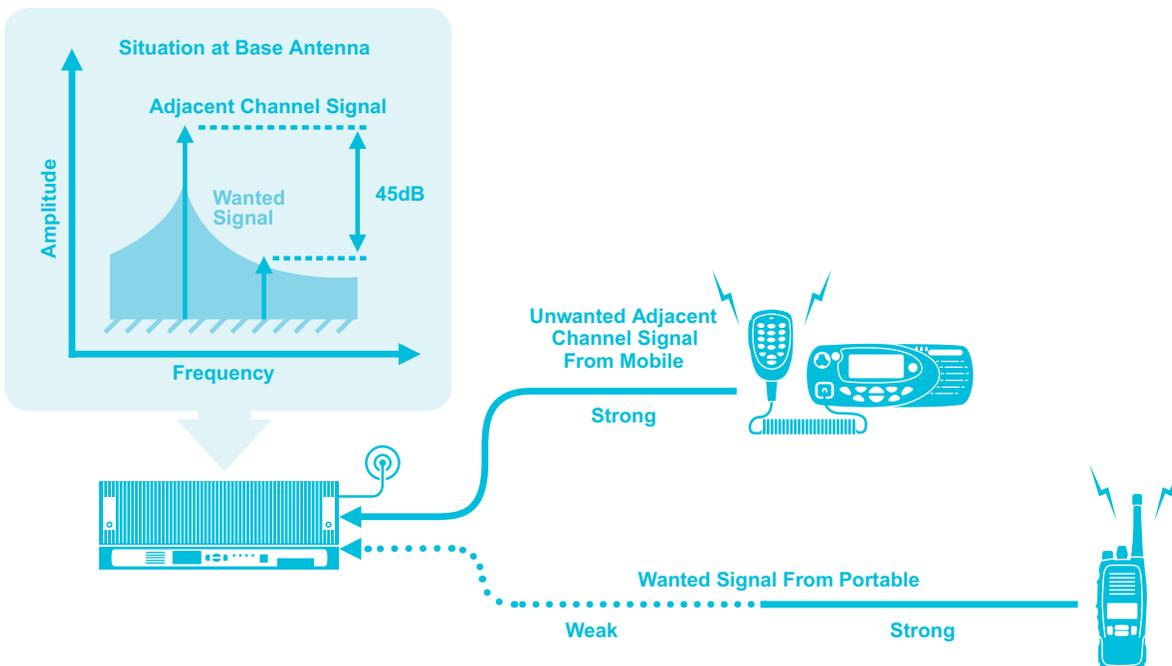
What happens to dPMR FDMA when we try to combine two 6.25kHz sub-channels in to an existing 12.5kHz channel? In narrowband analog FM, a signal in the adjacent channel is 12.5kHz away. As transmitted signals are not pure, some energy from the transmission in the adjacent channel ( $F_{n+1}$  in the following diagram) is present in the desired channel ( $F_n$ ). For example, if the signal amplitudes are the same, the noise in the desired channel ( $F_n$ ) generated by the transmitter operating in the adjacent channel ( $F_{n+1}$ ) would be about 65dB down.

Now consider the same situation using FDMA dPMR. As the signals are now only 6.25kHz apart, if we assume transmitter noise performance is the same, we can see the overlap now occurs at typically 45-50dB.



### What does this mean in practice?

The effect of this increased adjacent channel noise is that transmitters operating close by in one 6.25kHz slot could easily prevent reception of weak signals from distant transmitters operating in the other slot.



This effect would be most noticeable if the adjacent channel was analog. If two 6.25kHz spaced FDMA sub-carriers existed in the same 12.5kHz channel, the effect isn't as bad as a result of the channel filter of the digital radio excluding more of the interfering signal. However, the customer would experience noticeably worse interference than with analog FM. For a busy system, this can mean you can only operate one 6.25kHz slot per 12.5kHz channel, meaning spectral efficiency advantages of dPMR can be lost altogether.

Also, 6.25 kHz systems have lower tolerance for frequency accuracy, and drift over time. The crystal oscillators that set transmitter frequency stability and accuracy drift away from the desired centre frequency over time. This can result in the two 6.25kHz channels drifting even closer together, leading to worse adjacent channel interference. This effect can be seen when users are travelling at speed, caused by the Doppler Effect shifting the carrier frequency.

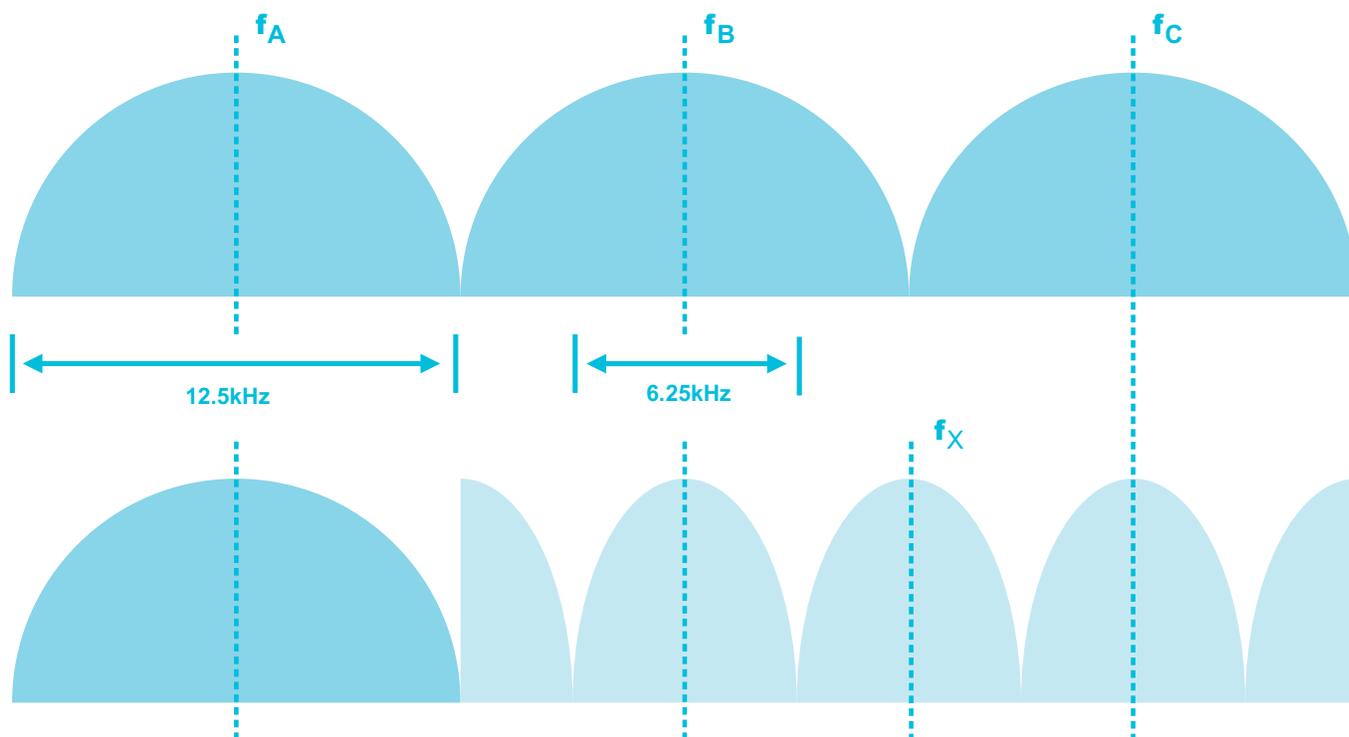
Contrast this with TDMA on DMR. Like legacy narrowband FM systems, there is only one signal occupying the 12.5kHz channel at any one point in time. Therefore, the adjacent channel performance, and the probability of interference is no worse than for the analog system.

### Minimizing frequency plan churn

If an organization already has licenses for 12.5kHz channels, it can move to a TDMA-based network, such as DMR, with no frequency plan churn because each channel can be used without any licensing change.

By contrast, in the United States, moving to an FDMA-based network with 6.25kHz channels requires re-banding and relicensing, where new 6.25kHz channels are assigned by Federal Communications Commission (FCC), each with the same centre frequency as the old licenses. This leaves half-channels on either side, which revert to the licensor and can only be used if the other half has also been freed, through re-licensing of the adjacent channel for 6.25kHz.

In the diagram below, three 12.5kHz channels ( $f_A$ ,  $f_B$ , and  $f_C$ ) belong to users A, B, and C respectively. Users B and C change to 6.25kHz channels. This frees up one additional channel ( $f_X$ ), which reverts to the FCC. It also results in half a 6.25kHz channel (between  $f_A$  and  $f_B$ ) which cannot be used. A similar process occurs when moving from 25kHz to 12.5kHz channels.



### ***Longer portable radio shift life***

Compared with an analog FM radio, a 2-slot TDMA radio using one timeslot is only transmitting for half the time. For portable radios, this dramatically reduces battery power consumption, as transmitting is a very power-intensive activity. In a standard operating pattern, (5% transmitting, 5% receiving, and 90% standby), power consumption is reduced by around 40%, greatly extending the battery charge duration and increasing talk time. Radios can operate over the longest shifts without recharging or replacement.

The improvements relative to 6.25kHz FDMA are not so large or so easily quantifiable. A radio transmitting FDMA with 6.25kHz bandwidth is transmitting its radio frequency energy into half the bandwidth of a 12.5kHz TDMA radio. In theory, transmit power of a dPMR radio can be halved and still obtain the same signal-to-noise ratio as the equivalent TDMA radio. In practice however, the FDMA radio cannot compress the signal into the narrow bandwidth as efficiently so will therefore have higher power consumption than TDMA radios with an equivalent operational range.

### ***Opportunity of reverse channel signaling***

Two-slot TDMA channels opens up possibilities for reverse channel signaling. This refers to signaling on the same channel, which goes in the reverse direction, from receiving equipment to the sending equipment. For example, where the second timeslot contains reverse channel signaling it can tell a transmitting radio to stop because an emergency call is waiting, or to inform it of its signal strength so that it can turn its transmit power down or up accordingly.

### ***Disadvantages of TDMA***

We have focused on the advantages TDMA brings in comparison to FDMA. However, there are disadvantages that we should be aware of on 2-slot TDMA.

- ▶ Multipath interference may affect call quality. For the same basic receiver design, TDMA cannot handle as much multipath as FDMA where there is more than one 'propagation' path between the transmitter and receiver. This can cause the received signal to be artificially strengthened or weakened.
- ▶ Direct mode (repeater talkaround) is not as spectrum-efficient. In some cases, radios may use both timeslots.

## LOOMING NARROWBANDING DEADLINES MEAN YOU WILL NEED TO MAKE DECISIONS IMMEDIATELY

Scarcity of radio spectrum and the growing demands of public safety for more frequencies have led the Federal Communications Commission (FCC) to propose a stringent plan to make better use of this resource. Until relatively recently it was common for public safety users to request allocation of VHF or UHF radio spectrum in 30 kHz or 25 kHz bandwidths. Each such bandwidth could support a single traffic channel consisting of a pair of frequencies: one for transmit and one for receive. Depending on the pattern of radio use, a single channel could service an agency with tens of officers.

With congestion in frequency bands below 512 MHz and interference from commercial users, the FCC and public safety agencies have faced a crisis in public safety communications. Apart from making new frequencies available, reshuffling frequencies between commercial and public safety users, opening up frequency bands below 512 MHz to more efficient trunked systems, the FCC has introduced a narrowbanding plan and schedule to put more users onto existing frequency allocations. In broad terms, if an agency could service a certain number of officers with an allocated 25 kHz frequency band, it would be required by the FCC timetable to move to a technology that could operate in a band half that size – in other words, in 12.5 kHz bands. With such a technology, the agency can support twice as many officers as before.

But the narrowbanding plan does not stop there. The FCC timetable also identifies later dates, when first manufacturers and then users must switch to a technology that can operate in still narrower bands: equivalent to half of 12.5 kHz (that is, in 6.25 kHz or equivalent bands). As a result, the number of supported users can be doubled again.

The FCC does not say how this can be accomplished, what technologies to use, or what funding is available to aid public safety agencies in the changeover. But as the national regulatory authority, it can mandate when the changes must occur. And the spectrum crisis is such that this timetable is unavoidable.

Although the FCC does not mandate the use of any particular technology, there is no doubt that P25 fits the FCC's narrowband plan extremely well:

- ▶ **P25 is frequency-independent**  
enabling users to adopt it for new frequency bands opened up for public safety use.
- ▶ **P25 supports trunked operation**  
which, if a department maintains a large number of channels, ensures that these are used most efficiently.
- ▶ **The current version of P25, Phase 1**  
bridges the transition from using 25 kHz or 30 kHz channels and operating in 12.5 kHz bands. Phase 1 P25 is optimized for use in 12.5 kHz bands. Maintaining backwards compatibility with analog equipment operating in the wider bands as part of the standard.
- ▶ **The next version of P25, Phase 2**  
bridges the transition from using 12.5 kHz bands and the new requirement to operate in 6.25 kHz or equivalent bands. Phase 2 P25 maintains backwards compatibility with 12.5 kHz Phase 1 equipment. The availability of Phase 2 P25 equipment within the next couple of years ensures that the FCC plan is achievable.

Please find the Tait FCC Narrowbanding Mandates Calendar on the next page for your information.

**FCC NARROWBANDING MANDATES CALENDAR**

<b>DATE</b>	<b>RADIO USERS VHF/UHF (150-174 MHz &amp; 421-512 MHz)</b>	<b>RADIO MANUFACTURERS VHF/UHF (150-174 MHz &amp; 421-512 MHz)</b>
<b>1/1/2011</b>	Applications for new systems using 25kHz channels, or modification applications that expansions that expand the authorized contour of an existing 25 kHz station, will not be accepted.	N/A
<b>1/1/2013</b>	Radio systems must operate in 12.5 kHz or narrower channels.	Equipment operating with a maximum channel bandwidth greater than 12.5 kHz shall not be manufactured or imported unless it demonstrates a 12.5 kHz or less equivalent spectrum efficiency.  Any new equipment submitted to FCC for certification must be capable of operating in 6.25 kHz channels or demonstrating an equivalent spectrum efficiency.
<b>No Date Set</b>	Modifications to existing systems - must employ equipment capable of operating in 6.25 kHz channels or demonstrate an equivalent spectrum efficiency.	N/A
<b>No Date Set</b>	Radio systems must operate in 6.25 kHz channels or demonstrate an equivalent spectrum efficiency.	N/A
<b>DATE</b>	<b>RADIO USERS 700 MHz</b>	<b>RADIO MANUFACTURERS 700 MHz</b>
<b>1/1/2015</b>	700MHz voice systems operating before this date can continue to operate in 12.5 kHz channels until 31/12/2016. All new systems must operate in 6.25 kHz channels or demonstrate an equivalent spectrum efficiency.	Any new 700 MHz equipment submitted to FCC for certification and sale must be capable of operating in 6.25 kHz channels or demonstrating an equivalent spectrum efficiency.
<b>1/1/2017</b>	All 700 MHz systems must operate in 6.25 kHz channels or demonstrate an equivalent spectrum efficiency.	

## EVALUATE YOUR CURRENT COMMUNICATIONS NETWORK

Beyond the pending narrowbanding deadlines there are other reasons why your department may re-examine and evaluate the communications system that it currently operates with a view towards upgrading or replacing it in the near future.

- ▶ The communications equipment may have reached the end of its economic life
- ▶ The number of officers using the system may have dramatically increased or the jurisdiction of the department has been enlarged
- ▶ A review of the communications traffic has recommended a more complex type of network
- ▶ The agency wants to add new capabilities (for example, with encrypted communications or with GPS/AVL or with data applications) not available with its current technology
- ▶ To meet budgetary targets and reduce communications expenditure, the agency plans to move from a single supplier, proprietary solution towards an open standard solution available from multiple suppliers
- ▶ The need to interoperate with other agencies (e.g. county sheriff with prisons, city police with fire department, other counties with neighboring county sheriff etc.) cannot be achieved with current equipment.

At the end of the day these considerations will drive a decision to either:

- ▶ Expand or otherwise enhance the existing network, perhaps with additional technologies such as cell phone,
- ▶ Replace the existing network including, perhaps, the existing technology, or
- ▶ Contract or lease some or all communication services or equipment from an external provider.

**The ability to communicate between agencies in the same county, or cross-county may be a reason to evaluate your current network.**



## SHOULD YOU IMPROVE OR REPLACE YOUR CURRENT COMMUNICATIONS SYSTEM?

Few fire departments are comfortable with giving up control of the availability, reliability, and security that ownership of a radio network brings, which often narrows the decision to one of improvement or replacement. This decision will hinge on considerations that encompass the communications capabilities listed earlier, but add equipment, support, changeover and business considerations such as:

- ▶ Coverage capability,
- ▶ Support for dispatch operations and equipment,
- ▶ Ease of migration from the current technology,
- ▶ Flexibility of system design,
- ▶ Ease of use and management,
- ▶ Increased privacy protection and access control, including the ability to exclude unauthorized users,
- ▶ Cost-effectiveness, including lifetime cost of operation,
- ▶ Future-proofing to ensure that the network can keep pace with future technology.



The Tait 9100 Series



The Tait 9400 Series

## **A FIREFIGHTER'S GLOSSARY OF P25 TERMINOLOGY**

### **AMBE**

The Advanced Multi-Band Excitation vocoder that converts voice to digital.

### **APCO**

Association of Public Safety Communications Officials.

### **APCO Project 25**

The first iteration of P25.

### **CAI**

The Common Air Interface that defines the digital transmissions at the heart of P25.

### **CAP**

Compliance Assessment Program - A government program that establishes a process for ensuring that equipment complies with P25 standards.

### **Conventional system**

Each group of users is permanently allocated a particular communications channel.

### **IMBE**

The Improved Multi-Band Excitation vocoder that converts voice to digital.

### **DMR**

Digital Mobile Radio.

### **dPMR**

Digital Private Mobile Radio.

### **Interoperability**

The ability of public safety personnel to communicate by radio with users from other agencies or departments.

### **Narrowbanding**

FCC mandate and timetable to deal with a scarcity of frequencies. The goal is to allocate more users onto existing frequencies.

### **Open standard**

A standard not proprietary to a single manufacturer. One technology for all users.

### **P25 Encryption**

Digital encryption that doesn't effect clarity or range of the system.

### **P25 Networks**

Offers multiple modes of network operation (Conventional, Trunked, Simulcast). Easier connectivity. Lower costs.

**P25 Phase 1**

12.5 kHz channel spacing, twice as effective as traditional analog. Interoperable with legacy analog systems.

**P25 Phase 2**

The next version of P25. Twice as efficient as Phase 1 (two voice/data streams into a 12.5 kHz channel. Phase 2 radios support Phase 1.

**SDoC**

Suppliers Declaration of Compliance: P25 compliant equipment requires one.

**Simulcast system**

For departments with few frequencies over a large geographic area.

**TIA**

Telecommunications Industry Association.

**TIA 102**

Official name for the P25 standards equipment that complies with P25 standards.

**Trunked system**

Requires more than 4 channels at a site. Uses a computer to control use of the channels. A more efficient way to handle radio traffic.

**TAIT COMMUNICATIONS**

Tait Communications is a global leader in designing and delivering radio solutions which are the right fit for a variety of industries including; public safety agencies, government services, utilities and urban transport providers.

**MORE INFORMATION**

For more information on TaitNet P25 network options: conventional, trunked and simulcast, please contact your nearest Tait dealer.

[www.taitradio.com](http://www.taitradio.com)