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MOTOROLA

TDMA Technology

Bringing Increased Capacity and Functionality to Professional Digital Two-Way Radio

WHITE PAPER

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Executive Summary

Licensed, professional two-way radio is on the verge of making the biggest leap forward since the invention of the transistor — the move from analog to digital. Digital radio offers many advantages over analog, including improved voice quality at greater range, better privacy, sophisticated call-control features, the ability to easily integrate with data systems, and more.

We're now at the beginning of what will quickly become a large-scale migration to digital radio in professional applications. At the same time, regulatory pressures combined with real-world operating needs are driving radio manufacturers and users to communicate more information in a given slice of RF spectrum — in other words, to increase "spectral efficiency." Channels that historically carried a single call at a time are now being divided so they can carry two.

Two technologies exist to enable this "splitting" of channels, allowing multiple access on a single channel. Frequency-Division Multiple Access (FDMA) splits the channel frequency into two smaller sub-channels that can carry separate calls side-by-side. Time-Division Multiple Access (TDMA) preserves the full channel width, but divides it into alternating time slots that can each carry an individual call. Both technologies are already being used in North America to accomplish the FCC-mandated split of 25 kHz channels into 12.5 kHz channels, and they're both being used worldwide to accomplish similar increases in spectral efficiency whether currently mandated or not.

In the coming years, new regulations will almost certainly require improvements in the effective capacity of 12.5 kHz channels: it is only a matter of time before the ability to carry two voice paths in a single 12.5 kHz channel — also known as 6.25 kHz equivalent efficiency — becomes a requirement. But because the technology exists today to accomplish this goal, there's no need for professional radio users to wait for the regulations to catch up with benefits that are immediately available. Even in the absence of a mandate, professional users can double the capacity of their existing licensed channels by adopting digital technologies that enable 6.25 kHz equivalent efficiency. With potential benefits including increased capacity, lower equipment costs, data integration, added features, and more, now is a compelling time for analog radio users to make the switch to digital systems that offer 6.25 kHz equivalency.

This white paper examines the two leading digital modulation technologies that are capable of achieving this doubling of spectral efficiency: 6.25 kHz FDMA and two-slot 12.5 kHz TDMA. Businesses looking to migrate to the most efficient professional digital systems to achieve greater capacity and performance will need to choose one or the other — FDMA and TDMA are not interoperable.

Two-slot 12.5 kHz TDMA-based systems, providing 6.25 kHz equivalency is the right choice for most mobile professionals. Professional radio standards based on TDMA technology are already widely used around the world, and future requirements for even greater spectral efficiency are almost certain to be based on TDMA as well. Today and tomorrow, TDMA technology provides advantages of feature flexibility, lower equipment costs, longer battery life, future-readiness, and the proven ability to increase spectral efficiency without risking increased congestion or radio channel interference.

Advantages of Digital Two-Way Radio

Since the first wireless transceiver was installed in a Bayonne, New Jersey police car in 1933, two-way radio has been a mission-critical technology for police, firefighters, search and rescue workers and others on the front lines of public safety. And increasingly, as new models have reduced the size and cost of two-way radios, the technology has been adopted by business professionals as well.

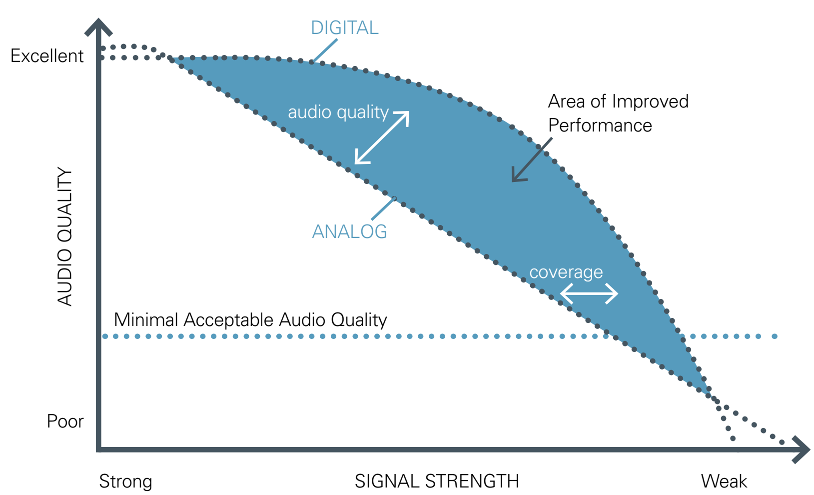
Industries including transportation, education, construction, manufacturing, energy and utilities, private security, government, hospitality, retail, and many others are finding that two-way radio can improve efficiency, worker productivity, and responsiveness by allowing mobile teams to share business and customer information instantly.

Through most of its history, two-way radio has meant analog voice — the representation of sound waves as either amplitude modulated (AM) or frequency modulated (FM) radio waves. In fact, this is one of the last areas of professional communications to be touched by digital technology. But that's changing, very quickly, for very good reasons.

Modulating the voice into digital signals, rather than analog, provides several advantages. First and foremost, digital technology provides better noise rejection and preserves voice quality over a greater range than analog. Especially at the farthest edges of the transmission range, users can hear what's being said much more clearly — increasing the effective range of the radio solution and keeping users responsive to changing situations in the field.

Depending on the technologies used, digital systems can also be designed to:
- Make more efficient use of available, licensed RF spectrum
- Combine voice and data access in the same device, delivering more information while empowering field workers with systems that are more portable, flexible, and much easier to use than two different and incompatible systems
- Enable integration and interoperability with back-end data systems and external systems
- Combine analog and digital voice in the same device, easing the migration to digital while preserving investments in analog technology
- Provide strong, practical, easy-to-use privacy solutions without the significant loss in voice quality that analog scrambling can cause
- Enable flexible and reliable call control and signaling capabilities
- Flexibly adapt to changing business needs and new applications through a modular architecture

Enhanced Digital Audio Performance



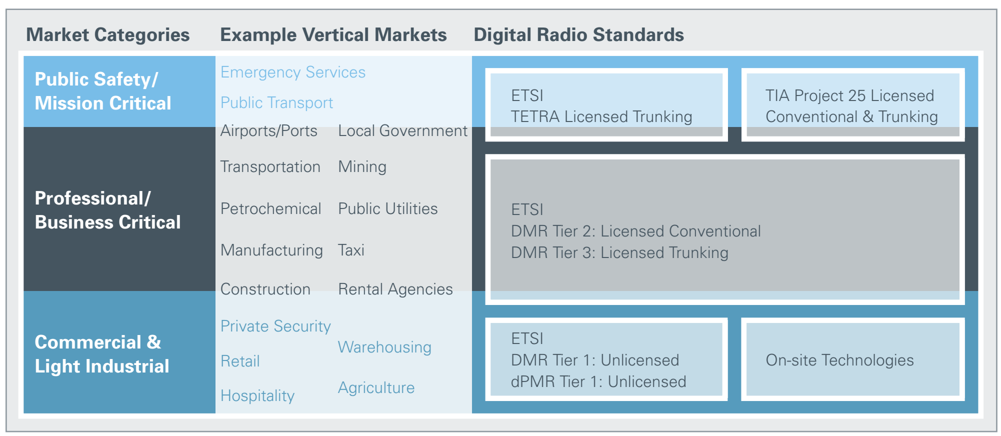
Digital voice retains better quality than analog as signal strength decreases.

The clear advantages of digital radio — along with increasing regulatory pressures to use RF spectrum more efficiently — will drive widespread adoption of professional two-way digital radio solutions in the coming years. If you're using analog today, you'll almost certainly be migrating to digital tomorrow. Now is the time to research the available technologies so that, when you're ready to make the move, you'll choose systems that provide the greatest benefit over the long term.

Digital Radio Markets and Standards

Although the market landscape for two-way radio varies somewhat throughout the world, markets can be roughly divided into three broad categories: (1) commercial and light industrial applications, (2) professional, business-critical applications, and (3) mission-critical public safety applications. With some overlap, there are relevant digital two-way radio standards that are generally applicable to each of these categories.

While we won't get into the specific regulatory requirements governing radio in various countries and regions, let's take a closer look at how the most important, internationally recognized standards map to the needs of users within the general market categories. An understanding of the entire market landscape will provide context for our discussion of the needs of users in the professional/business-critical category.



Worldwide digital two-way radio markets can be roughly divided into three categories

Commercial and Light Industrial. Multiple relevant digital technologies exist for this market, including on-site digital technologies such as Frequency Hopping Spread Spectrum (FHSS) utilized in unlicensed 900 Mhz and 2.4 GHz bands. The European Telecommunications Standards Institute, or ETSI, has also defined two Tier-1 protocols for digital mobile radio (DMR) in the unlicensed PMR446 band; the DMR Tier-1 protocol utilizes 12.5kHz FDMA, while the dPMR protocol utilizes 6.25kHz FDMA. Both protocols provide for consumer applications and low-power commercial applications, using a maximum of 0.5 watt RF power. With a limited number of channels and no use of repeaters, no use of telephone interconnects, and fixed/integrated antennas, Tier-1 DMR/dPMR devices are best suited for personal use, recreation, small retail and other settings that don't require wide area coverage and advanced features.

Mission-Critical Public Safety. This market category is defined by mission-critical communications, security, and interoperability needs. In countries covered by ETSI, a relevant digital standard is the TErrestrial Trunked RAdio (TETRA) standard, which is used to support multiple talk groups on multiple frequencies, including one-to-one, one-to-many and many-to-many calls. TETRA is a digital standard that uses four-slot TDMA in 25 kHz channels to increase spectral efficiency and allow multiple access.

In the U.S., the Telecommunications Industry Association (TIA) has established Project 25 to define similar capabilities for the mission-critical market. Unlike TETRA, Project 25 Phase I uses 12.5 kHz channels and currently uses FDMA for both trunked and conventional digital systems. Phase II will add two-slot TDMA capabilities for digital trunked radio. Both TETRA and Project 25-compliant systems rely on sophisticated infrastructure to achieve the fault-tolerant reliability and advanced calling functionality required in public-safety and other mission-critical applications.

Business-Critical Professional. In between the commercial/light industrial and mission critical/public safety market categories lies a huge market for organizations who aren't engaged in mission-critical work and don't have the budget or need for expensive, fault-tolerant infrastructure—but who can still benefit from increased capacity in licensed channels, advanced features, wide area coverage and other benefits usually associated with mission-critical systems. Businesses in this category include transportation, education, construction, manufacturing, private security, small municipalities, and many other industries.

The ETSI DMR Tier-2 standard is the relevant digital radio standard targeted to these users, providing spectral efficiency, advanced voice features and integrated IP data services in licensed bands for high-power communications. ETSI DMR Tier-2 calls for two-slot TDMA in 12.5 kHz channels. Two-slot TDMA technology is the primary focus of our discussion in this paper.

Analog radios have been used in business-critical applications for years. However, as manufacturers introduce high power digital radios to this market, they have a choice: they can either build their communications system using a proprietary technology such as digital 6.25kHz FDMA, or they can leverage standards-based TDMA. The two are not compatible or interoperable.

Motorola believes that two-slot TDMA is the best fit for most professional, business-critical digital two-way radio applications. Moreover, ETSI has selected TDMA as the standard protocol for Tier-2 professional two-way radio applications, and it satisfies ETSI channel emissions requirements and goals for spectral efficiency. Although the FCC does not mandate standard protocols, devices conforming to the ETSI Tier-2, two-slot TDMA standard will meet existing FCC channel emissions requirements for 12.5 kHz channels and exceed forward-looking requirements for spectral efficiency in the U.S. With technical advantages for the professional market, and the backing of the world's most influential telecommunications standards bodies, two-slot TDMA is the clear choice for organizations looking to deploy new digital two-way radio systems, or to upgrade their existing analog radio to digital.

Let's take a closer look at two-slot TDMA and why it's the best multiple-access technology for the majority of professional applications.

Multiple Access and Spectral Efficiency

The primary goal of any multiple-access RF technology is to achieve greater spectral efficiency, allowing more users to share a given channel in the licensed RF spectrum. Historically, the licensed airwaves were divided into relatively large 25 kHz channels. There was plenty of room for the broadcasters using these channels to exist side-by-side, without significant interference problems. Over the years, however, the airwaves have become increasingly crowded, creating a need for new standards and technologies that allow more radio users to share the available spectrum in any given area.

The demand for greater spectral efficiency is being driven, in part, by regulatory agencies. In the U.S., for example, the FCC is requiring manufacturers to offer only devices that operate within 12.5 kHz VHF and UHF channels by 2011. By the year 2013, all VHF and UHF users will be required to operate in 12.5 kHz — making it possible for roughly twice as many users to share the airwaves as compared with today's 25 kHz licenses.

The next logical step is to further improve the effective capacity of 12.5 kHz channels. While there's no current mandate requiring a move to 6.25 kHz, discussions are continuing at the FCC and other agencies, and it's only a matter of time before the ability to carry two voice paths in a single12.5 kHz channel, also known as 6.25 kHz equivalent efficiency, becomes a requirement in VHF and UHF bands. In the meantime, two-slot TDMA offers a way to divide a 12.5 kHz channel into two independent time slots, achieving 6.25 kHz-equivalent efficiency today.

With two-slot TDMA-based devices, there's no reason to wait for a government mandate to achieve more capacity on existing licensed channels. Business can take the initiative to achieve greater spectral efficiency well ahead of the inevitable regulations — and ahead of the competition. And even without a regulatory mandate, greater spectral efficiency offers many operational benefits. We'll discuss those benefits later, but first let's explore how two-slot TDMA works.

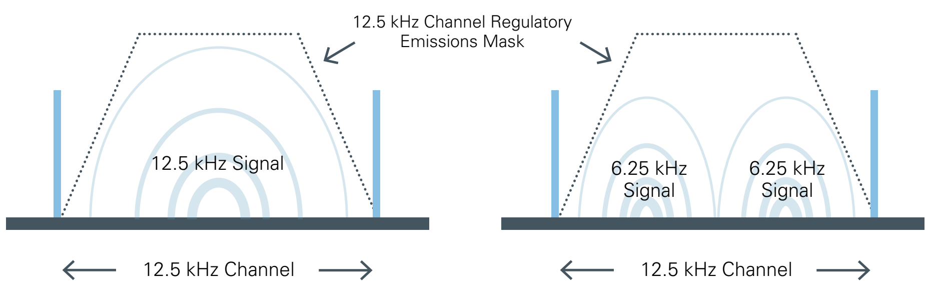
TDMA: How It Works

TDMA stands for "Time-Division Multiple Access." Like FDMA, or "Frequency-Division Multiple Access," TDMA is a technology that allows multiple conversations to share the same radio channel. Although the goal is the same, the two technologies work very differently.

6.25 kHz FDMA

In FDMA, a channel frequency is split into smaller subdivisions — for example, splitting a 25 kHz band into two narrower "sub-channels" that transmit side-by-side to achieve 12.5 kHz equivalent spectral efficiency. The same technique can be used to achieve 6.25 kHz equivalent efficiency in a 12.5 kHz channel — although how well this technique will perform hasn't yet been established in real-world implementations on a large scale.

As the subdivisions of a licensed channel become narrower, there's a growing likelihood of problems due to congestion and interference in an FDMA-based 6.25 kHz-equivalent system, as shown in the illustration.

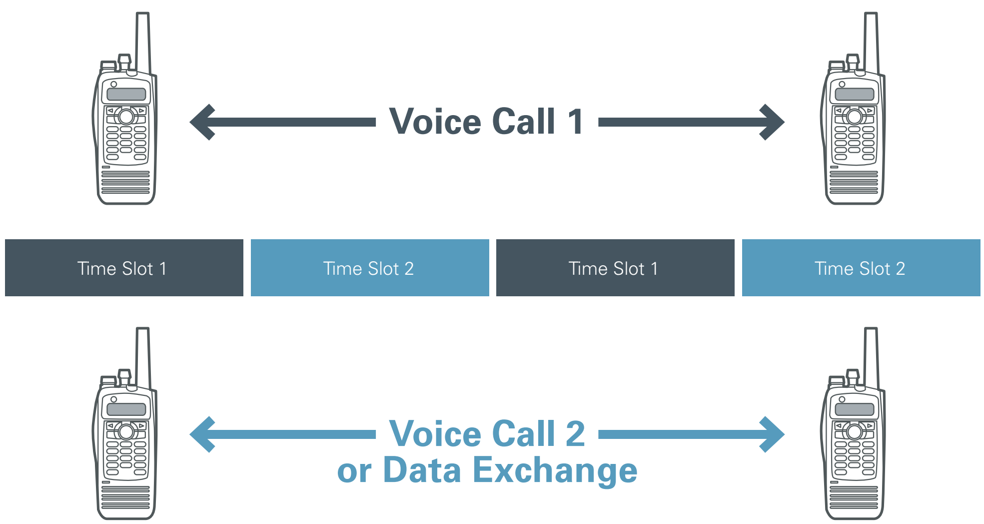


When FDMA technology is used to split a channel into two sub-channels, the resulting signals must still fit within the channel's required emissions mask

When you try to squeeze two 6.25 kHz signals into one 12.5 kHz channel, you still have to meet the channel's regulatory emissions mask. In order to do, the signal deviation (represented by the height and width of the lobes in the illustration) must necessarily be smaller than what can be achieved with a single 12.5 kHz signal. This smaller deviation means reduced sensitivity, which in turn reduces effective signal range in real world conditions. At the same time, there is very little tolerance for errors introduced by oscillator aging, and the 6.25 kHz signal contains more energy near the edges of the mask — making it more prone to adjacent channel interference and near/far interference problems. This results in reduced quality of service in real world conditions.

Two-Slot TDMA

By comparison, TDMA offers a proven method for achieving 6.25 kHz equivalency in 12.5 kHz repeater channels — a major benefit for users of increasingly crowded licensed bands. Instead of dividing the channel into two smaller slices, TDMA uses the full channel width, dividing it into two alternating time slots. As a result, TDMA essentially doubles repeater capacity while preserving the well-known RF performance characteristics of the 12.5 kHz signal.



TDMA divides a 12.5 kHz channel into two alternating time slots to achieve 6.25 kHz equivalent spectral efficiency when used with a repeater.

From the perspective of RF physics — that is, actual transmitted power and radiated emissions — the 12.5 kHz signal of two-slot TDMA occupies the channel, propagates, and performs essentially the same as today's 12.5 kHz analog signals. With the added advantages of digital technology, TDMA-based radios can work within a single repeater channel to provide roughly twice the capacity of analog while offering RF performance equivalent to, or better than, today's analog radio.

As we will see, the two time slots can potentially be used for a variety of purposes. Most organizations considering TDMA-based two-way radio will probably be interested in doubling the voice capacity per licensed repeater channel. By enabling 6.25 kHz equivalency, TDMA supports two simultaneous, independent half-duplex calls in a single 12.5 kHz repeater channel.

If you're used to thinking about analog radio, this two-for-one capacity in two different time slots might seem problematic. Wouldn't the two calls cut in and out as the time slots alternate, making both conversations nearly impossible to understand?

But remember, this is the digital world, where voices are encoded in bits. Although analog signals represent the actual duration of spoken words, digital signals can encode that duration in a way that allows for significant compression without compromising voice quality. Each TDMA time slot is quite brief — on the order of 30 milliseconds. The circuitry that translates voice into bits is actually able to pack 60 milliseconds worth of digitized speech into each 30 millisecond time slot. The receiver, in turn, unpacks those bits into speech that has its full 60 millisecond time value.

That's why, with TDMA, two conversations can happen simultaneously and seamlessly via a single repeater. The alternation of time slots is something that happens in the technology only, not in the user's experience. In fact, digital technology offers better background noise suppression than analog while preserving the integrity of the signal at the farthest reaches of the transmitter's range — so both digital conversations are likely to be much clearer than a single analog conversation would be over the same channel. And because both conversations use the channel's full bandwidth, there's no degradation in range performance, and no added risk of interference with adjacent channels.

Advantages of Two-Slot TDMA for Professional Organizations

If you're in the professional two-way radio category, and you're looking for increased system capacity in 12.5 kHz channels along with higher performance and advanced features enabled by digital radio solutions, you need to decide which technology to choose: 6.25 kHz FDMA or 12.5 kHz two-slot TDMA. 12.5 kHz FDMA remains an important technology in analog radio systems, and is currently the standard for mission-critical digital radio under Project 25, Phase I. However, 6.25 kHz FDMA is not well-proven and does not fit cleanly into today's 12.5 kHz channel structure. Professionals looking for a digital solution should strongly consider two-slot TDMA for the many advantages it provides.

Increased Spectral Efficiency

As we have discussed, two-slot TDMA offers a proven way to enable 6.25 kHz equivalent efficiency in licensed 12.5 kHz repeater channels. This doubles per-channel communications capacity, while satisfying future regulatory requirements for 6.25 kHz equivalent efficiency. And unlike 6.25 kHz transmission methods build on FDMA technology, TDMA fits seamlessly into existing licensed channel structures in UHF and VHF — known performance, no need for rebanding or relicensing, and no risk of new forms of radio channel interference. The choice of TDMA digital technology makes it quick and easy to gain spectrum efficiency and improve your two-way radio communications.

Lower Equipment Costs

Compared to 6.25 kHz FDMA, two-slot TDMA allows you to achieve 6.25 kHz equivalent efficiency while minimizing investments in repeaters and combining equipment. This is one reason why TDMA is so well suited to professional applications, where the budget for two-way digital radio may be limited compared to the mission-critical tier.

FDMA requires a dedicated repeater for each channel, plus expensive combining equipment to enable multiple frequencies to share a single base-station antenna. It can be particularly expensive to make combining equipment work with 6.25 kHz signals, and there's typically a loss in signal quality and range when it's used this way.

In contrast, two-slot TDMA achieves two-channel equivalency using single-channel equipment. No extra repeaters or combining equipment is required.

Advanced Features and Flexibility

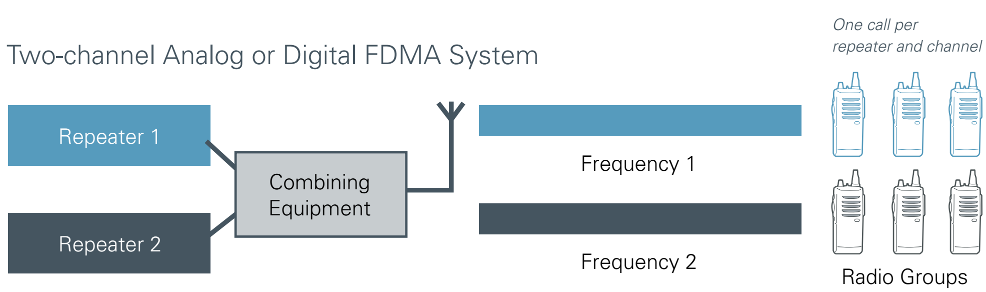
In a traditional FDMA two-way radio implementation, each transmission occupies a full 12.5 kHz channel. A single channel can accommodate a single, half-duplex call. Proprietary implementations that use FDMA to achieve two 6.25 kHz equivalent channels enable two conversations to take place within a 12.5 kHz channel — but again, both of these conversations are half-duplex, and there's no flexibility to put the extra capacity to any other use.

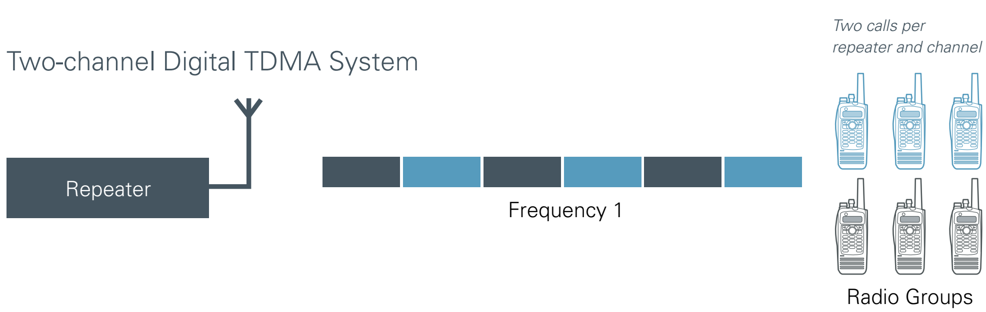
TDMA-based digital systems with two time slots aren't bound by these technical restrictions. The two time slots can be used to carry two half-duplex conversations — as with the two sub-channels in an FDMA-based system — but with no need for extra equipment and no danger of reduced performance. Unlike FDMA, however, it's also possible to use the second TDMA time slot for other purposes.

For example, device designs for the first-generation of TDMA-based two-way radio include the ability to use the second time slot for reverse-channel signaling. This capability can be used for priority call control, remote-control of the transmitting radio, emergency call pre-emption, and more. The second time-slot could also be used for transmitting application data such as text messaging or location data in parallel with call activity — a useful capability, for example, in dispatch systems that provide both verbal and visual dispatch instructions.

TDMA-based systems also offer the flexibility to adapt as new applications emerge to make additional use of the two time slots — preserving initial investments while providing an open path to future usage models for digital two-way radio. For example, the future roadmap for two-slot TDMA applications includes the ability to temporarily combine slots for increased data rates, or to use both slots together to enable full-duplex private calls.

Additional capabilities will also emerge, as driven by the real-world needs of two-way radio users in the professional marketplace. By choosing TDMA, professionals can immediately gain benefits such as 2:1 voice capacity and reverse-channel signaling within a single channel, with the option to add other capabilities as they become available. FDMA, in contrast, is optimized for a single purpose — half-duplex calling.





TDMA saves licensing and equipment costs by enabling the equivalent of two 6.25 kHz channels within a single licensed 12.5 kHz channel

Longer Battery Life

One of the biggest challenges with mobile devices has always been battery life. In the past, there have only been a couple of options for increasing the talk time on a single battery charge. One way is to increase battery capacity. Battery manufacturers have already done a remarkable job of maximizing capacity, but further gains are only possible by increasing the size of the battery pack — and therefore decreasing portability.

The other option is to decrease transmit power, which is by far the most energy-intensive function of two-way radio. But this means decreasing transmission range and increasing the potential for interference from other devices — an unacceptable tradeoff in professional situations.

Two-slot TDMA provides another, very effective option. Since each call uses only one of the two slots, it requires only half of the transmitter's capacity. The transmitter is idle half the time — that is, whenever it's the unused time-slot's "turn."

For example, in a typical duty cycle of 5 percent transmit, 5 percent receive, and 90 percent idle, the transmit time accounts for roughly 80 percent of the total current drain on the radio's battery. By cutting the effective transmit time in half, two-slot TDMA can thus enable an up to 40 percent reduction in current battery drain, or an up to 40 percent improvement in talk time. As a result, overall battery consumption per call is dramatically reduced, enabling much longer usage time in the field between recharges. Modern digital devices also include sleep and power-management technologies that increase battery life even further.

The Right Choice for Professional Two-Way Digital Radio: TDMA

For professional users, digital two-way radio in licensed bands is the wave of the future. Whether they're using analog radio today, or looking to implement their first two-way radio system, business organizations of all kinds will soon be choosing their first digital two-way radio solutions. The advantages and opportunities are simply too great to ignore — in transportation, education, construction, manufacturing, energy and utilities, private security, small municipalities and many other industries.

For most enterprises in these professions, TDMA provides the best method for achieving 6.25 kHz equivalent efficiency in licensed 12.5 kHz channels:

- TDMA is being leveraged in European and U.S. standards initiatives aimed at providing greater spectral efficiency for the land mobile radio market.
- Unlike FDMA methods of rebanding existing channels into discrete 6.25 kHz channels, properly designed two-slot TDMA systems fit cleanly into existing channel structures, with no rebanding or relicensing necessary.
- TDMA improves capacity today, while offering a path to compliance with further channel efficiency requirements that may be mandated in the future.
- Because it increases capacity without the need for additional repeaters and other infrastructure, TDMA can lower the overall costs of implementing digital two-way radio.
- TDMA offers the performance and flexibility to support the functional requirements of mobile professionals in virtually any industry.

Motorola's Next Generation TDMA-based Professional Digital Two-Way Radio

Motorola invented the first portable two-way radio, and has more than 65 years of experience delivering wireless communications systems for government and industry. Motorola has emerged as the recognized leader in digital two-way radio technology, with proven solutions in the mission critical, professional, and unlicensed tiers.

Now Motorola is enabling innovative solutions for licensed professional tier. MOTOTRBO™ Professional Digital Two-way Radio System is a digital communications platform that combines the best of two-way radio with digital technology based on TDMA to deliver increased capacity and spectral efficiency, integrated data applications and enhanced voice communications. MOTOTRBO is specifically designed to meet the requirements of professional organizations that need a customizable business critical communication solution using licensed spectrum.

MOTOTRBO is a private system that can be tailored to meet the unique coverage and feature needs of group-oriented and dispatch environments. And, MOTOTRBO provides a return on investment requiring only a small up-front investment with no recurring fees, and will typically pay for itself in less than 18 months compared with cellular or public carrier solutions.

For more information on the MOTOTRBO Professional Digital Two-Way Radio System visit www.motorola.com/mototrbo.

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