

The Dawn of Digital Communications in the Amateur Radio World

DIGITAL COMMUNICATIONS

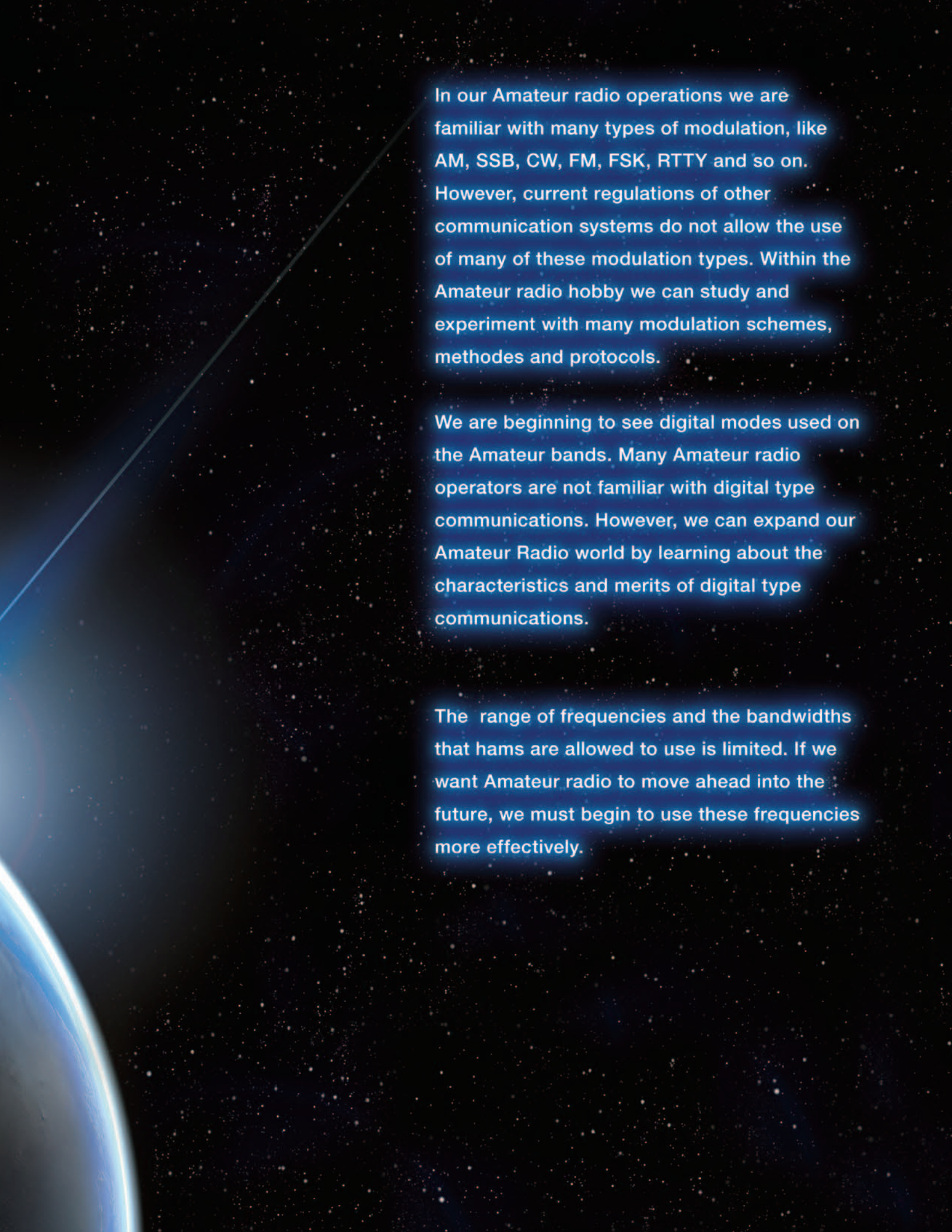
A Digital Communications Guide for Amateur Radio Operators

COMMUNICATION IN DIGITAL

Amateur Radio should be progressive

AM · SSB · CW · PSK · FSK · AFSK · RTTY · FM · **C4FM FDMA** · **C4FM TDMA**

The digital mode most suitable for
Amateur radio communications is **“C4FM”**



In our Amateur radio operations we are familiar with many types of modulation, like AM, SSB, CW, FM, FSK, RTTY and so on. However, current regulations of other communication systems do not allow the use of many of these modulation types. Within the Amateur radio hobby we can study and experiment with many modulation schemes, methods and protocols.

We are beginning to see digital modes used on the Amateur bands. Many Amateur radio operators are not familiar with digital type communications. However, we can expand our Amateur Radio world by learning about the characteristics and merits of digital type communications.

The range of frequencies and the bandwidths that hams are allowed to use is limited. If we want Amateur radio to move ahead into the future, we must begin to use these frequencies more effectively.

The history of Digital Communications

Digital communications modes have gained great popularity in the LMR (Land Mobile Radio) market because of their better performance in noisy environments and in the presence of interfering signals. In addition, the occupied bandwidth can be narrower than the current FM analog communications. The trend is to move communications systems from analog to digital.

The first digital radios appeared in the 1980's. At that time, The EDACS or TETRAPOL systems, using the GMSK (GFSK) modulation technique, were released. After that, various other digital systems were developed and used in the commercial markets. Currently, the GMSK format has lost popularity in the LMR market, and C4FM (4-level FSK, Frequency shift keying) has emerged as the dominant mode.

The progress and recent developments in Digital communications has been drastic. There is a big difference between the early digital systems

and the latest ones. The electronic devices have been greatly improved and the signal processing speeds, capacities, including the software and protocols, have made great advancements. The continued "step by step" progress of this technology revolution will expand the possibilities of digital communications, and reduce costs.

Additional advantages of digital communication systems are: The ability to transfer huge amounts of data in a short time; Better performance and immunity to interference; Complex systems can be developed; Increased security and protection from jamming; Increased capacity; Product and system cost reduction can be realized. When we can understand the merits and possibilities of digital communications, we can take advantage of these features, and consider newer features for our Amateur radios as never before.



Digital Systems in Amateur Radio

In 2003, a GMSK modulation type transceiver was released in the Amateur market. This was the first commercially viable Amateur digital radio. Then, in 2004, D-STAR, also using GMSK modulation was introduced to the Ham bands. Recently, in the USA, Motorola LMR radio introduced a Digital Mobile Radio, using C4FM (4-level FSK) TDMA that can be used on the Amateur radio frequencies. From this adaptation into the Ham world, an

Amateur Radio Club named DMR-MARC (www.dmr-marc.net/) has been organized to pursue this digital technology. At the 2011 Dayton Hamvention, many Hams were introduced to Digital communications and were able, for the first time, to use a DMR radio on the Amateur radio bands.

Dayton Hamvention



The DMR-MARC Worldwide Network
Home page: www.dmr-marc.net/

DMR-MARC

Home Networked Repeater TRBO FAQ Contact Us

The DMR-MARC Worldwide Network

Our network is an all-digital group of MOTOTRBO DMR repeaters in the USA, Germany, and Australia. We are at www.dmr-marc.net/ and members many of whom are Motorola Solutions employees, Motorola Service Station employees, dealers, system installers, and Motorola equipment aficionados.

All repeaters on our network are connected all the time. TRBO radios have great voice quality, great coverage, and extended battery life all in HALF the channel bandwidth of a traditional analog FM repeater. Isn't time you upgraded to digital radio's cutting edge?

Member Toolbox

- Latest OPS Contact List
- DMR-MARC/TRBO @Repeater ID Scheme
- Worldwide Repeater and Subscriber Databases
- Program your Radio
- Program your Repeater
- Motorola Software Updates

Latest News

New Repeater-Please welcome them!

- K1MAGT Hudson, NH
- W8PDM Portau, MI
- ZS073 Johannesburg, South Africa
- G1MAU Boston, MA

Other Interesting Items

- W4MOT Plantation has a new repeater psc 442-425.
- The TRBO subscriber and repeater ID database is up to date with all known worldwide subscribers and repeaters. If you are not on that list, please use our contact us link at the top to update the worldwide master repeater and subscriber ID database. Thanks.

Network Update

- The USA masters have been upgraded to R01.00.02. MTR-2000 owners are STRONGLY encouraged to make this firmware update ASAP! XPR-4000/4000 owners may update at their convenience.
- **C-BRIDGE UPDATE:** Over the last few months some of you have been noticing c-bridge network hiccups where you hear segments of transmissions and miss some. Our support team, as of 10 AUG, believes we have resolved many of the problems causing these issues. While the problems are not 100% fixed, system performance should be much better than the last couple of months. Rayfield Communications and the DMR-MARC team will continue to enhance features on the C-bridge and improve stability. If you notice any problems, complete the form under the Contact Us link at the top of the page. This way your observation gets routed to the operators. Considering on the air even during the weekly net, will do you no good. Thanks for your patience.

We are Worldwide

The distance between our east node and west node is 11,830 mi (19,000 km) which makes ours the longest distance amateur TRBO DMR network in the world.

Weekly Net

Join us for our weekly DMR-MARC net Saturdays at 1800 UTC (Noon EDT, 11AM CDT, 10am PDT, 8PM GMT, 3AM Melbourne) on Timeslot 1 (call ID 1).

[Listen to archived nets](#)

TECHNICAL pages

What Digital mode is suitable for Amateur radio?

◆ Kinds of digital communication systems

As mentioned earlier, Digital communications may not be familiar to those of us in Amateur radio, making it difficult for us to understand how it works. Digital has three specific categories that we need to understand. These are Modulation type, Communication type (multiplexing) and Protocol.

The first category is the Modulation type.

This is the modulation scheme used to convert the analog voice to Digital signals. There are three Modulation types; GMSK (MSK), 16QAM, $\pi/4$ DPQSK and C4FM (4-level FSK). Each modulation type has benefits and disadvantages.

The second is the Communication type.

This is the method of transmitting or multiplexing the modulated Digital signals. There are two Communication types, FDMA (Frequency Domain Multiple Access) and TDMA (Time domain Multiple Access). We should learn how each Communication type operates.

The third is the Protocol.

The protocol is the processing scheme used to relay the data from the transmitter to the receiver. A superior protocol is the most important issue in the design of a Digital radio, and determines the performance of the Digital radio, even if the modulation and the communication types are similar. The Protocol contains the logic that the error check/correction feature depends on. If the error correction is not realized in the receiver, the communication is suspended and the service range in mobile operation will be reduced.

As previously mentioned, in the analog system, we need to pay attention to the modulation type, but in the digital system, we also need to consider the modulation type, the communication type and the protocol.

◆ Let us begin by considering the advantages of each method of digital communication!

GMSK modulation

The GMSK modulation circuit is relatively simple, and this method was utilized in earlier cellular telephones as well as the older LMR TETRA POL system that was used from the 1980's to 1990's. Now this method is considered old fashioned and no longer used by LMR. Currently GMSK is still being used by D-STAR. Because C4FM (4-level FSK), (which we will discuss later) has provided superior performance from 1990's forward, it has become the mainstream protocol for professional digital radios.

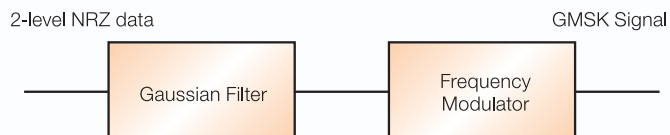


Fig. 1 Principle of the GMSK modulation

$\pi / 4$ DQPSK modulation : (called four-minute pie DQPSK)

This is known as the higher-grade modulation method. The $\pi / 4$ DQPSK modulation's biggest advantage is that it produces very low distortion. However, it requires linearity (the same as SSB amplifiers) and very complicated electrical circuitry; this also results in very low transmission

efficiency. For these reasons this method is not widely used for LMR systems, except for special applications.

A good example of this method is the European TETRA system.

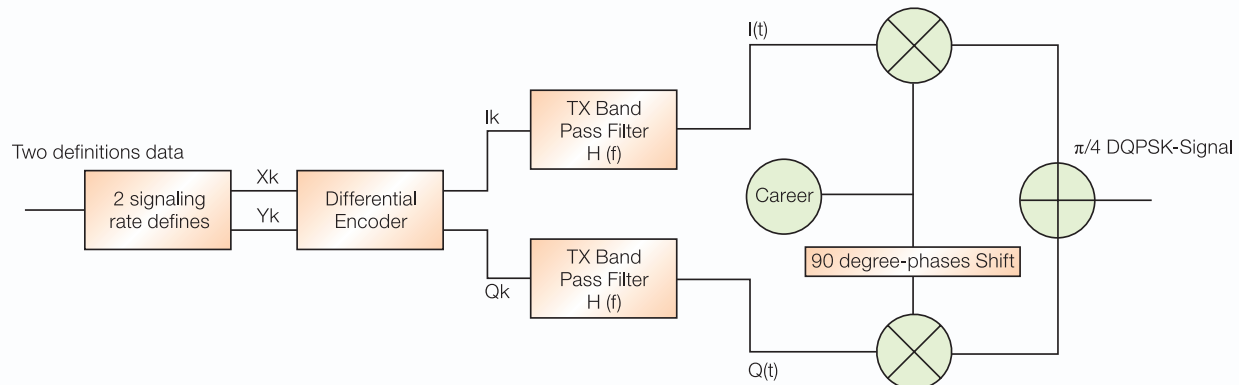


Fig. 2 Principle of the $\pi/4$ DQPSK modulation

C4FM (4-level FSK) modulation

Compared to the GMSK and $\pi/4$ DQPSK modulation systems above (when using the same bandwidth), the C4FM (4-level FSK) circuit can be simplified and the BER (Bit Error Rate) made much better. For this reason, C4FM (4-level FSK) has replaced GMSK as the main modulation method utilized in the latest LMR radios in the market. Radios using this modulation method are known as APCO P-25. APCO P-25 radios are primarily used in the Public Safety market, such as Police and Fire. An additional type of Digital radio system that uses C4FM (4-level FSK), and is very popular in

professional commercial markets, is known as DMR (Digital Mobile Radio). DMR is used primarily in the European and Asian markets, and is also known as dPMR.

We need to pay attention to the C4FM (4-level FSK) method because we believe this is the most important technology in digital communications. This method will definitely find increasing use in Amateur radio communications within the near future.

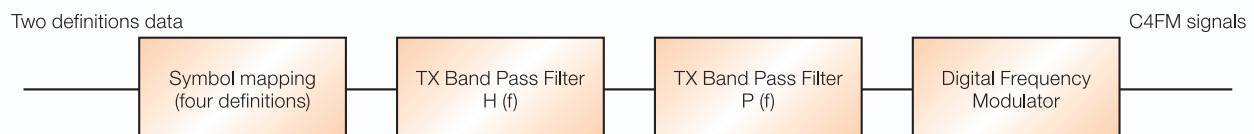


Fig. 3 Principle of the C4FM

Digital Communication Types

As explained before, there are two multiplex methods, FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access).

FDMA

(Frequency Division Multiple Access)

This technology divides the available frequency band into narrow bandwidth channels. When compared with TDMA the circuitry is simpler. Many communication systems utilize this method, like APCO P-25. Previously, GMSK was predominantly used, but now C4FM (4-level FSK) is dominant.

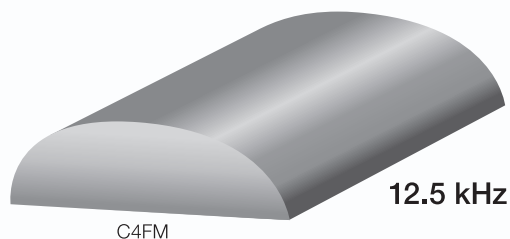
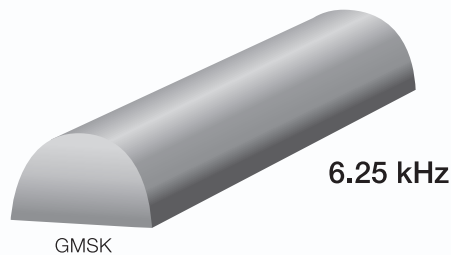


Fig. 4 FDMA conception diagram



VX-P820 series



VX-P920 series



VX-7100/7200 series

Vertex Standard APCO P-25 LMR radios

TDMA (Time Division Multiple Access)

Just as FDMA divides the spectrum into narrow bandwidth channels to accommodate many signals, TDMA utilizes time slots; so many signals can share the same frequency, permitting multiple communications. This method has a large advantage in Amateur radio operation because it allows multiple groups to use one repeater on the same frequency. Additionally, when the spectrum is shared by time division, the actual transmission time will be reduced by one-half or more. Thus, battery life will be longer. The TDMA method offers some big benefits to portable radios and repeater users.

Dividing the time into two time slots, is called "2 slot TDMA". The system that uses this method is the DMR (Digital Mobile Radio) technology that is used in LMR products. This method was standardized in 2005 by ETSI (European Telecommunications Standards Institute). TDMA has become the standard communication method in the USA and Asian markets.

Compared with other digital communication types, the service coverage is wider; the transmitted voice quality is better and clearer, the security performance is more reliable and the battery life is longer. In addition, a single repeater can repeat two communications on one channel. The cost to install one digital TDMA repeater is significantly less than the installation cost of two current technology analog repeaters. The cost merit is very important and a significant reason we should give this method our attention.

As explained above, TDMA has a lot of merit, but the circuit design is difficult and requires a high level of development ability, when compared with the FDMA systems. Presently there are only three companies that have developed and released DMR radios into the market. One is Motorola and another is Vertex Standard.

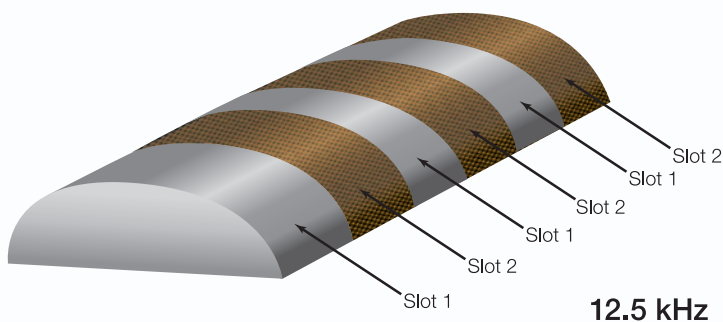


Fig. 5 TDMA conception diagram



VXD-720



VXD-7200



VXD-R70

Vertex Standard DMR (TDMA) LMR radios

Digital communications misunderstandings

Digital communication is a new field amateur operators, and very few of us understand this new technology development correctly. Some common misconceptions are introduced and discussed below.

Misunderstanding 1: *“Digital Communication is superior to Analog Communication.”*

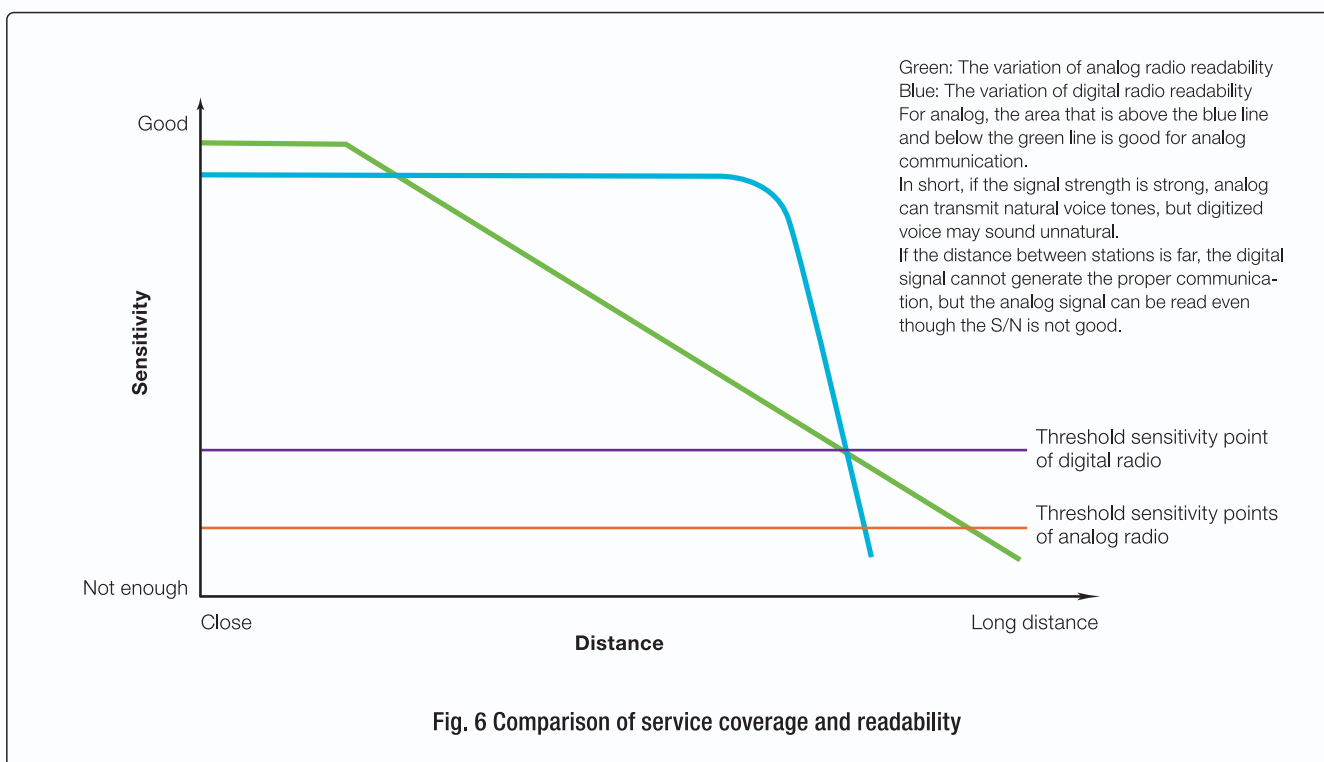
It may be easy to say, “Digital Communication is superior to Analog communication”, but there are various methods of producing Digital signals. Each method has advantages and disadvantages. One of the main themes of Digital communication discussion is the amount of current consumption needed and its affect on battery life. In order to convert the voice input to a digital signal, the modulation circuit is more complex and requires a large current drain. This affects battery life, and may cause it to be shorter than the analog FM radio battery life. In

addition, when the received digital signal falls below a certain sensitivity level, the audio output will shut down. In these circumstances, we cannot say that Digital is better than Analog. The important thing is to select the method that is best suited for Amateur radio communication purpose. For example, if the main purpose is to use a handy-talky transceiver for voice communication with another station, then an analog communication transceiver may have the advantage.

Misunderstanding 2: *“Digital Communications systems have better sensitivity and wider coverage area than Analog Communications systems”*

With analog FM modulation, 12 dB SINAD is considered the standard sensitivity point. In Digital communications, the standard is different. It is the point that can realize a 1 % bit error rate. In comparison, the Analog signal strength of 12 dB SINAD sensitivity is 3 dB higher than the digital mode 1% bit error rate level. In Digital communication, if the signal level is stronger than this point, even by a small amount, it is

possible to produce clearer RX audio with better S/N. However, if the Digital signal is lower than this point, the audio from the speaker will be intermittent and not understandable. In this case, the analog FM signal has the advantage, even if the signal becomes weaker, by opening the receiver squelch, you may be able to hear and understand what is being transmitted.



Misunderstanding 3:

“Digital Communications systems have faster communication data speeds than the Analog Communications systems”

One big advantage of digital communication methods is the ability to convey large amounts of data. However, if the bandwidth is narrowed, the data transfer speed is rapidly diminished. In contrast, our VX-8DR/DE or FTM-350AR/AE analog transceivers can exchange data at 9600 bps in the VHF/UHF frequency range. Compare this to D-STAR, which is limited to sending data at only 4800 bps in the same frequency

range; the analog radio definitely has the advantage. This means that the data speed of the Digital radio is actually slower than current Analog transceivers. It is preposterous to say this is the long awaited high-speed communication system.

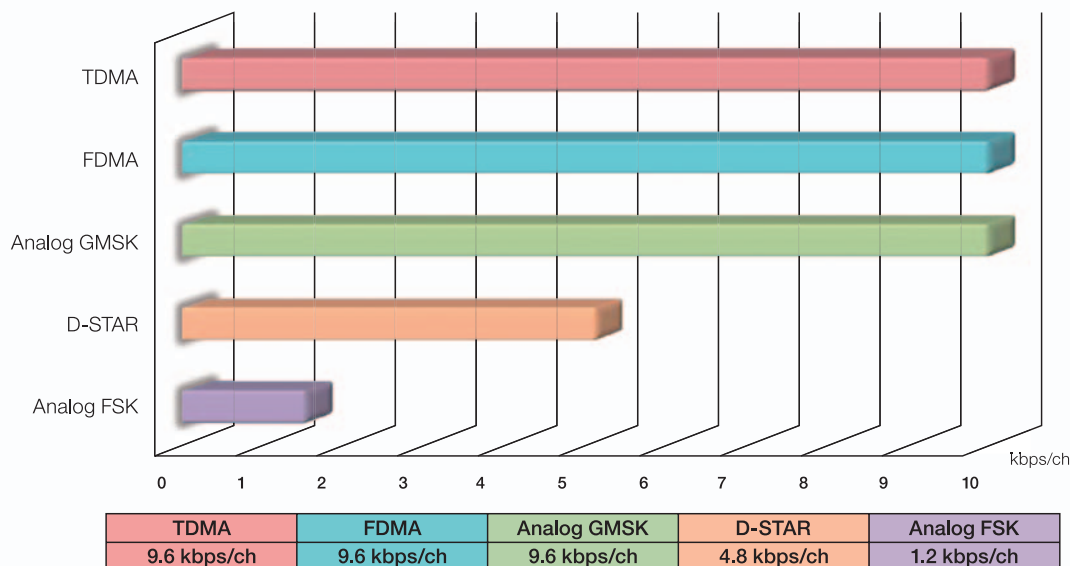


Fig. 7 Comparison of the data transferring speed

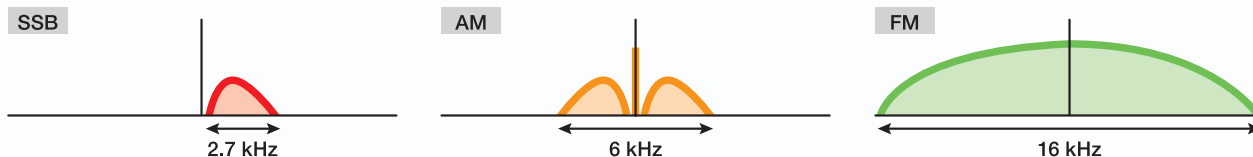
Misunderstanding 4:

“The ultimate function of Digital Communications is the narrow band width”

Current digital transceivers are using 6.25 kHz or 12.5 kHz bandwidths. Now consider that Hams have been using SSB for 2.5 kHz narrow

bandwidth voice communications for more than 50 years.

Analog modulation



Digital modulation

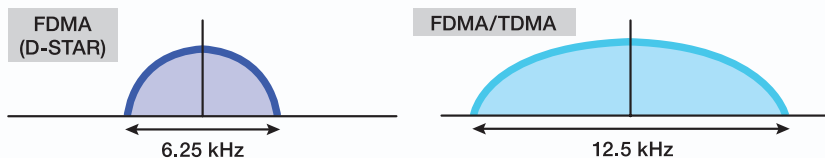


Fig. 8 Comparison of the occupied bandwidth

Misunderstanding 5: *“D-STAR is the standard Digital Communication for Amateur radio”*

This is not true. We are not sure why D-STAR, which uses GMSK, is recommended. However, it is neither good nor appropriate to limit the Digital radio selection to only one method for all Hams worldwide. If only one manufacturer is developing only one type of Digital radio for all Hams, the digital technology would not advance and Hams would be forced to use inferior equipment at higher costs. A good example is

the continued use of the older GMSK technology. We see no advantage in pursuing outdated technology when better technology exists. Remember, the spirit of Amateur radio is encouraging Hams to improve their radio skills and knowledge by experimenting and studying new technology.

Misunderstanding 6: *“When thinking about the future, it is better to purchase the digital transceiver now.”*

Digital radios cannot communicate effectively if the modulation methods, communication types and protocols are different between the transceivers. If the fast pace of progress made in the LMR Digital products is any indication, the odds are low that the Amateur Digital radios sold in today's market will be compatible in the future. A good

example is the GMSK radios that were very popular not too long ago; they have been decreasing in popularity. This trend will continue as Digital amateur radio enthusiasts pursue the new technologies.

Misunderstanding 7: *“All of the digital methods have similar performance.”*

The performance of the various digital communication systems is very diverse, and depends on the modulation modes, multiplex methods and protocols. Currently, the most reliable error correction perfor-

mance, superior audio, top-level service area coverage and longest battery life, are found in the latest C4FM (4-level FSK) FDMA or TDMA protocol DMR radios.



Moving from the age of quantity to a new era of quality

Remember that Hams seek knowledge, and believe in advancing the communication technologies. We should pay attention to the ongoing development of Digital communications and avoid persisting in one outdated digital mode. We must expand our horizons and investigate the latest digital communication techniques. Learning new technology is one of the pleasures of Amateur radio. From this, the future of Amateur radio will move ahead another step.

Now is the dawn of a new digital communications era. Previously we digitized the voice signal and called it "digital". Now we are at a stage of development to know the various digital technologies available, and we can choose the best system for use in our Digital radios. It is important to refer to the latest digital technology as it is used in commercial LMR radios, and apply these techniques to improving Amateur radio systems.

Important objectives for Amateur Digital radio

Vertex Standard has the following fundamental policy in developing radios for Amateur Digital communications:

- **Utilize the maximum advantages of Digital communications with minimum frequency bandwidth.**

As we learned previously, if the bandwidth is made narrower, the data transfer speed becomes slower than current Analog radios. For radios that only transmit callsign and the GPS position data, Analog radios are best. Changing the modulation to digital will only result in a slower data speed, and there is no advantage in doing this.

- **Adopt the latest digital modulation schemes for the future good of Amateur Radio.**

Vertex Standard will use the most appropriate, advanced and latest digital communications methods that are gaining acceptance in modern professional communications equipment. We will not use outdated systems for manufacturing convenience.

- **Explore the merits of Digital communication for Amateur radio.**

For example, if we use TDMA, one repeater could simultaneously broadcast multiple (multiplex) QSOs, providing a large cost saving. Using FDMA, with the C4FM (4-level FSK) modulation, the BER (Bit Error Rate) characteristic makes digital suitable for mobile operation. From this point of view, C4FM with FDMA or TDMA are the most interesting modulation methods for Amateur radio.

Digital communication in the future of Amateur radio

In the near future, appropriate systems for Amateur radio communications may be chosen from among the various digital communication methods. Every digital method has its own advantages and disadvantages. Limiting Amateur radio to only one method is shortsighted and does not benefit the future of Amateur radio.

At this point in time, Vertex Standard believes the C4FM (4-level FSK) FDMA or TDMA are the most suitable selections for Amateur radio applications. In early 2012, we will release a C4FM (4-level FSK) FDMA Handy-Talky and a Mobile transceiver into the Amateur radio market.

After our initial introduction, we plan to introduce a C4FM (4-level FSK) TDMA (2 slots) or TDMA Handy and Mobile transceiver into the Amateur radio market.

The most attractive benefit of digital communication is its ability to transfer large amounts of data. While it is commonly believed that narrowing the occupied bandwidth to efficiently utilize the frequency spectrum, is the primary advantage of Digital radio, we know that if the bandwidth is made narrower we lose the large data transmission

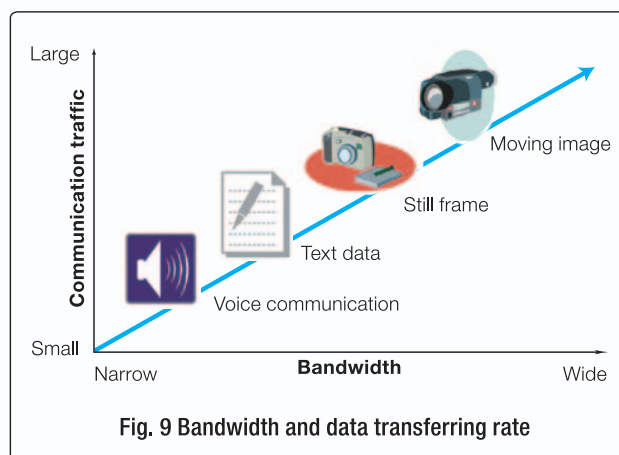
advantage. In this situation, it becomes difficult to understand why anyone would want to use Digital communication for this purpose.

The Amateur radio population in the US is currently at 699,737 licensees¹. Even though the rest of the world's Amateur radio population is decreasing, the US Amateur radio population has been increasing at a rate of 3% since 1999 (ibid). Adjusting to these trends, Amateur radio is moving from the world of quantity to one of quality. This means with VHF and UHF frequencies that are currently available, it is not difficult to find frequencies to communicate on the air. In the Digital radio world, it requires a high degree of quality to communicate. Utilizing a 6.25 kHz narrow bandwidth and sacrificing data speed is unacceptable. Enjoying Digital communications by knowing the advantages of this method is the real goal of Amateur radio!

¹Source "Graphs", FCC website accessed September 28, 2011.
<http://www.ah0a.org/FCC/Graphs.html>



Next generation C4FM (4-level FSK) FDMA handy transceiver



Compare Amateur digital communication specifications

		D-STAR ID-92	C4FM FDMA	TDMA VXD-720
General	Receive and Transmit frequency range	144,000 to 148,000 MHz and 430,000 to 450,000 MHz	144,000 to 148,000 MHz and 430,000 to 450,000 MHz	144,000 to 148,000 MHz and 430,000 to 450,000 MHz
	Emission type	F2D/F3E/F7W	F2D/F3E/F7W	F2D/F3E/F7W
	Temperature range	-20°C to +60°C	-20°C to +60°C	-30°C to +60°C
	Frequency stability	±2.5 ppm (-20°C to +60°C) 25°C at basis	±2.5 ppm (-20°C to +60°C) 25°C at basis	±0.5 ppm (-30°C to +60°C) 25°C at basis
	Speech coding speed	2.4 kbps	2.4 kbps	2.4 kbps
	Antenna impedance	50 Ω(SMA)	50 Ω(SMA)	50 Ω(SMA)
	Memory channel	1304 CH (include Memory, Call and scan edge memory CH)	1545 CH (include Memory, Call and scan edge memory CH)	512 CH
	Supply voltage	Nominal 7.4 V DC Operating 10.0-16.0 V DC	Nominal 7.4 V DC Operating 11.0-16.0 V DC	Nominal 7.5 V DC
	Case size	112 (H) x 59.0 (W) x 34.2 (D) mm	95.0 (H) x 60.0 (W) x 28.0 (D) mm	131.5 (H) x 63.5 (W) x 36.2 (D) mm
Transmitter	Weight	315g with standard battery	250g with standard battery	375g with standard battery
	RF power out put / Current consumption	VHF Hi 5 W @ 1.8 A (typ) UHF Hi 5 W @ 2.1 A (typ)	VHF Hi 5 W @ 1.7 A (typ) UHF Hi 5 W @ 1.9 A (typ)	
	Data baud rate speed	4.8 kbps	9.6 kbps	9.6 kbps (4.8 kbps x 2)
	Channel Spacing	6.25 kHz	12.5 kHz	12.5 kHz
	Modulation Type	FM/FM Variable reactance DV/GMSK Variable reactance	FM/Digital FM Variable reactance	FM/Digital FM Variable reactance
	Maximum deviation in Analog mode	FM Wide / ±5.0 kHz Narrow / ±2.5 kHz	FM Wide / ±5.0 kHz Narrow / ±2.5 kHz	
Receiver	Sensitivity	• FM :12 dB SINAD • DV :BER 1 % -11 dBμ typ (VHF), -10 dBμ typ (UHF) -7 dBμ typ (VHF, UHF)	-11 dBμ typ (VHF), -10 dBμ typ (UHF) -7 dBμ typ (VHF, UHF)	-7 dBμ typ (IMD more than 70 dB VHF, UHF) -5 dBμ typ (IMD more than 70 dB VHF, UHF) 5% BER
	Data baud rate speed	4.8 kbps	9.6 kbps	9.6 kbps (4.8 kbps x 2)
	Audio out put	More than 0.2 W @8 ohms for 10% THD (@7.4 V DC)	More than 0.2 W @8 ohms for 10% THD (@7.4 V DC)	More than 0.5 W @8 ohms for 10% THD (@7.4 V DC)

The future of Amateur Radio

When TV video and FM broadcast audio is digitized, the picture becomes finer and the sound clearer, but the impact is not that great on Amateur radio when the communication is digitized. Some Digital radio manufacturers advertise that “the service coverage will be wider”, but it is not true and statements like these are misleading. We are sorry to hear this. As explained in this booklet, analog FM can show an advantage over Digital radio in some areas.

It is wise to choose the best method based on the purpose of the communication. We need to be intelligent to find it.

In Amateur radio, we can use AM, SSB, PSK, FSK, AFSK, RTTY, FM and so on to enjoy our communication. However, we are limited by the frequency range, and by the characteristics of the radio wave and modulation method. I think it is important to take advantage of the best ideas from the available technology of the respective communications systems.

Amateur radio operators want quality communications. There are many and diverse ways to enjoy Amateur radio. Hams may consider numerous communications avenues to investigate and experiment with...

For example, WiRES-II (Wide-coverage Internet Enhancement System) is one VoIP mode Yaesu introduced in 2002. This system allows Hams to communicate worldwide by using inexpensive analog FM radios and

repeaters connected via the Internet. You can QSO with colleagues from Japan, London, Hawaii, Los Angeles or all around the world on the WiRES-II network.

In 2003, the APRS® (Automatic Packet Reporting System) was introduced to Amateur radio. The system exchanges position data acquired by a GPS receiver connected to an analog FM radio. Location, distance, speed, weather information and messages can be exchanged. Vertex Standard strongly supports this innovation and we have introduced the VX-8 series of handheld radios and the FTM-350 mobile transceivers that incorporate these features.

Amateur radio is a wonderful hobby that allows us to communicate by using radio waves. The knowledge and experience that we obtain through our hobby enables us to contribute a great service to society. Hams are always there to provide communications in disaster stricken areas, such as the recent catastrophic earthquake in Japan. Even if the infrastructure is damaged and communications are disrupted, Amateur radio operators can provided the needed communications to help save lives and assist in the important recovery work.

At Vertex Standard, we aspire to make important contributions to the advancement of Amateur radio.

*, APRS® is registered trademark of Bob Bruninga WB4APR.

YAESU

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