



Whitepaper

4 Level FSK/FDMA 6.25 kHz Technology

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dPMR[®] digital Private Mobile Radio 6.25 kHz Technology

Since the beginning of PMR radio, there has been a constant juggling act between available spectrum and channel size. As filter and modulation technology has advanced the channel size has progressively reduced, 100 kHz, then 50, followed by 25 and then the 12.5 kHz we have known for the last twenty or so years. Add to that the current policy of spectrum pricing and it becomes clear that a new advance was needed to make the most efficient and economical use of this scarce resource.

Traditionally PMR has always operated with FDMA (Frequency Divided Multiple Access) technology as that has offered the best flexibility to users. The initial plan for European standardisation was based on 2-slot TDMA (Time Divided Multiple Access) technology as several of the major PMR players have proffered that 6.25 kHz FDMA was simply not possible. Research by Icom and Kenwood however showed that 6.25 kHz FDMA was a practical proposition and they entered into a joint agreement to develop the technology further.

This new digital 6.25 kHz FDMA idea was taken up by ETSI (the European Telecommunications Standards Institute) and developed into a European Standard.

dPMR[®] became an open, non-proprietary EU standard and was published under the reference TS102 490 (License-free) and TS102 658 (Licensed).

History

Achieving 6.25 kHz channeling was impossible to do using analog technology, so it became necessary to develop a new digital protocol. Availability of high quality low bit rate voice codecs meant that 6.25 kHz was a practical plan if a suitable modulation scheme could be identified. Several methods were considered, including ACSB and the proposed APCO Project 25 Phase II CQPSK. However, both required a more expensive linear amplifier in the transmitter and neither is compatible with existing analog FM hardware.

Instead, 4-Level FSK (4FSK) modulation was selected using FDMA for the access method. This method has a number of advantages:

- better communication range
- simpler design
- easy to maintain and service
- lower cost for business and industry customers
- compatible with existing FM radio hardware

The first 6.25 kHz capable radios were introduced to the market in 2006. There are now 7 manufacturers that have 6.25 kHz FDMA products, with more manufacturers currently developing products. These new products operate in both digital conventional and digital trunking modes. To enable backwards compatibility, they also operate in 25 kHz and 12.5 kHz channel bandwidths.



Backwards compatibility to analogue only radios enables a planned migration path to “digital” with existing radios operating analogue only and new radios operating analogue and digital.

How the Technology Works

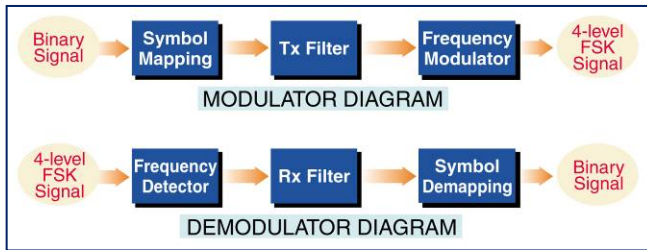
General specifications:

- Access Method: FDMA
- Transmission Rate: 4800 bps
- Modulation: 4-level FSK
- Vocoder: AMBE+2™
- Codec Rate: 3600 (Voice 2,450 + Error Correction 1,150 bps)

Modulation with 4LFSK uses a symbol mapping scheme. When the radio receives a binary number, that number is mapped to a symbol, which is interpreted as a 1050Hz frequency deviation.

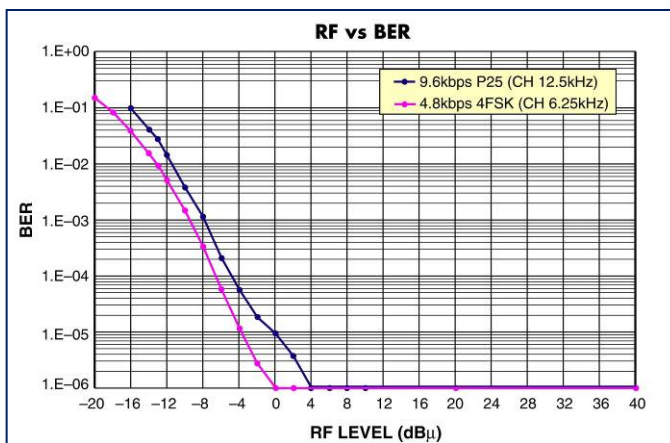
| Information | Symbol | Deviation |
|-------------|--------|-----------|
| 01 | + 3 | + 1050Hz |
| 00 | + 1 | + 350Hz |
| 10 | - 1 | - 350Hz |
| 11 | - 3 | - 1050Hz |

During demodulation, that deviation is detected, filtered and “unmapped” as a binary signal for transmission.



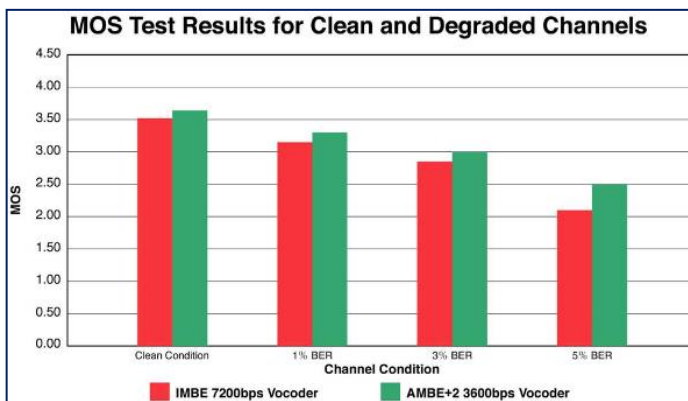
Signal Quality

The FDMA signal BER performance exceeds that of APCO Project 25 Phase 1 radios, which have already been accepted by the market as quality digital radios.



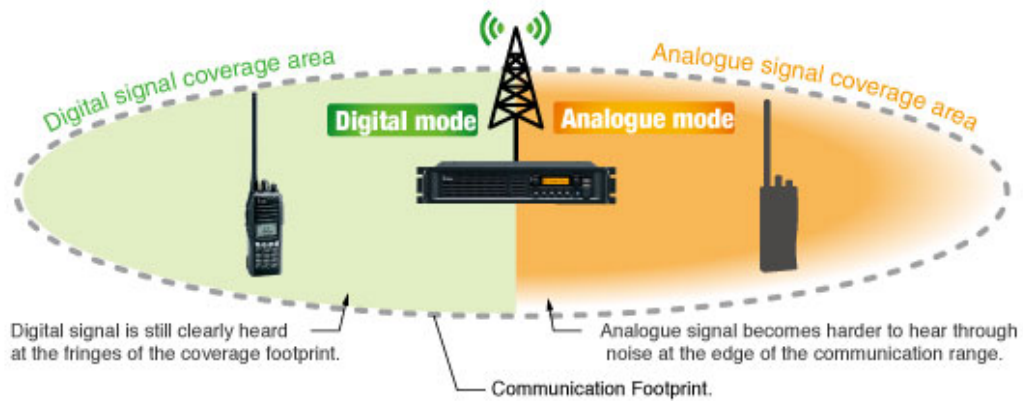
Audio Quality

The 6.25 kHz dPMR[®] technology also offers improved audio quality compared to P25 audio. Test engineers using a Mean Opinion Sample (MOS) found the audio quality was uniformly better, ranging from clean conditions to 5% BER. Using the AMBE+2[™] vocoder makes this possible.



Range

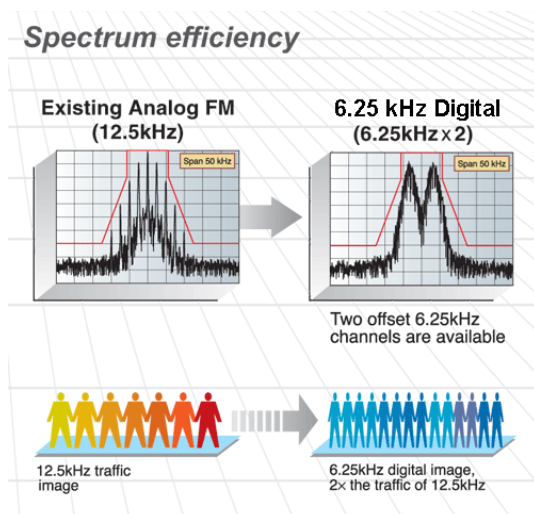
Audio quality over distance is also greatly improved with 6.25 kHz dPMR[®] technology. Instead of the early degradation of audio that you see in an analogue signal, the 6.25 kHz dPMR[®] digital audio quality remains higher over a comparable distance. This has been seconded in real life use from end users.



Spectrum Efficiency

A channel is defined by the deviation either side of the carrier frequency. Migrating from a 25 kHz channel to a 12.5 kHz channel on the same carrier frequency is a 1-for-1 move. There is no increase in the capacity to load radio users.

Some administrations have allocated 6.25 kHz frequencies/channels in their band plans, but most went unused because no 6.25 kHz radios were available. With dPMR[®] FDMA technology, spectrum coordinators have total flexibility to either assign one 6.25 kHz channel within an existing 25 kHz or 12.5 kHz channel or as a stand-alone frequency somewhere else on the band.



The emission mask above left is established for 12.5 kHz channels. The signal must operate within the mask.

The emission mask on the right shows that the dPMR[®] FDMA signal clearly operates within the mask (In this case 2 x 6.25 kHz signals in a 12.5 kHz channel). Accordingly, administrations around the world have certified 6.25 kHz capable radios for use and there are in excess of 400,000 units already in operation. These same radios were approved in Europe under EN301 166, again the first ever 6.25 kHz radios for this region.

Channeling Considerations

A number of frequency allocation options for 6.25 kHz are available in for each country. It is advised that you check with your local administration on the conditions for licensing and use of 6.25 kHz FDMA equipment, as not all regulations are uniform at this point.

Expand an Existing System

In most cases spectrum license holders or site owners/operators will have licenses to use 12.5 kHz channels. While it is recommended that consultation with your administration on how you can use/apply 6.25 kHz equipment in your system, current 6.25 kHz FDMA systems offered in the market can already be used 'as is', and thus let you begin the migration to a digital system now. As the basic architecture of the equipment is based on existing FM hardware, assimilating components into an existing analogue system is relatively easy. The same antennas, power supplies, duplexors, isolators and combiners etc. can be used, so only the cost of adding a digital channel (s) with the accompanying terminals is required upfront. This is not much different to replacing old analogue equipment.

Depending on local regulations, it may also be possible to increase the capacity of the system because of the narrower channel spacing of dPMR[®]. Applications for new additional 6.25 kHz channels and combine them with their current 25 or 12.5 kHz channels, or new frequencies could occupy the existing 25 kHz or 12.5 kHz bandwidth. Additional stand-alone 6.25 kHz channels could also be used.

Split a 25 kHz or 12.5 kHz Shared or Exclusive Channel

Because the emission mask is so tight, two 6.25 kHz dPMR[®] signals can be used next to each other within a 12.5 kHz channel without causing interference to each other or adjacent channels. Compliance with EN301 166 at 6.25 kHz for current equipment is one measure of guarantee that interference issues are no different than at 12.5 kHz or 25 kHz. Frequency co-coordinators in the U.S.A. have even made recommendations to the FCC that are expected to be approved soon, about setting up new 6.25 kHz systems adjacent to existing systems, outlining parameters to avoid harmful interference.

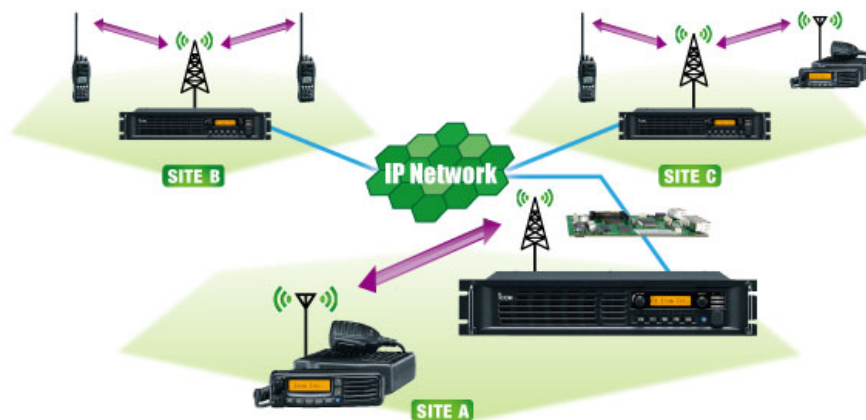
2-for-1 efficiencies may be realized by splitting existing 12.5 kHz channels. Using 6.25 kHz channels offset from the carrier frequency of a 12.5 kHz channel, it is possible to fit two 6.25 kHz channels into the 12.5 kHz bandwidth.

Again, we recommend that you contact the spectrum management service of your administration for details on how to modify your shared or exclusive 12.5 kHz license for operation of two 6.25 kHz signals.

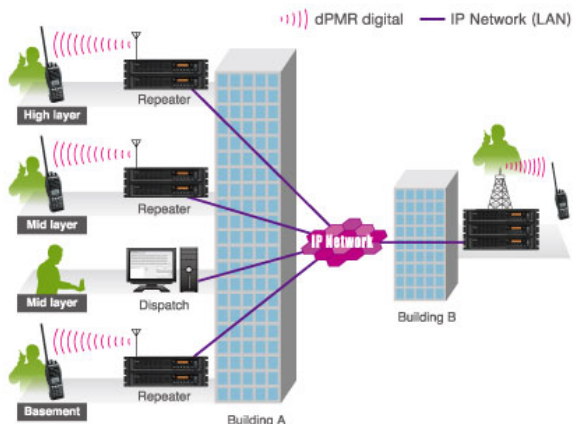
Current and Future Applications for 6.25 kHz Technology

The new digital land mobile technology can be a platform for future integration of IT and IP technologies. To this end, dPMR[®] manufacturers have developed a new generation of digital networking systems. The goal is to allow seamless migration from analog systems to new digital technologies.

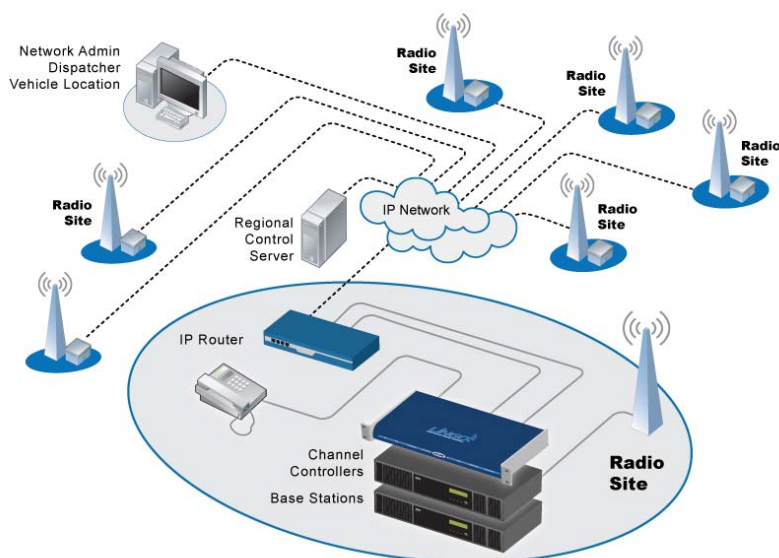
Multi-site IP Networks



In-building and Intra-building Networks



Trunking Networks



Handheld battery operated equipment

As already explained, dPMR technology offers better audio quality at the extreme fringes of radio coverage. In addition to this, the fact of using narrower 6.25 kHz channels means that receiver filters are narrower too and that the RF sensitivity can be increased. This allows users the choice of reducing the RF power used to extend the possible battery life.

Whilst this is possible, is it actually what is needed in real life?

Handheld radios usually are employed in two scenarios:

- integrated into a mobile network
- in a dedicated portable only network

Using handhelds in a network that is designed around mobile operation demands that the handhelds are operated for maximum possible range so that they come somewhere near the performance of the mobile units. In these cases the RF power is the first concern not the battery life.

When the handheld application is a portable only type of system, ie in-house or localised area, the typical requirements for coverage normally mean that the radios are operated at reduced power anyway. In such cases the battery life considerably exceeds the operational requirements.

dPMR offers a third option to add to these typical scenarios by integrating the localised area system into the full mobile network by means of a local repeater connected to the main network via an internet gateway.

By exploiting the full flexibility of the dPMR protocol, system planners can ensure the maximum potential of such mixed systems.

6.25 kHz and 'equivalence'

Many published comments and adverts use the term '6.25 kHz equivalent'. This is simply down to offering 2 voice channels in a 12.5 kHz bandwidth and thereby permit two separate radio systems.

dPMR being based on a 6.25 kHz FDMA format is by definition always 6.25 kHz. There is no need to hedge the definition with - quote equivalent unquote.

Where 6.25 kHz 'equivalence' is achieved by other means, such as a TDMA solution we can see why the definition ceases to be black and white.

The very nature of TDMA 'equivalence' is such that the advantages offered leads to compromises in other areas. A TDMA repeater may well offer a lower installation cost as a single repeater will not require a duplexer. But where the common requirement of direct mode operations is added we see that the operation reverts to 12.5 kHz FDMA and any idea of 6.25 kHz 'equivalence' is lost.

Similarly, the TDMA solution can offer the possibility of emergency break-in where another user can pre-empt a call in progress. However, this requires the use of two time slots to achieve, so again the possibility of two separate systems in 12.5 kHz has been lost.

With dPMR the fundamental issue of true 6.25 kHz operation is never compromised. It can also be said that when the day comes where 12.5 kHz spectrum is full, a dPMR system will still be a viable solution, thus potentially a longer-term, future proof technology and investment.

Appendix A: Adjacent Channel Power

Adjacent channel power is of primary interest to spectrum planners and coordinators. This is the measurement of how clean the modulation of the transmitter is and directly influences the possibility of using the channels either side of the user.

For older technologies using 12.5 kHz channels the requirements are specified in EN300 086 or EN300 113.

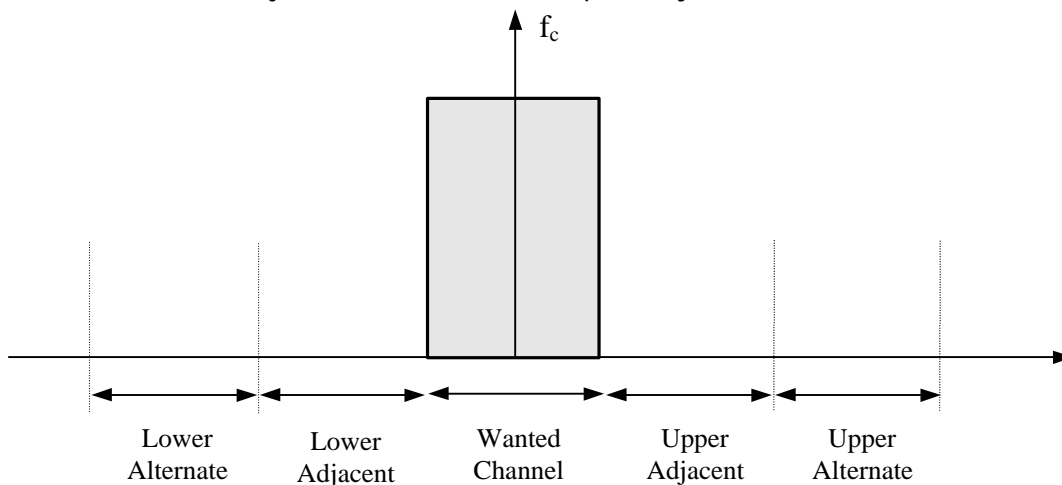
These standards both require a protection level of 60dB for 12.5 kHz channels. It should also be noted that older 25 kHz channels require a protection level of 70dB.

European standards have allowed for the reduction of channel size by permitting a 10dB degradation in adjacent channel power. It would therefore be totally reasonable to expect a similar 10dB relaxation when channel size is halved again to 6.25 kHz.

However, such a relaxation was not required.

For 6.25 kHz equipment it is the EN301 166 standard that applies for radio approval purposes.

EN301 166 has requirements for not only the adjacent channel power but also for the unwanted power that could be detected two channels away from the user. These are known in the standard as 'adjacent' and 'alternate' respectively:



The requirements of EN301 166 call for 60dB protection for the next 6.25 kHz channel and 70dB protection for the next channel.

The simple fact that dPMR 6.25 kHz technology meets the same level of adjacent channel power protection as current 12.5 kHz equipment is a significant achievement that will no doubt reassure spectrum managers that dPMR technology can co-exist with older 12.5 kHz technologies. As mentioned above, frequency co-coordinators in the U.S.A. already have recommendations about setting up new 6.25 kHz systems adjacent to existing systems, outlining parameters to avoid harmful interference that could serve as reference to administrations contemplating regulatory changes or advice to system operators.

Here is an illustrative example of the Busy Channel Lockout feature operation.

VHF Test Results

| | | | | | | | | |
|---------------------------------------|-----------------------|-------------------------|---------------|-------------------------|-------------------------|-------------------------|---------------|-------------------------|
| Freq Steps of Radio "A" in kHz | 157.000000 (0 offset) | | | | 157.007500 (7.5 offset) | | | |
| Sig Strength | Weak Signal | | Strong Signal | | Weak Signal | | Strong Signal | |
| No Modulation / Full Voice Modulation | Dead Carrier | Fully Modulated Carrier | Dead Carrier | Fully Modulated Carrier | Dead Carrier | Fully Modulated Carrier | Dead Carrier | Fully Modulated Carrier |
| Radio "B" Bandwidth | | | | | | | | |
| 25 kHz | AB | AB | AB | AB | --- | --- | A | A |
| 12.5 kHz | AB | AB | AB | AB | --- | --- | A | A |
| 6.25 kHz | AB | AB | AB | AB | --- | --- | AB | AB |

A = "A" radio "busys" out
 B = "B" radio "busys" out
 Weak Signal: 2 Radios 3 Meters apart without antenna, 1Watt
 Strong Signal: 2 Radios 3 Meters apart with antenna, 1Watt
 "B" Radio ALWAYS at 157.00000
 "A" Radio Starts at 157.00000 moves to 157.007500
 "A" Radio always in 6.25 mode

UHF Test Results

| | | | | | | | | |
|---------------------------------------|-----------------------|-------------------------|---------------|-------------------------|-------------------------|-------------------------|---------------|-------------------------|
| Freq Steps of Radio "A" in kHz | 460.000000 (0 offset) | | | | 460.00625 (6.25 offset) | | | |
| Sig Strength | Weak Signal | | Strong Signal | | Weak Signal | | Strong Signal | |
| No Modulation / Full Voice Modulation | Dead Carrier | Fully Modulated Carrier | Dead Carrier | Fully Modulated Carrier | Dead Carrier | Fully Modulated Carrier | Dead Carrier | Fully Modulated Carrier |
| Radio "B" Bandwidth | | | | | | | | |
| 25 kHz | AB | AB | AB | AB | --- | --- | AB | AB |
| 12.5 kHz | AB | AB | AB | AB | --- | --- | AB | AB |
| 6.25 kHz | AB | AB | AB | AB | --- | --- | AB | AB |

A = "A" radio "busys" out
 B = "B" radio "busys" out
 Weak Signal: 2 Radios 3 Meters apart without antenna
 Strong Signal: 2 Radios 3 Meters apart with antenna
 "B" Radio ALWAYS at 460.00000
 "A" Radio Starts at 460.00000 moves up to 460.00625 (6.25 kHz offset)
 "A" Radio always in 6.25 mode
 No interference when radio "A" is more than 12.5 kHz away from radio "B" under any conditions