DMR RADIO PERFORMANCE CHARACTERISTICS AND CHANNEL SHARING WITH OTHER RADIO TYPES

DMR Association White Paper

1. Introduction

One of the key design goals behind the creation of the ETSI DMR standard was to provide an easy migration path from analogue to digital PMR technology for users and spectrum regulators. To help achieve this aim DMR radios are required to have performance characteristics and specific features, such as Listen before Talk mode, which provide equivalence to those found in many legacy analogue products. Such an approach enables both an easy co-existence of analogue and digital radios within the same user fleet and by different licensed users sharing the same spectrum channels.

From a regulatory perspective the approach taken by the architects of DMR means that licensing authorities can confidently allow DMR radios to share or reside in adjacent channels to analogue radios and to share or reside in adjacent channels to other DMR digital radios, in the same way that analogue radios have coexisted in the spectrum for many years.

This short paper sets out the requirements of the DMR standard and technical characteristics of DMR radios which enable smooth migration from, and co-existence with, analogue from the perspective of European (CEPT) and North American regulatory requirements.

2. DMR radio performance

2.1 For radio technical performance the DMR air interface specification, TS 102 361 – 1, requires that radios comply with the European electromagnetic compatibility standards EN 300 113 and EN 300 390-2. These obligations are set out in the physical layer general parameters at paragraph 10.1 of TS 102 361-1:

"The DMR equipment shall comply with the essential requirements as stated in EN 300 113-2 [2] or EN 300 390-2 [4]."

2.2 The EN 300 113 and EN 300 390 standards are designed for radio performance in land mobile services operating on radio frequencies between 30 MHz and 1 GHz with channel separations of 12.5.kHz, 20 KHz and 25 kHz. The two standards set out radio performance parameters in the following key areas.

a) Technical characteristics of the transmitter and limits to emissions in non-desired channels
b) Receiver parameters
c) Detailed methods of measurement

2.3 Of high significance to the DMR standard, EN 300 113 and EN 300 390 are the *digital* equivalents of, and in many respects mirror, the European EN 300 086 standard which sets out the requirements of *analogue* radios operating in 12.5 kHz, 20 kHz and 25 kHz channels on frequencies between 30 MHz and 1 GHz. In other words because DMR radios have to comply with EN300 113 and EN 300 390 they can be managed in a very similar manner to 12.5 kHz analogue radios because they behave in essentially the same way from an electromagnetic compatibility perspective.

2.4 By specifying that DMR radios must comply with EN 300 113 or EN 300 390, the DMR standard ensures that DMR compliant radios will perform to a demanding overall electromagnetic performance level. The members of the DMR Association have been careful to argue that the strong requirements set out in EN 300 113 are maintained so as not to allow any relaxation of the performance of DMR products. In addition to complying with the electromagnetic compatibility standards, the DMR air interface requirements specify additional requirements for transmit frequency error in base stations and mobile stations and time based clock drift error[1].

2.5 The maximum Base Station (BS) transmits frequency error from the assigned RF carrier centre is defined in table 10.1 of the DMR air interface specification as follows:

BS transmit frequency error	**Frequency range BS maximum frequency error**
50 MHz to 300 MHz	±2 ppm
300 MHz to 600 MHz	± 1ppm
600 MHz to 800 MHz	±0.75 ppm
800 MHz to 1 GHz	±0.3 ppm

[1] The TS 102 361 (DMR) specification uses ppm values to define the acceptable limits of frequency error. The ETSI EN 300 113, EN 300 390 and 300 086 electromagnetic compatibility specifications set a maximum frequency drift in kHz. The values in the TS 102 361 specifications when converted are in all applicable cases equal to or more stringent than those in the ETSI Electromagnetic compatibility requirements of EN 300 113, EN 300 390 and EN 300 086.

2.6 The maximum Mobile Stations (MS) transmit frequency error from the assigned RF carrier centre is defined in table 10.2 of the DMR air interface.

MS transmit frequency error	Frequency range MS maximum frequency error
50 MHz to 600 MHz	±2 ppm
600 MHz to 1 GHz	±1.5 ppm

2.7 For both base stations and mobile stations the DMR standard sets out that the method of measurement for the above parameters will be that as defined in EN 300 113-1 [1] or EN 300 390-1 [3].

2.8 As DMR radios must meet an equivalent standard for frequency error to analogue radios meeting the EN 300 086 specifications, regulators can be assured that allowing DMR radios on 12.5 kHz channels previously used by analogue radios poses no greater risk of frequency drift and additional interference. For users it means that they will experience no degradation of service due to drift compared to analogue in DMR radios.

2.9 Although the DMR specifications refer specifically to European EN standards, through doing this the DMR standard also ensures compliance with the relevant FCC standards for the US which are no more stringent than the EN requirements. The equivalent specifications to EN 300 113 for the US market are defined by the Federal Communications Commission for the following requirements and mainly vary by frequency range as set out in Table 1 at the end of this paper:

- BS Transmit Frequency Error
- MS Transmit Frequency Error
- Authorised Bandwidth
- Receiver Conducted Spurious Limits
- Transmitter Conducted/Radiated Emission Limits
- Transmitter Transient Frequency Behaviour
- Transmitter Output Power & ERP Limits

2.10 This means that a national regulator that looks to either the European EN standards or the FCC rules as a benchmark for its own requirements can be assured that radios built to the DMR standard will meet both.

3. Co-existence of DMR and other radio types in various channel widths

The following sections detail further the ability of DMR radios to co-exist with other radio systems of various technologies, whether analogue or digital, whether on co-channel at 12.5 kHz width, or whether in adjacent channels. In the US, the FCC and the authorised frequency coordinating entities (FCC Frequency Co-ordinators such as Enterprise Wireless Associates (EWA) or the Utilities Telecommunications Council, (UTC)) have developed rules and coordination guidelines to minimise interference between such systems in the VHF and UHF for 25 kHz, 12.5 kHz or 6.25 kHz widths, and in the 800 MHz band for 25 kHz and 12.5 kHz channel widths.

4. Co-existence of DMR and other radio types in adjacent 12.5 kHz channels

Through meeting the specifications of EN 300 113 and EN 300 390, transmitting DMR radios will behave as neighbours in a 12.5 kHz channel raster in a similar manner to analogue radios that comply to the EN 300 086 standard. This is because for both the digital EN specifications and EN 300 086 analogue specification the limit to adjacent channel power is set at the same value - 60.0 dB of the transmitter power value in the carrier channel. Under FCC regulations DMR radios must comply with the same required emission masks for 12.5 kHz channels as analogue so there is equivalence between legacy analogue technologies and DMR radios. The DMR specifications mean that radios built to the standard will meet the FCC emission mask requirements.

5. Co-existence of DMR and other radio types in shared licensed channels

5.1 Shared Channels – background

5.1.1 In order to manage shared channel use, European harmonised standards EN 300 086 and EN 300 113, for analogue and digital modes respectively, set out the use of the so-called Listen Before Transmit (LBT) mode. This is defined as "monitoring mode in which the RF channel is checked for activity before transmitting and equipment is designed to prevent transmission for interference reduction purposes if a signal is detected on the channel". DMR radios are required to have this LBT functionality included by the DMR specifications in section 5.2 of TS 102 361-1. The standard requires that: "when determining whether activity is present on a channel, a DMR entity shall monitor the RSSI level. If after a maximum period of time... the RSSI level has not exceeded a configurable (within a predefined range) threshold… then the DMR entity shall assume that activity is not present on the channel...If however the RSSI level does exceed threshold, then the DMR entity shall assume that activity is present on the channel".

5.1.2 Different jurisdictions have different detailed rules on channel sharing. Meeting national regulations with DMR radios, as with analogue, is achieved through the appropriate software configuration of terminals of the required LBT functionality.

5.1.3 The introduction of digital systems has not altered the types of problems to deal with in terms of coexistence-joint use, as the scenarios given below will show.

5.1.4 As regards the DMR standard, the ETSI TS 102 361 technical specifications set out the use of the LBT mode, to be used for the coexistence of DMR equipment with other DMR equipment, as well as for the coexistence of DMR equipment with other analogue equipment, but also broaden their concept by introducing the use of the so-called “colour code” to the channel access rules. DMR Colour Codes are analogous to the sub-audible tones used by transmitting analogue radios to alert radios in a pre-defined target group to activate speakers – other radios in the vicinity not programmed to respond to a particular tone remaining silent even when a signal is detected.

5.1.5 Subsection 5.2 of the DMR TS 102 361-1 specification establishes the channel access possibilities, using three LBT concepts “Polite to all” - don’t transmit if there is activity on the channel, “Polite to own colour code” - don’t transmit if radios in a pre-defined colour code group are occupying the channel and “Impolite”. Subsection 5.2 of TS 102 361-2 sets out how these rules are used for managing access to the channel for voice calls, while subsection 5.4 of TS 102 361-3 sets out how these rules used for managing access to the channel for data calls. For a publically shared channel the key concept is that of “polite to all” which when implemented will mean that a DMR radio will not interfere by transmitting when another radio, either DMR or analogue, is active on the channel

5.1.6 As well as requiring LBT mode to be available, paragraph 6.1 of part 2 of the DMR standard states:

> “DMR MSs shall have a transmit “Time out timer”… which limits the time of a single transmission item... This enables the setting of maximum lengths for transmissions. The standard specifies that the length can be set at various lengths to a maximum of 180 seconds to comply with user requirements and/or national regulations”

5.1.7 In addition to LBT and the “Time out Timer” many DMR products also have a configurable parameter for a “Time Out Timer Reactivation Delay” - an enforced delay before re-transmission which can also be called upon to meet regulatory requirements although this feature is not mandated in the DMR specifications.

6. Scenario Analysis for co-existence/joint use between analogue and DMR 12.5 kHz systems

6.1 Digital DMR to analogue

6.1.1 This is where a user belonging to a DMR user group wishes to transmit on a shared channel when the channel is already in use by analogue users; the analogue/digital users can be from either the same or different licensees.

6.1.2 The DMR terminals currently available on the market can comply with current regulations applicable in various jurisdictions by correctly configuring internal software parameters inside the terminals. These parameters being those discussed in section 4 above i.e. :

- "Listen Before Transmit" mode which can be set on the DMR radios to:
    - Impolite
    - Polite to all
    - Polite to own colour code: before enabling transmission, the radio checks that the specified colour code is not currently in use.
- "Time Out Timer" i.e. maximum transmission length
- "Time Out Timer Reactivation Delay" i.e. enforced delay before re-transmission

6.1.3 So in this case an analogue user sharing a channel with a DMR user will have the same experience as if sharing with other analogue users. The only difference will be in the operationally unusual case where an analogue user has configured their radio to un-mute on the receipt of any traffic, irrespective of whether it is targeted at them. In this case the analogue user will hear the digital modulation of DMR which will *sound* different to analogue traffic on the channel, but *functionally* there is no difference – a busy channel is a busy channel.

6.2 Analogue to digital DMR

6.2.1 This is where a user belonging to an analogue user group wishes to transmit on a shared channel when the channel is occupied by users with DMR radios; the analogue/DMR users can be from either the same or different licensees.

6.2.2 The analogue terminals currently available on the market can comply with current regulations by correctly configuring some internal software parameters inside the terminals themselves; the most common parameters are the following:

- "Listen Before Transmit" for sharing the channel which can be set on the analogue radios to:
    - Impolite
    - Polite to all
- "Time Out Timer"
- "Time Out Timer Reactivation Delay"

6.2.3 So in this case a DMR user sharing with an analogue user will have an experience of channel sharing that is just like analogue users sharing. In practice today all DMR products on the market have both an analogue and digital mode with automatic switching between modes when analogue or digital traffic is detected. As a result interfering analogue traffic will be heard by the DMR radios in analogue mode in the event that user's radios are configured to un-mute speakers for all traffic. For digital only radios in future the interfering analogue signal will be heard as noise if the DMR radios are configured to un-mute to all detected signals.

6.3 Digital DMR to digital DMR

6.3.1 This concerns the situation where a user belonging to a DMR user group wishes to use a shared channel, which is occupied by another group of DMR users; the two groups can belong to either the same or different licensees.

6.3.2 The terminals currently available on the market comply with current regulations by configuring the internal software parameters inside the terminals themselves. These parameters being those discussed in section 4 above i.e.:

- "Listen Before Transmit" mode which can be set on the DMR radios to:
  - Impolite
  - Polite to all
  - Polite to own colour code: before enabling transmission, the radio checks that the specified colour code is not currently in use.
- "Time Out Timer" i.e. maximum transmission length
- "Time Out Timer Reactivation Delay" i.e. enforced delay before re-transmission

6.3.3 So in this case a DMR user sharing with another DMR user will have an experience of channel sharing that is just like analogue users sharing except that existing traffic on the channel will sound digital if a radio un-mutes to it.

7. Conclusions

The short discussion above demonstrates that both from the perspective of the user and from that of a regulator the DMR standard was designed to facilitate easy co-existence of analogue and digital radios in shared and adjacent channels. This easy co-existence enables the migration from analogue to digital in a seamless manner. Both users and regulators will have their different requirements met without disrupting legacy channel plans or services, or requiring changes in regulations or user behaviour. All the extensive benefits of digital DMR (6.25 kHz spectrum efficiency, efficient use of infrastructure, power saving, easier use of data, novel voice features) can easily be realised.

Table 1: Federal Communications Commission Requirements from 1st January 2013

				BS Frequency Error	MS Frequency Error	Receiver Conducted Spurious	Transmitter Conducted/ Radiated Emission	Transmitter Transient Frequency Behaviour	Transmitter Power
Frequency Range	**Channel Bandwidth**	**Channel Spacing and Bandwidth**	**Authorised Bandwidth**	**Frequency Stability**	**Frequency Stability**	**Conduction Limits**	**Radiated Limits**	**Transient Frequency Behaviour**	**Transmitter Output Power and ERP Limits ****
150-174 MHz	12.5 kHz	7.5 kHz***	11.25 kHz	+/- 2.5 ppm	+/- 5.0 ppm	-57 dBm*	-20 dBm*	t1 = 5ms, < +/- 12.5 kHz t2 = 20ms, < +/- 6.25 kHz t3 = 5ms, < +/- 12.5 kHz	Base = 500 watts ERP
421-512 MHz	12.5 kHz	12.5 kHz	11.25 kHz	+/- 1.5 ppm	+/- 2.5 ppm	-57 dBm*	-20 dBm*	t1 = 10ms, < +/- 12.5 kHz t2 = 25ms, < +/- 6.25 kHz t3 = 10ms, < +/- 12.5 kHz	Base = 500 watts ERP*
851-854 MHz*	25 kHz**	25 kHz**	20 kHz	+/- 1.0 ppm	+/- 1.5 ppm	-57 dBm*	-13 dBm**	N/A	Base = 1000 watts ERP, Mobile = 100 watts maximum output power
854-869 MHz	25 kHz	25 kHz	20 kHz	+/- 1.5 ppm	+/- 2.5 ppm	-57 dBm*	-13 dBm**	N/A	Base = 1000 watts ERP, Mobile = 100 watts maximum output power
896-901 MHz	12.5 kHz	12.5 kHz	13.6 kHz	+/- 0.1 ppm	+/- 1.5 ppm	-57 dBm*	-13 dBm**	N/A	Base = 1000 watts ERP, Mobile = 100 watts maximum output power
FCC Rule Number		**90.209**	**90.209**	**90.213**	**90.213**	**15.111 & 15.33**	**90.210**	**90.214**	**90.205 & 90.635**
*Public Safety Only Band	** 25 kHz channel bandwidth at 12.5 kHz channel spacing	** 25 kHz channel bandwidth at 12.5 kHz channel spacing *** 12.5 kHz channel bandwidth at 7.5 kHz channel spacing				* 15.111 Limit is 2 Nanowatts, which equals -57 dBm out of ½ waved dipole antenna (316 microvolts across 50 ohms). 15.33 requires spurious to be measured from the lowest frequency generated to 10th harmonic of highest frequency.	*90.210(d) Radiated or conducted spurious emissions attenuated by lesser of 70 dB or 50 + $\log_{10}$ (power out in Watts), or an equivalent absolute level of -13 dBm (50mW) at greater than 250% of authorised bandwidth). **90.210 (in general) Radiated or conducted spurious emissions attenuated by 43 + 10 $\log_{10}$ (power out in Watts) dBdB at offset of > 12.5 kHz		* 421-430 MHz – see 90.279 for ERP/HAAT limits, maximum Base ERP = 250 Watts. ** There may be restrictions on transmitter output power or ERP and/or antenna height on specific frequencies.

About the DMR Association

The DMR Association is focused on making DMR the most widely supported 21st Century digital radio standard for the business world. Through a combination of interoperability testing, certification, education, and awareness, the Association seeks to ensure that business buyers of today's digital radio technology gain ongoing value through the competition and choice derived from an open, multi-vendor value chain.

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