Underperformance of digital PMR systems – commonly overlooked implementation issues and solutions.

Tom Johnson,
Chair, Technical Working Group, DMR Association
The DMR Association

• Industry body representing the DMR market.

• Established in 2005 as the DMR-MOU Association to support ETSI during the DMR standardisation process our membership is open to any organisation or individual interested in using or building DMR products or in supporting the DMR standard in other ways. We’re in frequent and direct dialogue with regulators, trade bodies and standards organisations around the world to maintain the DMR standard both for our members and for all other users.
Mission and Objectives

- For DMR we will:
  - support the growth of the market
  - create and maintain an interoperability testing and certification program
  - offer education, promotion and discussion about the standard
  - work with regulators to develop an environment in which the technology can flourish
DMR Association - Membership

Membership Year by Year

153 Members
(November 2018)

www.dmrassociation.org

Company General Use
Membership By Category

DMR Association - Membership

- Manufacturers: 60
- System Integrators & Value Added Reseller: 28
- Users & Operators: 65

[Image of pie chart]
Membership By Region

- Australasia: 10
- European Economic Area: 37
- North America: 32
- Far East: 14
- Eastern Europe: 31
Tom Johnson: Introduction

- Ex Chief Engineer: Fylde Micro Ltd
- Network designer and hardware/software developer.
- Contracted to DMR Association part time as Chair of the Technical Working Group (TWG)
Technical Working Group (TWG)

- TWG meets every 6 weeks approximately
- Considers matters relating to
  - DMR Standards
  - Interoperability (IOP)
  - DMRA Standards (Encryption/AIS etc)
  - Conformance and compliance.
- Direct input to ETSI (TGDMR).
  - ETSI<>DMRA MoU in place agreed June 2018
DMR Overview

- Low cost, low complexity, open standard
- Higher traffic capacity & spectral efficiency
  - 2 for 1,
  - half the equipment.
- Access to digital features for improved functionality, voice quality & security
- Smooth migration from analogue with existing spectrum & licensing
- Longer battery duration
- Conventional, Trunking, Simulcast
DMR Tier I: Unlicensed
• Products for license-free use in the 446 MHz band.

DMR Tier II: Conventional
• Licensed conventional radio systems operating in LMR frequency bands 30 to 1000 MHz. Targeted at users who need spectral efficiency, advanced voice features and integrated IP data services in licensed bands.

DMR Tier III: Trunked
• Trunking operation in frequency bands 30 to 1000 MHz. The ETSI Tier III standard supports voice and short messaging handling similar to MPT1327.
The current version of ETSI standards as of September 2018 are:

- ETSI TS 102 361-1 DMR Air Interface Protocol (V2.5.1)
- ETSI TS 102 361-2 DMR Voice and Generic Services (V2.4.1)
- ETSI TS 102 361-3 DMR Data Protocol (V1.3.1)
- ETSI TS 102 361-4 DMR Trunking Protocol (V1.9.2)
- ETSI TR 102 398 DMR General System Design (V1.3.1)

Can be freely downloaded from the ETSI or DMR Association websites
Recent Developments

• ETSI 102 361-4 V1.8.1 (Tier 3)
  – introduced a powerful new set of group related features
    • Talkgroup Subscription
    • Talkgroup Attachment

• ETS 102 361-4 V1.9.1 (Tier 3)
  – 3 major function additions
    • TSCCAS (Alternate control channel)
    • Unified Single Block Data Polling Service
    • Channel authorization
DMR Performance

• Fundamentals
  – 9600 baud 4 Level FSK
  – 4800 symbols per second

• Special filters ensure modulation complies with transmission mask as specified ETS EN 300 113 (Root Raised Cosine Filter) allowing DMR systems to co-exist in existing 12.5kHz assigned channels (no exclusive frequencies required)
Performance

• In theory performance (range) should be better than equivalent analogue transmission (with same RF power etc).

• In practice
  – Some say it is
  – Some say it isn’t
  – For those that say it isn’t, lets have a look at some of the possible reasons:
Performance

- Noise Floor.
  - The issues for the digital systems is carrier to noise (C/N). The (C/N) performance for DMR is 10 to 12dB. This means that the signal level must be 10 to 12 dB higher than the noise to successfully retrieve the data (voice). Interference also manifests itself similar to noise so C/N can also be C/I. In contrast an analog system is able to tolerate a signal/noise (S/N) of 6 to 7dB (FM capture effect in the demodulator).
Noise Floor Mitigation

• Whether the signal is analogue or digital the signal/noise (or interference) must be better than a certain value to provide an acceptable grade of service.
• If the transmission is analogue the noise will be heard above the voice.
• If the transmission is digital if the carrier/noise is not high enough nothing will be heard at all.
• IF THE NOISE FLOOR AT THE RECEIVER ANTENNA IS HIGH, THIS NOISE ADDS TO THE NOISE FLOOR OF THE RECEIVER.
• This means that the added receiver sensitivity can only be realised if the received signal is 10dB to 12dB higher than the noise (or interference).
  – For example a signal at -112dBm will only be successfully received if the noise floor is better than -122dBm.
Noise Floor Mitigation

- Digital does not fix poor Radio Site Engineering.
- Digital does not fix a high noise floor
  - Inappropriate choice of radio site
  - Proximity of receiver antenna to other transmitter antennas (wide band and spread spectrum 3G/4G LTE etc)
  - Incorrect or badly positioned antenna
  - Poorly designed or adjusted antenna duplexer/combiner
  - External interference (LED Floodlights !!)
  - Poor Grounding, cable screening etc
Example Photos
Example Photos
Example Photos
Frequency Stability

The maximum BS transmit frequency error from the assigned RF carrier centre shall be as defined in table 10.1.

Table 10.1: BS transmit frequency error

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>BS maximum frequency error</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 MHz to 300 MHz</td>
<td>±2 ppm</td>
</tr>
<tr>
<td>300 MHz to 600 MHz</td>
<td>±1 ppm</td>
</tr>
<tr>
<td>600 MHz to 800 MHz</td>
<td>±0.75 ppm</td>
</tr>
<tr>
<td>800 MHz to 1 GHz</td>
<td>±0.3 ppm</td>
</tr>
</tbody>
</table>

The maximum MS transmit frequency error from the assigned RF carrier centre shall be as defined in table 10.2.

Table 10.2: MS transmit frequency error

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>MS maximum frequency error</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 MHz to 600 MHz</td>
<td>±2 ppm</td>
</tr>
<tr>
<td>600 MHz to 1 GHz</td>
<td>±1.5 ppm</td>
</tr>
</tbody>
</table>

The method of measurement is defined in ETSI EN 300 113-1 [1] or ETSI EN 300 390-1 [3].
Frequency Stability

• It has been noted by the presenter that some manufacturers networks performance is significantly affected by frequency error than others.

• It is certainly worth a test, set a BS to limit of tolerance one way and an MS the other and see how performance degrades.
Modulation Fidelity

• DMR uses 4 level FSK signalling
• 4800 bit symbol rate, each symbol carrying 2 bits of information
• Four frequencies -1944Hz, -648Hz, +648 Hz, +1944Hz used for the 4 FSK levels.
• Special filters used to ensure radio does not over-deviate into adjacent channel (Root Raised Cosine Filter – RRC) and transmission complies with the masks and other essential criteria defined in ETS EN 300 113 and EN 300 390.
Effect of Low Modulation Fidelity

- Equivalent to noisy signal
- Makes it more difficult for receiver to distinguish the correct symbols (closing of the eye).
- Increased BER at lower signal levels
- Reduced range.
- Firmware upgrades and “dodgy” alignment procedures seem to be the major cause.
- Check on a digital test set, analogue test sets will not give the full picture.
FSK Fidelity Examples

• The following slides are pictures of 4FSK fidelity from different manufacturers MS units.
• An FSK error of <5% is considered a good transmitter.
• FSK magnitude error of <1% is considered to be acceptable.
  – FSK Magnitude error
  
  \[ \text{Mag. Err} (\%) = \left( \frac{\text{rms (magnitude error at all symbols)}}{\text{rms (envelope)}} \right) \times 100 \]

  where \( \text{rms (envelope)} = \text{rms of the carrier envelope} \)
• Symbol clock error rate of up to 48mHz (milli Hertz) is acceptable.
Test Set signal fed back at -60dBm
Test Set signal fed back at -105dBm
Example A (Distribution).
Example A (Eye Diagram)
### Example A (Advanced Analysis)

#### Advanced Analysis Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal Pwr</td>
<td>8.4dBm</td>
</tr>
<tr>
<td>Slot1 Pwr</td>
<td>8.4dBm</td>
</tr>
<tr>
<td>Slot2 Pwr</td>
<td>-63.4dBm</td>
</tr>
<tr>
<td>FSK Err</td>
<td>1.1%</td>
</tr>
<tr>
<td>Freq Err</td>
<td>-200.1Hz</td>
</tr>
<tr>
<td>Sym Clk Err</td>
<td>-0.9mHz</td>
</tr>
<tr>
<td>Sym Dev</td>
<td>1927Hz</td>
</tr>
<tr>
<td>Mag Err</td>
<td>0.17%</td>
</tr>
<tr>
<td>Bit 1 (0)</td>
<td>0</td>
</tr>
<tr>
<td>Bit 0 (1)</td>
<td>1</td>
</tr>
<tr>
<td>Symbol</td>
<td>+3</td>
</tr>
<tr>
<td>Target 4FSK Dev</td>
<td>+1.944</td>
</tr>
<tr>
<td>Error</td>
<td>0.73%</td>
</tr>
<tr>
<td>Error Peak</td>
<td>1.12%</td>
</tr>
<tr>
<td>Mag Error</td>
<td>0.12%</td>
</tr>
<tr>
<td>Mag Peak</td>
<td>2.98%</td>
</tr>
<tr>
<td>Actual</td>
<td>1929.77Hz</td>
</tr>
<tr>
<td>Dev</td>
<td>641.31Hz</td>
</tr>
<tr>
<td>Dev</td>
<td>-642.80Hz</td>
</tr>
<tr>
<td>Dev</td>
<td>-1929.11Hz</td>
</tr>
</tbody>
</table>

**Reset** **Meters**

**Return**
Example B (Eye Diagram)
Example C (Distribution)
Example C (Eye)
Example D (Distribution)
Example D (Eye)
## Example D (Advanced Analysis)

<table>
<thead>
<tr>
<th>Signal Pwr</th>
<th>37.4dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slot1 Pwr</td>
<td>37.4dBm</td>
</tr>
<tr>
<td>Slot2 Pwr</td>
<td>-36.3dBm</td>
</tr>
</tbody>
</table>

### Signal Analysis

<table>
<thead>
<tr>
<th>Bit 0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
</table>

### Symbol Analysis

<table>
<thead>
<tr>
<th>Symbol</th>
<th>+3</th>
<th>+1</th>
<th>-1</th>
<th>-3</th>
</tr>
</thead>
</table>

### Target 4FSK Dev

<table>
<thead>
<tr>
<th>Dev</th>
<th>+1.944</th>
<th>+0.648</th>
<th>-0.648</th>
<th>-1.944</th>
</tr>
</thead>
</table>

### FSK Err

<table>
<thead>
<tr>
<th>FSK Err</th>
<th>3.4%</th>
</tr>
</thead>
</table>

### Freq Err

<table>
<thead>
<tr>
<th>Freq Err</th>
<th>-316.9Hz</th>
</tr>
</thead>
</table>

### Sym Clk Err

<table>
<thead>
<tr>
<th>Sym Clk Err</th>
<th>-2.5mHz</th>
</tr>
</thead>
</table>

### Sym Dev

<table>
<thead>
<tr>
<th>Sym Dev</th>
<th>1943Hz</th>
</tr>
</thead>
</table>

### Mag Err

<table>
<thead>
<tr>
<th>Mag Err</th>
<th>0.12%</th>
</tr>
</thead>
</table>

### Error

<table>
<thead>
<tr>
<th>Error</th>
<th>4.50%</th>
<th>6.57%</th>
<th>7.41%</th>
<th>0.60%</th>
</tr>
</thead>
</table>

### Error Peak

<table>
<thead>
<tr>
<th>Error Peak</th>
<th>5.71%</th>
<th>7.76%</th>
<th>12.65%</th>
<th>0.99%</th>
</tr>
</thead>
</table>

### Mag Error

<table>
<thead>
<tr>
<th>Mag Error</th>
<th>0.15%</th>
<th>0.11%</th>
<th>0.11%</th>
<th>0.12%</th>
</tr>
</thead>
</table>

### Mag Peak

<table>
<thead>
<tr>
<th>Mag Peak</th>
<th>0.26%</th>
<th>0.17%</th>
<th>0.19%</th>
<th>0.16%</th>
</tr>
</thead>
</table>

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[DMR ASSOCIATION.ORG](http://www.dmrassociation.org)
Example E (Distribution)
Example E (Eye)
Example E (Advanced Analysis)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal Pwr</td>
<td>-12.3dBm</td>
</tr>
<tr>
<td>Slot1 Pwr</td>
<td>-12.3dBm</td>
</tr>
<tr>
<td>Slot2 Pwr</td>
<td>-79.1dBm</td>
</tr>
<tr>
<td>FSK Err</td>
<td>3.7%</td>
</tr>
<tr>
<td>Freq Err</td>
<td>285.6Hz</td>
</tr>
<tr>
<td>Sym Clk Err</td>
<td>5.0mHz</td>
</tr>
<tr>
<td>Sym Dev</td>
<td>1790Hz</td>
</tr>
<tr>
<td>Mag Err</td>
<td>24.23%</td>
</tr>
<tr>
<td>Bit 1</td>
<td>0</td>
</tr>
<tr>
<td>Bit 0</td>
<td>1</td>
</tr>
<tr>
<td>Symbol</td>
<td>+3</td>
</tr>
<tr>
<td>Target 4FSK</td>
<td>+1.944</td>
</tr>
<tr>
<td>Dev</td>
<td>+0.648</td>
</tr>
<tr>
<td>Actual Freq</td>
<td>1778.08Hz</td>
</tr>
<tr>
<td>Error</td>
<td>8.53%</td>
</tr>
<tr>
<td>Peak</td>
<td>13.10%</td>
</tr>
<tr>
<td>4FSK Error</td>
<td>9.46%</td>
</tr>
<tr>
<td>Peak</td>
<td>13.10%</td>
</tr>
<tr>
<td>Mag Error</td>
<td>23.04%</td>
</tr>
<tr>
<td>Peak</td>
<td>40.78%</td>
</tr>
<tr>
<td>Mag Peak</td>
<td>35.41%</td>
</tr>
<tr>
<td>Mag Peak</td>
<td>45.84%</td>
</tr>
</tbody>
</table>

DMR Association

Company General Use
Example F (Eye)
The DMR specification defines the power ramp in a timeslot.
Example A
Example C
Example E (Oops)
Example E
Example F
Reciprocity (or lack of)

• A common problem with DMR, typically the path from the BS to the MS is better than the path MS to BS (especially with portable MS’s)
  – MS can hear BS so remains in service but BS cannot hear MS.

• Can be circumvented with careful adjustment of MS transmit powers, down-tilt antenna’s and careful use of Vote Now and Adjacent Channel MS functions, though implementations in different manufacturers differ and can be problematic to optimise.
Networks

- Most BS’s and central nodes are connected together via IP networks using private and sometimes public networks.
- When calculating the IP bandwidth required from the BS to central node or other BS remember the various overheads the signalling layers add. RTP and UDP/TCP headers can significantly add to the required bandwidth. Some manufacturers do not include this in their bandwidth statements.
- Jitter is the enemy of reliable voice transmission. Some networks allow jitter buffers to be optimised, increase the size of the jitter buffers should reduce any IP dropped packets but will increase the speech delay.
In Summary

- Minimise BS noise floor by sensible site location, good site engineering, grounding etc, and look out for potential noise sources.
- Check BS and MS frequency alignment and modulation fidelity properly (using digital test set).
- Check reciprocity from BS and optimise coverage/adjust BS output power.
- Take time to correctly set vote now and adjacent site MS parameters (background hunt levels etc)
- Check network jitter and adjust jitter buffers accordingly.
And Finally: what can be achieved

This customer was able to make a group call with a DMR handheld terminal on a boat distanced ~182 km from the BS with perfect audio quality.
Thank you!
For more info: twgchair@dmrassociation.org
IMPRESSUM

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