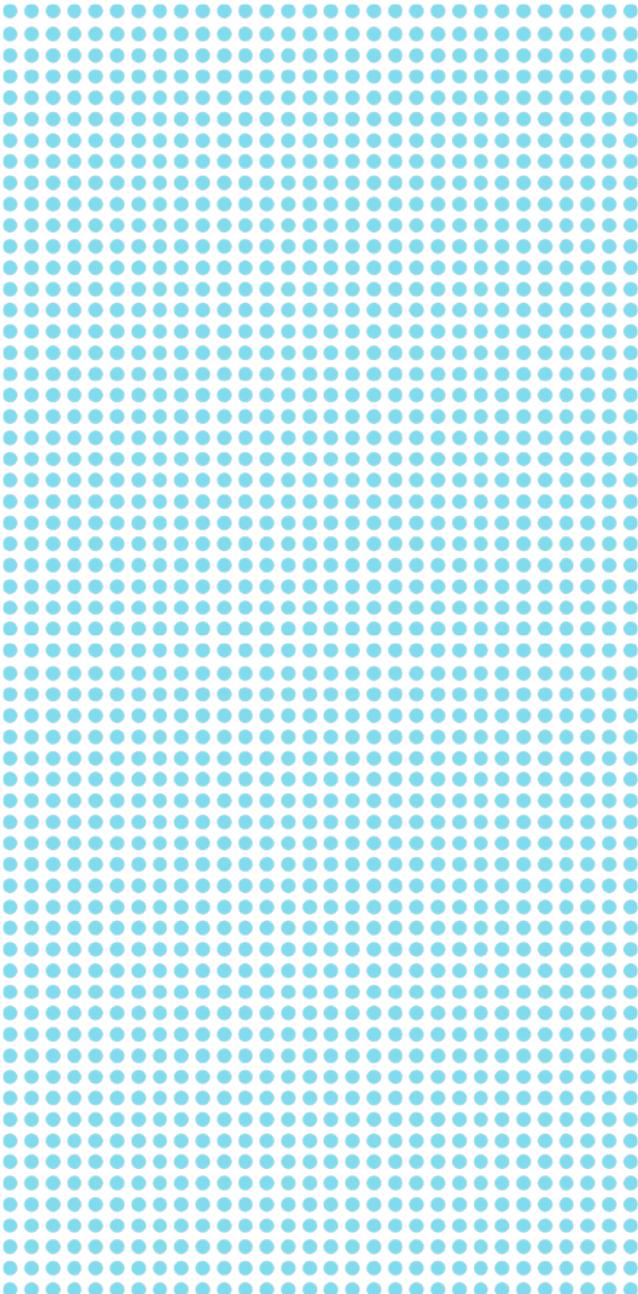

TECHNOLOGY COMPARISON



Comparing Voice Coverage: DMR and Analog NBFM

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EXECUTIVE SUMMARY

This paper provides a technical comparison between DMR and NBFM (Narrowband Analog Frequency Modulation) voice coverage. It discusses the measurable factors affecting coverage, how they affect relative coverage between the two technologies, and explains how these conclusions were reached.

The measurable factors affecting coverage are:

- Link Budgets,
- Delay Spread,
- TDMA Guard Time.

Also relevant in real systems are terrain and external interference, but these factors cannot provide insight in to comparative voice coverage from a theoretical viewpoint. The many variables within terrain and external interference make comparing the coverage of different types of radio systems a very imprecise science. We can focus on the factors that are independent these variables.

The analysis in this paper shows:

- DMR Tier 3 trunked and Analog NBFM voice coverage is similar overall,
- DMR and Analog NBFM voice coverage is similar for DAQ2.0 (speech understandable with considerable effort),
- DMR Tier 2 voice coverage is greater than Analog NBFM for DAQ3.0 (speech understandable with slight effort) or better,
- DMR maintains DAQ3.0 (or better) voice quality until the edge of coverage, while Analog NBFM audio quality diminishes further from the site. This is because DMR's advanced digital voice encoding and error correction techniques remove much of the noise reproduced on the Analog NBFM audio output.

DMR Tier 2 voice coverage is greater than DMR Tier 3, because Tier 3 requires a received signal level greater than DAQ3.0 voice quality in order to set up the call..

The conclusions in this paper assume:

- the same site is communicating with a DMR terminal and a NBFM terminal that are side by side,
- the power outputs from the DMR and NBFM site transmitters are the same,
- the antenna systems are the same,
- neither system is simulcast.

GLOSSARY

This section provides an explanation of the technologies and concepts employed in this comparison. These principles will provide a more meaningful understanding of the comparison.

DMR

DMR (Digital Mobile Radio) is a standardised system that complies with the common air interface defined in ETSI TS 102 361-1. It is two-slot TDMA (see below) operating in 12.5kHz channels, using four level frequency modulation (4FSK) at a data rate of 9.6kb/s.

DMR systems may be conventional (DMR tier 2) or trunked (DMR tier 3). The choice of conventional or trunked systems has different coverage implications which can be weighed against the benefits that trunked systems provide.

Analog NBFM

Narrowband Analog FM LMR systems comply with ETS300-086 (Europe), AS4295 (Australia/New Zealand) and FCC (USA) regulations. In the USA, EIA-603 defines the accepted industry performance.

The majority of Analog NBFM systems operate in 12.5kHz channels and use frequency modulation with a maximum deviation of 2.5kHz. Analog NBFM systems may be either conventional or trunked (eg: MPT-1327).

DAQ

With analog systems, received signal strength (RSSI) is a reasonable indication of audio quality. However, this is not always true for digital systems, so a new measure of audio quality was developed by the TIA to measure and compare audio, whether analog or digital.

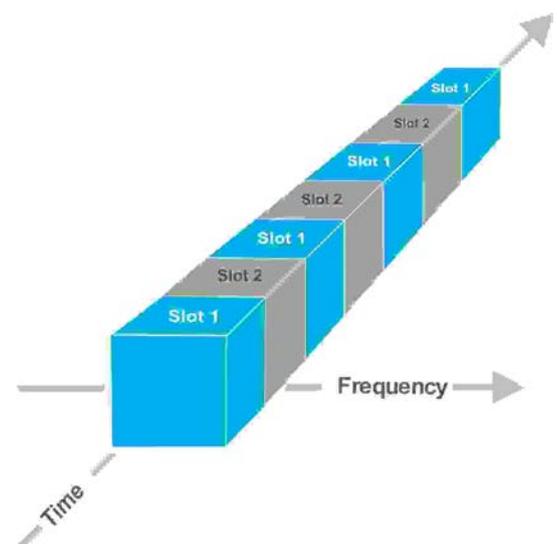
Delivered Audio Quality is a qualitative measure of audio quality used to quantify the audio quality over a radio system. DAQ levels are defined by the following scale.

- DAQ 1: Unusable. Speech present but not understandable.
- DAQ 2: Speech understandable with considerable effort. Requires frequent repetition due to noise or distortion.
- DAQ 3: Speech understandable with slight effort. Requires occasional repetition due to noise or distortion.
- DAQ 3.4: Speech understandable without repetition. Some noise or distortion present.
- DAQ 4: Speech easily understandable. Little noise or distortion.
- DAQ 5: Perfect. No distortion or noise discernible.

SINAD and RSSI remain useful for analog systems; BER (Bit Error Rate) is common alongside DAQ.

TDMA

DMR uses Time Division, Multiple Access technology. In a DMR system, each channel is divided into two time slots, each transmitting on the same RF frequency, but each capable of carrying a separate conversation. This means two radio terminals can transmit to (and from) the same base station; one on time slot 1, and one on time slot 2.



Link Budgets

In its simplest form, a radio system consists of a transmitter, a receiver, operating over a channel. The link budget quantifies the performance of each, to provide a figure for the maximum possible path loss between the transmitter and receiver, for the link is to meet its performance objectives (eg: understandable received audio quality).

A typical **downlink** budget includes the Base Station Transmitter, mobile or portable terminal and the channel.

Base-station Transmitter

To determine the Transmitted Effective Radiated Power, (Tx ERP):

1. Quantify the transmitter output power.
2. Subtract the output power losses between the transmitter and the antenna associated with combining networks, cavity filters, duplexers and cable losses.
3. Add the specific gain from the transmitting antenna, which may be either omni-directional, or directional (radiates more efficiently in some directions than others).

From these figures, we arrive at:

$$\text{Tx ERP (dBm)} = \text{Tx power (dBm)} - \text{Tx to Antenna Losses (dB)} + \text{Tx antenna gain (dBi)}$$

Mobile/Portable Receiver

We need to consider the thermal noise floor of the receiver. Thermal noise is present at all frequencies - the wider the receiver bandwidth, the higher the thermal noise floor will be:

$$\text{Receiver Thermal Noise Floor (dBm)} = -174 + [10 * \log (\text{Band Width})]$$

The circuitry within the receiver raises the thermal noise floor. The total amount is the Noise Figure of the receiver.

- External interference raises the true noise floor of the receiver higher. (TIA TSB88.3-C contains some nominal noise floor values for different environments).
- Add the carrier-to-noise and interference ratio ($C_f/(N+I)$) for minimum acceptable link performance.
- Losses from cables between the receiver and antenna must be taken in to account, although these are usually small. Mobile receiver antennas are isotropic (omni-directional) so will have little gain; a portable antenna may even have significant loss.

Together, this gives us the minimum signal level required at the receive antenna, or Isotropic Receiver Level (IRL):

$$\text{IRL (dBm)} = \text{Thermal Noise Floor (dBm)} + \text{External Noise Rise (dB)} + \text{Rx Noise Figure (dB)} + \text{Receiver to Antenna Cable Losses (dB)} - \text{Antenna Gain (dBi)}$$

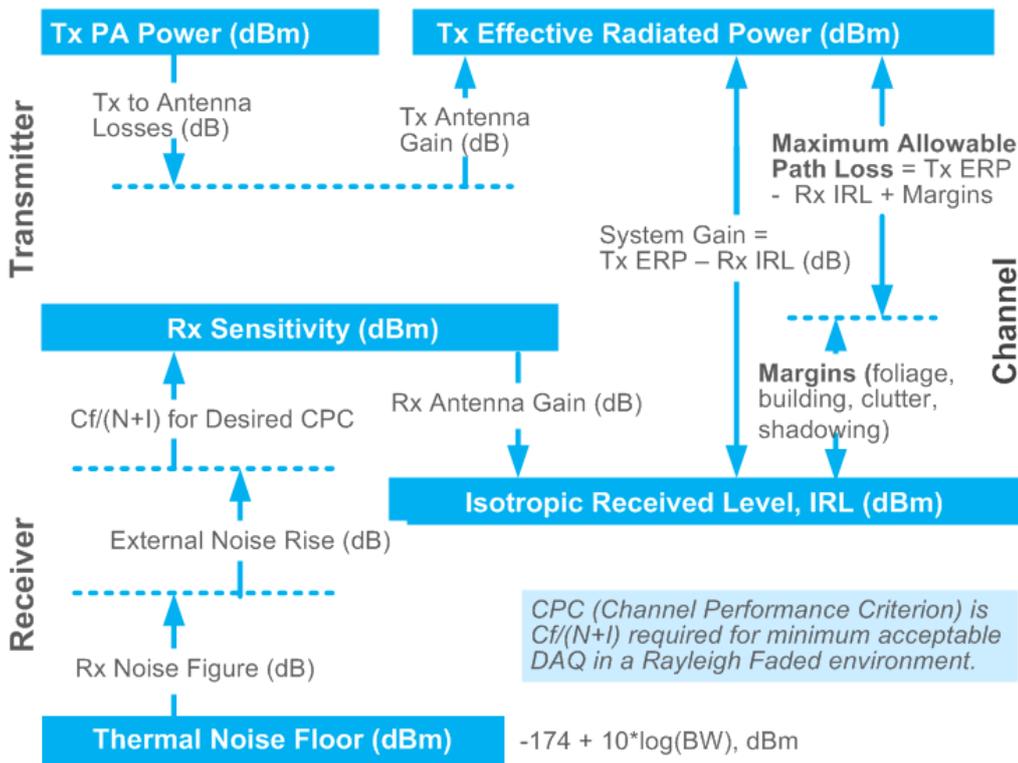
Channel

A link budget includes margins for Large Scale Fading (shadowing) and considers “clutter” (based on land use), building penetration loss, foliage loss and body loss.

Examples of channel margins in a link budget might be:

Margin	Typical Figure
Large Scale Fading (Shadowing)	
Large City	12dB
Small City	10dB
Suburban	8dB
Rural	6dB
Foliage Loss	5dB
Body Loss	6dB
Building Penetration	10dB
Clutter (Land use)	6dB

Putting all this in to a diagram helps to illustrate link budgets more clearly:



The Rayleigh fading margin is built in to the Cf/(N+I) figure at the Receive end of the link.

System Gain (dB) = Tx ERP - IRL

Maximum Allowable Path Loss (MAPL), dB = Tx ERP - IRL + Margins



This comparison focuses on the three factors affecting coverage that can be measured from a theoretical perspective. These are:

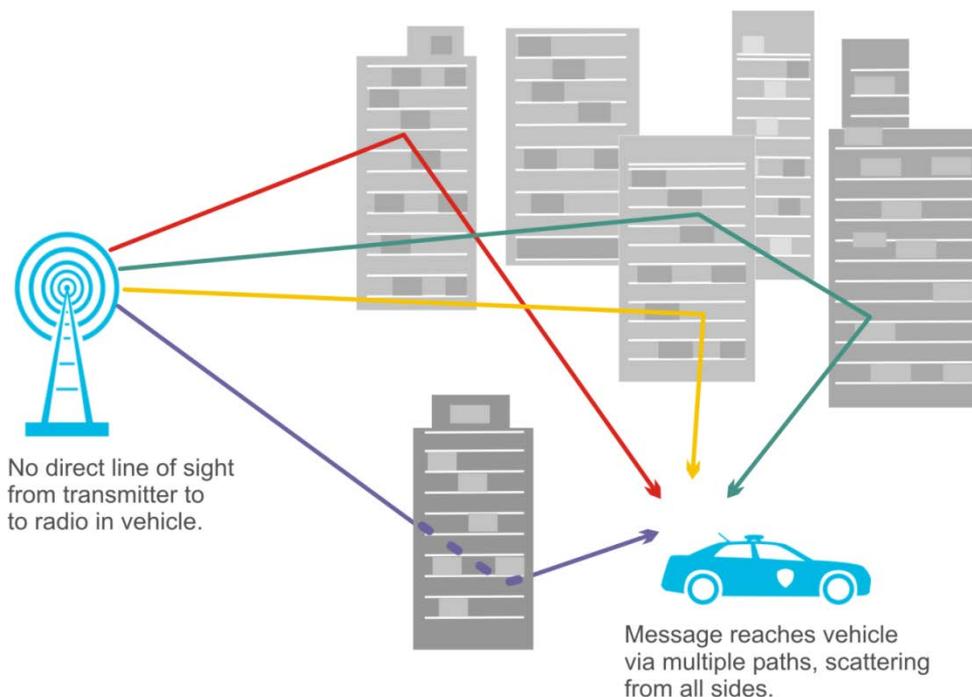
- Link Budgets,
- Delay Spread
- TDMA guard time.

The following sections describe these factors, their relevance to coverage comparison between DMR and Analog NBFM, how we make the comparison, and the conclusion reached.

DELAY SPREAD

A signal can travel from the transmitter to the receiver via many different paths, creating multiple copies of the signal. Because these copies travel different distances, they can arrive at slightly different times. The time difference between receiving the first multipath component of the signal, and the last is called Delay Spread.

If a signal is received at a given time, and a replica is received via a different path a fraction of a second later, the result is a 'blurring' of the information. If the delay spread becomes too great, the information cannot be understood – even if the signal level is well above the receiver's sensitivity level. This diagram illustrates the effect.



In the first line, the multipath components arrive at the receiver within a short time of one another. So, while there is some degradation, the information is still understandable. In the second line, the delay spread increases and it is harder to determine the information. In the third line, the delay spread exceeds the symbol time and the information is no longer understandable, so communication is lost.

For analog systems, the maximum delay spread is important; the maximum time difference between the arrival of the first and last multipath components. For Digital systems such as DMR, the relevant figure is essentially two times the RMS delay spread.

TDMA GUARD TIME

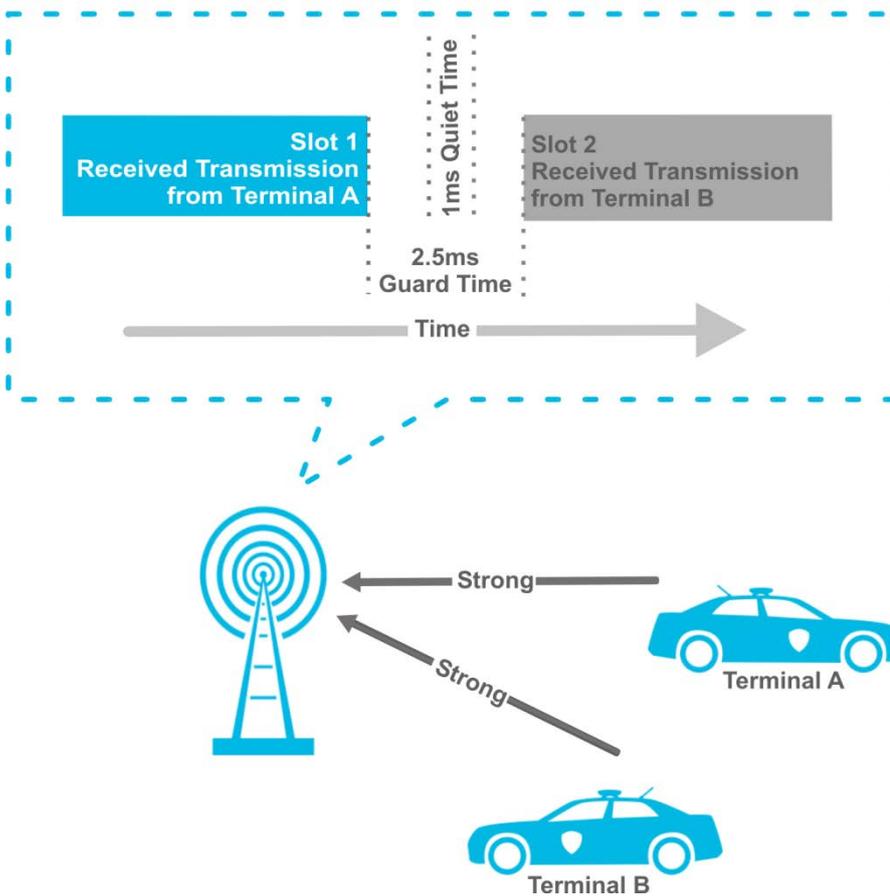
DMR TDMA means two radio terminals can transmit to (and from) the same base station; one on time slot 1, and one on time slot 2.

To prevent interference between the two time slots, a guard time of 2.5ms between the time slots separates the transmissions, to compensate for the transmission timing differences when one terminal is transmitting much closer to the base station than the other. Interference can occur when the end of one transmission overlaps with the start of another, due to timing differences.

In a TDMA (Time Division Multiple Access) system, the channel is split into time slots. Each slot can carry a separate conversation.

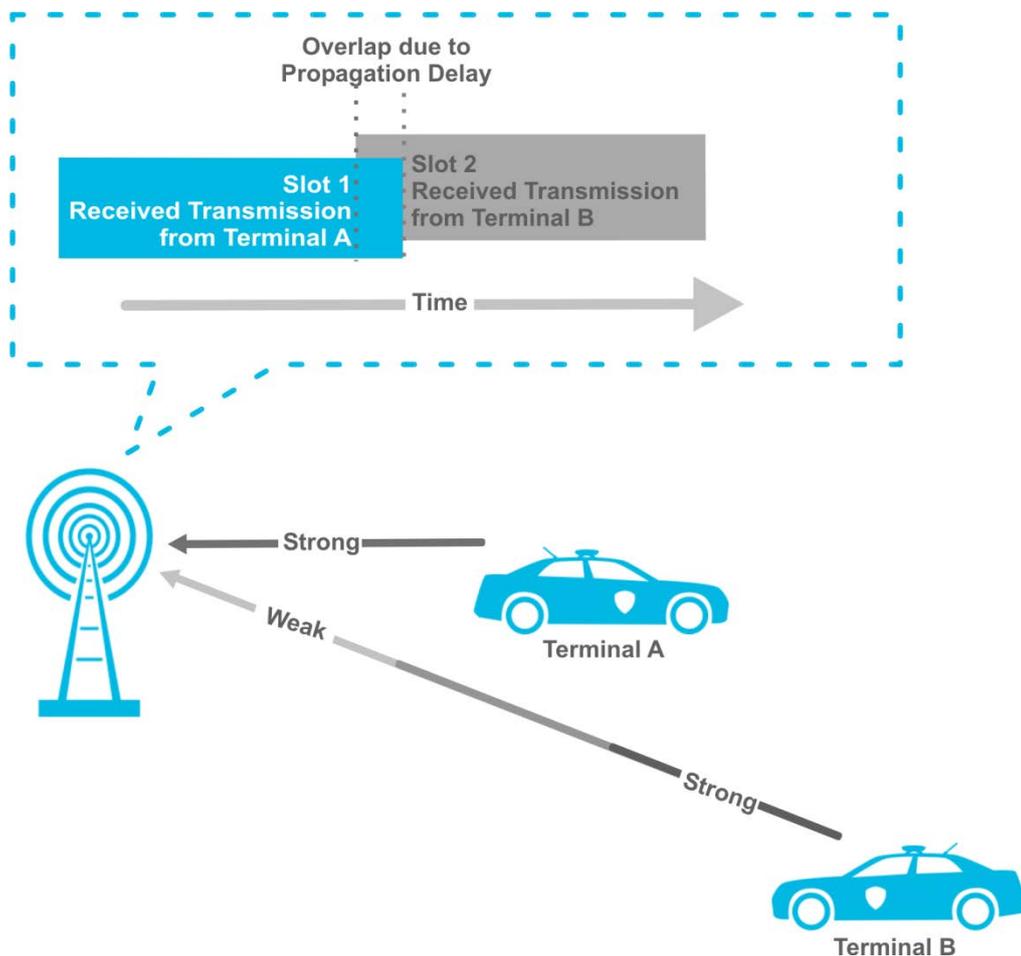
In a 2-slot TDMA system like DMR, two terminals can transmit to the same base station on the same channel, with one transmitting in time slot 1, the other in time slot 2.

The guard time between the TDMA slots for a DMR system is 2.5ms, but once transmitter ramp up and ramp down times are subtracted, the actual quiet time between the slots is 1ms. If the two terminals are the same distance from the Base Station Receiver, then we see the full guard time between receiving the two transmissions:



Guard time is needed when one terminal is close to the base station and the other one is much more distant. So if one radio is further away from the Base Station, the Propagation Delay (the time taken for the radio's transmissions to reach the Base Station) is longer. (Sometimes, the clock frequencies running the DSPs in the radios may be slightly different, so the respective transmissions could start slightly earlier or later than is ideal.)

If one radio kept travelling away from the Base Station, propagation delays would eventually mean the Base Station would still receive the back end of the transmission from terminal transmitter A at the same time as the transmission from terminal transmitter B began:



Because the signal from terminal transmitter B is stronger, due to its proximity to the base station, the end of the transmission from terminal A would be lost.

This issue, known as the TDMA Near/Far problem can be easily addressed. TDMA guard time determines the maximum coverage for a system with uniform distribution of radios, so the longer the guard time, the greater the Base Station coverage radius will be.

LINK BUDGETS

The link budget quantifies the transmitter, receiver and channel properties, and results in a figure for the maximum acceptable path loss between the transmitter and receiver for the link to meet its performance objective (eg: understandable received audio quality).

If the transmitted power of the DMR and Analog NBFM systems are the same, and they operate over the same channel using the same antennas, then the key figure is the Carrier to Noise and Interference ratio (C/(N+I)) required at the receiver for acceptable demodulated Delivered Audio Quality (DAQ).

DMR and Analog NBFM C/(N+I) Ratios Required for Given DAQ

The Carrier to Noise & Interference ratio required at the receiver for a given DAQ for different modulation methods are defined Table A1 from TSB88 Part 1-D (CPC Table for Given DAQ for Different Modulation Methods).

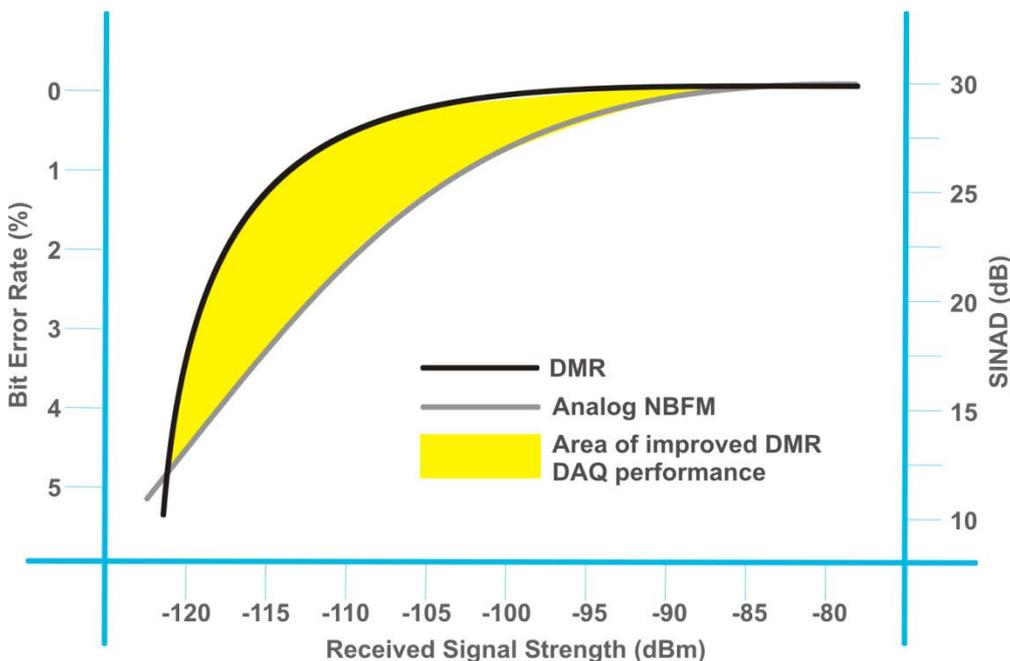
From this, we can extract the Channel Performance Criterion (CPC) for DMR and Analog NBFM for various DAQ thresholds, in the table.

Technology	DAQ 2.0 Static (Cs/N)	DAQ 3.0 Faded (Cf/(N+I))	DAQ 3.4 Faded (Cf/(N+I))	DAQ 4.0 Faded (Cf/(N+I))
DMR	5.3dB (5%BER)	14.3dB (2.6%BER)	15.6dB (2%BER)	19.4dB (1%BER)
Analog NBFM	7dB (12dB SINAD)	23dB (17dB SINAD)	26dB (20dB SINAD)	33dB (25dB SINAD)

DAQ2.0 is a static measurement from a sample receiver on the bench, while the figures for DAQ 3.0, DAQ 3.4 and DAQ 4.0 are for a practical 'real life' system with Rayleigh Fading.

Link Budget

The diagram below shows the behaviour of SINAD vs Received Signal Strength for an Analog NBFM system, and that of BER vs Received Signal Strength for DMR in a **static, non-faded environment**.



- In an Analog NBFM system. SINAD influences DAQ – the higher the SINAD, the higher the DAQ.
- In the DMR system, Bit Error Rate (BER) influences DAQ – the lower the BER, the better the DAQ.

Minimum useable DAQ 2.0 results when the BER consistently around 5% for DMR, (assuming the bit errors are evenly distributed) and at a SINAD of around 12dB for the Analog NBFM system. These occur at about received signal level of -122dBm in both systems.

But this is a bench measurement. When real life multipath Rayleigh fading is added, the relationship between carrier-to-noise and interference ratio ($Cf/(N+I)$) and the BER for DMR is less steep than the characteristic shown here.

The relationship between $Cf/(N+I)$ and BER depends on factors such as Doppler shift (related to speed) and Fading Rate (related to speed and wavelength). Despite these additional influences, we can still be confident that the DMR system will achieve DAQ of 3.0 or better with a $Cf/(N+I)$ ratio less than Analog NBFM.

So for DAQ of 3.0 or better, DMR Tier 2 coverage is greater than Analog NBFM coverage.

For a DMR Tier 3 trunked system, coverage cannot be defined solely in terms of DAQ. The trunked system call set up request (up link) and the "go to channel" response (down link) must both be received correctly, so the Message Error Rate (MER) becomes important. A single attempt of each at a low MER (say 5%) could require 5 dB or more power than that required for DAQ 3.0.

DMR Tier 3 trunked coverage is very similar to Analog NBFM. This can potentially be improved by sending more than one call set up request and "go to channel" response, thus trading off control channel loading for call set up success.

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