

Enhancing Digital Radio Performance

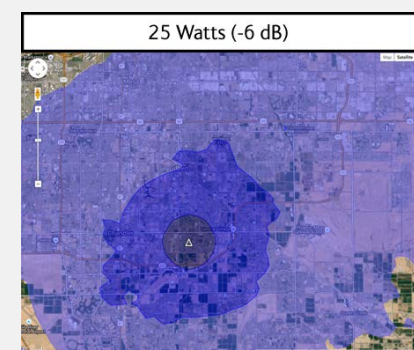
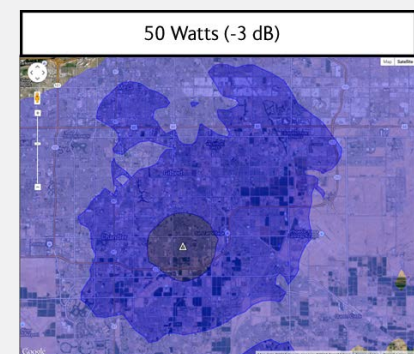
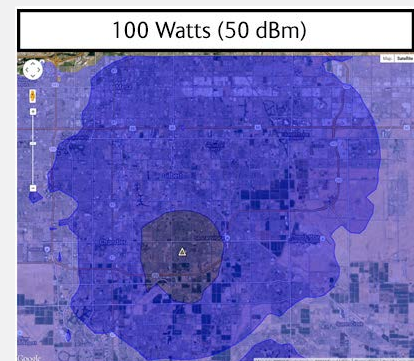
Proper testing and verification of RF modulation parameters ensures optimal digital network performance.

As much of the world transitions from analog to digital radios, it is important to understand that digital networks require more precise alignment than analog to achieve optimum performance. Testing and verification of radio frequency (RF) alignment parameters is required to maximize and deliver the high performance that digital technology provides. Improper alignment causes degraded digital modulation accuracy, which has a significant impact on the receiver's ability to recover the digital data.

Introduction

Most RF professionals are aware of coverage studies that are related to transmit power variations. Assuming all things are equal except for power level, the coverage area becomes smaller as the radio's transmitter power level decreases. This is expected and is true for both analog and digital systems.

However, with digital systems, the quality of the transmitted digital signal has a significant effect on the coverage area. Lab testing shows that improper modulation alignments of a radio's transmitter parameters negatively affect performance of another



digital radio's receiver. For example, a 20% calibration error can affect range to the same extent as a 75% reduction in power.

An understanding of digital radio operation and alignment, proper setting of audio filter parameters, and the use of accurate deviation meters will significantly improve the performance of digital radios. Conversely, using inaccurate deviation meters, improper filter settings, and lack of knowledge of meter specifications and operation will dramatically and negatively impact digital radio performance.

Analog and Digital Differences

Digital RF transmitters have attributes that must be measured to verify the quality of the digital signal. In many digital radios, the signal quality is directly related to frequency modulation (FM) deviation. The receiver must see a good quality digital signal to decode the digital ones and zeros. This requires precise and accurate measurements to ensure that the radio is aligned to published specifications.

Many digital radio technologies use modulation based on four-level frequency shift keying (4FSK) to represent the digital ones and zeros used to transmit information over the air. 4FSK modulation means that there are four allowed frequency deviation states of the RF carrier (also called symbols) that represent the digital data. These symbols are called "dibits" and represent two bits of data per symbol: 00, 01, 10, and 11. The deviation states must be precisely synchronized with the symbol clock. For Project 25 (P25), these deviation points are -1800 hertz (Hz), -600 Hz, +600 Hz, and +1800 Hz and are referenced to a symbol clock of 4,800 symbols per second. Because there are two bits per symbol, the bit rate is 9,600 bits per second (bit/s).

Digital radio receiver performance is tested using bit error rate (BER) measurements to determine the receiver sensitivity compared to the signal-to-noise-and-distortion (SINAD) ratio. Problems in the receiver will

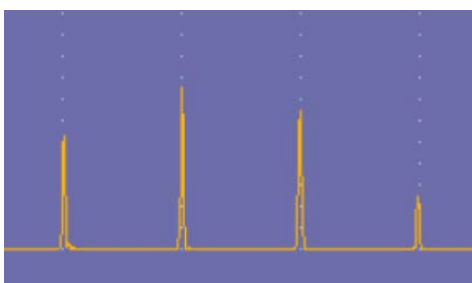
increase BER and negatively affect system performance. In a digital two-way communications system, the quality of the sending radio's transmitter also impacts the receiver BER.

Because the transmitter must modulate the carrier with 4FSK to the precise symbol deviation at symbol clock time, how close these symbols are to the ideal frequency deviation points impacts the receiving radio's operation. The measure of the transmitter's accuracy is stated as modulation fidelity (in P25 systems) or 4FSK error. Transmitting a poorly modulated 4FSK signal may work during a short-range radio check; however, across any significant distance, the RF air interface between radio transmitter and receiver causes additional impairment of the RF signal. Effects such as noise, interference, multipath, and inter-symbol interference (ISI) degrade the quality of the received signal.

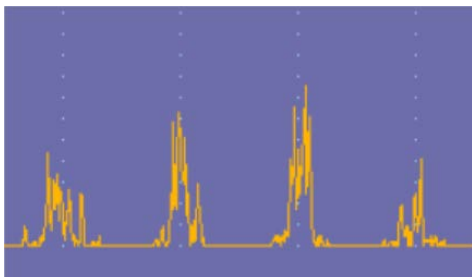
All RF signals, both analog and digital, lose amplitude and are more susceptible to noise as the radio wave propagates across a given distance. With analog signals, the noise is directly demodulated and present at the speaker. However, with digital 4FSK signals, the noise degrades the symbol quality, making recovery of the data more difficult. Improper FM deviation alignments cause the same problem, reducing effective range and decreasing voice quality.

Because the relation to the specified deviation state at the symbol clock time is critical for the receiver to decode the correct symbol, digital systems must be maintained and aligned correctly to ensure best performance. The accuracy of the alignments is significantly affected by the accuracy of the deviation meter used for digital alignments. Both the absolute and relative accuracy of the meter over the modulating frequency range are important factors for correct FM deviation measurements. After an alignment is completed on a radio, the digital modulation performance (symbol deviation and modulation fidelity or FSK error) must also be verified. This ensures that the analog alignment produces a good digital signal.

In the example shown, a receiver will have difficulty decoding the poorly modulated signal once the signal quality is further impaired over its propagated distance.



Good 4FSK Signal



Poorly Modulated 4FSK Signal

Deviation Meters

A deviation meter can be viewed as a peak responding alternating current (AC) voltmeter that is measuring the audio of the demodulated output from the test receiver. There are two different types of FM deviation measurements common in the alignment of digital radios: absolute and relative.

Absolute measurements must reference an absolute value, RF power, frequency error, audio level, and deviation are all parameters referenced to an absolute standard. It is important to consider all factors that can impact these measurements. FM deviation meters are peak reading; therefore, other frequency components will combine and add to the deviation level displayed on the meter. Noise is the largest additive contributor to deviation measurements. Most test receivers or modulation meters that use a super-heterodyne receiver allow the audio frequency (AF) and intermediate frequency (IF) filters to be set to limit the amount of noise allowed to pass through and affect the measurement.

As an example, a typical measurement for P25 radios is setting of the deviation level of a 1200 Hz tone to 2.83 kHz. This is a common adjustment and an example where absolute accuracy is required to set the deviation level, because it will directly affect the symbol deviation of the transmitter's digital signal.

Relative measurements reference a level of a tone in relation to another tone. In P25 and Digital Mobile Radio (DMR) digital radios, a low tone (for example 100 Hz) is measured and the corresponding high tone (3 kHz to 6 kHz) is set to exactly match the level of the low tone. The 3 kHz or 6 kHz tone is relative to the 100 Hz tone.

FM deviation meters must have no change in accuracy from one frequency to the next. In other words, there should be no "tilt" from one frequency to another. This is a critical parameter, as shown by one manufacturer's specification that requires the high tone to be within 0.05 decibels (dB) of the low tone. Flatness is critical in a deviation meter for doing relative measurements.

Alleviate Errors

When selecting AF and IF filters, a wider filter will allow more noise to pass through, and that will become part of the measured signal. Therefore, the filter settings should be no wider than necessary to reduce errors caused by allowing too much noise to pass through and affect the measurement, while at the same time allowing adequate bandwidth so that the filter does not attenuate the level. There are methods to determine the proper setting. For the AF filter, the filter is typically set to twice the frequency of the tone to accommodate the tone frequency.

For IF filters, a modified Carson's rule determines the bandwidth setting. This variation of Carson's bandwidth rule states that two times the sum of the rate and deviation will pass 98% of the audio energy for an analog system. For digital systems, we need to obtain greater than 98% of the energy to obtain the most accurate reading, so the basic rule is to use three times the sum of the rate and deviation: $3 * (\text{rate} + \text{deviation})$.

Older FM deviation meters typically use an analog meter movement. The meters have a needle that moves a certain amount on the meter face to indicate the measured level of FM deviation. A typical specification from such an FM deviation meter is:

Range	2 kHz to 60 kHz (full scale, 2-6-20 sequence)
Accuracy	±5% of reading, ±3% of full scale (1 kHz tone)

While the meter appears to have a fair level of accuracy at ±5%, the specification also states ±3% of full scale. For this meter, the available meter ranges are 2 kHz to 60 kHz in a 2-6-20 sequence. If we look at a signal modulated at 3 kHz deviation, we would use the 6 kHz range. The specification says that you also must add ±3% of the meter at full scale. Thus, the meter's true accuracy can be calculated.

Measuring at 3 kHz deviation:

- ±5% of 3000 Hz reading = ±150 Hz
- ±3% of 6000 Hz full scale = ±180 Hz
- Total potential error = ±330 Hz
- Actual accuracy = 330 Hz / 3000 Hz = ±11%

Another significant issue is that this type of meter is not specified for performance at audio tones other than 1 kHz. When looking at relative deviation measurements, we need to know if the meter is flat between the frequencies of 100 Hz and 6 kHz. With the given specification, we simply do not know the deviation meter accuracy at 100 Hz and 6 kHz. Analog meters often roll off after 4 kHz and can produce measurement errors of more than 20% when combined with improper

IF and AF filter settings. Digital meters have similar limitations in their specifications. A typical specification for a meter is 3% absolute accuracy with 0 dB flatness.

By understanding how FM deviation meter errors can affect a radio's digital FSK performance, we can determine the impact that the quality of the transmitted signal has on the ability of a receiver to decode the modulation. The table below shows the impact on a P25 receiver. Because of the similarity in modulation types, these results are typical for current digital radios. In this example, using an FM deviation meter with poor accuracy, improper IF filter and AF filter settings, or too much slope in the meter flatness will cause a receiver sensitivity impact equivalent to a 72% reduction in power.

Calibration Error	-5%	-10%	-15%	-20%
Receiver BER Degradation	-0.2 dB	-1.6 dB	-3.3 dB	-5.5 dB
Equivalent Reduction in Power	-5%	-31%	-53%	-72%

Conclusion

With a proper understanding of digital radio operations, system performance can be significantly improved. The proper setting of audio filter parameters and the use of accurate deviation meters can improve digital radio performance. Conversely, the use of inaccurate FM deviation meters compounded by improper audio filter settings and lack of knowledge of meter specifications and operation can dramatically and negatively impact digital radio performance.



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