

# Receiver Testing with the Anritsu MS2830A Signal Analyzer, MG3710A Vector Signal Generator, and S412E LMR Master™

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## Introduction – Receivers in the New Narrowbanded RF Space

Public safety receivers are built to perform in the harshest environments. Physically they appear to be up to any challenge. Some even work under water. Unfortunately, it is not easy to see how they will perform in a harsh RF environment. Narrowbanding moves adjacent channel performance to a new level. New spectrum allocations push public safety radios up in frequency near 3G and 4G transmissions. Digital radios such as those that utilize the APCO Project 25 (aka P25) standard react to interference differently from analog radios.

Figures 1 and 2 show likely spectrum scenarios where public safety P25 radios are close in frequency to 3G and 4G transmissions. This white paper discusses the common test procedures for analog and digital receivers and proposes new procedures that can better predict digital receiver performance under the emerging narrowband spectrum allocations.

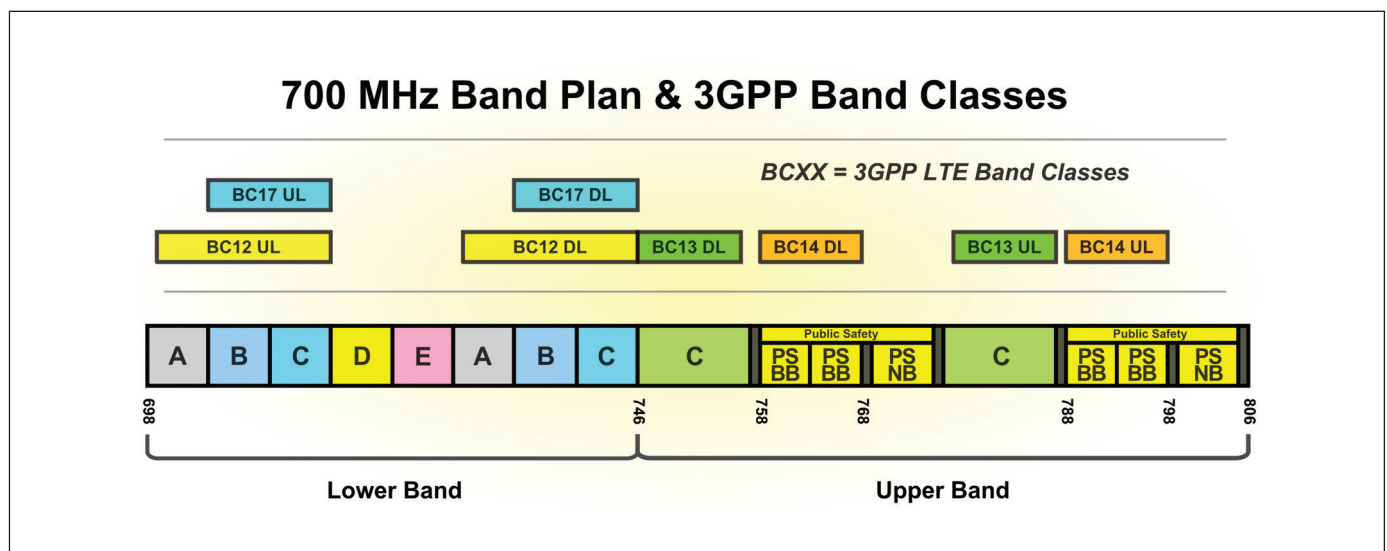


Figure 1. New 700 MHz Band w/ FirstNet "D Block."

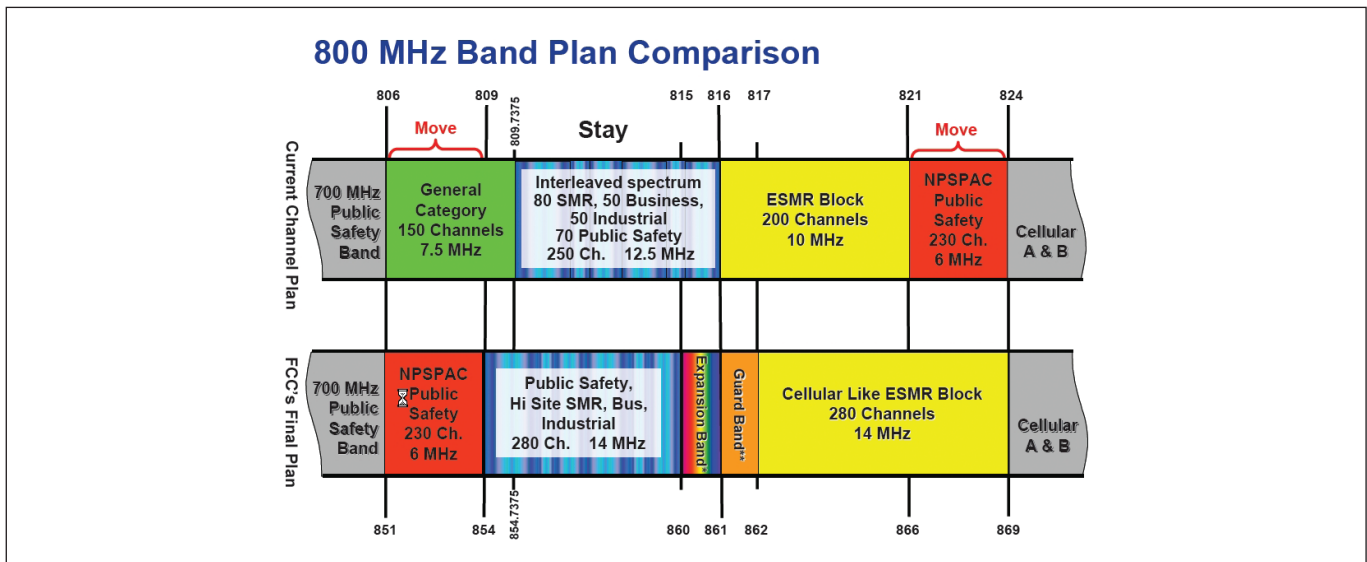


Figure 2. 800 MHz Rebanding Plan.

### Testing Digital Receiver Sensitivity

A common method to verify performance of an analog receiver is to send the receiver an RF test signal consisting of a single audio tone with specific characteristics (e.g., deviation for an FM receiver). The audio output from the receiver is brought back into an audio input on the test system for measurement of SINAD, the ratio of Signal+Noise+Distortion divided by Noise+Distortion, expressed in dB. For public safety receivers, SINAD is commonly measured using a 1 kHz tone modulation. A 1 kHz audio notch filter in the test set is used to remove the tone from the received audio, the SINAD is then derived from the measurement ratio. Analog receiver sensitivity is measured by monitoring the SINAD level as the RF signal power is lowered. The RF input power resulting in 12 dB SINAD is typically considered the specified sensitivity of the receiver.

For a digital receiver, the key performance measure is BER (Bit Error Rate). Most public safety digital radios have a test mode that provides BER measurement and display for a few BER test patterns. For P25 Phase 1 (as defined by TIA-102.CAAA-C) the 1011 Hz pattern is used. The 1011 Hz pattern is a near Pseudo-Random Binary Sequence (PRBS) that also provides an audio tone output from the vocoder. The tone indicates to anyone listening to a channel that it is out of service, similar to the situation with the 1 kHz tone for SINAD testing of an analog receiver. If a BER test mode is not available in the receiver, then the receiver needs to provide an output with the received data bit stream so the test system can compare the transmitted data pattern with the received pattern. The specified sensitivity of the receiver is typically the RF signal level for which the measured BER is 5%.

Digital receiver sensitivity is specified and measured with just the single test signal applied to the receiver. Receivers in real-world use are impacted by a wide variety of other signals in addition to the desired signal. In testing and predicting receiver performance in these real-world situations, the fundamental measure of the receiver performance measure remains the 5% BER level.

One problem with receiver testing is that the desired signal level is very near the receiver sensitivity level. Interfering signals must be generated and combined with as little distortion as possible. Careless management of interfering signals can result in spurious signals larger than the desired test signal, fogging the test results. Refer to “Notes on Attenuators and Isolators to reduce source-generated intermodulation products” later in the document.

Another problem with testing digital receivers is that (unlike a CW signal) digital modulation is very “noise like” and the displayed spectrum analyzer level will change with the resolution bandwidth setting. Figure 3 illustrates the test setup for a sensitivity measurement on a P25 receiver.

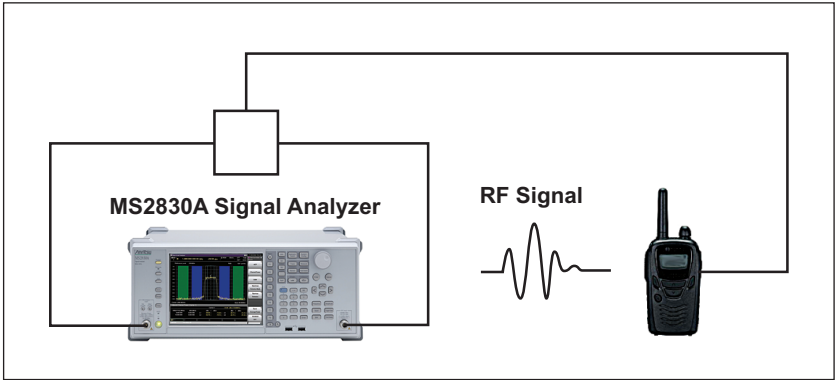


Figure 3. P25 Sensitivity Measurement block diagram.

The Anritsu MS2830A Signal Analyzer is a powerful yet affordable spectrum analyzer and signal analyzer for measuring signal levels during receiver testing. The MS2830A signal analyzer offers  $\pm 0.3$  dB power level accuracy to support accurate received level measurements. An optional vector signal generator can be used to support a wide variety of test signals. The power combiner/divider in Figure 3 is used to supply the MS2830A spectrum analyzer input with the same signal level supplied to the test receiver. Anritsu's MG3710A Vector Signal Generator further extends receiver testing with a wide variety of interference signals with two independent signal sources, each with two combinable vector modulation sources.

To assist in making accurate test signal level measurement both the MG3710A and the signal generator in the MS2830A have a front panel button to switch off the modulation, leaving a CW signal with the same power level. This allows the modulated signals to be adjusted until the radio BER display indicates 5% BER, at which time the modulation is switched off to allow accurate power level measurement on the MS2830A spectrum analyzer display.

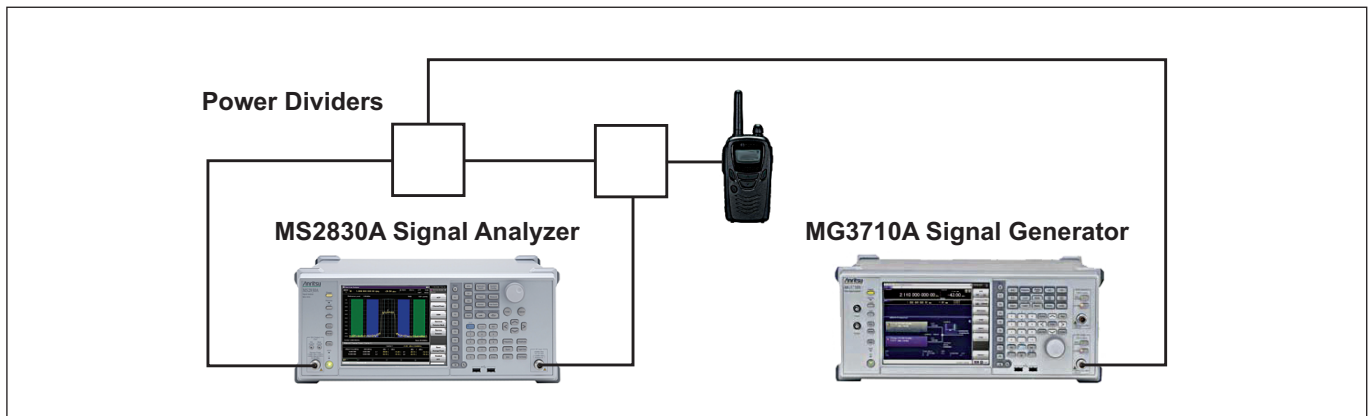
## Testing Digital Receiver Performance Under Interference Situations

Receiver manufacturers provide limited specifications on performance under interference situations. Common receiver specifications are:

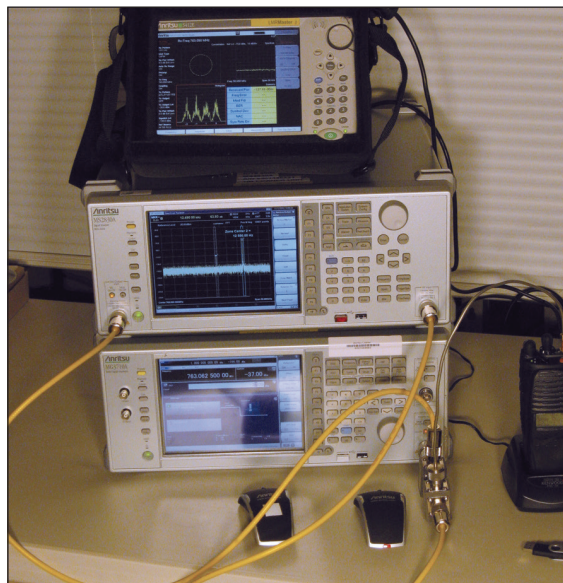
1. Adjacent Channel Rejection
2. Spurious Response Rejection
3. Intermodulation Rejection

### Adjacent Channel Rejection

Adjacent channel rejection measures the ability of the receiver to process the desired signal with a stronger signal in an adjacent channel. Figures 4 and 5 show the block diagram and setup for adjacent channel rejection measurement. Figure 5 also shows an LMR Master S412E being used as a setup monitor.



**Figure 4.** Adjacent Channel Rejection block diagram.



**Figure 5.** Adjacent Channel Rejection setup.

Often a CW signal is used as the interfering signal for adjacent channel rejection measurements. Figure 6 shows the spectrum display for a CW interferer. Figure 7 shows the same setup but with the modulation turned off on the desired P25 signal to show the power levels of  $-112\text{ dBm}$  for the sensitivity  $+3\text{ dB}$  and  $-49\text{ dBm}$  for the interferer, a difference of  $63\text{ dB}$ .

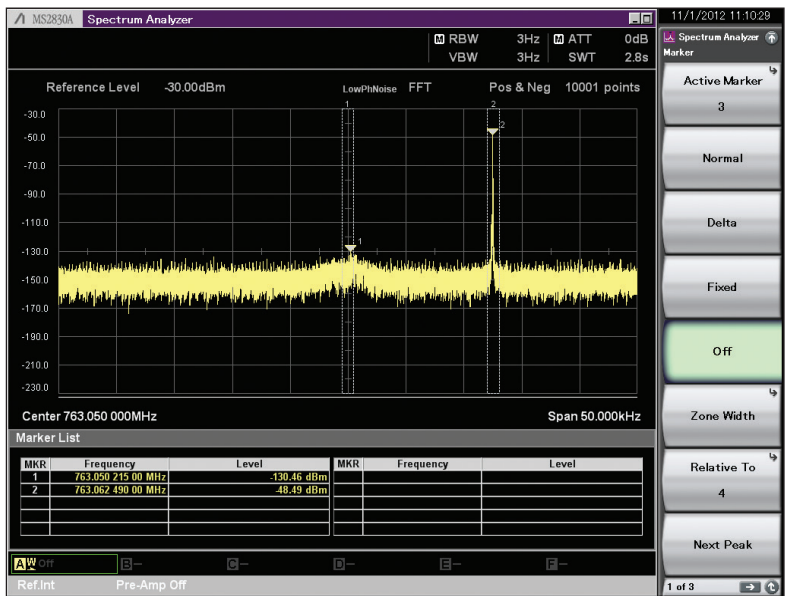


Figure 6. Spectrum display of CW interferer.

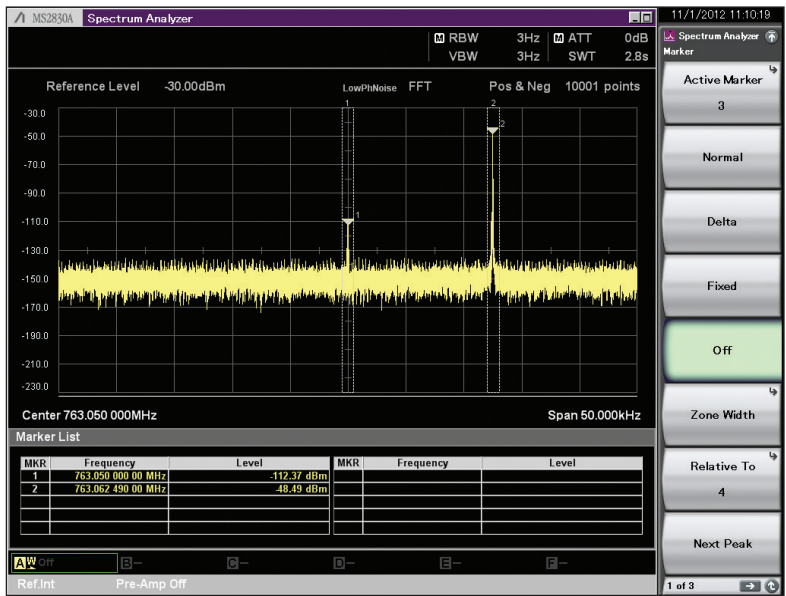


Figure 7. Spectrum display w/ modulation off.



The adjacent channel rejection test procedure for a 12.5 kHz P25 Phase 1 radio is defined by the TIA-102.CAAA-C standard. The interfering signal should be a standard interference test pattern uncorrelated with the desired P25 BER test signal pattern. A second power divider is used to combine the interfering signal from the MG3710A vector signal generator with the desired P25 signal from the generator in the MS2830A signal analyzer. For P25 radios, the adjacent channels are 12.5 kHz offset from the desired signal. The desired signal level is set 3 dB above the previously measured sensitivity level. Figure 8 shows a spectrum display of an adjacent channel measurement using a P25 Phase 1 interferer. Figure 9 shows the same setup but with the test signal modulations turned off to show the power levels of  $-112$  dBm for the sensitivity  $+3$  dB and  $-62$  dBm for the interferer – a difference of 50 dB.

In the United States all “narrowband” modulations must pass a common 12.5 kHz emission mask test defined in FCC Part 90.210. P25 linear simulcast modulation (LSM) signals can have significant AM content as a result of opening up the eye diagram to support varying arrival times from multiple repeaters.

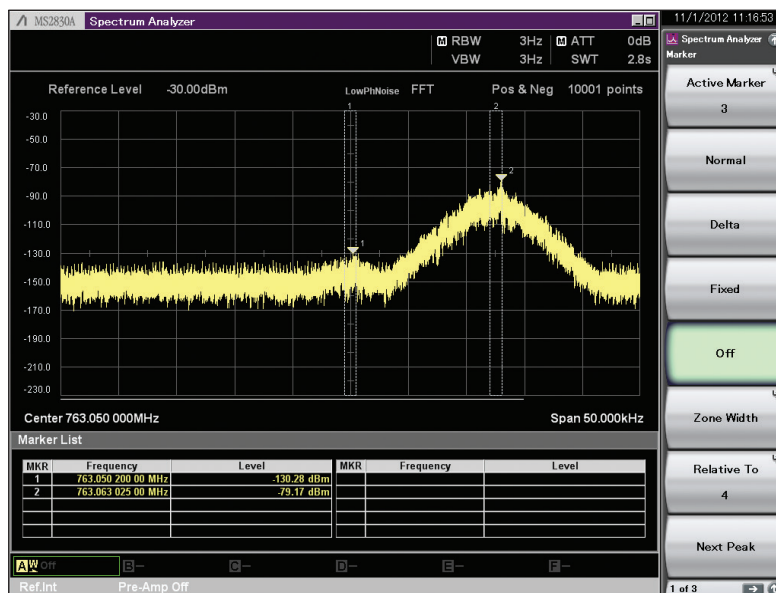


Figure 8. Adjacent Channel w/ P25 Phase 1 interferer.

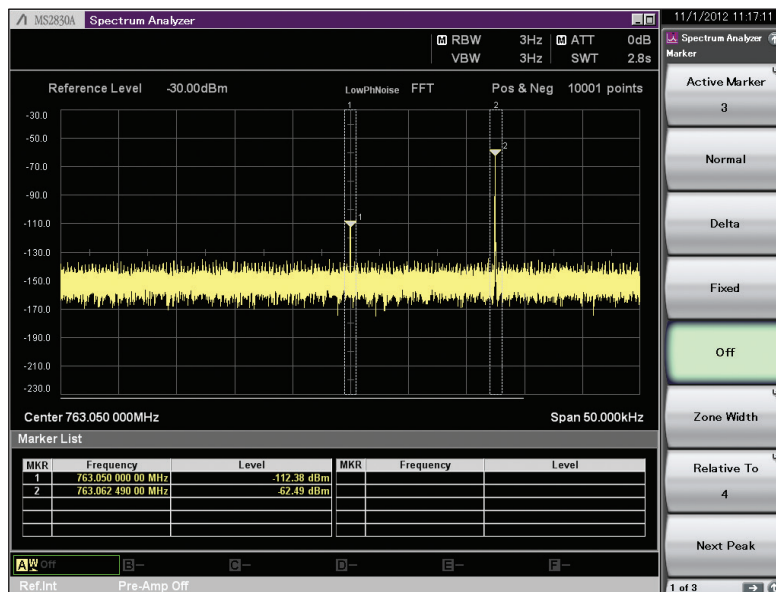


Figure 9. Adjacent Channel Rejection w/ modulation off.

Complimentary Cumulative Distribution Function (CCDF) provides an indication of possible peak power levels of interfering signals. Adjacent channels with peak power levels well above their average power level could cause nonlinear distortion in the receiver and affect the receiver performance. To better predict real world results, the best method is to test receiver adjacent channel performance with a variety of adjacent channel modulation types. This can easily be done by loading the vector signal generator with a number of modulation types and then switching through them during receiver testing. In cases where the interferer of interest is not available in the pre-defined modulation types, the Anritsu MS2830A Signal Analyzer supports capturing signals off the air and then replaying them at other frequencies and power levels.

Figures 10 and 11 show CCDF measurement comparisons between a P25 Phase 1 C4FM modulation and a P25 Phase 1 LSM QPSK modulation. The blue trace is the reference trace of Gaussian noise for reference. The C4FM signal has no AM content and the yellow trace is just a vertical line - the peak power is essentially the same as the average power. The QPSK signal has amplitude peaks 5.3 dB greater than the average, and 10% of the time the amplitude is 3 dB greater than the average. If an adjacent channel is a P25 LSM signal, the victim receiver will likely have reduced adjacent channel rejection.



Figure 10. CCDF of P25 Phase 1 (C4FM).



Figure 11. CCDF of P25 LSM (QPSK).

Figure 12 shows a spectrum display of an adjacent channel measurement using a P25 LSM interferer. Figure 13 shows the same setup with the test signal modulations turned off to show the power levels of  $-112$  dBm for the sensitivity  $+3$  dB and  $-66$  dBm for the interferer – a difference of 46 dB.

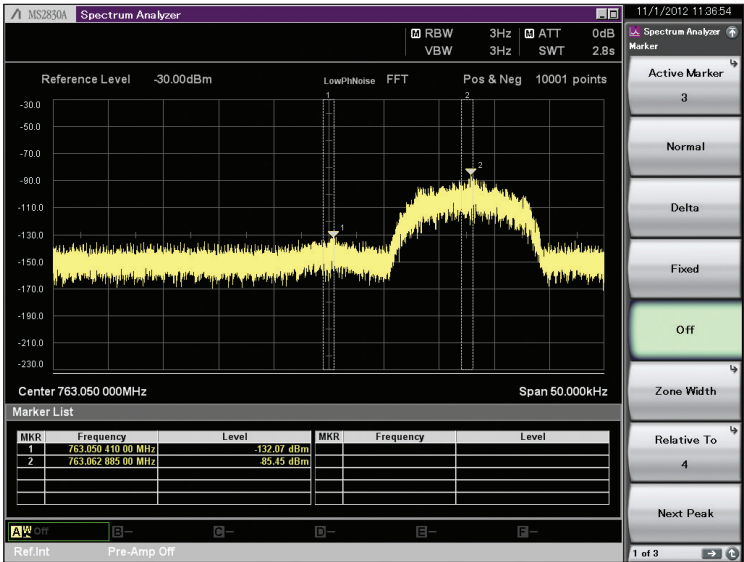


Figure 12. Adjacent Channel w/ P25 LSM interferer.

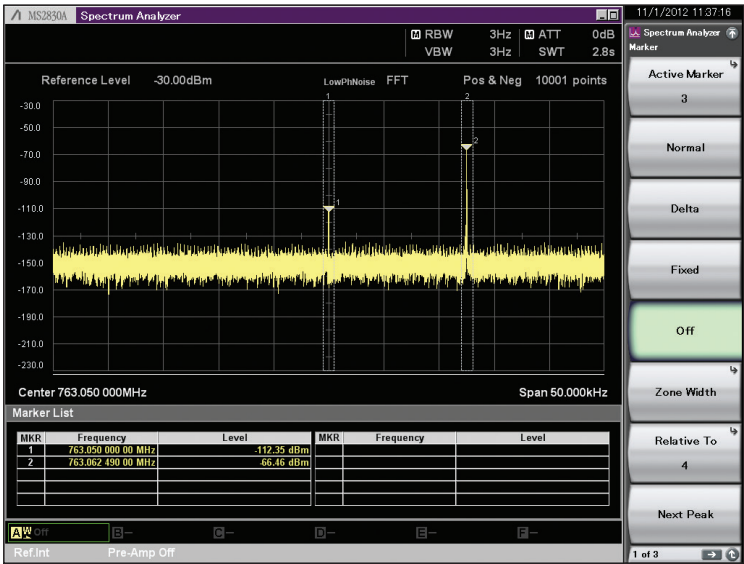


Figure 13. Adjacent Channel w/ modulation off.

### Spurious Response Rejection

The spurious response rejection is the ability of a receiver to prevent a single unwanted signal from causing degradation to the reception of a desired signal. The measurement procedure for a 12.5 kHz P25 Phase 1 radio is defined by the TIA-102.CAAA-C standard. The setup for this measurement is the same as for adjacent channel rejection measurement shown in Figure 4. The Spurious rejection is the difference in power in dB between the reference sensitivity and the level of an unwanted input signal that degrades a wanted signal 3 dB in excess of the reference sensitivity to be degraded to 5% BER. TIA-102.CAAA-C prescribes that the interfering signal be frequency modulated with a 400 Hz tone at 1500 Hz deviation. Similar to adjacent channel rejection, it is best to test receiver spurious rejection with a variety of modulation types; including cellular signals such as GSM, UMTS, 1xRTT, EVDO, and LTE, which are likely to be found in adjacent bands. TIA-102.CAAA-C also prescribes that the frequency of the interfering signal be adjusted over a range from one half of the lowest IF frequency in the receiver to twice the receiver frequency, or 1 GHz (whichever is greater). The range within 50 kHz of the desired signal frequency is avoided, as this range is covered by the adjacent channel rejection measurement described above.

For example, a Kenwood TK-5410 700/800 MHz P25 handheld radio has a first IF of 58.05 MHz, and second IF of 450 kHz. If the TK-5410 is set to receive 751.000 MHz, the interfering signal generator (Anritsu MG3710A, Figure 4) should be tuned from 225 kHz to 750.950 MHz, and 751.050 MHz to 1 GHz, while watching the BER display of the P25 signal at 751.000 MHz, with power level 3 dB above the sensitivity level. The Kenwood receiver has a bandpass filter prior to the receiver preamplifier, making it unlikely to be affected by signals far away from the desired receive frequency. The most likely spurious frequency responses are the receive frequency 751.050 MHz  $\pm$  58.05 MHz and 751.050  $\pm$  450 kHz.

Figure 14 shows a spectrum display of spurious rejection measurement using a 400 Hz tone at 1500 Hz deviation at the desired P25 frequency minus the second IF frequency of 450 kHz. Figure 15 shows the same setup but with the test signal modulations turned off to show the power levels of  $-112$  dBm for the sensitivity + 3 dB and  $-31$  dBm for the interferer – a difference of 81 dB.

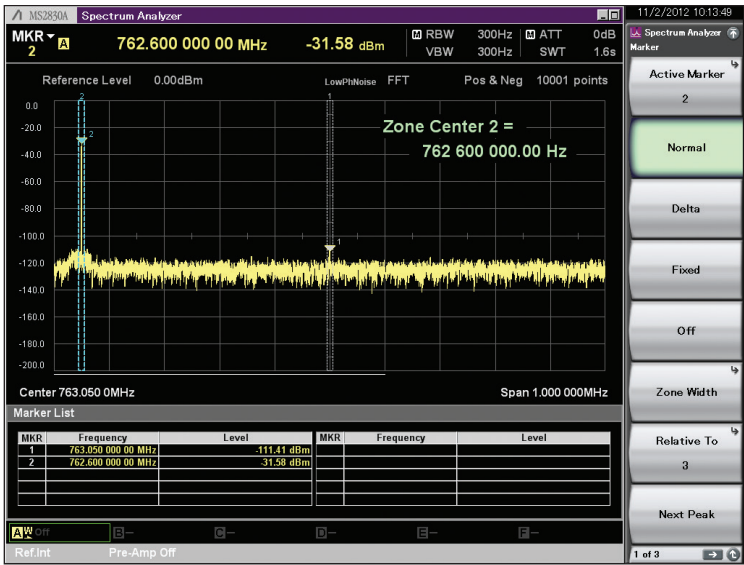


Figure 14. Spurious response w/ a 400 Hz tone @ 1.5 kHz deviation.

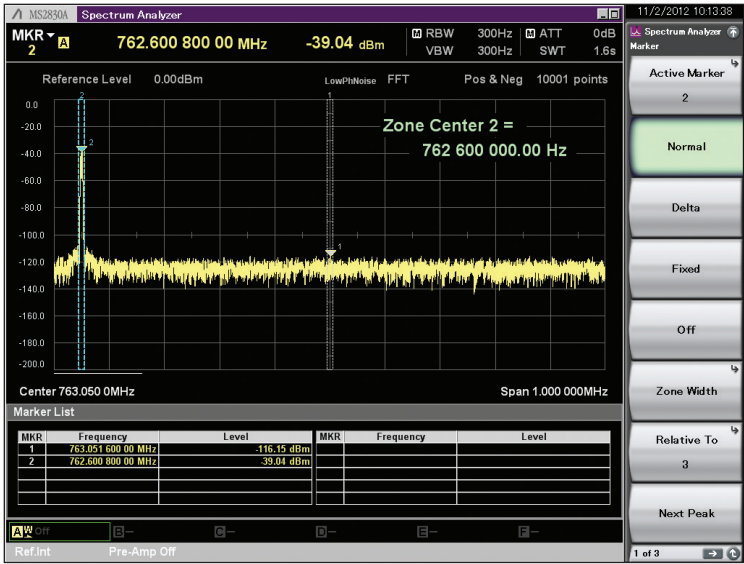
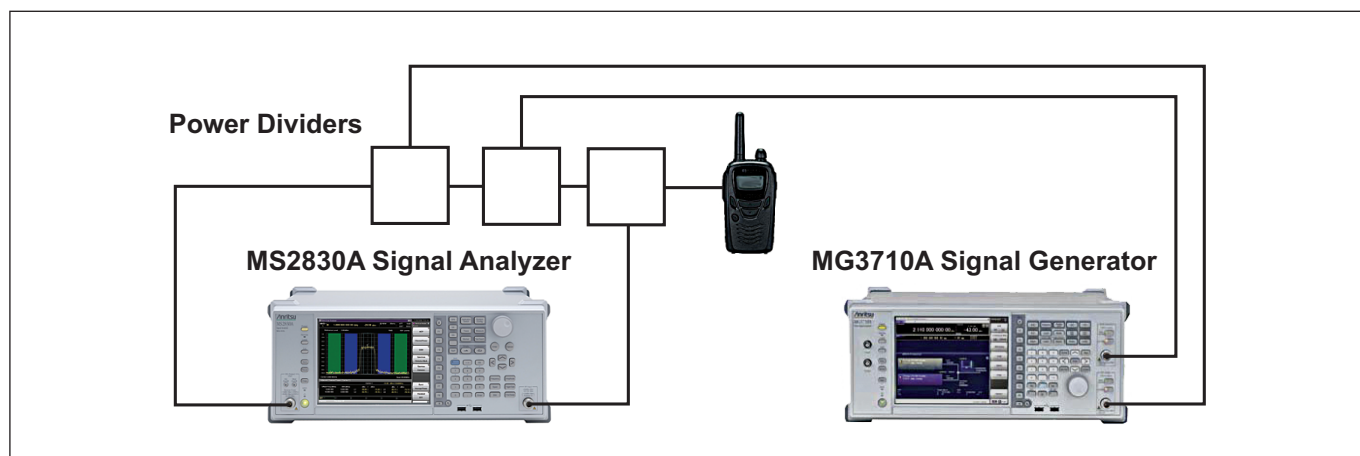


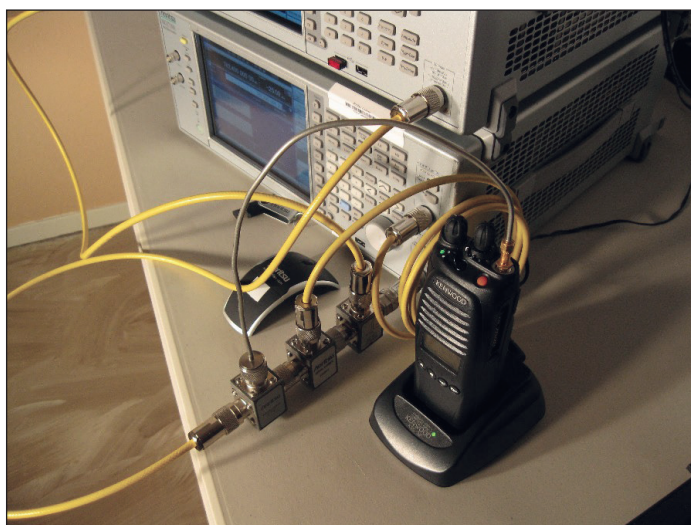
Figure 15. Spurious Response w/ modulation Off.

## Intermodulation Rejection

The intermodulation rejection is the ability of a receiver to prevent two unwanted input signals, with a specific frequency relation to the wanted signal frequency, from causing degradation to the reception of a desired signal. TIA-102.CAAA-C describes this measurement. It is expressed as the ratio of the level of two equal level unwanted signals to the reference sensitivity. The unwanted signals have amplitude that causes the BER produced by the wanted signal 3 dB in excess of the reference sensitivity to be degraded to the standard BER. TIA-102.CAAA-C specifies for 12.5 kHz P25 Phase 1 that a CW signal and an uncorrelated P25 standard interference test signal be combined together with the desired P25 BER signal. Two separate tests are performed; first with the CW 50 kHz above the desired signal frequency and the P25 interference signal 100 kHz above the desired frequency. The second test is with the CW signal 50 kHz below the desired frequency and the P25 interference signal 100 kHz below the desired frequency. The combined interference signals are increased until they degrade the desired signal by 3 dB in excess of the reference sensitivity i.e., the 5% BER level. The overall intermodulation distortion value is the smaller of the high side and low side measurements. The Anritsu MG3710A can be configured with two independent signal generators. Figure 16 shows the block diagram for this setup. A third power divider is used to combine the two signal generators in the MG3710A. One signal generator is used for the CW signal, the other for the P25 standard interference signal. Figure 17 shows a photograph of the setup including the three power dividers. Alternatively, the CW and P25 interference signals could have been created using one generator in the MG3710A. The two separate arbitrary waveform generators for each signal source can be internally combined with better than 80 dBc IM3 performance.



**Figure 16.** Intermodulation Rejection block diagram.



**Figure 17.** Intermodulation Rejection setup.



Figure 18 shows a spectrum display of IMD measurement using a CW signal 50 kHz above the desired P25 signal and a P25 standard interference signal 100 kHz above the desired P25 signal. Figure 19 shows the same setup but with the test signal modulations turned off to show the power levels of  $-112$  dBm for the sensitivity  $+3$  dB and  $-41$  dBm for the interferer – a difference of 71 dB.

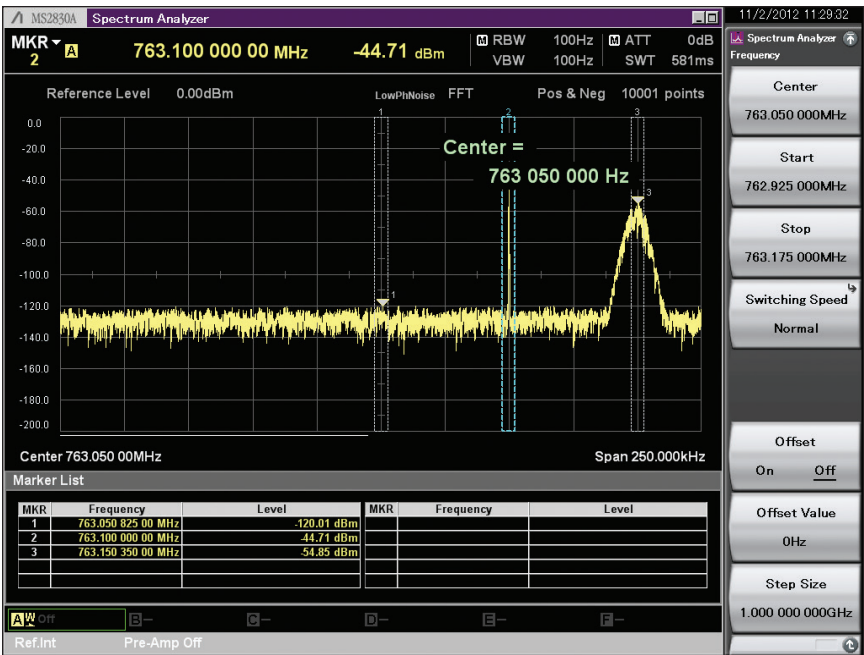


Figure 18. IMD w/ CW and P25 interferers.

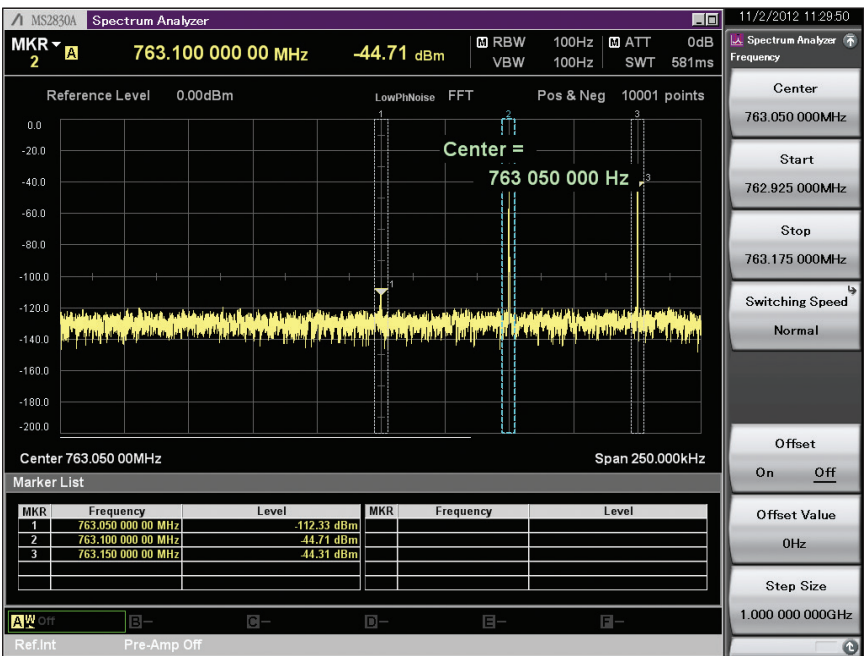


Figure 19. IMD w/ modulation off.

## Blocking or Out-of-Band Interference Measurement Using Standard Waveform Patterns

Receiver performance can also be affected by strong signals from other wireless services many MHz removed from the frequency bands allocated for public safety radios. New, spectrum efficient, broadband digital modulation techniques such as those used in 3G/4G cellular data can have high peak powers. In a near-far environment where the P25 transmitter is miles away and the P25 receiver is very near a 3G/4G cellular site, the receiver preamplifier or mixer can be overloaded – preventing reception of the weaker P25 signal. TIA-102.CAAA-C unfortunately does not offer a blocking measurement procedure. Measurement of blocking performance is similar to the previous intermodulation rejection measurement, with the exception that the number of possible interfering signals can be large. Figure 20 is an image from a suburban shopping center parking lot, and Figure 21 shows the crowded 850 to 900 MHz spectrum from the site.



Figure 20. Tower crowding near a suburban shopping center.

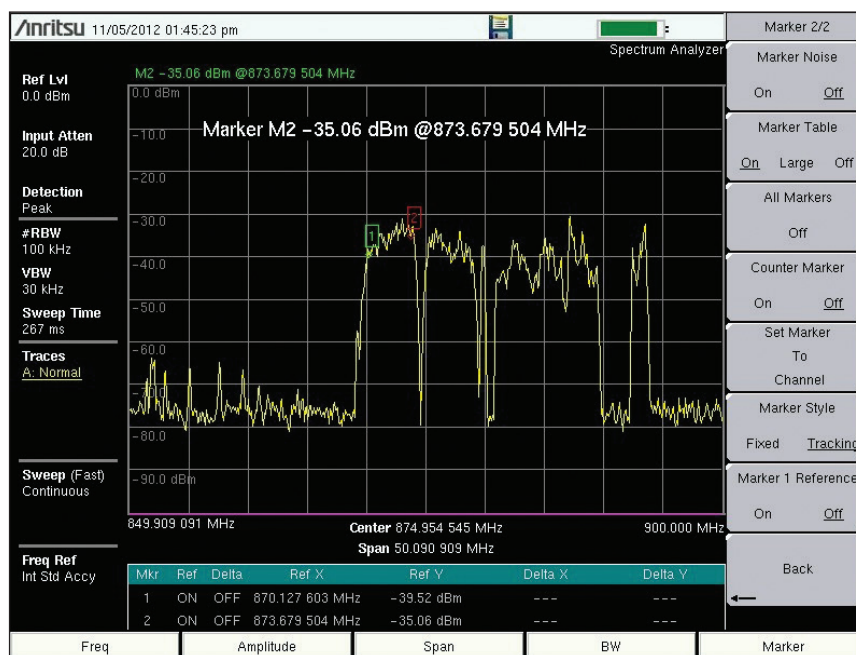


Figure 21. Spectrum crowding from the suburban tower in Figure 20.

Given this RF environment, a public safety P25 receiver operating at 860.050 MHz may not receive even a relatively strong P25 signal while parked in that shopping center parking lot.

An “out of band” or blocking measurement of the receiver can be made using the test setup shown in Figure 16. Similar to the TIA-102.CAAA-C methods described previously, the desired signal level is set 3 dB above the measured sensitivity level at 860.050 MHz. The spectrum bandwidth of the two nearest signals on the Figure 21 spectrum is approximately 5 MHz wide, indicating that they are UMTS / WCDMA signals. The nearest frequency UMTS signal appears to be centered around 872 MHz. The Anritsu MG3710A includes, at no charge, a wide variety of waveform patterns to create many common 2G, 3G, and 4G cellular waveforms.

Figure 22 shows a spectrum display of blocking measurement using two UMTS signals at 871.500 and 876.500 MHz which are blocking a P25 signal at 860.050 MHz. Figure 23 shows the same measurement, but with the test signal modulations turned off to show the power levels of  $-120$  dBm for the sensitivity  $+3$  dB and  $-28$  dBm for the interferers – a difference of 92 dB.

Up to four of the signals seen from the shopping center parking lot spectrum can be simulated using the MG3710A. It is not easy to identify visually the many types of signals on the spectrum display of Figure 21, but presumptions can usually be made that for any given cellular site there will be a mix of 2G/3G and increasingly 4G signals.

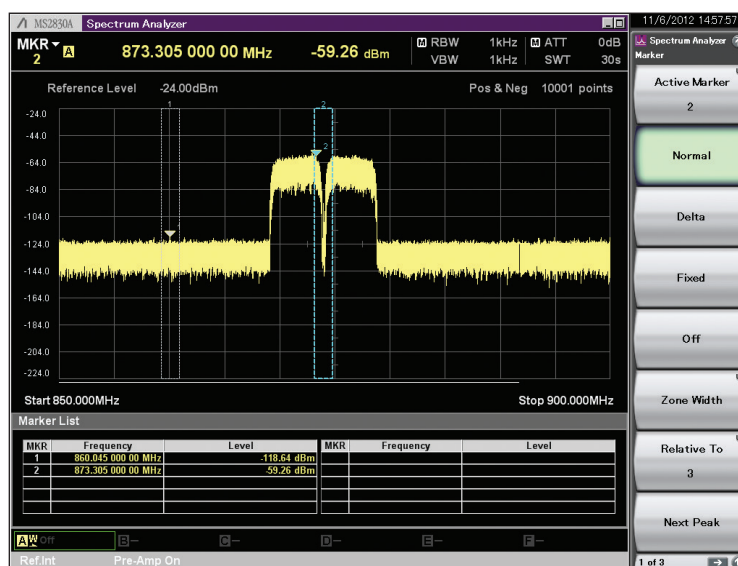


Figure 22. Two UMTS interferers blocking a P25 Phase 1 signal.

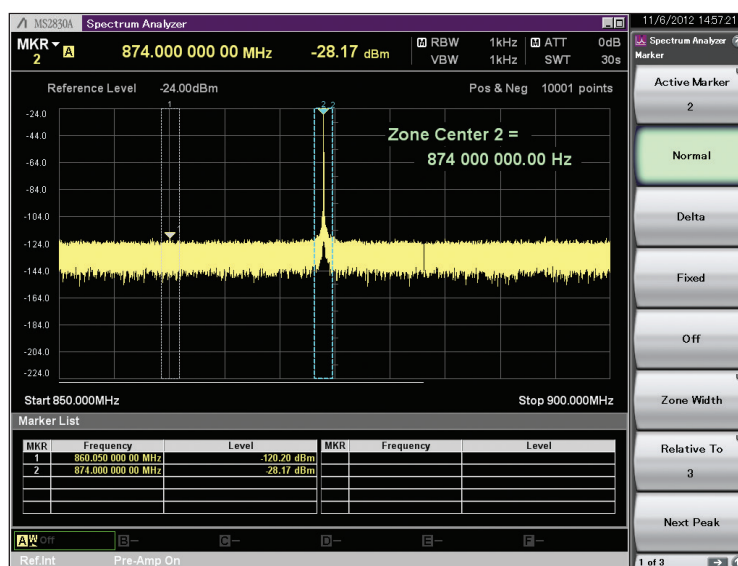


Figure 23. Two UMTS transmitters w/ modulation off.

## Blocking or Out-of-Band Interference Measurement Using Captured “Over-the-Air” Waveforms

The easiest way to recreate the interference scenario in the shopping center parking lot is to capture a 31.25 MHz block of the spectrum using the MS2830A Signal Analyzer and convert it into a signal generator file for replaying as an interfering signal. A two second record can be captured of the 31.25 MHz span. Figure 24 shows the block of spectrum. Figures 25 and 26 show the CCDF and Power vs. Time for the captured 31.25 MHz block.

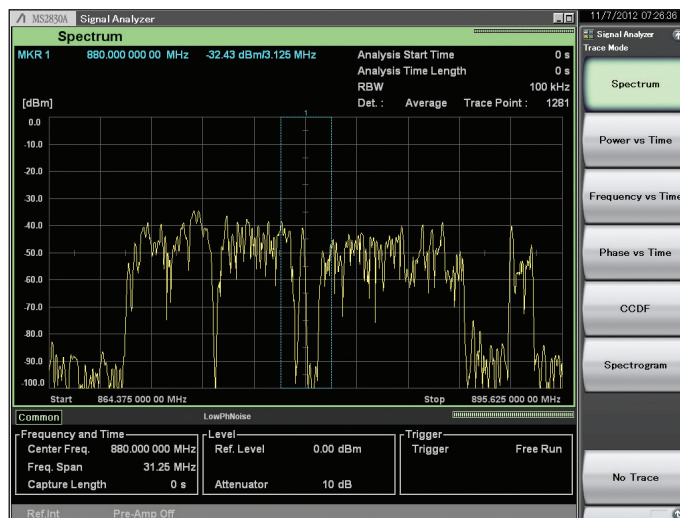


Figure 24. Crowding in upper end of 800 MHz band.



Figure 25. CCDF of a captured 31.25 MHz spectrum block.

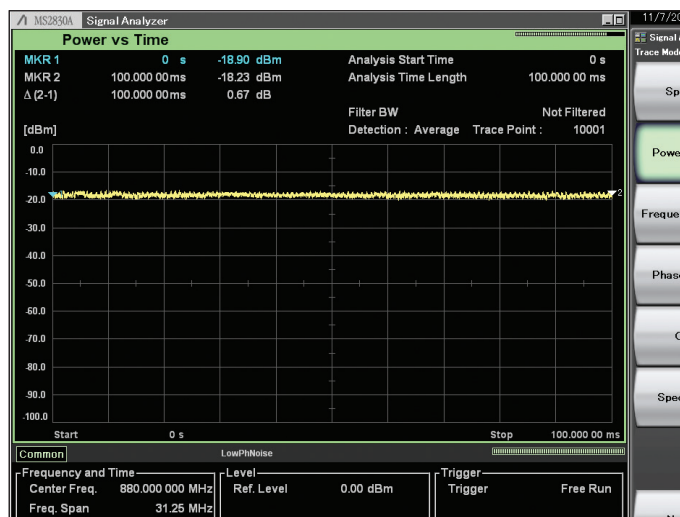


Figure 26. Power vs. Time of a captured 31.25 MHz spectrum block.



Figure 27 also shows a spectrum display of blocking measurement using the 31.25 MHz block of captured spectrum which in turn is transmitted to simulate blocking of a P25 signal at 860.050 MHz. Figure 28 shows the same setup but with the test signal modulations turned off to show the power levels of  $-119\text{ dBm}$  for the sensitivity  $+3\text{ dB}$  and  $-33\text{ dBm}$  for the interferers – a difference of  $86\text{ dB}$ .

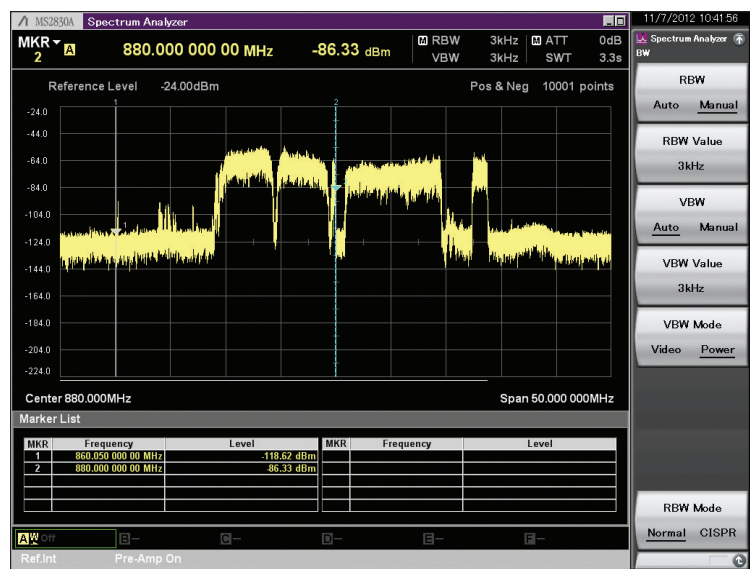


Figure 27. P25 blocking measurement using captured spectrum as the interferer.

### “In the Field” Testing

An in-the-field receiver test can be done with the Anritsu S412E LMR Master™. See Figures 29 and 30. The handheld instrument’s signal generator output is used to provide the P25 test signal combined with the off-the-air signal from a mobile antenna.

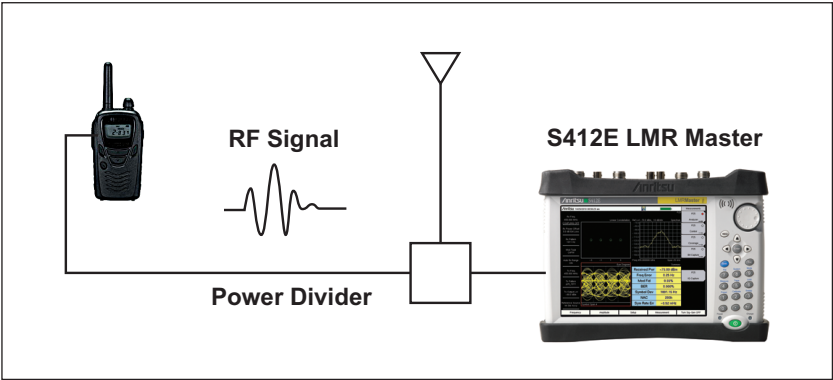


Figure 29. Block diagram of receiver field testing setup.



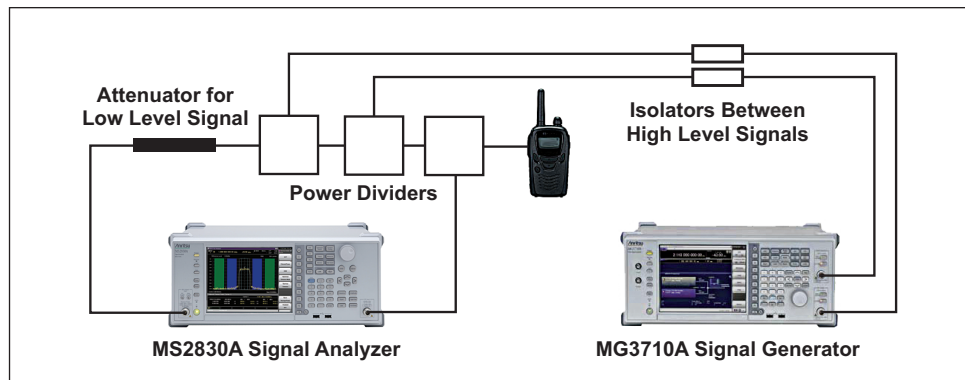
Figure 30. S412E LMR Master mounted on a vehicle dashboard.



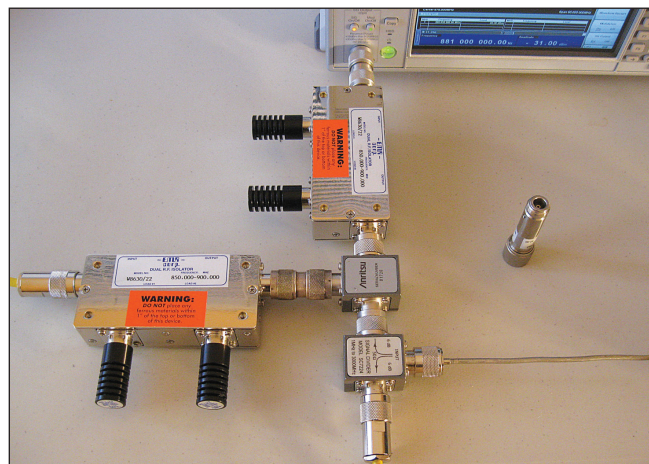
A power divider is used to combine an off-the-air signal from an antenna with the P25 signal at 860.050 MHz set to 3 dB above the 5% BER sensitivity level (with the antenna removed). This test is somewhat unscientific, as the open antenna can allow more than just the cellular signals into the receiver. It took 6 dB of additional power from the P25 test signal to unblock the Kenwood receiver when in the shopping center parking lot. The blocking level can also vary as the traffic on the cell site changes. While not rigorously scientific, this test does give an indication of how strong the P25 signal must be for a given radio to function at the location.

## Notes on Attenuators and Isolators

Many of the measurements in this white paper require combining signals together into a receiver input. Resistive power combiners can provide very precise levels, however they provide only 6 dB of isolation between ports. Most signal generators have active leveling loops to provide accurate output power level even when the load is varying. Thus it is possible for a strong signal from one signal generator to interact with the leveling circuitry of another, causing inaccurate levels and/or intermodulation products. To prevent this unwanted interaction, attenuators can be placed on generator ports providing the low level desired signals to isolate the source from the high level signal generators, and isolators can be placed on ports generating high level signals. In the forward direction, isolators have very low power loss to the receiver under test, while providing over 40 dB of isolation in the reverse direction. A rule of thumb is that 1 dB of isolation can reduce intermodulation product levels by 3 dB.



**Figure 31.** Isolators should be used at the ports of high level signals. An attenuator can be used at the port of low level signals.



**Figure 32.** Example 40 dB attenuator and 850 to 900 MHz isolators.

## Conclusion

Push-to-talk voice communication has long been the safety line for first responders. The reliability of public safety communications systems is being challenged by spectrum crowding, site crowding, and rapidly increasing consumer use of, and demand for, wireless data. The difficulties of signal reception in a “near-far” situation are exacerbated by a growing number of co-located transmitters with high-order modulation. This white paper describes a series of receiver measurement techniques, utilizing the latest signal analysis technology, to provide realistic signal scenarios for receiver characterization. The hope is that public safety system engineers can use the techniques outlined in this white paper to better predict receiver performance and make adjustments to maintain communications in an increasingly hostile RF environment.



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Application Note No. 11410-00694, Rev. A Printed in United States 2013-01  
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