Application Note

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# Receiver Blocking Analysis

## What is Receiver Blocking?

Receiver blocking occurs when strong RF emissions from unwanted sources intrude on communication channels, causing reduced performance in the receiver circuitry which manifests as a reduction in sensitivity. In general, receiver blocking occurs in one of three ways:

- Preamplifier overload – caused by strong RF signals which drive the preamplifier transistors out of linearity and into compression.
- Mixer overload – where strong RF passing through the receiver front end and preamplifier drives the first mixer into non-linearity.
- ADC overload – where the signal levels coming out of the IF section are too large and exceed the dynamic range of the analog-to-digital converter.

*Figure 1. Receiver blocking is an increasing problem*

Receiver blocking is essentially a manifestation of the "Near-Far Problem", where RF energy in the receiver passband from nearby sources becomes stronger than the distant intended source. Receiver blocking effects to conventional land mobile repeaters can occur when transmitters from other services such as cellular are installed near LMR antenna sites, causing the repeater's receiver to become less sensitive.

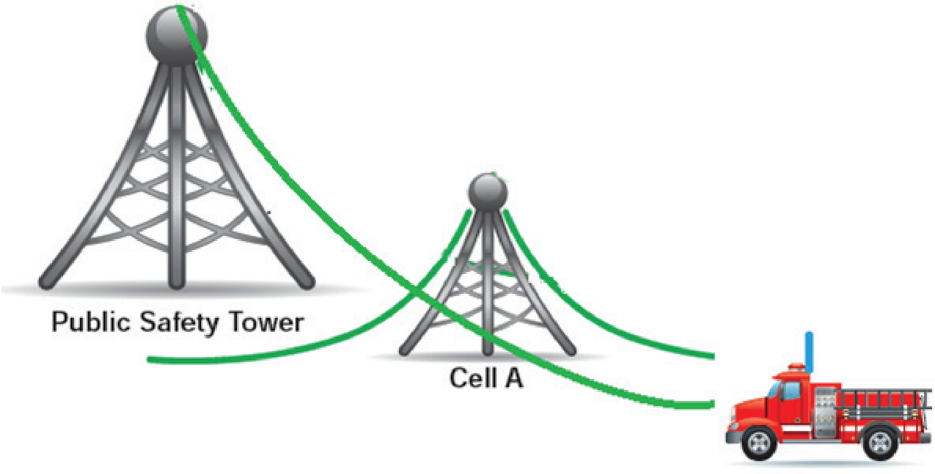



*Figure 2. Strong nearby signals can overwhelm distant desired signals*

Depending on the type of blocking source, the problem can be either intermittent or continuous. For example; if the source of the interference is a cellular data system, the blocking effect will be more pronounced during times of high subscriber data usage.

Receiver blocking will tend to mostly affect users in the system's fringe coverage areas, because the coverage area of the repeater's receiver is effectively reduced by RF from the blocking source. Effects to LMR trunked repeaters are similar, but will typically manifest as deflected calls, where the subscriber unit won't give the go-ahead signal to the user despite being in coverage and the system being unloaded.

Receiver blocking of subscriber units (mobiles and handhelds) can also occur. These cases are often harder to troubleshoot, because subscriber units are typically not stationary and the blocking sources may not transmit continuously, or the blocking effect may only manifest when the blocking system is heavily used. Years ago, the Nextel iDEN system was deployed and later found to be interfering with 800 MHz public safety. In recent years, problems with repeaters and subscriber units on 800 MHz public safety radio systems have been traced to cellular sites operating in the Commercial Mobile Radio Service (FCC Part 20) and in particular to HSPA/EVDO (3G) and LTE (4G) sites, especially those in the lower half of the 3GPP E-UTRA Band 5 (formerly called the analog cellular "Band A").

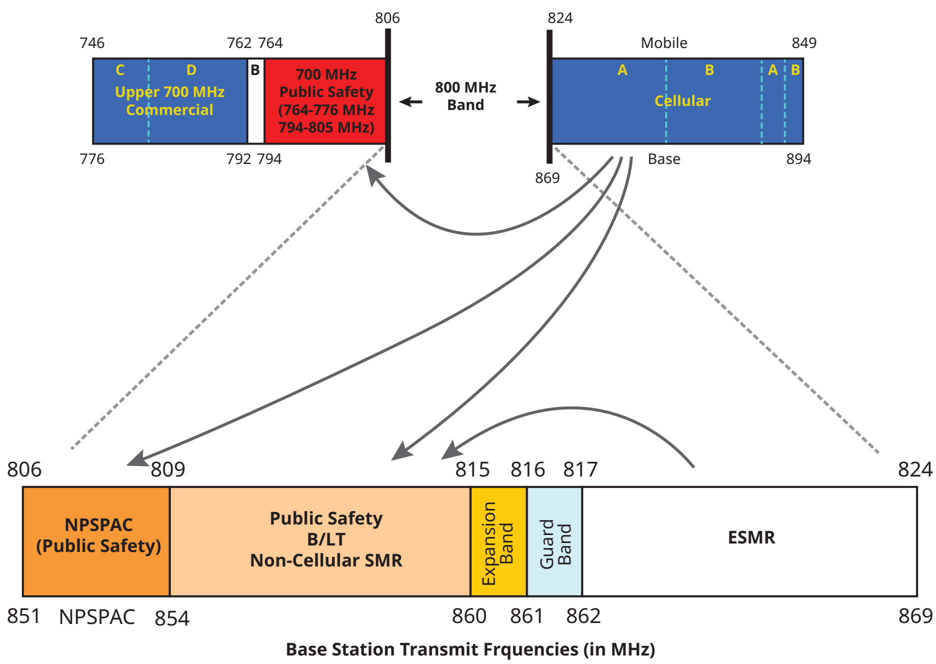



*Figure 3. Wireless broadband networks can impact public safety LMR*

## Cause Analysis

To understand how digital cellular networks generate sideband noise; recall that the Fourier transform of a fast amplitude transition in time domain generates a transient wideband response in the frequency domain. The faster the transition, the wider the frequency response. On its own, a digital cellular system may pass regulatory compliance for spectrum mask, but when several systems are operating simultaneously under heavy user load the aggregate sideband noise can easily exceed these spectrum masks – and unfortunately there is no "per site" spectrum limit. LTE systems are especially problematic because they use an Orthogonal Frequency-Division Multiplexing (OFDM) air interface - which uses multiple pilot and data carriers – each of which has a digital data stream that additively contributes to the aggregate sideband noise. Site, permitting costs, and the need to support exponentially increasing subscriber data usage often force carriers to install several cellular transmitters at one site.

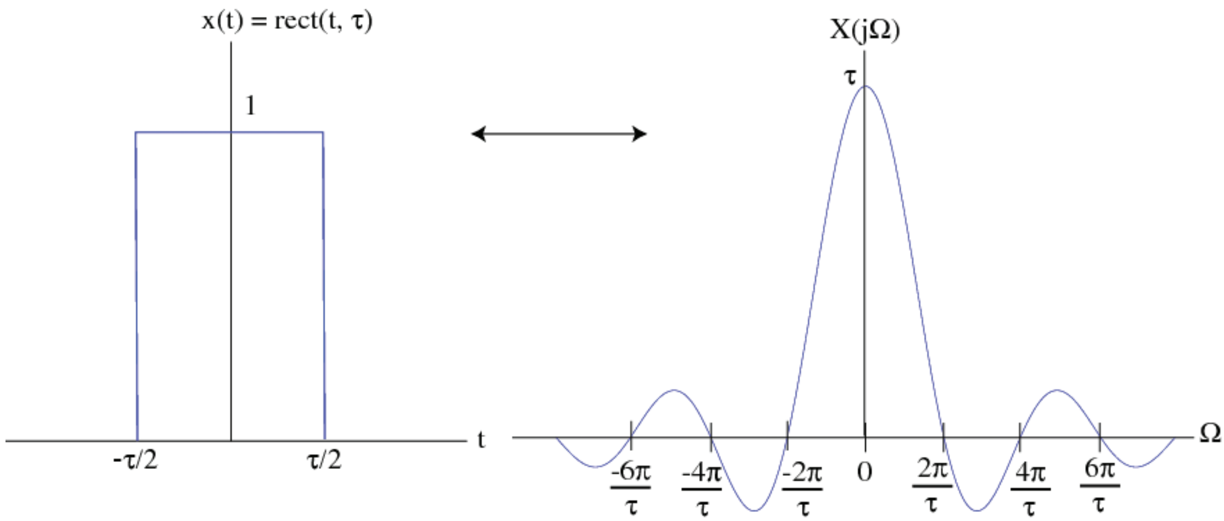



*Figure 4. A narrow pulse in time creates a wide transient in frequency*

Receiver blocking of 800 MHz public safety from 3G and 4G cellular sites is caused by the aggregate sideband noise generated from the digital air interface of these systems. As subscribers use more data on cellular networks, the sideband noise increases and can cause receiver blocking in the 850 MHz public safety bands. We should expect and plan for similar problems to be caused by 4G systems in the E-UTRA Band 13 and Band 17 which will impact 700 MHz narrowband public safety networks and FirstNet. In fact, FirstNet itself may create problems for those narrowband networks.

The problem of receiver blocking to public safety systems caused by cellular networks will likely increase as the wireless telecom industry moves to deploy Small Cell and Distributed Antenna Systems (DAS) to either replace or augment their traditional Macro Cell sites. This shift in architecture is called "densification" and it refers to the strategy of using smaller footprint cell sites to achieve a net increase in system capacity without the need for additional spectrum. While these Small Cell sites operate at lower power, they're also installed at street-level on utility poles, street lights, and building walls which creates a potential for increased receiver blocking. And because there are more of them, if receiver blocking occurs, the problem would not be localized but rather widespread. Likewise, DAS networks used in buildings may cause problems for public safety handhelds when responders enter those properties where DAS are deployed.

## Future Directions

The wireless industry is changing rapidly and each year brings new challenges from emerging technologies. For example; as local governments and contractors begin deploying "Smart City" projects, we may begin to see interference to 900 MHz public safety networks from wireless networks supporting the "Internet of Things" and "Machine-to-machine" networks. Prudent LMR engineers and system managers will want to monitor these standards as potential future sources of receiver blocking.

- IEEE 802.11ah – Announced in January 2016 and known as "Wi-Fi HaLow"; this technology is designed to provide data for Internet of Things and Machine-to-Machine networks. Operating in the license-exempt Industrial-Scientific-Medical band of 902 – 928 MHz, Wi-Fi HaLow is right in the middle of the 900 MHz Business/Industrial/Land Transportation (B/ILT) band.
- IEEE 802.11af – Sometimes referred to as "White-Fi"; this is a new cognitive-radio technology which takes advantage of unused (aka "White Space") television spectrum in the VHF and UHF bands from 54 – 790 MHz to create data links up to 1 kilometer.
- IEEE 802.22 – Similar to 802.11af; this standard uses White Space spectrum to create regional data links spanning distances of up to 100 kilometers.

All of these new wireless technologies use an OFDM-encoded air interface – and as we've seen with LTE which uses an OFDM air interface – this can generate sideband noise that combines to show up several MHz away, possibly in the public safety bands.

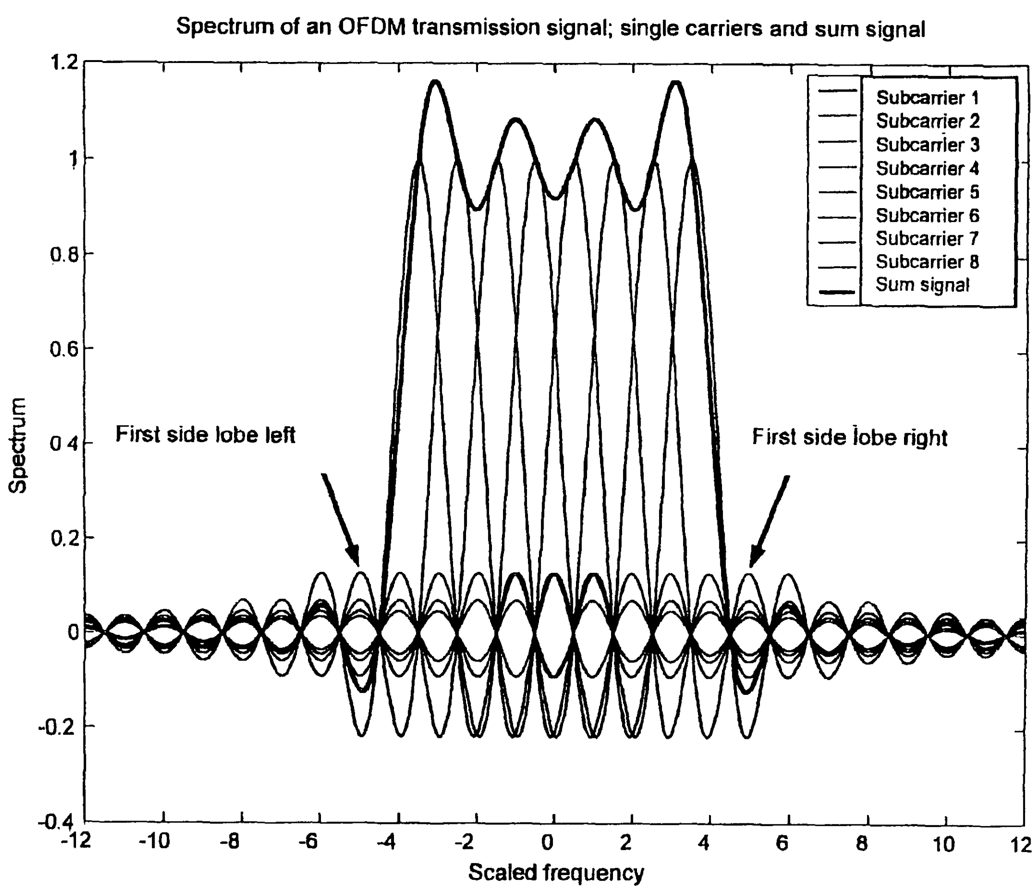



*Figure 5. Sidebands of multiple OFDM carriers can combine to create wideband noise*

## Resolution Strategies and Methods

In a perfect world, we would be able to coordinate all wireless systems on all frequencies to create a situation where receiver blocking could not occur. The realities of physics, economics, politics, and real-world variables make this impossible. We must rely instead on an understanding of the causes to create viable solutions. To resolve receiver blocking, the industry will need to take one, some, or all of the following steps:

- Increase desired signal strength – It's possible to increase the output power of mobile subscriber units, either by increasing the RF power setting of installing antennas with higher gain. Modification to licensing may be required. Increasing the output power of handheld subscriber units is typically not possible due to issues with heat dissipation and concerns about increased battery drainage. Handhelds with modified antennas are not generally type-accepted by regulatory authorities.
- Decrease blocker signal strength – This is the most likely course of action. Once the source of interference is identified, contacting the system owner/operator can help if they're willing to be cooperative. Most system owners, when faced with the possibility of regulatory authority intervention on behalf of public safety systems, will gladly work with you to resolve issues. If not, contact regulatory authorities who may order the owner/operator of the interfering system to reduce power, install directional antennas, or add transmitter filtering.
- Improve receiver performance – Better receiver circuitry and filtering can help, but would result in added hardware cost. At the repeater site, this is usually possible with small changes to budget. Adding cost to mobile and handheld subscriber units might be prohibitive, especially in larger systems with a high number of users. Nevertheless, in a world where the number of interference challenges is only going to increase, radio vendors will need to develop better blocking rejection strategies and improved designs for receivers.
- Interference-aware spectrum planning – This is a long-term solution and will require a great deal of commitment and vision from both regulatory agencies and the user community. Unfortunately this will likely take a very long time. Consider that rebanding of only 800 MHz was supposed to take three years, but ended up taking over a decade. In fact, the interference source which prompted rebanding (Nextel – Sprint's iDEN network) was decommissioned before the 800 MHz rebanding was completed. Nevertheless, planning strategies such as spectral separation are most likely the solution that doesn't rely on engineering heroics.
- Equipment standards update – Current standards guidance needs to be updated to reflect the realities of interference from modern digital communications. As it exists today, the TIA-102 standards specify receiver blocking for APCO Project 25 (P25) receivers against a single CW tone – which is a lot more innocuous than a multi-transmitter OFDM system operating under heavy load. The TR-8 committee needs to revisit receiver blocking and deliver an updated specification update.
- Receiver standards – In the US the FCC has historically avoided mandating receiver standards, relying instead on spectral masks for transmitters. As noted earlier, this approach fails when the interference is not from a single transmitter, but is from the aggregate effect of several co-located transmitters. Receiver standards would allow regulatory agencies to pack users more closely, making better use of scarce spectrum. Instead of receiver standards, the FCC is developing policy around "Harm Claim Thresholds" which attempts to address the issue of aggregate effects, but it places the burden of testing and proof on the owner/operator of the system experiencing the interference. It remains to be seen how well this policy will work in practice.

## Techniques for Testing & Analysis

When faced with user complaints of poor system performance, field testing is necessary to determine if interference is causing the problem. There are several techniques for field testing which are helpful:

- ACPR measurement and mapping – Adjacent Channel Power Ratio is the decibel difference between RF energy in an adjacent channel (outside the channel of interest) to the desired signal in the main channel of interest. Ideally, ACPR is low – indicating that RF energy outside the main channel is low and thus unlikely to be the source of interference. Mapping of ACPR can help locate sources of interference and identify areas where receiver blocking may occur. Of course, the ACPR measurement method doesn't address cases where interference types such as discrete harmonics or narrowband image signals are appearing inside the main channel itself, but ACPR measurement is a good way to analyze interference from digital transmitters, since they tend to generate wideband noise.

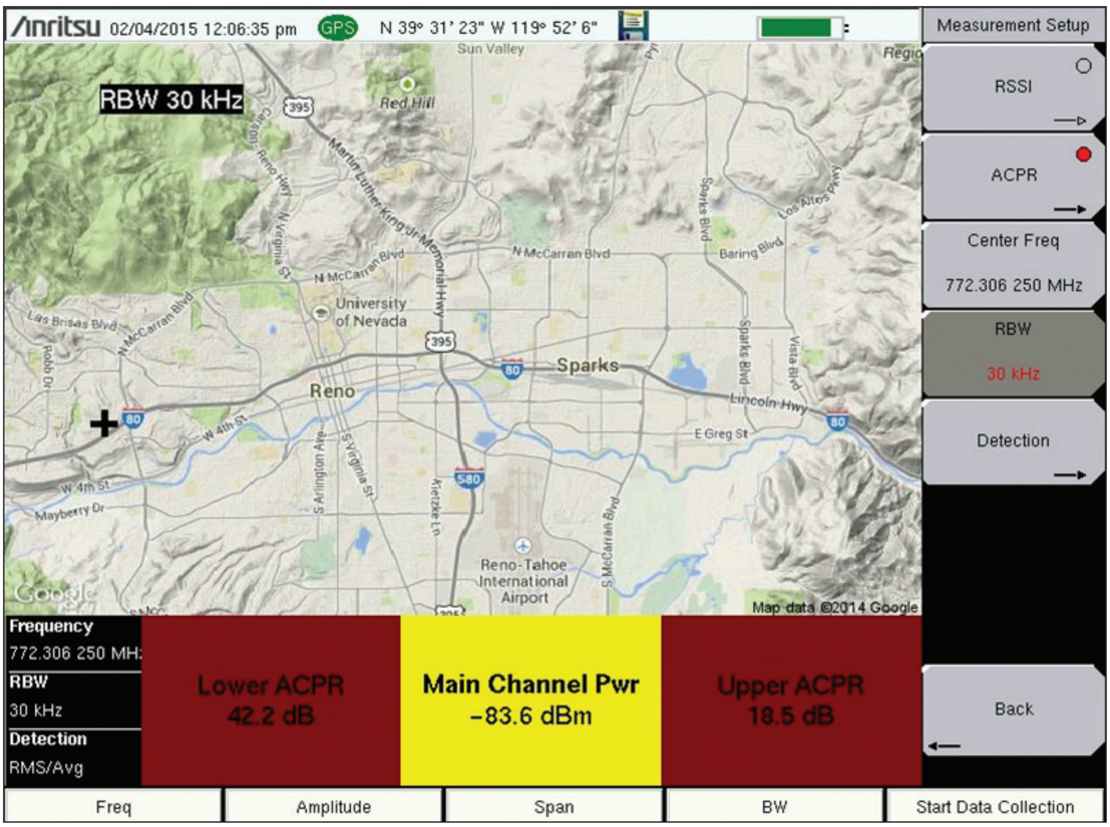



*Figure 6. ACPR_Display*

- External SINAD measurement and mapping – This measurement is useful because, unlike simplistic RSSI measurements, SINAD shows the performance of the receiver under test in the presence of both the desired signal and RF noise from the environment. Implementing an External SINAD test requires that the transmitter be configured to modulate an FM carrier with sinusoidal tone (typically 1 kHz). An audio adapter cable is attached to the receiver under test and is connected to the SINAD meter input. Measurement of SINAD is direct. Mapping of External SINAD is easily accomplished with a GPS antenna and a mapping tool. As the instrument is moved around the analysis area, SINAD measurements are logged with location coordinates, and color-codes are assigned to ranges of those measurements indicating level ranging from Very Good to Poor. Exporting these maps into a GIS tool such as Google Maps™ easily identifies areas where SINAD is poor, indicating where signal propagation might be low or environmental RF noise might be high and thus causing receiver blocking.

*Figure 7. ESINAD_Setup*

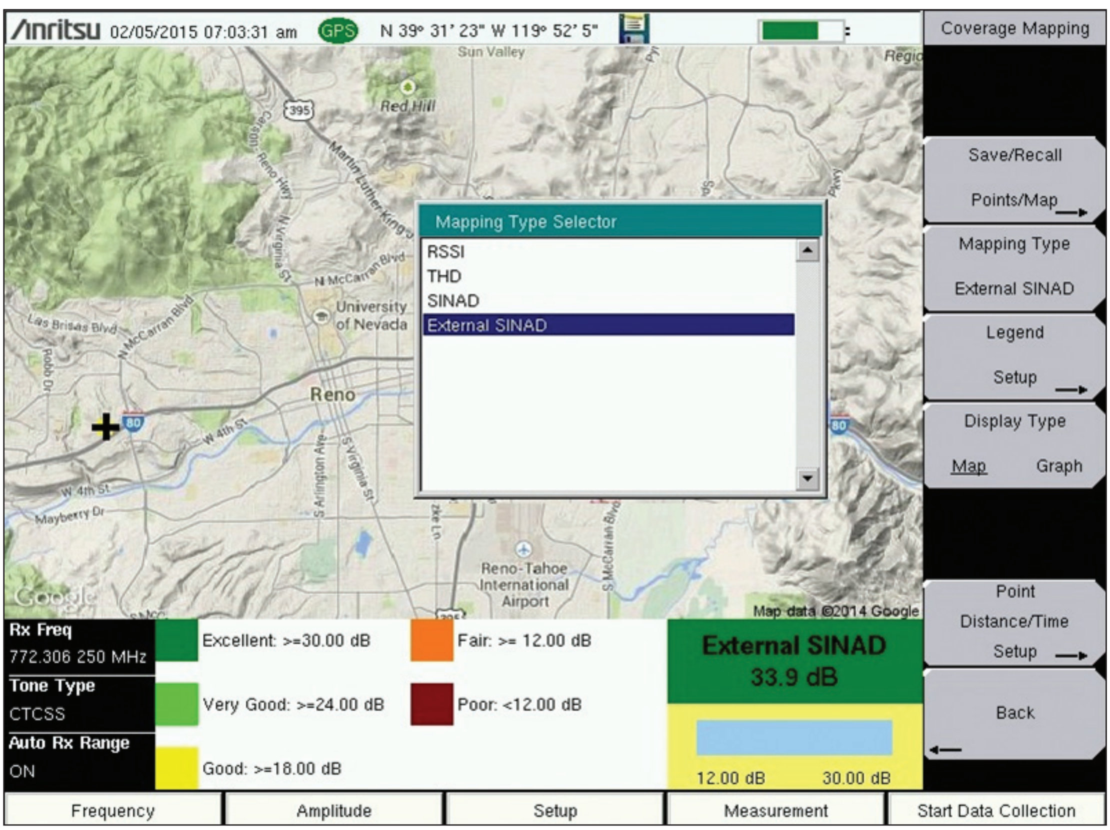
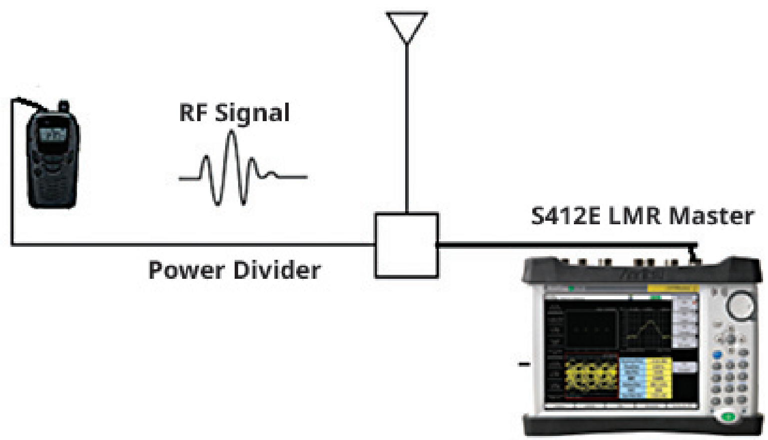



*Figure 8. External SINAD mapping is useful to analyze real-world receiver performance*

- Field receiver performance analysis – For the APCO Project 25 receivers, the TIA-102 family of standards contains specifications for performance of receivers in the presence of a CW interference source. Unfortunately, this does not show how a receiver will perform in the real-world against complex environmental RF noise sources. A better method is to combine environmental signals from a typical antenna (installed or perhaps a mag-mount type) with a known-good source from a signal generator, and then injecting the combined signals into a radio running in BER test mode. Placing a 6 dB or better power divider between the environmental antenna and the signal generator will help to isolate unwanted interaction. Ideally, the radio under test will be programmed to a receive-only mode in order to protect the signal generator output from damage due to inadvertent action of the radio's PTT. A coaxial fuse, such as the Alan Industries 50FL8 series, on the signal generator can also be used. The radio under test is then set to show received BER, and the signal generator level is increased until the BER is at 5%. This level (minus the loss of the power divider) will reflect the actual performance of the receiver in that location, showing how much desired signal is needed to overcome environmental RF noise. If there is strong RF interference, the desired signal level can be quite high; indicating that strong environmental RF noise is present and radio performance in that location will be impaired.




S412E LMR Master mounted on a vehicle dashboard

*Figure 9. Receiver BER performance in the field is affected by ambient RF noise*

- EMF measurements – This technique is typically used when the interference source has been located, and a question of whether to file for regulatory intervention is being considered. Most regulatory agencies have specific guidelines for limiting human exposure to Electromagnetic Fields (EMF). When considering whether or not regulatory intervention is needed, analysis of the electric and magnetic field strength of an interference source can help build a case for intervention. If the transmitter in question is emitting RF energy which when measured at ground level is in excess of the regulatory guidelines, intervention may be necessary. Measurement of EMF is done with a specialized antenna that repeatedly measures the electric or magnetic fields in each of three dimensions (x, y, and z) then calculates field strength based on those vector values. The antenna and instrument should be regularly calibrated, and the measurement must be done with no nearby metal, otherwise the pattern could be distorted. If the instrument is to be mounted for hands-free use, use a wooden easel or surveyor's tripod.

*Figure 10. Receiver BER performance in the field is affected by ambient RF noise*

It's important to remember when doing ACPR, Field receiver performance, or EMF measurements, and the suspected interference source is cellular or other modern data networks, that antennas for these are typically not static. These systems almost always use Multiple-input and Multiple-output (MIMO) antennas to direct signals in the most optimum direction and to take advantage of multipath to create multiple channels. At any given time, a MIMO-enabled system may be directing energy in one of several different directions as the users move around and multipath conditions change. Also, the amount of data being used on the system has an effect on the sideband noise – more usage means more noise. The suspect system must be observed over time and under data load to get meaningful results.

Anritsu envision : ensure


**• United States**
**Anritsu Company**
1155 East Collins Boulevard, Suite 100,
Richardson, TX, 75081 U.S.A.
Toll Free: 1-800-267-4878
Phone: +1-972-644-1777
Fax: +1-972-671-1877

**• Canada**
**Anritsu Electronics Ltd.**
700 Silver Seven Road, Suite 120,
Kanata, Ontario K2V 1C3, Canada
Phone: +1-613-591-2003
Fax: +1-613-591-1006

**• Brazil**
**Anritsu Electrônica Ltda.**
Praça Amadeu Amaral, 27 - 1 Andar
01327-010 - Bela Vista - São Paulo - SP - Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

**• Mexico**
**Anritsu Company, S.A. de C.V.**
Av. Ejército Nacional No. 579 Piso 9, Col. Granada
11520 México, D.F., México
Phone: +52-55-1101-2370
Fax: +52-55-5254-3147

**• United Kingdom**
**Anritsu EMEA Ltd.**
200 Capability Green, Luton, Bedfordshire LU1 3LU, U.K.
Phone: +44-1582-433280
Fax: +44-1582-731303

**• France**
**Anritsu S.A.**
12 avenue du Québec, Batiment Iris 1-Silic 612,
91140 Villebon-sur-Yvette, France
Phone: +33-1-60-92-15-50
Fax: +33-1-64-46-10-65

**• Germany**
**Anritsu GmbH**
Nemetschek Haus, Konrad-Zuse-Platz 1
81829 München, Germany
Phone: +49-89-442308-0
Fax: +49-89-442308-55

**• Italy**
**Anritsu S.r.l.**
Via Elio Vittorini 129, 00144 Roma Italy
Phone: +39-06-509-9711
Fax: +39-06-502-2425

**• Sweden**
**Anritsu AB**
Kistagången 20B, 164 40 KISTA, Sweden
Phone: +46-8-534-707-00
Fax: +46-8-534-707-30

**• Finland**
**Anritsu AB**
Teknobulevardi 3-5, FI-01530 VANTAA, Finland
Phone: +358-20-741-8100
Fax: +358-20-741-8111

**• Denmark**
**Anritsu A/S**
Kay Fiskers Plads 9, 2300 Copenhagen S, Denmark
Phone: +45-7211-2200
Fax: +45-7211-2210

**• Russia**
**Anritsu EMEA Ltd.**
**Representation Office in Russia**
Tverskaya str. 16/2, bld. 1, 7th floor.
Moscow, 125009, Russia
Phone: +7-495-363-1694
Fax: +7-495-935-8962

**• Spain**
**Anritsu EMEA Ltd.**
**Representation Office in Spain**
Edificio Cuzco IV, Po. de la Castellana, 141, Pta. 8
28046, Madrid, Spain
Phone: +34-915-726-761
Fax: +34-915-726-621

**• United Arab Emirates**
**Anritsu EMEA Ltd.**
**Dubai Liaison Office**
P O Box 500413 - Dubai Internet City
Al Thuraya Building, Tower 1, Suite 701, 7th floor
Dubai, United Arab Emirates
Phone: +971-4-3670352
Fax: +971-4-3688460

**• India**
**Anritsu India Pvt Ltd.**
2nd & 3rd Floor, #837/1, Binnamangla 1st Stage,
Indiranagar, 100ft Road, Bangalore - 560038, India
Phone: +91-80-4058-1300
Fax: +91-80-4058-1301

**• Singapore**
**Anritsu Pte. Ltd.**
11 Chang Charn Road, #04-01, Shriro House
Singapore 159640
Phone: +65-6282-2400
Fax: +65-6282-2533

**• P. R. China (Shanghai)**
**Anritsu (China) Co., Ltd.**
27th Floor, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road Shanghai, Xu Hui Di District,
Shanghai 200233, P.R. China
Phone: +86-21-6237-0898
Fax: +86-21-6237-0899

**• P. R. China (Hong Kong)**
**Anritsu Company Ltd.**
Unit 1006-7, 10/F., Greenfield Tower, Concordia Plaza,
No. 1 Science Museum Road, Tsim Sha Tsui East,
Kowloon, Hong Kong, P. R. China
Phone: +852-2301-4980
Fax: +852-2301-3545

**• Japan**
**Anritsu Corporation**
8-5, Tamura-cho, Atsugi-shi,
Kanagawa, 243-0016 Japan
Phone: +81-46-296-6509
Fax: +81-46-225-8359

**• Korea**
**Anritsu Corporation, Ltd.**
5FL, 235 Pangyoyeok-ro, Bundang-gu, Seongnam-si,
Gyeonggi-do, 463-400 Korea
Phone: +82-31-696-7750
Fax: +82-31-696-7751

**• Australia**
**Anritsu Pty Ltd.**
Unit 20, 21-35 Ricketts Road,
Mount Waverley, Victoria 3149, Australia
Phone: +61-3-9558-8177
Fax: +61-3-9558-8255

**• Taiwan**
**Anritsu Company Inc.**
7F, No. 316, Sec. 1, Neihu Rd., Taipei 114, Taiwan
Phone: +886-2-8751-1816
Fax: +886-2-8751-1817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