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A Measurement Technique for Characterizing Performance Degradation Caused by EMI on Radio Equipment

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ABSTRACT

By using a radio frequency (RF) audio distortion measurement test setup, communication devices can be evaluated for degradation caused by electromagnetic interference (EMI) from active vehicle components. This measurement technique can be used to determine the performance of a radio receiver under a variety of conditions.

The test setup consists of making measurements on a baseband audio signal that is sent to the device under test (receiver) via over-the-air RF transmissions. Once a baseline is established, active components on the vehicle can be powered on to determine their contribution to the receiver's degradation. The degradation measured is a result of distortion caused by conducted, radiated, and/or coupled EMI from active components into the receiver's passband.

INTRODUCTION

The use of electronics and sensitive communication devices continues to increase in automotive applications. It is often assumed that as long as the power and space requirements for the electronic equipment are satisfied, the device should operate as expected. In the case of adding sensitive radio receivers to vehicles, special care should be taken to maintain optimal performance from the receiver. This paper does not discuss methods to optimize the communications device performance, but rather it presents a test method that can be used to quantify the amount of degradation to which the receiver is subjected. After determining the amount of degradation affecting the communications device, corrective actions can be taken, and the unit can be re-tested to determine the effects of the corrective actions. In some cases, this may simply be the relocation of the communications equipment and/or antenna away from known sources of EMI. Other cases may require the application of proper grounding and/or shielding of existing equipment, either original equipment manufacturer (OEM) or aftermarket sources of EMI.

An example of such an occurrence with OEM hardware was recently found using the proposed measurement technique. While performing the proposed degradation test on a high frequency (HF) transceiver installed in a newer model diesel chassis, a degradation of more than 20 dB was discovered on particular channels located in the lower portion of the HF spectrum. The source of degradation was the result of EMI radiating from the factory diesel injector wiring harness. To reduce the EMI being radiated from the wiring harness in this particular case, ferrite cores with a specific permittivity were installed around the diesel injector harness in an area that was accessible on the front firewall of the engine bay. The scope trace illustrated below (Figure 1) shows the fuel injector harness feed for cylinder numbers 1, 3, 5, and 7 traced in yellow. The green scope trace depicts the activity on the fuel injector for cylinder number 5. The high-voltage transients shown are the root cause of the measured HF receiver degradation.

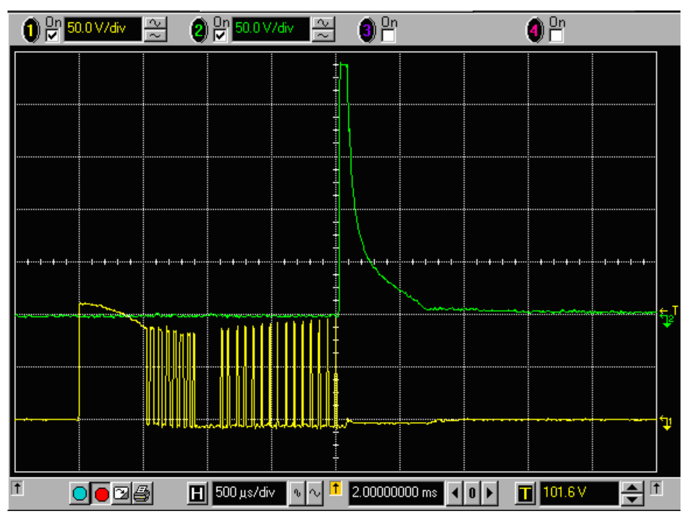

Figure 1. Scope trace of diesel injector driver module

The proposed degradation test should be performed by personnel experienced with RF sources of radiation. Although the setup and the actual data collection for measurement are relatively basic, the path forward once you start gathering data is not necessarily obvious. An understanding of RF and experience are invaluable at this point. The measurement may not reflect the actual amount of degradation that indeed exists if the operator does not know to make the measurement while the vehicle components are in that particular state of degradation. In the case presented above, the operator performed a baseline measurement with the engine of, repeated the measurement with the engine running, and thus found a significant source of degradation. In the past, diesel engines were preferred over gasoline engines for vehicles outfitted with communications equipment because diesels lacked the high-voltage ignition systems found in typical gasoline engines. Now, modern diesel engines are incorporating electronic diesel injectors that can produce EMI.

SINAD DEFINITION

A common reference used to measure a communication receiver's sensitivity is the signal plus noise and distortion (SINAD) measurement. SINAD offers a better measure of the receiver's capability to reproduce the modulation of the carrier frequency correctly over other common receiver sensitivity measurements [L.T. Jones, 1988]. The SINAD measurement provides a quantitative measure to the quality of the receiver's audio signal. SINAD can be viewed as the reciprocal of THD+N (total harmonic distortion plus noise), one of the most common audio measurements. SINAD expressed in dB is a measurement of signal quality given by:

$$\mathrm{SINAD}_{\mathrm{dB}} + 20\ \log_{10}\left(\frac{\mathrm{Noise(V)} + \mathrm{Distortion(V)} + \mathrm{Signal(V)}}{\mathrm{Noise(V)} + \mathrm{Distortion(V)}}\right)$$

Using the above definition of SINAD, it can be seen that a higher value of SINAD correlates to an improvement in audio quality. SINAD is the power ratio of the total signal level to the unwanted signal level.

Assuming that the desired signal is much greater than that of the noise, the SINAD measurement provides a close approximation to the received signal-to-noise ratio (SNR). A standard value of 12 dB SINAD is often used in testing the sensitivities of receivers because this value enables all pertinent components of the receiver to contribute to receiver's sensitivity measurement [L.T. Jones]. A SINAD value of 12 dB, corresponds to a 4:1 SNR or a signal containing 25 percent distortion.

THE SINAD RECEIVER MEASUREMENT

To make the SINAD measurement a known signal, a 1 kHz audio tone is typically used to modulate the carrier frequency for which the receiver is tuned for proper demodulation. The power level for the received total signal can now be determined. The total signal contains the known audio signal, noise, and distortion.

Next, a bandstop filter centered at the known audio tone is applied to the audio output of the receiver. The second power level is now acqired of the signal that contains only the noise and distortion components of the total signal. This power level is compared to the first power level and their ratio provides the SINAD value.

The theory of how a SINAD measurement is taken is presented here, but in practice, SINAD measuring devices are available that have all of the needed elements to take?? the measurements from a connection to the receiver's audio output terminals.

AUDIO TONE

The desired signal or audio tone that is used for the measurement is typically a 1 kHz sine wave. The 1 kHz audio tone represents the mid-band frequency for voice communications. This audio tone is used for the modulation of the carrier frequency.

METER

The voltmeter used as the distortion meter should be a true root mean square (rms) voltmeter. Typical distortion meters contain an average responding voltmeter that provides an accurate measure of the rms value for a sine waveform. A known relationship exists between the average and rms values of a sine wave .However, once noise and other signal components are added to the sine wave the known relationship between the average and true rms value may be unclear. Therefore, the use of a true rms voltmeter is required for accurate measurements.

AUDIO FILTER

No one standard filter is used for SINAD measurement, but two filters are commonly used. The C-MESSAGE filter is most often used in North America, and the CCITT filter (P53) is the filter recommended by the International Telecommunications Union.[‡]

SOURCES OF ERROR

Since SINAD measures the amount of audio distortion contained in the receiver's audio section, any source in the receiver that can effect audio distortion can affect the SINAD measurement. An example of this is the audio amplifier contained in the receiver. Typically, audio amplifiers in land mobile radios are limited to adding a few percent of audio distortion.

The theory presented for the SINAD measurement assumes that an ideal bandstop filter is used. This ideal filter completely removes the audio signal without altering the noise and distortion signals. Since ideal filters are not realizable, a source of error is introduced into the SINAD measurement. A realizable bandstop filter will have a bandwidth greater than that of known audio tone along with a certain amount of passband ripple. The distortion components will be affected less than that of the noise components by the imperfections of the filter. Distortion components will occur at harmonics that are related to the fundamental audio tone that will be displaced in spectrum from the bandstop center frequency.

[‡]CCITT—Comité Consultatif International Téléphonique et Télégraphique—is the former, but still widely used, name for the ITU-T, a Geneva-based organization that sets international communications standards. The ITU-T coordinates standards for telecommunications on behalf of the International Telecommunications Union (ITU).

RECEIVER DEGRADATION MEASUREMENT

How can this measurement be applied to radio equipment installed in a vehicular application to characterize its performance degradation from EMI. Noise sources from EMI that can be conducted, radiated, and/or coupled, can reduce the dynamic range of communications equipment and hinder the performance capability of the equipment.

The intent of the test procedure is to start with a baseline measurement that represents the highest obtainable sensitivity of the radio as it is installed in the vehicle with no external EMI sources and then systematically begin powering up components in the vehicle to measure their individual contributions to receiver degradation. Starting with the baseline configuration, which represents the minimal amount of electrical devices which are active in the vehicle, potential EMI sources can now be added to the measurement.

As an example, a VHF radio obtains a 12 dB SINAD measurement with an RF generator power of –60 dBm. Next, an auto-tracking satellite system is powered up, and an RF generator power of -57 dBm is required to obtain the 12 dB SINAD measurement figure. The satellite system incurs 3 dB of degradation upon the VHF radio when it is powered on. This degradation may only occur when the satellite aperture is in motion or when the aperture's main lobe is pointing towards the VHF antenna. At this point, experienced RF personnel can determine what test configurations should be tested.

Consider this scenario: an emergency response vehicle is outfitted with a two-way land mobile radio and receives an emergency dispatch over the radio from its call center. The vehicle communications operator receives the dispatch and responds back to the call center that they are en route to the emergency site. The driver of the vehicle turns on the emergency response lighting and proceeds to the site. The lighting contains high-voltage strobe lights that were not properly grounded and shielded when installed in the vehicle, and consequently, electromagnetic energy is radiated along the cables running from the high-voltage power supply to the lighting. This energy is now being coupled into the land mobile radio's receiver via the antenna port. This energy being radiated into the receiver's passband is effectively raising the noise floor seen by the receiver, i.e., de-sensing the receiver. As a result of this de-sensing, an incoming update over the radio was not received by the emergency vehicle.

THE MEASUREMENT TECHNIQUE

To measure the degradation to the mobile receiver (or radio under test [RUT]), the SINAD measurement is made with the RUT installed in the vehicle. When in place, the RUT will operate within the exact EMI environment. Therefore, every effort must be made not to disturb or alter any EMI coupling paths which exist for the RUT.

Test Equipment

The test equipment used to measure the degradation must be portable and easily adaptable to a vehicle platform. Care must be taken to ensure that the power supply for the test equipment does not generate any EMI, which could result in inaccurate measurements. A good solution is to use battery-operated test equipment. that. A communications system analyzer with built-in SINAD meter and a 600-ohm audio transformer connected to the speaker output of the RUT is often used by the author to obtain degradation measurement data.

Test Setup

The test setup for measuring the radio's degradation in the vehicle environment is different than measurements made for receiver sensitivity in the laboratory environment. Instead of using direct cable connections from the test equipment to the receiver, the vehicle's antenna, which is connected to the radio, must be included as part of the radio system. By using the radio's antenna, radiation sources that are coupled into the receiver's front-end from the antenna are included in the measurements. The baseline test should ideally have no contributions from any external EMI sources, but in reality, a small amount of energy will almost always be present.

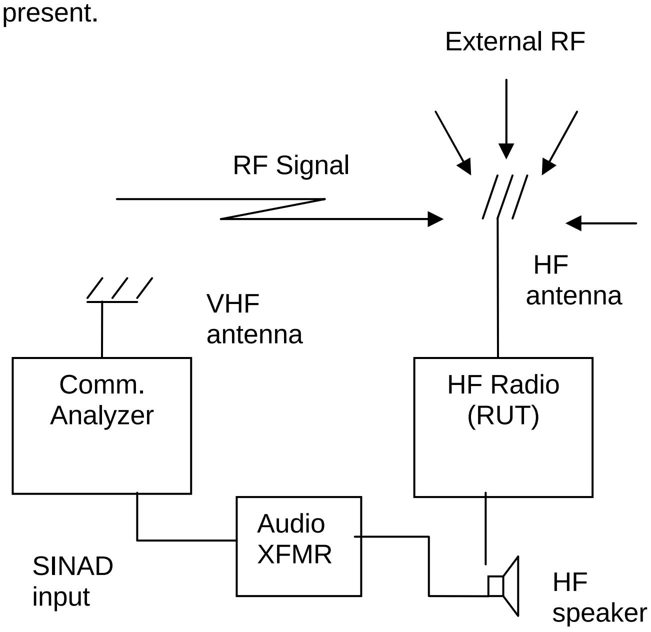

Figure 2. Measurement setup

To incorporate the vehicle's antenna as part of the radio system, an external RF signal is generated(with the appropriate characteristics for demodulation by the RUT) and is coupled into the radio's antenna via RF propagation. This setup is accomplished by using a second antenna connected to the output of the RF generator. The antenna that is used by the RF generator does not necessarily have to be resonant to the carrier frequency for the RUT. The radiating antenna could be a portable antenna magnetically attached to the rooftop of the vehicle or another antenna installed in the vehicle that is not in use. Once the baseline measurement is obtained, the degradation calculations are made relative to baseline measurement. The only requirement of the radiating element and generator is that sufficient effective radiating energy is present to achieve a 12 dB SINAD measurement on the RUT for all of its test configurations.

Test Location

Locating a good test site to perform this test can be a challenge, particularly when the RUT is in the HF spectrum. The optimal test location would be inside of an anechoic chamber. Although such facilities that can handle vehicles do exist,, they are often expensive and can be located quite a distance from your facility. A rural area can oftentimes provide satisfactory “RF quietness” from EMI. Areas to avoid include industrial areas, overhead power lines or substations, and sites subject to high winds. Once identified, a site should undergo a quick check of the background noise level to determine if the noise floor is acceptable.

The Baseline Measurement

The first measurement that needs to be established is the baseline measurement, which can be determined only with the RUT and test equipment powered on.

Degradation Measurements

Once the baseline measurement is established, degradation measurements can be systematically taken. Active components can now be powered up and adjustments made to the RF generator to achieve the baseline SINAD figure:12 dB. The difference in required RF generator power represents the amount of degradation that the active component induced onto the RUT. Active components should be measured independent of other active components in order to determine their individual contributions. In most cases, the overall degradation is desired, which represents a full-up system where all active components are powered up for the degradation measurement.

Repeatability

Strict control of the vehicle configuration must be maintained to help reduce the amount variance in the test measurements. Any changes in the vehicle layout—such as body panels, cabling, antenna placement—can impact the measurements As an example, when the measurements are taken, the doors should be closed. An open door represents an aperture to the inside of the vehicle where outside energy may be coupled into or out of the vehicle. Positioning of test personnel can also be critical during the actual testing; personnel and equipment should be identically positioned for each test.

CONCLUSION

The technique presented above provides a method to quantify the amount of degradation upon the RUT caused by EMI from active vehicle components. The described measurement technique can be used to determine if satisfactory performance of a radio is expected with the other active components of the vehicle or if an engineered solution needs to be taken to reduce the amount of EMI. This measurement technique has been useful in determining sources of EMI, quantifying the amount of degradation, evaluating communication vehicles for their receiver performance, and for testing the effectiveness of EMI solutions in laboratory and actual field environments.

REFERENCES

L.T. Jones, "When 12 dB SINAD is not 12 dB SINAD," Mobile Radio Tech., Vol. 6, No. 3, pp. 42–47, March 1988.

CONTACT

Paul C. Haddock received a B.S. degree in electrical engineering from New Mexico Institute of Mining and Technology, an M.S. degree in electrical and computing engineering from New Mexico State University, and is currently completing his thesis for a doctoral degree in Electrical and Computer Engineering Specializing in Communications Theory, also from New Mexico State. He is a member of the Institute of Electrical and Electronics Engineers, Inc. and Eta Kappa Nu. He is a senior member of the technical staff at Sandia National Laboratories where he works with communication systems. His current research interest lies in remote sensing of the earth’s atmosphere to study radio wave propagation for non-geostationary satellite communications.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

dB: decibel
dBm: decibel referenced to 1 mW
EMI: electromagnetic interference
HF: high frequency
kHz: $1.0 \times 10^3\ s^{-1}$
OEM: original equipment manufacturer
RF: radio frequency
rms: root mean square
RUT: radio under test
SINAD: signal plus noise and distortion
SNR: signal-to-noise ratio
THD+N : total harmonic distortion plus noise

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