dbSpectra

TECHBOOK

Series

SENSITIVITY

- RF Filters
- RF Distribution Design
- Antennas
- Understanding PIM
- Intermodulation
- Sensitivity

What is dbSpectra TECHBOOK series

To ensure a high-quality RF distribution system there are subjects that must be understood. dbSpectra "**TECHBOOK**" series provide simple discussions of important topics and show ways to ensure the highest quality is designed into the delivered system. Understanding these topics and working with our professional RF system engineers, will allow the design requirements to be met in the first design. Each booklet will discuss topics in as low a technical manner as possible. The **TECHBOOK** series is the first step in understanding complex and complicated RF Topics. Detailed training is available from dbSpectra that will provide more in-depth discussions and understanding. Contact dbSpectra for more information and to schedule training.

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Introduction

This TECHBOOK will explore and demonstrate how to successfully measure, use, apply, and improve sensitivity. While sensitivity has been used for decades to provide an understanding of the ability of a receiver to receive weak signals, this document will outline not only the use as it applies to a receiver but also to a receive system and interference mitigation. Receive systems consist of the basic receiver in conjunction with its antenna, receive filter and any multicoupler or tower top amplifier system that may be in use.

What is Sensitivity?

Sensitivity is a measurement methodology that provides information on how successful a receiver or receive system is operating. We use the term measurement methodology because the data collected depends on how the test was taken, what it is compared with, and the configuration of the receiver. The resulting sensitivity value obtained must have the measurement methodology identified. Several standards organizations such as IEEE, EIA, TIA, and others have defined the actual sensitivity test but the application of sensitivity has not been used appropriately by the industry. Sensitivity can be the basic specification sheet receiver sensitivity or static sensitivity, system sensitivity, effective receiver sensitivity, test port sensitivity, test port sensitivity with load, and test port sensitivity with antenna. Each of these different sensitivity tests utilize a specific test methodology. Without knowing how the test was ran the data is useless. For this reason, it is critical to not only provide the data but clarify how the data was obtained.

Sensitivity definition - Before we look at sensitivity it is important to review how a receiver works and clarify what modulation is. RF systems communicated by having a transmitter radiate an RF carrier or signal to the receiver on an assigned common frequency. Intelligence is applied to the RF carrier as analog or digital modulation. The intelligence may be voice, data, or a combination of the two. When the carrier signal is present, the receiver extracts or demodulates the intelligence from the carrier. The signal strength of the carrier where demodulation can occur with an acceptable amount of error is called sensitivity. Essentially, "How strong a signal is required to extract acceptable intelligence from a carrier".

Components of Sensitivity

Static (or chassis) Sensitivity – Static sensitivity is the sensitivity measured with test equipment connected directly to the receiver. It is the hardware evaluation sensitivity. This is the sensitivity figure published in radio manufacturers specification sheets. ***Figure 1*** shows the components of Static sensitivity.

- Thermal Noise (kTB) – Thermal noise is the theoretical noise floor of the bandwidth under test. The Thermal Noise or also referred to as kTB from the formula for the thermal noise floor, is determined by physics and is the lowest noise possible.
- Noise Figure (NF) – All electronic or powered equipment generates noise. The Noise Figure represents how much noise is generated in the hardware. Noise Figure is added to the thermal noise to establish the internal noise floor of the hardware.
- Carrier to Noise (C/N) – C/N is the amount of additional signal above the composite noise of the hardware required to produce minimum demodulation of the carrier. C/N is always used as the relationship to the minimum signal required. The C/N will change depending on the modulation type, bandwidth, or testing methodology.

- Static Sensitivity – The static sensitivity is the measured sensitivity of the hardware. Whether measuring the receiver alone, receiver multicoupler, or Tower Top Amplifier (TTA), the static sensitivity is the sensitivity operational sensitivity is compared with. The static sensitivity is the best sensitivity possible.

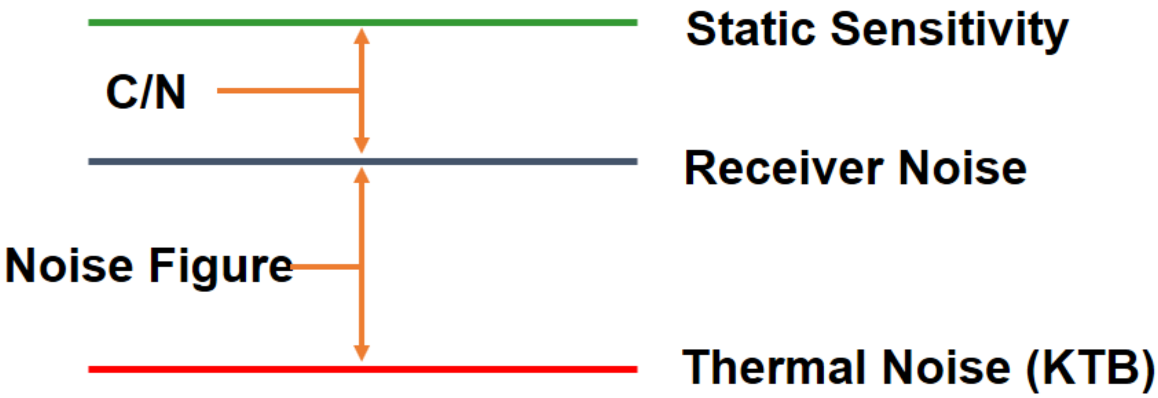

Figure 1: Static Sensitivity components

Effective Receiver Sensitivity – Effective Receiver Sensitivity (ERS) ***Figure 2***, also called *operational sensitivity*, is the sensitivity as seen in the real world when connected to the antenna. When the receiver or receive system is connected to the antenna it picks up external RF noise and possibly interfering signals. Adding these external RF signals creates the operational noise floor. Unlike the static noise floor, the operational noise floor is not constant. It will vary between frequencies, frequency bands, sites, antennas, time of the day, and site environments. This variability in the external noise floor is why ERS must be measured at the site, not calculated.

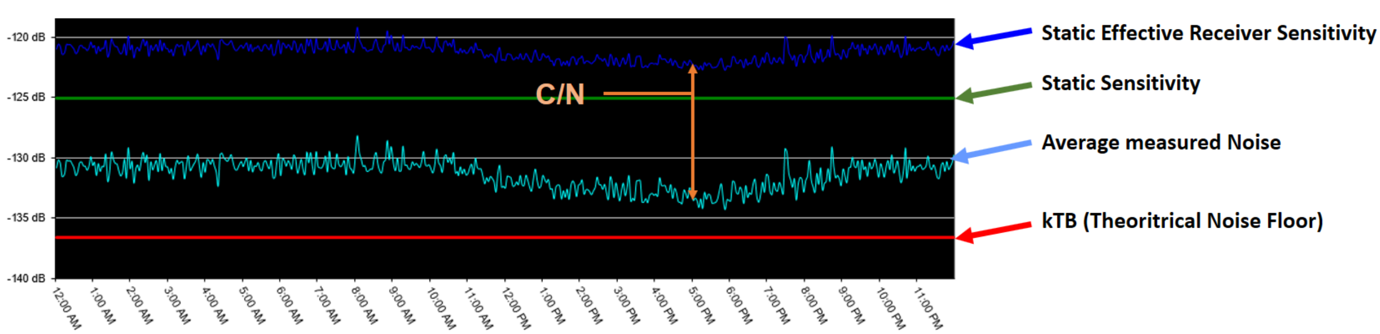

Figure 2: Effective Receiver Sensitivity components

Sensitivity Measurement Techniques

Sensitivity is a measurement to describe what level of on-frequency signal is required to properly demodulate intelligence. In Land Mobile (LMR) operation one radio transmits a modulated carrier and another receives this carrier. To properly demodulate or extract the information contained in the modulated carrier the signal power level must be a certain level above the noise. The relationship between the carrier and noise is called carrier to noise ratio (C/N). There are many factors that affect this relationship.

Remember, it's important to include the measurement technique as part of any sensitivity measurement documentation. Without that reference, the actual measurement numbers have no practical meaning. Here are three accepted measurement techniques:

- **Twenty dB quieting or 20 dBq** – This test was used on analog FM radios in the past. Using an AC voltmeter across the receiver's loudspeaker voice coil, audio output is set to a high reference value. One then applies an unmodulated RF carrier at the receiver input at a level that produces full quieting, or the point where the noise is no longer detectable. The applied RF signal is then slowly decreased in level while measuring the residual noise present on the demodulated audio signal. When the residual noise decreases 20 dB below that measured at the reference point without signal, the applied signal level is the measured 20 dB quieting sensitivity. This is a very basic test, it does not test the ability to demodulate information or audio. This test was popular until test equipment technology improved and is rarely used today.
- **SINAD** – SINAD is an audio quality measurement for analog radios that evaluates Signal + Noise + Distortion divided by Noise + Distortion ***Figure 3*** and it is expressed in dB.

$$\text{SINAD} = \frac{P_{\text{signal}} + P_{\text{noise}} + P_{\text{distortion}}}{P_{\text{noise}} + P_{\text{distortion}}}$$

Figure 3: The formula for calculating SINAD

SINAD requires an audio test set that can filter out the 1 kHz tone used for modulation at 60% of full deviation. It evaluates not only the actual sensitivity (C/N) of the receiver but also the ability to properly extract the 1 kHz tone contained in the modulation with minimal distortion. The audio test set filters the 1 kHz tone and compares the signal before filtering with the recovered signal after filtering. When the applied signal level produces a 12 dB SINAD point, that is the measured sensitivity of the receiver. The ability to measure SINAD is included in modern service monitors and RF test sets.

- **Bit Error Rate (BER)** – BER testing is used for digital radios. The carrier is modulated with a standard digital test pattern and the recovered signal is compared with the standard. The resulting BER is then used to determine the quality of the recovered signal. The BER is measured as a Percentage where 0% BER would be perfect recovery of the injected test signal. In most cases the recovered signal and receiver sensitivity is evaluated at 5 % BER. To lower the BER requires more signal to noise or a higher carrier level. In some cases, the BER may be referenced to 3% BER or even 1% BER. It is critical that the target BER value be included with the measured data to ensure the information is used and understood correctly. Most digital receivers feature a test computer interface that allows determination of received BER. Essentially the test equipment is built in to the digital receiver. A test signal with a proper bit pattern is applied and the signal level is reduced until the prescribed BER point is reached. The applied signal level defines the receiver's sensitivity. Most high-quality digital receivers have internal error detection and correction to improve the demodulation of the digital carrier. This allows the receiver to extract useful data when the actual quality of the RF carrier is poor. This is called Forward Error Correction (FEC).

Sensitivity Measurement Methodologies

Validating operational performance – This is accomplished by injecting and adjusting the applied signal level until the test is satisfied. This is the best sensitivity measurement and provides information that may be used for coverage testing as well as interference mitigation. This test identifies the actual sensitivity of the receive system.

Injecting a specific level and determining if the test is satisfied - This is more of a pass/fail test and does not establish exactly what the receive sensitivity is. This test provides a quality indicator of sensitivity only and is used to verify the equipment can meet a specific target goal. It should never be used for interference or coverage testing.

Test Port

A test port is an isolated injection port used to inject a test signal without disturbing a receive network. A test port is critical if receive system testing is to be done non-intrusive to operation. Without a test port the system must be taken out of operation while testing is performed but with a test port the receive system can be tested while the system is operating normally. Additionally, a test port allows the system to be tested while connected to the antenna and have all external signals present including interference. Using the test port is the best method to validate the presence and strength of interference. Newer dbSpectra receive systems include test ports. A test port provides a specified isolation (normally 30 dB) between the test port and the receive network. This isolation must be taken into consideration when evaluating the test port sensitivity. There are two types of test ports available: *Directional Coupler* and *Capacitive Coupler*.

- The **directional coupler** is the best type of test port because it provides directivity into the receive network which increases the isolation to the antenna. This is important to prevent high-level signals from damaging test equipment. Additionally, the directional coupler provides proper termination to the test equipment for accurate measurements.
- The **capacitive or inductive coupler** (also called an Iso-Tee) is simply an air gap connection that isolates the test port. This connection is normally high impedance, unless additional circuitry is included, and provides no directivity between the ports which provides the least accuracy for measurement.

Test ports are provided in quality tower top amplifier systems and VHF or UHF receive multicoupler systems. Repeatable measurements are difficult or impossible without test ports. All dbSpectra receive systems include test ports as standard equipment or as recommended options. ***(Figure 4)***

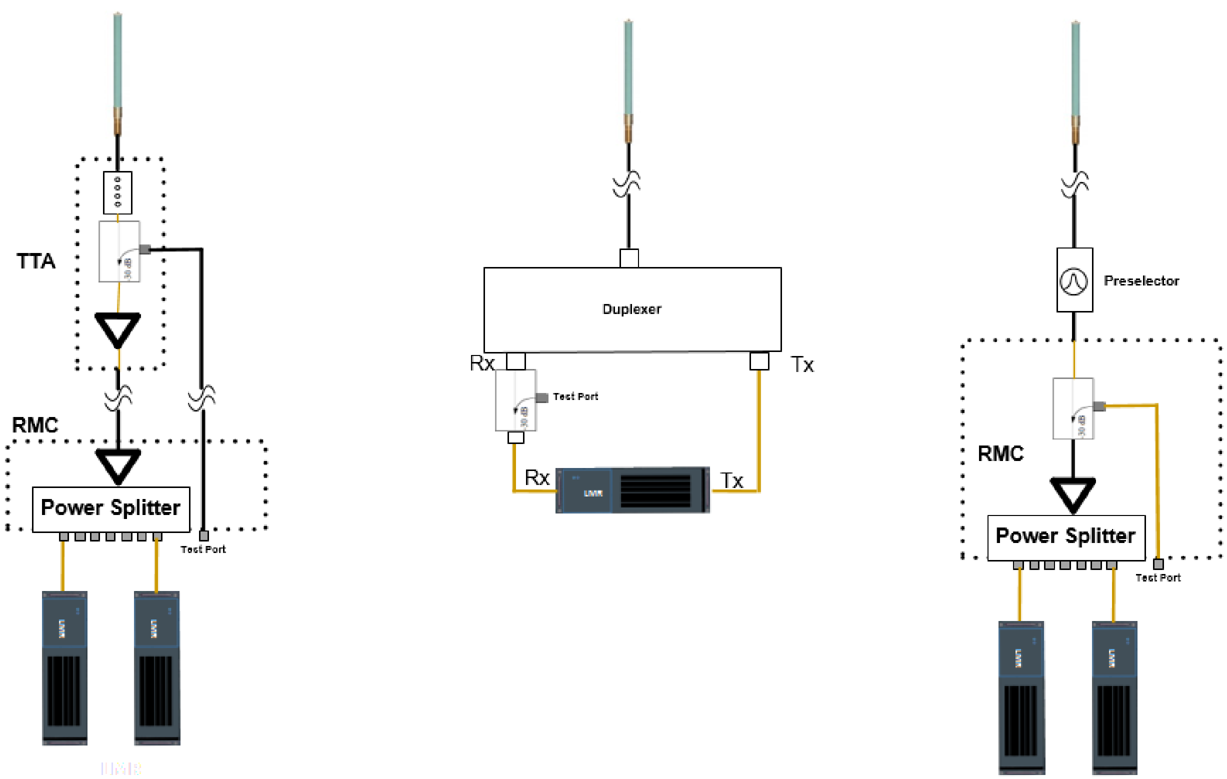

***Figure 4*: Test Port Configurations**

Sensitivity collection points

Not only is the measurement technique important but also where it is measured within the system. There are many reference points that are important to understand operation.

- **Static Sensitivity *(Figure 5)*** – Static sensitivity is the basic sensitivity to which other measurements are compared. It is used to evaluate the basic sensitivity of a receiver. This is normally the sensitivity used to compare the operation to the manufacturer specified sensitivity. This sensitivity is called *Static* because it uses the signal generator connected directly to the receiver to make the measurement.

***Figure 5*: Static Sensitivity Testing of a receiver**

- **Test Port Sensitivity (With 50 Ohm load) *(Figure 6)*** – To measure sensitivity under actual operation requires a reference. This is taken with a sampling or test port. The test port allows non-intrusive testing without disturbing the system operation. The first step is to measure the signal level required for the testing methodology (SINAD^{Analog} or 5% BER^{Digital}) into the test port while connecting the output to a 50-Ohm load. Some TTA systems allow the 50-Ohm load to be switched in and out for testing. The 50-Ohm load provides the reference and is equivalent to the Static Sensitivity adjusted by the coupling loss (Normally 30 dB). After establishing the reference test port sensitivity, it can be documented and used in the future without disturbing the system. Remember that the system is off the air when the 50-Ohm load is switched in. Always measure the static sensitivity in front of the first amplifier or on the antenna side of the receive system.

Test Port Sensitivity (With Load) = Static Sensitivity + 30 dB

Figure 6: Test Port Sensitivity with a load

Test Port Sensitivity (With Antenna) ***(Figure 7)*** – The final test is the sensitivity into the Test Port with the antenna connected. This test allows site environmental noise, interference, transmitter carriers and other interfering signals into the receive network. This sensitivity is the Effective Receiver Sensitivity (ERS). ERS represents actual operational conditions, therefore it emulates normal operation as seen by the subscriber. The difference between this test and the 50-ohm load test is the degradation the system is encountering. ERS should ideally be performed for every channel both with all the transmitters active and with all the transmitters inactive.

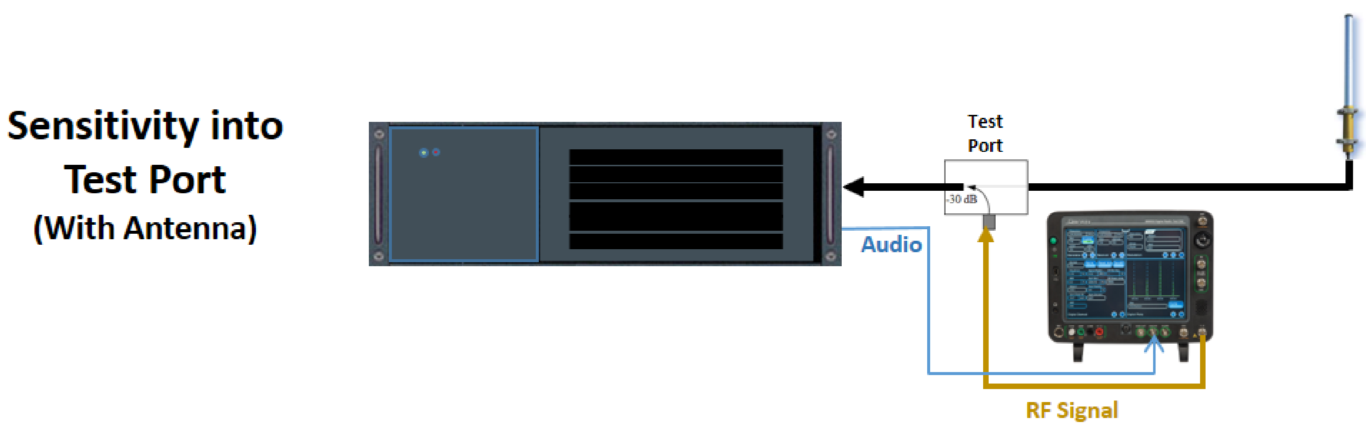

Figure 7: Test Port Sensitivity with an antenna

Degradation

Understanding the effects of external interference is critical in understanding the actual delivered sensitivity of a receiver as it relates to coverage. When the static system sensitivity and the ERS is properly measured, the difference between these two tests is called **Degradation**. Degradation is very important because it reveals the magnitude of interference and its effects on coverage. It should never be assumed that a receiver connected to an antenna will operate as prescribed in the specifications or tested on the bench.

- **Internal vs. External sensitivity measurement** - The measurement of **Internal** and **External** sensitivity relies on measuring at the correct location. A common field measurement mistake is to attempt to measure sensitivity after an amplifier, such as a tower top amplifier, receive multicoupler, or an amplified receive distribution network. Doing so will provide data that is unusable in understanding operation.

There are three different locations, depending on the hardware used, where measurements may be made successfully:

Tower Top Amplifier (TTA) application – At higher frequencies, Tower Top Amplifiers (TTA) are used to overcome the cable loss between the receive antenna and the receive distribution equipment. Most quality TTA systems have test ports included that require a separate small cable (normally ½ inch) in addition to the main receive cable. The test port is included in the TTA and allows the injection of a test signal into the input to the TTA. ***Figure 8*** shows the locations in a TTA system that sensitivity can be made and points that should be avoided. Never take sensitivity measurements after an amplifier. Most TTA systems also provide circuitry to switch the 50-Ohm load in and out from within the site. This allows validation of hardware and determine if any degradation is internal (within the hardware) or external (caused by external interference).

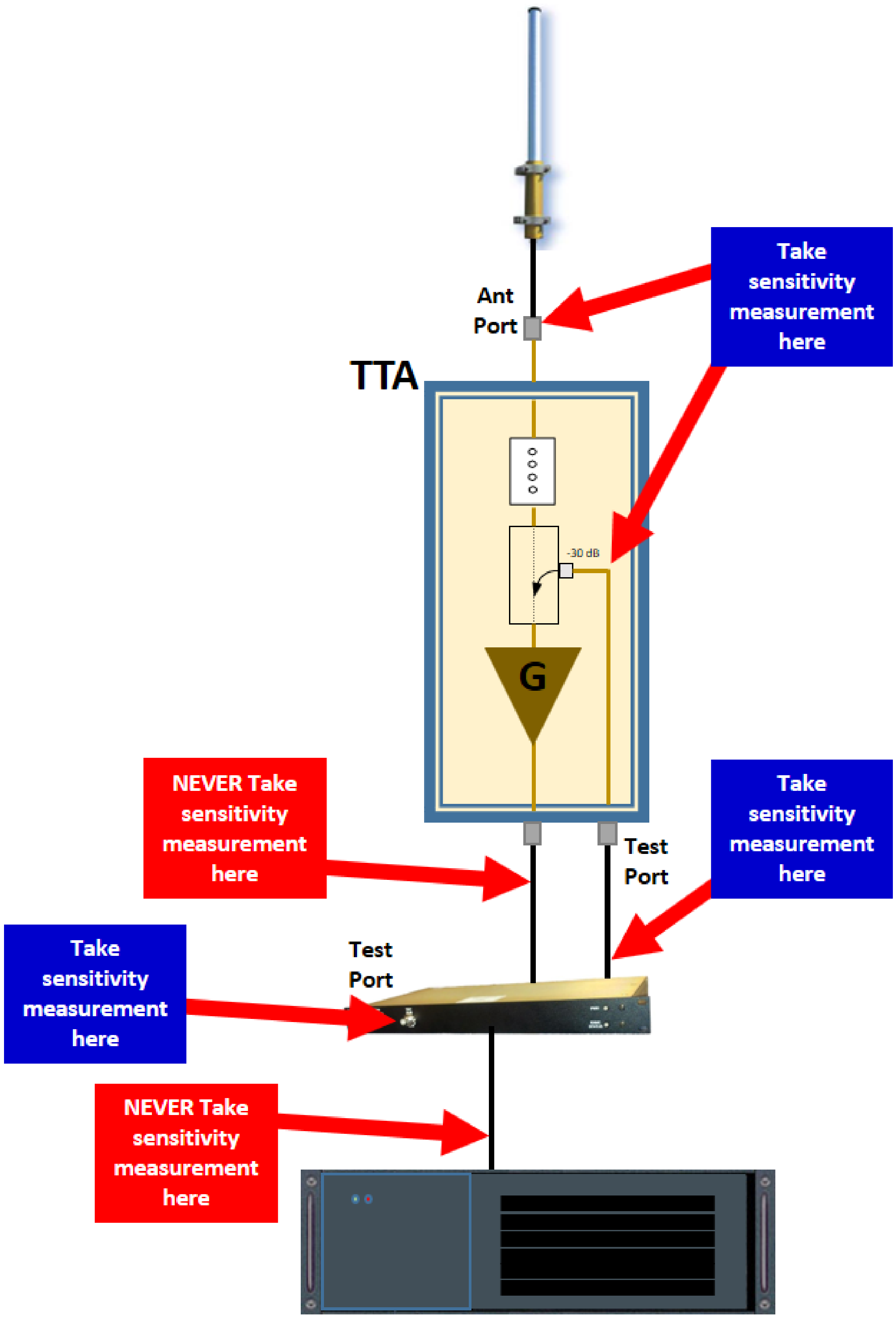

Figure 8: TTA Test Port Sensitivity

Receive Multicoupler (RMC) – At lower frequencies, such as VHF and UHF, the need for TTA components are unnecessary because the receive cable loss is very low. An RMC is used to overcome the distribution loss and the noise figure of the receiver. In these systems, a test port is made available internal to the receiver multicoupler that allows injection into the antenna network. This technique is acceptable because there are no amplifiers between the receive antenna and the test port. This test port is normally internal to the RMC and should always be used for operational sensitivity measurements. All losses between the measurement and the antenna decreases the actual receive system sensitivity. *Figure 9* shows the locations that sensitivity can be made and points that should be avoided.

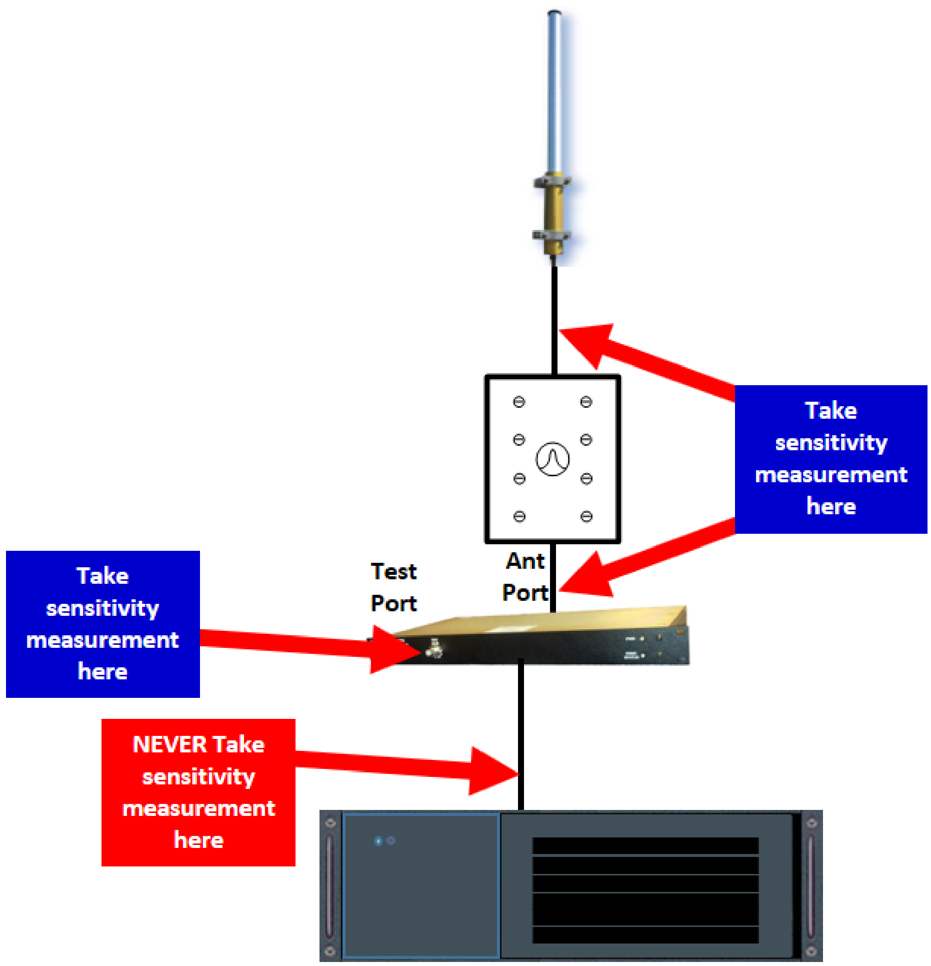

***Figure 9*: Receive Multicoupler sensitivity testing**

Duplexer application – An external test port is recommended for standalone stations such as duplexed repeaters and single receivers on a single antenna *(Figure 10)*. This testing arrangement is important to fully understand the receive capability when the transmitter is active.

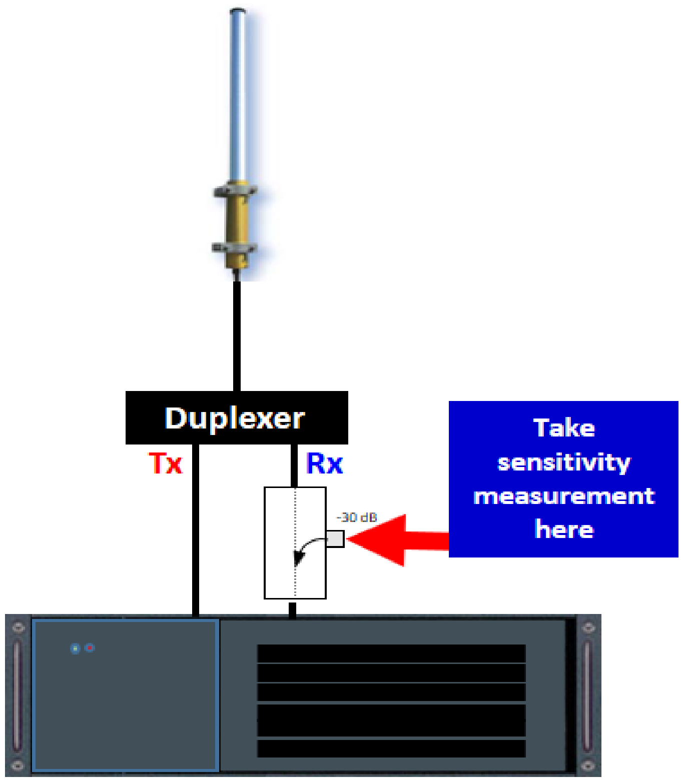

Figure 10: Receive Duplex sensitivity testing

Documentation of Sensitivity Measurements

Detailed results are the only meaningful results, and critical information should be documented so that it presents a clear picture of sensitivity. When sensitivity measurements are made, it is critical to document the type of test (SINAD, or DAQ), the location of the test (TTA test port or RMC test port), in front or behind the receive filter, and the measurement configuration used. It is also critical to document whether the antenna is connected or a 50-Ohm load is being used. The data collected is incomplete without this information. The system sensitivity should be taken with and without the transmitter active to emulate normal operation and understand any degradation that may be internally generated.

Only by accurately collecting and documenting this information can one determine a system's operational quality. Today's documentation becomes tomorrow's benchmark, allowing the operator to detect changes in performance over time and equipping them to determine if changes are due to internal or external issues, so such issues can be quickly and affordably remedied.

Documented data should include:

Static Sensitivity – Sensitivity taken directly into the receiver. This should match the receiver specification

Static System Sensitivity – Sensitivity taken directly into the Receive System including all splitters, amplifiers, and filters. This test will normally be taken between the receive antenna and the first amplifier.

Degradation - The difference between the Test Port sensitivity into a 50-Ohm load and directly into the antenna. Should be taken with and without the transmitters active.

Effective Receiver Sensitivity (ERS) – Sensitivity as seen by the subscriber. It includes the Static System Sensitivity degraded by the degradation. This is the actual sensitivity that determines coverage.

Taking the Mystery out of Sensitivity

Sensitivity is not a singular measurement, and as we've seen, it's not even really a fixed quantity. It's a snapshot into the efficiency of a receive system, at a certain place and under certain circumstances. To arrive at a meaningful understanding of sensitivity, it takes a variety of methods and techniques, each performed in a specific way, to create insightful visibility into a network's operation.

dbSpectra builds this understanding into our solutions because we understand that sensitivity is not just a specification printed on the box, but an ongoing process of measurement, evaluation, adjustment, and refinement. That's just one way we help our customers get the most from their RF networks and the reason they see us as *always, a better value.*

Release History

Release 1.0 – March, 2017

Release 2.0- September, 2019

Notes