DETERMINING ANTENNA PERFORMANCE VIA COMPARATIVE METHOD

Frank Cruz
Air Force Test Center
Edwards AFB, CA, 93524

Mark Radke
Bevilacqua Research Corporation (BRC)

ABSTRACT

Recent advanced digital phased array antennas use sophisticated signal processing techniques that deviate from classical spatial beamforming. Currently, a method does not exist to obtain direct far-field G/T measurements of active large aperture phased array antennas lacking the ability to spatially beam point. Due to this constraint, solar calibrations cannot be performed to achieve a value for G/T. Also, availability of anechoic chambers of adequate size for far-field measurements of large apertures are scarce, forcing an outdoor range configuration as a requirement for testing. Therefore, a comparative method using transmitted power differences with respect to bit error rate (BER) has been developed. Using the known G/T of a reference antenna will allow the determination of G/T for a large aperture active antenna without the need for a well characterized signal source. This paper will outline the methodology used to establish G/T of an active array antenna using measurement and analysis.

INTRODUCTION

The Spectrum Efficient Technology (SET) group is a Test Technology Area (TTA) under the Test Resource Management Center (TRMC), Test and Evaluation Science and Technology (T&E/S&T) portfolio. TRMC has funded the development of phased array antennas for the T&E community for many years. Testing for these antennas has been conducted by the Spectrum Efficient Technology (SET) office throughout the lifecycle(s) of various projects.

As arrays have increased in size, far-field anechoic chamber testing of full-sized systems has become more challenging. Also, some of the algorithms used in these arrays do not allow them to be pointed in a traditional sense, causing the inability of direct solar calibration measurements [1] to estimate G/T. Due to the advanced nature of these antennas a new method to measure G/T needed to be developed. Development of this new method leverages well established techniques for measuring G/T and antenna sensitivity. The combination of these techniques is used in this new method using comparisons to estimate G/T and are not limited to only non-steerable array but can be applied to any receive system.

To describe the G/T comparison method created, this paper will outline the following topics: Established Measurement Methods; Comparative Methodology; Test Architecture; and Results. The Established Measurement Methods will introduce the currently used and well-established methods for G/T and receiver sensitivity measurements defining the basis of the reference antenna used in the comparative method. The Comparative Methodology section will explain how the established methods are combined and a mathematical proof is provided to show the various relationships of the test setup. Test Architecture will generally explain how the comparative method is applied during testing. The Results section will provide a real-world example from the derived comparative method. Ultimately, this paper will provide the reader with a proven comparative method for obtaining G/T of an active antenna while allowing flexibility to meet the users needs.

ESTABLISHED MEASUREMENT METHODS

There are accepted methods of measuring G/T of an antenna system and sensitivity of a telemetry receive system. Using these methods to measure G/T and BER, a technique for the type of antenna system and constraints outlined in the introduction was created. This section will give a general overview of both measurement methods needed for the follow-on comparative method presented.

A crucial piece of this comparative method is a reference antenna G/T definition. There are several established methods to achieve a measurement of G/T. A well-defined and commonly used solar calibration method [1] using hot/cold sky pointing and solar flux to derive G/T, shown in figure 1. A passive antenna with noise figure method can be used to find a value for antenna system temperature with a known gain [2]. Multiple far-field anechoic chamber techniques exist and require calibrated equipment throughout the test setups. Two examples are given in [3,4]. Lastly antenna G/T measurements can be obtained through chamber measurements using a near-field scanner [5,6].

The second essential measurement for the comparative method is testing receiver sensitivity. In Figure 2, a block diagram of a telemetry sensitivity test, or BER test, is shown. A signal source with a carrier/operating frequency, modulation (PCM/FM, SOQPSK, or CPM), data rate, and Pseudo Random Bit Stream (PRBS) sequence type is configured at the source. A variable attenuator is placed in series with the source transmitter and source antenna, enabling source signal power to be adjusted to a given output power level. A telemetry receiver(s) with configuration(s) matching the source signal characteristics will receive the signal and demodulate the data to be sent to a BER analyzer. The bit stream is then compared to the selected

PBRS and a BER value of the received stream is measured. By utilizing the variable attenuator in series with the telemetry source, power levels can be changed to achieve a target BER for use in a comparison.

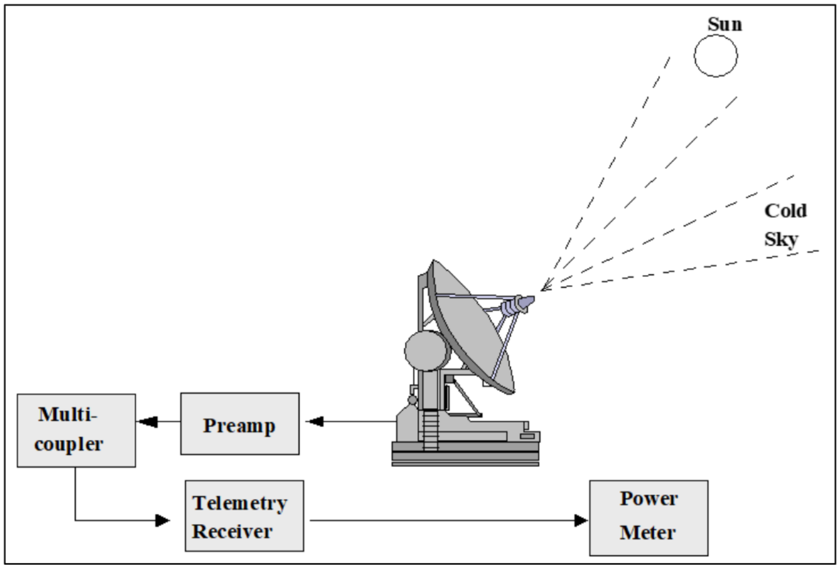

Figure 1 – Dish antenna G/T measurement

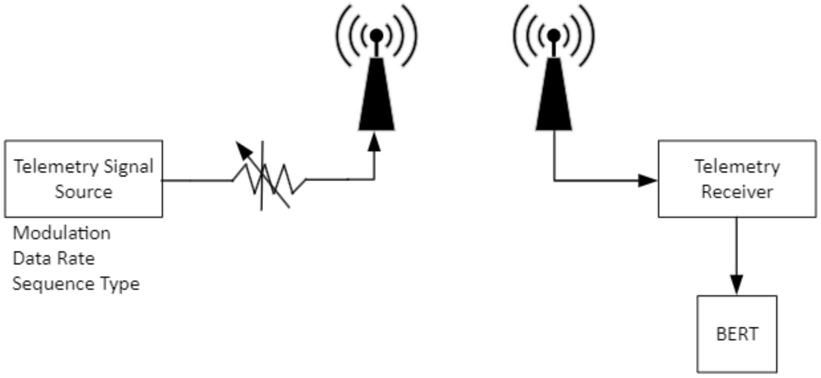

Figure 2 – BER Test Setup

COMPARATIVE METHODOLOGY

The method developed of measuring G/T of an active array, or system under test (SUT), combines the measurement methods in the previous section into a single comparative test methodology. A characterized reference antenna will serve as a reference for G/T of the overall test configuration. Sensitivity tests are used to establish an independent BER point for each antenna system. The difference in the transmitted power allows for a computation of G/T for a SUT.

The comparison method uses a signal source with well characterized G/T receive reference system using the sensitivity method shown in figure 2 for each receive antenna system. The receive antennas, the reference system and the SUT, are then compared. The data collected will produce two independent BER detection values, one for the reference antenna system and the other for the SUT. The output of the detection values displays the transmitted power P_t along the x-axis and BER along the y-axis (shown in figure 5). A value of P_t at an equal BER detection value will serve as the reference point for each detection value gathered, allowing for an evaluation of the difference between the reference and SUT antenna systems. Figure 3 shows one source with two receive antenna systems. With only one source present, the SUT and reference antenna are placed at a similar distance and angle from the source thus minimizing any physical location artifacts that may be present otherwise. A single source with co-located receive antennas will drive the comparative method to obtain a G/T for an active array. NOTE: BER detection values do not need to be gathered simultaneously. Figure 3 is the recommended setup. If the environment has changed significantly between the two measurements, this may affect the accuracy of the G/T calculations.

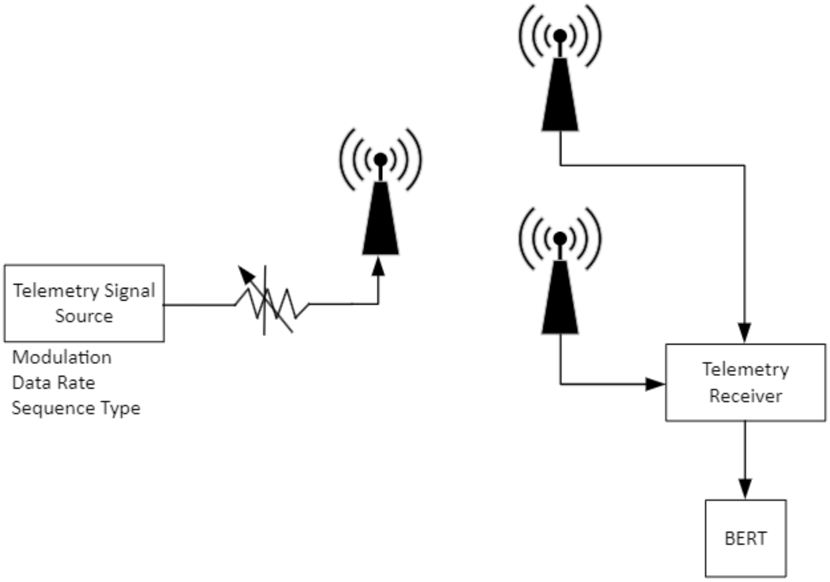

Figure 3 – SUT Sensitivity Test Architecture

Output power adjustment from the transmitter is key to gathering a value for BER. A good quality step attenuator or signal generator is required. It is imperative that the difference in the power levels between the reference and SUT measurements are accurate. The actual effective isotropic radiated power (EIRP) of the source is not. This power adjustment serves as a dial to achieve a BER of choice and also results in a value for transmitted power P_t from the source. In this case the term P_t is not EIRP, but transmitter port output power. Transmitter front end losses, source antenna gain, accurate distance measurement from source-to-receive systems, and free space path loss (FSPL) are of no consequence when using this method. This is due to the use of a mutual source and the colocation of SUT and reference antennas (terms cancel in the mathematical derivation). A relative measurement is produced thus canceling the need for a well characterized source system. Adjustment of the output power is required to attain a specific BER (modulation dependent and values are typically found in the manufacturer specifications) detection value thus creating a transmitted power reference point.

Once a receiver sensitivity reference point is established at P_t vs. BER, the same process of tuning P_t can be used to find the BER value of a SUT. Once a value for the antenna array is gathered the difference in the two transmitted powers P_{t1} (SUT) and P_{t2} (reference antenna), with respect to the BER detection value, are calculated resulting in G/T of the active array. For clarity, the next paragraph will give a mathematical representation of this methodology. Also, the results section presents a visual example of this technique.

To validate this method, the Friis Transmission Formula Eq.1 [7] is combined for each receive antenna system. For a system in free space with no antenna polarization loss factor,

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r \qquad \text{(Eq.1)}$$

Since G_t is equal for both receive antennas and co-located, the Friis Transmission Formula [7] can be combined for each antenna system:

$$G_t = \frac{P_r(4\pi R)^2}{G_r P_t \lambda^2} \quad \rightarrow \quad \frac{P_{r2}(4\pi R)^2}{G_{r2} P_{t2} \lambda^2} = \frac{P_{r1}(4\pi R)^2}{G_{r1} P_{t1} \lambda^2}$$

Where,

$P_{ri} = Power\ received$

$P_{ti} = Power\ transmitted$

$G_{ti} = Gain\ transmitter$

$G_{ri} = Gain\ receiver$

$\left(\frac{\lambda}{4\pi R}\right)^2 = Free\ space\ path\ loss\ (FSPL)$, where R = Range and λ = wavelength

Subscripts of i *= 1 corresponding to the reference antenna*

Subscripts of i *= 2 corresponding to the SUT antenna*

Terms are then reduced to,

$$\frac{P_{t1}}{P_{t2}} P_{r2} = \frac{G_{r2}}{G_{r1}} P_{r1}$$

The received power P_{r1} and P_{r2} at the input of the receiver demodulator can be written as:

$P_{ri} = carrier\ power = \left(\frac{E_b}{N_o}\right) kTR_b$, where $E_b = \frac{C}{R_b}$ $and\ N_0 = kT,\ N = kTB$

Rearranging and substituting for P_{r1} and P_{r2} yields:

$$\frac{P_{t1}}{P_{t2}}\left(\frac{E_b}{N_o}\right)_2 kT_2R_b = \frac{G_{r2}}{G_{r1}}\left(\frac{E_b}{N_o}\right)_1 kT_1R_b$$

Simplifying:

$$P_{t1}\left(\frac{E_b}{N_o}\right)_2\left(\frac{G_{r1}}{T_1}\right) = P_{t2}\left(\frac{E_b}{N_o}\right)_1\left(\frac{G_{r2}}{T_2}\right)$$

In logarithmic scale:

$$P_{t1}(dBm) + \left(\frac{E_b}{N_o}\right)_2(dB) + \left(\frac{G_{r1}}{T_1}\right)(dB/K) = P_{t2}(dBm) + \left(\frac{E_b}{N_o}\right)_1(dB) + \left(\frac{G_{r2}}{T_2}\right)(dB/K)$$

General equation for SUT G/T:

$$\left(\frac{G_{r2}}{T_2}\right)(dB/K) = \left(\frac{E_b}{N_o}\right)_2(dB) - \left(\frac{E_b}{N_o}\right)_1(dB) + P_{t1}(dBm) - P_{t2}(dBm) + \left(\frac{G_{r1}}{T_1}\right)(dB/K) \quad \text{(Eq.2)}$$

Where,

$\left(\frac{E_b}{N_o}\right)_i = Energy\ per\ bit\ noise\ needed\ to\ obtain\ BER\ detection\ value$

$P_{t1} = BER\ target\ point\ of\ the\ reference\ antenna,\ 1e - 5\ typically\ used$

$P_{t2} = BER\ target\ point\ of\ the\ SUT\ antenna,\ 1e - 5\ typically\ used$

$G_{T1} = G/T\ of\ the\ reference\ antenna$

$G_{T2} = G/T\ of\ the\ SUT\ antenna$

This can be seen in Eq.2 when $\left(\frac{E_b}{N_o}\right)$ are equal and terms cancel. For this reason, is why an equal detection value for BER (typically 1e-5) is chosen for SUT and reference antenna.

TEST ARCHITECTURE

An example of test setup is provided below. This is a general case and is meant to provide a basic application to then perform testing as one chooses.

A test architecture below is typical of sensitivity testing conducted on an outdoor range. The setup of the test is as follows:

1. Establish a source with antenna. The carrier frequency, PBRS, data rate, and modulation are user dependent. Remember, the source system does not need to be well characterized.

2. A consideration of SUT aperture size needs to be taken into account for far-field measurements. The minimum far-field distance needed is $R > D^2/$, where D is equal to the largest antenna aperture diameter and λ equal to wavelength [7], the range R requires enough distance from source to SUT.
3. With an established G/T for the reference, setup the reference antenna in a sensitivity test condition.
4. Place the SUT within a reasonable distance to the reference antenna and place the SUT in a sensitivity test condition. Collocation is critical to minimize differences in the channel conditions seen by each antenna.
5. A single telemetry receiver can be used by conducting independent measurements. Or two telemetry receivers of the same type can be used for ease. Simultaneous measurements can mitigate environmental impacts degrading accuracy of the measurements, i.e., RF and temperature.

To run a test point, the test must be configured in a BER test condition. With the source emitting a signal, adjust the source power until a target BER value (1e-5 typical and to obtain accurate measurements) is achieved for the reference antenna. The data point is collected and the same process of dialing output power for the SUT will be conducted.

Figure 3 in the COMPARATIVE METHODOLOGY section gives a visual representation of the general test setup.

RESULTS

Testing was performed on an outdoor range and used the method described throughout the body of work above. The SUT consisted of a large non-steerable, digital front end, receive only phased array antenna. A well characterized G/T standard gain horn (SGH) system is typically used as the reference antenna during testing. Simultaneous measurements were done to mitigate natural environmental differences over time, RF environment impairments, and enable the use of time correlated comparisons. NOTE: Reference antenna aperture size does not matter. Only the characterized value for G/T of the reference.

An output data example is given below in figure 5, driving the calculation to derive SUT G/T. The reference antenna will typically present a consistent BER curve (modulation and data rate dependent) and if there were any difference in the reference antenna curve the SUT curve would also display the difference. A common cause of reference antenna difference is attributed to time of day. When testing in the morning, for example, the environment is cooler as opposed to the middle of the day. The equipment can increase in temperature and differences will be observed in the reference. Simply put, the reference antenna is just that. It creates a base from where to measure no matter the environment the test is conducted in.

Example:

For this example, a BER detection value of 1e-5 was used for evaluation. This detection point of 1e-5 is used for two reasons. The first, as a result of the outdoor nature of testing conducted, any impairments that occur will have less of an impact when compared to testing done at a BER detection of 1e-6 (error free). Second, using the known (E_b/N_0) needed to achieve a BER detection point of 1e-5 allows P_t tuning for each system to create the difference in P_t allowing for a SUT G/T computation.

The co-located receive antennas were positioned adjacent to one another with roughly 10 feet of separation creating an invisible plane with the front of both apertures. The invisible plane created is placed in a position perpendicular to the source. This configuration allows for the test setup to utilize a like EIRP and FPSL negating the need for a well characterized source and accurate FSPL measurement. This establishes the transmit plane of the test setup. As for the receive plane of the test setup, SUT cable loss and noise will contribute a small error associated with the final calculation using Eq.2. The cable from SUT to telemetry receiver will have a cable with similar loss to that of the reference antenna to mitigate any differences. The G/T of the reference antenna is measured as a full system from antenna to receiver taking into account all gain (LNA near the antenna port), losses, and temperatures associated with the full system. The G/T of the reference antenna system uses a total system noise figure measurement to derive the system's electronic noise and a bounded approximation of sky temperature to derive G/T of the system.

For the purposes of the plot in figure 5, each tick mark on the plot is equal to 2. Transmitted power level is decreasing to the left. A transmitted power of -10dBm and -23dBm at a BER of 1e-5 are used for the reference and SUT antennas respectively. A G/T of -3dB/K is used as the reference antenna G/T. To find G/T of the SUT, first locate the reference antenna transmitted power level vs. 1e-5 BER tick mark. Count the amount of transmitted power level tick marks to the SUT 1e-5 BER mark. In this case roughly 13 ticks. Add the difference number of ticks to the G/T result of the reference antenna, in this case -3dB/K. The resultant G/T of the SUT is 10dB/K.

Note: For well-known system behaviors, if the BER curves below are inverted, this can indicate an error (in setup or SUT) if SUT aperture size is larger than the defined reference.

From Eq.2,

$$\left(\frac{G_{r2}}{T_2}\right)(dB/K) = \left(\frac{E_b}{N_o}\right)_2(dB) - \left(\frac{E_b}{N_o}\right)_1(dB) + P_{t1}(dBm) - P_{t2}(dBm) + \left(\frac{G_{r1}}{T_1}\right)(dB/K) \quad \text{(Eq.2)}$$

$$\left(\frac{G_{r2}}{T_2}\right)(dB/K) = 11.2 - 11.2 + (-10 + 23) - 3 = 10dB/K$$

13(dB) - 3(dB/K) = 10dB/K, SUT G/T

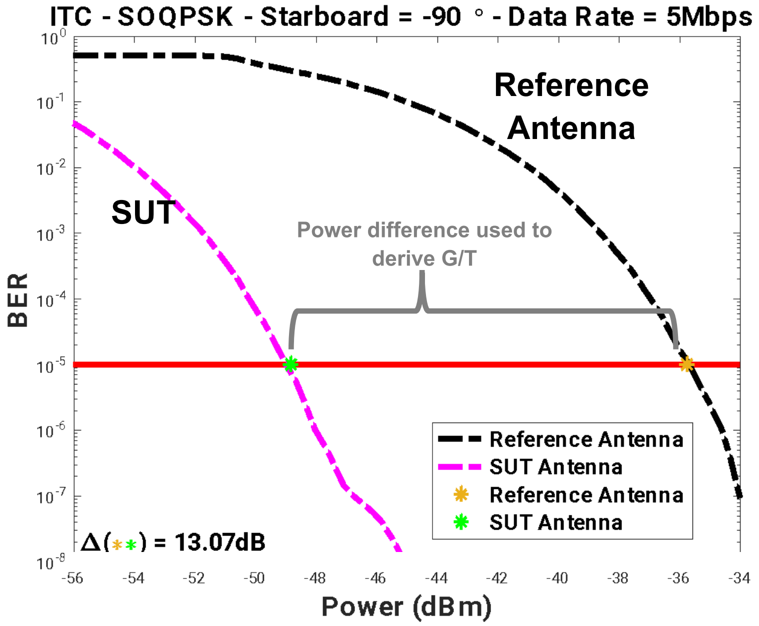

Figure 5 – Reference Antenna to SUT BER curves

As a sanity check, G/T estimation numbers are typically produced by the vendor building an active antenna array. When comparing the results using the difference method for G/T to vendor analytical estimations, the average of results is typically within reason.

CONCLUSIONS

Direct measurement of G/T for a large aperture active antenna is sometimes impractical or not possible. As a result, a method needed to be developed using test equipment that is readily available. The choice was made to use single source with a well-defined G/T as a reference antenna to then use as a reference for G/T measurement. This paper does not take into account multipath and other sources of interference. Future work may include impairment analysis opening the door for follow on studies.

Throughout the past few years of using this method of testing, it has proven to provide reliable measurements not only in a controlled environment, but also in an operational environment. The method outlined has provided an estimated G/T performance metric that correlated well to real world performance during operation usage.

REFERENCES

[1] Telemetry Standards, Inter-Range Instrumentation Group of the Range Commanders' Conference Std. IRIG 118-22, 2022 Volume 2 Release 2

[2] Telemetry Standards, Inter-Range Instrumentation Group of the Range Commanders' Conference Std. IRIG 120-21, 2021

[3] V. Rodriguez, C. Osborne, "A Reduced Uncertainty Method for Gain over Temperature Measurements in an Anechoic Chamber", Antenna Measurement Techniques Association, 2015

[4] R. Wansch, "A Method for Measuring G/T Antenna Performance in an Anechoic Chamber", Fraunhofer Institute for Integrated Circuits, Erlangen, Germany

[5] A.C. Newell, P. Pelland, S.F. Gregson, D. Janse Van Rensburg, "Measurement of Antenna System Noise Temperature Using Planer Near-Field Data", Antenna Measurement Techniques Association, 2017

[6] Ryan T. Cutshall, Brett T. Walkenhorst, Justin Dobbins, Jacob Freking, Bruce Williams, "A Review of the CW-Ambient Technique for Measuring G/T in a Planer Near-Field Antenna Range", Antenna Measurement Techniques Association, 2019

[7] Balanis, Constantine A., *Antenna Theory Analysis and Design*, 4th ed., Wiley Publishing, ISBN-13: 9781118642061, pages 31-33, 88-90, 136-137