"Army SATCOM OTM Full Elevation Performance Characterization"

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ABSTRACT

The Army has a well established requirement for satellite communications (SATCOM) on-the-move (OTM), in order to support the needed level of real-time, tactically-relevant information on a non-contiguous battlefield. The US Army CERDEC Space and Terrestrial Communications Directorate Joint SATCOM Engineering Center (JSEC) is doing relevant research and development in order to provide the best SATCOM OTM technology for transition to the Warfighter. Part of this is the development of a technical test and characterization capability for SATCOM OTM systems. This SATCOM OTM Lab will utilize both motion simulator based testing and vehicle based testing on APG cross-country courses.

The SATCOM OTM Lab will support a multitude of development and testing capabilities, but will focus on measuring acquisition and tracking performance. This paper will focus on the motion simulator based SATCOM OTM test and characterization approach, to include a way to simulate operation, given a specified motion profile, over a full range of elevation angles. The recent technical achievements in developing this technical capability will be discussed. Initial test data will be presented and technical challenges will be addressed.

Motion Simulator Laboratory Testing

US Army CERDEC will be receiving a three axis motion simulator to be delivered in the October2011 timeframe. The motion simulator was designed with the intent to accommodate a wide array of antenna systems, with a specific concentration on Army ground vehicle mounted antenna systems. The expectation is that the simulator may be able to support other antenna systems, such as Navy ship or airframe mounted antenna systems which may have more demanding size and weight specifications, but less burdensome dynamics requirements than those required for a tracked vehicle in a cross-country environment. The motion simulator will be located at the JSEC Facility at Aberdeen Proving Ground. The JSEC facility has a concrete pad facing south with full east-west clearance. The satellites utilized for outdoor testing will be geostationary, such as Wideband Global SATCOM (WGS)-3. The motion simulator testing will be extended into a laboratory environment using a simulated satellite test setup. The objective of this test is to provide a more controlled environment for more accurate tracking performance characterization. Un-controllable variables such as weather and multi-path are removed to assure more precise power measurement accuracy is attained using a calibrated test set. This laboratory testing will also be designed to test at a range of elevation angles. This is important because tracking performance of a SATCOM antenna system can vary greatly as elevation angle changes and the "keyhole" is approached at zenith. This is an extremely significant technical challenge and represents a potentially unique capability within the Department of Defense.

Test Method

The motion simulator based testing will be accomplished utilizing a motion simulator capable of supporting the range of motion, maximum acceleration, and maximum velocity of the courses we are emulating. The motion simulator also needs to support the maximum weight, size, and power requirements of the antenna systems we need to test. Operation of the motion simulator using a satellite to conduct tracking testing is relatively straightforward. Operation of the motion simulator in a laboratory environment in order to achieve a much finer tracking performance measurement (a tenth of a degree) at multiple elevation angles has a number of technical challenges associated with it. Figure 1 shows the basic concept. An RF Network Analyzer and four test apertures will be used in conjunction with the motion simulator to evaluate tracking performance. A beacon signal will be transmitted from a fifth aperture. The panel of test apertures can be moved in order to evaluate performance at different elevation angles, see Figure 1.

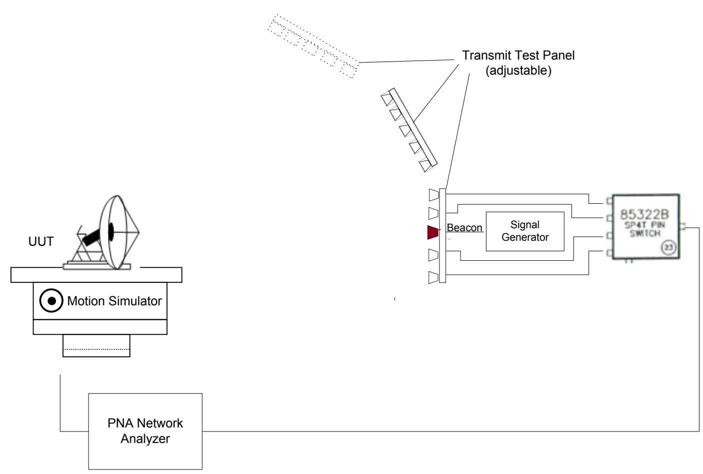


Figure 1. Motion Simulator Laboratory Testing Concept

The four test apertures are arranged in a square diamond pattern with an upper and lower aperture, as well as a left and right aperture; their signals are potentially separated and identified by time using a high speed PIN diode switch. The beacon antenna is in the center of all four test apertures, simulating the target source to be tracked. All apertures are linearly polarized for these tests. The four test apertures are used in H plane mode, see Figure 2.

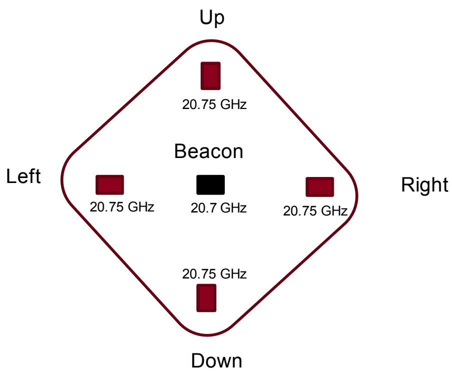
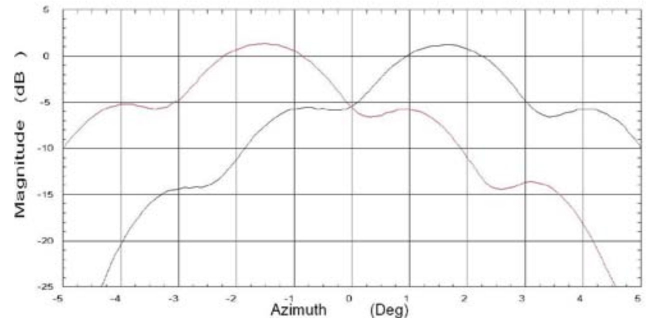
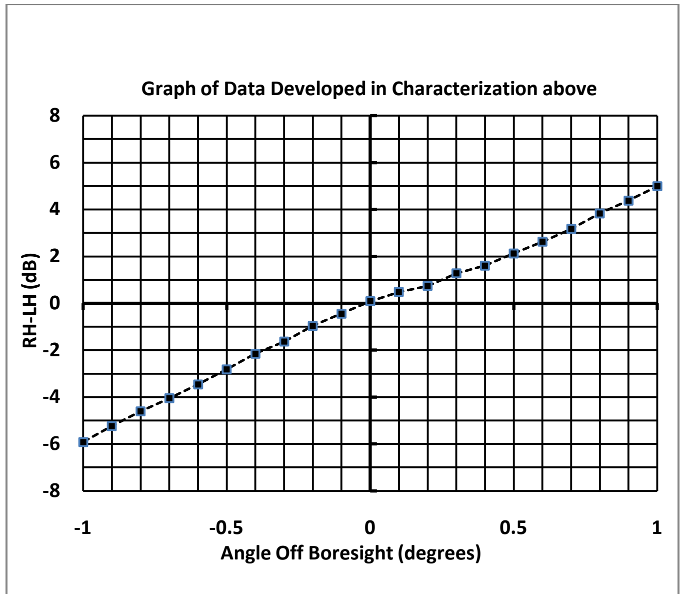


Figure 2. Test Aperture Panel

The beacon aperture will transmit an appropriate signal and the four test apertures will transmit at another frequency to the Unit Under Test (UUT). Initial characterization consists of sweeping through the beam of the UUT with a horizontal and vertical cut versus angle to acquire the data shown as a sample, in one plane, in Figure 3. Characterization alternatives are being evaluated and full two dimensional characterization may be required. After characterization and data processing, power measurements will be taken at the output of the UUT versus time while the motion simulator moves following a predetermined profile in order to evaluate tracking performance. Beam position is resolved into vertical and horizontal components of angle off boresight, (defined as the axis between the UUT and beacon antenna). Vertical signal amplitudes are compared to generate the vertical error component and likewise, horizontal signal components compared produces the horizontal error component. These two orthogonal components can produce the Cartesian coordinates of the beam position at any instant of time; thus, vector beam position is measured, and to within less than 0.1° resolution. The test signal pairs, (up, down) and (left, right) are processed by subtracting one from the other in each pair, to develop an X and Y component of error. These components are used to produce vector pointing position values from the characterizations developed before and after each test. See Figure 3 for a sample azimuth data reduction. For this method to be reliable, the difference data need to produce changes of about 2.5 dB/°, or more, as shown by the sample slope curve shown in Figure 3. The RH and LH antenna labeling in the table refers to left and right hand antennas on the test panel. Note that data can only be used within several beamwidths of the boresight of the UUT. Observe that measurements need to be taken within the main beam of the UUT, (not to include the first sidelobes to avoid ambiguity of beam position measurement).

Figure 3 shows sample measured data from a pair of test apertures to serve as characterization for beam position.





Characterization Data			
Angle (deg)	RH (dB)	LH (dB)	RH-LH (dB)
-1.1	-5.93	0.65	-6.58
-1	-5.52	0.40	-5.92
-0.9	-5.29	-0.05	-5.24
-0.8	-5.01	-0.40	-4.61
-0.7	-5.00	-0.95	-4.05
-0.6	-5.00	-1.54	-3.46
-0.5	-4.98	-2.16	-2.82
-0.4	-5.01	-2.85	-2.15
-0.3	-5.18	-3.55	-1.64
-0.2	-5.26	-4.30	-0.96
-0.1	-5.17	-4.73	-0.44
0	-5.12	-5.21	0.09
0.1	-4.89	-5.38	0.48
0.2	-4.55	-5.29	0.74
0.3	-4.08	-5.35	1.27
0.4	-3.44	-5.05	1.61
0.5	-2.84	-4.96	2.12
0.6	-2.23	-4.85	2.62
0.7	-1.60	-4.78	3.17
0.8	-0.98	-4.81	3.84
0.9	-0.51	-4.89	4.38
1	0.00	-4.99	4.99
1.1	0.28	-5.15	5.43

Figure 3.Typical Characterization Pair

The graph shown indicates a slope of about 6.2 dB/degree and the line does not reverse direction; there is a one to one relationship over the range shown. Thus lookup tables can be generated for both azimuth and elevation, or X and Y, so that vector pointing information can be obtained.

Design Considerations

Because a major focus of this technical characterization and testing is to evaluate performance at high elevation angles, and due to building space considerations; we need to limit the range between the UUT and the test panel. This drives a number of technical considerations:

1. The UUT must be mounted on the motion simulator such that, when testing, it is rotated about the apparent center of radiation in order to avoid an artificial angular change between the beacon and UUT; this would represent an apparent change in beacon/satellite position. This is not significant along the axis between the UUT and beacon; but is important for the up, down, and left, right axes. Mitigation of this relative motion error is essential to prevent errors of several degrees which would be reflected as tracking errors of similar magnitude. Tracking of live satellites is not critical for this as the distortion caused by displacement is insignificant to a distant satellite.

2. Measurements need to be made mostly in the near field of the UUTs because the dimensions of some antennas, primarily at K band and higher frequencies, drive far field distances of more than 150 feet. The test range is required to operate in the 15 ft to 25 ft range between UUT and test panel in order to accommodate the ability to test high elevation angles. As a near worst case, operating at K band, (20.750 GHz.), a unit with a 20" diameter parabolic reflector was tested at a distance of 14' from the source and found to produce very useable results. That represents operation at a range of nearly $0.1(2D^2/\lambda)$, or 1/10th of the far field distance. Any closer than that is not useable as the main beam of a parabolic reflector type UUT is not formed; see Figure 4. A measured pattern is shown at $0.08(2D^2/\lambda)$, the dashed line in figure 4, and it can be seen that the main beam of the UUT has sidelobes at the same level as the main beam, and is unusable for the technique described above. Although the main beam is somewhat broadened and the sidelobes are greatly deteriorated at close range, the response is very useable for this technique at as little as $.1(2D^2/\lambda)$.

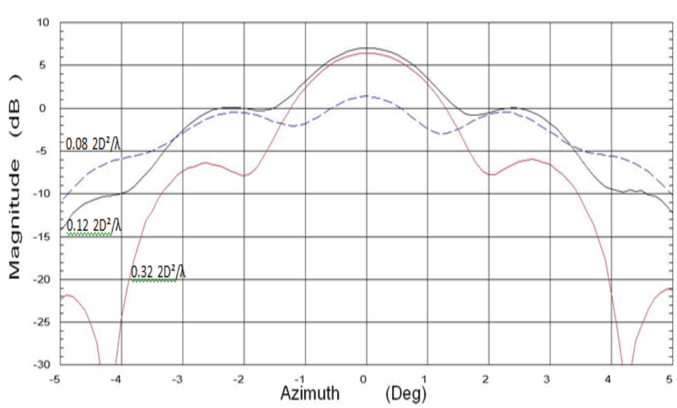


Figure 4 Measured Patterns at Various Fractions of $2D^2/\lambda$. (Main beam is still well formed at 0.12 but not at 0.08 $2D^2/\lambda$)

3. For any UUT frequency, beamwidth, and UUT to test panel distance; there is an optimum spacing between the test panel antennas to produce the most useable data. Spacing should be such that the radiation patterns cross over at the bottom of the first null, just before the first sidelobe, see Figure 3. Optimum spacing allows measurement of system tracking over two to three UUT beamwidths with a resolution of better than 0.1°, see Figure 3. The range of separations at a test distance of about 15' would be about 10" separation at K band for a system with about 2° 3dB beamwidth, to about 42" spacing for an X band system with a 5.2° beamwidth at the same 15' test distance. Some systems to be measured will fall outside the ranges covered here and may require special consideration.

4. Measuring performance at various angles of elevation inside the lab will be accomplished by moving the 5 antenna test panel up relative to the horizon of the motion simulator; it is anticipated that elevation angles up to about 33° will be able to be accomplished using the physical space available inside, based on anticipating moving the test panel through a vertical range of at least 10'. The horizon of the systems mounted on the motion simulator will be 8' above the floor; a maximum height of 18' allows just enough space to the ceiling for reflection control with microwave anechoic absorber. Equivalent operational elevation angles will be further emulated by pre-loading the motion simulator with a negative pitch, to achieve, in sum, a higher elevation angle for the test. Pre-loading the motion simulator may not be desirable for all UUTs. Discussion with the UUT vendor to determine any possible performance degradation due to a motion simulator preload will be taken into consideration prior to testing. Additionally, it may be possible to set up a 5 antenna test panel on the edge of the building roof outside to test high elevation angles with the motion simulator in its outside position; this would also allow some greater range between test panel and UUT than can be accomplished inside.

5. Some SATCOM OTM systems require GPS input for tracking operation. It is anticipated that a GPS emulator will be required to support testing both outside with a live satellite and in the laboratory. The GPS emulated signal will need to be synchronized with the motion profile utilized during a given test so that the UUT is properly oriented.

Laboratory Setup Considerations

The SOTM test lab is a totally new facility and has to be configured to support the testing covered here. Of particular concern are:

1. The placement of the motion simulator needs to be appropriate to allow it to be moved inside or outside for either the live satellite outdoor testing or indoor full elevation testing covered here. The simulator will be mounted on rails to allow it to be moved; thus the positioning of the rails will be the limiting factor for positioning choices. Ideally, we want to have the longest feasible indoor range to minimize near field problems and apparent relative motion between the UUT and simulated beacon antenna, as covered above.

2. An antenna pattern measurement system is to be part of the indoor test range with an elevation over azimuth test pedestal utilized with the motion simulator moved out of the range. Careful positioning of the antenna pedestal is necessary to allow maximum utility for the test range.

3. Developmental testing has been performed with portable RF microwave absorber walls to control reflections. Microwave anechoic absorber material will be strategically employed in the test range to control reflections. The systems employed have relatively narrow beamwidths and "well behaved" patterns, so that reflection concerns are primarily specular which can be anticipated and identified. This limits the need for reflection control and, by testing already done, indicates very good control with the limited anechoic absorber walls employed. There will be some regions in the test zone which will need more extensive reflection control because of working with the test panel near the ceiling of the building. It will also be necessary to use absorber material strategically on the motion simulator when testing some systems.

4. Additional equipment and software will be needed to implement the motion simulator indoor testing as the signal processing system in use in the developmental test range needs to be integrated with the simulator. Testing on the simulator will be dynamic with respect to time; whereas all experimental testing is currently controlled with respect to angular position.

5. Additional investigations of the possibility of testing with the differential beam position measurement system outside the building will be undertaken. This would, potentially, allow for higher elevation angles and greater distances to be employed in the range. This would facilitate the measurement of larger antennas than were initially planned. The highest elevation angles tested would allow evaluation of performance of the UUT system in the "keyhole" region, near zenith.

SUMMARY

The CERDEC SATCOM OTM Lab located at Aberdeen Proving Ground, MD is meeting the Army's need to rigorously test and characterize SATCOM OTM acquisition and tracking performance. A highly flexible and comprehensive tracking evaluation system is being developed with considerable capability for testing a wide variety of SOTM systems and accurately measuring tracking, to include the high elevation angle case. The technical challenges and current progress toward addressing these challenges have been presented for the motion simulator based testing portion of the SATCOM OTM Lab.

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