EVALUATION OF THE COMPACT RANGE
FOR MILLIMETER WAVE ANTENNA MEASUREMENTS

(Abstract)
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The compact antenna range has been recognized as an effective means of testing microwave antennas. Antennas which normally require long outdoor ranges for testing can be tested under far field conditions at an indoor facility, using the compact range.

The compact range operates on the principal that a parabolic reflector will transform an incident spherical wave into a collimated plane wave in its near zone. The plane wave produced is suitable for testing antennas, thus simulating far field electromagnetic criteria in the near zone. The typical compact range is housed in a room approximately 20 feet wide, 40 feet long and 20 feet high.

The performance of the compact range has been well documented and specified over a frequency range of 3.95 GHz to 18.0 GHz. Now, through recent testing performed at Scientific-Atlanta, the compact range can be specified for operation up through 60.0 GHz.

This paper describes the tests that were performed, discusses the results of these tests and establishes performance specifications for operation at these millimeter frequency bands.
When introduced by Scientific-Atlanta in 1974, the compact antenna range offered the user the ability to test in relatively small indoor chambers, antennas which normally required outdoor antenna ranges hundreds or even thousands of feet long. Today, the Model 5751 Compact Range is widely used to test antennas up to 4 feet diameter at frequencies between 4 to 18 GHz.

The compact range was the result of several years of development by Scientific-Atlanta, the Georgia Institute of Technology and others. It operates on the principal of a parabolic reflector's ability to transform an incident spherical wave into a collimated plane wave (Figure 1). This plane wave accurately simulates the far field electromagnetic criteria normally applied to the design of outdoor far field antenna ranges.

Extensive testing and widespread use of the compact range has resulted in well documented and specified performance over the 3.95 to 18 GHz frequency range. Typical specifications for the Scientific-Atlanta Model 5751 are:

**TEST ZONE (Quiet Zone)**
- Cylindrical
- Diameter: 4 feet
- Length: 4 feet

**FREQUENCY RANGE**
- 4 GHz to over 18 GHz
AMPERAGE
Taper
0.5 dB typical
Total Variation about the overall taper
3.95 to 5.85 GHz: ≤ 1.0 dB
5.85 to 8.20 GHz: ≤ 0.5 dB
8.20 to 18 GHz: ≤ 0.3 dB

TOTAL PHASE VARIATION
Less than 10 degrees (maximum)
Less than 5 degrees (typical)

MAXIMUM EXTRASINE SIGNAL LEVEL
8.2 to 18 GHz: -35 dB (-40 dB typical)
5.8 to 8.2 GHz: -30 dB (-35 dB typical)
3.9 to 5.8 GHz: -25 dB (-35 dB typical)

CROSS POLARIZATION
-25 dB (-35 dB typical)

RANGE COUPLING (Multipath Interaction)
Less than -45 dB (typical)

Extensive testing conducted recently at Scientific-Atlanta has verified performance of the compact range at frequencies through 60.0 GHz. These tests were conducted at several discrete frequencies between 18 and 60 GHz.

To properly evaluate the performance of the compact range, it is necessary to evaluate the purity of electromagnetic field in the quiet zone. Three factors greatly effect this field; feed illumination, reflector surface tolerance and extraneous reflected energy. The feed antenna must be designed to illuminate the offset parabolic reflector with a spherical wave having a uniform amplitude over the full reflector surface. Deviation in this field will result in corresponding deviations in the amplitude and phase taper of the field in the test zone. As the surface of the reflector varies from a true parabola, perturbations in the test zone are created by the effects of energy which is not collimated. These perturbations are usually in the form of phase and/or amplitude ripple across the test zone. Large reflector surface inaccuracies can result in excessive phase and amplitude taper as well.
FIGURE 2  TYPICAL COMPACT RANGE FACILITY
Extraneous reflected energy is any energy arriving in the test zone other than from the reflector. This may include reflection from the room itself; walls, floor, ceiling, etc., as well as reflections from compact range components. This includes test positioner structure, feed positioner and reflector edges. There is also the possibility of excessive back radiation from the feed. This stray radiation can cause perturbations in both the phase and amplitude components of the test field.

All of these factors were considered during the development of the compact range and design of the compact range components was carefully chosen to minimize these effects. It is nevertheless important that these effects be accurately measured and evaluated since they can cause errors in antenna measurement data.

For this evaluation, two methods were employed to characterize and evaluate the electromagnetic fields at millimeter frequencies; field probing and pattern comparisons. Field probing consists of attaching a probe antenna to a linear beam device (phase probe) which can accurately position the probe within the test zone. The phase probe is attached to the polarization axis of the test positioner providing the capability to obtain both horizontal and vertical cuts through the 4 foot diameter test zone. The phase probe used for this evaluation can traverse a 6 foot linear section.

By measuring horizontal and vertical phase and amplitude deviations throughout the test zone, predictions can be made as to the accuracy of antenna measurements obtained in the field.

Pattern comparison measurements make use of a test antenna installed on the test positioner and positioned within the test zone. Principal plane patterns are run successively at different range lengths by traversing the test positioner over several inches. These patterns are all recorded superimposed on one another. If no reflections were present in the test zone, all patterns would be identical and should therefore overlay precisely. Reflections present, however, will cause errors in the pattern due to their phasing in and out with respect to the directly radiated energy. By measuring the level of these errors, primarily in sidelobes and nulls, the level of the reflection can be accurately calculated.
Analysis of the data obtained from the field probe and pattern comparisons at millimeter frequencies indicate that the compact range compares favorably with outdoor range criteria in terms of field uniformity. Field probe data shows the following: (Refer to Figures 3-6 amplitude and 7-10 phase)

AMPLITUDE TAPER (4 foot aperature)
Horizontal Plane
Best Case: .7 dB @ 30 and 35 GHz
Worst Case: .9 dB @ 60 GHz
Typical: .8 dB

Vertical Plane
Best Case: .7 dB @ 30 GHz
Worst Case: 1.2 dB @ 60 GHz
Typical: .8 dB

PEAK TO PEAK AMPLITUDE VARIATION ABOUT THE TAPER (ripple)
(4 foot aperature)
Horizontal Plane
Best Case: .4 dB @ 30 GHz
Worst Case: .8 dB @ 60 GHz
Typical: .6 dB

Vertical Plane
Best Case: .5 dB @ 30 GHz
Worst Case: 1.0 dB @ 60 GHz
Typical: .7 dB

TOTAL PHASE VARIATION
(4 foot aperature)
Best Case: 4° @ 35 GHz
Worst Case: 19° @ 60 GHz
Typical: 10°

Analysis of the phase probe pattern indicates a significant similarity in the pattern ripples between all phase probes which suggests that a portion of the phase variations is due to inaccuracies in the probe positioning system, not in the compact range itself. If it were possible to remove the errors, one would expect to see an improvement in this data.

This data compares favorably and in many ways exceeds probe data taken on many "good" outdoor ranges. Most outdoor ranges are designed to the $2D^2/\lambda$ criterion which results in a $22.5^\circ$ phase taper across the test aperature. Amplitude variations cannot be directly compared with an outdoor range since the cause of the variations are due to different factors in each case.
A better evaluation of the performance of the compact range in an actual test condition is through pattern comparison measurements techniques. For this evaluation, pattern comparisons were performed on several different types of antennas at different frequencies within the 18-60 GHz band. The results of these tests follow:

<table>
<thead>
<tr>
<th>Example</th>
<th>Antenna</th>
<th>Number of Cuts</th>
<th>Extraneous Signal Level</th>
</tr>
</thead>
</table>
| #1      | 18 inch parabolic | 3 at 2, 15, 28 inches | Number of Points Calculated: 18  
Best Case: -83.4 dB  
Worst Case: -58.7 dB  
Typical: -70 dB |
| #2      | 12 inch parabolic | 4 at 10, 15, 20, 25 inches | Number of Points Calculated: 10  
Best Case: -83 dB  
Worst Case: -61.4 dB  
Typical: -65 dB |
| #3      | Scientific-Atlanta Model 12-60 Standard Gain Horn (H Plane) | 4 at 27, 28, 29, 30 inches | Number of Points Calculated: 7  
Best Case: -54 dB  
Worst Case: -41 dB  
Typical: -44 dB |
18 inch parabolic antenna
Freq: 32.6 GHz
3 cuts: 2, 15 + 28 inches
5-19-80

Fig. 11
Az CUT ±90°
GUIDE ±30°, ±29° ±28° ±27°
Hor. Pol.
AUT 5GH (12-60)
COMPACT WAVE REED OPERATING
1250 RECEIVER
6-28-80 EK

FIG. 14
Example #4 (Figure 14)

Antenna: Scientific-Atlanta Model 12-60 Standard Gain Horn (E Plane)
Frequency: 60 GHz
Number of Cuts: 4 at 27, 28, 29, 30 inches (relative slide position)

Extraneous Signal Level:
Number of Points Calculated: 13
Best Case: -49.9
Worst Case: -41.5
Typical: -50

As the pattern comparisons show, extraneous signals present in the test zone are quite small and comparable to (and in many cases better than) most outdoor antenna ranges. It should be noted, however, that there is an increase in extraneous signals as the frequency is increased to 60 GHz. This is due in part to effects of the compact range room itself, absorber efficiency, etc., but is also a result of the wider beam width of the standard gain horn test antenna which "sees" a broader area of the quiet zone and consequently more stray signals, especially those arriving from above and below the test zone.

Based upon the results obtained from the field probe and pattern comparison data, the compact antenna range performance can be specified for use in the millimeter frequency bands. For the most part, the specifications listed below assume the worst case figures listed in the above examples. As the test data shows, however, actual performance is typically much better than the specifications throughout most operating conditions.

Model 5751 Compact Antenna Range specifications for millimeter frequencies 18 GHz - 60 GHz.

FREQUENCY RANGE
18.0 GHz - 60 GHz

TEST ZONE (Quiet Zone)
Cylindrical
Diameter: 4 feet
Length: 4 feet

AMPLITUDE
Taper: 1.0 dB
TOTAL VARIATION ABOUT THE TAPER (Ppk-Pk)
18 GHz - 26 GHz: ≤ 0.5 dB
26 GHz - 40 GHz: ≤ 1.0 dB
40 GHz - 60 GHz: ≤ 1.0 dB

TOTAL PHASE VARIATION
Less than 20 degrees (maximum)
Less than 10 degrees (typical)

MAXIMUM EXTRANEOUS SIGNAL LEVEL *
-35 dB (-40 dB typical)

CROSS POLARIZATION
-20 dB (-25 dB typical)

RANGE COUPLING (Multipath Interaction)
Less than -45 dB (typical)**

*Calibrated using Scientific-Atlanta Series 12 Standard Gain Horns
**Dependent upon test antenna characteristics; gain, aperture, etc.

SUMMARY

Scientific-Atlanta introduced the Compact Antenna Range, Model 5751 as a commercial product in 1974. Since its introduction, the compact range has been accepted as a viable alternative to outdoor testing. It is being used to test microwave antennas with diameter of up to four feet and larger over frequencies of 3.95 GHz to 18 GHz. The data presented herein verifies the performance of the compact range at frequencies up to 60 GHz. Now all the advantages of outdoor testing, including reduced test time, elimination of large outdoor range facilities and real estate, improve security, elimination of unwanted surveillance, and immunity to adverse environmental factors are available to users involved in the testing of millimeter antennas.