THE APPLICATION OF A SMALL COMPACT RANGE TO THE TESTING OF MILLIMETER ANTENNAS

J.D. Huff and D.W. Hess

ABSTRACT

Since the first commercial compact range was introduced in 1973, the compact range has become a very popular alternative to far-field ranges. In recent years larger and larger compact ranges have been built, increasing the size of antennas that may be tested and lowering the operating frequency. However little has been done in the other direction, to increase the operational frequency and to decrease the size of the compact range. This paper reports on the design and fabrication of a small compact range having a 1 foot test zone and operating at 95 GHz.

Keywords: Antenna Measurement, Compact Range, Millimeter Antenna

1. INTRODUCTION

The invention of the compact range is credited to Dr. Richard Johnson of the Georgia Institute of Technology. The test problem to which it was initially applied was the testing of X and Ku band airborne radars. These antennas were typically three feet in diameter and the far field criteria dictated range lengths of several hundred feet. The compact range allowed these antennas to be tested indoors in a relatively small chamber, typically 40 feet in length. As the accuracy and convenience of the compact range came to be appreciated, it was applied to other more difficult test problems. When the need arose to measure the radar cross section of objects in an indoor, secure environment, the capabilities of the compact range were expanded to test large objects, some up 50 feet in extent, at frequencies below 1 GHz.

With the increasing use of physically small but electrically large millimeter antennas in smart munitions, satellite-to-satellite communication links and radiometers, there now exists a need for smaller compact ranges that can be used in a laboratory or production line environment. This paper reports on the design and fabrication of such a compact range.

2. BACKGROUND

In principle the compact range is very straight forward. In its simplest form, the compact range consists of a precision parabolic reflector that mechanically collimates the spherical wave radiated by a small feed antenna placed at its focus. Thus a plane way is generated having the necessary phase and amplitude flatness to fulfill the far-field criteria for testing antennas. This concept is depicted schematically in Figure 1.

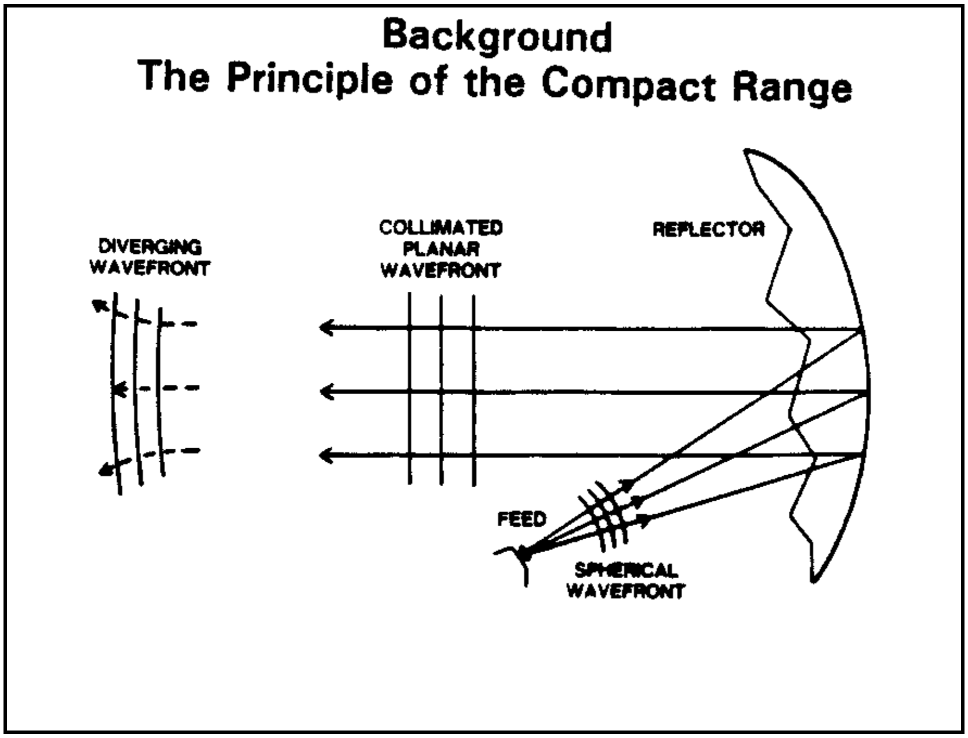

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Figure 1

Of course in practice it is always more difficult than it is in theory. Early work on the development of the compact range identified problem areas that had to be addressed in order for the compact range to be a useful test device.

One of the first discoveries of the compact range developers was that the surface accuracy of the reflector was critical if a pure plane wave was to be generated. Peak surface errors of greater than .007 of a wavelength were found to produce unacceptable ripples in the amplitude flatness of the test zone. As a result significant effort went into the development of a manufacturing technique for the compact range reflectors.

A second discovery was that the diffraction effects from the edge of the reflector could cause significant measurement errors. Over the last 20 years much work has been done to reduce the edge diffraction effects, culminating today in fairly sophisticated edge designs consisting of serrations, rolls or material treatment.

A third significant problem that was identified and solved by the early researchers was that of a suitable feed antenna. Fundamentally the requirement of the feed antenna was to generate a nearly perfect spherical wave. This required symmetrical E and H plane radiation patterns with coincident phase centers. The design that was found to best achieve these requirements was a circular aperture with a few concentric choke rings to reduce the back-scattered radiation.

3. THE FAR-FIELD CRITERIA

The commonly accepted criterion for antenna range length is that the range should be longer than $2D^2/\lambda$ where D is the antenna under test diameter and λ is the wavelength at the test frequency. This criterion corresponds to a phase taper of 22.5 degrees across the aperture of the antenna under test. There are of course cases where this “rule of thumb” may not be appropriate, but it is generally the starting point in determining if a given far-field range can be used to test a particular antenna.

In the case of an antenna operating at millimeter wavelengths, this criterion can lead to the requirement for very long range lengths. Table 1 shows the minimum range length for a 12 inch (30.5 cm) diameter antenna at selected frequencies.

Frequency (GHz)	Wavelength(cm)	Range Length(m)
35	.8571	22
45	.6667	28
60	.5000	37
95	.3158	59

Table 1
Minimum Range Lengths
Required to Test a 12 inch Diameter Antenna

In most cases the range lengths indicated in Table 1 necessitate the use of either a compact range or an outdoor range since the majority of indoor far-field ranges fall short of the minimum range length requirement.

4. DESIGN OBJECTIVES

The design objective was to build a small table top compact range that could be used to replace a far-field range. The entire range was required to be free standing and suitable for use in either a laboratory or production environment. In this particular case, production volumes of the antennas to be tested were anticipated to be high, so consideration had to be given to the ease of mounting and dismounting the test articles.

The required test zone size was 1 foot in diameter and the range should be able to test antennas from 60 to 110 Ghz. This would allow the compact range to replace free space ranges of up to 224 feet in length.

The phase and amplitude variation in the test zone were desired to be less than 20 degrees and .5 dB respectively. The extraneous signal level was to be less than -30 dB, corresponding to a .5 dB peak to peak ripple in the amplitude across the test zone. Both linear and circular polarization were required.

The chamber size was to be restricted as much as was practical consistent with the electromagnetic requirements. Since the chamber might need to be moved within the facility that it was located, its height must be such that it could pass through standard doors. Casters were to be placed on the chamber to ease in relocation.

A three-axis positioner was required, having a roll over elevation over azimuth configuration. The maximum load was specified at five pounds.

The requirements of the millimeter compact range are summarized in Table 2.

Test Zone	
Size	1 foot diameter by 1 foot deep
Amplitude Taper	0.5 dB maximum
Phase Variation	20 Degrees Maximum
Extraneous Signals	-30 dB
Polarization	Dual Linear & Circular
Chamber	76 in High
Size	54 in Wide
	102 in Long
Positioner	
Axis	Roll over El over Az
Load	5 lbs Maximum
Accuracy	+/−0.20 Degrees Roll
	+/−0.05 Degrees Elevation
	+/−0.02 Degrees Azimuth
Speed	1/3 RPM

Table 2
Millimeter Compact Range Specifications

5. DESIGN ISSUES

Three design issues were identified at the start of the development effort. These three issues were:

1. How to achieve a surface accuracy of 0.001 inches (peak)

2. How to minimize edge diffraction effects.

3. How to minimize the footprint of the range.

It is interesting to note that these are essentially the same design issues that were addressed to make the first compact range operate at X band.

6. THE FINAL DESIGN

A prime focus virtual vertex design was selected for the compact range. A prime focus configuration was selected rather than a subreflector configuration for two main reasons. The first of these was to avoid the additive effects of surface inaccuracies from two reflectors. Since the usable upper frequency would be ultimately determined by the surface accuracy of the reflector, every effort would be made to machine the reflector as accurately as possible. If a subreflector were used, the cumulative surface accuracy of the both main and sub reflector would be worse than the main reflector by itself, thus reducing the useable upper frequency. A second reason for selecting prime focus was cost. All of the requirements could be met with a single reflector, prime focus design. This being the case there was no reason to add the cost, complexity and weight of a dual reflector design.

The virtual vertex design is one that was pioneered by Scientific-Atlanta. The reflector is designed such that the vertex is below the surface of the reflector. This allows the feed assembly at the focal point to be below the collimated energy, thus minimizing scattering and diffraction of energy from the feed support structure.

A serrated edge was designed for the reflector to minimize the edge diffraction effects. With the serrated edge approach, the reflector could be machined in one piece and there would be no junction between the reflector body and the edge to scatter extraneous energy into the test zone. The final reflector design is shown in Figure 2.

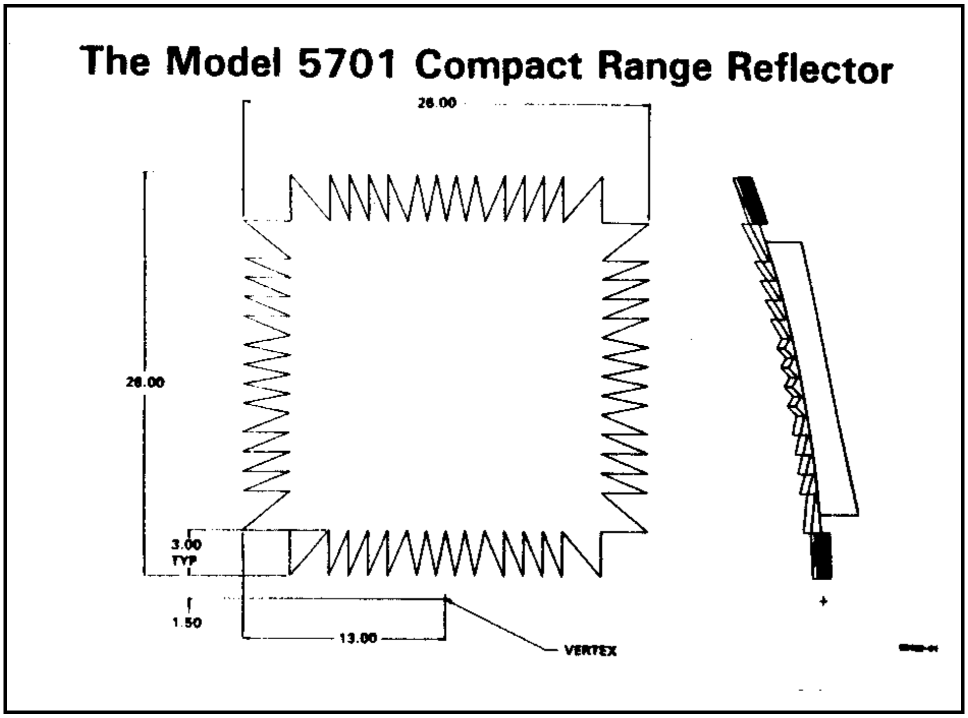

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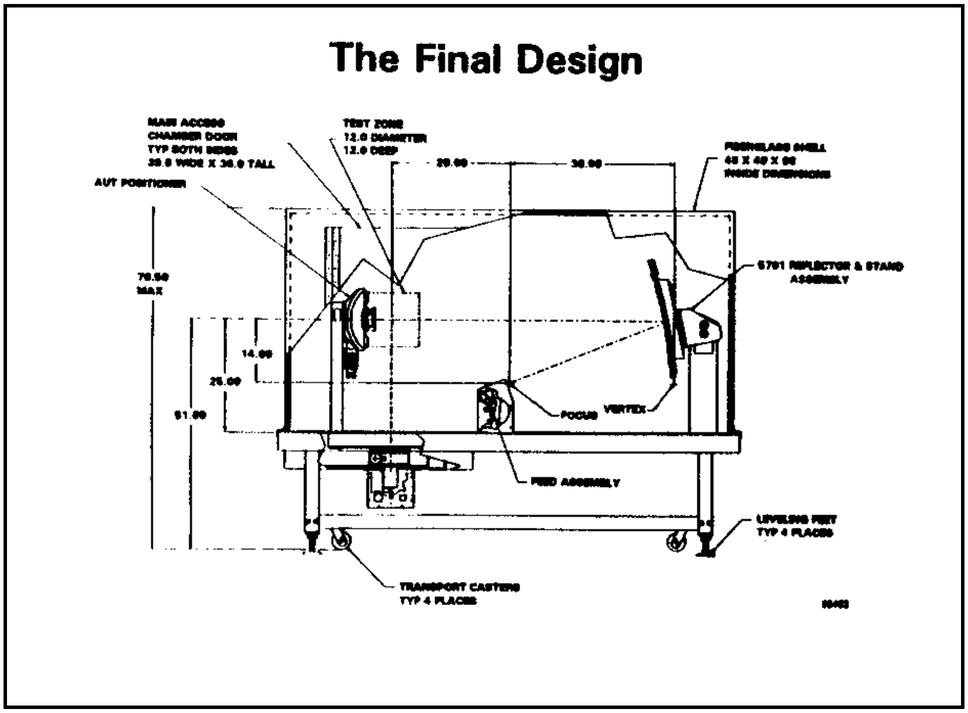
Figure 2

A dual polarized feed was designed which utilized a circular aperture with choke rings to reduce the backscatter in the direction of the test zone. An orthomode transducer produces dual linear capability and a polarizer provides dual circular capability.

The chamber design is shown in Figure 3. It consists of a rigid steel table to which are mounted the reflector, the positioner and the feed. A fiberglass shell encloses the range and has access doors on either side of the positioner. The entire assembly is mounted on casters and has leveling feet.

The test positioner was fabricated using commercially available stepper motor drive axes. The roll axis is a manual axis having detentes at 0 and 90 degrees. The elevation axis is a cradle which allows the antenna under test to be rotated around its phase center. An offset bracket is designed such that the elevation axis intersects the azimuth axis.

The reflector was machined out of a single block of aluminum using a numerically controlled milling machine. The surface accuracy was verified using a three axis coordinate measuring system. A best fit parabola was determined from the measured data. The peak variation of a measured point from the best fit parabola was typically less than 0.001 inch. A coat of white dielectric paint was applied to protect the aluminum surface and to retard its oxidation.



The Final Design

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Figure 3

7. MEASURED PERFORMANCE

The characteristics of the test zone where measured by making both vertical and horizontal field probes using a standard gain horn as a probe. Measurements were made at 95 GHz. The results of these measurements are shown in Figures 4 & 5. These measurements show amplitude tapers of less than 0.5 dB and phase tapers of less than 20 degrees. The measurements show that the test zone easily meets the 1 foot diameter requirement.

A test antenna with approximately a 3 inch aperture and a center frequency of 95 GHz was measured on the range. A principal plans pattern of this antenna is shown in Figure 6. No other measurements on this antenna were available to use as a comparison, but certain conclusions can be drawn with some confidence from the single measured pattern. The main beam is symmetrical and free from any amplitude ripples. The sidelobes are symmetrical and the dynamic range sufficient to see the necessary pattern features. More work remains to be done to quantify the measurement accuracy of the range.

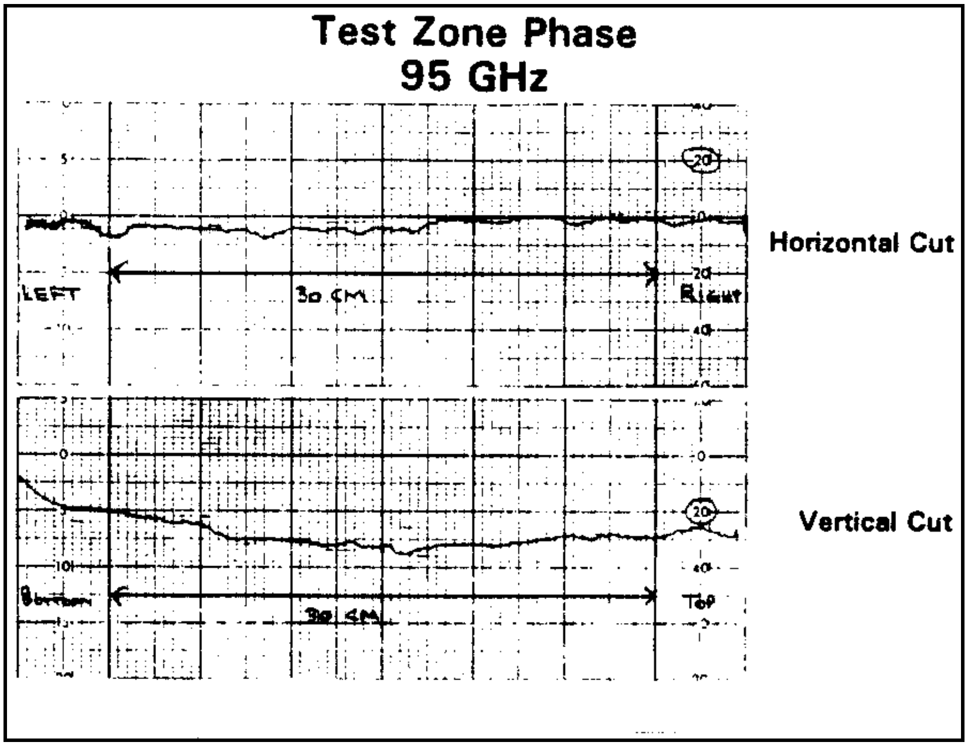

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Figure 4

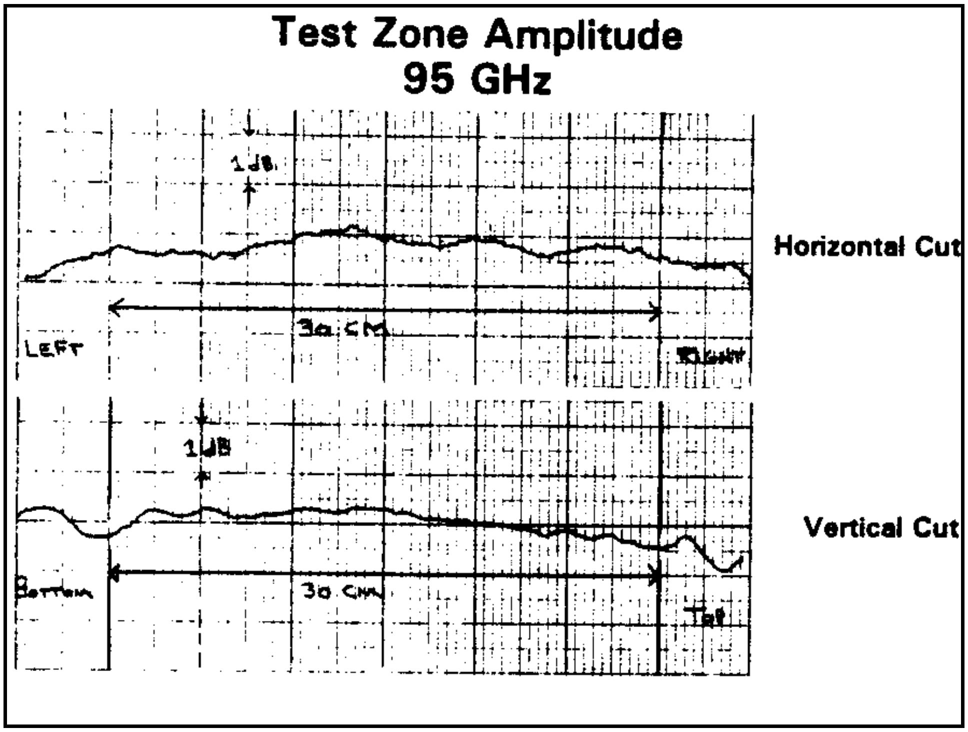

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Figure 5

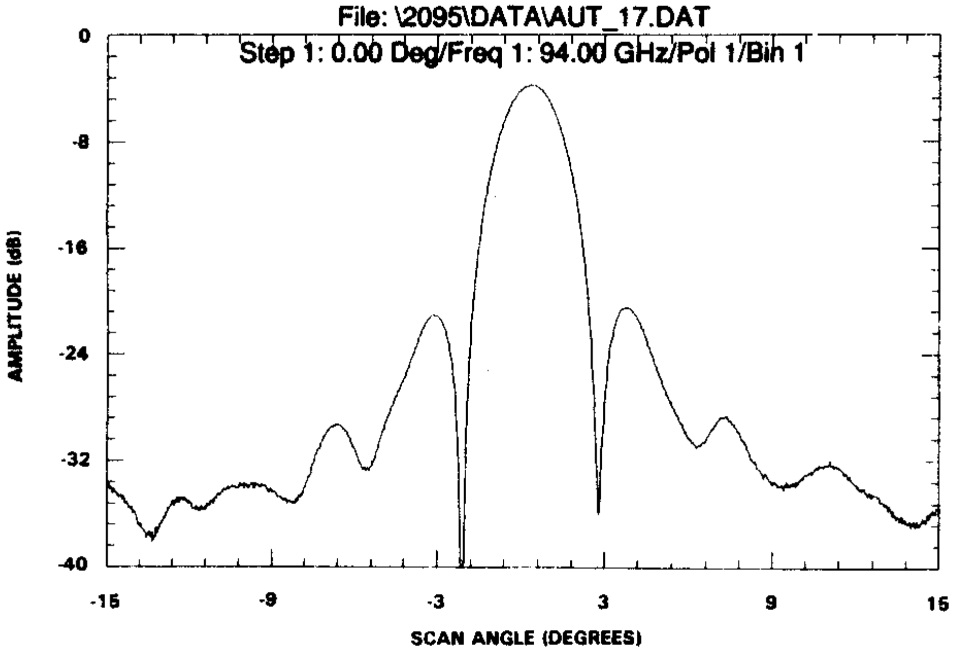

Figure 6

8. SUMMARY & CONCLUSIONS

These results prove the viability of scaling the compact range down in size and up in frequency in order to test physically small but electrically large antennas. Although this range was only tested to 95 GHz, we are confident that it would perform adequately up to 200 GHz and perhaps beyond. Because of its small size, it can be placed directly in the laboratory or on the production floor, and this has the potential of significantly reducing the design and manufacturing times for millimeter antennas. With the anticipated production volumes of many of the smart munitions that might make use of this type of antenna, this could be a significant savings in production and facility cost.

9. REFERENCES

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