A MILLIMETER COMPACT RANGE

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ABSTRACT

The compact range mechanically collimates electro-magnetic energy, thus creating a plane wave useful for testing antennas in a far field environment. Since this collimation can be achieved in a relatively small space, the tests can be performed in an environmentally controlled chamber. With the increasing use in both military and commercial applications of antennas operating at millimeter wavelengths, there is increasing need for small compact ranges operating in the 26.5 to 100 GHz frequency range. This paper describes the development of a small compact range with a two foot diameter test zone that operates from 26.5 GHz to greater than 100 GHz.

Keywords: Compact range, millimeter wave reflector, serrated edges.

INTRODUCTION

The increasing use of millimeter waves has been predicted for a long time. Offering small size and light weight, millimeter wave antennas seemed ideal for many applications. However, technical difficulties and the laws of physics conspired to slow the development of millimeter wave antennas. Now with the advent of smart munitions, millimeter wave communication satellites and earth resource radiometers operating above 100 GHs, the long predicted need for test equipment for millimeter wave antennas has arrived.

Because of the short wavelengths involved and the resulting tight mechanical tolerances required in millimeter wave antennas, outdoor testing of these antennas is both difficult and frustrating. The effects of wind and temperature on these antennas make it highly desirable to test them in a controlled environment, but their large electrical size requires the use of very large chambers to achieve far-field conditions.

The compact range offers a solution to these test problems, combining a small size consistent with sensible chamber sizes and millimeter wave operation needed to test the antenna.

BACKGROUND

The invention of the compact range is credited to Dr. Richard Johnson working at the Georgia Tech Research Institute. A diagram of the compact range is shown in figure 1. The compact range consists of a small feed antenna radiating a spherical wave and a large parabolic reflector which mechanically collimates the spherical wave into a plane wave suitable for testing antennas, radomes, and low radar cross section targets. Although extremely simple in concept, numerous technical difficulties had to be overcome before a viable test range was developed.

First, it was found that the surface tolerance of the reflector had to be extremely good. This requirement dictated a machined reflector. However, the size of the reflector required exceeded the capabilities of the machine tools of the period. Scientific-Atlanta solved this problem by designing a large milling machine specifically for machining compact range reflectors.

Second, it was found that the diffraction effects from the edges of the reflector caused high levels of extraneous, non-collimated energy which degraded the measurement accuracy of the range. This problem was solved by designing serrated edges for the reflector which directed the diffracted energy away from the test zone.

Third, a feed antenna had to be designed which had a constant beamwidth over its frequency band, illuminated the reflector uniformly but did not radiate in the direction of the antenna under test, and whose cross section was small enough not to set up standing waves between itself and the antenna under test. These requirements were met by a using a small circular aperture with a 1/4 wave choke flange.

Solving these three technical problems resulted a test range that could match and often exceed the accuracies obtained on far field outdoor ranges. Over the last two decades, compact ranges have been built with test zones of up to 30 feet in diameter. They have been applied to the measurement of antennas, radomes, and low radar cross section targets. Frequencies of operation have been extended to below 1 GHz and above 100 GHz.

THE MILLIMETER TEST PROBLEM

Suppose that one has an antenna with a two foot diameter aperture that operates at 44 GHz. The conventional far field criteria for this antenna of twice the aperture diameter squared divided by the wavelength would result in a test range length of 358 feet. This would result in a phase curvature of 22.5 degrees across the aperture of the test antenna. This variation from true plane wave conditions results in some accuracy degradation, and many engineers prefer to test at longer range lengths in order to reduce errors from this source.

However, even at a range length of 358 feet, it is not really practical to test this antenna indoors in a conventional far field range. Hence the need for a small compact range operating at millimeter frequencies to test this type of antenna.

THE MODEL 5702 COMPACT RANGE

Key specifications for the Model 5702 are shown in table 1. Since the lower operating frequency drives the reflector size and hence the room size, 26.5 GHz was chosen as the lower operating frequency. The upper frequency limit has been specified as 100 GHz, but this is a somewhat artificial limit. At the present time no tests have been made above 100 GHz, and hence we are reluctant to specify performance in this range. It is expected however, that the true upper frequency limit of this compact range will be approximately 200 GHz.

Table 1. Key Specifications
Model 5702

Test Zone	Horizontal Cylinder
Size	24 inches diameter 40 inches long
Frequency Range (GHz)	26.5 - 100
Amplitude Taper (dB)	0.4
Phase Variation	20°
Cross Polarization	-30 dB
Minimum Chamber Size	8 ft (H) 8 ft (W) 15 ft (L)

Reflector Dimensions	52 in (H) 52 in (W)
Reflector Weight	950 lbs
Focal Length	7 ft

A profile of the Model 5702 in shown in figure 2. In this view the prime focus design of the Model 5702 is obvious. A prime focus design was chosen in order to extend the upper frequency of operation as far as possible. The upper frequency bound on a prime focus system is set by the main reflector surface accuracy while on a subreflector system the upper frequency bound is set by the cumulative effects of both the subreflector and main reflector accuracies. Hence if one starts with a state-of-the-art main reflector surface and equivalent upper frequency limit, one can only degrade it with the addition of a subreflector.

The room size required by the Model 5702 is 8 feet wide by 15 feet long by 8 feet high -- roughly the size of a large office or a small conference room. This small room size requirement means that the Model 5702 can be co-located with an engineering lab or production facility.

Serrated edge design was used to control the diffraction effects from the edges. Because of the short wavelengths involved, these edges end up being very modest in size. The standard feeds used in other Scientific-Atlanta compact ranges were found, as expected, to provide the required performance.

CONSTRUCTION TECHNIQUE

The reflector of the Model 5702 was machined from a block of 6061 aluminum using a numerically controlled milling machine. Many of the techniques used are proprietary and cannot be discussed here. However, the resulting reflector achieved a peak to peak surface accuracy of 0.0015 inches. A thin coat of white dielectric paint was applied to protect the aluminum surface from oxidation.

The feed positioner was attached to the main reflector support with two parallel beans. Once the reflector was focused, these beams were drilled and pinned to both the feed positioner and the main reflector support. This design allows the system to be disassembled for shipment and reassembled without the need of refocusing electromagnetically.

Because of the small size of this system, it was practical to add wheels to both the main reflector and feed positioner. Disassembled, the system can be rolled through standard height personnel doors. Thus the Model 5702 can be installed in virtually any location in an existing building. It can even be moved from location to location within a building should the need arise.

ELECTROMAGNETIC PERFORMANCE

The Model 5702 was tested using a standard phase probe with standard gain horns as the probe antennas. The test zone was probed both vertically and horizontally through its center. Measurements were made with the range both vertically and horizontally polarized. Sample test results are shown in figures 3, 4, and 5. One will note that typical total phase variations across the test zone of 10 degrees were achieved. Amplitude taper across the test zone is typically 0.3 dB, and amplitude ripples of less than 0.3 dB are typical.

CONCLUSION

The Model 5702 has been shown to be suitable for testing electrically large millimeter wave antennas in a relatively small indoor chamber. The advantages in improved accuracy and test efficiency of a compact range can be achieved in either the engineering laboratory or on the production floor.

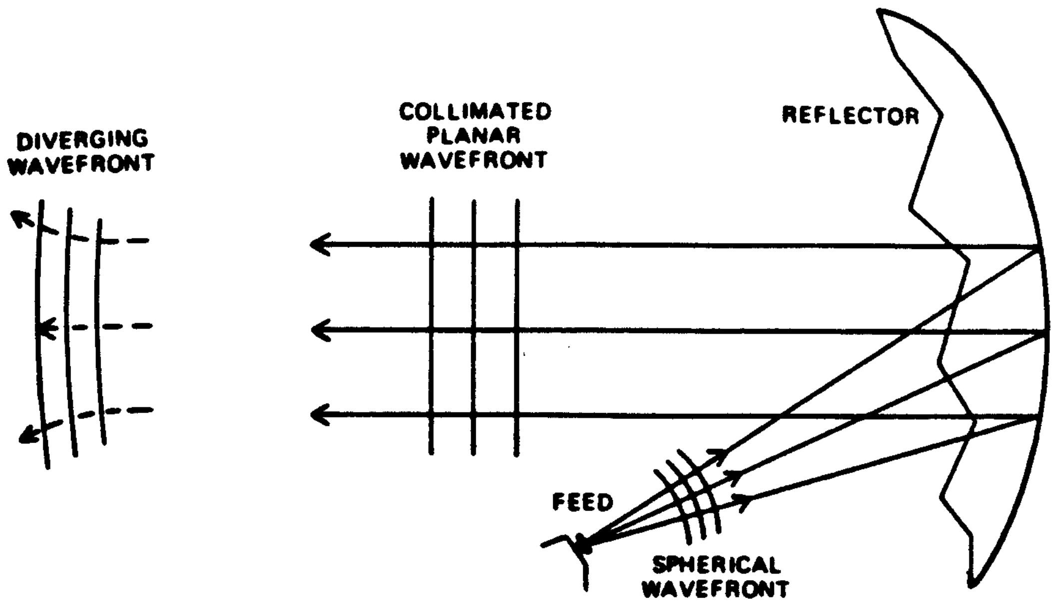

Figure 1. Compact Range Diagram

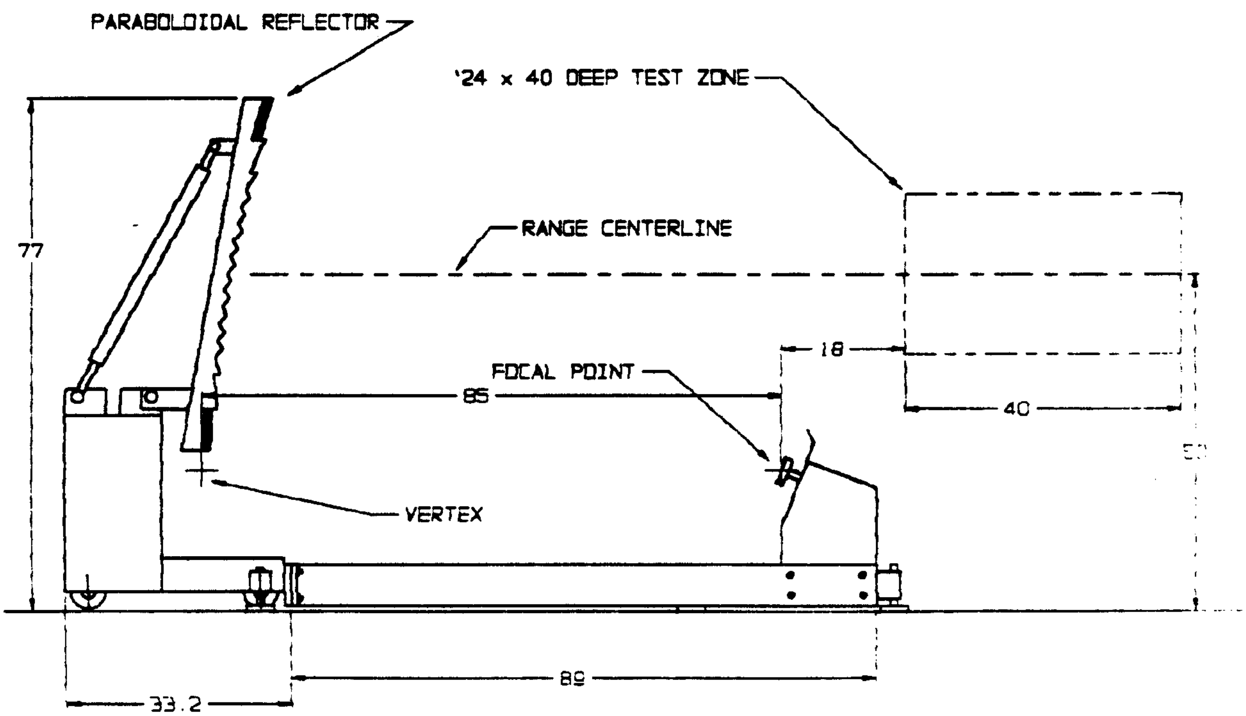

Figure 2. Model 5702 Virtual Vertex Compact Range
(Dimensions in Inches)

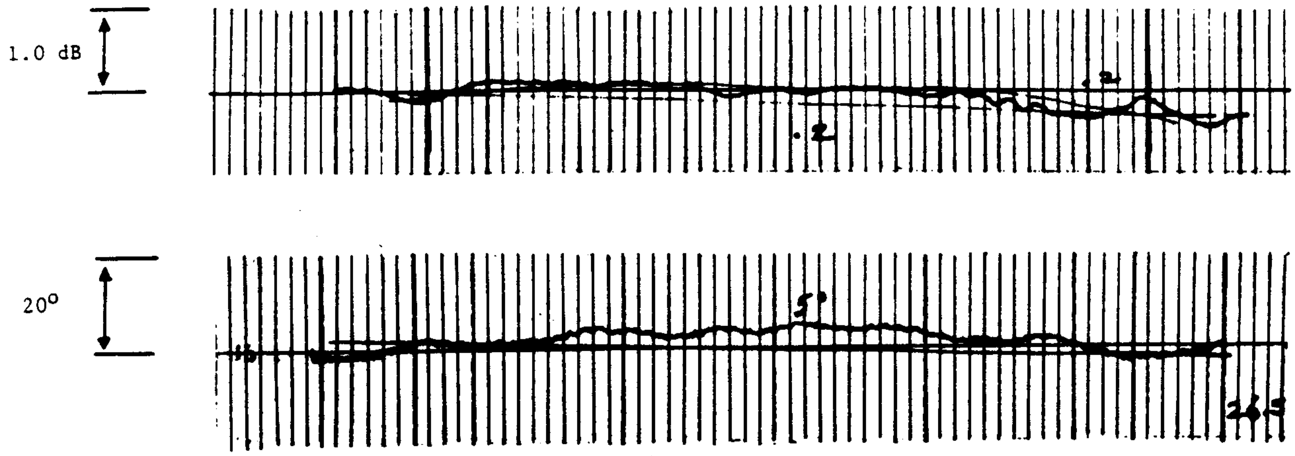

Figure 3. Amplitude and Phase at 26.5 GHz

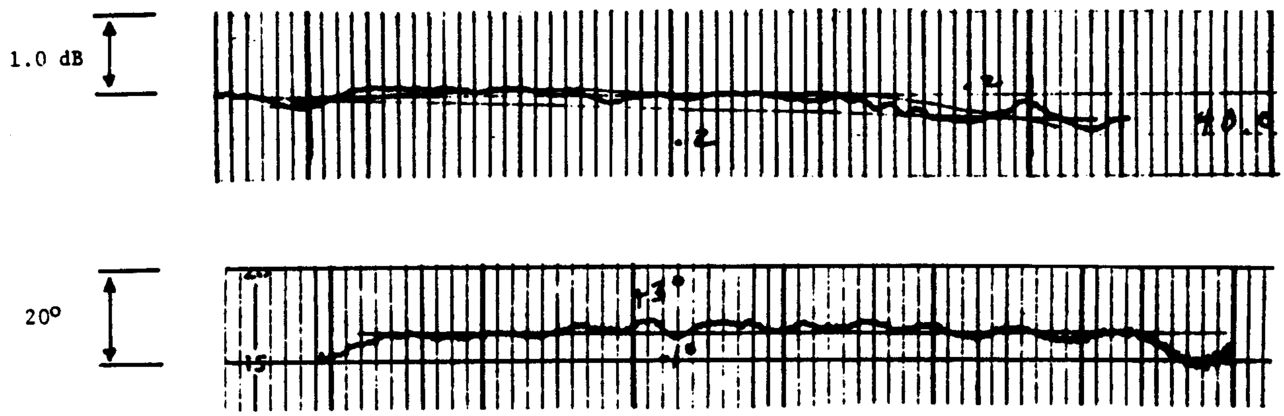

Figure 4. Amplitude and Phase at 40 GHz

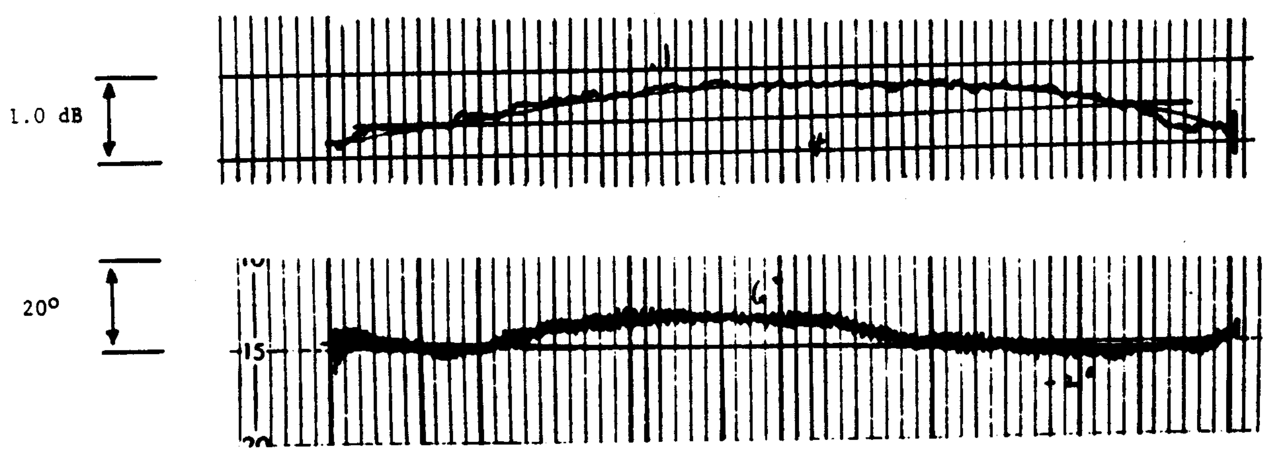

Figure 5. Amplitude and Phase at 94 GHz