# MEASUREMENT OF ELECTRICALLY LARGE ANTENNAS AT MILLIMETREWAVES

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## INTRODUCTION

The millimetrewave band is now being opened up for communications, radar and remote sensing [1]. There will be increasing need at these frequencies to measure the radiation characteristics of electrically large antennas. An example is the antennas used with millimetrewave sounders on the next generation of meteorological satellites which will need to have narrow footprints on the earth and hence a large antenna on the spacecraft. This paper reviews the methods available to measure medium and large antennas. It concludes that the compact antenna range is the only viable option. An experimental millimetrewave compact antenna range is described.

## TYPES OF RANGE

The measurement of antennas at millimetrewaves is basically similar to the measurement of antennas at microwaves but the shorter wavelength imposes constraints which limit the choice of test range. Four types of range will be considered: far-field outdoor ranges; far-field indoor ranges (anechoic chambers); near-field ranges and compact ranges.

Far-field outdoor ranges consist of a source on a tower and the test antenna of diameter D also on a tower separated by a distance R. R is normally greater than the far-field distance ($2D^2$/wavelength). This is plotted in Fig. 1. for representative apertures across the millimetrewave spectrum. Ranges which are shorter than the far-field distance suffer from amplitude and phase tapers which have the effect of filling in the recorded nulls and broadening the main beam. Millimetrewave far-field outdoor test ranges are feasible, particularly for small to medium size antennas. For large antennas the range distance becomes long and this makes the implementation extremely difficult, though not impossible. A 2.4m diameter antenna at 183 GHz has a far-field distance of about 7 km. At some frequencies the water vapour attenuation in the atmosphere is high and this limits the usable range length.

Outdoor far-field ranges suffer from the severe limitations imposed by environmental conditions which can reduce the operational time available for measurements. The test antenna is also prone to pick up external sources of interference, although this is generally less of a problem at millimetrewaves.

Anechoic chambers are the name usually given to indoor far-field ranges in which the reflections from the walls, roof and floor of the chamber are controlled by radar absorbing material (RAM). The same far-field design criteria apply as in the outdoor range. They are an excellent test range for measuring small antennas, such as horns and feeds. As Fig. 1 indicates, the range distances are small and it is easy to set up a high quality anechoic chamber. RAM is relatively inexpensive at millimetrewaves because the depth of material is small. The range length makes it impractical to construct an anechoic chamber for medium or large antennas.

Near-field ranges use the test antenna as a source and the fields are measured on a surface which is close to, and partly surrounds, the test antenna, [2]. The fields are accurately sampled in amplitude and phase over the surface. They are than transformed to the far-field with a relatively powerful computer and for this reason are often called near-field/far-field (NF/FF) ranges. Considerable development work has taken place in the last decade and they are now widely used at microwaves. There are three main types depending on whether the near-field surface is planar, cylindrical or spherical. The planar type has two sub-types - plane rectangular and plane polar. NF/FF transform algorithms have been developed for each type.

The advantages and disadvantages, compared to far-field ranges, can be summarised as follows:

| ADVANTAGES | DISADVANTAGES |
|---|---|
| No interference | Automated (costly) system needed |
| No weather problems | Large amounts of data to record and process |
| Relatively small space | Computer analysis needed |
| All pattern data obtained | High precision scanners needed |
| High accuracy | Probe needs to be characterised |
| Clean room possible | Phase needs to be measured. |
| Secure environment | Good quality anechoic chamber needed |
| Very low sidelobe antennas can be measured | Sampling criteria needs to be known |
| Large dynamic range | Computing time is considerable |
| 24 hr operation possible | |

The rate at which the near-field needs to be sampled determines both the time taken on measurement and the computer time needed for the NF/FF transformation. Near-field ranges have so far mainly been used at microwaves. There are two major controlling factors at millimetrewaves. The first is the positional accuracy needed on the probe scanning mechanism. To achieve a typical measurement accuracy of 0.01 wavelengths at 183 GHz requires a positional accuracy of 16 microns. This is not impossible to achieve, but given that it has to be maintained over the complete scanning area, would be difficult and expensive. The other factor is the amount of data required. If the size of the antenna is greater than about 300 wavelengths, the sampling and computing time become considerable. This is particularly true for spherical or plane polar ranges and effectively rules them out of consideration.

Compact ranges produce a quasi-plane test region by collimating the field from a point source with a parabolic reflector, Fig. 2. The test region is only a short distance in front of the compact range reflector. Its width can be about one third of the range reflector width. The phase across the test region will be theoretically constant but the amplitude will have a taper due to the feed and a superimposed ripple due to diffraction from the edges of the reflector and distortion of the reflector surface. Compact ranges are usually constructed with an offset paraboloidal surface for the range reflector but they can also be made from two cylindrical parabolic reflectors. The design of the range depends on controlling the unwanted field components, Fig 2. The direct ray (1) is the wanted ray. There are two rays diffracted from the edge of the reflector (2). If the surface is distorted, there will be extra rays arriving at the test point (3). The spillover from back radiation of the feed arrives at the test antenna (4). Finally there are the reflections from the walls of the room (5). At millimetrewaves the main limitation is due to the accuracy of the reflector surface. The other factors have the same significance as at microwaves and can be controlled by good design of the feed and edge of the reflector. The accuracy of the surface of the reflector is not a fundamental limitation and can be overcome by good manufacturing precision. Hence it can be concluded that compact ranges are viable for the measurement of medium and large test antennas at millimetrewaves. A large test antenna will need to be measured with a range reflector which is 2 - 3 times larger. There is considerable experience of building accurate large reflector antennas.

## MILLIMETREWAVE COMPACT RANGE USING PANELS

Compact ranges which have been constructed to date have usually been made with a solid reflector which has been carefully machined to the required profile. This is not the practice with large reflector antennas which are made from panels mounted on a backing structure. It was therefore decided to make a panelled compact range and to use precision panels which had been designed and developed for a millimetrewave radio telescope [3]. For this reason the shape of the range reflector is a segment from a circle.

The compact range, Fig. 3., is 3 m wide and between 2 m and 4.3 m high so that a 3 m diameter aperture fits inside the segment. It is made of 18 panels with surface accuracies of between 11 microns and 16 microns. The accuracy of the reflector surface comes from the random panel surface error, the systematic panel tilt error and thermal expansion errors. The root sum square of all the errors is about ± 20 microns at the centre of the reflector and ± 40 microns at the edge of the reflector. These vales will easily allow operation of the compact range up to at least 200 GHz.

The panels are supported on a space-frame backing structure with panel adjusters. This was carefully designed by using a finite element analysis package [4]. The feed is mounted on a 219 mm diameter rigid steel support tower. For prime focus operation there will be a variety of horns depending on the test frequency and test antenna, chosen so that the field at the edge of the reflector is about -10 dB less than the field in the centre of the reflector. This reduces edge diffraction.

The panels of the millimetrewave compact range must be accurately aligned to the basic paraboloidal surface. The panel adjusters allow movement in the longitudinal direction and a procedure is needed for setting the panels. After investigating various schemes it was decided to use two theodolites mounted on rigid posts about 4 m from the compact range reflector. The calibration is provided by a precision carbon-fibre scaling bar. Optical targets are placed on the panel surfaces, adjacent to each panel mounting point. The theodolites are used to measure the angles between the targets and the ends of the scaling bar and then computations are used to calculate the actual position of the panels. An error analysis on the geometry shows that the achievable accuracy is between 36 microns and 70 microns.

The range is being tested at 40 GHz, 95 GHz and 180 GHz. At 180 GHz a 400 mm diameter antenna has been successfully measured.

## REFERENCES

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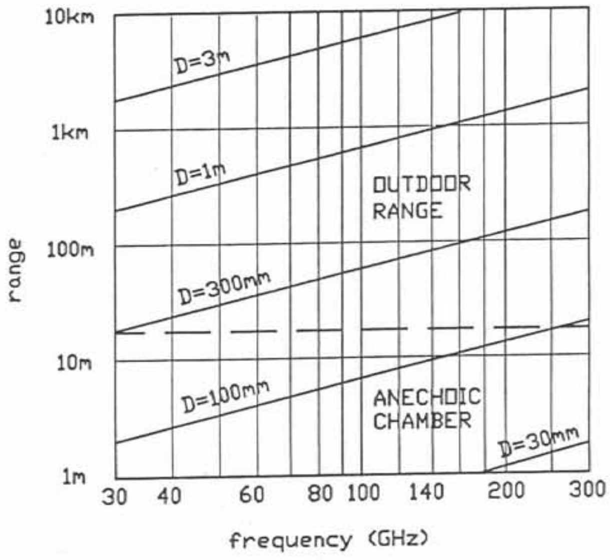


Fig. 1. Far-field distance

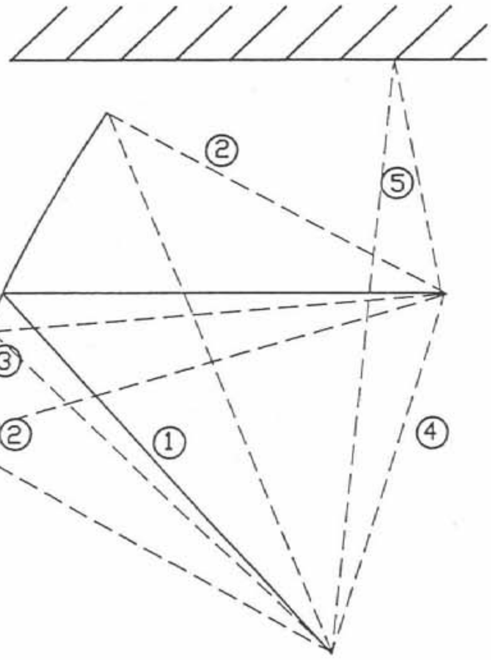
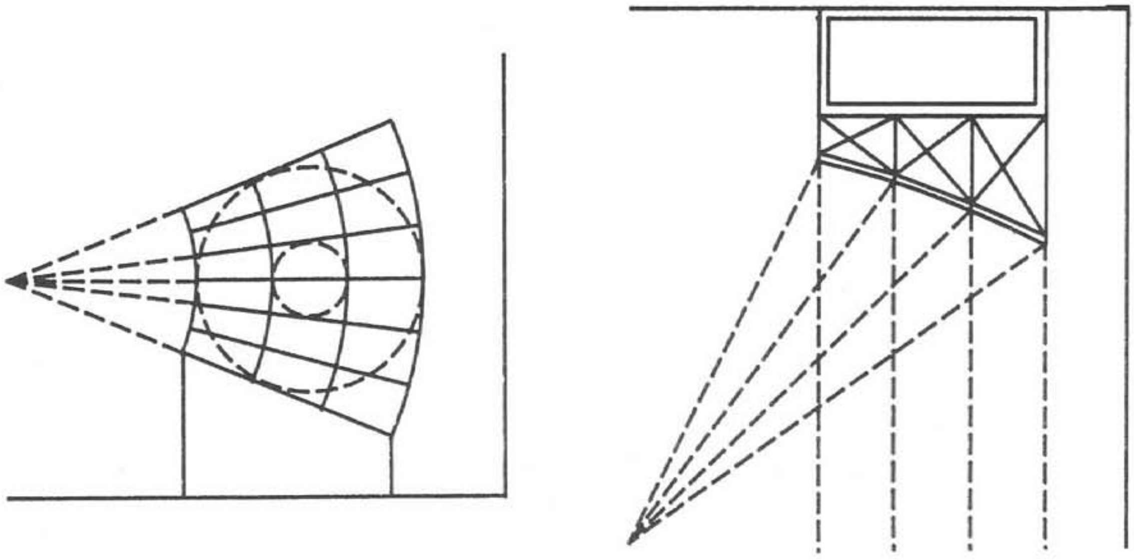


Fig. 2. Compact antenna range and distorting factors



SIDE VIEW

PLAN VIEW

Fig. 3. QMC millimetrewave compact antenna range