Measuring Satellite Antennas with a Compact Hologram Test Range

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ABSTRACT

Testing of satellite antennas at high millimeter and submillimeter wavelengths has some specific problems not encountered at lower frequencies. The atmospheric attenuation due to water and oxygen molecule resonances at certain frequency bands can be substantial. Therefore, conventional far-field test methods for electrically large antennas are ruled out by the required far-field distance of kilometers or even tens of kilometers. However, the compact antenna test range (CATR) makes such far-field tests possible within an indoor chamber having a controlled atmosphere. The application and ongoing development of a CATR based on a hologram as the focussing element are outlined in this paper.

INTRODUCTION

Satellite antennas and instruments operating at millimeter and submillimeter wavelengths are needed for many scientific space missions. These include the European Space Agency's (ESA) missions Planck and Herschel Space Observatory for astronomy, and MASTER for Earth observation [1]. The diameters of the involved reflector antennas range from 0.5 to 3.5 meters, and operating frequencies from 200–3000 GHz. Accurate electrical and functional testing of these high frequency systems has necessitated the recent development of nonconventional methods. The most feasible techniques for electrically large antennas are the near-field scanning method and the compact antenna test range (CATR). They use reasonably-sized chambers having a controlled atmosphere and temperature. The near-field method requires sampling of the antenna aperture field with a very dense scanning grid, thus extending the measuring time even to several days. The inherent instrumentation instabilities during the long acquisition time make this scheme impractical for electrically large antennas.

The CATR is based on the idea of generating an artificial plane wave from an incoming spherical wavefront with the help of a set of reflectors, a lens, or a hologram. The volume where an accurate plane wave is present is called the quiet-zone, and it is where the antenna-under-test (AUT) should fit. The CATR allows direct measurement of the antenna far-field pattern with relatively small distance between the source and receiver, thus with little attenuation. Reflector CATRs have been employed at frequencies up to 200 GHz, the surface inaccuracy of the reflector limiting the highest operating frequency. The surfaces of the AUTs are already made as accurate as possible and to be able to test these, the CATR reflector should be 20–30% larger and have substantially better surface accuracy. If an accurate enough reflector can be made, it will be very costly. Lens-type CATRs are not suitable for submm-wave operation due to manufacturing and material difficulties. The hologram CATR has some advantages over reflectors, the most important being the less stringent surface accuracy demand and potentially lower manufacturing costs.

THE HOLOGRAM CATR

The most recently introduced CATR collimator is the binary amplitude hologram. It was introduced for antenna measurements by HUT Radio Laboratory in 1992 [2]. The amplitude hologram is a slot pattern etched on a thin copper-plated polyester film. Conventional printed-circuit board techniques or more advanced laser processing can be used for manufacturing. The hologram optimization process is a combination of the finite difference time domain (FDTD) and physical optics (PO) methods [3]. The hologram is a transmission-type device and has less stringent surface accuracy demands compared to the reflector, making it more suitable for high frequency operation. Figure 1, on next page, shows the layout of the CATR and a typical hologram pattern.

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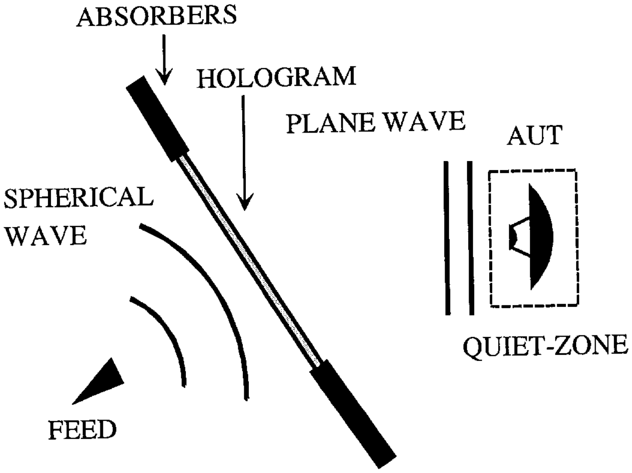

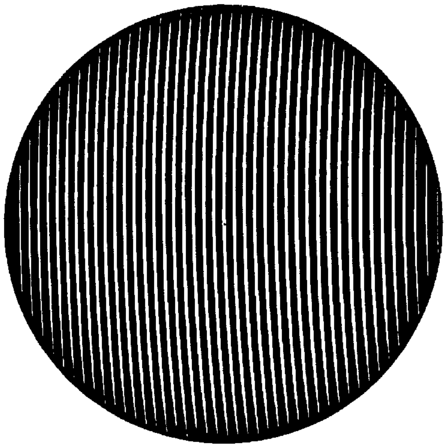

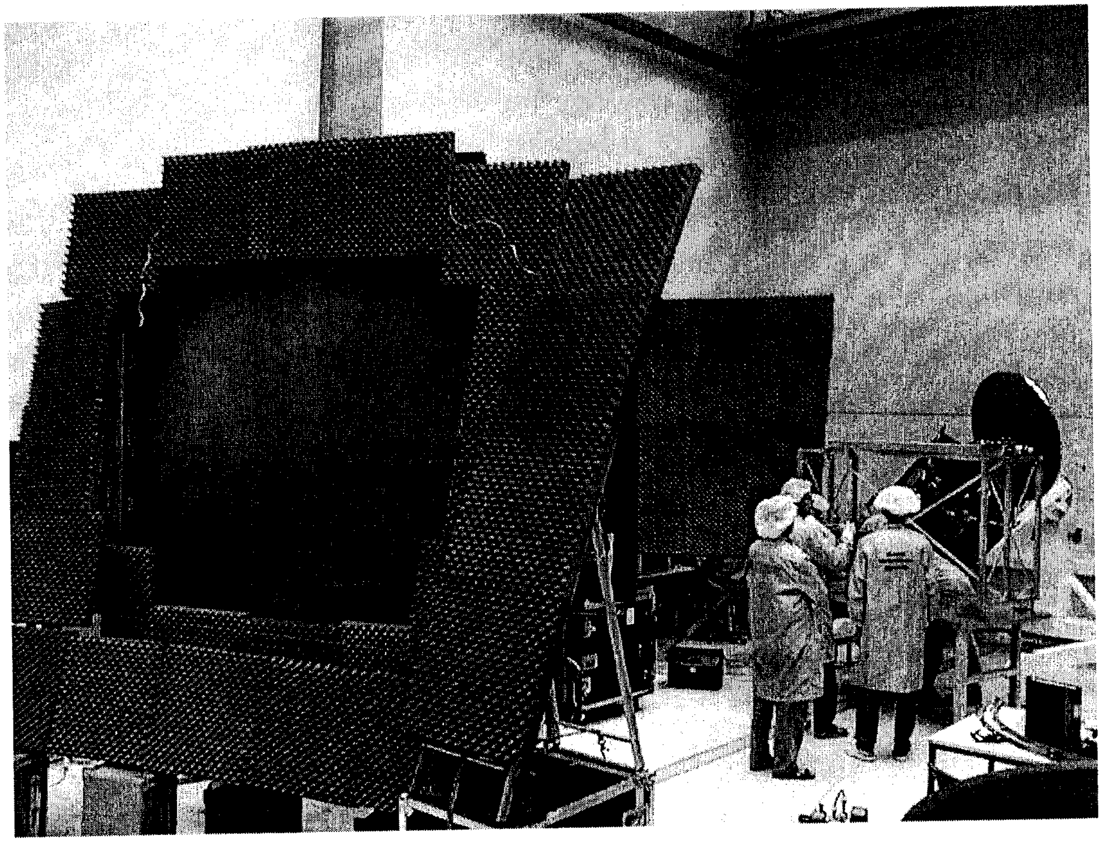

Fig. 2. The Odin spacecraft positioned for testing with a hologram CATR at 119 GHz

The hologram is designed to generate the plane wave to an angle of 33° from the hologram normal in order to prevent the unwanted diffraction modes (see Figure 8, on page 18) propagating along the normal from disturbing the quiet-zone.

The quality of the quiet-zone field has to be verified before the CATR can be put into operation. An alignment of the collimating element is also needed before the quiet-zone requirements are met. Testing of electrically large narrow beam telescopes typically requires peak-to-peak amplitude and phase ripples inside the quiet-zone to be below 1 dB and 10°, respectively.

We use a planar near-field scanner for the quiet-zone field verification procedure. The sampling vector receiver is moved across the quiet-zone area, and two-dimensional amplitude and phase maps are obtained. Recently, we have found out that the phase measurement accuracy of the system can be improved by

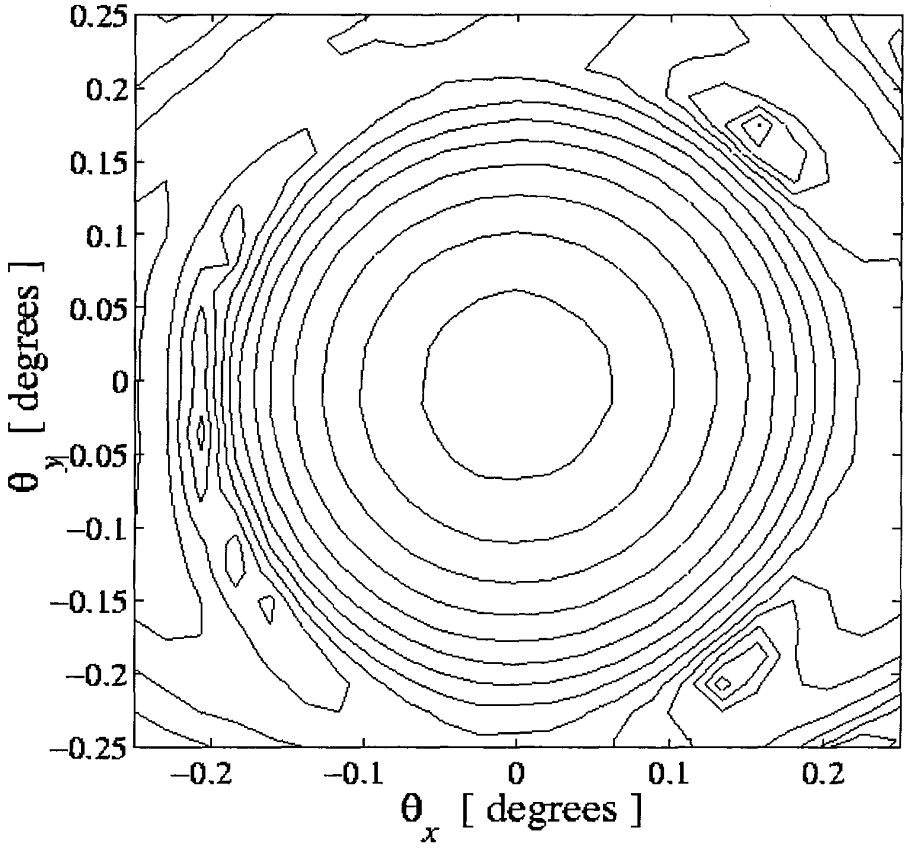

Fig. 3. The measured main beam of the Odin telescope assembly at 119 GHz

measuring and correcting the phase errors generated by the flexing microwave cable connected to the receiver. The phase correction subsystem is based on the use of a pilot signal to measure changes in the electrical length of the cable caused by flexing. A detailed description of this system can be found in [4].

TESTING OF THE ODIN SPACECRAFT

The Odin satellite was successfully launched into low Earth orbit in February 2001. It observes both aeronomical and astronomical molecular spectral lines. Odin has an offset telescope antenna with diameter of 1.1 meters and heterodyne receivers for several frequencies between 119–580 GHz. The telescope was tested at 119 GHz with a hologram CATR in August 1998 [5]. The size of the used hologram was 2.4 ×2.0 m^2, and it was spliced together from seven pieces with polyester tape. The maximum size of one piece is 1.2×1.0 m^2, and it is located in the center of the hologram. The measured worst peak-to-peak amplitude ripple in the quiet-zone width of 1.4 meters is 3 dB. However, the ripple is below 1.5 dB in most parts. The spacecraft positioned for testing at the Saab Ericsson Space facilities in Linköping, Sweden is shown in Figure 2, on previous page.

The main beam of the telescope was measured by feed scanning, i.e., steering the plane wave direction by transverse movement of the feed system. Feed scanning eliminates the need to rotate the spacecraft assembly. Unfortunately, only a small angular range can be covered by feed scanning and a rotational table is needed to cover the full angular range. The obtained symmetrical main beam pattern is shown in Figure 3 with contour spacing of 3 dB.

TESTING OF A SUBMM-WAVE CATR

In order to show the applicability of the hologram method for submillimeter wavelengths, a demonstrator CATR has been designed for operation at 310 GHz. The diameter of the hologram is 60 cm, and its focal length is 1.5 meters. The test setup in our laboratory is shown in Figure 4, on next page. The near-field scanner used to measure the quiet-zone fields is shown on the left, the hologram in the middle, and the feed system on the right. The measured quiet-zone amplitude and phase at a distance of 1.5 meters along the horizontal centerline of the hologram are shown in Figure 5, on next page. The width of the quiet-zone is about 25 cm and the maximum height about 20 cm. The complete co- and cross-polar test results for the demonstrator are presented in references [6] and [7].

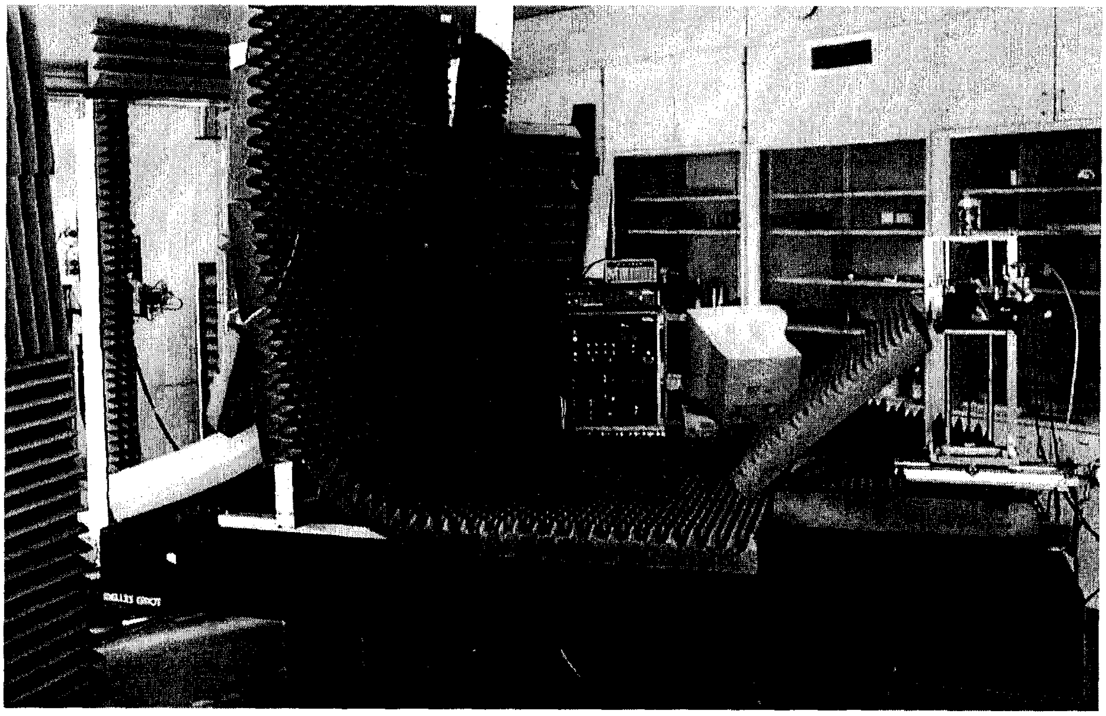

Fig. 4. Submm-wave hologram CATR demonstrator at 310 GHz

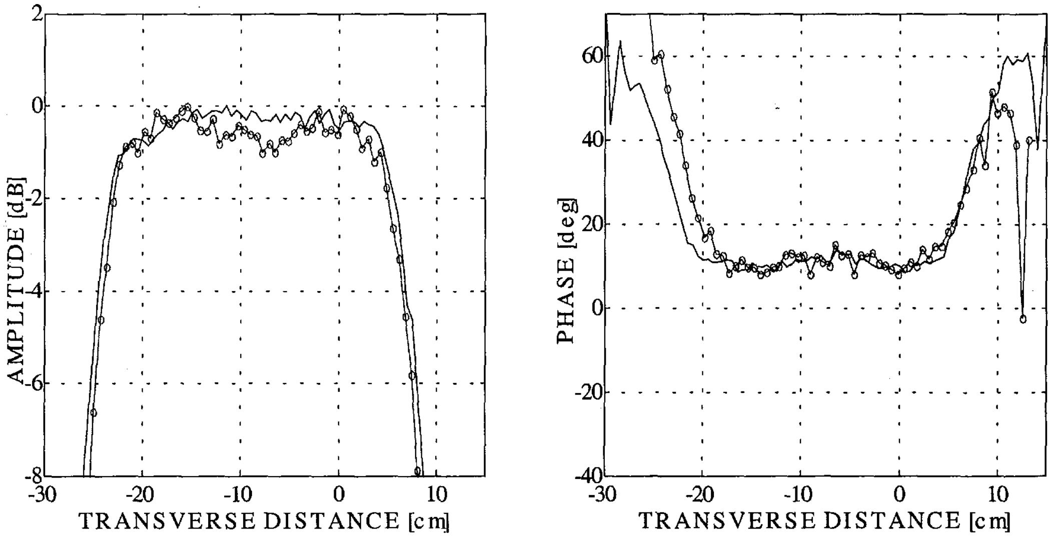

Fig. 5. Measured (line with circles) and calculated amplitude and phase along the horizontal centerline of the quiet-zone at 310 GHz

FUTURE IMPROVEMENTS

The ongoing ESA project in HUT Radio Laboratory involves development of two novel hologram CATRs. The one is intended to be suitable for testing the ESA ADMIRALS technology demonstrator antenna at 322 GHz. The diameter of the main reflector antenna is 1.5 m and the quiet-zone diameter has to be at least 1.8 m. A hologram of 3 m in diameter is found to be adequate. The other one is for demonstrating the feasibility of the technique at the frequency range of 500–1000 GHz. Operational frequency of 650 GHz was chosen because suitable instrumentation was available at this frequency. A diameter of 1 m for the 650 GHz hologram was chosen as the maximum size which can be manufactured in a single piece with the required accuracy. In both CATRs, a horn is used as

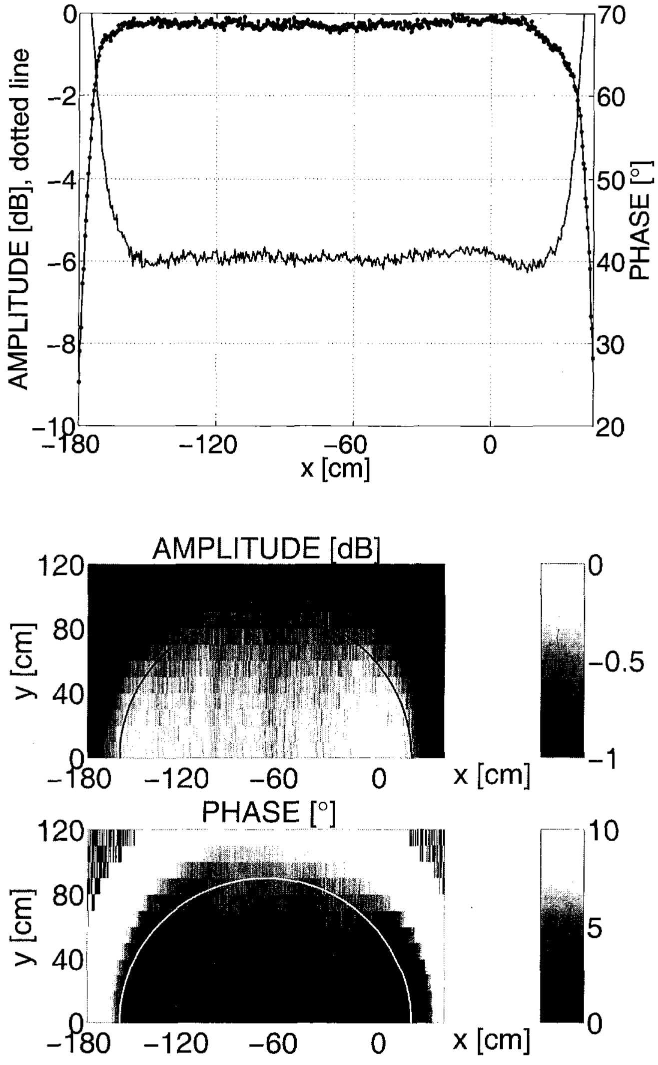

Fig. 6A. (top) and Fig. 6B. (Bottom) Simulated quiet-zone fields of the 322 GHz hologram CATR

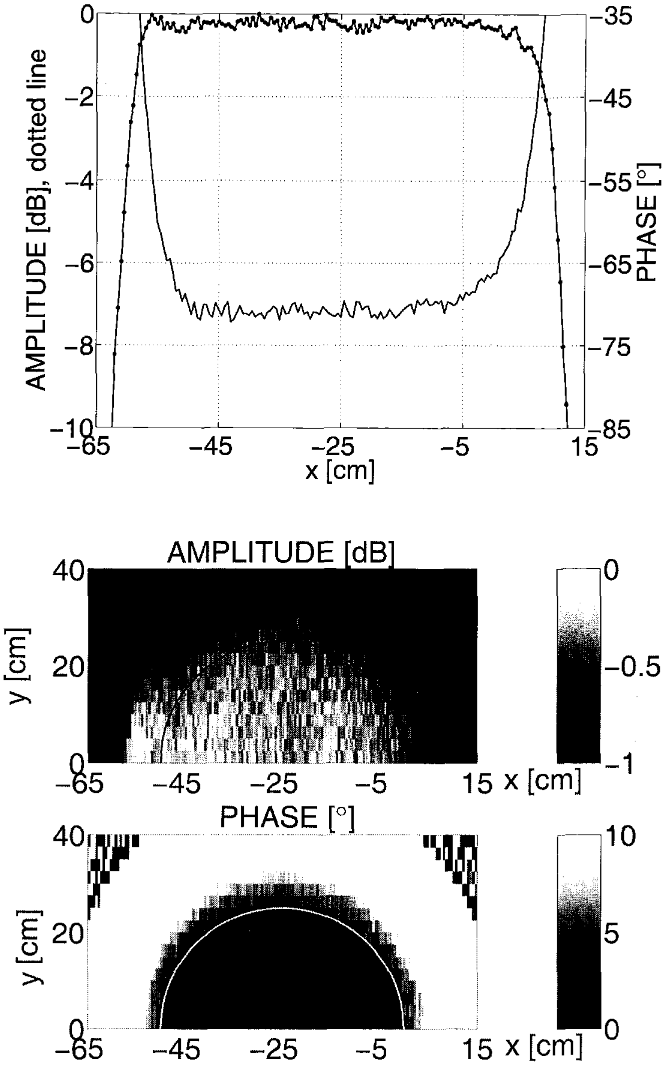

Fig. 7A. (top) and Fig. 7B. (Bottom) Simulated quiet-zone fields of the 650 GHz hologram CATR

the feed antenna (see Figure 1). The distance between the feed and the hologram is 3D, where D denotes the diameter of the hologram. The quiet-zone is optimized at a distance of 3D from the hologram.

The almost completed design process has been quite straightforward due to the experience gathered in earlier projects. Nevertheless, the manufacturing of the holograms is a challenging task. Both holograms are planned to be manufactured using wet etching combined with a direct laser writing of the pattern. The accuracy of the direct laser writing is about 5 μ – estimated to be sufficient also at 650 GHz. The hologram patterns are etched on a thin copper-plated polyester film (5 μ copper, 50 μ polyester). Due to the lack of 3 m wide polyester film and an appropriate manufacturing capability, the 322 GHz hologram has to be fabricated from three separately etched 1 m wide horizontal pieces which will be joined together. In earlier experiments, tape and glue have been used for joining. Now, also soldering has been found to have some potential.

Simulated quiet-zone fields at a distance of 3D are shown in Figure 6 and Figure 7. The horizontal and vertical directions in the quiet-zone are denoted as x and y, respectively The field along the horizontal center line of the quiet-zone (y = 0) is shown in the left hand side and the field in the upper-half of the xy-plane is shown in the right hand side (the circles have diameters of 1.8 m and 0.5 m and they indicate the required quiet-zone size). As can be seen, the quiet-zone sizes of the 322 and 650 GHz holograms are greater than 1.8 m and 0.5 m, respectively. The simulated peak-to-peak amplitude and phase ripples are less than 0.6 dB and 4° for both holograms.

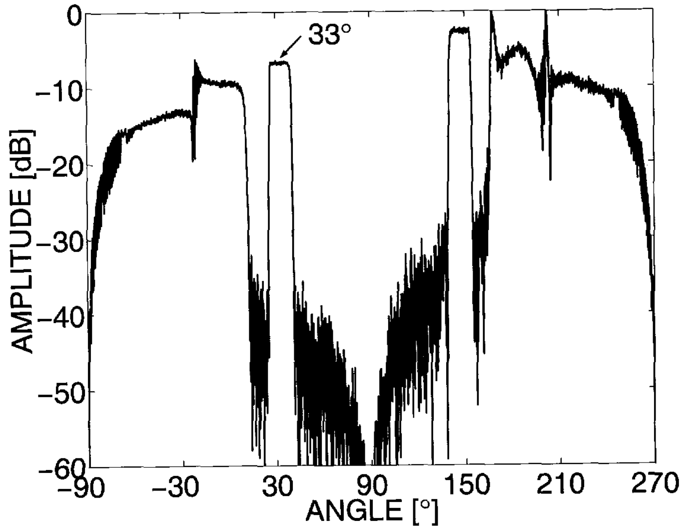

Fig. 8. Diffracted beams from the 650 GHz hologram at a distance of 3 m

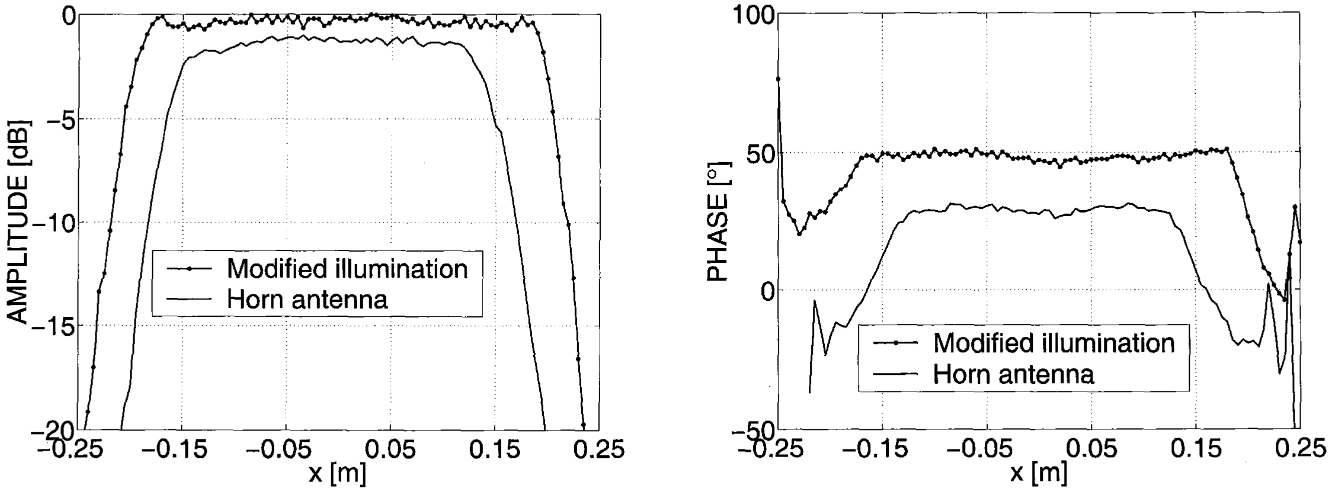

Fig. 9A (l) and Fig. 9B (r)
The increase in the quiet-zone size with modified hologram illumination

The hologram diffracts several beams in different directions as can be seen in Figure 8 for the 650 GHz hologram.

The beam marked by an arrow at the angle of 33° from the hologram normal is the desired plane wave of the quiet-zone field. When the other beams are reflected from Enclosure walls, they can cause significant errors in the measurements. To ensure good performance of the CATR, absorbing material has to be placed in appropriate places to prevent disturbing reflections. The reflectivities of several commercial submillimeter wave absorber materials have been measured [8].

The results show that even at these high frequencies, reflectivities below –30 dB can be achieved for most angles of incidence. Selection of the best material for the most critical locations is crucial for the submillimeter wave CATR operation.

The quiet-zone area of the hologram compact antenna test range can be increased by modifying the illuminating electromagnetic field of the hologram. An amplitude taper is needed to reduce edge diffraction in the hologram pattern. This tapering has been accomplished by narrowing the slots in the hologram pattern at the edges. The narrowing of the slots leads to manufacturing difficulties at submillimeter wave frequencies. The amplitude taper can be realized into the hologram illumination, which also enlarges the achievable quiet-zone size of the hologram.

The predicted increase in quiet-zone size of a 60 cm hologram at 310 GHz by using modified illumination is shown in Figure 9. A Butterworth-type smooth illumination function with –7 dB edge taper was used in the simulations. In this specific case, the quiet-zone diameter is increased by approximately from 45% to over 60% of the hologram diameter, which is a significant improvement to the hologram operation. However, with a larger hologram the ratio of the quiet-zone size over the hologram size is larger [3], which decreases the achievable relative increase with the modified illumination.

The hologram illumination can be modified with a dual reflector feed system (DRFS). The reflectors change the radiation of a feed horn into the desired hologram illumination. The reflector surfaces of the DRFS are shaped and they can be designed with geometrical optics based reflector synthesis [9].

CONCLUSIONS

The hologram CATR is a potential method for testing electrically large radiotelescopes with reasonable costs compared to reflector CATRs. It has already been used at millimetre wave frequencies for measuring the 1.1 meter Odin telescope antenna at 119 GHz. We have demonstrated the validity of the design and manufacturing processes with a submillimeter wave demonstrator at 310 Ghz.

Future goals include testing of a 1.5 m class satellite antenna at 322 GHz, and constructing a technology demonstrator for 650 GHz. Modified illumination of the hologram by using shaped reflectors is also studied as a possible way to increase the relative quiet-zone size of the CATR.

ACKNOWLEDGMENTS

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