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A REFLECTION-TYPE AMPLITUDE HOLOGRAM AS A COLLIMATING ELEMENT IN THE COMPACT ANTENNA TEST RANGE

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ABSTRACT

In this paper, we study the possibility to use an amplitude hologram as a reflection-type collimating element to produce a plane wave in the compact antenna test range (CATR). So far, we have used holograms as transmission-type elements only. The hologram studied here has a diameter of 600 mm and it operates at the frequency of 310 GHz. It is a computer-generated slot pattern etched on a thin metal-plated dielectric film. We have simulated and measured the plane wave field reflected from the hologram. The maximum measured ripples are only 1.6 dB and 20°, peak-to-peak. The reflection-type hologram has some advantages over the transmission-type one. For example, the power loss is about 4 dB lower for the reflection-type hologram. In addition, a CATR based on the reflection-type hologram can be situated in a much smaller space. To demonstrate the capability of the reflection-type hologram in actual antenna testing, the radiation pattern of a small reflector antenna was measured at 310 GHz.

Keywords: Compact range, Hologram, Sub-millimeter wave

1. Introduction

In the Radio Laboratory of the Helsinki University of Technology (TKK), we are developing a new kind of compact antenna test range (CATR) that is based on the use of an amplitude hologram as the collimating element. The amplitude hologram (Figure 1) is a slot pattern that is generated by a computer and etched on a thin dielectric film [1]. For example, the hologram discussed here is manufactured on a 50-μm-thick Mylar film that has a 17-μm-thick copper layer atop. The slots on the hologram are 30-330 μm in width so that they are tapered towards the edges of the pattern to eliminate edge diffraction. The hologram operates at the vertically polarized electric field, as all amplitude holograms we have designed so far. The simulations and measurements presented here are all done for the vertically polarized electric field.

Especially, we are interested to develop a hologram based CATR for sub-millimeter waves where the need for novel testing methods for large reflector antennas lies in future. These antennas are used, e.g., in space research satellites. We have showed the capability of the hologram CATR by carrying out demanding antenna tests at 119 and 322 GHz [2, 3, 4]. In addition, we have demonstrated our method to be suitable up to 650 GHz where experimental tests have been done successfully [5, 6].

The reflector-based CATR is the conventional method for testing of large satellite antennas. However, at sub-millimeter wavelengths, a high surface accuracy, λ/100 [7], is required for reflectors, what makes manufacturing of them extremely difficult and highly expensive. We have used holograms as a transmission-type element because the surface accuracy requirement is then only λ/10 [8], which makes the use of holograms attractive also at high sub-millimeter waves.

The amplitude hologram has a planar structure and it can be manufactured relatively easily by using the conventional printed-circuit-board technology. Here, we study the possibility to use a hologram as a reflection-type element and consider advantages given by this method. Because of the planar structure and simple manufacturing the reflection-type hologram is considered to be still much easier and less expensive to manufacture than a conventional reflector that satisfies the required surface accuracy.

In this paper, we show by simulations that an amplitude hologram designed originally for the transmission-type setup operates also as a reflection-type element. Measurement results are used to verify the high quality of the reflected plane wave field (i.e., the quiet-zone field). Testing of a small reflector antenna at 310 GHz shows that the reflection-type hologram can be used as the collimating element in CATR. For comparison, all simulations and measurements are done also for the hologram in the transmission-type setup.

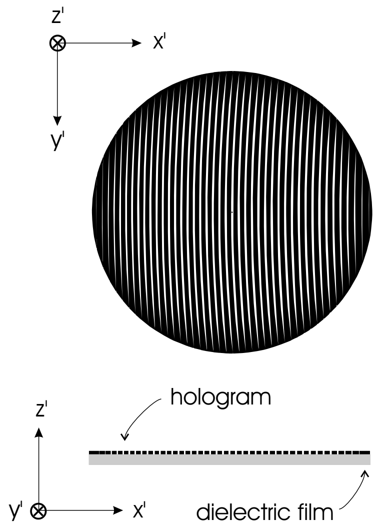

Figure 1. An amplitude hologram. Slots are in white, metal strips in black.

2. The Reflection-type Hologram Setup

2.1 The Operational Principle

When the hologram is illuminated with a feed antenna (typically a corrugated horn) it diffracts several beams into different directions [9]. According to simulations presented here, the hologram produces two high-quality plane waves, which can be used in CATR; one of the plane waves is transmitted through the hologram, the other is reflected. We have typically designed holograms so that the transmitted plane wave propagates in an angle of 33° with respect to the normal of the hologram surface. In this way, the desired plane wave is separated from the other beams so that they will not cause disturbances in the quiet-zone where the antenna under test is located. The reflected plane wave propagates also in a 33°-angle with respect to the surface normal but from the other side of the hologram. The unwanted beams are terminated to absorbers to eliminate reflections.

Figure 2 shows the CATR studied in this paper. The hologram is in the reflection-type setup. The hologram has a diameter of 600 mm and it operates at 310 GHz. It is designed originally for the transmission-type operation. In the reflection-type setup, the feed (a corrugated horn) is placed at a distance of 1.8 m. Its orientation in respect to the hologram is chosen to produce an optimal illumination in the hologram aperture. In the transmission-type setup, the feed is exactly in the same orientation in respect to the hologram but on the other side. The quiet-zone is optimized at a distance of 1.8 m from the hologram.

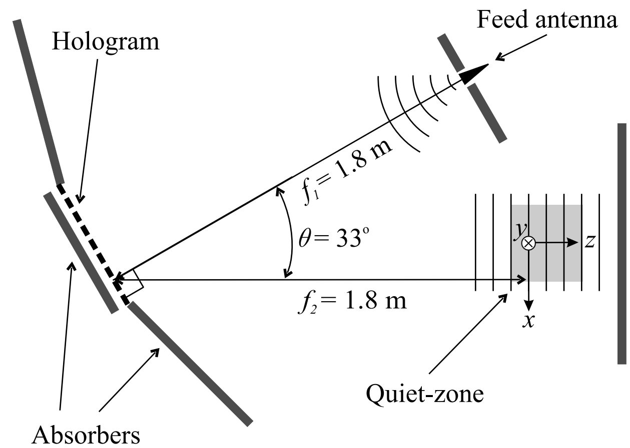

Figure 2. The CATR based on the reflection-type hologram studied in this paper.

2.2 Simulation of the Quiet-zone Field

The operation of the hologram can be simulated by using the FDTD (Finite-Difference Time-Domain) method [1, 10]. In the FDTD simulation, the hologram structure is illuminated with a feed horn radiation and the field transmitted through the hologram or reflected from it is computed. The FDTD gives only the field in the vicinity of the hologram; the field in the quiet-zone is calculated from this field by using physical optics.

Figure 3 shows the simulated horizontal cut of the quiet-zone field for the 600-mm hologram at 310 GHz. Both the reflected and transmitted plane waves are simulated. It can be noticed that the amplitude and phase ripples are slightly higher for the reflected plane wave, 0.7 dB and 5°, peak-to-peak. For the transmitted plane wave, the ripples are 0.3 dB and 3°, peak-to-peak. The ripples are larger for the reflected plane wave because the hologram is not optimized for the reflection-type operation. However, the ripples in both cases are well within the 1-dB/10°-requirement typically set for the quiet-zone field quality. The size of the quiet-zone is the same in both cases.

It is also worth noticing that the amplitude is ca. 3 dB higher for the reflected plane than for the transmitted one resulting to a higher dynamic range in measurements. The losses caused by the hologram are discussed in the end of Section 3.2.

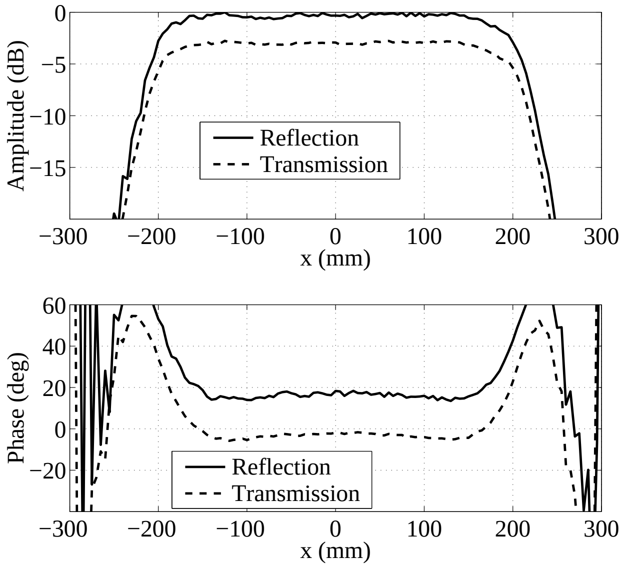

Figure 3. Simulated horizontal cut of the quiet-zone for the reflection- and transmission-type holograms.

3. Quiet-zone Measurements

3.1 Measurements

The simulation results were verified by measurements. The quiet-zone field was measured at 310 GHz with a millimeter wave vector network analyzer (AB Millimètre MVNA-8-350) and a planar near-field scanner. The non-planarity of the scanner had been measured earlier and it is removed computationally from the phase results. Figure 4 shows the measured horizontal cut of the quiet-zone field at 1.8 m from the hologram. Figure 5 shows the vertical cut, respectively. The measurement results both in the reflection- and transmission-type setups are shown. The peak-to-peak amplitude and phase ripples are ca. 1.6 dB and 20° in the reflection-type setup and they are ca. 1.2 dB and 10° in the transmission-type setup. The size of the quiet-zone remains approximately the same in both setups. According to measurements, the amplitude level is ca. 4 dB higher for the reflection-type hologram.

In the reflection-type setup, the quiet-zone was measured by placing an absorber wall behind the hologram at several distances between 2-50 cm (see Figure 2). Also, a measurement was done when the absorber wall was removed so that there was a free space of ca. 3 m in depth behind the hologram. The absorber wall was made of pyramidal millimeter wave absorbing material (Eccosorb VFX-NRL-2). No difference was seen in the quiet-zone field quality between the measurements, i.e., the absorbing material seems to have no effect on the operation of hologram. Therefore, the reflection-type hologram can be placed against an absorber-coated wall and the space required for the CATR can be reduced to a half of that needed in the transmission-type setup. The measurements with the reflection-type hologram are done with the absorber wall placed at ca. 2-cm-distance behind the hologram.

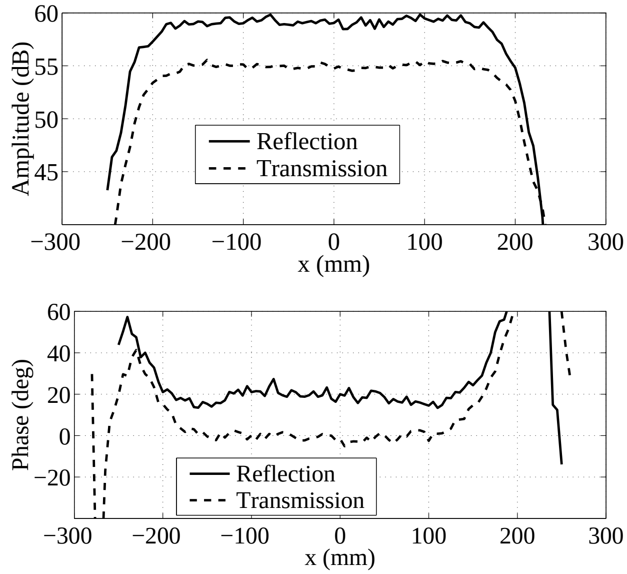

Figure 4. Measured horizontal cut of the quiet-zone for the reflection- and transmission-type holograms.

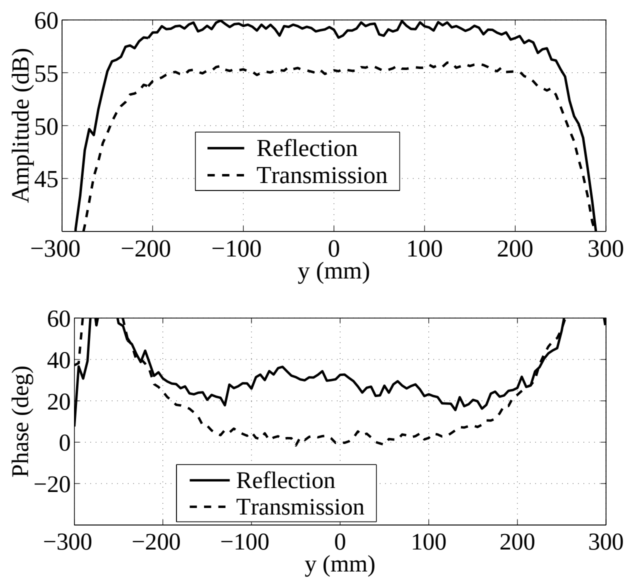

Figure 5. Measured vertical cut of the quiet-zone for the reflection- and transmission-type holograms.

3.2 Analysis of the Measurement Results

The amplitude and phase ripples are larger for the reflection-type hologram. As shown by the simulations, this is partly because the hologram is not optimized for the reflection-type operation. The measured ripples are larger than the simulated ones for both holograms. This is apparently caused by manufacturing inaccuracies of the hologram pattern, as well as the surface planarity errors. The hologram was manufactured by using photolithography based on a photo mask and chemical wet-etching. Higher manufacturing accuracy could be achieved by using a direct laser writing of the pattern to the photo resist atop of the hologram substrate. The effect of surface planarity errors is larger for the reflection-type hologram, which explains partially the larger ripples in the reflected plane wave. An adequate surface planarity of the transmission-type hologram is ensured by tensioning it to a rigid frame. Good results indicate that this method is suitable also for the reflection-type hologram.

According to measurements, the amplitude levels for the reflection- and transmission-type holograms differ by 4 dB that is ca. 1 dB larger than the simulated result. This can be caused by a slight systematic manufacturing error that has a different effect on the amplitude level depending on the setup.

The power loss of both holograms was measured. A part of the transmitted power is lost due to a spill-over of the feed radiation. In addition, some power propagates in the other diffraction modes (beams) produced by the hologram. The power loss caused by the hologram itself was measured in both setups. The measured quiet-zone amplitudes were compared to the direct radiation of the feed horn placed at a distance of 1.8 m from the receiver. By this method, the power loss caused by the reflection-type hologram is estimated to be 7.4 dB. The power loss caused by the transmission-type hologram is estimated to be 11.4 dB, respectively.

The measured phase is slightly different between the different setups. This is due to the fact that when the setup is changed the location of the feed does not remain exactly the same in respect to the hologram. A small change in the feed location affects mainly the phase, not the amplitude of the quiet-zone field.

4. Antenna Measurements

The antenna pattern of a small dielectrically-loaded reflector antenna was measured at 310 GHz to verify that the reflection-type hologram is suitable for actual antenna testing. The test antenna has been designed and constructed in the Radio Laboratory [11]. It is used as a test object in antenna testing, e.g., in development of the hologram-based CATR. The antenna consists of a flat main reflector of 120 mm in diameter, which has a dielectric loading made of Teflon atop. A flat sub-reflector directs the corrugated feed horn radiation to the main reflector. The test antenna was placed on a rotation stage so that it could be rotated in the azimuth direction.

Figure 6 shows the measured radiation pattern in the azimuth plane from –15° to 15°. Figure 7 shows the close-up of the main beam. The antenna pattern measured with the transmission-type hologram is shown for comparison. The radiation patterns agree very well. Therefore, it can be concluded that the reflection-type hologram is suitable for antenna measurements.

Small variations between the radiation patterns can be caused by the different ripples and deviations in the quiet-zone fields, as well by the different reflections from the surroundings.

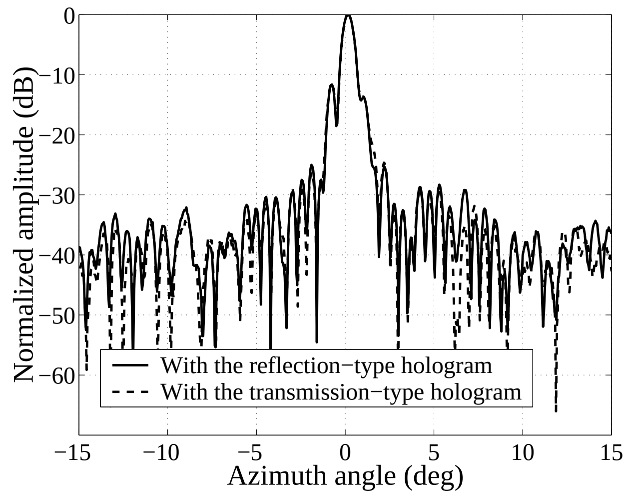

Figure 6. Antenna radiation pattern in the azimuth plane at 310 GHz measured with the reflection- and transmission-type holograms.

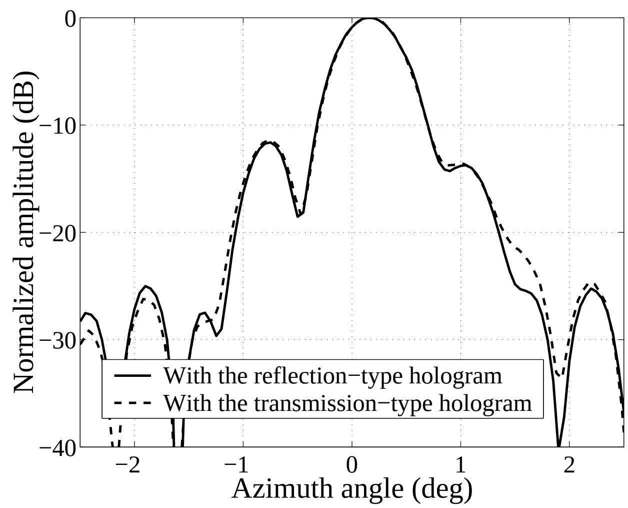

Figure 7. Close-up of the antenna main beam.

5. Conclusions

So far, we have used holograms only as transmission-type collimating elements in the compact antenna test range. Now, we have studied the possibility to use an amplitude hologram as a reflection-type collimating element. The simulations and measurements done here for a 600-mm hologram at 310 GHz show that a high-quality plane-wave is also reflected from the hologram. The measured ripples for the reflected plane wave are at maximum 1.6 dB and 20°, peak-to-peak, and they are only slightly larger than the ripples for the transmitted plane wave. Larger ripples in the reflected plane wave are partly because the hologram is not designed for the reflection-type operation but for the transmission-type operation. Also, surface planarity errors have a larger effect in the reflection-type operation. The antenna radiation pattern measurement of a small test antenna shows that the reflection-type hologram is suitable for actual antenna testing.

The planar structure and simple manufacturing of the amplitude hologram make it easier to accomplish the manufacturing accuracy requirements than it would be in the case of conventional reflectors. Therefore, a reflection-type hologram can be considered to be suitable also for sub-millimeter waves. The simple method to ensure the high planarity of the hologram by tensioning it to a frame is adequate also for the reflection-type hologram.

According to this study, the reflection-type hologram has some advantages over the transmission-type hologram. First, the hologram can be placed against an absorber-coated wall so that the space required for the CATR can reduced to a half. In addition, its power efficiency is about 4 dB higher than that of the transmission-type hologram.

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