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Performance of a Small 650 GHz Hologram

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Abstract

For the first time, we present measurement results of a small amplitude hologram operating at 650 GHz. The hologram transforms an incident spherical wave to a plane wave which can be used in a compact antenna test range (CATR). Preliminary measurement results are encouraging: they agree fairly well with simulations.

1 INTRODUCTION

The compact antenna test range (CATR) is a feasible method for testing large reflector antennas at mm-wave frequencies [1, 2]. In CATR, a focusing element transforms a spherical wave radiated by a feed antenna (e.g, a horn) to a plane wave. The antenna under test (AUT) is illuminated by the plane wave, and the radiation pattern can be measured simply by rotating the AUT. To ensure a sufficient measurement accuracy, the amplitude and phase ripples should not exceed certain criteria in the region (called a quiet-zone) around the AUT. The criteria for ripples are typically 1 dB and 10 degrees, peak-to-peak, respectively. In this work, we have started to extend this antenna testing method to high submm-wave frequencies.

The focusing element of a CATR is conventionally a set of 2-3 reflectors. At submm-wave frequencies, reflectors suffer, however, from a very tight surface accuracy requirement ($\sim \lambda/100$) which makes their fabrication difficult and highly expensive. We are developing a CATR based on a hologram, Figure 1. As the hologram is a transmission-type element its surface accuracy requirement ($\sim \lambda/10$) is much lower.

A hologram diffracts several beams into different directions. One of them is the plane wave used in measurements, the others are damped by absorbers. The plane wave propagates intentionally in a tilted angle of 33 degrees with respect to the normal of the hologram. This prevents the other diffraction modes produced by the hologram from disturbing the quiet-zone field.

The hologram pattern used in CATR is generated by computer. It is a slot pattern, which has been etched on a metal layer on top of a thin dielectric film. Sufficient flatness is ensured by tensioning the hologram to a stiff frame. An example of pattern is shown in Figure 2 where radio-transparent slots are in white and metal stripes between them in black. The slots have been tapered towards the edge of the hologram to reduce edge diffraction.

Due to some factors (e.g., a dielectric film, an edge diffraction and a non-ideal transmittance of slots) which are not taken into account in the hologram generation, the initial hologram pattern does not directly produce a quiet-zone adequate for antenna measurements. The hologram pattern can be modified appropriately and the quiet-zone field optimized by using a simulation method of our own based on the FDTD (Finite-Difference Time-Domain) method and physical optics [3].

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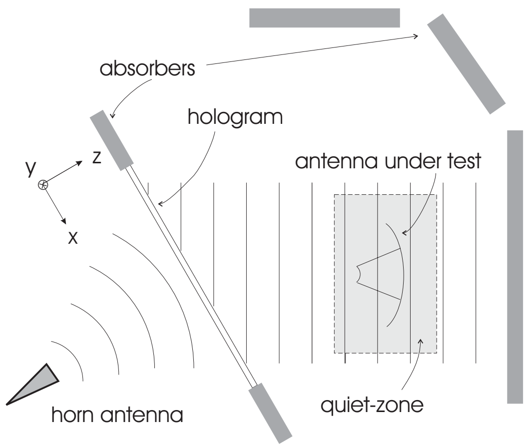

Figure 1: A schematic layout of hologram based CATR.

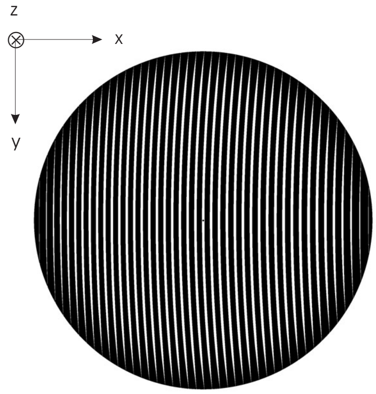

Figure 2: An example of hologram pattern used in CATR. Slots are in white, metal stripes in black.

2 A SMALL HOLOGRAM FOR 650 GHZ

In the ongoing work, we first demonstrated our methods to be appropriate to design and fabricate small holograms at 322 GHz. No significant obstacles have been seen to utilize these methods at even higher frequencies. Now we have designed and fabricated a small hologram for 650 GHz which has a diameter of 0.3 m.

2.1 Design and Simulation

The hologram pattern was generated with an accuracy of 5 μm which should be adequate at 650 GHz. A suitable material was found to be a 25 μm thick Mylar film plated with a 5 μm thick copper layer. A thicker film, previously used at lower frequencies, would now result in internal reflections inside the film disturbing the quiet-zone field. Holograms up to 1 m wide can be fabricated in a single piece on this 25 μm film.

The transmitting horn is placed at a distance of 0.9 m from the hologram. The optimized quiet-zone is also at 0.9 m from the hologram. The widths and spacings of slots along the horizontal center line are shown in Figure 3. The widths vary from 30 to 170 μm, and the number of slots is 415. Slots are separated by metal stripes which are 460-925 μm wide.

The simulated quiet-zone field along a horizontal cut $y = 0$ at a distance of 0.9 m is shown in Figure 4. The width of the quiet-zone is about 0.15 m. The amplitude and phase ripples are less than 0.5 dB and 5 degrees, peak-to-peak, respectively.

2.2 Fabrication

Fabrication was done outside MilliLab. The pattern was exposed with a laser directly to a photo resist on top of the film. After this, the pattern was wet-etched. The laser exposure eliminates the need for using masks, and thus increases the accuracy of fabrication process. The nominal accuracy of exposure is 5 μm. We have used this method successively to fabricate small (0.3 m) test holograms for 322 GHz. Preliminary inspection shows this method to work well also for fabricating holograms for 650 GHz. The method allows etching slots down to 30 μm wide. It has been noticed by visual inspection that also the tapered slots at the hologram edge have been etched completely. Therefore, the edge tapering should work properly.

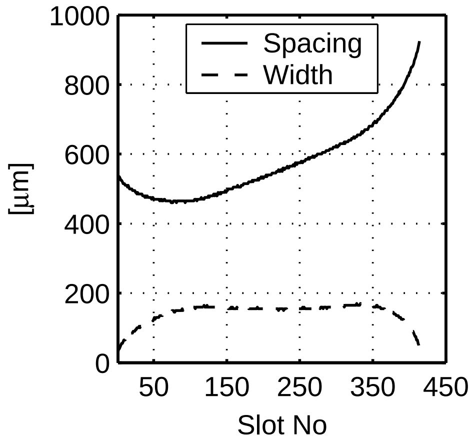

Figure 3: Widths and spacings of slots along the horizontal center line of the hologram.

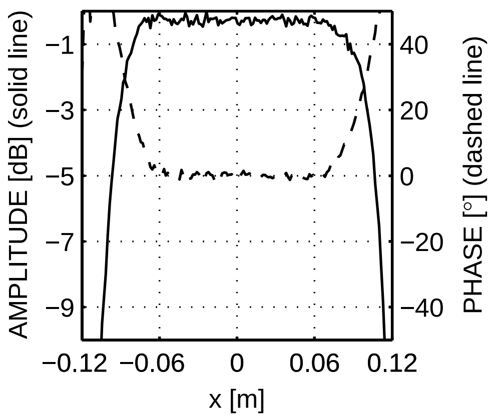

Figure 4: Horizontal cut ($y = 0$) of simulated quiet-zone field at 0.9 m from the hologram.

3 MEASUREMENT RESULTS

The preliminary measurements were done using a Gunn oscillator and a frequency multiplier as the power source at the transmitting end. Currently, this allows only a dynamic range of about 20 dB, that increases apparently the amplitude and phase ripples in the measured results. Estimated uncertainty is 1 dB and 4 degrees. The measured amplitude at a distance of 0.9 m from the hologram along a horizontal cut $y = 0$ is shown in Figure 5(a), and along a vertical cut $x = 0$ in Figure 5(b). The width of the quiet-zone is about 0.16 m in the horizontal direction, and about 0.2 m in the vertical direction. The amplitude ripple is about 2.5 dB, peak-to-peak.

The phase measurements show 25 degrees peak-to-peak variation but they are not presented in this paper due to a considerable estimated phase uncertainty in the measurements. The phase uncertainty is partly due to a small dynamic range, but also due to flexing of measurement cables in the planar scanner during a measurement run, and due to a planarity error of the scanner.

A real-time phase correction system has been developed at the HUT Radio Laboratory to reduce the phase error caused by flexing cables [4]. It has been used successfully at 310 GHz and it is going to be used also in the further measurements at 650 GHz.

The planarity of our 1.5 m × 1.5 m planar scanner has been measured recently. The planarity over a 0.6 × 0.6 m^2 area was found to be 90 μm peak-to-peak with a standard deviation of 20 μm. The repeatability of the scanner was also tested. Because of a good repeatability the planarity error may be corrected in the quiet-zone scanning.

A BWO (backward wave oscillator) enabling a much larger dynamic range will be used in further measurements. Also, the phase correction system and the correction of planarity error of the scanner are going to be utilized in future.

4 CONCLUSIONS

In this paper, we present preliminary measurement results of a small hologram operating at 650 GHz. The measurements were done using a Gunn oscillator and a frequency multiplier as a transmitter, and a harmonic mixer as a receiver. Therefore, the dynamic range was only about 20 dB. Preliminary results are encouraging: design and fabrication process are feasible. Further investigations will tell more about hologram's capability to operate as a focusing element of CATR also at submm-wave frequencies above 600 GHz.

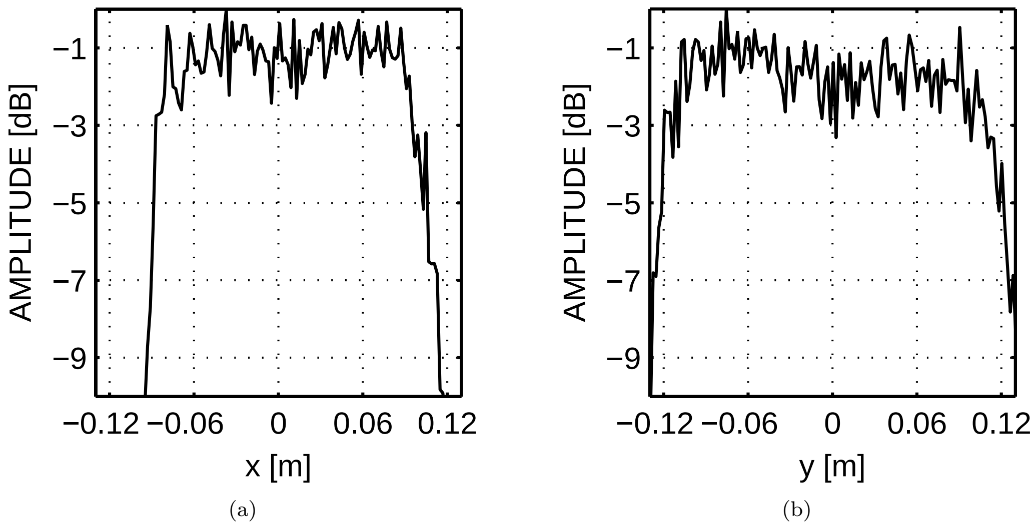

Figure 5: Measured amplitude of the quiet-zone field at 0.9 m from the hologram: (a) along a horizontal cut $y = 0$, (b) along a vertical cut $x = 0$.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

[1] J. Ala-Laurinaho, T. Hirvonen, P. Piironen, A. Lehto, J. Tuovinen, A. V. Räisänen, and U. Frisk, "Measurement of the Odin Telescope at 119 GHz With a Hologram-Type CATR," *IEEE Transactions on Antennas and Propagation*, vol. 49, no. 9, pp. 1264-1270, 2001.

[2] T. Hirvonen, J. Ala-Laurinaho, J. Tuovinen, and A. V. Räisänen, "A compact antenna test range based on a hologram," *IEEE Transactions on Antennas and Propagation*, vol. 45, no. 8, pp. 1270-1276, 1997.

[3] J. Ala-Laurinaho, T. Hirvonen, J. Tuovinen, and A. V. Räisänen, "Numerical modeling of a nonuniform grating with FDTD," *Microwave and Optical Technology Letters*, vol. 15, no. 3, pp. 134-139, 1997.

[4] J. Säily, P. Eskelinen, and A. V. Räisänen, "Measurement and correction of the phase errors introduced by flexible cables in submm-wave planar near-field testing," *Proceedings of the 23 rd Annual Meeting & Symposium of the Antenna Measurement Techniques Association (AMTA)*, Denver, CO., USA, October 21-26, 2001, pp. 78-83.