A PHASE HOLOGRAM BASED COMPACT RCS RANGE FOR SCALE MODELS

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ABSTRACT

A compact radar cross section (RCS) test range for scale model measurements is being developed. The test range is based on a phase hologram that converts the feed horn radiation to a plane wave needed for RCS determination. The measurements are performed at 310 GHz using continuous wave operation. A monostatic configuration is realized using a dielectric slab as a directional coupler. The main advantage of a scale model RCS range is that the dimensions of radar targets are scaled down in proportion to the wavelength. Therefore, RCS data of originally large objects can be measured indoors in a controlled environment. So far simple test objects such as metal spheres have been measured. The feasibility of the phase hologram RCS range has been verified. The basic operation and first measurement results of the monostatic measurement range are reported here.

Keywords: Hologram, Radar Cross Section, Compact Range, Quiet-Zone, Scale Model Measurements

1. Introduction

Target RCS data is needed for both radar system development and target RCS reduction. Computer simulations are used for predicting the RCS but modeling of complicated structures is difficult and simulations are time-consuming. The results should be verified with measurements. When measuring RCS, the object has to be illuminated with a plane wave. This is possible either by measuring the object in the far-field region of the antenna or measuring it in a compact range. Traditionally, measurements have been done in the far-field ranges which are usually placed outdoors and are therefore subject to changing weather conditions and unwanted observation.

While using a compact test range, targets can be measured indoors due to the decreased measurement distance. Compact ranges can also be used for scale model measurements. The main advantage of a scale model RCS range is that the dimensions of radar targets are scaled down in proportion to the wavelength. Therefore, RCS data of originally large objects can be measured in a small chamber in a controlled environment. After model measurements, the obtained RCS data is scaled back in order to get the real-sized target parameters. Ranges for scale model measurements have been built for submillimeter wave frequencies at 524 and 585 GHz [1,2]. These ranges are based on reflectors. The difficulty with reflectors at high frequencies is the required high accuracy of the reflector surface. The hologram is introduced as an alternative focusing element. The holograms used are transmission type elements, and thus the accuracy requirement for the holograms is less stringent (by the order of 10) than for the reflectors.

Amplitude holograms have been previously used for antenna measurements [3], but phase holograms are better suited for RCS range applications due to their higher conversion efficiency. The conversion efficiency can be defined as the ratio between the field intensities in the quiet-zone and before the hologram. The conversion efficiency of the hologram has been evaluated by measuring the power level first at the plane of the hologram surface and then at the quiet-zone. The measured conversion efficiency of the phase hologram used here is –4 dB [4]. It is assumed that the conversion efficiency will be nearly the same also for larger holograms but this remains to be verified.

In a phase hologram RCS range, the plane wave needed for the RCS determination is generated using a phase hologram. Computer-generated phase hologram is a diffractive element which consists of milled grooves on one surface of a dielectric plate. Fig. 1 shows a schematic layout of the compact range intended for scale model measurements.

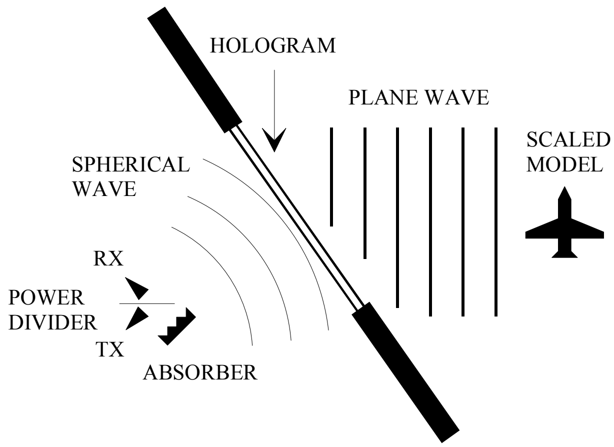

Figure 1. Hologram based test range for scale model RCS measurements.

The hologram transforms the incident Gaussian wave (with a spherical phase front) to a plane wave. The target is illuminated with the plane wave. The wave reflected back from the target is focused by the hologram to a receiver horn, which in a monostatic configuration is placed behind a dielectric slab used as a 3 dB power divider. This is an improved version of the previously used quasi-monostatic system where the receiving and transmitting corrugated horn antennas were placed side by side with a small bistatic angle of 1.7° [5].

2. Phase Hologram

In phase-type holograms, the hologram structure features a locally changing effective thickness. The phase holograms are realized as milled grooves on a dielectric plate (see Fig. 2). The field passing through the grooves acquires a phase difference with respect to that between the grooves, leading to a phase modulation of the transmitted field. A locally binary groove structure is optimized for the desired operation. Groove width and depth of the hologram profile is designed by rigorous electromagnetic theory to locally produce the required amplitude and phase modulation. [6]

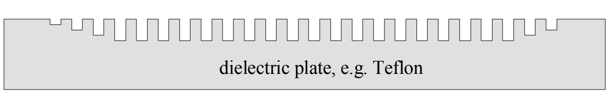

Figure 2. Typical cross-cut of a phase type hologram.

The hologram structure can be manufactured on a dielectric plate by a computer-controlled milling machine. Teflon has been found to be a suitable material for holograms due to its machinability, its well-known characteristics at millimeter wave frequencies and low losses. The surfaces of the test holograms are quite good and their quality is seen adequate for operation at 310 GHz. Other materials have also been considered. First tests were made with a hologram manufactured from Obomodulan®, but it was found to have relatively high loss, 0.8-1.0 dB/mm at 310 GHz [4], which decreases the dynamic range available for RCS measurements.

A hologram structure used in these measurements of size 28 cm x 24 cm was fabricated on a 5 mm thick Teflon plate. The amplitude and phase variations of this small-sized test hologram are approximately 2 dB and 10 degrees peak-to-peak, respectively. The diameter of the quiet-zone is about 12 cm. [6]

3. RCS Measurement Range

A large dynamic range is required in RCS measurements. In our case, the instrumentation is based on a millimeter wave vector network analyser (AB Millimètre MVNA-8-350) with sub-mm wave extensions. The test measurement facility is shown in Fig. 3. In this test setup the distance from the RX/TX to the hologram and also from the hologram to the target is 1m.

Figure 3. Test RCS measurement facility.

A phase-locked Gunn oscillator followed by a harmonic multiplier has been used as the submm-wave source (ESA-1 extension). The receiver used consists of a Schottky harmonic mixer pumped with a phase-locked Gunn oscillator (ESA-2 extension). The Gunn oscillator is identical to the one used in the source. The vector measurement capability is essential for typical sensitivity enhancing methods used in scale model RCS ranges. Initial estimations indicate that there is sufficient dynamic range available in a phase hologram RCS range. The maximum available (flange-to-flange) dynamic range for the configuration of the source and receiver is about 120 dB at 310 GHz. Reflections from the background and conversion efficiency of the hologram affect the obtainable dynamic range. Corrugated horn antennas are used as the transmitting and receiving antennas. A planar scanner is employed to obtain the two-dimensional field profile of the quiet-zone to verify the field quality. RCS measurements are done using the same system; the receiving antenna is brought from behind to the front of the hologram so that the configuration is monostatic. The target is placed behind the hologram in the quiet-zone.

Absorbers (Eccosorb VFX-NRL2) are used around the hologram and around the whole setup to block the wave propagating straight from the transmitter to the quiet-zone and to minimize reflections. The desired beam propagates into an angle of 33° to avoid interference with the wave propagating straight through the hologram. The measurements are done at 310 GHz. The background reflections have been separated from the reflection from the target by moving the object along the *z*-axis (direction of the plane propagation). Simple and well-known radar test and calibration targets, e.g. a gold-plated metal spheres, are used at the current stage of the phase hologram RCS range development. Continuous wave (CW) operation instead of, e.g. pulsed operation has been considered most feasible since fast enough switching is a problem at frequencies as high as the one used here.

The measurement system is made monostatic using a dielectric slab as a directional coupler. The dielectric slab is made out of Mylar film. It is placed in an angle of 45 degrees compared to the axes of the receiving and transmitting corrugated horn antennas. The frame of the slab is also covered with absorbing material. The setup can be seen in Figs. 4 and 5. The place of the load absorber is optimized to minimize the power reflected from the load and surroundings. The places of the antennas, slab and the load are fixed to assure repeatability.

According to the measurements, the dielectric slab works with a – 3 dB power division ratio as designed. It was also tested that the quiet-zone field does not chance due to the coupler. The quiet-zone field was measured with the transmitter at the TX port of Fig. 4 and again with the transmitter at the RX port. The field stayed the same regardless of the port chance so it does not affect the measurement and the system works as designed.

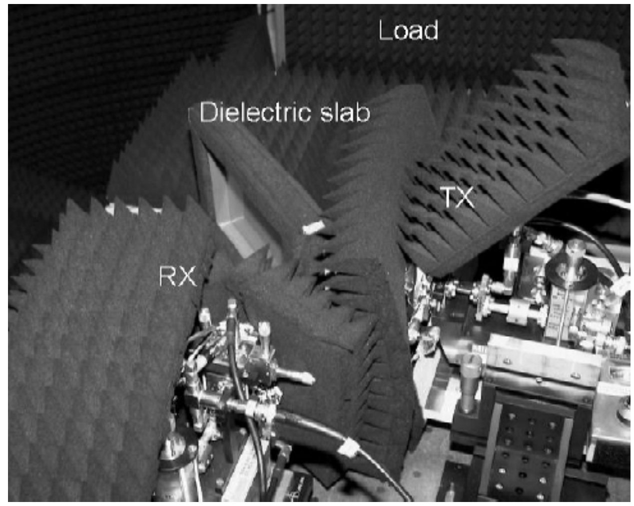

Figure 4. Monostatic radar setup.

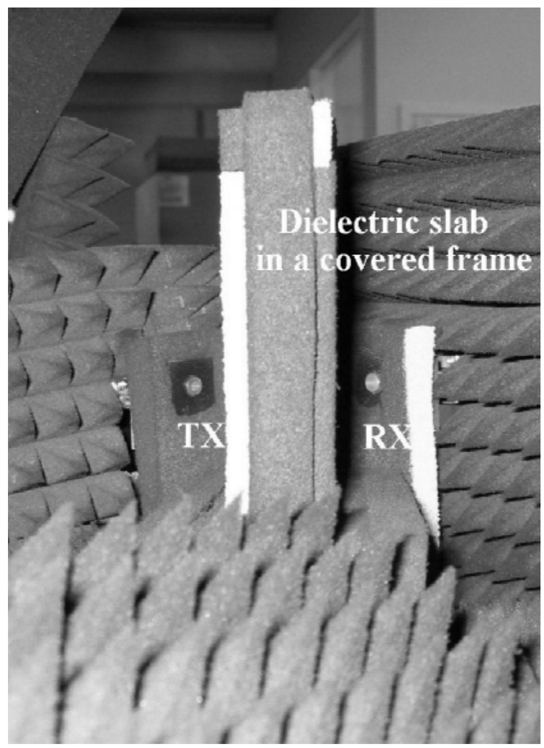

Figure 5. Front view of the monostatic radar.

The target and its support are placed on a computer controlled micro translation stage. The support is a column made of extruded polystyrene foam (Styrofoam^{TM}). The dielectric constant of Styrofoam^{TM} was measured and found to be 1.048 at 310 GHz. Thus the reflections from the support column are so low that with current measurement setup it is not possible to separate them from the background reflection.

The setup is based on a relatively small test hologram primarily intended for evaluation of design and manufacturing methods. A test hologram with quiet-zone size of 250 mm has been manufactured and it is waiting for measurements at the moment. It is estimated that a few decibels of the dynamic range will be lost compared to the smaller setup due to an increasing measurement distance, or, in other words, an increasing quiet-zone diameter. At that stage, the transmission power may be increased by adapting a phase-locked backward wave oscillator (BWO) into the system.

4. Measurement Results

To verify the range operation, the RCS of two small spheres was measured. The effect of the quiet-zone field quality was also studied.

The radar cross section of the target can be evaluated from the radar equation by taking into account the conversion efficiency of the hologram [4]:

$$P_R / P_T = G_T \, G_R \, \lambda^2 \, \eta_H^2 \, \sigma / [(4\pi)^3 R^4] \quad (1)$$

where P_R and P_T are the received and transmitted powers, G_R and G_T are the receiver and transmitter antenna gains, λ is the wavelength, σ is the RCS of the scale model target, and R is the distance from TX/RX to the hologram. The conversion efficiency of the hologram is squared as the received echo signal has passed through the hologram twice. The distance from the hologram to the scale model target does not appear in Equation (1) because, as the target stays in the quiet-zone (the plane wave zone used for measurements), this distance is irrelevant.

The reflection from the target was separated from the background reflection by moving the target in the z-direction. The total movement was 1 cm and it can be expected that the quiet-zone field does not chance at this distance The target was moved in 50 µm steps and the power level at the receiver was read at each step. As a result, a periodic response was found. From the variation of the power level the field component caused by the moving target can be evaluated. Power reflected from the target can be calculated from the measured power. The measured power is proportional to the squared resultant of the coherent field vectors reflected from the background and the target:

$$P_{measured} \sim | \boldsymbol{E}_{background} + \boldsymbol{E}_{target} |^2 \quad (2)$$

$\boldsymbol{E}_{background}$ consists of the reflections form the absorbers and the surroundings. The collected data is Fourier transformed from time-domain to frequency-domain. The peak coming from the target is selected and the data transformed back to time-domain.

The influence of the target location in the quiet-zone was studied. The amplitude and phase ripples at the quiet-zone of the hologram studied are 2 dB and 10 degrees respectively [6]. A gold-plated metal sphere of radius 2.5 cm was used as a target. Its radar cross section was measured in four different (x,y) locations. The measurement done in the center of the quiet-zone was taken as a reference so direct calibration is obtained instead of the previously used indirect roof top reflector calibration [5]. Using the basic radar equation a relation can be found between the radar cross sections and the measured power levels:

$$\sigma_{target} = \frac{P_{target}}{P_{reference}} * \sigma_{reference} \quad (3)$$

The measurement results are gathered into Table 1.

Table 1. The measurement results of the RCS of a 2.5 cm radius gold-plated metal sphere in different locations.

coordinates (x,y) [cm]	RCS [m^2]	radius [cm]	difference from (0,0) [%]
Ref. (0,0)	0.00196	2.5	0
(2,2)	0.00153	2.21	11.7
(4,4)	0.00067	1.46	41.7
(0,1.5)	0.00222	2.66	-6.4

It can be seen that with a small target the location i.e. the quality of the QZ field strongly affects the measurement result. At the location (4,4) there is almost a 2 dB difference in the QZ field amplitude and in (2,2) a 0.5 dB difference compared to location (0,0). These differencies agree very well with the differencies in the measured power levels used for calculating the RCS results presented in Table 1. So it is important to place the reference target and target under measurement to the same place in the QZ. To get accurate results, the target size and the RCS level should also be quite close to the reference target size and RCS value.

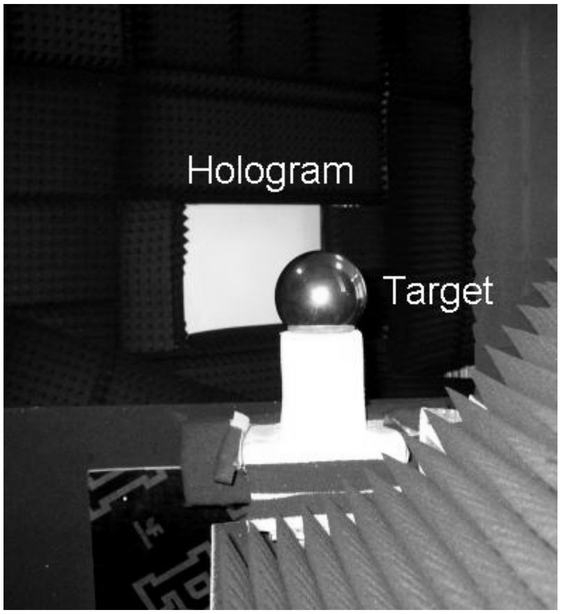

Figure 6. A gold-plated metal sphere of radius 4 cm used for RCS range evaluation measurements.

A gold-plated metal sphere of radius 4 cm (Fig. 6) was measured in the position (0,0). The measurement result of the smaller sphere in location (0, 1.5) was used as a reference. The centers of the spheres were in the same location in the QZ. The measured RCS of the 4 cm radius sphere is 0.00577 m^2 so it looks like a sphere with radius 4.28 cm. The difference in radius is 7 % which is quite small compared to the difference that a move of the target into a different place in the quiet-zone can cause. The target was not in the center of the quiet-zone so nonequivalent illumination might also cause inaccuracy to the result. The larger sphere also fills larger part of the quiet-zone so the field quality changes can be seen in the result. The theoretical RCS of the larger sphere is 2.56 times larger than the theoretical RCS of the smaller sphere.

5. Conclusions and Future Work

A novel compact range based on a phase hologram is being developed for scale model RCS measurements and its feasibility has been verified. The test range is based on a phase hologram that converts the feed horn radiation to a plane wave needed for RCS determination. The measurements were performed at 310 GHz using a monostatic configuration where the identical receiving and transmitting corrugated horn antennas were placed on opposite sides of a dielectric slab working as a directional coupler. Power division of 3 dB was used in the design of the coupler. Continuous wave operation was used. So far, simple test objects such as metal spheres have been measured. First measurement results are encouraging. In the future, also another monostatic configuration, based on a waveguide directional coupler, will be tested. A more realistic, complex, test RCS target will be both simulated and tested using the phase hologram based compact range. Measurements of absorber reflectivity levels could also be done in plane wave conditions in the RCS range and this will be tested later this year. Also measurement facilities like translation stages used for target alignment will be improved, i.e. for rotating the target. At this stage, a RCS range with a 0.25 meter quiet-zone is the final goal of development as a transportable compact indoor facility accommodating models of potential targets.

6. REFERENCES

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