Investigation of Surface Profiles of a Reflector from Near-field Beam Measurements

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ABSTRACT

We have investigated a technique to map out surface defects of a reflector from near-field vector measurements. In our experiment a near-field range is set up to measure the beam reflected from a test surface at 240 GHz. A full-wave numerical method based on a vectorial Green's function is implemented to project the measured beam profile onto the mirror's surface. We then examine the differential phase pattern constructed from two separate scans, one with a known artifact and another without, to reveal features due to the artifact. Our experiments demonstrate that resolution down to a few degrees in phase can be obtained with this method.

I. Introduction

This report describes a technique to examine surface defects of reflectors using near-field measurements at a frequency of 240 GHz. The motivation is to investigate the application of such a technique on large parabola reflectors which usually span a few meters in diameter and which require a high accuracy in the surface profile.

In this technique a reflector, which is the test surface, is placed in the near-field of a transmitter, and the reflected beam pattern, including power and phase, is measured with a planar scanner also located at the near field. A computation code based on a vector Kirchhoff integral is implemented to construct, from the scanned data, the complex beam pattern at the reflector surface. Surface defects on the reflector can be associated with anomalous phase pattern in the calculated phase profile.

II. Near-field measurement and numerical calculation technique

The near-field measurement technique presently used is similar to those applied extensively at microwave frequencies. Figure 1 shows a schematic of the measurement setup. The signal is generated from a phase-locked Gunn oscillator operating at 80 GHz. After multiplication, the corrugated feed emits a signal at a frequency of 240 GHz. The reflector is a 90-degree, off-axis paraboloidal mirror with an aperture of 50 mm in diameter. The horn aperture is placed at the focal plane of the mirror with its beam axis perpendicular to the mirror axis. In the scan plane a WR-3 open wave-guide equipped with a harmonic mixer serves as the scanner probe. The scan plane is aligned to be perpendicular to the mirror axis at a distance of 108.2 mm away from the mirror center. The measured signal is down-converted and detected by a vector voltmeter. In the current setup we achieve a dynamic range of 40 dB.

The corrugated feed is made for the Sub-Millimeter Array (SMA) project. In a previous measurement the aperture field of the feed has been shown to conform to the HE11 mode to a purity of better than 99%, and the cross-polar power is less than 0.5% of the co-polar component [1].

The numerical method is a computation program based on a vector Kirchhoff integral [2]. Assuming an arbitrary source located in the half space z<0, the electric field at z > 0 can be expressed in an integral form, in terms of the field distribution on the plane z = 0, as

$$\vec{E}(\vec{r}) = \frac{1}{2\pi}\int_S \frac{e^{ikR}}{R^2}\left[ik - \frac{1}{R}\right]\cdot\vec{R}\times\left[\hat{z}\times\vec{E}(\vec{r}_0)\right]\cdot dS \qquad (1)$$

where k is the propagation constant, $\hat{z}$ the normal vector of the plane z = 0, and $\vec{\boldsymbol{R}} = \vec{\boldsymbol{r}} - \vec{r}_0$. Based on the above formulation, a numerical program is implemented to calculate the electric field on a target plane of interest from an initial plane with known field distribution. In our application, the scan data becomes the initial field and the code is used to generate the field pattern on the reflector.

III. Measurements and Results

To simulate surface defects, a small piece of aluminized tape with a thickness of 50 μm, equivalent to 1/25th of the signal wavelength, is attached to the reflector. Two separate scans are carried out; one with a taped reflector, and another without. Both scanned data are processed to construct their relevant beam patterns on the reflector. Finally, the difference in phases between both runs is used to generate a differential phase map on the reflector surface. By examining the differential phase profile we have avoided the complexity introduced by the setup alignment and the possible intrinsic defect of reflector surface.

Prior to the measurements, simulations of the near-field scanning were carried out to evaluate the effects caused by the discrete sampling points and finite scan area. The simulations assume an ideal field (HE11 mode) in the feed aperture, and the numerical code based on Eq. (1) is used to calculate the scan patterns reflected from both a perfect and a defect paraboloidal mirror. In this case, a reflector with surface defects is simulated by introducing phase delay on part of the reflector surface when calculating the beam pattern projected from the horn aperture. Both the simulated scan data are used to construct the differential phase profiles on the reflector.

Figure 2 shows the contours and a horizontal cut through the center of a phase map from a simulation in which a phase delay of 9 degrees has been added to a region around the center of the reflector. In this case the scanner is assumed to sample the field at a resolution of 81 x 81 points at a regular spacing of 0.625 mm. Also shown in the center cut for reference is this 9 degrees phase delay on the reflector surface. In a subsequent simulation we increase the scan area to 131 x 131 points, and the resulting plots are shown in Fig. 3. Compared with the previous run the phase map shows less phase ripples and a profile more closely related to the added phase artifact (refer to Fig. 3B).

The phase stability of the measurements is a critical factor toward achieving better surface resolution. Short-term phase fluctuation of less than 5 degrees is recorded during a typical measurement run. However, a slow drifting in phase may occur during the measurement due to the environmental change in the setup, which would ruin the result. Thus, too long a scanning duration is avoided. Two different scan sizes have been used in this report. In our setup, it takes about an hour to scan 85 by 85 points, and 100 minutes for a scan of 115 by 115. The distance between each point is 0.6 mm. Figure 4 presents the plots of the phase map obtained from a scan of 85 x 85 points. Accompanying the contours is a plot showing horizontal cut through the maximum peak of the phase map. The main feature in these plots showing the anomalous phase contours, near the center of the reflector, which resembles the shape of the tape. Although it is clear that the tape's cross-sectional profile is not resolved due to insufficient scanning area, a peak value of 13 degrees in the anomalous contours indicated a maximum path-length difference of 45 μm, which is close to the actual thickness of the tape. As shown in Fig. 4B, the phase profile shows that there are a few degrees of peak-to-peak phase fluctuation near the center of the reflector, and this increases to more than 5 degrees near the edge of the reflector. A surface plot of the phase map is shown in Fig. 4C.

Figure 5 shows the plots from the results constructed from a scan of 115 x 115 points. From the contour map the morphology of the defect area is clearly seen, which in this case is a triangular in shape. In contrast to the simulation of larger scan area, as shown in Fig.3, the tape's profile is still not shown, and the noise floor has somewhat larger fluctuation compared to the previous result. This may be caused by lower signal-to-noise data when the probe is scanning outside the reflector's aperture.

IV. Summary

Using a near-field measurement setup operating at 240 GHz, we have demonstrated that the surface profile of a reflector in the signal path can be examined via a numerical method based on the vector Kirchhoff integral. To achieve better phase resolution of this technique, the phase stability and signal-to-noise in the measurement, and the scan resolution must be improved. In this preliminary report, we have shown that surface defects that introduce a few degrees of phase error on the reflector's surface can be resolved.

References:

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2. A. J. Yaghijian, "An Overview of Near-field Antenna Measurements", IEEE Trans. Antenna Propagat., vol. 34, pp. 30-45, Jan. 1986.

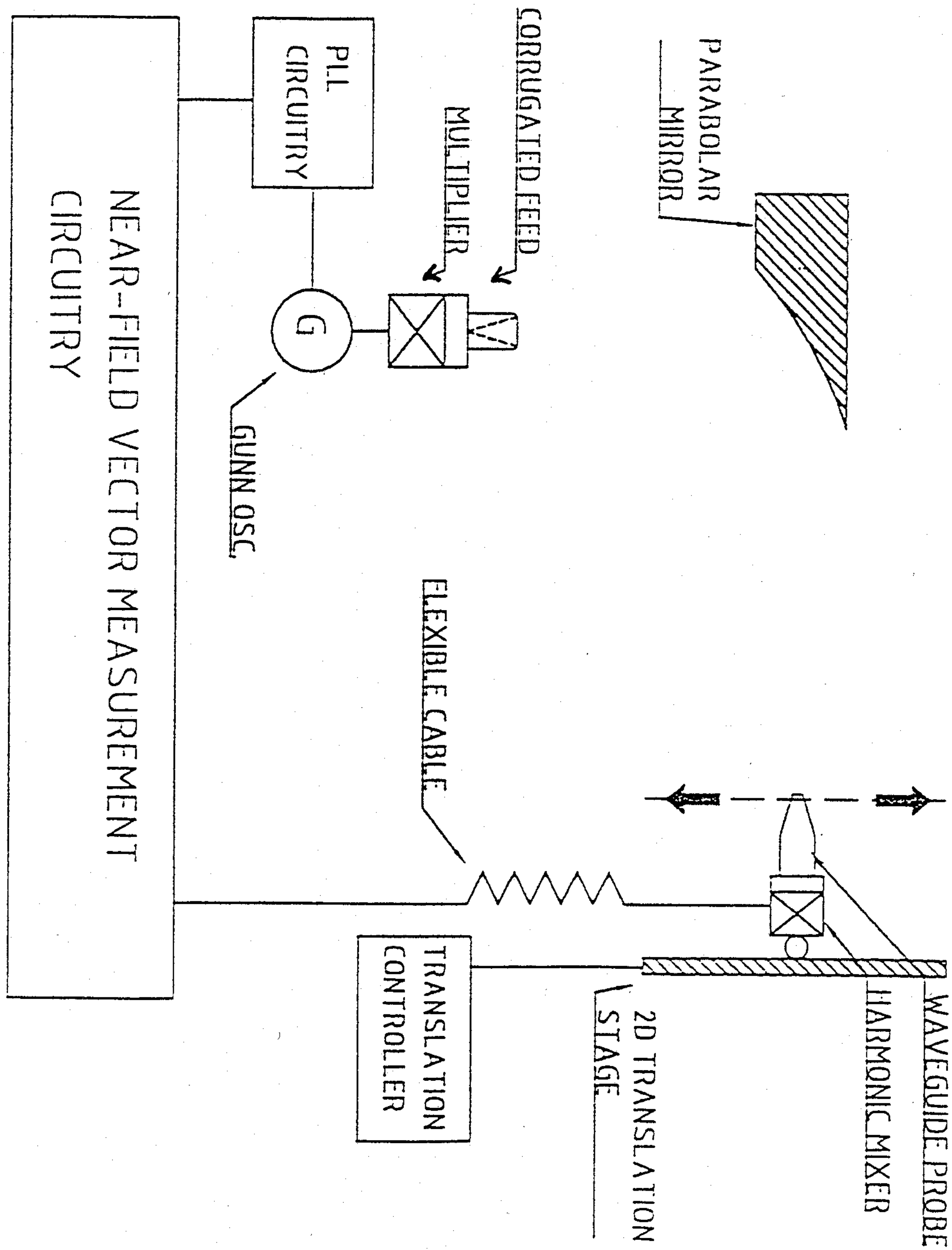

Figure 1. Schematic of near-field measurement setup.

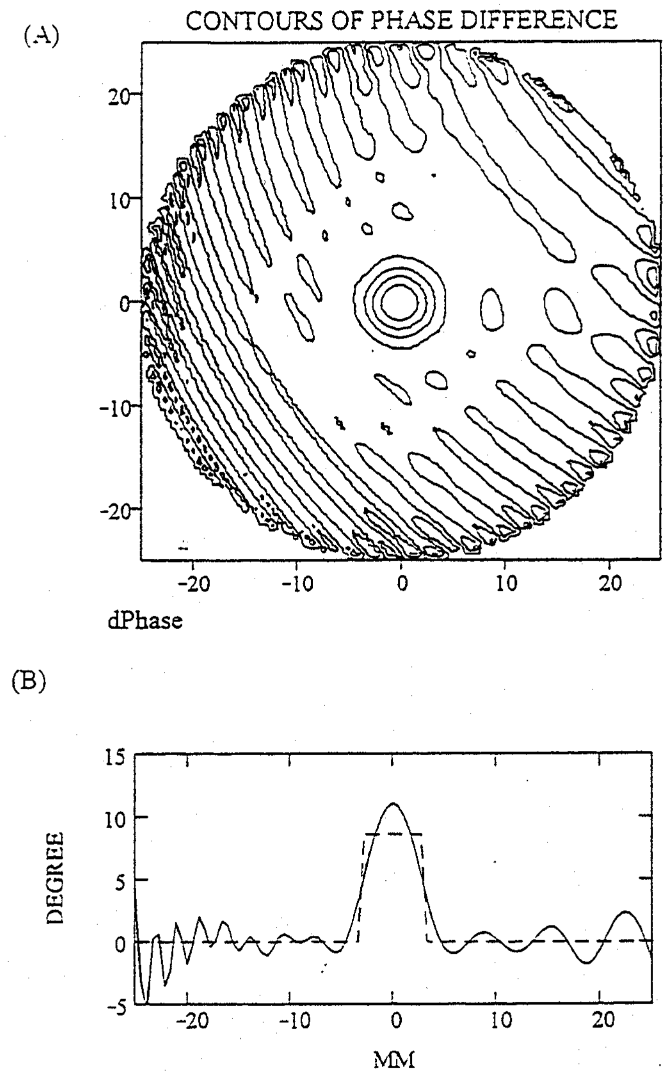

Figure 2. (A) Contour plot of the differential phase map, and (B) a horizontal cut through the contour center on the reflector's surface. The result is obtained from a simulation of 81 x 81 scan points spaced regularly at 0.625 mm in between. The dashed line in (B) is the phase delay used in the simulation as the surface defect.

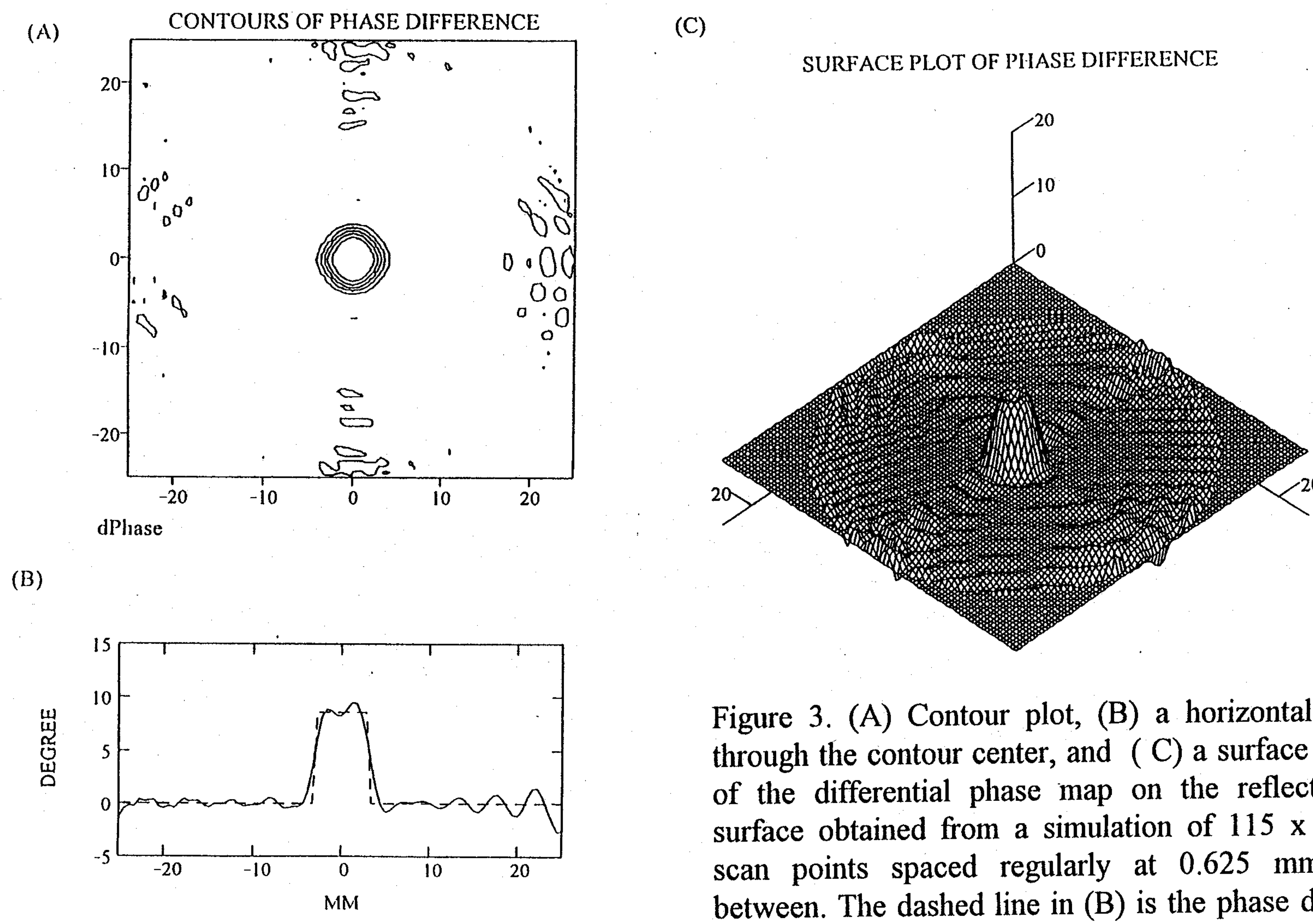

Figure 3. (A) Contour plot, (B) a horizontal cut through the contour center, and (C) a surface plot of the differential phase map on the reflector's surface obtained from a simulation of 115 x 115 scan points spaced regularly at 0.625 mm in between. The dashed line in (B) is the phase delay used in the simulation as the surface defect.

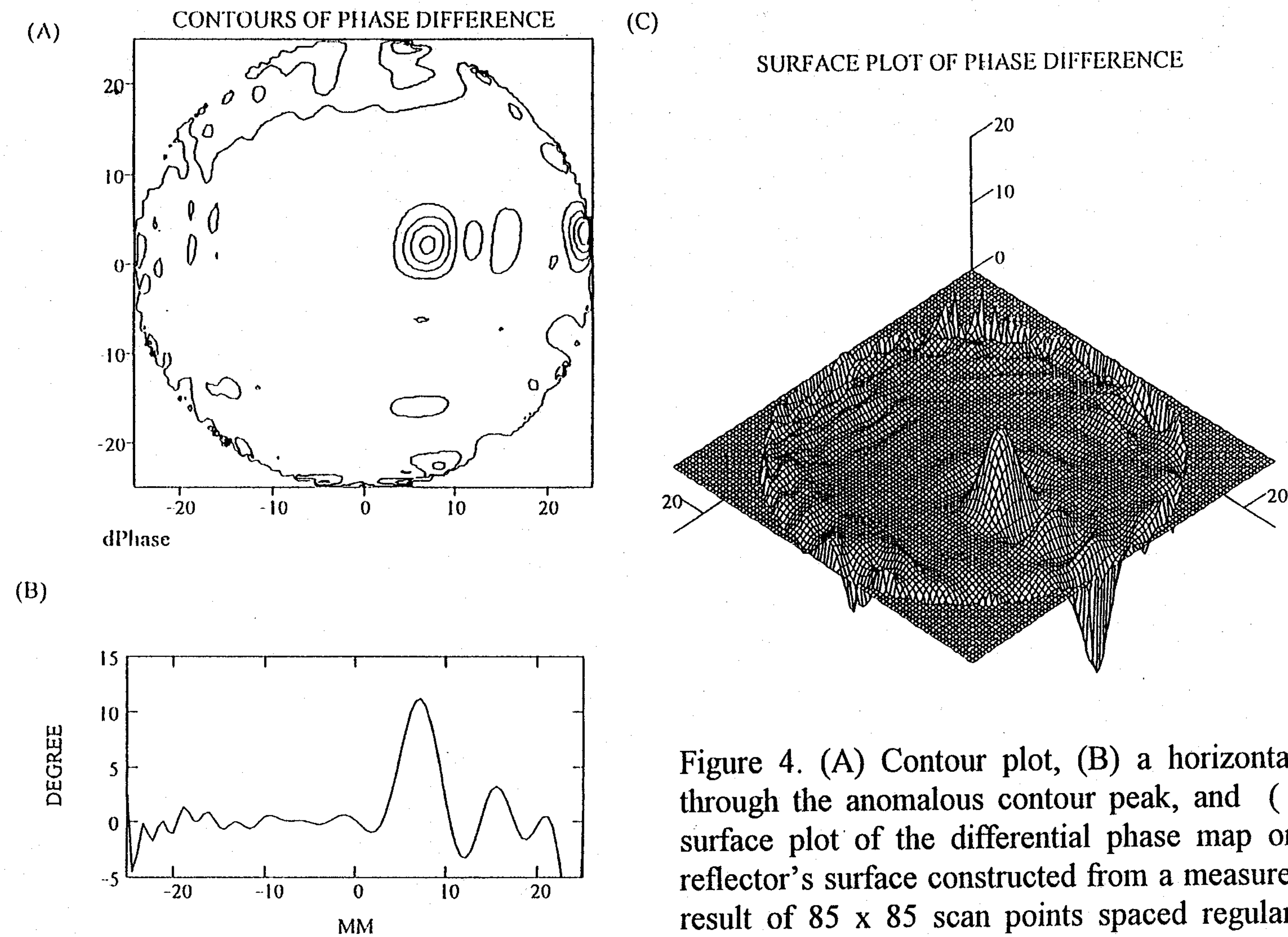

Figure 4. (A) Contour plot, (B) a horizontal cut through the anomalous contour peak, and (C) a surface plot of the differential phase map on the reflector's surface constructed from a measurement result of 85 x 85 scan points spaced regularly at 0.6mm in between.

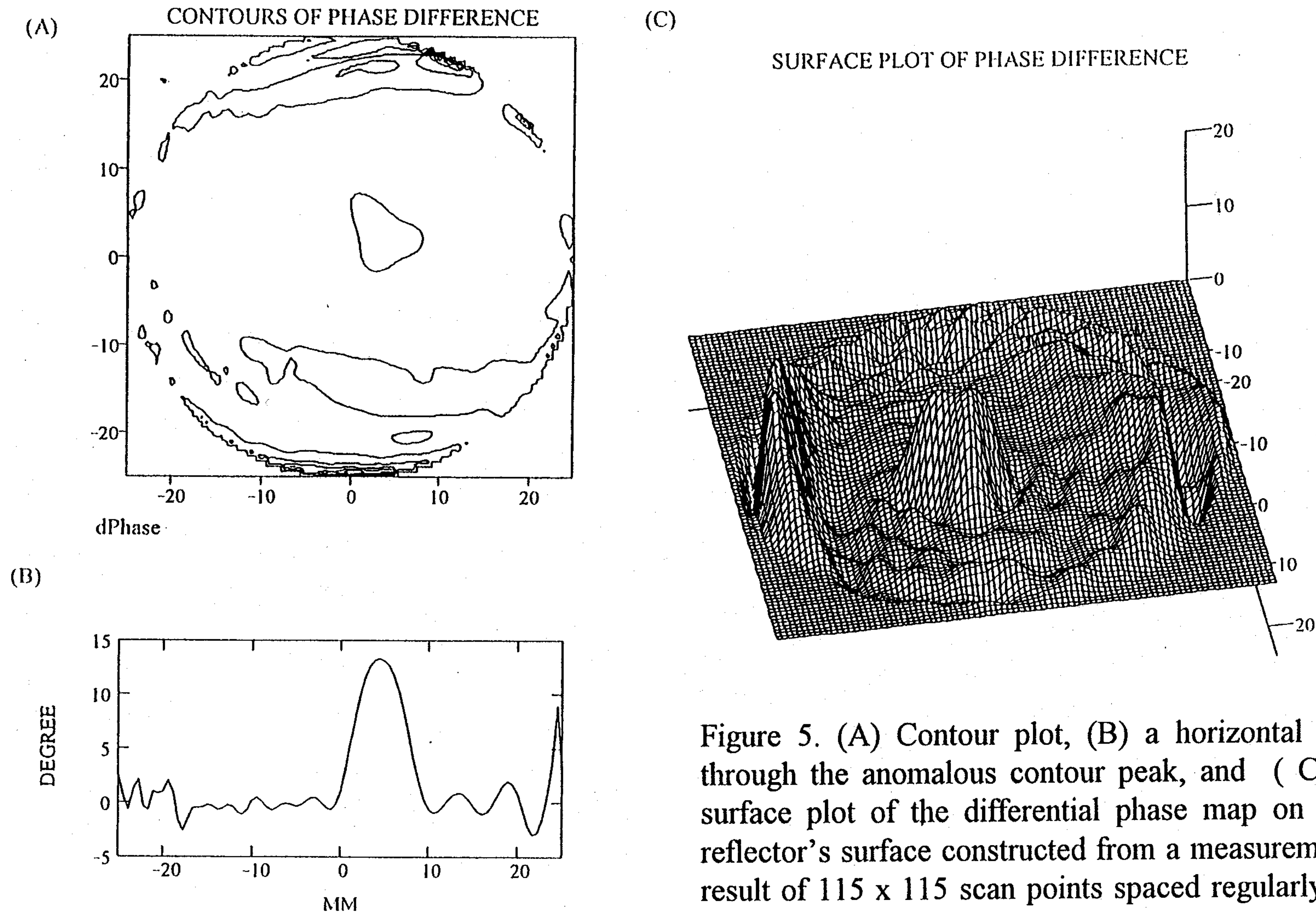

Figure 5. (A) Contour plot, (B) a horizontal cut through the anomalous contour peak, and (C) a surface plot of the differential phase map on the reflector's surface constructed from a measurement result of 115 x 115 scan points spaced regularly at 0.6mm in between.