Error Analysis for the Surface Measurement Method of Large Reflector Antennas using REV Method

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1 Introduction

In large millimeter and submillimeter telescopes the reflector should be very accurate in order to achieve a very high sensitivity. We proposed a new indoor surface measurement method[1] using the REV (Rotating Element-field Vector) method[2] for such reflector antennas which consist of a number of panels. In contrast to the standard holographic methods[3], the proposed method requires only amplitude measurement and can avoid the effect of temperature variation and wind.

In this method, a large plane mirror is installed in front of the antenna under test(AUT). The EM-wave from the antenna is reflected by this plane mirror, and then received by the same antenna. The phase of reflected wave at a panel is changed by moving its position. The received power is measured while changing the position of one panel, and then the phase in initial state of reflected wave at this panel is obtained by the REV method. Applying this procedure to all panels iteratively, the overall aperture phase distribution could be obtained.

In this method, the AUT receives the reflected wave from the plane mirror. The wave broadens during propagation between the plane mirror and the AUT. Therefore, there are inherent measurement errors due to the beam-broadening effect. Furthermore, there are also practical problems caused by the finite size and the surface error of the plane mirror.

In this paper, some major effects on the measurement error are discussed such as aperture field distribution, frequency characteristics and the plane mirror size.

2 Error Analysis by a Numerical Simulation

Fig.1 shows the configuration of the proposed method. Under the condition that the plane mirror is sufficiently larger than the diameter of the main reflector of the AUT, the receiving power of the AUT is considered to be equal to the coupling coefficient of the antenna and its image. This coupling coefficient is calculated by the synthesis of the scattering matrix that is defined by the plane wave, and each plane wave spectrum is given by the electric field distribution at the plane mirror. Then, the movement of the panel is simulated by changing the phase of the corresponding part of the aperture. Fig.2 shows the sketch of the calculation model, and Table.1 shows the parameters of the calculation.

Fig.3 shows the coupling power variation when moving the panel B. This coupling power simulates the receiving power of the AUT in the practical measurement. Fig.3(a), (b) correspond to the initial phase offset of 0°, 45°, in the panel B respectively. In these figures, it is shown

that the maximum coupling power is obtained when phase = initial phase $\pm$ nπ. The ambiguity of $\pm$nπ is not a problem in actual measurements, because the reflector surface is adjusted mechanically within a small fraction of the measurement wavelengths. Then, we obtain the estimated initial phase of the panel from this best-fit sinusoidal curve by the REV method[2].

Fig.4 shows the estimated phase error of each panel when the panel B having the initial phase offset (hence, initial aperture phase distribution is not uniform). The estimated phase error is defined by difference between the estimated initial phase and the given initial phase offset.

Fig.5 shows the estimated phase error of each panel as the edge level of the aperture amplitude distribution changes (see Fig.6). In this figure, the coupling power calculated for the case that the initial aperture phase distribution is uniform. Fig.5 indicates that the variation of the estimated phase errors across the aperture decreases when the edge level becomes close to 0dB. The panel illuminated with low power yields larger error than the panel illuminated with high power, since the former is much influenced by the surrounding panels. Therefore a shaped reflector antenna with uniform aperture amplitude distribution is expected to be measured with good accuracy.

Fig.7 shows the frequency characteristics of the estimated phase error when the initial aperture phase distribution is uniform. It is shown that the estimated phase error of each panel decreases almost identically as frequency increases. When frequency becomes higher, the wave front of the EM-wave from the panel approaches uniform, and the behavior of the EM-wave is well approximated with the geometrical optics.

In this method, the plane mirror should be large enough for approximating to the infinite size. Fig.8 shows the electric field distribution at the plane mirror position. It is shown that the field density falls rapidly out of the main reflector of the AUT. Fig.9 shows the estimated phase error of each panel as the diameter of the plane mirror changes. Again uniform initial aperture phase distribution is assumed. Finite size of the plane mirror is modeled by replacing the electric field outside of the plane mirror with 0 amplitude. Fig.9 shows that the plane mirror is not necessary to be so large compared with the main reflector of the AUT, because diameter of main reflector of the AUT is sufficiently larger than wavelength.

3 Conclusion

Some major effects on the measurement error is discussed, such as, effects of the aperture field distribution of the AUT, frequency characteristics, and effects of size of the plane mirror. Further study is required to evaluate the effects of imperfect plane mirror for the practical application of this method.

In this paper, we consider that the phase of reflected wave at each panel of the main reflector is changed by moving its position, but the phase could be changed at any reflecting mirror located between the transmitter and receiver including the large plane mirror.

References

[1] T.Mizuno, et.al. "A New Surface Measurement Method for Large Reflector Millimeter-wavelength Antennas using REV Method," 2000 IEEE AP-S International Symposium Digest, to be published.

[2] S.Mano and T.Katagi, "A Method for Measuring Amplitude and Phase of each radiating element of phased array antenna," Trans. IEICE Japan, vol.5, pp.555–560, May 1982 (in japanese).

[3] M.Ishiguro, et.al. "Improvement of the Surface Accuracy of the Nobeyama 45m Telescope Using Radio Holographic Metrology," Symposium Digest of IEEE AP-S International Symposium, pp.531–534, 1986.

Table. 1: Parameters of calculation

diameter of aperture	10m
distance from the aperture to the plane mirror	10m
frequency	230GHz
aperture amplitude distribution	−10dB tapered Inflected Bessel
initial aperture phase distribution	uniform
number of data in the aperture plane	256 × 256
interval of data in the aperture plane	62.5mm
range of the aperture plane	16m × 16m
panel size	1m × 1m
movement of the panel	range : $-180^\circ \sim 180^\circ$, interval : 22.5°

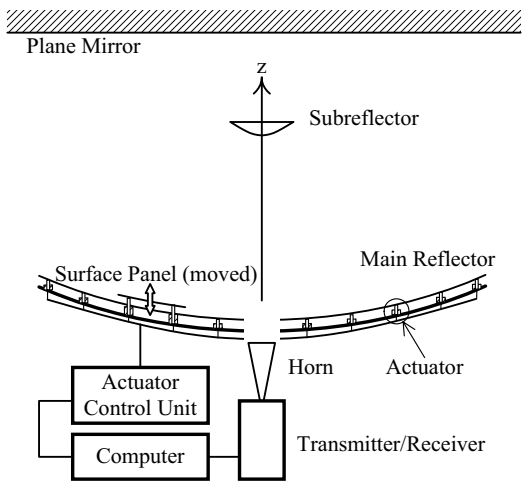


Fig. 1: Configulation of the proposed method.

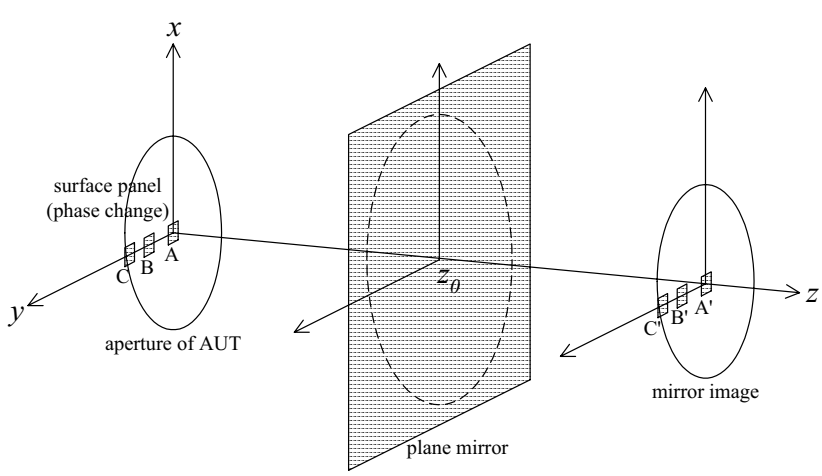
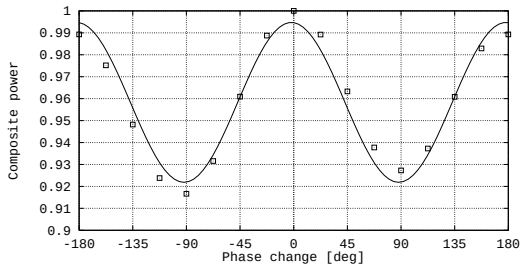
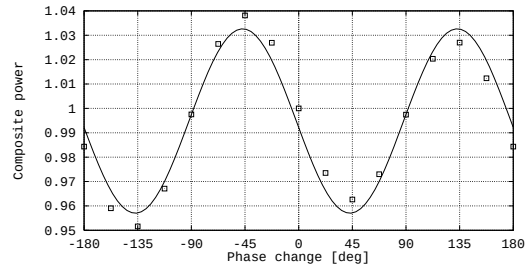


Fig. 2: Sketch of the calculation model.



(a) Initial phase offset = 0 [deg].



(b) Initial phase offset = 45 [deg].

Fig. 3: Received power versus phsase change of the panel B.
□ calculated coupling power, — best-fit sinusoidal curve for the REV method.

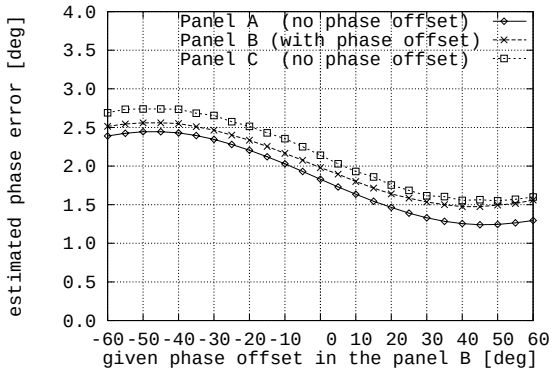


Fig. 4: The estimated phase error versus initial phase offset in the panel B.

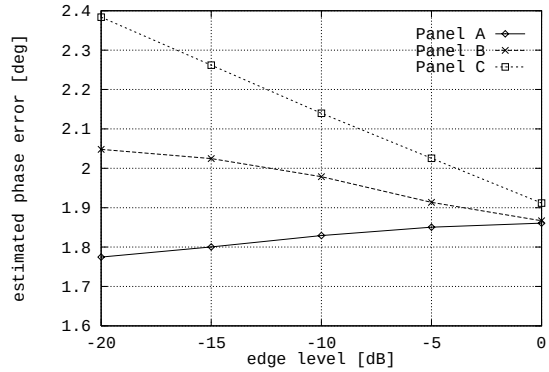


Fig. 5: The estimated phase error versus the edge level of aperture amplitude distribution.

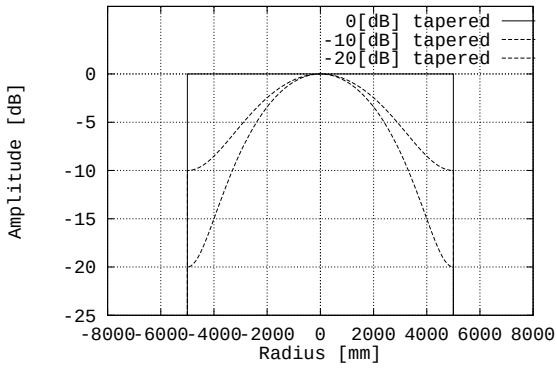


Fig. 6: Aperture amplitude distribution.

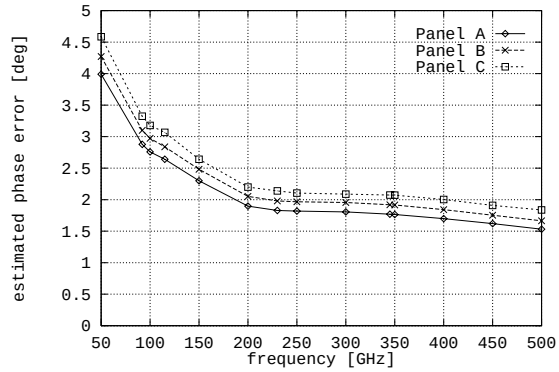


Fig. 7: Frequency characteristics of the estimated phase error.

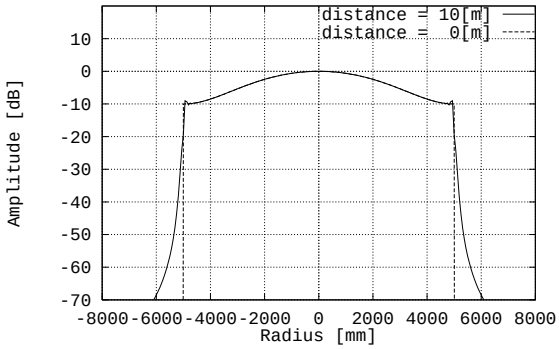


Fig. 8: Electric field distribution on plane mirror.

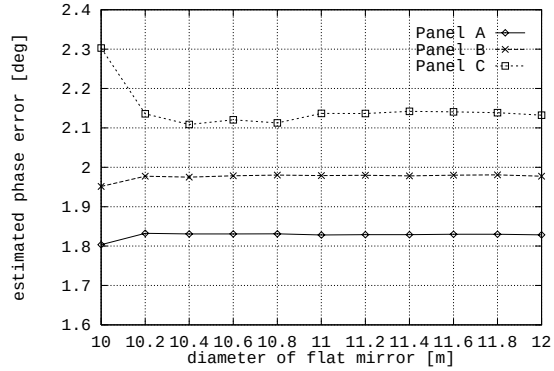


Fig. 9: The estimated phase error versus the diameter of plane mirror.