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PLANE-WAVE SYNTHESIS FOR COMPACT ANTENNA TEST RANGE BY FEED SCANNING

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Abstract—The plane-wave synthesis is brought to the CATR. The feed scans in the focal plane and antenna pattern is measured several times in different feed positions. The corrected antenna pattern is obtained by weighting the measured patterns. The weight is obtained by the least squares method for the electric fields in the aperture plane of the test antenna. The fashion, number and spacing of feed scanning are investigated. By the plane-wave synthesis in the CATR, a larger antenna can be tested, and higher test accuracy can be obtained than that of the CATR. Lower test number and less test time are needed than the conventional plane-wave synthesis. The technique proposed in this paper is numerically investigated in an offset single paraboloid CATR and verified experimentally in a Cassegrain CATR at 100 GHz.

1. INTRODUCTION

In many cases, it is impractical or impossible to measure antenna patterns on a conventional far-field range. It is often desirable or necessary to determine far-field antenna patterns from measurements made in the radiating near-field region [1]. Several techniques for determining the far field from the radiating near field have been developed. They may be divided into two groups [2]: those in which numerical manipulation of measured complex near-field data is employed to predict the far-field pattern (the so-called near-field/far-field transformation), and those in which the far-field measurement conditions are produced or simulated at the antenna under test.

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The methods in which the far-field measurement conditions are simulated in the near-field fall into two subgroups. One is the compact antenna test range (CATR) [3] in which the far-field pattern is measured directly without the requirement of computational manipulation. The other method is plane-wave synthesis by which a plane-wave region is produced at the test antenna by a synthetic aperture [2, 4–7].

The plane-wave synthesis method is based on the fact that an element of the far-field pattern represents the antenna response to a point source located at a far-field distance in the direction concerned. In the region of the test antenna, such a source produces a uniform plane wave propagating in a direction away from the source. If a plane wave can be produced in the region of the test antenna by some means other than the far-field source, the far-field response may equally well be measured [5]. There are two methods of synthesizing a plane wave in the zone of the test antenna. One method is to construct an antenna consisting of an array of elements [8–11]. The array of elements is really built and all elements radiate at the same time. In the second approach, instead of having a feed at all element positions as the feed array, a single scanning feed is stepped from one position to the next. A plane wave is not directly generated in the test volume. What is generated is a sequence of field distributions each of which is separated in time. By properly weighting the near-field distributions when stepping form one position to the next, the sum of the distributions can be made to approximate a plane wave [12]. Synthesizing a plane wave by a scanning radiator is the reciprocal case to predicting far-field parameters from near-field probing. Therefore, the same weight functions can be used in the two cases [12].

In the CATR, the diameter of the quiet zone is limited by the edge diffraction and the amplitude taper imposed by the feed and is about half the diameter of reflector [13]. The test antenna needs be smaller than the range itself, so the test of large antennas becomes quite difficult. In this paper, the plane-wave synthesis is brought to the CATR. The antenna pattern is measured several times in different feed positions. The corrected antenna pattern is obtained by weighting the measured patterns. By the plane-wave synthesis in the CATR the larger antenna can be tested and the higher test accuracy can be obtained in comparison with the CATR, and less test number and less test time are needed in comparison with the conventional plane-wave synthesis. This technique proposed in this paper incorporates the principle of the CATR and the plane-wave synthesis.

2. PROPOSED METHOD

The proposed method brings the plane-wave synthesis to the CATR. The feed scans in the focal plane of reflector and radiates from each scanning position. A sequence of field distributions is obtained in the region of the test antenna. If their relative weight has been correctly chosen an approximate plane wave may be synthesized in the region of the test antenna. By reciprocity the same weight applied in the receive case will give a point in the radiation pattern of the test antenna. Repeating the process for other directions of the test antenna will yield the entire antenna radiation pattern. The size of the synthesized plane wave is larger than that of the plane wave in the CATR, and in the quiet zone of CATR the quality of synthesized plane wave is better than that of the plane wave in the CATR. These mean that the larger antenna can be tested and the higher test accuracy can be obtained by the plane-wave synthesis in comparison with the CATR. Furthermore, the number of feed scanning is less because of a sequence of approximate plane waves, but not spherical waves in the previous plane-wave synthesis [2, 4–7], is synthesized.

An offset single paraboloid CATR is employed for illumination and numerical calculation, as shown in Fig. 1. The origin of the Cartesian coordinate system $(x,\ y,\ z)$ is at the apex of the parent paraboloid. The reflector is described as the intersection of a surface S and a cone with a flare angle θc. The apex of the cone is at the focus of paraboloid, and the cone axis is the axis z_h. The axis z_h makes an angle θ_0 with the axis z. The origin of the feed coordinate system $(x_h,\ y_h,\ z_h)$ is

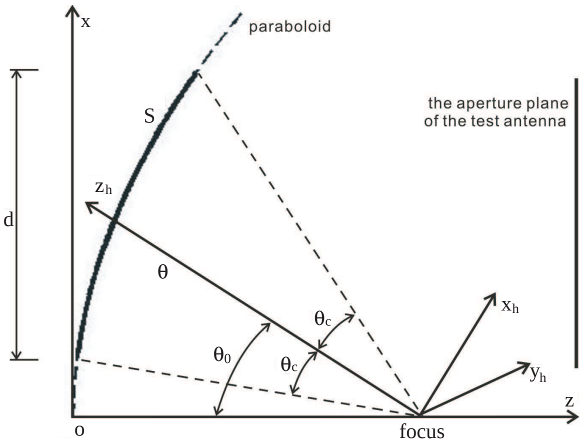

Figure 1. Offset paraboloid configuration.

at focus, and the feed central axis coincides with axis z_h. The plane $x_h y_h$ is in the same plane as the plane xz. The d is the diameter of the reflector.

The plane $x_h y_h$ is defined as the focal plane [14, 15]. A near-field distribution in the aperture plane of the test antenna is obtained for every feed position when the feed scans are in the focal plane. The near-field distributions of the entire feed scanning are $[F]$, that is

$$[F]_{M\times N} = \begin{bmatrix} F_{11} & F_{12} & \dots & F_{1N} \\ F_{21} & F_{22} & \dots & F_{2N} \\ \vdots & \vdots & \dots\dots & \vdots \\ F_{M1} & F_{M2} & \dots & F_{MN} \end{bmatrix} \tag{1}$$

where M is the field sampled number for every field distribution, and N is the number of field distribution or the number of feed scanning. The weight $[W]$ is

$$[W]_{N\times 1} = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_N \end{bmatrix} \tag{2}$$

The desired field distribution is $[F_0]$, that is

$$[F_0]_{M\times 1} = \begin{bmatrix} F_{01} \\ F_{02} \\ \vdots \\ F_{0M} \end{bmatrix} \tag{3}$$

The synthesis problem can now be represented by

$$[F][W] = [F_0] \tag{4}$$

Generally, M is greater than N in which case the least squares solution to (4) is

$$[W] = [F^H F]^{-1}[F^H][F_0] \tag{5}$$

where H denotes complex conjugate transpose, which is obtained by minimizing the quantity $\|[F][W] - [F_0]\|^2$.

The field distributions $[F]$ in the aperture plane of the test antenna in the quiet zone can be obtained by calculation or test. The desired field distribution $[F_0]$ is set to unity or taper distribution [2]. The weight $[W]$ is obtained from (5), and by reciprocity, the same weight applied to the receipt case will give a point in the radiation pattern of the test antenna. Repeating the process for other directions of the test antenna will yield the entire antenna radiation pattern.

3. FEED SCANNING FASHION

Transversal movement of the feed degrades the quiet-zone quality. When implementing the proposed method, we can accept some degradation of the quiet zone, because the method is still able to compensate the unwanted effects. However, at certain point it is no longer beneficial to move the feed more since moving the feed causes more distortions to the quiet-zone field than what the method can compensate. Thus the feed displacement should be as small as possible. And for a certain number of feed scanning, the spacing of feed scanning should also be small. Furthermore, based on the consideration of decreasing the test time, the number of feed scanning should be small. The number of feed scanning depends on the size of the synthesized plane wave as well as the required accuracy of the synthesized plane wave. Some accuracy may be sacrificed to reduce the number of feed scanning and the test time.

Two fashions of feed scanning are investigated: Cartesian coordinate scanning method and polar coordinate scanning method, as shown in Fig. 2. Compared to the polar coordinate scanning method by calculation, the ripple of near field is smaller by employing Cartesian coordinate scanning with the same number of feed scanning. So the Cartesian coordinate scanning method is employed. The spacing of feed scanning is Δx_h, Δy_h respectively in x_h, y_h direction. The number and the spacing of feed scanning are investigated.

4. CALCULATION RESULTS AND ANALYSIS

The calculation is carried out for the offset paraboloid, as shown in Fig. 1. The paraboloid is fed with a corrugated horn. The physical optics method is employed in the calculation of the near field of

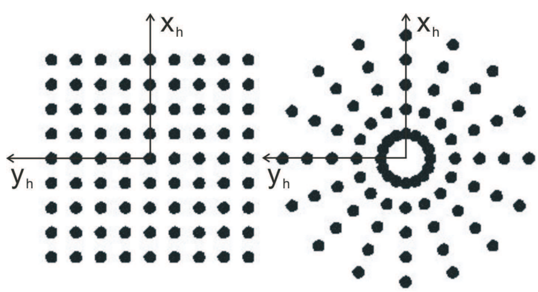

Figure 2. Feed scanning fashion on the focal plane. (a) Cartesian coordinate scanning. (b) Polar coordinate scanning

reflector [16]. The reflector is defined as follows:

$$\begin{aligned} \text{frequency} &= 100\,\text{GHz} \\ \theta_0 &= 36^\circ \\ \theta_c &= 17.1^\circ \\ f &= 90\lambda \\ d &= 60\lambda \end{aligned}$$

The distance from the apex of the parent paraboloid to the aperture plane of the test antenna is 120λ. The field distribution in the aperture plane of the test antenna for a feed position is calculated and stored in a column of the $[F]$. When the field distributions are calculated for all feed positions, the entire $[F]$ is obtained. Choose the size of the optimized zone and the corresponding data in the $[F]$. Letting $[F_0] = 1$, then the W is obtained from (5) for the optimized zone of the chosen size.

The number of feed scanning is investigated. The spacing of feed scanning is chosen as $\Delta x_h = \Delta y_h = 0.5\lambda$, and the number of feed scanning, N, is chosen as 9, 25, 49 and 81, respectively. The maximum ripples of the magnitude and the phase which vary with the size of the optimized zone along the axis x are shown in Figs. 3 and 4, respectively.

As shown in Figs. 3 and 4, the size of the optimized zone seriously influences the ripples of the magnitude and phase. The ripples of the magnitude and phase increase with the increase of the size of the optimized zone. Additionally, the ripples decrease with the increase

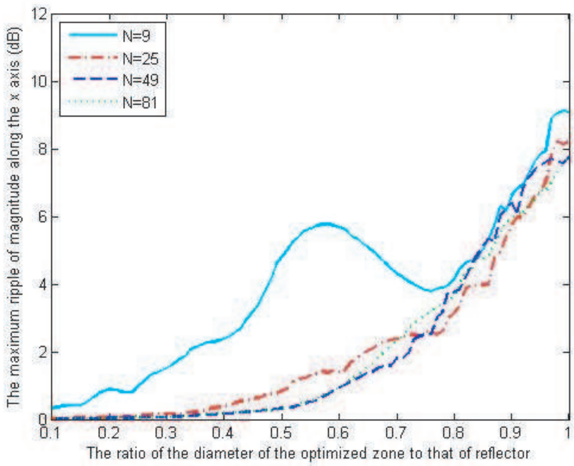

Figure 3. The maximum ripple of magnitude along the axis x for different numbers of feed scanning.

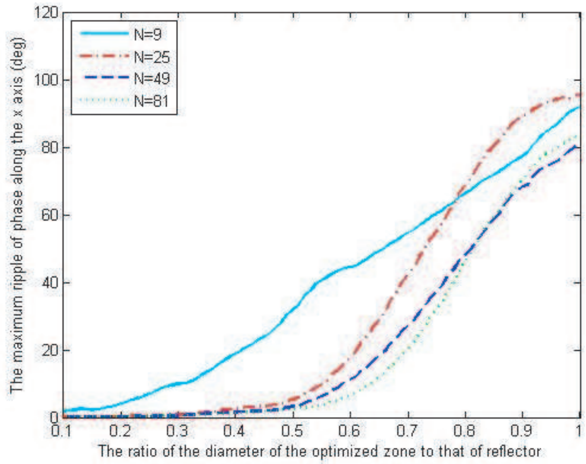

Figure 4. The maximum ripple of phase along the axis x for different numbers of feed scanning.

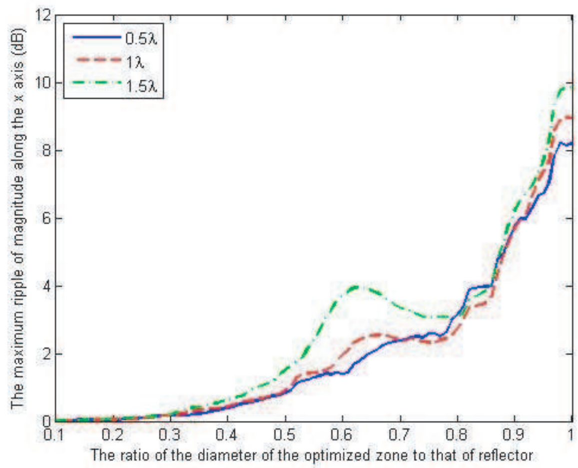

Figure 5. The maximum ripple of magnitude along the axis x for different spacings of feed scanning.

in number of feed scanning. But the decrease of ripples is limited when the number of feed scanning is large enough. When the number of feed scanning is large enough, the improvement of ripples is not manifested by increasing the number of feed scanning. The ripples of the magnitude and phase which vary with the size of the optimized zone along the axis y are analogous to that along the axis x.

The spacing of feed scanning is investigated, which is 0.5λ, 1λ and 1.5λ, respectively, and the number of feed scanning is 25. The maximum ripples of the magnitude and phase, which vary with the size of the optimized zone for different spacings of feed scanning, are shown in Figs. 5 and 6, respectively.

From Figs. 5 and 6, it can be seen that the ripples of the magnitude and phase along the axis x are small when the spacing of feed scanning

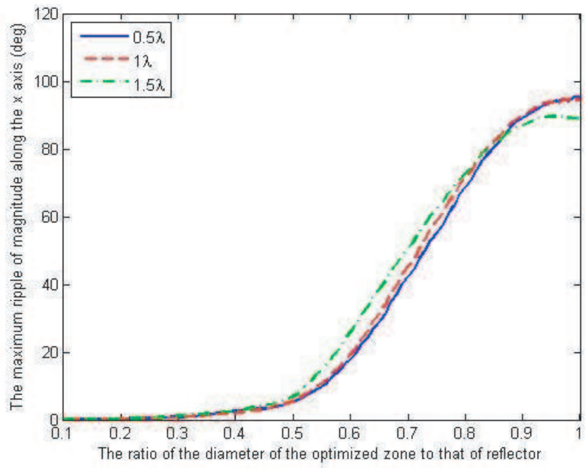

Figure 6. The maximum ripple of phase along the axis x for different spacings of feed scanning.

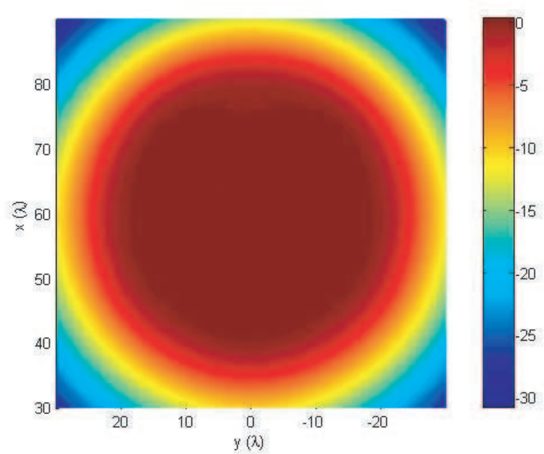

Figure 7. The magnitude distribution in the aperture plane of the test antenna.

is small. The ripples of the magnitude and phase along the axis y are analogous to those along the axis x.

The number of feed scanning is 49, and the spacing of feed scanning is 0.5λ. The ratio of the diameter of the optimized zone to that of reflector is 0.5. The synthesized results of the near-field distributions in the aperture plane of the test antenna are given in Figs. 7–10. The dashed line is the edge of the optimized zone.

These plots show that when the ratio of the diameter of the optimized zone to that of reflector is 0.5, the maximum ripple of magnitude along the axis x is 0.3 dB, and the maximum ripple of phase along the axis x is 3.2°. The ripples are less than those in the definition of quiet zone: ±0.5 dB in magnitude and ±5° in phase [17]. When the feed is in the focal point, the ripples of the magnitude and phase are 5.6 dB and 28.9°, respectively. So the ripples are greatly decreased compared with those in the single feed.

5. TEST RESULTS AND ANALYSIS

The method is tested in a Cassegrain CATR at 100 GHz. The CATR is fed with a conical horn. The feed scans at nine positions in the focal plane and spacing of feed scanning is 1λ. The nine feed positions are symmetrical about the focus in the focal plane. The electric field distribution in the central plane of the quiet zone for every feed position is obtained by planar probe scanning. The weight is obtained from (5).

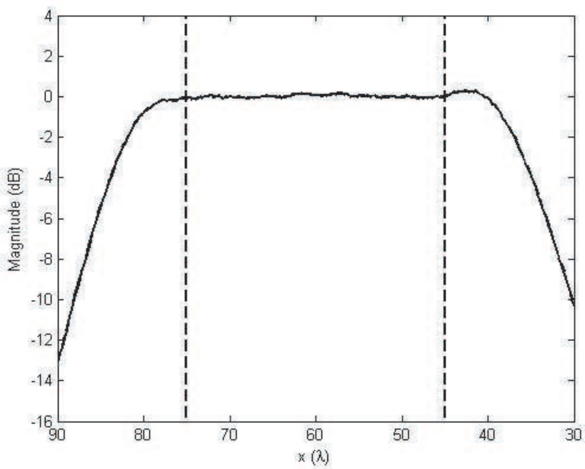

Figure 8. The magnitude distribution in the aperture plane of the test antenna along the axis x.

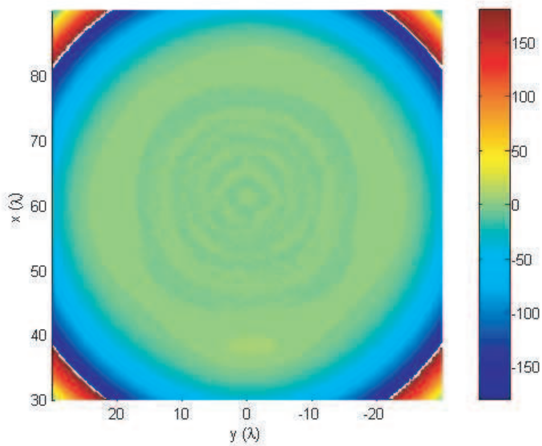

Figure 9. The phase distribution in the aperture plane of the test antenna.

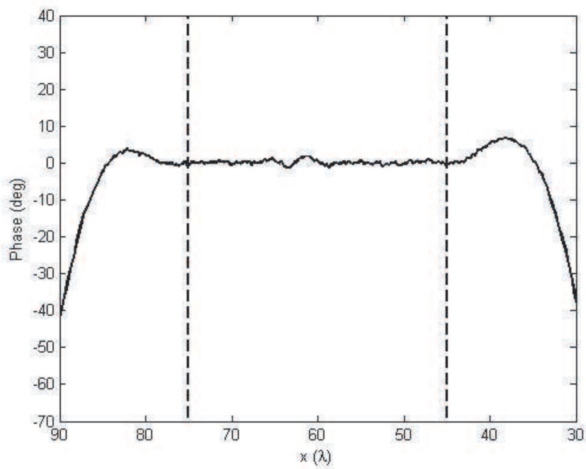

Figure 10. The phase distribution in the aperture plane of the test antenna along the axis x.

The magnitude and phase of weight are shown in Fig. 11.

The synthesized electric distributions are summed which are multiplied by weighting functions. The magnitude distributions along the horizontal direction of the synthesized electric field and the single feed are shown in Fig. 12. The phase distributions along the horizontal direction of the synthesized electric field and the single feed are shown in Fig. 13.

In the Cassegrain CATR, the relative positions of the two reflectors are not finely adjusted. So in Figs. 12 and 13, the ripples of

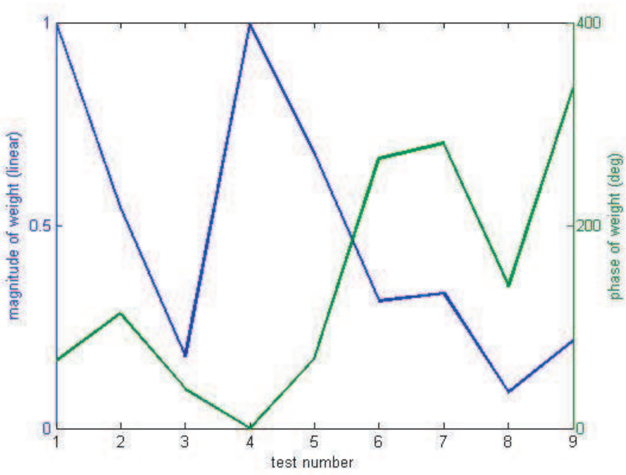

Figure 11. Magnitude and phase of weight for nine tests.

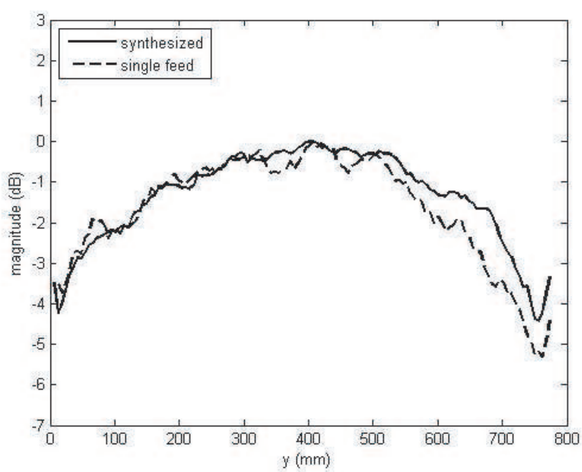

Figure 12. Magnitude distributions along the horizontal direction of the synthesized electric field and the single feed.

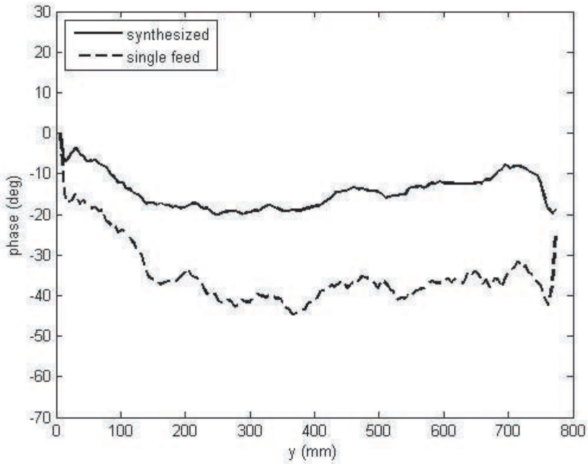

Figure 13. Phase distributions along the horizontal direction of the synthesized electric field and the single feed.

the magnitude and phase are up to 2.0 dB and 11.2° for the y ranging from 200 mm to 600 mm for the case of the single feed. Even with these and the lower number of feed scanning (nine), the ripples of the magnitude and phase are improved to 1.3 dB and 8.1° by the plane-wave synthesis. For the antenna test, the weight in the Fig. 11 can be employed.

6. CONCLUSIONS

In this paper, the plane-wave synthesis is brought to the CATR. The feed scans in the focal plane and antenna pattern are measured several times in different feed positions. The corrected antenna pattern is obtained by weighting the measured patterns. The weight is obtained by the least squares method for the electric fields in the aperture plane of the test antenna. Two fashions of feed scanning are investigated, and the Cartesian coordinate scanning is employed. The fashion, number and spacing of feed scanning are investigated.

By the plane-wave synthesis in the CATR, a larger antenna can be tested, and higher test accuracy can be obtained than the CATR, and lower test number and less test time are needed than the conventional plane-wave synthesis. The technique proposed in this paper is numerically investigated in an offset single paraboloid CATR and verified experimentally in a Cassegrain CATR at 100 GHz.

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