230 GHz Beam Pattern Measurements of a Dipole Array-Fed Dielectric Filled Parabola

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Abstract

The Dielectric Filled Parabola (DFP) has been proposed as an efficient feeding structure for high *f*-number quasi-optical systems, combining the advantages of a parabolic reflector and a substrate lens. A DFP has been designed and constructed for operation at 230 GHz, and integrated with a 2x5 dipole array for imaging applications. We report here the measurement of antenna beam patterns for the elements of the array at 230 GHz.

1. Introduction

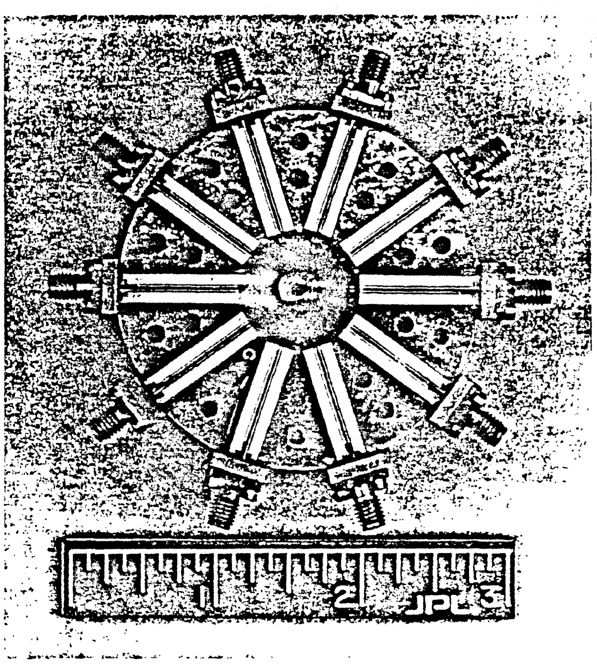
The Dielectric Filled Parabola (DFP) has been proposed as an efficient feeding structure for high *f*-number quasi-optical systems [1, 2]. It is well known that an antenna on a dielectric half-space does not lose power into substrate modes, and radiates preferentially into the dielectric, making the pattern of a normally bi-directional antenna nearly unidirectional [3]. The ratio of power radiated into the dielectric to that radiated into the air is $\varepsilon_r^{3/2}$ for slot and dipole antennas at normal incidence. The broad beamwidths associated with planar antenna elements can be matched to high gain quasi-optical systems by placing a low-*f*-number prime-focus parabola in front of the antenna. The DFP design combines the advantages of the dielectric substrate lens with those of a high-gain parabolic reflector in a single structure.

The main component of the DFP is a plano-convex dielectric lens with the convex surface in the shape of a parabola with an *f*/D ratio of 0.25. The parabola face is metalized and planar antenna elements are integrated at the center of the flat surface of the dielectric lens. Intermediate frequency (IF) removal and DC biasing is accomplished by means of coplanar stripline feeds. Incident RF radiation enters the dielectric, reflects off the parabolic surface, and is focused onto the planar antennas/detectors. Off-axis rays enter the dielectric substrate inclined from normal incidence and are refracted, focusing off-center. Thus, the elements of an array arranged about the focus will each "look" in a different direction providing an imaging capability. There is a reflection loss at the dielectric-air interface, which can be eliminated by using a quarter-wavelength matching layer. The major features of the DFP are summarized below:

1. The parabola has an f/D ratio of 0.25 and can thus accommodate planar antennas with beamwidths approaching 180°.
2. The parabolic reflector is in the far-field of the planar antenna elements, and paraxial rays travel an equal distance in the dielectric to the focal point.
3. For heterodyne receiver operation the local oscillator (LO) can be injected from the back through a hole in the center of the reflector, eliminating the need for quasi-optical diplexing.
4. Antenna elements/detectors can be readily heat-sunk through the dielectric paraboloid to the backing metal, which is especially important for SIS mixers.
5. For array use, off-axis elements produce beams inclined from the optical boresight; the presence of the dielectric increases the extent of the off-axis beam tilt for a given lateral displacement of the antenna in the focal plane.

2. Construction of the 230 GHz Dielectric Filled Parabola

A photograph of a 230 GHz DFP (without cover plate installed) is shown in Fig. 1(a). An exploded schematic detailing the DFP assembly is shown in Fig. 1(b).



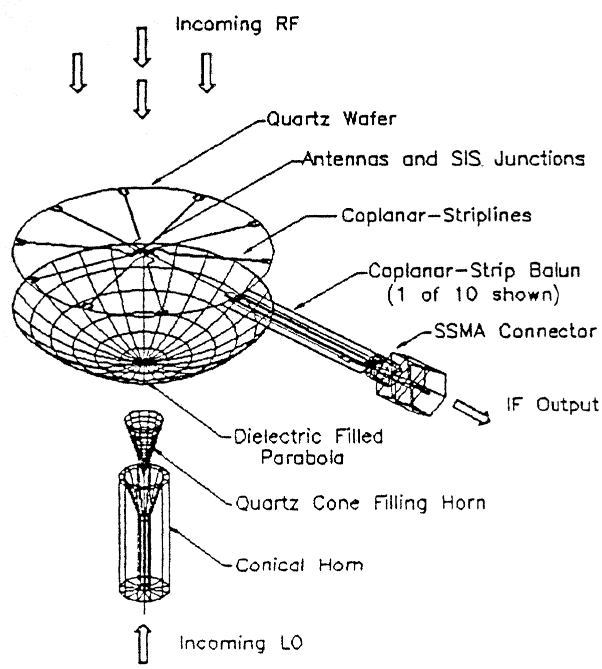


FIGURE 1. (a) Photograph of 230 GHz DFP without cover plate installed. (b) Exploded schematic of the DFP assembly.

The structure is composed of four basic parts: (1) the quartz wafer containing the antennas and feedlines; (2) the dielectric paraboloid; (3) the LO feed horn; and (4) the IF output, balun transformer, and DC bias lines. The 2x5 dipole array was fabricated on a 254 μm (10 mil) thick quartz wafer 19.5 mm (0.768") in diameter. The array layout and numbering convention is shown in Fig. 2.

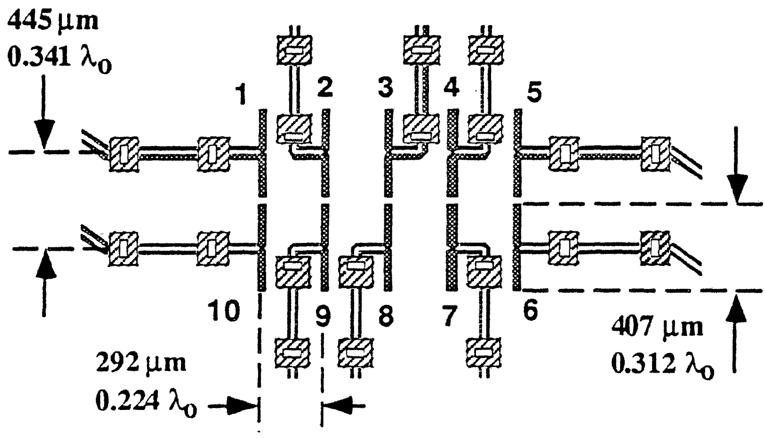


FIGURE 2. 2x5 dipole array layout and numbering convention.

Dipoles 3 and 8 are referred to as center elements, dipoles 2, 4, 7, and 9 are intermediate elements, and dipoles 1, 5, 6, and 10 are edge elements (Note: the "center" elements are not centered in the E-plane). The antenna and feed line pattern was formed by evaporation and liftoff of 4000 Å Cr/Au. The dipoles are 407 μm long which corresponds to the resonant length on a quartz substrate. The element spacing in the horizontal direction (292 μm) was chosen to achieve a 3 dB overlap in the individual element H-plane patterns, and the element spacing in the vertical direction (445 μm) was made as close as practical. The spacings were optimized using 20 GHz model pattern measurements. These feed antennas provide an effective optical system *f*-number of 0.4 due to under-illumination of the parabola aperture. RF blocking capacitors are located $\lambda_g/4$ and $3\lambda_g/4$ from the dipoles, ensuring RF open circuits at the detectors. SIS mixers were fabricated in this configuration and mixer results were reported in [4]. For the 230 GHz pattern measurements, bismuth bolometers were used as detectors. A photograph of the bismuth bolometer dipole array is shown in Fig. 3.

The thickness of the DC feed lines is 2.0μm of Cr/Au/Ti/Al/Ti/Au to just before the first set of capacitors in order to reduce the series resistance of the thin coplanar strips. The rest of the pattern is 4000 Å Cr/Au to allow for step coverage of the capacitor dielectrics and bismuth bolometers. The capacitor dielectrics are SiN_x deposited at a thickness of 2000 Å by PECVD and defined by CF_4 plasma etching; the upper plate metallization was 3500 Å of evaporated Cr/Au. A 1500 Å thick bismuth bolometer is evaporated at each antenna apex in order to achieve good sensitivity while keeping a reasonable match with the dipole impedances.

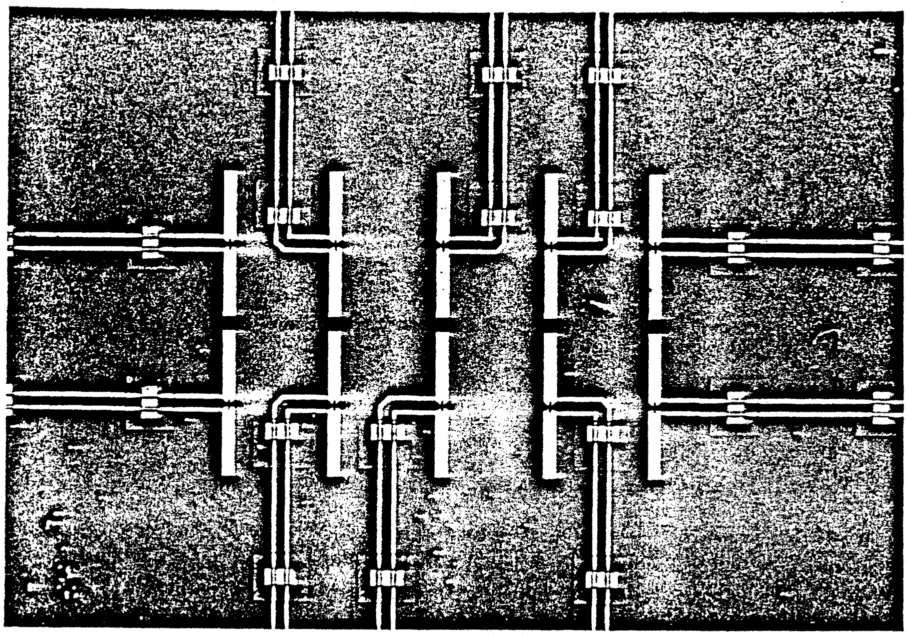


FIGURE 3. Photograph of the 230 GHz bismuth bolometer dipole array.

The dielectric parabola was ground from fused quartz to have a diameter of 19.5 mm (0.768") and an *f*/D ratio of 0.25. Once ground and polished, the parabolic substrate lens was vacuum coated with several skin depths of gold. A small rectangle sized to match the LO feed horn aperture was masked off at the center of the parabola before depositing the metal. The holder for the parabola was fabricated from brass and contains a parabolic depression for accurately mating to the quartz lens. The center of the housing contains a pyramidal feed horn for injection of the LO. The feed horn tapers to the face of a standard WR-3 waveguide flange on the rear of the holder. A quartz insert fits into the horn in order to minimize the mismatch presented to the LO.

The ends of the coplanar lines on the wafer flare out to form bonding pads where they are wire bonded to the planar balun transformers. The IF baluns are designed to work from 1-2 GHz and convert the balanced 200 Ω coplanar strip line impedance on the quartz wafer to 50 Ω unbalanced coaxial line impedance. The quarter wavelength delay is achieved through the use of chip capacitors, which behave as open circuits to the bolometer DC bias.

A brass cover plate bolts down to clamp the whole assembly together.

3. 230 GHz Antenna Pattern Measurements

Antenna pattern measurements at 230 GHz for the 2x5 bolometer array were made at the University of Michigan. The DFP was illuminated using a 77 GHz Gunn diode oscillator feeding a tripler with a conical horn output. An automated 2D mount was used to scan the DFP boresight through θ and ϕ. The axis definitions are shown in Fig. 4. The x-axis is the boresight of the DFP. Since the elements of the array are not located exactly at the focus of the parabola, the main beams of their antenna patterns are scanned away from the x-axis.

Two-dimensional patterns are centered on the boresight of the DFP; elevation scans in the theta direction and azimuth scans in the phi direction about this origin. The pattern planes of interest are cuts taken through the main beam of a given element. Hence, the "E"-plane of an element is that plane parallel to the E-field of the dipole intersecting the peak of the given element's main beam ($\phi = \phi_{max}$). The true "H"-plane of an element does not occur at constant θ, but since the elements were displaced by relatively small amounts in the vertical direction, "H"-plane cuts taken with $\theta = \theta_{max}$ are considered to be accurate.

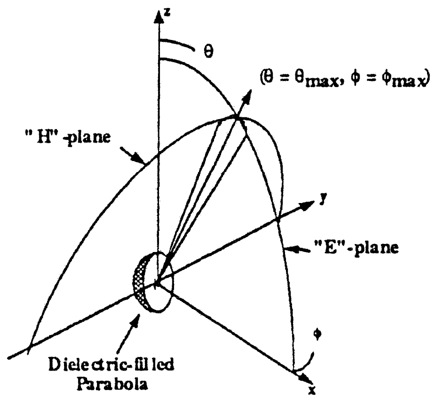


FIGURE 4. Axis definitions of the measurement system.

Measured 230 GHz two-dimensional patterns for typical center, intermediate, and edge elements are shown in Fig. 5.

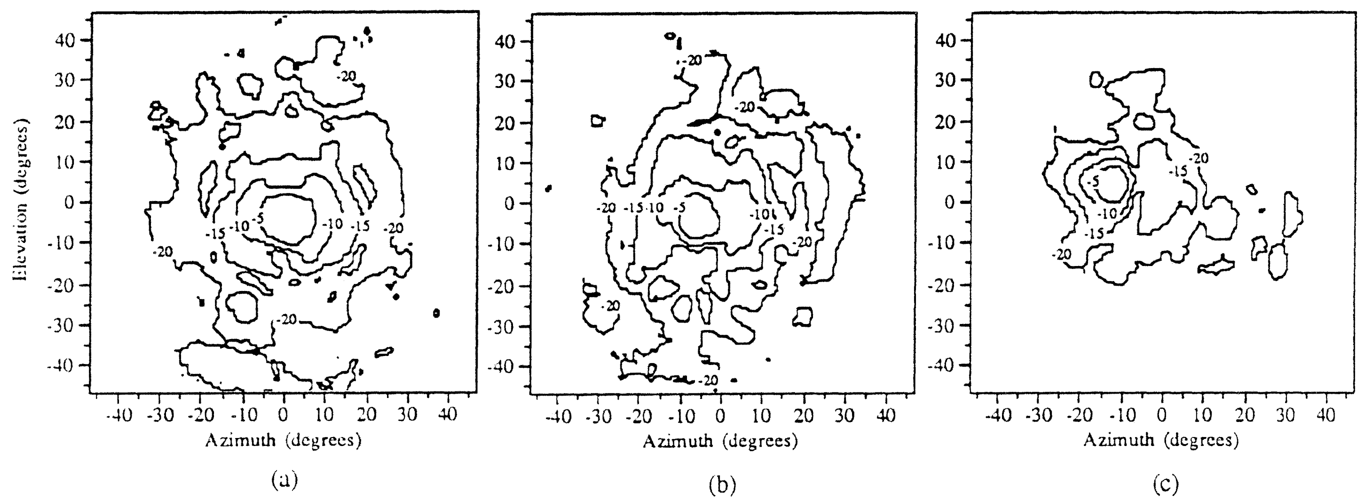


FIGURE 5. 2D patterns for typical elements: (a) Center (#3); (b) Intermediate (#4); (c) Edge (#6).

The center element (#3) has its main beam scanned to -4.6° in elevation and -0.9° in azimuth. The beam should ideally be at 0° in azimuth, indicating a slight misalignment between the 2x5 array and the dielectric parabola. The directivity is calculated from the 2D-pattern data at 21.4 dB. The intermediate element (#4) has its main beam scanned to -3.6° in elevation and -7.4° in azimuth, and a directivity of 22.1 dB. The edge element (#6) has its main beam scanned to +4.6° in elevation and -12.0° in azimuth, and a directivity of 23.4 dB. The trend in directivities does not represent an increase in gain as the element position moves away from the boresight since each pattern was normalized to its respective peak and no absolute power calibration was done for the detectors. However, there is a definite sharpening of the main beam as off-axis position is increased. This is similar to the behavior noted in [5] for off-axis elements on extended dielectric substrate lenses. It is felt that more uniform directivities could be achieved for the off-axis DFP elements through a change in extension length as has been proposed for the substrate lenses. Actual gain is expected to decrease as the element is moved off axis due to increased reflection and dielectric losses, as was seen in the 20 GHz model measurements.

"E"-plane scans for a typical upper row/lower row pair of antennas, and "H"-plane scans for typical center, intermediate, and edge elements are shown in Fig. 6.

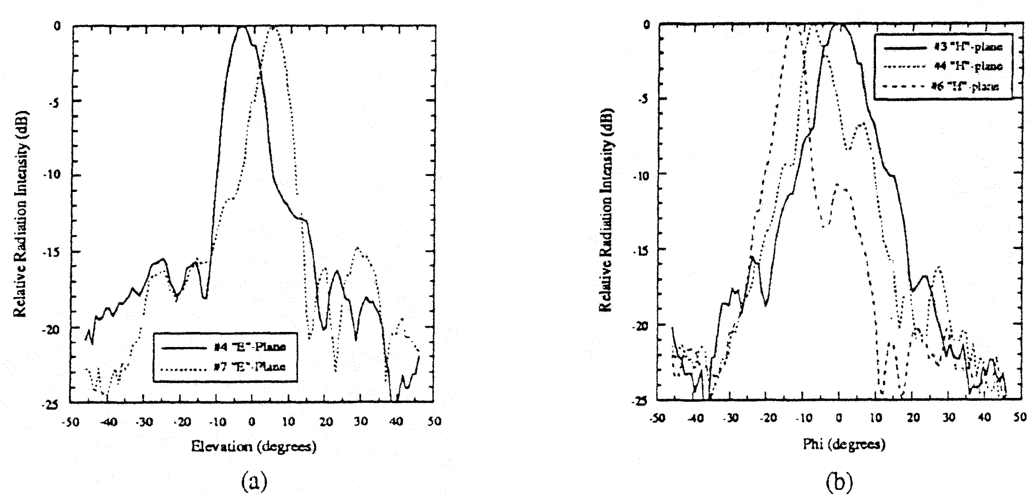


FIGURE 6. (a) "E"-plane scans (elements #4 and #7). (b) "H"-plane scans (elements #3, #4, #6).

The "E"-plane scans show that the lower and upper row elements scan in elevation by approximately ± 4°. The increased sidelobe levels are due to a combination of dipole air radiation and aperture blockage. Some comatic aberration can be seen emerging from each main lobe on the side towards the DFP boresight at about -12 dB. The "H"-plane scans show that the center, intermediate, and edge elements scan in azimuth by approximately 0°, 7°, and 12° respectively. The narrowing of the main lobe with off axis position can be clearly seen. The most significant feature, however, is the behavior of the coma lobe. Both theoretical work [6] and 20 GHz model measurements show that the primary coma lobe should increase monotonically with off axis position. However, the 230 GHz measurements have a higher intermediate element coma lobe level (-7 dB) than edge element coma lobe level (-11 dB). All element scan angles, and the center and edge element coma lobe levels show good agreement between the 20 GHz model and the 230 GHz version (see Table 1). The only physical difference between the two is the presence of the LO feed horn in the back of the 230 GHz DFP. It is possible that this discontinuity in the reflector may be contributing differing amounts of aperture blockage for the intermediate and edge elements, raising the intermediate element coma lobe level, but this has not yet been confirmed. The effect of the LO feed could be eliminated by coating the gap in the reflector with metal.

TABLE 1. Comparison of 20 Ghz model and 230 GHz DFP pattern measurements.

	"H"-plane Scan Angle (|degrees|)		Coma Lobe Level (dB)	
Element	**20 GHz**	**230 GHz**	**20 GHz**	**230 GHz**
Center	0.0	0.9	- 18	- 16
Intermediate	5.8	7.4	- 16	- 7
Edge	12.4	12.0	- 12	- 11

4. Conclusions and Future Work

Beam pattern measurements at 230 GHz have been performed for a 2x5 dipole/bolometer array on a Dielectric Filled Parabola (DFP). The measured patterns agreed well with those obtained from a 20 GHz model with the exception of the intermediate element coma lobe level which was significantly higher. The only physical difference between the two versions is the presence of the LO feed horn in the back of the 230 GHz DFP, but this has not been confirmed to be the cause. Further measurements with the gap in the reflector metalized will be performed to determine the effect of the LO feed. Also, software is currently under development to model the off-axis properties of the DFP and will be used to help diagnose the cause of the high coma lobe levels.

5. References

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