Millimeter-Wave Double-Dipole Antennas for High Efficiency Reflector Illumination

D.F. Filipovic, W.Y. Ali-Ahmad and G.M. Rebeiz

NASA/Center for Space Terahertz Technology
Electrical Engineering and Computer Science Department
University of Michigan
Ann Arbor, MI 48109-2122

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ABSTRACT

A double-dipole antenna integrated on a thin dielectric membrane and backed by a large ground plane is presented. The double-dipole design results in nearly equal E and H-plane patterns with a gain of 12-13 dB, a cross-polarization levels lower than -27 dB, and a main-beam efficiency of 90%. The input impedance is around 50Ω and will match well to a Schottky-diode or SIS detector. Pattern measurements at 234 GHz, 246 GHz and 258 GHz agree well with theory.The double-dipole antenna is a simple antenna to fabricate with a very low cross-polarization component, and is useful for millimeter and submillimeter-wave applications requiring a ±5% bandwidth.

I. INTRODUCTION

The use of thin dielectric membranes for millimeter-wave integrated-circuit antennas is now a well established technique for high-efficiency designs [1,2].The membranes are very thin compared to a free-space wavelength, and the antennas do not suffer from dielectric and substrate-mode losses. It is possible to integrate a radiating structure consisting of two dipole antennas on a dielectric membrane and backed by a ground plane that results in equal E and H-plane patterns and a very low cross-polarization component (Fig. 1). Double-dipole antennas have been previously investigated at millimeter-wave frequencies and have showed promise for high-efficiency applications [3,4]. The detector is integrated at the center of the coplanar stripline. A low-pass filter is used to isolate the IF/bias lines from the antenna. The double-dipole antenna is very simple to fabricate, and results in similar directivities to the integrated-horn antenna and with a high coupling efficiency to f/0.7-f/0.9 reflector systems.

II. DOUBLE-DIPOLE ANTENNA DESIGN

The antennas are integrated on a thin dielectric membrane and it is therefore possible to use free-space radiation techniques. The antennas have the same current distribution due to the detector position and symmetry. For far-field pattern calculations, the antenna current distribution is given by the standing-wave current on an open-circuited transmission line. The method of images is used to account for the ground plane [4]. An optimization program was written to yield nearly equal E and H-plane patterns by changing the antenna lengths (l), the antenna spacing (d) and the membrane position from the ground plane (h). The dipole input impedance is found by assuming a more exact current distribution [5] and taking into account the mutual impedance effects between the antennas and their images. The dipole impedance is then transformed using transmission-line theory to the detector terminals. The double-dipole antenna input impedance is half the transformed impedance due to the parallel combination of the two dipoles. The coplanar-stripline characteristic impedance (Z_{cps}) is chosen to yield a final input impedance around 50Ω. It is possible to add a short coplanar stub along the transmission-line for impedance tuning considerations.

III. THEORETICAL AND EXPERIMENTAL RESULTS

A double-dipole antennas with parameters (l, d, h, Z_{cps}) of $(0.7\lambda, 0.55\lambda, 0.77\lambda, 300\Omega)$ was build for 246 GHz applications. The design yields nearly equal E, H and 45°-plane patterns with a 10-dB beamwidth of 78° and 70°, and a directivity of 11.7 dB, respectively. The measured input impedance on a 2 GHz microwave model is 50Ω for a $\pm 5\%$ bandwidth (Fig. 2). The measured patterns agree quite well with theory up to 45° (Fig. 3) where diffraction effects from the measurement set-up dominate (Fig. 4). The design indicates a sidelobe level lower than -13 dB and a -27 dB cross-polarization component in the 45°-plane. The sidelobe level could not be confirmed due to the measurement set-up, but a cross-polarization component less than -22 dB was measured at $30-35°$. Patterns measurements at $0.95 f_0$ (234 GHz) and $1.05 f_0$ (258 GHz) agree well with theory and result in symmetric patterns (Fig. 5). The slight dip of 1 dB at normal incidence at 254 GHz is not predicted by theory and could not be explained. The double-dipole antenna results in a theoretical coupling efficiency to a gaussian beam with $\theta_0 = 30°$ of 77%, 83%, and 84% at $0.95 f_0$, f_0 and $1.05 f_0$, respectively (Fig. 6). The measured electromagnetic coupling between two double- dipole antennas in the H-plane was lower than -20 dB (or -30 dB) for a center-to-center spacing of 1λ (or 1.5λ). The coupling in the E-plane was negligible for center-to-center spacing greater than 1.25λ. It is therefore possible to array the antennas for diffraction-limited imaging. We are now investigating the possible use of these antennas to high-gain submillimeter-wave reflector systems.

ACKNOWLEDGEMENTS

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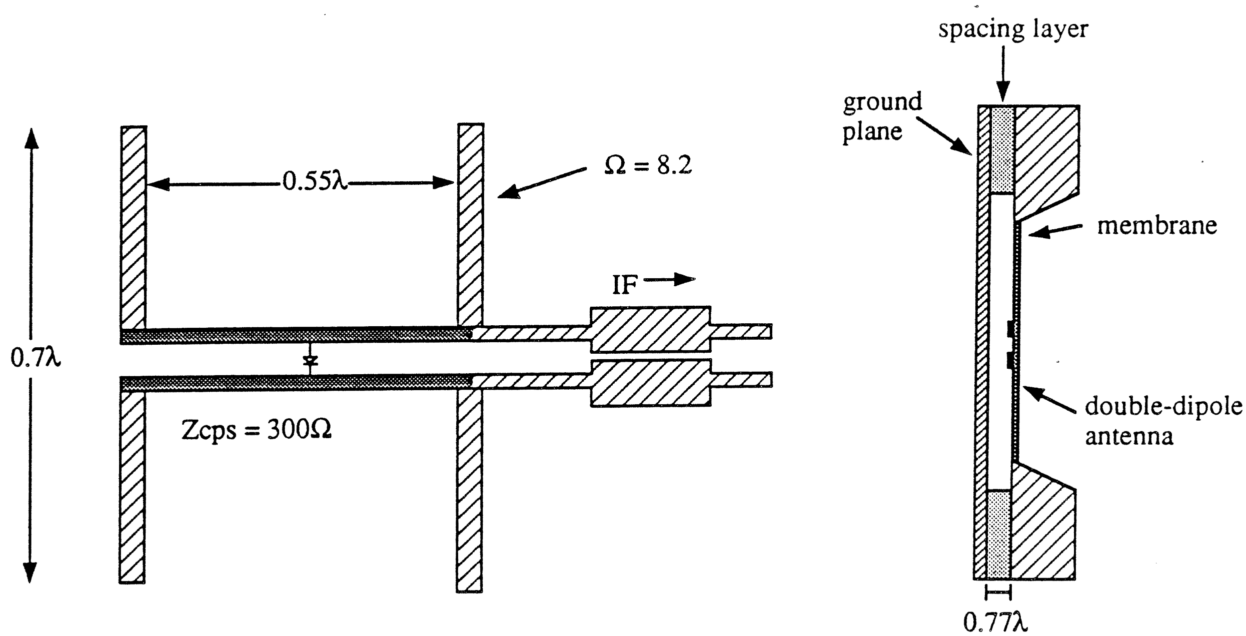

Figure 1: The double-dipole antenna on a thin-dielectric membrane and ba.·ked by a ground plane.

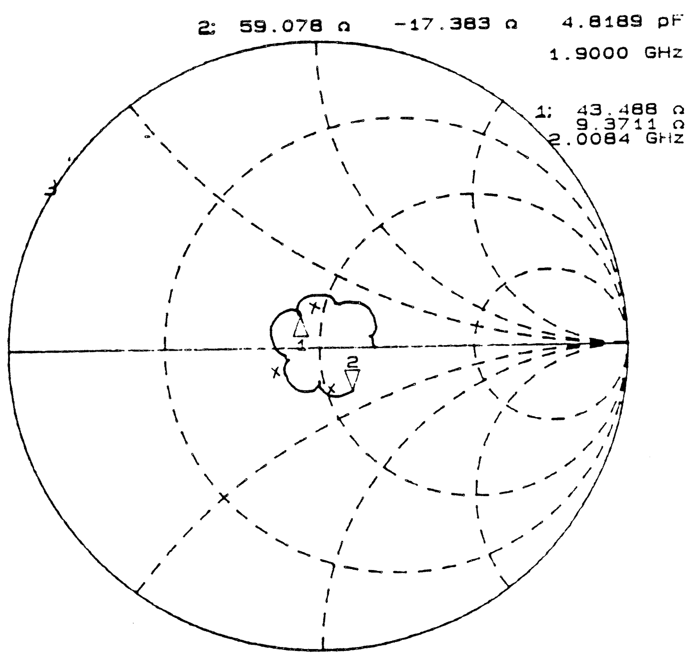

Figure 2: Measured input impedance of the double-dipole antenna at 2 GHz.

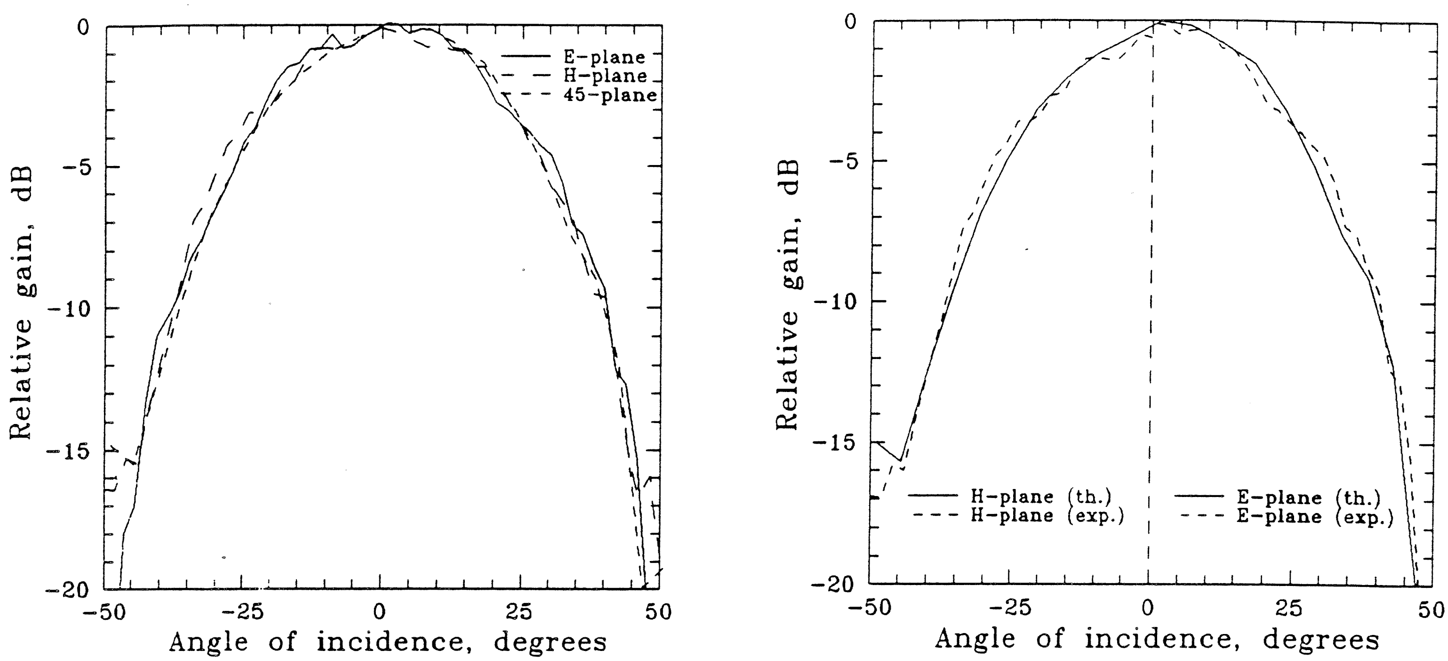

Figure 3: The measured E, H and 45° patterns at 246 GHz (left), and the comparison with theory for the E and H-plane patterns (right).

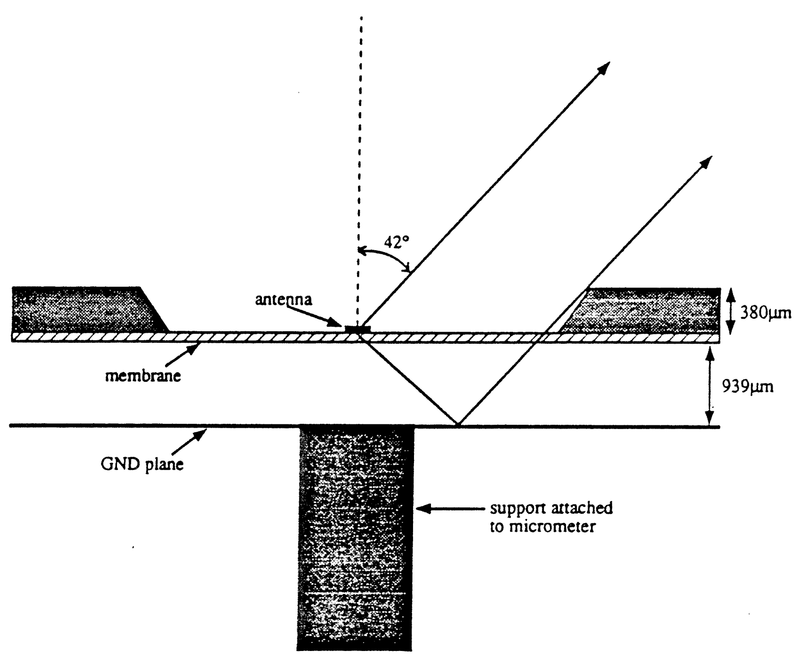

figure 4: The measurement set-up at 246 GHz. The finite size of the membrane introduces blockage and limits the measurement angle to ±40°.

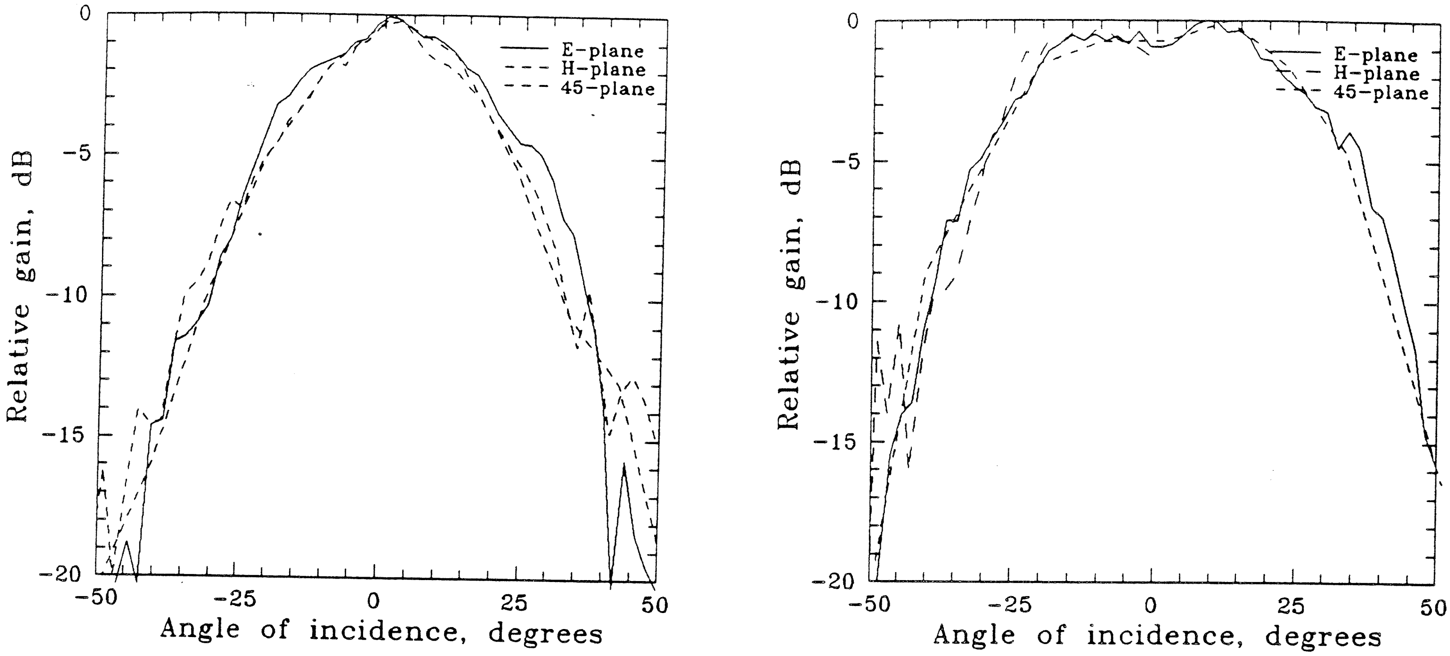

figure 5: The measured E, H and 45° patterns at $0.95f_0$ (234 GHz-left) and $1.05f_0$ (258 GHz-right).

Freq	Z_{ANT}	Gain	X-pol	ε_{mb} (-20dB)	$\varepsilon_{Gaus}(\theta_0=30°)$	$\varepsilon_{Gaus}(\theta_0=27°)$
0.90 f_0	~ 50Ω	-	-	-	64.7%	66.5%
0.95 f_0	~ 50Ω	11.8dB	-27dB	82%	77.4%	77.1%
f_0	~ 50Ω	11.7dB	-26dB	88%	83.4%	81.1%
1.05 f_0	~ 50Ω	11.2dB	-25dB	91%	84.8%	80.9%
1.10 f_0	~ 50Ω	-	-	-	82.7%	77.3%

figure 6: Calculated antenna parameters vs. frequency. ϵ_{mb} is defined as the main-beam efficiency till the -20 dB points and ϵ_{Gauss} is defined as the coupling efficiency to gaussian-beams of parameter θ_0.