

A Planar Cavity Based Antenna by Leaky Parallel-Plate Wave Guiding and Practical Surface-Wave Launching

Abstract

A dual-layer antenna that utilizes bound surface waves for leaky wave excitation is presented for microwave and millimeter-wave applications. Specifically, by placing a superstrate dielectric layer and ground plane on top of a base grounded dielectric slab a resonant cavity can be realized defining a parallel-plate guiding structure. Antenna leakage can be achieved by an annular ‘bull-eye’ grating of slots etched in the top ground plane for two-side beam scanning. In addition, a single pencil beam at broadside can be observed over a large radiating bandwidth (21.9 GHz to 23.9 GHz) with measured antenna gain values > 12.6 dBi from 22.3 GHz to 23.7 GHz. Essentially the bidirectional field distribution on the aperture is excited by a non-directive surface-wave launcher (SWL) source embedded in the bottom ground plane. This dual-layer structure and printed SWL feed may be useful for new parallel-plate wave guide configurations and other planar leaky-wave antennas.

Introduction

Dielectric multilayer antennas have received much interest and attention in the electromagnetics community, and these low-profile designs are attractive for their compatibility with other planar devices, low cost, and directive beam patterns. Generally these leaky-wave antennas (LWAs) can be defined by a stackup of two or more dielectric layers characterizing a resonant cavity and realizing a leaky, parallel-plate guiding structure [1]. More specifically, by the appropriate dielectric coverings, cylindrical leaky-wave (LW) field distributions [2] can be efficiently excited on the top dielectric layer defining a partially reflecting surface (PRS). Essentially, a high-low

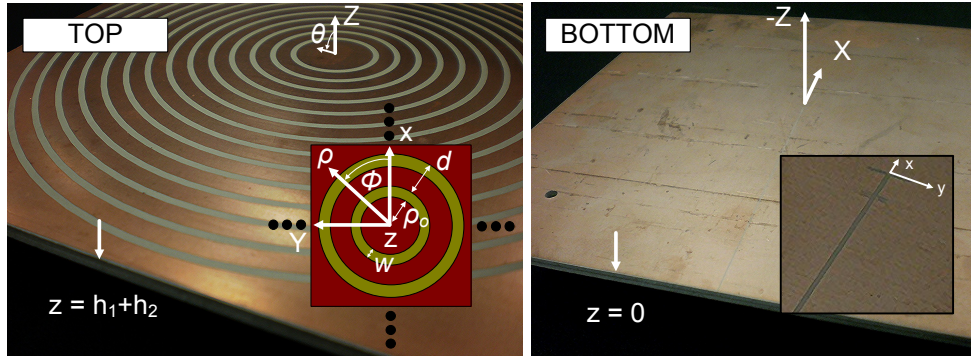


Figure 1: Investigated planar antenna with 14 annular slots ($w = 1.4$ mm, $d = 5$ mm, $\rho_o = 9.3$ mm) etched in the top ground plane defining the PRS. The two layer guiding structure can be characterized by a high-low dielectric stack up ($\epsilon_{r1} = 10.2$, $h_1 = 50$ mil, $\epsilon_{r2} = 3$, and $h_2 = 60$ mil) covered by two ground planes. The antenna is fed by a non-directive SWL and a 50Ω coplanar waveguide transmission line etched in the bottom ground plane.

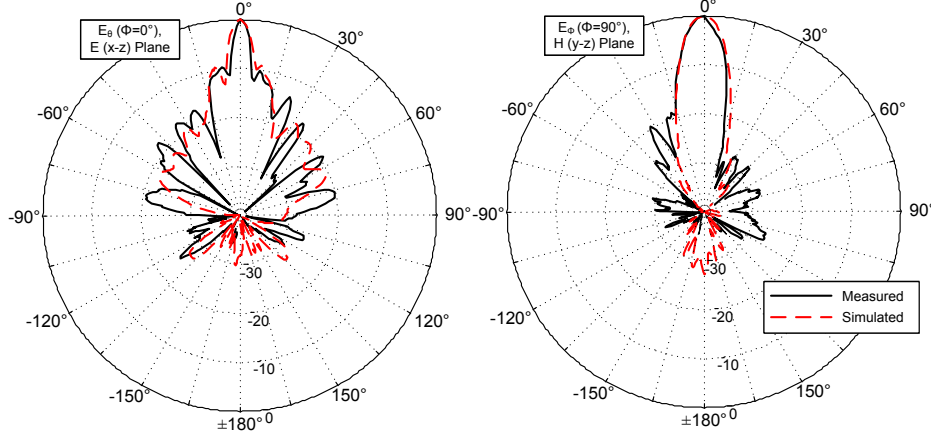


Figure 2: Measured beam patterns at 22.8 GHz with maximum gain values of 15.6 dBi. Results are normalized and shown in dB (E/H planes referenced to main slot of the SWL). Agreement is observed with the simulations and 3 dB beam widths $< 6^\circ$ [10°] are realized in the E [H] plane.

dielectric constant profile is required to efficiently match the bound field distributions to free space. Leakage from the antenna can be explained by the excitation of both TM and TE field distributions on the guiding surface and theoretical concepts have been reported in [1] and [2] demonstrating that directive radiation at broadside is possible as well as two-sided conical-sector beam patterns in the far field.

Unfortunately, for optimal radiation performance and increased antenna gain relatively high dielectric constant values are required for the top layer with very particular thickness requirements [1]. For example, high gain values may be achieved at a desired pointing angle, θ_p , if the dielectric material thicknesses are chosen according to the following relation, $h = \lambda_0/4(\epsilon_r - \sin^2 \theta_p)^{\frac{1}{2}}$, where λ_0 is the wavelength in free space and ϵ_r is the relative dielectric constant. In practice acquiring such exact substrate characteristics, for a particular design frequency, with high dielectric constant values ($\epsilon_r > 12$) can be very challenging. Furthermore, high precision tooling or milling may be required to achieve the required top layer thickness and thus antenna fabrication costs can escalate. In addition, with increased dielectric constant values ($\epsilon_r \gg 12$) antenna gain can increase, but regrettably, with a resultant decrease in the radiating bandwidth [1]. Thus when low cost planar antenna

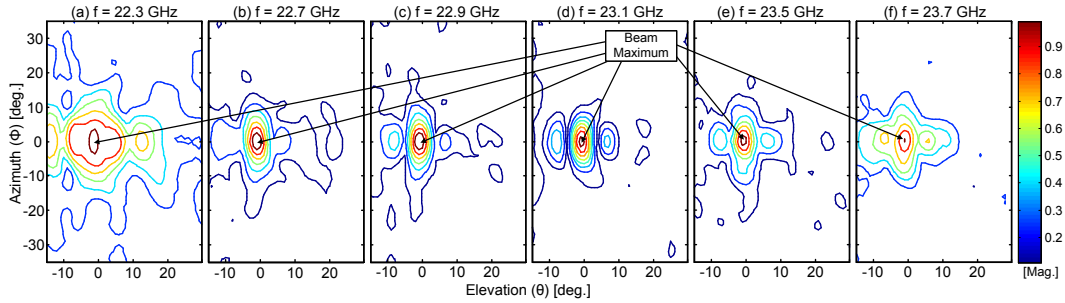


Figure 3: Measured 2D gain patterns in the azimuth and elevation. A single pencil beam pattern at broadside is observed from 22.3 GHz to 23.7 GHz (with a 1.36 GHz 3 dB radiating bandwidth). Values have been normalized to observed maxima and results are shown in linear units.

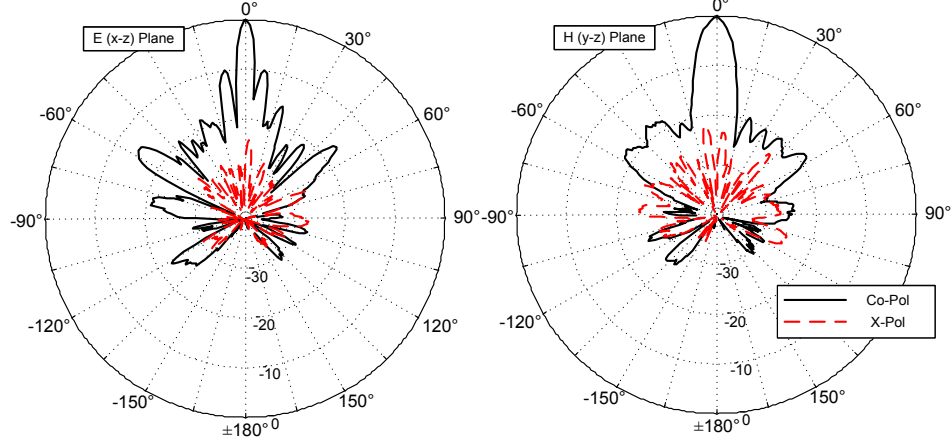


Figure 4: Measured beam patterns at 23.0 GHz. Side lobe levels are 10 dB below the main broadside beam and minimal radiation into the antenna back-side is observed.

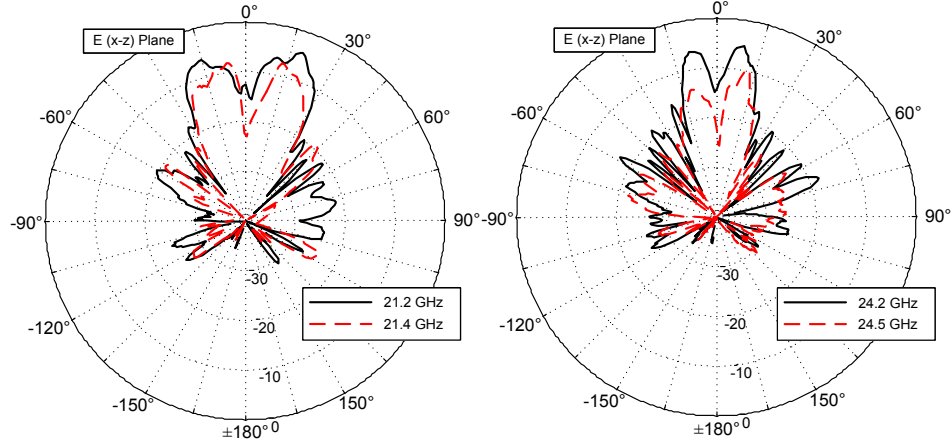


Figure 5: Measured beam patterns for non-broadside radiating frequencies ($f < 21.9$ GHz and $f > 23.9$ GHz). Results shown in dB and normalized to observed maximum at 22.8 GHz (Fig. 3).

configurations are required, novel design techniques may be of interest.

Antenna Design, Results, and Discussion

This work investigates a new low cost multilayer LWA configuration composed of two commercially available grounded dielectric slab layers ($\epsilon_{r1} = 10.2$, $h_1 = 50$ mil, $\epsilon_{r2} = 3$, and $h_2 = 60$ mil) affixed at their respective air-dielectric interfaces. The parallel-plate guiding structure is fed by a non-directive SWL source at the center of the bottom ground plane [3]. To achieve antenna leakage and radiation into the far field an annular grating of slots is etched into the top ground plane (as shown in Fig. 1). The printed ‘bull-eye’ slot grating ($w = 1.4$ mm, $d = 5$ mm, $\rho_o = 9.3$ mm) defines an effective PRS and LW radiation can be achieved by a fast spatial harmonic [3], [4]. In effect, this grating configuration replaces the need for a high dielectric constant top layer and a resonant response is ensured due to high-low profile of the two dielectric layers within the parallel-plate guiding structure; ie. $\epsilon_{r1} > \epsilon_{r2}$.

The presented LWA can radiate a single pencil beam at broadside ($\theta_p = 0^\circ$) from

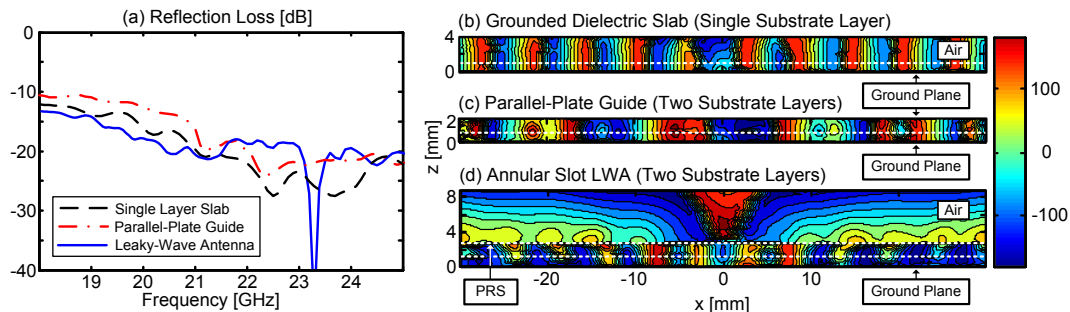


Figure 6: (a): Simulated reflection losses of the single layer GDS (no top ground plane), dual-layer parallel-plate guide (with top ground plane), and LWA (with annular slot grating PRS). (b), (c), and (d): $\angle E_x(x, z)$ field distribution at 23.3 GHz (above the air-dielectric boundaries and within the substrates, interfaces defined by dotted white lines). All excited by a non-directive SW source embedded in the origin of the ground plane and a coplanar waveguide feeding line.

21.9 to 23.9 GHz with a measured maximum gain of 15.6 dBi at 22.8 GHz (as shown in Fig. 2) with a 3 dB radiating bandwidth of 1.36 GHz and minimal radiation into the antenna backside. Contour 2D gain patterns in the azimuth and elevation are shown in Fig. 3 and side lobe and cross polarization levels are respectively, ≤ 10 and 20 dB below the observed beam maximum (Fig. 4). Furthermore, two-sided conical-sector beam patterns are observed below and above 21.9 GHz and 23.9 GHz, respectively, (Fig. 5) and simulated reflection loss values are less than 10 dB for the LWA structure from 18 - 25 GHz with resonant behavior at 23.3 GHz as shown in Fig. 6(a). In addition, by observing the reflection losses and the phase of the E_x field distribution throughout the air and dielectric layer regions, for various substrate stackup configurations, insight into the operation of the parallel-plate guiding structure can be further understood as shown in Fig. 6(b)-(d).

Conclusion

By taking advantage of the frequency beam scanning behavior associated with grating antennas and the resonant response of cavity based LWAs, a novel dual-layer antenna can be realized for two-sided beam patterns and directive broadside radiation. Measured maximum gain (15.6 dBi) is observed at 22.8 GHz with a 3 dB radiating bandwidth of 1.36 GHz at broadside. In addition, a pattern beamwidth $\leq 6^\circ$ can be achieved in the $E(x-z)$ plane with minimal radiation into the antenna back side. This dual-layer parallel-plate wave guiding structure and SWL feed may be useful for new antennas and other planar microwave and millimeter-wave circuits.

References

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