A MILLIMETER-WAVE SLOT-V ANTENNA

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Abstract—**A new V-shaped slot antenna built on a dielectric substrate is presented. The antenna is a non-resonant, travelling-wave design, with a predicted impedance in the range from 50 Ω to 80 Ω. Calculations indicate that this antenna should have a gain of 15 dB with 3-dB beamwidths of 10° in the H plane and 64° in the E plane. Pattern measurements at 90 GHz support the theory. It should be possible to equalize the two beamwidths with a cylindrical lens. The broad bandwidth and high gain characteristics make the slot-V a good candidate for picosecond optoelectronic measurements. Fabrication is simple, and it should be possible to make this antenna at wavelengths as short as 10 μm with conventional photolithography.**

INTRODUCTION

Antennas on dielectric substrates suffer from losses to substrate modes, and tend to have low gain and poor patterns. An example of this is the bow-tie antenna [1]. An elegant way to solve the substrate problem is to fabricate the antennas on silicon-oxynitride membranes inside horns [2], but this requires sophisticated fabrication techniques. An alternative is to add a superstrate so that the antenna is entirely inside the dielectric, to make a sandwich. This has been demonstrated with a V antenna [3]. Here we propose a simpler approach, a slot antenna in the shape of a V (Figure 1). One can get a feeling for how the slot-V works

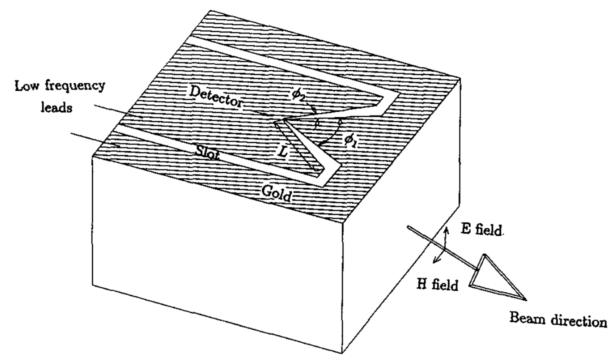

Figure 1. Diagram of the slot-V antenna on fused quartz. The arm length L is $5\lambda_d$. The slot angles are $\phi_1 = 57.5°$ and $\phi_2 = 10°$. The substrate is 25 mm square and 14 mm thick.

by considering how waves propagate along conductors at a dielectric interface. A wave in a slot tends to propagate at a velocity that is intermediate between the velocity of waves in air and the velocity of waves in the dielectric. The wave is slow compared to the air velocity, and excites primarily evanescent waves in the air. This means that little power radiates directly into the air. On the other hand, the wave velocity is fast compared to the dielectric velocity, and the antenna radiates strongly into the dielectric at an angle $\psi = \arccos(v_d/v_s)$, where v_s is the slot phase velocity and v_d is the dielectric velocity [4]. When the angle between the slot arms is twice this radiation angle, the radiation from the two arms adds in phase, producing a strong beam on the V axis.

THEORY

This is a non-resonant travelling-wave antenna, and we can estimate the impedance as a special case of a conformal-mapping formula developed for V-couplers [5].

$$Z = \left(\frac{\eta_0}{4n_e}\right)\left(\frac{K'(m)}{K(m)}\right) \tag{1}$$

where η_0 is the free-space wave impedance, and n_e, the effective refractive index, is given by $\sqrt{\frac{\epsilon_r+1}{2}}$. The assumption is that propagation is similar to that in a material that has a dielectric constant that is the mean of the dielectric constant of the substrate and the dielectric constant of air. The dielectric constant of fused quartz is 3.78 [6]. The functions K and K' are elliptic integrals, and the parameter m is given by

$$m = \left(\frac{\tan(\phi_1/4)}{\tan(\phi_1/4+\phi_2/2)}\right)^2 \tag{2}$$

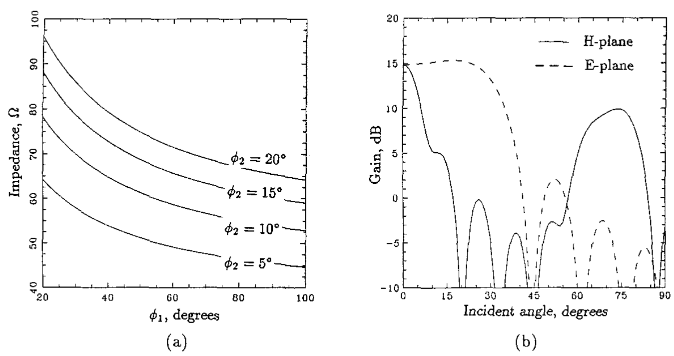

Figure 2. (a) Impedance of the slot-V, calculated from Equation 1. (b) Calculated slot-V patterns in the dielectric.

Figure 2a shows a plot of the impedance as a function of ϕ_1, with ϕ_2 as a parameter. For convenient angles the impedance ranges between $50\,\Omega$ and $80\,\Omega$. To estimate the radiation pattern of the slot-V, we assume a radial magnetic current in the left slot of the form $I_m = \exp(-jn_e k_0 r)$, where k_0 is the propagation constant of free space. The magnetic current for the right slot changes sign. We can then integrate these currents to calculate the magnetic radiation vectors and the pattern in the dielectric [7]. The patterns are shown in Figure 2b. The gain on axis is 15 dB and the 3-dB beamwidths are 10° in the H-plane and 64° in the E-plane. There is a 5 dB sidelobe at 75° in the E-plane.

FABRICATION AND MEASUREMENTS

The antenna is fabricated by evaporation and lift-off. The metal film is a 1600-Å layer of gold on top of 120 Å of chrome. A M/A-Com GaAs Schottky diode (MA 40417), mounted across the slot at the apex of the V, acts as a detector. The diode is biased at $100\,\mu$A. The substrate is covered with absorber on the bottom face and three side faces, so that the antenna receives power only from the front and top faces. The source is an HP 83558A mm-wave multiplier, driven by an HP 83620 synthesized sweeper with an HP 8349B amplifier.

The measured patterns are shown in Figure 3. In the E-plane (Figure 3a), the antenna is much more sensitive to radiation from the dielectric side. The peak in the pattern is not along the antenna axis but is 20° off. We suspect that this effect comes from the fact that the edge of the groundplane is only 12 mm from the apex of the V. The measured pattern decays faster than theory predicts, and this may be due to the fact that the substrate is only 14 mm thick. In the H-plane (Figure 3b), theory and experiment agree. The patterns are broader than in Figure 2b, primarily because of refraction at the front face of the substrate.

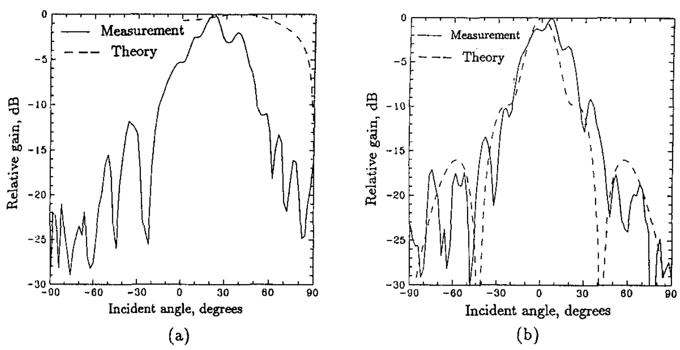

Figure 3. (a) Measured 90-GHz E-plane pattern. For positive angles, radiation is incident from the dielectric, and for negative angles, radiation is incident in the air. The theoretical pattern is for dielectric incidence only, and takes reflection and refraction through the front face into account. (b) Measured 90-GHz H-plane pattern. This pattern is actually measured at 20° in the E-plane, where the gain is maximum. The theory is for an E-plane angle of 0°, and takes reflection and refraction through the front face into account.

Conclusions

We have developed a new slot-V antenna on a dielectric substrate and tested it at 90 GHz. The predicted impedance is in the range from $50\,\Omega$ to $80\,\Omega$. The calculated gain is 15 dB with 3-dB beamwidths of $10°$ in the H plane and $64°$ in the E plane. Pattern measurements at 90 GHz support the theory. In many applications it is desirable that E-plane and H-plane beamwidths be the same so that the antenna can couple efficiently to an optical system. It should be possible to equalize the two beamwidths with a cylindrical lens that would reduce the E-plane beamwidth without changing the H-plane beamwidth. The broad bandwidth and high gain characteristics make the slot-V a good candidate for picosecond optoelectonic measurements [8,9]. Fabrication is simple, and it should be possible to make this antenna at wavelengths as short as $10\,\mu$m with conventional photolithography.

Acknowledgments

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