Active Cavity-Backed Slot Antenna Using MESFET's

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Abstract— **An active cavity-backed slot antenna for quasi-optical arrays is described. A packaged GaAs MESFET with a coplanar matching network was used for the oscillator circuit. This configuration yields the expected slot antenna radiation pattern with a compact layout, low cross-polarization, and increased directivity due to the cavity backing. The measured patterns with cavity backing show a significant improvement compared with the same oscillator without cavity-backing.**

I. INTRODUCTION

ACTIVE MICROWAVE antenna arrays can be used for efficient power combining of solid-state sources [1], [2]. Prototype arrays have been fabricated with microstrip patch antennas and either Gunn diodes, IMPATT's, or MESFET's as the active elements [3]–[5]. However, it is difficult to integrate three-terminal devices with patch antennas in a convenient form for monolithic processing. A compact design is also desirable. The slot antenna provides an attractive solution; it is simple to excite with a coplanar waveguide feed, and as such is easier to integrate with FET's and to fabricate monolithically. A drawback to using slots is the inherent bi-directional radiation characteristics. This problem is exacerbated on high dielectric constant materials, as the slot tends to radiate preferentially into the substrate [6]. We report a cavity backed slot antenna excited by a coplanar FET oscilllator. The cavity backing makes the antenna unidirectional, thus increasing its directivity [8]. Furthermore, the cavity backing improves the radiation characteristics of the active slot, as will be shown.

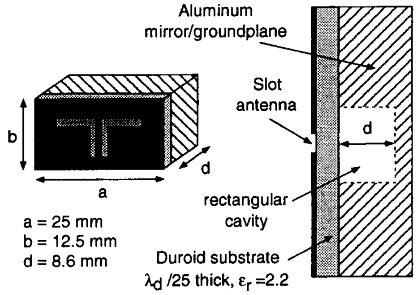
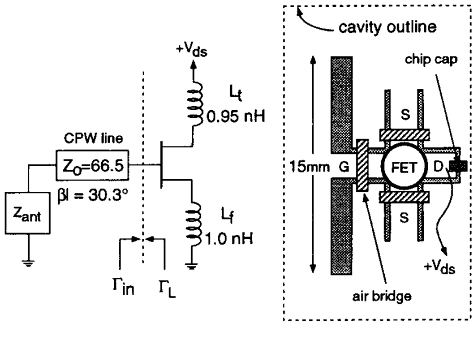


Fig. 1. Slot antenna with a rectangular cavity backing.



(a) (b)

Fig. 2. (a) Lumped element equivalent circuit, and (b) physical layout of the CPW-fed slot antenna oscillator. Two inductors are realized with CPW stubs. The slot, FET, and matching circuitry fit within the cavity dimensions.

II. SLOT ANTENNA AND CAVITY DESIGN

A design frequency of 10 GHz was chosen, with the length of the slot antenna set at one-half a free-space wavelength, or 15mm. The width of the slot was chosen as one-tenth of the length. The substrate material used was Rogers Duroid 5880, with a dielectric constant of $\epsilon_r = 2.2$ and thickness of 0.787 mm. In contrast to the traditional cavity-backed slot [8] where the cavity metal makes electrical contact to the slot metal, our topology has the cavity flange forming a ground plane to the dielectric substrate that supports the slot, as shown in Fig. 1. This arrangement should be easier to realize monolithically. In the present case, a low dielectric constant was chosen to minimize the effects of the substrate-cavity interface. The cavity is essentially a shorted rectangular waveguide, one-quarter of a guide wavelength deep. The cut-off frequency of the guide was chosen to be 6 GHz for the TE_{10} mode, which gives a long dimension of 25 mm. The short dimension was set at one-half the long dimension. The closest higher order modes are then the TE_{20} and TE_{01} modes that propagate at 12 GHz, making it safe to operate the antenna at the design frequency of 10 GHz. For a waveguide of these dimensions, one-quarter of a guide wavelength is 9.4 mm at 10 GHz. The cavity was constructed out of aluminum and actually made 8.6 mm deep to account (approximately) for the thickness of the substrate.

III. OSCILLATOR DESIGN

An equivalent circuit model for the oscillator is shown in Fig. 2(a). The first step in the oscillator design was to characterize the impedance of the cavity backed antenna,

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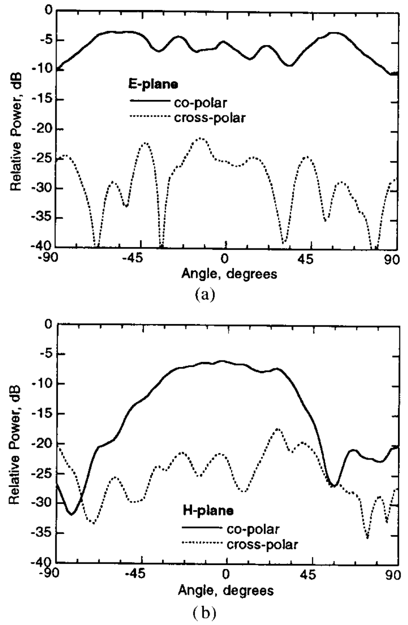
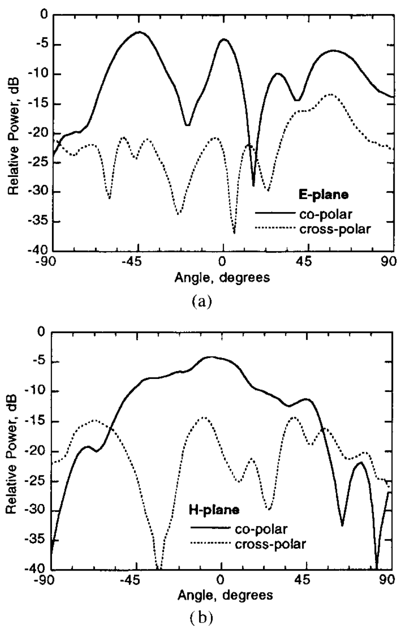


(a)

(b)

Fig. 3. Measured radiation patterns for an X-band prototype with cavity-backing. (a) E-plane patterns. (b) H-plane patterns. Ripples in the E-plane are due to ground plane edge diffraction.



(a)

(b)

Fig. 4. Measured radiation patterns with cavity-backing replaced by a ground plane. (a) E-plane patterns. (b) H-plane patterns. Note the change in the E-plane co-polar pattern as compared with the cavity-backed slot (Fig.3), and the increased cross-polarization in both pattern planes.

Z_{ant}. A 50-Ω microstrip-to-coplanar waveguide transition was implemented to allow the antenna and feed structure to be characterized on a network analyzer. The second step was to develop a negative impedance network to be connected to the load. This network used an NEC75083 GaAs MESFET in the common source configuration, and short-circuited coplanar waveguide stubs for the terminating (drain) and feedback (source) inductors. The network was designed on Touchstone using the manufacturer's small-signal s-parameters (our simulations used $\epsilon_{\text{eff}} = 1.54$ and a gap width of 0.13 mm for the CPW lines). Then, the network was constructed with a 50-Ω microstrip feed to facilitate network analyzer measurements.

Both the measured antenna impedance and the measured reciprocal reflection coefficient of the negative resistance network were plotted on a Smith Chart, indicating that a CPW line length of about 40° was required to transform the load impedance such that the oscillation conditions could be satisfied [9]. The complete circuit layout is shown in Fig. 2(b). The oscillator was designed using a FET gate bias of $V_{gs} = 0$ Volts to simplify the layout. This would make it easier to develop a large array of these oscillators, where little space is available for routing control signals and bias lines. Note that the final oscillator size was very compact, allowing it to sit directly over the cavity. This will lead to increased packing density in an array, and hence large power per unit area.

IV. MEASUREMENTS AND RESULTS

Initially, several different lengths of coplanar line were used to connect the antenna to the device, which were selected close to the 40° suggested by the impedance measurements. These different lengths gave slightly different oscillation frequencies as expected. The final oscillator used for the radiation pattern measurements operated at 10.27 GHz, with a CPW line length of 30°. From a measurement of maximum received power, we compute an effective radiated power (ERP) of 22.4 mW. Assuming a typical value for slot directivity of 3.2 (1.6×2 to account for the cavity), we obtained a total radiated power of approximately 7 mW. The dc power dissipated by the device was 120 mW with V_{ds} =3 V, I_{ds} =40 mA. This gives a poor conversion efficiency of less than 10%, which is a result of both the zero gate bias and the use of small-signal s-parameters in the design. A rough phase-noise measurement was performed using an HP8563 spectrum analyzer, giving −80 dB/Hz at 100 kHz from the carrier.

The measured E-plane pattern (Fig. 3(a)) exhibits ripples that are characteristic of a slot antenna with a finite ground plane as shown by Kraus [10]. The good cross-polarization levels indicate that there is little feed radiation from the coplanar transmission line as well as little excitation of higher order modes in the slot and cavity. The H-plane also shows good symmetry and cross-polarization for most of the range of measurement. The aberration near the end of the range may be due to the discontinuities caused by the presence of the oscillator and the feed. When the cavity-backing is replaced by a substrate ground plane, the measured radiation patterns of Fig. 4 were observed. The patterns show higher levels of cross polarization than the cavity-backed circuit, as well as a significantly different E-plane co-polar pattern, which shows severe interference nulls which were not present in the cavity-backed measurements.

V. CONCLUSION

Exciting a cavity backed slot antenna with a CPW FET oscillator shows reasonable radiation patterns and good directivity, and is compatible with monolithic processing techniques. Such cavity backing could be an integral part of the substrate, fabricated by highly anisotropic etching techniques [7], which could also reduce the deleterious excitation of surface waves in the substrate. Future inquiries into the nature of slot antennas on a dielectric excited by coplanar feeds may further explain the obtained radiation patterns, and will answer questions regarding the level of surface wave modes excited in the substrate. More work is planned to improve the dc-to-RF efficiency of the oscillators, and to fabricate a large array for power-combining using this unit cell.

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