A Tunable Second-Resonance Cross-Slot Antenna

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I. Introduction

SECOND-RESONANCE slot antennas, due to their ability to transmit and receive on both sides of a microstrip ground plane, are often employed in planar active antenna arrays [1]–[5]. For example, in an amplifier array, the input and output of an amplifier circuit are connected to orthogonally polarized antennas. The purpose of using orthogonal polarizations is to ensure amplifier stability [6]. In this paper, we present a 7 GHz cross-slot antenna designed to be used in a mixer/phase detector active antenna. By incorporating a varactor diode into the microstrip feed line, the cross-slot resonance can be electronically tuned over a 10% bandwidth. By mechanically varying the feed line (tuning stub) length, a 45% 2:1 VSWR bandwidth is possible.

II. Design

A. Passive Antenna

The second-resonance cross-slot antenna presented in this paper is designed to reduce the size of the unit cell of an amplifier array by combining the two orthogonally polarized antennas into a single cross antenna. As seen in Fig. 1, the unit cell employing the cross-slot antenna requires less space then the unit cell with two slot antennas. In the example of a mixer/phase detector active antenna, shown in Fig. 1, the use of the cross-slot antenna also eliminates the need for a Wilkinson power combiner, further reducing the size of the unit cell of the active antenna array.

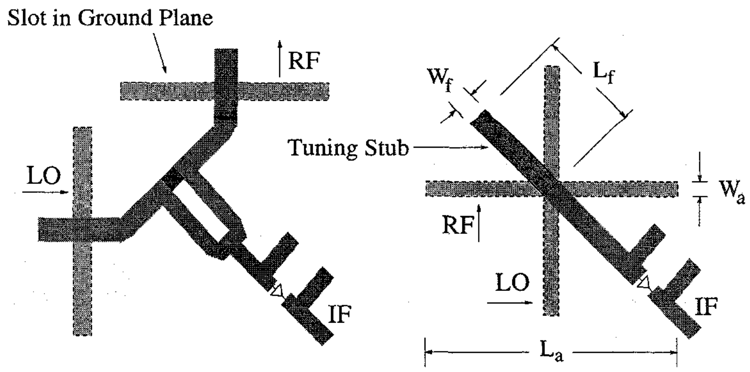

Fig. 1. Original and modified active antenna mixer/phase detector with important design parameters labeled.

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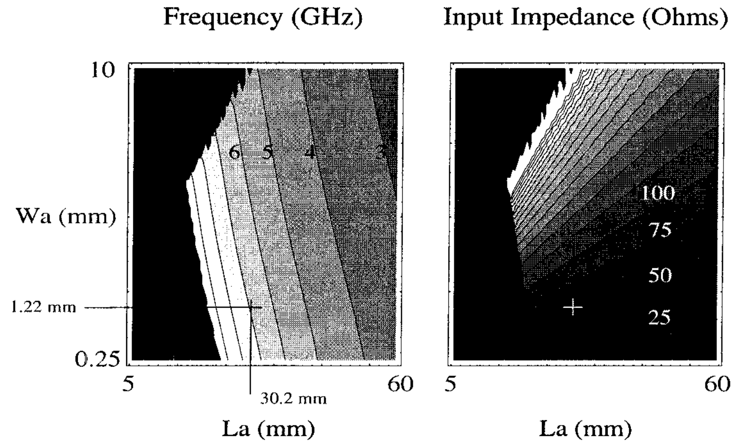

Fig. 2. Simulated resonant frequency and corresponding antenna input impedance versus W_a and L_a.

For a given substrate, the design parameters of the cross-slot antenna reduce to four variables: the aperture length and width (L_a and W_a), and the tuning stub length and width (L_f and W_f) (labeled in Fig 1).

The simulated dependence of the resonant frequency and the input impedance as a function of W_a and L_a is shown in Fig. 2 along with the parameters chosen for the final design. The antenna has $W_a = 1.22\,\text{mm}$ and $L_a = 30.2\,\text{mm}$, which correspond to an input impedance of $50\,\Omega$ and a resonance at 6.9 GHz. The antenna is fabricated on RT Duroid with $\epsilon_r = 2.2$ and a thickness of 0.508 mm. The data shown in Fig. 2 were generated using an approximate full-wave tool *WireZeus* [7] which simulated 4400 geometries over the course of 8 hours on a 133 MHz Pentium.

B. Active Antenna

The resonant frequency of the active cross-slot antenna can be electronically tuned by varying the reverse-bias voltage of a varactor diode connected at the end of the mircostrip feed line. A tunable antenna can be used in a multi-frequency communication system.

A MA/Com MA46610-186 varactor diode was used as the tuning element. Measurements of the varactor diode reactance suggest that a maximum of 84.7° of equivalent electrical length could be added to the tuning stub by the varactor diode. The varactor diode cathode is DC- and RF-shorted to the ground plane, and an extra $\lambda/4$ section is added at the end of the feed in Fig. 1(b) to preserve the RF open. The bias voltage to the anode is provided through the antenna's feed line.

III. Experimental Results

A. Passive Antenna

The s_{11} of the fabricated antenna from 1 to 14 GHz, as measured on an HP 8510B Network Analyzer, is shown in comparison to the simulated results in Fig. 3(a). The E-plane, H-plane, and cross-polarization pattern measurements of the cross-slot antenna are shown in Fig. 3(b). Using the Kraus approximation for estimating the directivity of planar arrays from

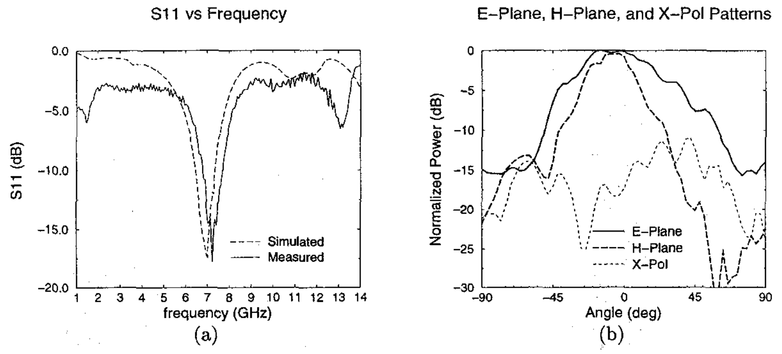

Fig. 3. Comparison of the simulated reflection coefficient and the measured reflection coefficient (a). Measured far-field radiation patterns for the cross-slot antenna (b).

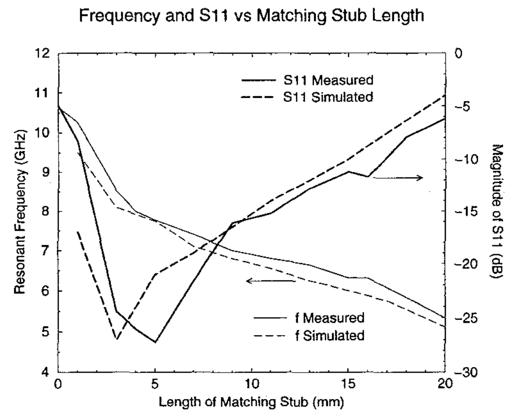

Fig. 4. Frequency and s_{11} versus tuning stub length L_f.

their pattern measurements [8], the predicted directivity of the antenna is 16.2 (12.1 dB).

Upon completion of the basic cross-slot antenna measurements, the effects of varying L_f, the length of the feed tuning stub were investigated. By first extending the tuning stub and then manually trimming it, the dependence of s_{11} and the resonant frequency on stub length was measured. As seen in Fig. 4, the 2:1 VSWR bandwidth of the mechanically tuned antenna was over 3 GHz or 45% of the center frequency.

The simulated results of varying the length of the tuning stub are plotted with the measured data in Fig. 4. A Method-of-Moments simulation package, *Ensemble*, was used to generate the data. In Fig. 3(a), *Ensemble* predicted the resonant frequency within 400 MHz. In Fig. 4, the simulated data are within 500 MHz and 5 dB of the measured data.

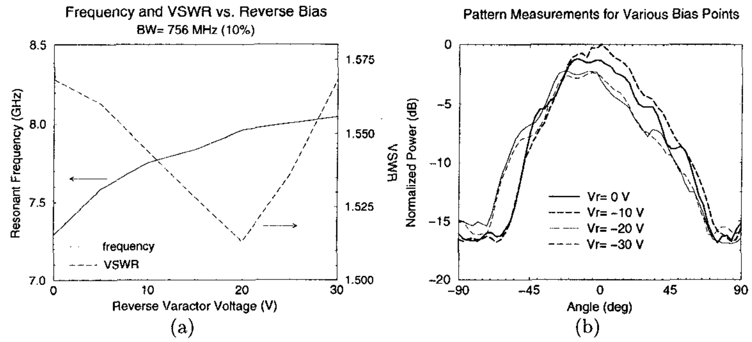

Fig. 5. Frequency and VSWR versus reverse varactor diode voltage (a). Far-field E-Plane radiation pattern measurements for different varactor bias points (b).

B. Active Antenna

By varying the reverse voltage of the varactor diode from 0 to 30 V, the antenna can be tuned from 7.3 to 8.1 GHz (756 MHz or 10%) with a VSWR below 1.57 (Fig. 5(a)). The peak directivity varies by 2.5 dB over the tuning range, as can be seen in pattern measurements taken at various diode bias points in Fig. 5(b).

IV. Conclusions

This paper presents the design of a second-resonance cross-slot antenna which reduces the size of a unit cell of an active antenna array. In addition, the demonstrated results show that the resonant frequency can be be mechanically tuned over a 45% bandwidth or electrically tuned over a 10% bandwidth with the given varactor diode.

Acknowledgements

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References

[1] J. Schoenberg, T. Mader, B. Shaw, and Z. B. Popović, "Quasi-optical antenna array amplifiers," in *1995 IEEE MTT-S Int. Microwave Symp. Dig.*, (Orlando, FL), pp. 605–608, May 1995.

[2] A. Axelrod and M.Kisliuk, "Broadband microstrip-fed slot radidator," *Microwave J.*, pp. 81–92, June 1989.

[3] H. S. Tsai and R. A. York, "Experimental and theoretical investigations of folded-slot antennas for quasi-optical arrays," in *IEEE AP-S Symp. Dig.*, 1994.

[4] B. K. Kormanyos, W. Harokopus, L. P. B. Katehi, and G. M. Rebeiz, "CPW-fed active slot antennas," *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 541–545, Apr. 1994.

[5] T. M. Weller, L. P. B. Katehi, and G. M. Rebeiz, "Single and double folded-slot antennas on semi-infinite substrates," *IEEE Trans. Ant. and Prop.*, vol. 43, pp. 1423–1428, Dec. 1995.

[6] J. S. H. Schoenberg, S. C. Bundy, and Z. B. Popović, "Two-level power combining using a lens amplifier," *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 2480–2485, Dec. 1994.

[7] B. D. Popović, *WireZeus wire antennas and scatterers*, pp. 1–3. University of Belgrade: User's Manual, 1996.

[8] C. A. Balanis, *Antenna Theory*, p. 135. New York: John Wiley & Sons, Inc, 1982.