A Single-Layer CPW-FED Active Patch Antenna

Kenneth H. Y. Ip, Tommy M. Y. Kan, and George V. Eleftheriades

***Abstract*—A single-layer CPW-fed active patch antenna oscillator at 2.76 GHz is presented. The patch antenna acts both as a resonator and a radiator. Electromagnetic coupling is utilized for providing the appropriate closed-loop positive feedback. The active antenna is built around a commercially available GaAs MMIC on a low-permittivity $\varepsilon_r = 2.33$ Duroid 5870 substrate. The measured effective isotropic radiated power (EIRP) is 20 dBm, whereas the front-to-back ratio is about 12 dB with the cross-polarized fields better than −15 dB. The measured phase noise is −87.5 dBc/Hz at a 100-kHz offset away from the carrier. The structure only requires a single substrate, is compatible with uniplanar technology, and results into a low-component count.**

***Index Terms*—Active antenna, coplanar-waveguide (CPW), oscillator, phase-noise.**

I. Introduction

IN RECENT years, various planar active antennas have been developed for applications such as collision avoidance, spatial power combining, phased-array and radar, and proximity sensing [1]–[6]. Recently, the concept of realizing active antennas by means of a feedback loop, formed by twin slots electromagnetically (EM) coupled to a patch, has been demonstrated in [1]–[3]. This EM-coupling approach results to a more compact layout with a reduced number of components. In addition, it offers the advantage of a dc decoupled feedback loop, thus leading to a simplified bias network. However, previously reported designs of this kind relied solely on microstrip technology which requires a two-layer structure and the presence of via holes for providing the necessary ground for dc bias [1]–[3].

In this letter, an EM-coupled active antenna is presented based on CPW fed twin-slots, electromagnetically coupled to a patch antenna. In the proposed approach, only a single-layer substrate is required and no via holes are necessary. In addition, the overall complexity and therefore the cost of the structure is reduced. Furthermore, no degradation of performance has been observed, despite the absence of an isolating ground-plane which is inherent in microstrip implementations [1]–[3].

II. Active Antenna Configuration and Design

The active antenna described here is shown in Fig. 1. As shown, the front side of the substrate hosts the patch whereas the active circuitry is accommodated at the back side in 50-Ω CPW technology. The patch antenna acts both as a radiator and a feedback resonator for the oscillator. Two capacitively coupled coplanar slots are used in the design, a longer centralized one acting as a feed slot to the patch [6] and a shorter one at the edge of the patch to electromagnetically close the feedback loop. To achieve oscillation, the Barkhausen oscillation criterion must be met at the design frequency

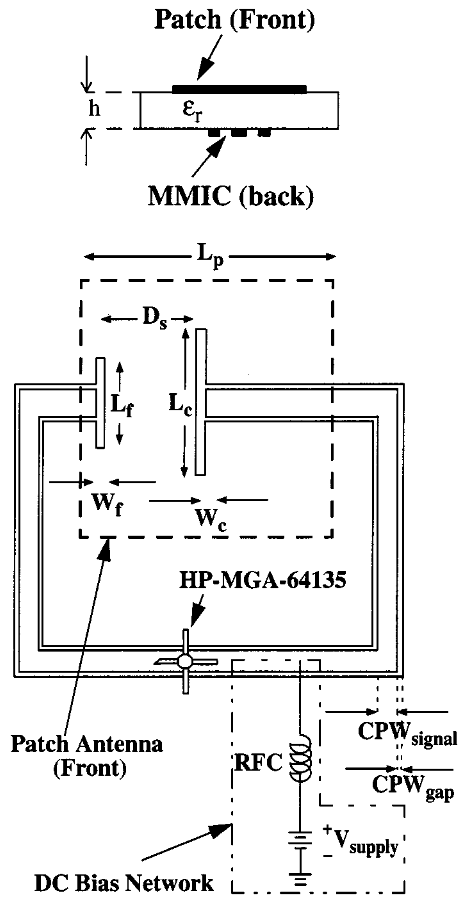

Fig. 1. Schematic of the active antenna layout, $\varepsilon_r = 2.33$, $h = 1.57$ mm, $L_p = 31$ mm, $L_c = 16$ mm, $W_c = 0.8$ mm, $L_f = 10$ mm, $W_f = 0.8$ mm, $D_s = 12.5$ mm, $\text{CPW}_{\text{signal}} = 3$ mm, $\text{CPW}_{\text{gap}} = 0.2$ mm.

$$S_{21}(\text{Passive Network}) + S_{21}(\text{Amplifier}) = 0\ (\text{dB}) \quad (1)$$

$$\angle(\text{Loop Gain}) = 2n\pi \text{ where } (n \in \text{ Integer}). \quad (2)$$

The design of the structure is based on HP-ADS and HP-momentum. First, the size of the patch and the main feed-slot have been designed to achieve antenna resonance at 2.8 GHz, maximize the front-to-back ratio and yield a good return loss on the feeding CPW line. This was followed by experimental testing of the passive antenna for verification purposes. Subsequently, the magnitude of the transmission coefficient S_{21} has been adjusted, by the proper choice of the position and geometry of the offset slot, to meet the oscillation condition of (1) at 2.8 GHz.

Manuscript received November 8, 1999; revised January 20, 2000.
The authors are with the Department of Electrical and Computer Engineering, University of Toronto, Toronto, ON M5S 3G4, Canada.
Publisher Item Identifier S 1051-8207(00)03147-0.

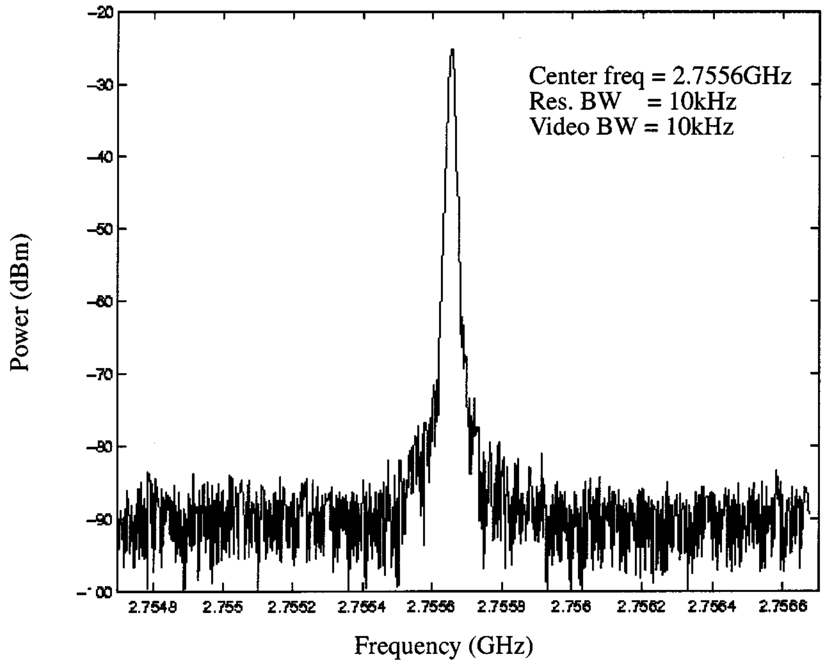

Fig. 2. Measured spectrum of the radiated RF power.

Finally, the length of the interconnecting 50-Ω CPW line has been adjusted for achieving the required 360° loop phase shift, dictated by (2).

III. Experimental Results

The active antenna is built on a Duroid 5870 substrate of $\varepsilon_r = 2.33$ with a thickness $h = 1.57$ mm, as shown in Fig. 1. The circuit is biased at 10-V dc and 50 mA by means of a radio frequency (RF) choke which is situated at the output of the monolithic microwave integrated circuit (MMIC) as shown in Fig. 1. The RF-spectrum has been measured at a distance of 5 m away from the active antenna using a HP8563E spectrum analyzer connected to a receiving horn-antenna and is shown in Fig. 2. The oscillation frequency has been found to be 2.76 GHz which is close to the design frequency of 2.8 GHz. In addition, the phase noise of the oscillation has been measured manually using the same spectrum analyzer. The sideband power was found to be $P_{\text{sideband}} = -57.5$ dB at a 100-kHz offset with respect to the $P_{\text{carrier}} = 0$ dB carrier power. Taking into account a resolution bandwidth of RBW $= 1$ kHz and based upon the definition of phase noise [7]

$$P_{\text{noise}} = P_{\text{sideband}} - P_{\text{carrier}} - 10\log(\text{RBW})\,\text{dB} \qquad (3)$$

the single sideband phase noise has been estimated to be -87.5 dBc/Hz at a 100-kHz offset from the carrier. It should be mentioned that this is inconsistent with a -100 dBc/Hz phase noise, measured using the phase noise software utility for the HP8563E spectrum analyzer. The so-measured -100 dBc/Hz is judged to be overoptimistic. Similar inaccuracies, arising when using the same phase noise utility with free-running oscillators, have been observed and reported in [8].

The active antenna patterns of the device have been tested in the anechoic chamber of the University of Toronto. Figs. 3 and 4 show the measured E- and H-plane radiation patterns. As shown, the worse cross-polarization appears in the E-plane but does not exceed the level of -15 dB. On the other hand, the measured front-to-back ratio has been found to be 12 dB. Both the measured cross-polarization levels and front-to-back ratio compare favorably with those of the two-layer microstrip structures of [1] and [2], indicating no degradation of the performance of the proposed single-layer CPW approach. Finally, the effective isotropic radiated power (EIRP) has been measured, based on the method described in [2]. Using this procedure, an EIRP of 20 dBm has been calculated from measurements. The MMIC amplifier specifications indicate a typical output power of 12.5 dBm at the oscillating frequency. This implies an antenna gain of $20 - 12.5 = 7.5$ dB which is consistent with typical expected values for patch antennas.

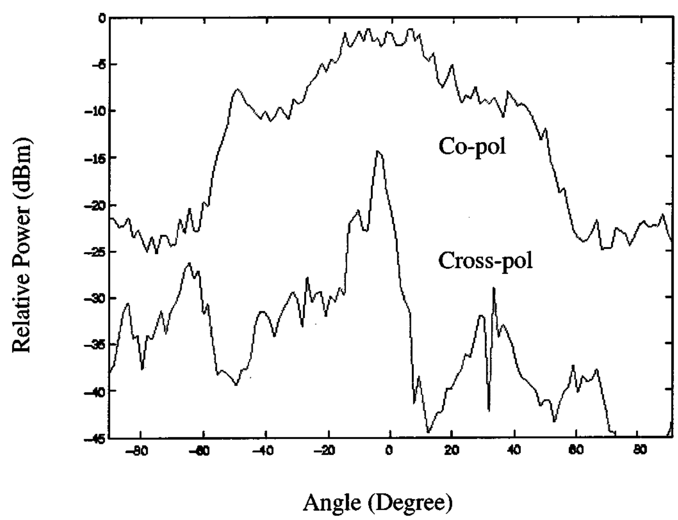

Fig. 3. Measured E-plane active radiation pattern.

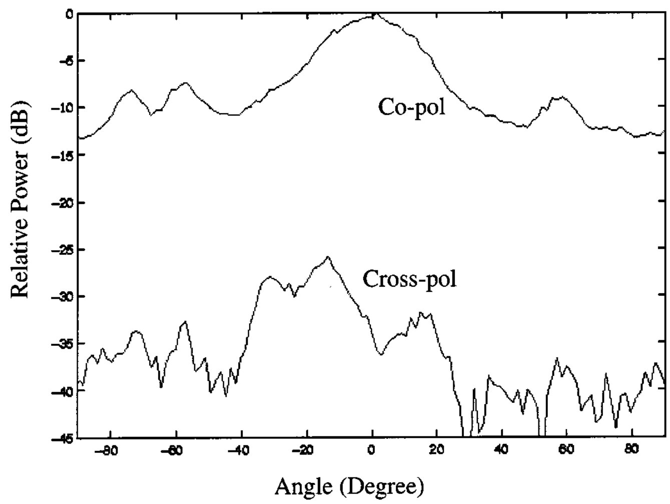

Fig. 4. Measured H-plane active radiation pattern.

IV. CONCLUSION

A single-layer active antenna oscillator based on 50-Ω CPW technology has been successfully designed and tested at 2.76 GHz. The active antenna utilizes electromagnetic coupling for closing the feedback loop. The structure leads to a layout with no via-holes, a reduced component count, and a simplified dc bias network. The active antenna achieves an EIRP of 20 dBm, a front-to-back ratio of 12 dB and the cross-polarization level is better than −15 dB on the principal planes. On the other hand, the measured phase noise is −87.5 dBc/Hz at a 100-kHz offset away from the carrier. The active antenna can find applications in low-cost proximity sensing, collision avoidance, power-combining or communications. For the latter applications, further reduction of the phase noise would be possible by means of injection-locking techniques [3], [5].

REFERENCES

[1] W. J. Tseng and S. J. Chung, "Analysis and application of a two-port aperture-coupled microstrip antenna," *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 530–535, May 1998.

[2] J. F. Zürcher and Y. Brand, "An active strip-slot-foam inverted patch antenna," *Microwave Opt. Technol. Lett.*, vol. 13, no. 3, pp. 114–119, Oct. 1996.

[3] H. Shiomi, K. Hayata, Y. Kido, and S. Kawasaki, "Quasioptical patch resonator antenna array," in *Proc. Asia Pacific Microwave Conf.*, vol. 3, 1997, pp. 945–948.

[4] B. 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] J. A. Navaro and K. Chang, *Integrated Active Antennas and Spatial Power Combining*. New York: Wiley, 1996.

[6] L. Giauffret, J. M. Laheurte, and A. Papiernik, "Study of various shapes of the coupling slot in CPW-fed microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. 45, pp. 642–647, Apr. 1997.

[7] R. W. Rhea, *Oscillator Design and Computer Simulation*, 2nd ed. New York: McGraw-Hill, 1997, pp. 115–116.

[8] A. R. Brown, "High-q integrated micromachined components for a 28 GHz front-end transceiver," Ph.D. dissertation, Univ. Michigan, Ann Arbor, 1999.