Low Cost and Compact Active Integrated Antenna Transceiver for System Applications

Robert Flynt, Lu Fan, Julio Navarro and Kai Chang

Department of Electrical Engineering
Texas A&M University
College Station, Texas 77843-3128, U.S.A.

Abstract

An FET transistor and a Schottky barrier mixer diode have been integrated within an inverted patch antenna for transceiver applications. Preliminary results exhibit a 5.5 dB isotropic mixer conversion loss at 6 GHz for an intermediate frequency of 200 MHz with the FET serving as both the transmitter and the local oscillator at 5.8 GHz. The low cost, compact circuit should be useful for communication, sensors, and radar applications.

I. Introduction

Integrated and active integrated antennas receive a great deal of attention because they can reduce the size, weight and cost of many transmit and receive systems. Passive and active solid-state devices can be integrated with antennas to provide various functions. This paper describes the novel integration of an FET and a mixer diode on the surface of an inverted patch antenna. The FET is configured within the inverted patch structure to oscillate at C-band. The oscillator acts as a transmitter and it also couples a portion of the power to the mixer as a local oscillator. The optimal position for placing the mixer diode on the patch is determined. A Schottky barrier diode is placed within the antenna cavity and it receives a portion of the oscillator power that mixes with an incoming RF signal. For a 5.8 GHz LO and a 6 GHz incoming RF signal, the 200 MHz IF exhibits 5.5 dB isotropic conversion loss (L_{iso}). Very good antenna patterns were obtained. This system differs from those presented in [1-3], because the mixer and the oscillator are mounted directly onto the patch antenna, reducing the need for interconnect lines. This structure can be used for many applications such as wireless communications, sensors and radar systems. A two way communications system using these transceivers was demonstrated.

II. Circuit Design and Optimization

The inverted stripline patch configuration removes the ground plane from the substrate backside and inverts the conductor over a ground plane support. The electromagnetic fields are primarily concentrated in the air between the patch and the ground plane providing a lower effective dielectric constant(ε_{eff}), a longer guided wavelength and higher characteristic impedance over a comparable line width in microstrip. The inverted patch uses a circular enclosure to isolate the antenna element and choke out possible surface modes which may occur. The resulting trapped inverted microstrip geometry is a subset of the more general stripline-type transmission lines, hence the name [4], inverted stripline antenna(ISA).

Figure 1 shows the FET and mixer integrated with the inverted stripline antenna. For the integrated antenna, the introduction of several DC blocks for biasing dramatically changes the performance with respect to the original circular patch. Gaps are etched to isolate the source, gate and drain for DC biasing. Chip capacitors were used to provide some RF continuity between the two halves of the patch. DC bias is achieved with voltage across the drain-to-gate(V_{DG}) and a 2 Ω chip resistor from the source to the gate. A similar integrated antenna with only an FET device [5] has previously demonstrated good oscillation and excellent radiation performance. Due to the physical considerations for placing the mixer diode onto the patch, the cavity depth had to be changed. This resulted in a gain of 6 dB which is lower than the value reported in [5].

The best possible position for the mixer diode was determined by trying to obtain a good impedance match between the diode and the patch at a location where there is sufficient LO power. When the diode is placed at a location where there is sufficient LO power, the diode will be positively biased due to the rectified DC current from the LO source. The relative received power as a function of position can be approximated by measuring the rectified DC voltage that results from power applied from an external source while the FET is turned off. This is plotted as a function of position in Figure 2. It was determined that the FET produced sufficient LO power for any practical position for the diode. This is shown in Figure 3 along with the measured IF power plotted as a function of position. The final position was a compromise between the

CH3577-4/95/0000-0953$01.00 © 1995 IEEE

impedance matching, relative received power, and the physical constraints of mounting the diode. The position was also chosen so that the active antenna radiating pattern was not adversely affected. The optimized position was determined to be 8 mm from the center of the patch on the gate side of the bias cut, as shown in Figure 1. A low pass filter was designed and placed behind the cavity to filter out the LO and RF signals.

III. Circuit Performance

The FET transistor used is an NEC-76184AS. The bias (V_{DG}) is set between 3 and 5 Volts with a typical drain current of 40 mA. Bias tuning range is approximately 2.2 % at 5.84 GHz. The transceiver showed an isotropic conversion loss of 5.5 dB with a 200 MHz IF using the method presented in [6]. The LO operated at 5.8 GHz and the RF input was 6 GHz. The antenna has a gain of 6 dB resulting in an approximate conversion loss for the mixer of 11.5 dB.

The transmit radiation patterns are similar to previous results for a passive inverted stripline antenna given in [7]. The half-power beamwidths and cross polarization level(CPL) for the transmitter H-plane pattern are 67° and 18.8 dB, respectively. The H-plane pattern is shown in figure 4. Figure 5 shows the E-plane pattern. The half-power beamwidths and CPL for the transmitter E-plane pattern are 49.3° and 18 dB, respectively.

IV. Two Way Communications

A two-way communications system consisting of two integrated active patch antenna transceivers is shown in Figure 6. Each transceiver can be used to transmit and receive. The receive pattern is perpendicular to the transmit pattern for LO to RF isolation. One antenna can be rotated 90° with respect to the other, thus causing the transmit polarization for one transceiver to be equal to the receive polarization of the other transceiver. This allows for the polarization of a signal propagating in one direction to be perpendicular to a signal propagating in the opposite direction. The maximum distance that the two transceivers can be separated was found to be 4.8 Km for a bandwidth of 6 MHz using the Friis transmission equation. The minimum detectable signal was determined using the method described in [8]. The noise figure for the system is approximated to be equal to the conversion loss for the mixer.

V. Conclusions

An integrated active antenna transceiver has been designed and successfully demonstrated as a two-way communication system. The active components were placed directly onto the patch antenna without compromising radiation performance. The circuit operates well with low conversion loss and low cross polarization level. The circuit is well suited for commercial and military applications.

VI. Acknowledgments

Julio Navarro is supported by a training grant from the NASA-Lewis Research Center in Cleveland, Ohio. This investigation was funded partially by the U. S. Army Research Office and the Texas Higher Education Coordinating Board's Advanced Technology Program. The substrate material was provided by the Rogers Corporation.

References

[1] R. D. Martinez and R. C. Compton, "A Quasi-Optical Oscillator/Modulator For Wireless Transmission," *IEEE MTT-S Int. Microwave Symp. Dig.*, 1994, pp.839-842.

[2] K. Cha, S. Kawasaki, and T. Itoh, "Transponder Using Self-Oscillating Mixer and Active Antenna," *IEEE MTT-S Int. Microwave Symp. Dig.*, 1994, pp.425-428.

[3] D. Sanchez-Hernandez and I. Robertson, "60 GHz-band active microstrip patch antenna for future mobile systems applications," *Electron. Lett., Vol.* 30, no. 9, pp. 677-678, April 28th, 1994.

[4] J. A. Navarro, Lu Fan and K. Chang, "Active Inverted Stripline Circular Patch Antennas for Spatial Power Combining," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-41, No. 10, pp. 1856-1863, October 1993.

[5] J. A. Navarro, L. Fan and K. Chang, "Novel Quasi-Optical Active Antenna Using Integrated FET Inverted Stripline Patch," *Electronics Letters*, No. 8, pp. 655-657, April 14, 1994.

[6] K. D. Stephan and T. Itoh, "Recent Efforts on Planar Components for Active Quasi-Optical Applications," *IEEE MTT-S Int. Microwave Symp. Dig.*, 1990, pp.1205-1208.

[7] J. A. Navarro, J. McSpadden and K. Chang, "Experimental Study of Inverted Microstrip for Integrated Antenna Applications," *Proceedings of IEEE Antennas and Propagation International Symposium*, 1994, pp. 920-923.

[8] K. Chang, *Microwave Solid-State Circuits and Applications*. New York: John Wiley & Sons, Inc., 1994, Ch. 7.

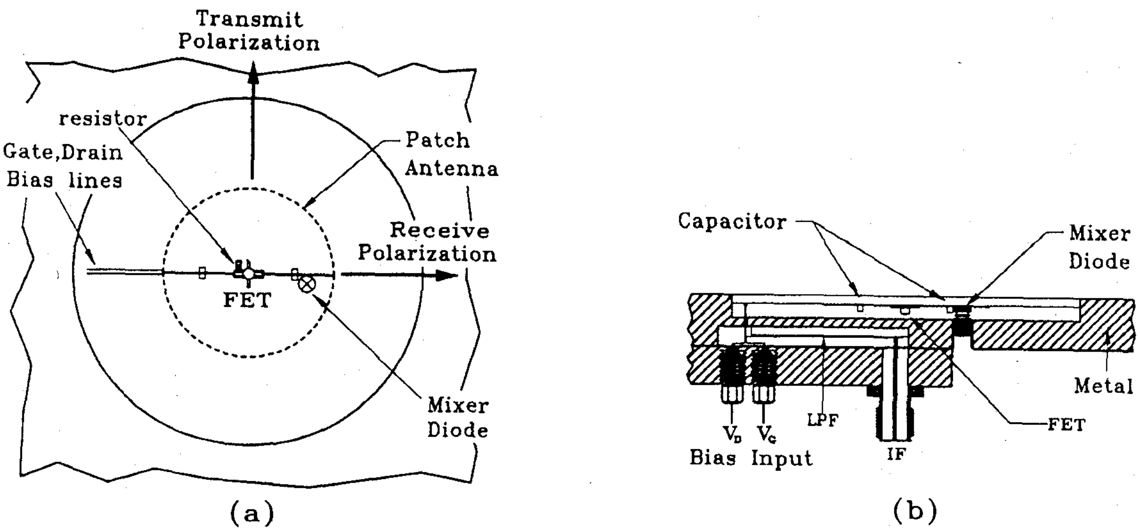

Fig. 1. Complete active integrated antenna transceiver (a) top view (b) side view.

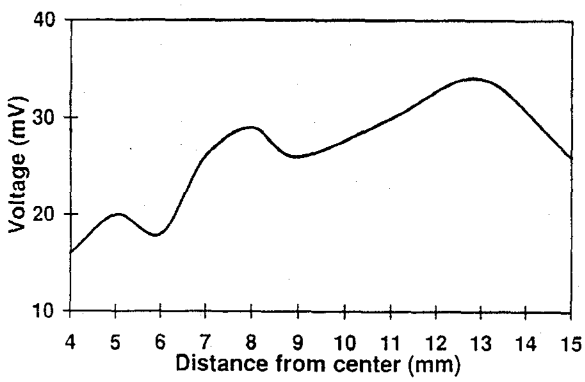

Fig. 2. Rectified DC voltage measured parallel to the bias cut.

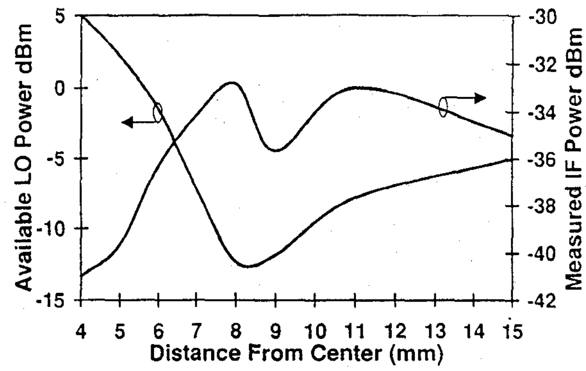

Fig. 3. Available LO power and measured IF power vs position.

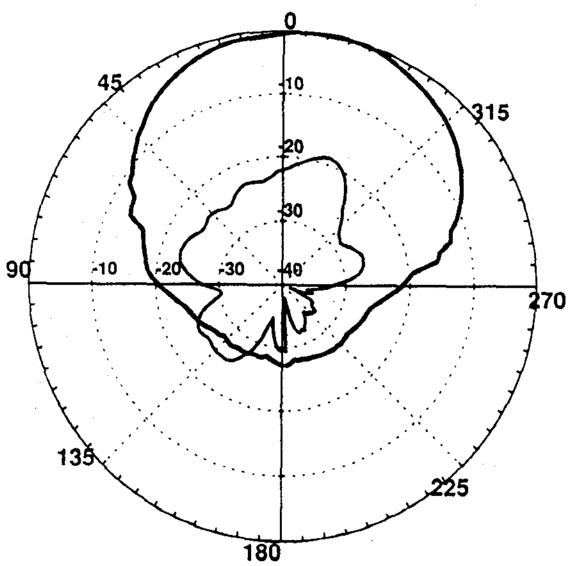

Fig. 4. H-Plane pattern with the mixer diode in place. The cross polarization level = -18.84 dB and the HPBW = 67.0°.

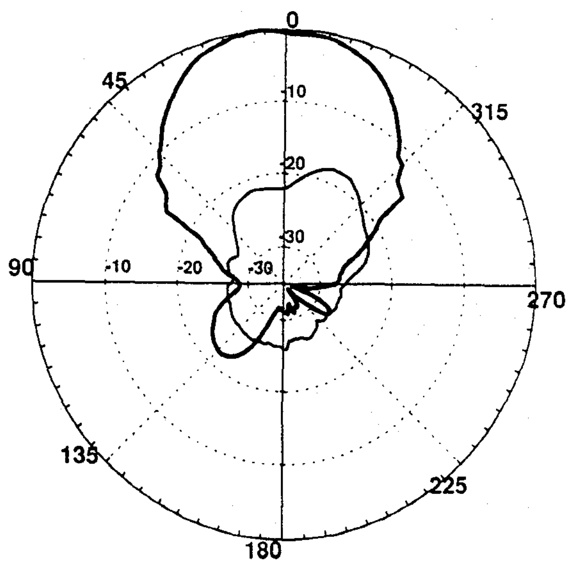

Fig. 5. E-Plane pattern with the mixer diode in place. The cross polarization level = -17.99 dB and the HPBW = 49.3°.

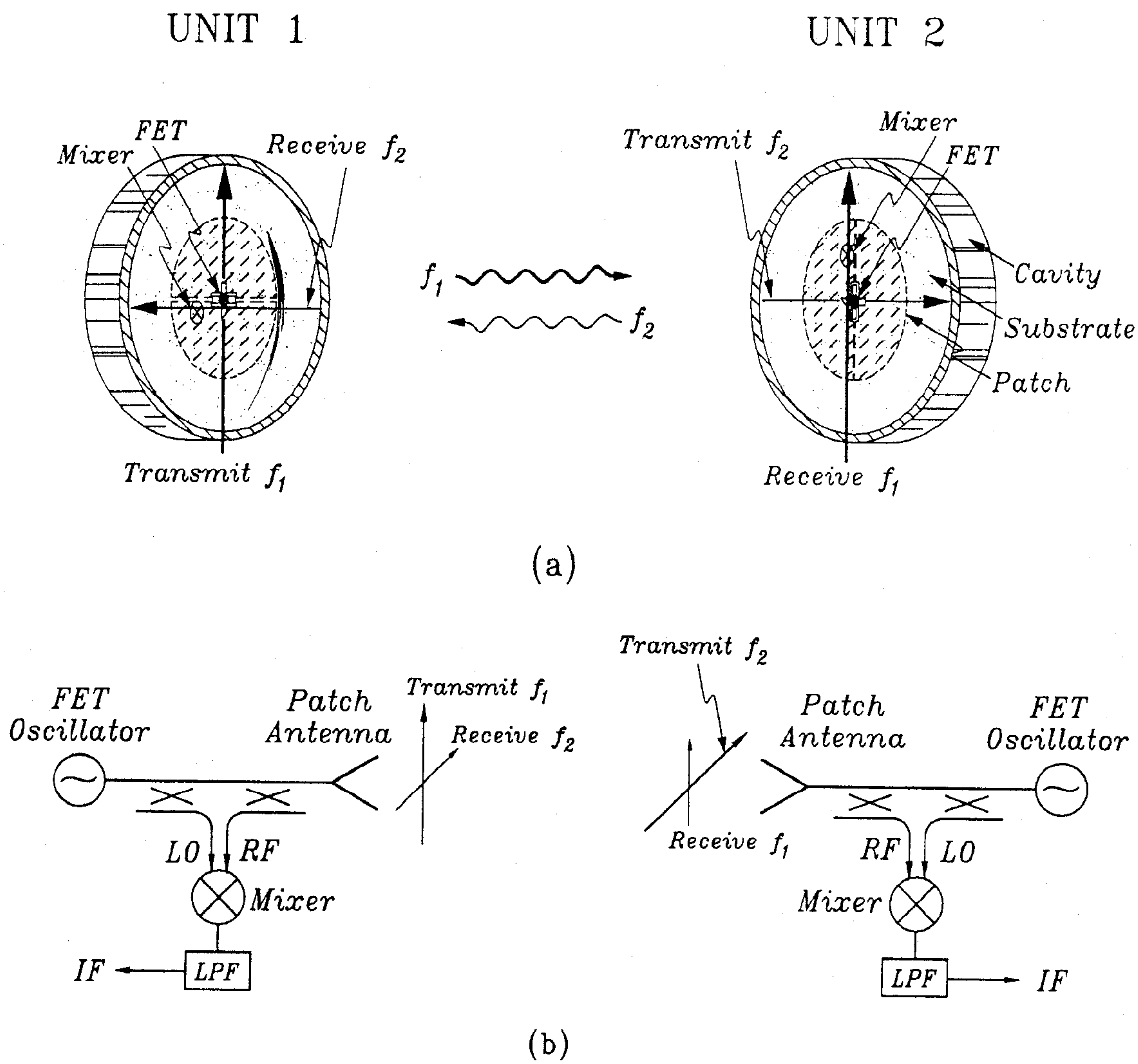

Fig. 6. Two-way radio using active antennas (a) configurations (b) block diagram.