A Low-Cost Active Antenna for Short-Range Communication Applications

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***Abstract*—A low-cost active antenna to be used in a miniature microwave transponder is presented. This active antenna operating at 9.9 GHz consists of a compact microstrip array antenna of electromagnetically gap-coupled rectangular resonators and a novel ASK demodulator/differential phase-shift keying (DPSK) modulator circuit. In order to minimize the power consumption and to reduce the cost of the active antenna, this novel microwave circuit employs a single "cold" MESFET which performs both the modulator and demodulator functions. The original methods used to realize the active antenna provide high performance, size reduction, and low power consumption.**

***Index Terms*—Active antenna, GaAs MESFET, power detector, reflection modulator.**

I. Introduction

IN RECENT years, there has been growing interest in the development of communications systems for the localization and the identification of objects [1], [2]. In this letter, such major applications as security and access control, automatic tolling, and livestock management will be mentioned. Compared to other techniques, the use of microwaves in such systems offers a variety of advantages including contactless information data transfer and large bandwidth for high-speed data transfer.

For short-range communication systems, the half-duplex mode is preferred since it requires a less complicated setup for the transponder as well as for the interrogator. Therefore, backscattering modulation of the incoming signal by the active antenna results in low cost and low power consumption, which are of primary importance in these systems. In most transponders operating in half-duplex mode, the modulation and demodulation functions are realized by two subcircuits which consequently increases the cost of the transponder. A suitable approach to solve this problem consists of associating several functions with the same device.

Therefore, a novel X-band active antenna using a single "cold" MESFET for both modulation and demodulation functions has been investigated. This active antenna is used in a miniature transponder whose transmission link operates as follows: First, the base station sends an ASK-modulated signal for down-link operation. Second, the transponder responds by means of a differential phase-shift keying (DPSK) reflection modulation for up-link operation.

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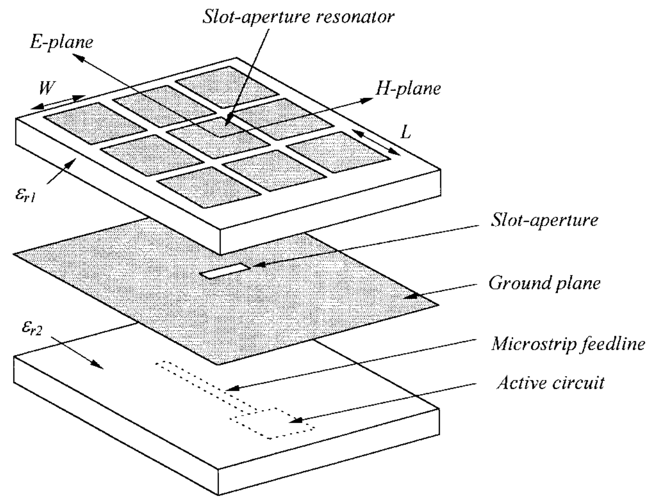

Fig. 1. Multilayered structure of the active tranceiver antenna.

II. Description of the Active Antenna

The structure of the active antenna is presented Fig. 1. It is a two-layer structure whose radiating part is a 3×3 array of rectangular resonators. These patches working in the resonant mode TM_{01} are etched on a low-loss dielectric substrate with a low relative permittivity of $\varepsilon_{r1} = 2.33$ which assures a good radiating efficiency. To avoid any interaction with the resonators, the active circuit is built on the opposite side of the antenna on a high-permittivity substrate with a relative permittivity of $\varepsilon_{r2} = 10.8$. Contrary to the conventional array antennas which avoid the coupling between the resonators, the latter are strongly gap-coupled in the E- and H-planes of the antenna. To feed the patches two techniques are used: 1) the driving patch is fed by electromagnetic coupling to a 50-Ω microstrip feedline through a slot-aperture in the common ground plane [3] and 2) this driving patch then feeds the gap-coupled resonators which form the array of the antenna. The design provides a good tradeoff between the bandwidth and the beamwidth by adjusting the gap-spacing between the resonators, with a smaller size compared to conventional array antennas [4]. Furthermore, it also allows a reduction of the complexity and the losses of the feeding network which is reduced to a simple transmission line.

The active circuit employing a common-source GaAs MESFET is connected to the microstrip feedline of the radiating section. Fig. 2 presents the layout of the ASK demodulator/DPSK modulator circuit. During the ASK demodulation, the MESFET works as a detector and the binary signal is

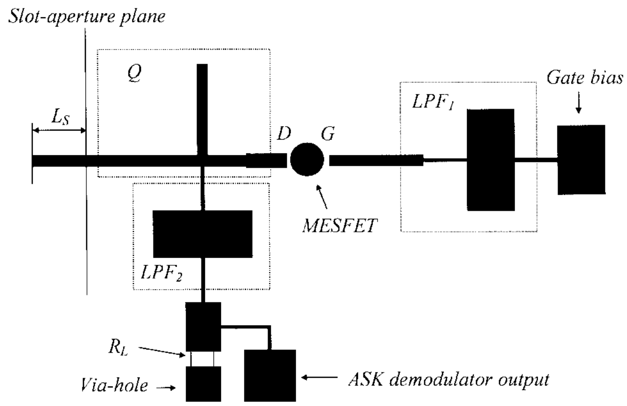

Fig. 2. Layout of the ASK demodulator/DPSK modulator using a "cold" GaAs MESFET.

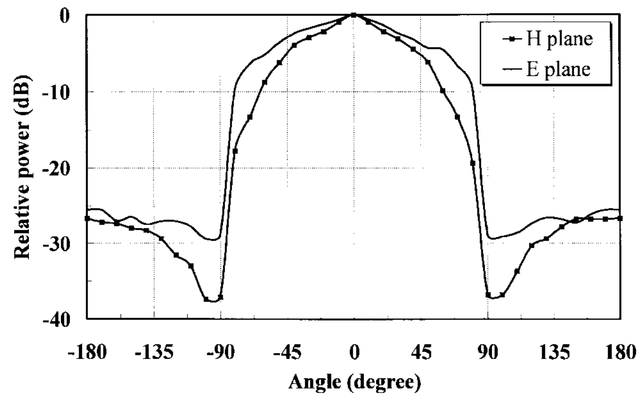

Fig. 3. E- and H-plane radiation patterns of the active antenna ($f = 9.9$ GHz).

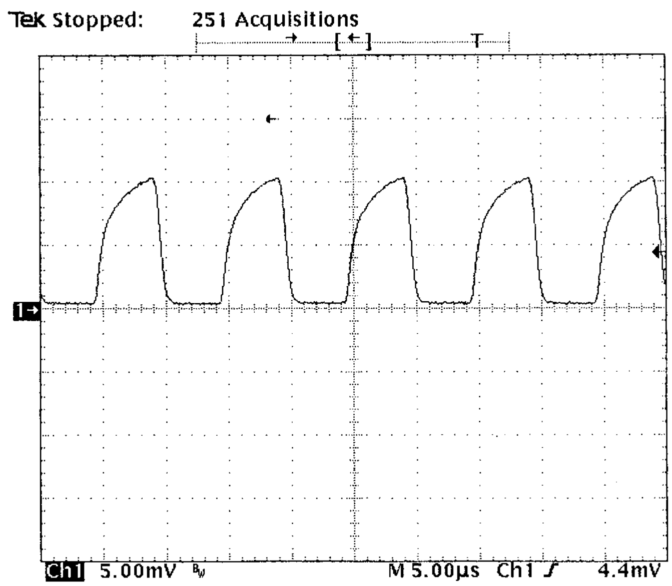

Fig. 4. Demodulation performance of the active antenna, the microwave circuit being in its ASK demodulation mode (carrier $f = 9.9$ GHz, square modulating signal $f_M = 100$ kHz).

detected on the load resistance R_L. LPF_1 and LPF_2 are low-pass filters, and the stub of length L_S performs the matching with the antenna. The MESFET detector exploits the nonlinear evolution of the channel conductance as a function of the drain voltage. Thus, the detection does not make use of the Schottky contact of the MESFET, which is inversely biased. The negative gate voltage is optimized in order to obtain a maximum sensibility of the detector. For a voltage $V_{\rm gs} = V_d$ just superior to the pinch-off voltage V_p, a maximum nonlinearity $I_d(V_{\rm ds})$ is acquired.

During the modulation state, the MESFET works as a reflection modulator. The binary modulation signal is applied to the gate and thus alters the reflection coefficient at the drain of the transistor. The "off" and "on" states are obtained for a gate voltage $V_{\rm gs} = 0$ V and $V_{\rm gs} = V_d$. In both cases, the drain bias voltage is set to $V_{\rm ds} = 0$ V. The matching network Q is designed to transform the reflection coefficients at the drain into a DPSK modulation at the input of the antenna [5], i.e., in the plane of the slot-aperture. These reflection coefficients have been optimized to provide the best performance in the modulation and demodulation modes of the circuit.

The use of a "cold" MESFET for both the modulation and demodulation provides several distinct advantages.

1) Since there is no direct biasing current, there is no $1/f$-noise generated over a large range of input power.
2) Up to transient gate currents in the modulator state, there is no power consumption of the analog circuitry to be considered.
3) The fast switching speeds of the MESFET allows for high-speed data transfer.
4) The use of only one semiconductor device which comprises both analog functions of the transponder permits inexpensive and reliable manufacturing of such a system.

III. Experimental Results

An antenna was first built to allow the measurements of the E- and H-plane patterns presented in Fig. 3. The width and the length of the resonators are $W = 11.3$ mm and $L = 9.0$ mm, respectively. The gap-spacings are $S_W = 0.4$ mm and $S_L = 1.0$ mm in the H- and E-planes. The coupling aperture size is 4×0.5 mm^2. The measurements show a wide beamwidth due to the configuration of the array. However, the array can be adapted to reduce the beamwidth [4], depending on the application in which the transponder is used. The crosspolar measurement is not reported here but has been found to be lower than -25 dB. A bandwidth superior to 500 MHz and a gain of 10.5 dB was also measured.

A GaAs MESFET NE72089A was employed to realize the complete active antenna and was then tested under interrogation. A test system at a distance of 2.0 m sends a carrier signal at 9.9 GHz with 10-dBm power modulated by a 100-kHz square signal into a 17-dB pyramidal horn antenna. Fig. 4 depicts the received signal at the demodulator output ($R_L = 11$ kΩ) of the active antenna. The gate voltage of the MESFET was set $V_{\rm gs} = -1.8$ V ($V_p = -2$ V) to assure a maximum detection, and a sensitivity of 2.4 mV/μW was achieved. The slight distortion in the demodulated signal is due to parasitic effects introduced during the measurements by the connections.

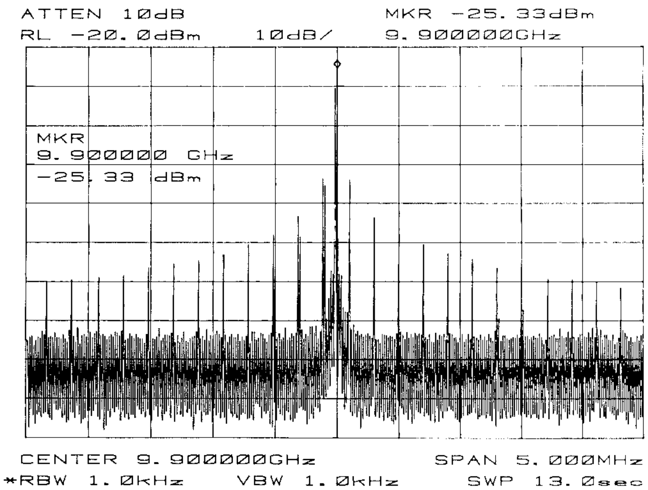

Fig. 5. Power spectrum emitted by the active antenna when the microwave circuit operates as a DPSK reflection modulator (carrier $f = 9.9$ GHz, square modulating signal $f_M = 100$ kHz).

For up-link operation, the test system transmits an unmodulated carrier of 10-dBm power which is DPSK modulated and reflected by the active antenna. This scattered response signal is detected by the test system with a 17-dB pyramidal horn antenna and a low-noise amplifier. Fig. 5 shows the power spectrum of the modulated signal emitted by the active antenna. A square signal of 100 kHz was applied to the gate of the MESFET. The power spectrum presents a good suppression of the even harmonics and is in good agreement with the theoretical DPSK power spectrum. The presence of the carrier of 9.9 GHz is due to a crosstalk at the reception level. The crosstalk is eliminated during the DPSK demodulation process and does not affect the information contents.

IV. Conclusion

A novel active antenna for short-range communication applications has been presented. The novel techniques used to realize the radiating section and the microwave circuit provide high performance, size reduction, low cost, and low power consumption. Furthermore, the design of the novel ASK modulator/DPSK demodulator can be extended to a MPSK modulation scheme to increase the rate of data transmission.

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