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An Integrated Doppler-Radar Transceiver Front End Using Two FET Active Antennas

Zhengping Ding and Kai Chang

***Abstract*—An integrated X-band Doppler-radar transceiver front end has been developed. This front end consists of two adjacently spaced field-effect transistor (FET) active antennas, with one of them being biased to oscillate as its transmitter and the other being biased not to oscillate, but to act as its mixer. This design has the advantage of lower noise at low Doppler frequencies as compared to a self-oscillating mixer scheme. The circuit can be used in low-power Doppler-radar systems to detect slow-moving objects such as pedestrians, intruders, automobiles, etc., with high sensitivity.**

***Index Terms*— Active antennas, Doppler radar, integrated antennas, transceivers.**

I. Introduction

In recent years, efforts have been made in searching for appropriate active antenna designs for seemingly promising spatial power-combining technology [1]–[6]. Mixers built directly on antennas have also been reported [7], [8]. These innovations are very attractive in realizing compact radio-frequency (RF) front ends in portable communications and radar systems. Active antennas used for communications have been reported in literature [9]. On the other hand, active antennas used for radar systems have not been paid sufficient attention.

To probe into potential applications of active antennas in low-power Doppler-radar systems, a compact X-band Doppler-radar transceiver front end was built and tested. In this design, two field-effect transistor (FET) active antennas were adjacently integrated on one substrate. One FET active antenna is biased to oscillate and radiate as the transmitter, while the other is biased not to oscillate, but to serve as the mixer/receiver. The local oscillator (LO) signal of the mixer is from the oscillating active antenna via mutual coupling. The RF signal is reflected from any moving object in the beam of the active antennas. Compared to the self-oscillating mixer scheme, this design demonstrated much lower noise at low Doppler frequencies ranging from hertz to kilohertz order. Therefore, it can be used in Doppler-radar applications for the detection of slow-moving objects.

II. Circuit Design and Operation

The integrated RF front end was fabricated with two Hewlett-Packard ATF-26 836 FET's on an RT/Duroid 5880 dielectric substrate of $\varepsilon_r = 2.20$ and thickness $h = 0.787$ mm, as shown in Fig. 1. The

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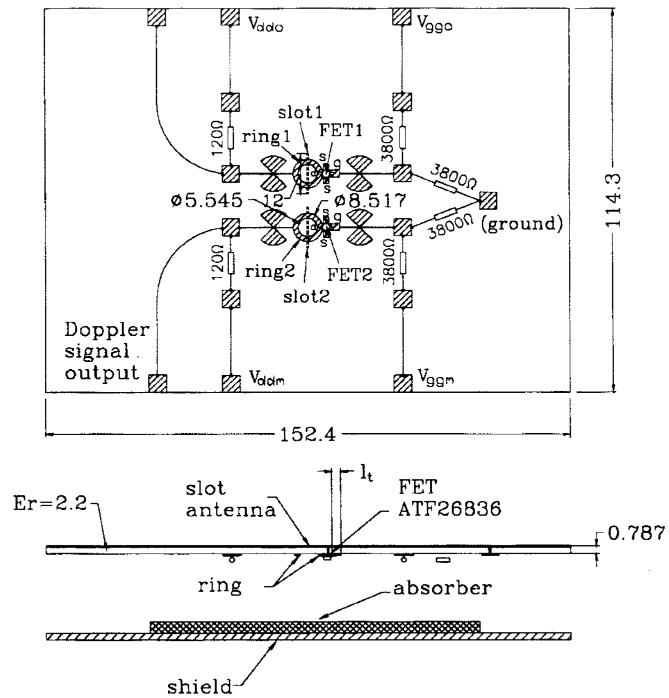

Fig. 1. Circuit design (all dimensions are in millimeters).

design frequency was chosen at 10 GHz. The design of the FET active antenna is similar to the one reported earlier with Gunn diodes [6]. The active antenna uses a ring stabilized FET oscillator coupled to a slot antenna. The bias circuits and FET's are hidden behind the metallization. This active antenna design has the advantages of low spurious radiation, low cross polarization, ease of integration, etc. The circumference of the 67-Ω microstrip ring resonator was designed such that their first resonance is at the design frequency. The length of the 0.5-mm-wide slot antenna was designed such that their first resonance is also at the design frequency. The reason that the first resonance of the microstrip ring and the slot antenna was designed to be at the same frequency is to avoid possible mode-jumping phenomena due to multiple resonance of the circuits [10]. The drains of the FET's were connected to the resonant microstrip rings. Their sources were grounded through via holes. Their gates were terminated with an RF reactance X_t, which was realized by an open-circuited microstrip stub. Both FET active antennas were designed identically. One FET active antenna (FET 1) was biased to oscillate/radiate, while the other (FET 2) to mix/receive. The two FET active antennas are closely spaced such that certain LO power can be coupled from the oscillating/radiating active antenna to the mixing one. This makes the pair of active antennas a monostatic Doppler-radar transceiver front end. Doppler signals are extracted from the drain of the FET in the mixer/receiver circuit. A shield plate was introduced a certain distance behind the circuits to avoid any back radiation.

The dimensions of the 67-Ω microstrip ring and the 0.5-mm-wide slot antenna were determined by means of EEsof's LineCalc software. The dimensions of the open-circuited microstrip stub in the circuit was determined by means of the small-signal approach for the design of the FET oscillators [11].

Fig. 2 shows the schematic equivalent circuits of this active antenna, including both the oscillator/transmitter circuit and the

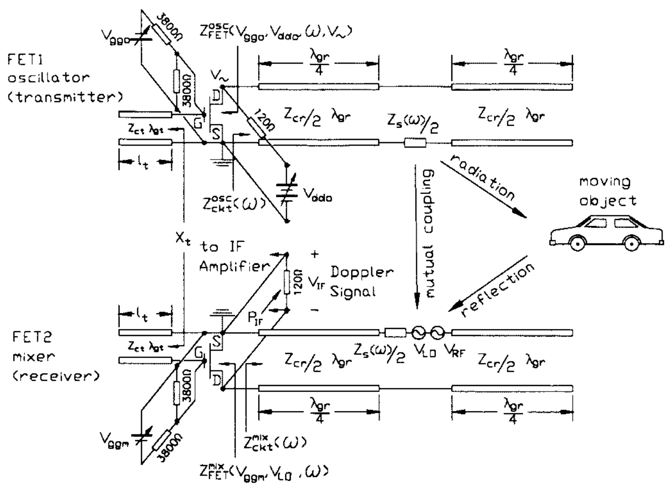

Fig. 2. Equivalent circuits.

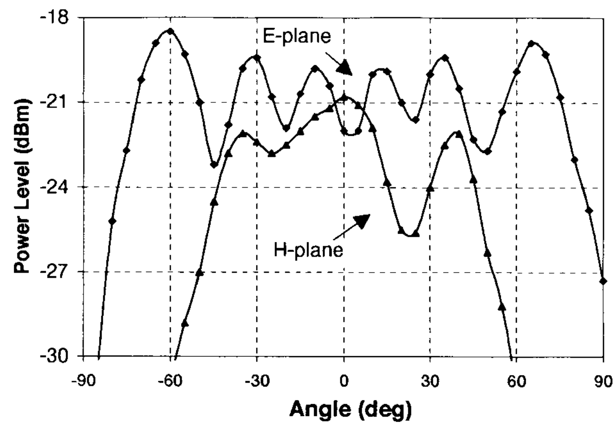

Fig. 3. E- and H-plane patterns of the active antenna.

mixer/receiver circuit. In the oscillator/transmitter circuit, the drain of the FET is connected via a 120-Ω resistor to a positive voltage source $V_{\rm ddo}$, the gate is biased with a voltage divider circuit and a negative voltage source $V_{\rm ggo}$. In the mixer/receiver circuit, the drain of the FET is grounded via another 120-Ω resistor, and the gate of the FET is biased with another voltage divider circuit and another negative voltage source $V_{\rm ggm}$.

When appropriately biased with $V_{\rm ggo}$ and $V_{\rm ddo}$, the oscillator/transmitter circuit will oscillate and radiate as the transmitter. Given a specific FET, the output power of this oscillator/transmitter can be adjusted by means of the two biasing voltages $V_{\rm ggo}$ and $V_{\rm ddo}$. A small portion of the output power of the oscillator/transmitter circuit will be coupled to the adjacent mixer/receiver circuit as the LO signal of the later. The remaining majority of the output power of the oscillator/transmitter circuit will be radiated via its slot antenna to illuminate any moving object in the beam of the slot antenna. The reflected RF signal from the moving object will be picked up by the slot antenna of the mixer/receiver circuit, which has essentially the same pattern as the slot antenna of the oscillator/transmitter circuit.

With its drain grounded via the 120-Ω resistor, the mixer FET operated at the origin of its I–V characteristic. It is a resistive mixer. No oscillation is possible. Its input impedance seen by the LO and RF signals can be changed with its bias gate voltage $V_{\rm ggm}$. The Doppler/IF signal is extracted from its drain. The frequency $f_{\rm IF}$ of the output Doppler/IF signal depends on the operation frequency f_o of the active antenna and the radial velocity ν_r of the moving object relative to the active antenna, i.e.,

$$f_{\rm IF} = \frac{2\nu_r}{c} f_o \tag{1}$$

where c is the propagation velocity of the RF wave in the surrounding media of the active antenna (or 3×10^8 m/s in the air). The output Doppler/IF signal power depends on the matching condition between $Z_{\rm FET}^{\rm mix}(V_{\rm ggm}, V_{\rm LO}, \omega)$ and $Z_{\rm ckt}^{\rm mix}(\omega)$ which can be adjusted by means of $V_{\rm ggm}$.

III. Experiments

Experiments were conducted to test the performance of the oscillator/transmitter and the whole circuits (including both the oscillator/transmitter and the mixer/receiver) as a Doppler-radar transceiver front end.

It was found that when the oscillating/transmitting FET was biased at $V_{\rm ggo} = -2.0$ V, and $V_{\rm ddo} = 8.9$ V, the output power of the oscillator/transmitter approached its maximum point and the quiescent current and operating frequency were around 17 mA and 11 GHz, respectively. The E- and H-plane radiation patterns of the oscillator/transmitter were measured, as shown in Fig. 3. The ripples in the E-plane pattern were due to the diffraction from the two edges of the finite ground plane of the substrate. The average gain of the antenna was estimated by means of Kraus' formula [13] to be around 5.0 dB. The radiated power was estimated by use of the Friis transmission equation [14] to be around 11 mW. The coupling between the oscillator/transmitter and the mixer/receiver active antennas was around -20 dB. Thus, the LO power of the mixer was estimated to be around 110 μW or -9.6 dBm.

To test the sensitivity of the mixer/receiver circuits, a low-frequency amplifier, based on Fujitsu 2N3904 bipolar transistors, with a gain of 74.5 dB and a 3-dB passband from 4 to 130 Hz was used. In the 3-dB passband, the input impedance of the amplifier was designed so high that its introduction would not disturb the operation of the mixer/receiver circuit, which possesses only a low output impedance.

An experimental system to measure the performance of the Doppler-radar transceiver front end was set up in the anechoic chamber of our laboratory. A square trihedral corner reflector with 5.5-cm-length sides was made and used as a standard radar target. When its symmetry axis was aimed at the Doppler-radar transceiver front end, the corner reflector presented its maximum radar cross section, which was determined by [15] to be $\sigma_{\max} = 0.42$ m^2 in our experiments. This corner reflector was put in the beam of the Doppler-radar transceiver front end and around 1 m away from it. When the corner reflector was made to move back and forth in a small range relative to the Doppler-radar transceiver front end at a speed between 0.055 and 1.8 m/s, the approximate peak-to-peak value of the amplified Doppler/IF signal was read out of the screen display of an oscilloscope. As pointed out in Section II, the intensity (power) of the output Doppler/IF signal would change with the bias voltage $V_{\rm ggm}$ of the mixing/receiving FET. This was verified by the measurements at a Doppler frequency of around 23 Hz, as shown in Fig. 4. The measured noise levels corresponding to the bias voltages are also shown in this figure. From Fig. 4, the Doppler-radar transceiver front end yielded its maximum sensitivity when biased at $V_{\rm ggm} = -2.3$ V. At this optimum bias voltage, the Doppler/IF signal to noise ratio at the output port of the amplifier reached 31 dB. However, when the input port of the amplifier was connected to the drain of the oscillating/transmitting FET, as in the self-oscillating mixer scheme, the Doppler/IF signal-to-noise ratio at the output port of the amplifier was only from 5 $V_{\rm p-p}$ to 3 $V_{\rm p-p}$ (or 4.4 dB) for the corner reflector at the distance of 1 m from it. Therefore, the

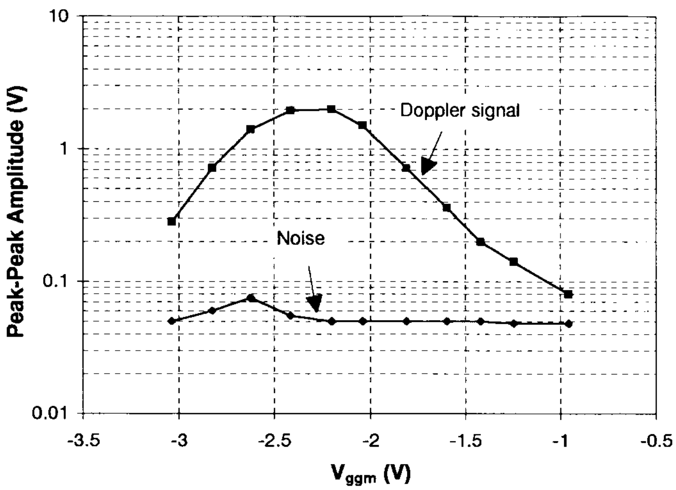

Fig. 4. Signal and noise output as a function of the bias voltage of the mixer.

sensitivity of the self-oscillating mixer scheme was about 27 dB worse than that of the optimum biased Doppler-radar transceiver front end. This is because of the high $1/f$ noise and shot noise of the oscillator FET. In the integrated Doppler-radar transceiver front-end design, the mixer FET operates at the origin of its I–V characteristics does not produce $1/f$ or shot noise [16]. Therefore, the overall system performance is greatly improved and independent of the used semiconductor devices.

IV. Conclusions

An integrated low-power Doppler-radar transceiver front end was developed using two adjacently spaced low-power FET active antennas, with one of them being biased to oscillate as the transmitter and the other being biased not to oscillate, but to act as the mixer. Operation theory was discussed and experimentally verified. This design demonstrated higher sensitivity at low Doppler frequencies than the self-oscillating mixer scheme. It can be used as the front end in low-power Doppler-radar systems such as intruder detectors.

Acknowledgment

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60-GHz Monolithic Down- and Up-Converters Utilizing a Source-Injection Concept

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***Abstract*—This paper deals with the design considerations, fabrication process, and performance of coplanar waveguide (CPW) heterojunction FET (HJFET) down- and up-converter monolithic microwave integrated circuits (MMIC's) for V-band wireless system applications. To realize a mixer featuring a simple structure with inherently isolated ports, and yet permitting independent port matching and low local oscillator (LO) power operation, a "source-injection" concept is utilized by treating the HJFET as a three-port device in which the LO signal is injected through the source terminal, the RF (or IF) signal through the gate terminal, and the IF (or RF) signal is extracted from the drain terminal. The down-converter chip incorporates an image-rejection filter and a source-injection mixer. The up-converter chip incorporates a source-injection mixer and an output RF filter. With an LO power and frequency of 7 dBm and 60.4 GHz, both converters can operate at any IF frequency within 0.5–2 GHz, with a corresponding conversion gain within -7 to -12 dB, primarily dominated by the related filter's insertion loss. Chip size is 3.3 mm$\times$2 mm for the down-converter, and 3.5 mm $\times$ 1.8 mm for the up-converter.**

I. Introduction

Recent advances in wireless services have motivated development of low-cost small-size frequency-converter modules with 1–2 GHz IF

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