A FULLY MONOLITHIC INTEGRATED TWIN DIPOLE ANTENNA MIXER ON A GaAs SUBSTRATE

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The first fully monolithic X-band twin-dipole antenna mixer consisting of a uni-planar twin-dipole antenna and a GaAs MESFET single gate mixer on the same GaAs substrate fabricated by monolithic microwave integrated circuit technology (MMIC) is reported. The total chip size is 5x5 mm^2. This circuit received an RF signal of 10 GHz and down- converted it to an IF signal of 1 GHz with a worse case conversion loss of 22 dB, defined as the ratio of output IF power dissipated in a 50 Ω load to the RF available power received by the twin-dipole antenna. The experimental results demonstrate that this topology has potential applications in future low-cost millimeter-wave receivers for smart munitions seekers and automotive-collision-avoidance radars.

1. INTRODUCTION

There is considerable interest in the development of low-cost millimeter-wave receivers, transmitters, and imaging arrays for applications such as smart munitions seekers, aircraft landing systems, and automotive-collision-avoidance sensors [1]-[3]. The monolithic integrated circuit (IC) approach, consisting of planar antennas directly integrated with amplifiers and mixers, offers several advantages over waveguide based systems [4]-[7] at millimeter-wave frequencies. The monolithic integrated systems are smaller, and less expensive to build than waveguide systems and can be easily produced in large numbers for millimeter-wave imaging applications. Different types of antennas integrated (hybrid or monolithic) with different solid-state devices, such as FETs, HBTs, Schottky diodes and SIS devices, have already been demonstrated with excellent results. Hence we are motivated to investigate the feasibility of integrating the twin-dipole antenna with a single gate mixer by standard GaAs MMIC technology. The dipole antenna was chosen because of its simplicity for design and its wide bandwidth characteristic. The experimental results show that the twin-dipole antenna mixer could convert a RF signal of 10 GHz to an IF signal of 1 GHz with a worse case conversion loss of 22 dB. The success of our experiment demonstrates that a complete monolithic wideband receiver or even transceiver realized on one chip can be expected in near future.

2. ANTENNA MIXER DESIGN

The photograph of our fabricated integrated antenna mixer is shown in Fig. 1(a) while the schematic layout and circuit diagram of this antenna mixer is shown Fig. 1(b) and (c), respectively. As shown in Fig. 1(c), the LO and RF signals are designed to be received by the twin dipole antenna and then applied to the input port (gate-to-source) of the MESFET, in which mixing operation is performed. The desired IF signal is extracted from the output port (drain-to-source) of the MESFET. Specifically, the balanced RF signal is received by the two parallel dipole antennas spaced half wavelength apart and then fed to input of the FET through a pair of coplanar strips. The unbalanced IF appears at the output of the FET and is transmitted out by a coplanar waveguide transmission line. In our experiment, the IF signal is measured at the terminal of the coplanar waveguide transmission line. Half wavelength rather than full wavelength dipole antennas were used in order to minimize the chip size. One reason that two dipole antennas are spaced half wavelength apart (see Fig.1 (b)) is to make the main beam of the resultant antenna pattern directed perpendicular to the GaAs substrate as is simulated by the full-wave *Zeland software's IE3D* (see Fig. 2). Since the FET is located at midway between two dipole antenna, the distance between the FET and one of the antennas is quarter wavelength. That is, the coplanar strips connecting the FET and two dipole antennas can be used as quarter wavelength transformers to fulfill the impedance matching of the twin-dipole antenna and the FET. This is the other reason that two dipole antennas are spaced half wavelength apart. A 0.1 nH inductor has to be inserted between the quarter wavelength transformers and the MESFET to resonate out the imaginary part (gate-to-source capacitance, C_{gs}) of the FET input impedance. The wavelength was chosen to be the free-space wavelength of a 10 GHz signal. The single gate mixer is based on a 4-finger (total gatewidth 200 μm) MESFET working at X-band with gate length 1 μm. The FET is biased near the pinch-off region, where the nonlinear characteristics of drain-to-source current versus gate-to-source voltage are used. This whole circuit is built on one side of a 200 μm thick GaAs substrate. Note that coplanar strip (CPS) and coplanar waveguide transmission lines are used, which allows fully uni-planar process technology and thus requires no via holes.

3. EXPERIMENTAL RESULTS

The characteristics of the transconductance (g_m) and the characteristics of drain current (I_{DS}) versus gate voltage (V_{GS}) are shown in Fig. 3. To achieve higher degree of non-linearity for frequency mixing, a gate-to-source bias voltage of –1.6 V near pinch-off region is used. Drain-to-source voltage of 2 V is chosen to ensure that the FET is operated properly in the saturation region when the FET is turned-on by the LO signal.

The experiment setup for the testing of the integrated twin-dipole antenna mixer was is shown in Fig. 4. The RF and LO signals are provided by an X-band Horn antenna (antenna gain=18 dBi), which is placed above the mixer 6 cm away in the direction of the main beam of the twin-dipole antenna. The IF power was measured by a *CASCADE MICROTECH* probe at the output terminal of the coplanar waveguide transmission line connected to the drain port of the FET. Since the direct measurement of actual RF and LO power level received by the twin-dipole antenna or the FET is not available at this time in our laboratory, Friis transmission formula is used to estimate their available power received by the antenna. In the calculations the antenna gain of the twin-dipole antenna is assumed to be 3.1 dBi as predicted by IE3D software. The conversion loss is defined as the ratio of the IF output power dissipated in a 50 Ω load to the RF available power received by the twin-dipole antenna. Note that, by this definition, the conversion loss we obtained is the worse case because the actual power level entering the gate port of the FET is always less than the available power from the antenna due to the possible mismatch between the twin-dipole antenna and the FET. In Fig. 5, the conversion loss was plotted as a function of IF frequency under the condition that RF signal is fixed at 10 GHz and RF and LO available power levels received by the antenna before entering the gate of the FET are fixed at 7.2 dBm and 6.5 dBm, respectively. From this figure, it is clearly that the IF signal peaks at 1 GHz with a mixer conversion loss of 22 dB. The large loss is suspected to be caused by the mismatch between the twin-dipole antenna and the FET. Fig. 6 shows the measured results of conversion loss versus LO signal (9 GHz) power level for a fixed RF (10 GHz) available power of 7.2 dBm before entering the gate port of the FET. Clearly, the conversion loss has not reached its saturation value, which means that lower conversion loss still can be expected if the LO power is further increased or the mismatch between the antenna and the FET is improved.

4. CONCLUSION

The fully monolithic integration of an X-band twin-dipole antenna with a MESFET single gate mixer on the same GaAs substrate is successfully demonstrated for the first time. This integrated antenna mixer exhibits a mixer conversion loss of 22 dB, which can be improved further by increasing the LO power level. The success of our work suggests that this topology is promising for millimeter-wave receivers for smart munition seekers and automotive–collision-avoidance radars, where the requirments for low cost, compact size and wide bandwidth are needed.

ACKNOWLEDGMENT

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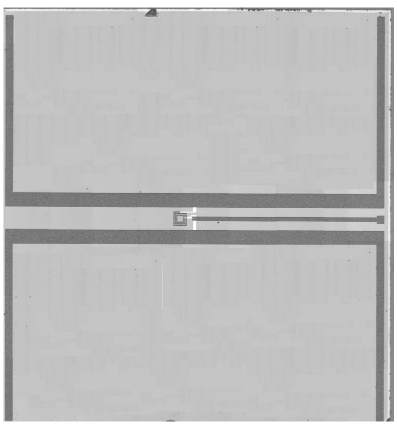

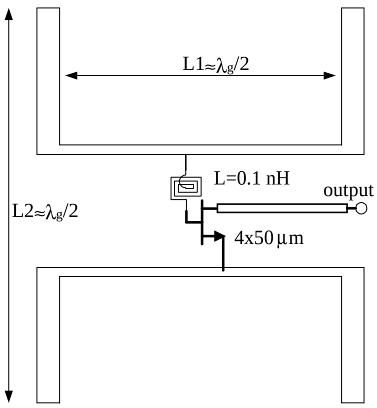

Fig. 1(a) The photograph of the integrated twin-dipole antenna mixer fabricated by GaAs MMIC technology. The chip area is 5x5 mm^2.

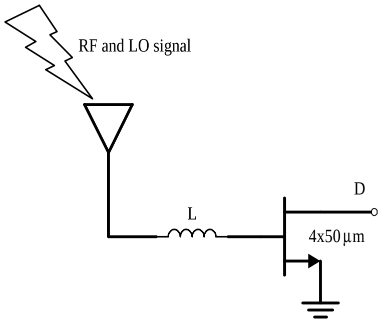

Fig. 1(c) The schematic circuit diagram of the antenna mixer.

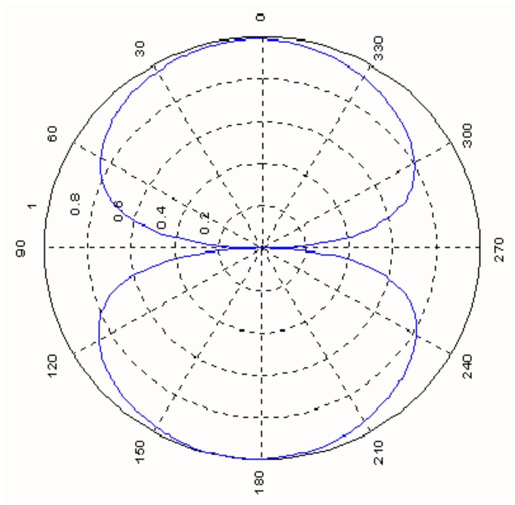

Fig. 2. The antenna pattern of the twin dipole antenna at E-plane simulated by IE3D software. Frequency is at 10 GHz (linear voltage scale, arbitrary normalization) and 0^o represents the direction perpendicular to the GaAs substrate surface.

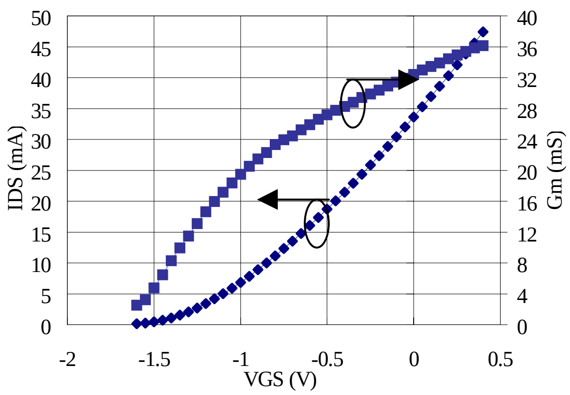

Fig. 3 The measured characteristics of g_m and I_{DS} versus V_{GS} of 4x50 µm MESFET at V_{DS}=2 V.

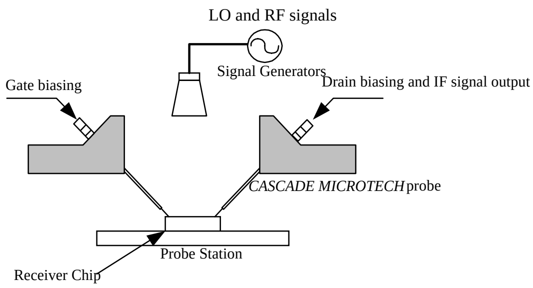

Fig. 4. Experiment setup for measuring the conversion loss of the receiver via on wafer probing method .

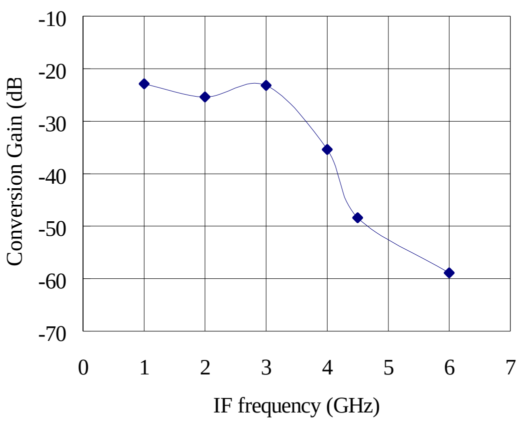

Fig. 5. The measured characteristic of mixer conversion loss versus IF frequency. V_{DS}=2 V, V_{GS}=-1.6 V, RF freq.=10 GHz, P_{RF}=7.2 dBm, P_{LO}=6.5 dBm.

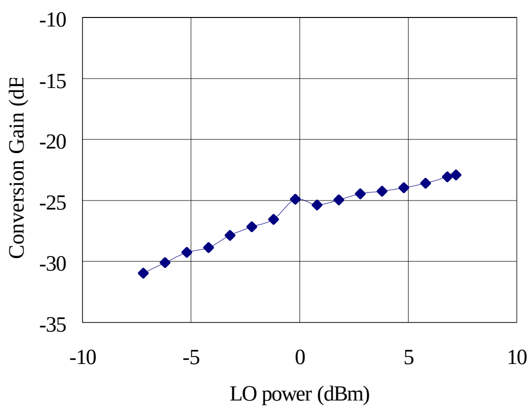

Fig. 6. The measured characteristics of conversion loss versus LO power level. V_{DS}=2 V, V_{GS}=-1.6 V, RF freq. =10 GHz, LO freq.=9 GHz, IF freq. =1 GHz, P_{RF}=7.2 dBm.