QUASI-OPTICAL PLANAR FET TRANSCEIVER MODULES

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ABSTRACT

We present the design and performance of quasi-optical planar transceiver modules suitable for communication and Doppler radar. The designs incorporate microstrip antennas which function as resonant loads for FET oscillators. The FETs operate as oscillators and self-oscillating mixers for down-conversion of the received signal. The circuits are simple and inexpensive, and are suitable for incorporation as elements of an active transceiver array. X-band prototype circuits are reported and their use for Doppler motion detection is demonstrated.

INTRODUCTION

Recently there has been interest in planar circuits for quasi-optical systems (1-3). In this paper, the term quasi-optical is used to refer to components which contain integral antennas, and make connections to the remainder of the system using free space propagation. These circuits are useful in the millimeter wave range where conventional guiding structures become difficult to use.

In this paper we describe a new type of quasi-optical transceiver module composed of FET oscillators integrated with microstrip antennas in a simple planar circuit. In our design, all of the components of a typical transceiver, including antenna, transmitter, and mixer, are integrated into one unit. The microstrip antennas operate in the leaky-wave mode and function as both the radiating element and the frequency selective resonant element in the oscillator circuit (4). In addition to serving the signal source, the FETs function as self-oscillating mixers for down conversion to the IF frequency. As a result, these circuits are inexpensive and simple to construct, and require few components.

Test results of two types of circuits are reported: the first is a single ended design using one FET and a single microstrip antenna for the transmission and reception, and the second uses two FETs in a push-pull configuration as a balanced mixer with separate transmit and receive antennas. Both circuits are characterized in terms of their isotropic receive and transmit conversion efficiencies.

Prototypes were constructed to operate at X-band for demonstration purposes, to simplify construction. In addition to their use when scaled to higher frequencies, these circuits have also been demonstrated to perform well as Doppler motion detection modules at 10 GHz.

DESIGN

In the oscillator circuits described here, the FETs serve as the negative resistance element, while the resonant circuit consists of a periodic microstrip structure operated in the leaky-wave stopband.

By terminating the gate and source of an FET in the appropriate impedances, we may cause the resulting circuit to exhibit negative resistance at the drain port. In practice, this may be accomplished by placing microstrip open circuit stubs at these ports and adjusting their lengths as required. For the purposes of oscillator design, this circuit may be viewed as a one-port negative resistance device, and the oscillator is completed by attaching a resonant element which causes the total impedance at the junction to equal zero.

For the resonant element, we use a periodic microstrip array operated in the leaky-wave stopband, where the periodicity of the structure is equal to the guide wavelength (5). At this point, the reflections from the individual elements add in phase at the input, creating a high VSWR on the structure. Therefore, the antenna serves as a resonant element, while at the same time it radiates energy in the broadside direction, normal to the plane of the circuit.

Figure 1 shows the single-ended configuration. The leaky-wave resonator/antenna consists of a linear microstrip patch array, in which the patches are spaced one microstrip wavelength apart at the desired operating frequency of 10 GHz. The widths of the patch elements are varied along the length of the array, in order to reduce the bandwidth of the stopband. The widest elements, in the middle of the array, are designed as optimal single patch elements using the design rules given in (6). The electric field is polarized along the axis of the antenna.

The gate of the FET is terminated in a band stop filter in this case, to prevent oscillation at one half of the desired frequency, caused by the surface wave stopband of the antenna. The FET is biased near to I_{DSS} by dc grounding both the source and the gate. This causes the FET to operate in a highly non-linear manner, improving the mixer gain.

In this circuit, the RF signal is injected into the drain of the oscillating FET. The IF signal is extracted at the drain using a transformer, which provides a dc path for the bias.

The balanced Transceiver module is shown in Figure 2. In this case, the leaky-wave resonator/antenna consists of two microstrip rampart-line antennas with periodic coupled sections, shown in Figure 3. The rampart line antenna, two of which make up our coupled resonator, has been described by

Hall (7). This type of antenna will radiate when excited in the odd-mode, that is, when then input signals are 180 degrees out of phase. The electric field is polarized perpendicular to the axis of the antenna.

To insure that the FETs oscillate in the odd-mode, the even and odd mode impedances of the coupled sections of microstrip line are designed such that Z_{oe} = 50 ohms and Z_{oo} < 50 ohms. The remaining sections have a characteristic impedance of 50 ohms. Therefore, the coupled antennas exhibit the leaky-wave stopband in the odd mode only, and appear as matched loads in the even mode.

The receive antenna consists of a single microstrip rampart line antenna connected to the gates of the FETs. In the even mode, the short circuit stub coupled with the 50 ohm resistor forms a resonant circuit at the design frequency of 10 GHz. This also provides about 7 dB of return loss at 5 GHz, to prevent odd mode oscillation at the surface wave stopband of the coupled antennas.

For this circuit, the received signal is injected into the gate of the FET. In the case of balanced operation, the oscillation is in the odd mode, while the received signal is injected in the even mode. For this reason, the IF signal must be extracted using a hybrid circuit, which in this case is a center tapped IF transformer. The IF is again extracted at the drain port, and the transformer provides the dc bias path.

CONSTRUCTION

Prototype circuits were designed to operate at a frequency of 10 GHz using the Touchstone microwave CAD program. The FETs used in both circuits were NE71083 packaged devices from NEC.

The single FET design used a 12 element patch antenna, on Rogers RT/Duroid 6010.2 with a relative dielectric constant of 10.2, and a thickness of 25 mils. The balanced circuit was constructed using a 5 period coupled rampart line transmit antenna, and a 5 period receive antenna, on Rogers RT/Duroid 5880, with a relative dielectric constant of 2.2, and a thickness of 20 mils. The overall length of each circuit was approximately 7 inches,which was the maximum size for ease of processing.

The single FET was biased near to I_{DSS} by connecting the source to ground and connecting the gate to ground using a 50 ohm resistor. In the balanced case, the gate was left open circuited and the FETs were operated in the self-biased mode. These configurations were shown to provide the highest receiver gain

PERFORMANCE

The single FET design oscillated at 9.87 GHz, or within 1.3 % of the design frequency. The balanced circuit oscillated at 9.2 GHz, about 8% off from the design. This was due to the fact that the resonant antenna for the balanced circuit was electrically much shorter, causing it to be less selective.

To determine receiver performance, a signal was injected using an external source and a horn antenna. The frequency of the external signal was adjusted so that the IF was approximately 5 MHz. The modules were placed it the far field of the horn, and receive patterns were measured. Transmit and receive patterns for the circuits are shown in Figures 4-7. The fact that the balanced module was oscillating below design frequency caused the circuit to be somewhat "cross-eyed".

We define the isotropic receiver gain as the ratio of IF output power of the receiver to that of an isotropic receiver with 100% RF to LO conversion efficiency (8). Similarly, the isotropic transmitter gain is defined as the ratio of radiated power to that of an isotropic source which radiates at 100% DC to RF efficiency. These quantities are plotted in Figures 8-11.

The balanced circuit exhibits lower receiver gain compared to the single ended design because its receive antenna is shorter, and because it operates further off from the design frequency. Both of these factors cause the receive antenna gain to be reduced. It has been observed that by lengthening the resonant transmit antenna, circuits of this type will oscillate much closer to the design frequency, obviating these problems. For our prototypes, however, the circuit was kept short to facilitate processing.

When the circuits were set up as Doppler motion detection modules, with the audio frequency IF signal displayed on an oscilloscope, both showed similar performance. For example, the signal caused by waving a metal box at a distance of 20 feet was easily detected. The signal due to a person walking about in the room at a distance of 10 to 20 feet was also easily detected, indicating that these circuits have applications as low-cost, planar motion detection modules.

CONCLUSION

By combining all features of a transceiver module in a single, uniplanar circuit using FETs we can acheive good transmit and receive conversion efficiency. This concept may be scaled to higher frequencies for quasi-optical applications. In addition, the circuits may be used for Doppler motion detection applications at X-band, where they are smaller and lighter than conventional circuits.

For Doppler radar and motion detection applications, the single ended approach is preferred because the same antenna is used for transmit and receive functions. One advantage of the balanced circuit over the single ended approach, however, is that an RF premplifier may be inserted between the receive antenna and the mixer to significantly improve the receiver gain and noise figure.

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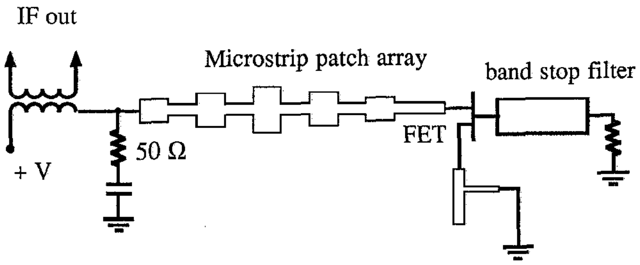

Figure 1. Schematic view of single-ended transceiver circuit.

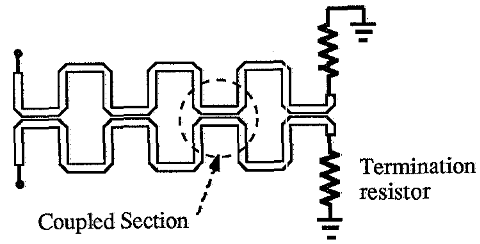

Figure 3. Four section coupled rampart line antenna.

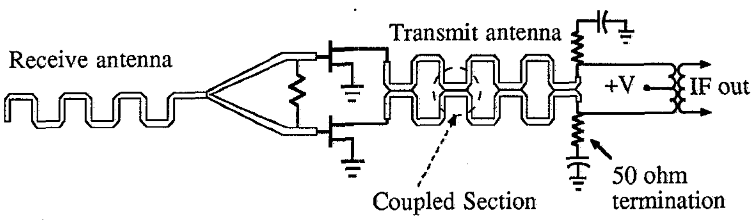

Figure 2. Schematic view of balanced transceiver circuit.

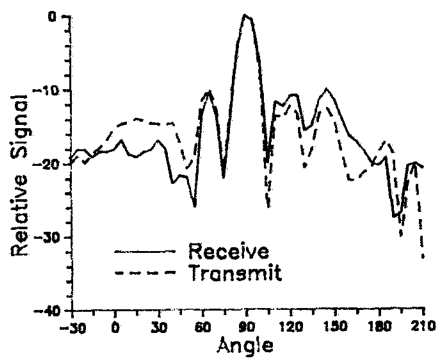

Figure 4. E–plane transmit and receive patterns for single ended transceiver.

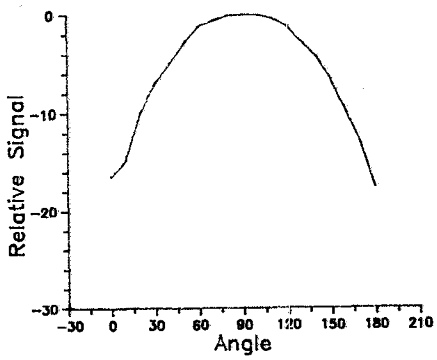

Figure 5. H–plane transmit pattern for single ended transceiver.

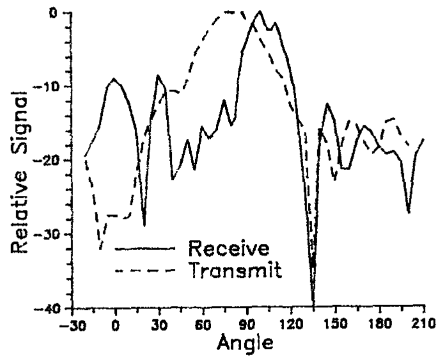

Figure 6. H–plane transmit and receive patterns for balanced transceiver.

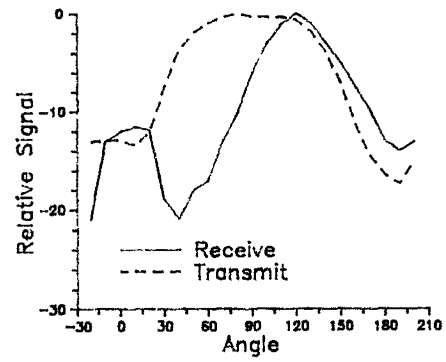

Figure 7. E–plane transmit and receive patterns for balanced transceiver.

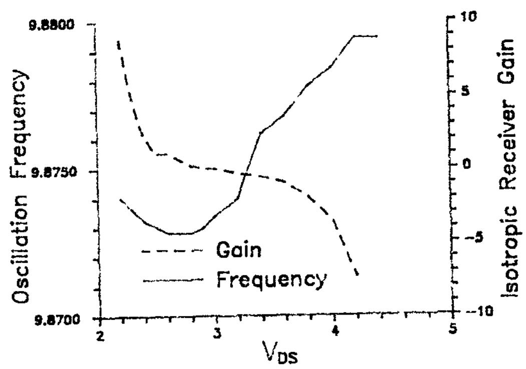

Figure 8. Frequency and receive gain vs. V_{DS} for single ended transceiver.

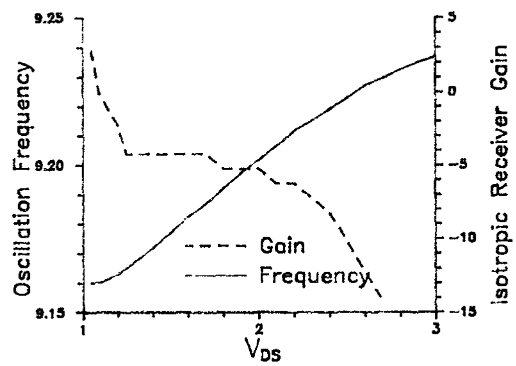

Figure 9. Frequency and receiver gain vs. V_{DS} for balanced transceiver.

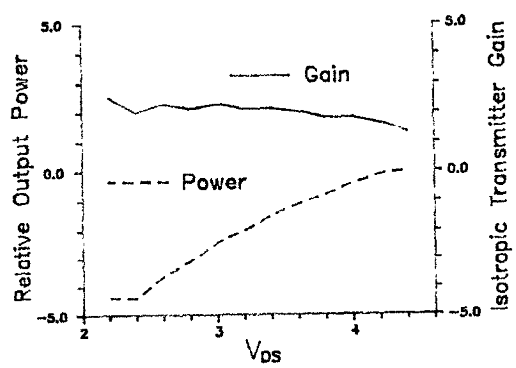

Figure 10. Power and transmitter gain vs. V_{DS} for single ended transceiver.

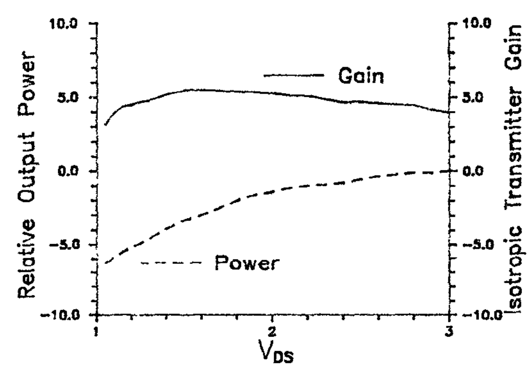

Figure 11. Power and transmitter gain vs. V_{DS} for balanced transceiver.