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A 30 GHz FET RECEIVER

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This paper describes a GaAs FET receiver operating from 27.5 to 30.0 GHz with a 4.6 dB noise figure and 17 dB conversion gain at band center. A three-stage FET amplifier (4.4 dB noise figure, 17.5 dB gain), a 25 GHz FET oscillator (10 mW output), and dual-gate FET mixer (3 dB conversion gain, 10 dB noise figure) were developed for this receiver.

Introduction

In order to meet the future requirements of military and commercial systems, the noise and power capabilities of FET devices are constantly being improved and extended to higher frequencies. With the development of new FET structures and technology, millimeter-wave FET devices[1,2] and components[3,4] have been reported whose performance is comparable to the best diode-based components. We anticipate that superior performance will be achieved at millimeter-wave frequencies as the FET technology matures.[5] This paper describes the first all-FET receiver operating from 27.5 to 30.0 GHz.

Receiver Configuration

The receiver block diagram is shown in Figure 1. The receiver consists of an isolator, preamplifier, bandpass filter, mixer and local oscillator. The completed receiver is shown in Figure 2. Each component uses standard hybrid circuit MIC construction techniques and Cr-Au microstrip circuitry. The main housing contains a waveguide-to-microstrip transition, a three-stage low noise FET amplifier, the image rejection filter, the dual-gate FET mixer, and the FET local oscillator. The components were evaluated and optimized individually before being mounted in the receiver housing. In normal operation, the top of the receiver is covered by a plate that provides the transition back-short and also holds the oscillator tuning screw. The waveguide isolator mounts beneath the unit, as do the bias and regulation networks. The IF output is obtained on the bottom of the housing via an SMA connector. The dimensions of the unit are 2.7x1.5x1.8 inches.

Devices

Four different FET device structures, shown in Figure 3, were employed in the receiver. A key element is the realization of a 0.25 μm gate length FET. The newly developed SM-8 FET consists of two E-beam defined gate fingers, 0.25x75 μm, for a total periphery of 150 μm. A single chip contains two such 150 μm unit cells. The device is shown in Figure 3(a). The second FET device structure, made by direct-write E-beam lithography for all mask levels, is shown in Figure 3(b). The gate length of this device is 0.5 μm. The gate finger width is 50 μm, for a total of 100 μm for each unit cell. The third device, shown in Figure 3(c), is 0.5x300 μm in gate size. The dual-gate FET structure, fabricated by direct-write E-beam lithography for all mask levels, is shown in Figure 3(d). It has a 150 μm gate periphery and a 0.5 μm gate length, with 1 μm spacing between the two gates.

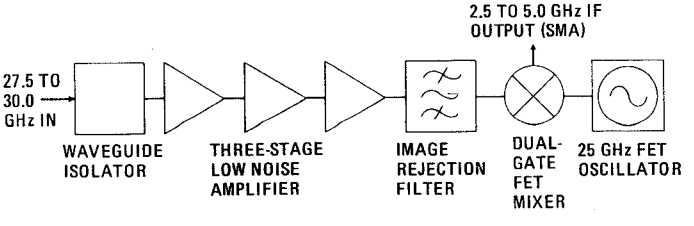

Figure 1. Block diagram of FET receiver.

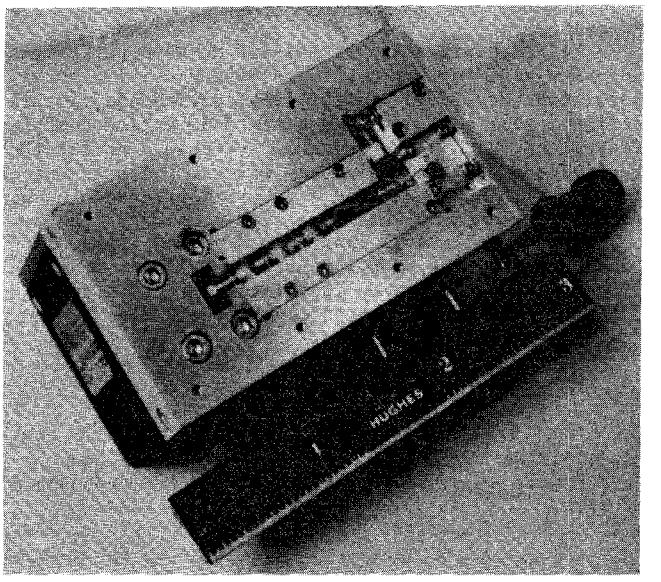

Figure 2. 30 GHz receiver.

Components

Three key state-of-the-art components, a low noise FET amplifier, a dual-gate FET mixer, and a FET oscillator, were required for the all-FET receiver development. The low noise amplifier was configured as a three-stage amplifier with sufficient gain to mask the relatively high (approximately 10 dB) dual-gate mixer noise figure. The amplifier carriers are invar with dimensions of 0.390x0.250 inch. The critical first two stages contained the 0.25 μm gate length devices, while the third stage employed a 0.5x100 μm device. The devices were mounted on the carriers between two MIC matching networks fabricated on 10 mil thick quartz substrates. Low loss chip capacitors and high impedance, λ/4, transmission lines were used for the bias networks.

The noise figure and associated gain achieved by the three-stage low noise amplifier are shown in Figure 4. The minimum noise figure, 4.4 dB with 17 dB associated gain, was achieved at bond center, 28.75 GHz. The best single stage amplifier result reported to date is a 3.6 dB noise figure with 4.1 dB gain at 29 GHz.[5] The 1 dB noise bandwidth extends from 27.5 to 29.5 GHz. The gain is 17 ±0.5 dB over the band, but extends from 26.5 to over 30.5 GHz. This data includes the loss (0.3 dB/transition) through the input and output waveguide-to-microstrip transitions. The maximum gain can be achieved by adjusting the bias conditions on the third stage, and has little affect on the noise figure of the unit. Under these conditions, greater than 20 dB gain can be achieved over the band. The 1 dB gain compression point occurred at an output power of +4 dBm. This represents the first reported

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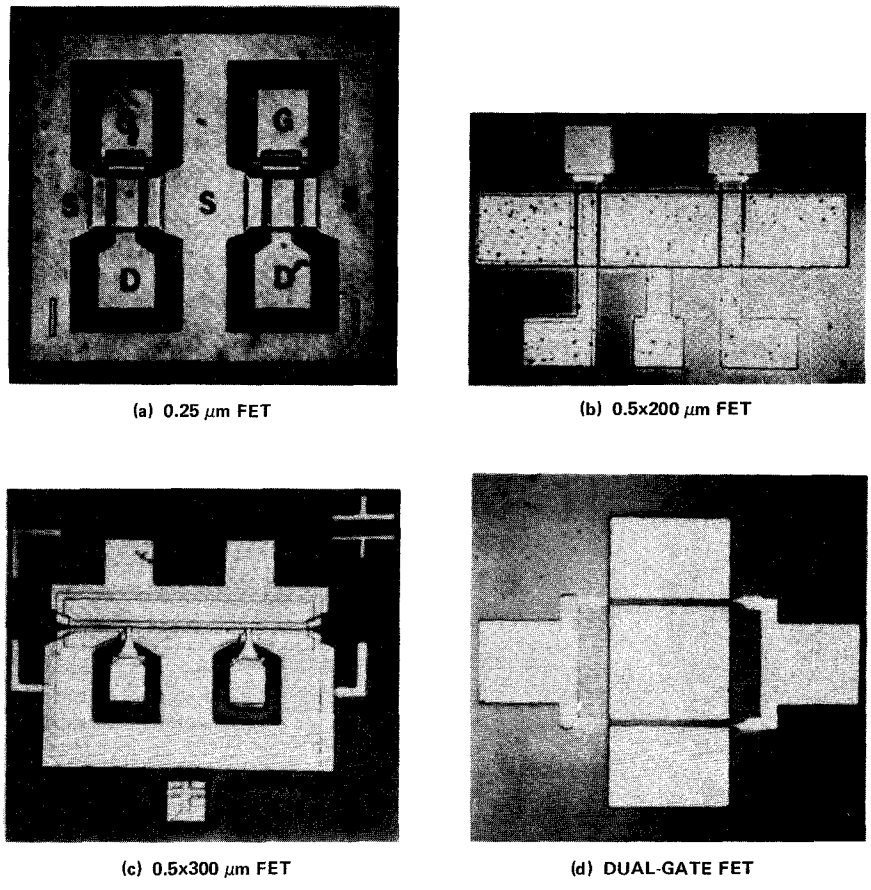

(a) 0.25 μm FET

(b) 0.5x200 μm FET

(c) 0.5x300 μm FET

(d) DUAL-GATE FET

Figure 3. Photograph of devices used in 30 GHz FET receiver.

three-stage FET amplifier at 30 GHz. Its noise performance is equal to and in some cases superior to single-device results that have been previously reported.

The local oscillator consisted of a dielectric resonator stabilized FET oscillator operating at 25 GHz. A common gate configuration was selected, with the load coupled to the drain. The oscillator circuit is fabricated on a 25 mil thick alumina substrate. A dielectric resonator (ε_r=38) was used to stabilize the oscillator by coupling it into the drain circuit. The load was capacitively coupled to the oscillator by a gap in the microstrip line. The oscillator uses the 0.5x300 μm device described earlier. The output spectrum of the oscillator is shown in Figure 5. The noise sidebands are -70 dBc/Hz at an offset frequency of 25 kHz. The oscillator frequency is mechanically tunable ±100 MHz via a metal tuning screw that loads the resonator. The output power is typically 10 dBm at 25 GHz, with 3 to 5% efficiency. The temperature stability of the oscillator was 0.18 MHz/°C (7 ppm) measured from 26° to -40°C.

The RF to IF frequency conversion was performed by a dual-gate FET mixer. The RF frequencies were applied to gate 1, the gate closest to the source, with the 25 GHz local oscillator driving gate 2. The IF frequency was extracted from the drain. The best results achieved were +3 dB conversion gain with 10 dB noise figure at 28.75 GHz. Typically, the conversion gain ranged from 0 to -2 dB. Problems with IF matching resulted in relatively narrow band (1 GHz) conversion performance. However, the noise performance was typically much broader. This work represents the first reported application of dual-gate FET devices as a mixer at Ka-band frequencies.

Image frequency rejection was provided by a two-resonator parallel-coupled microstrip bandpass filter fabricated on 10 mil thick quartz. The frequency response of the filter is shown in Figure 6. The passband insertion loss was 1.0 B, while rejection at the image frequencies was 23 to 29 dB and 15 dB at the local oscillator frequency.

The waveguide junction isolator was optimized for low insertion loss. At band center, its insertion loss is 0.25 dB and rises to 0.6 dB at the band edges.

FET Receiver Performance

The noise figure and conversion gain of the overall receiver are shown in Figure 7. The minimum noise figure achieved at 28.75 GHz is 4.6 dB with 17 dB RF to IF conversion gain. This noise figure parallels that of the amplifier, but is degraded at the band edges by the waveguide isolator. The conversion gain variation is due primarily to the dual-gate FET mixer. The 1 dB gain compression point of the receiver occurred at an output power of -3.5 dBm (16 dB gain). No attempts have yet been made to flatten the noise figure and conversion gain of the overall receiver.

Conclusion

The first all-FET low noise receiver operating at 30 GHz has been demonstrated with noise performance equal to the best diode-mixer-based units. It employs MIC fabrication techniques for minimum size, weight and cost. Further improvements in GaAs FET technology are expected to yield FET receivers with sub 4 dB noise figures. The GaAs FET, as a three-terminal device, is clearly superior to negative resistance diodes in low noise amplifier applications. It is capable of lower noise amplification, inherent input/output isolation, and is suitable for hybrid or monolithic MIC inclusion.

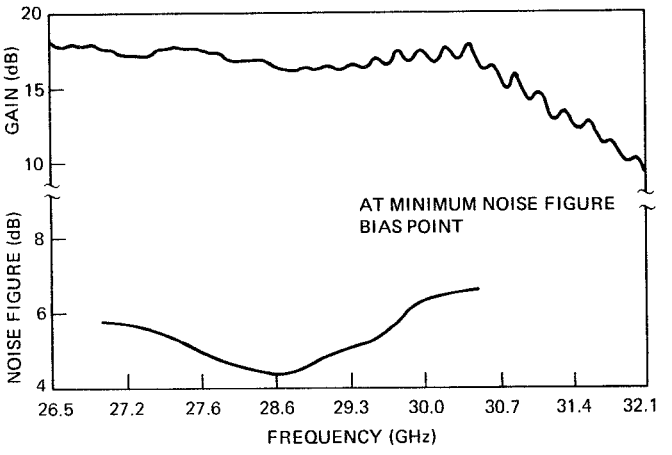

Figure 4. Frequency response of three-stage FET amplifier.

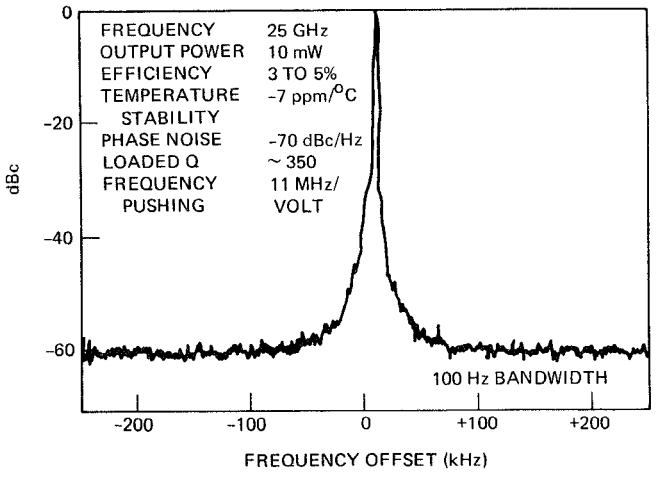

Figure 5. Output spectrum of 25 GHz FET LO.

Acknowledgements

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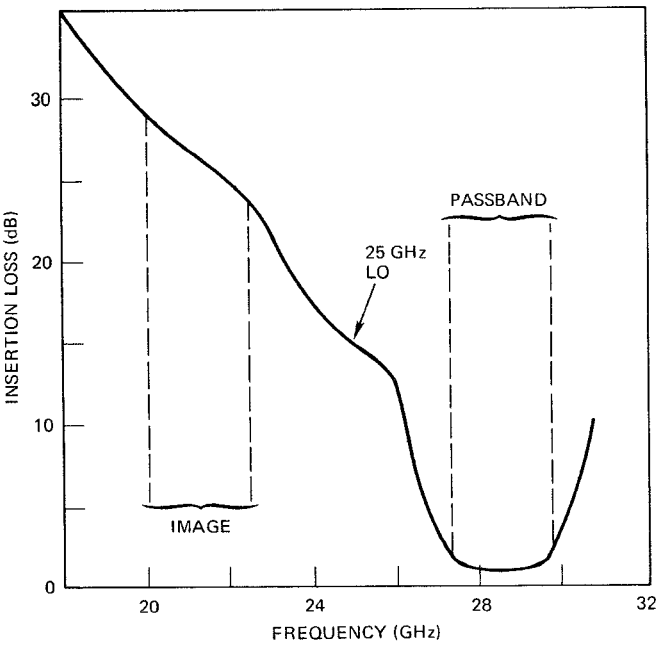

Figure 6. Two-resonator, parallel-coupled microstrip bandpass filter response.

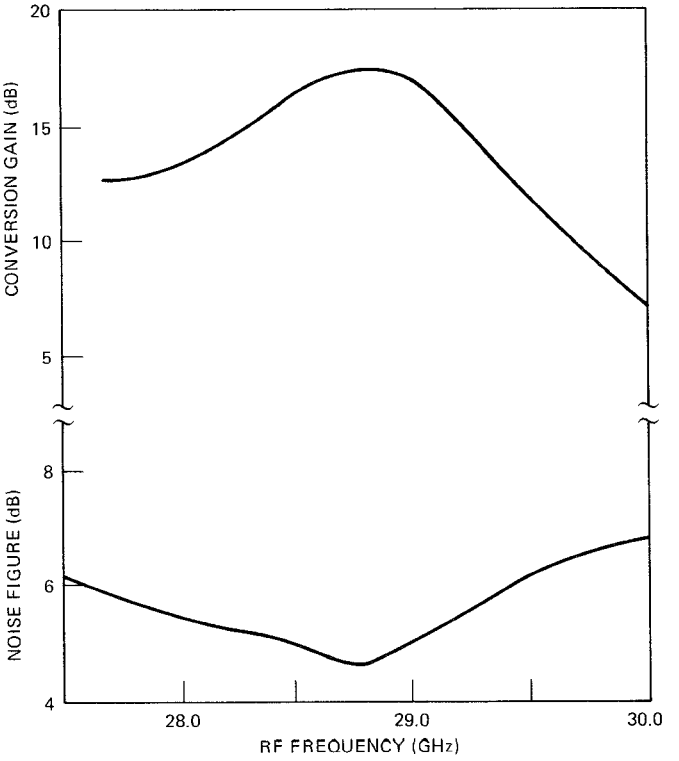

Figure 7. Frequency response of full receiver.

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