A 26.5-40.0 GHz GaAs FET Amplifier

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ABSTRACT

Sub-half-micron gate GaAs FET's have been used to fabricate a MIC balanced amplifier module with 4.2 dB of minimum gain over 26.5-40.0 GHz. The module and devices are described and data is presented for gain, VSWR, noise figure, and power on the module.

INTRODUCTION

Millimeter wave applications as well as the need to replace the last of the low noise TWT's with more compact and reliable solid state components have been the driving forces for the development of a sub-half-micron gate GaAs FET. (1,2,3) In this paper experimental data will be presented on an amplifier module which covers the entire 26.5-40 GHz frequency band with a minimum of 4.2 dB of gain by utilizing a sub-half-micron FET. The FET, test fixturing, and circuit details are discussed below.

DEVICE DESCRIPTION

The sub-half-micron FET channel region is fabricated using direct ion implantation into semi-insulating GaAs substrates. Processing sequences include chemical mesa etch, Au/Ge/Ni ohmic contacts, and TiW/Au gate metallization. The recessed gate is less than half a micron long and is delineated by optical lithography. The gate metallization is widened at the top by gold plating. (1) At typical operational biases (Ids < 1/2 Idss), the device has been designed to have an intrinsic transconductance of 120 mmhos and an input gate capacitance of 0.4 pF for each millimeter of gate width. A simulation of an equivalent circuit for the device projects the Fmax to be about 150 GHz.

For the 26.5-40.0 GHz modules, a device with a total gatewidth of 75 microns was used. A micrograph of this device is shown in Figure 1. Measured MAG on individual devices was 14 dB at 18 GHz and 11 dB at 26 GHz. In Table 1 we list some of our best results at 18 GHz and 32 GHz. These results are representative of state of the art performance in low noise GaAs FET's.

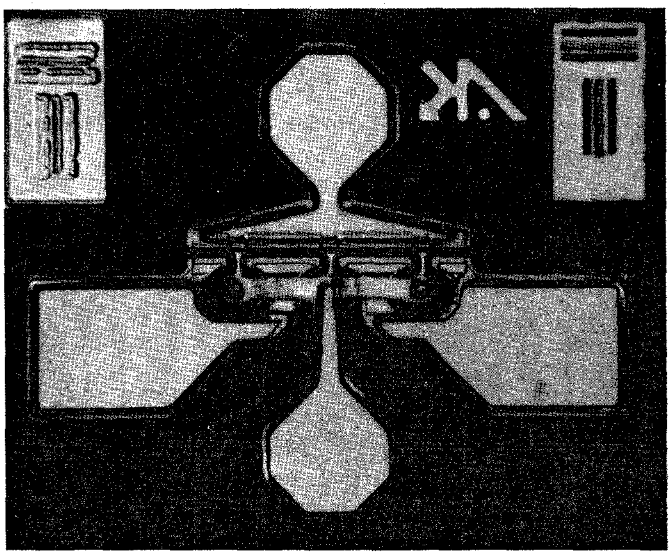

FIGURE 1. 75 micron GaAs FET.

SAMPLE	FREQUENCY GHz	GATE WIDTH microns	NOISE FIGURE dB	GAIN dB
A	18	150	1.7	8.7
B	18	75	1.9	10.1
C	18	75	2.1	11.7
D	32	75	3.2	5.3

Table 1: Noise figure and associated gain of GaAs FET's at 18 GHz and 32 GHz.

TESTING

Almost all of the test equipment for the 26-40 GHz band is waveguide. The FET's are three terminal in nature and the transmission medium chosen for the circuit was microstrip. Thus testing of the modules required a broadband waveguide to microstrip transition capable of mode free performance across the entire 26-40 GHz band. This was achieved by converting from waveguide (WR-28) to coax (3mm) and then from coax to microstrip using two separate transitions. Both in-house and commercially available waveguide to coax transitions with less than 1.25 VSWR were used for the first part of the transformation. In house developed coax (also 3 mm) to microstrip transitions were used to complete the waveguide to microstrip interface. The transitions were evaluated for VSWR using a 50 ohm microstrip load on 0.25 mm thick alumina with a plated thru "via" hole for grounding. Although the VSWR of the coax-microstrip transition was sensitive to the center assembly, VSWR's of better than 1.4:1 were achieved for the complete waveguide-coax-microstrip interface with a loss of less than 0.30 dB per coax-microstrip transition.

A photograph of one of the balanced modules mounted in a test fixture is shown in Figure 2. Circuits were mounted down to the test fixture with and without carriers. A channel was incorporated into the test fixture that surrounded the circuit in order to minimize losses due to unwanted signal propagation.

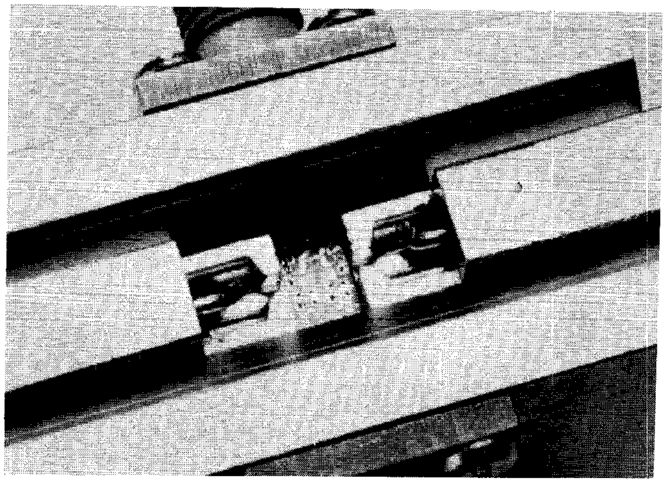

FIGURE 2. Test fixture with module and coax to microstrip transitions.

AMPLIFIER DESCRIPTION

Microstrip circuitry was utilized to fabricate both single ended and balanced amplifier modules. The balanced amplifier module (two Lange couplers, two single ended amplifiers, matching circuitry, and d-c biasing resistors) was realized on a single piece of 0.25 x 3.25 x 4.88 mm alumina. A photograph of one of the balanced modules is shown in Figure 3 with the substrate mounted on a Kovar carrier. A 0.25 mm thick substrate was chosen to be as thin as possible to minimize moding but was kept thick enough to allow the fabrication of Lange couplers. The 90 degree quadrature interdigitated "Lange" coupler was designed for 2.5 dB coupling with a center frequency of 30 GHz. Evaluation of the couplers determined a typical loss of less than 0.45 dB per coupler.

Plated through via holes were used as RF grounds throughout the substrate. The quality of the grounding that the holes provided in the 26-40 GHz band was evaluated by grounding a 50 ohm transmission line with a hole pattern consistant with that used for the device mounting. Measurements of VSWR and "thru" isolation gave VSWR's of greater than 25:1 and isolations of 28 dB minimum over the band. This indicated that the plated thru "via" holes provide an acceptable RF ground in the 26-40 GHz band.

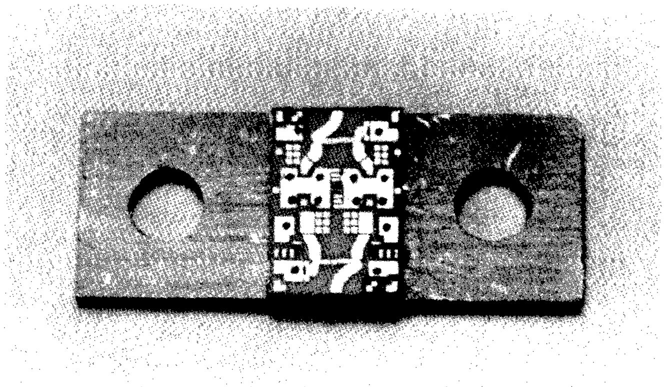

FIGURE 3. Balanced module mounted on carrier.

The input and output matching topologies were based on simple equivalent circuits of the gate and drain since scattering parameters of the device were not available above 26.5 GHz. These equivalent circuits were derived from measured scattering parameters taken below 26.5GHz. A simple schematic of the balanced module showing the gate and drain matching networks is shown in Figure 4. All of the inductors in the matching network were realized with gold bond wires of either 0.7 mil or 1.0 mil diameter. The DC decoupling capacitors in line with the RF output as well as the RF bypass capacitors used in the DC biasing circuitry are chip MOS capacitors.

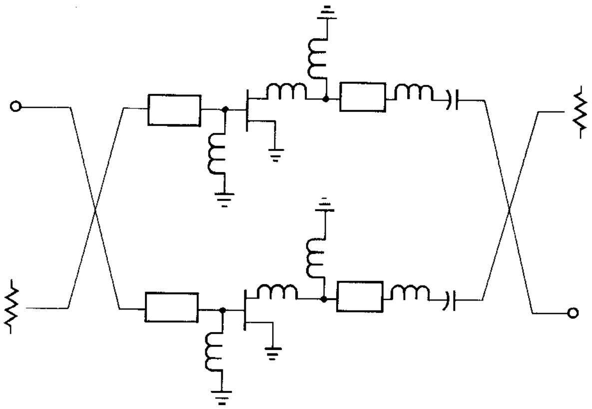

FIGURE 4. Schematic diagram of balanced module with gate/drain matching networks.

Tuning of the matching networks was achieved on the most part by varying the proximity of the bond wires (used as the inductors) to either the ground plane, the transmission lines, or to adjacent bond wires. Some additional tuning was realized by bonding in capacitive pad's to the transmission lines in order to vary the line impedances.

MODULE PERFORMANCE

Figure 5 shows the gain of a single ended amplifier which consisted of the device and the gate/drain matching networks. The gain had a maximum of 6 dB at 38.6 GHz with the VSWR's ranging from 6:1 at 26.5 GHz to better than 2.5:1 at 40 GHz. The combined mismatch losses due to the input/output VSWR's gave a 5.8 dB/octave positive slope to offset the 6 dB/octave rolloff of the device resulting in a fairly flat gain response. Although scattering parameters with phase information were not available, we have plotted a pseudo unilateral gain (assuming S12 = 0) on the same plot. MSG (maximum stable gain) was also measured on devices with 13.5 dB at 26.5 GHz and 10.5 dB at 40.0 GHz being recorded. A conservative estimate of 7 to 9 dB of MAG (maximum available gain) at 40.0 GHz for the devices is made based on the measured data.

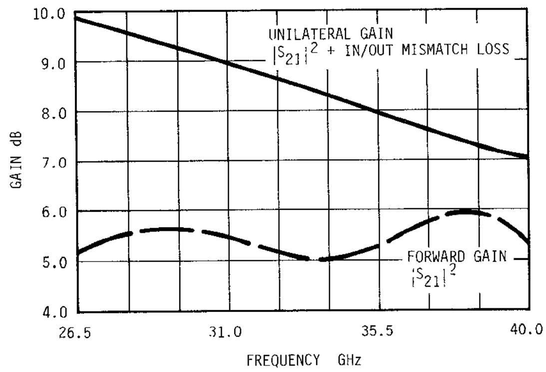

FIGURE 5. Forward and unilateral gain of single ended 26.5-40.0 GHz amplifier.

Gain, input and output VSWR, noise figure, and 1 dB power compression were evaluated at room temperature on a balanced module. The results are given in Figures 6 and 7. The gain varied from a minimum of 4.2 dB at 26.5 GHz to a maximum of 5.5 dB at 37.3 GHz. VSWR's of the input and output measured a maximum of 2.3:1 which is somewhat higher than expected when compared to the performance of the "Lange" coupler that had 10 dB minimum of return loss with the coupled and thru ports open ended. The measured noise figure of the module was less than 9.3 dB across the 26.5 to 40.0 GHz band. 1 dB gain compression measurements were made on the module with power levels of +12 dBm and greater being recorded.

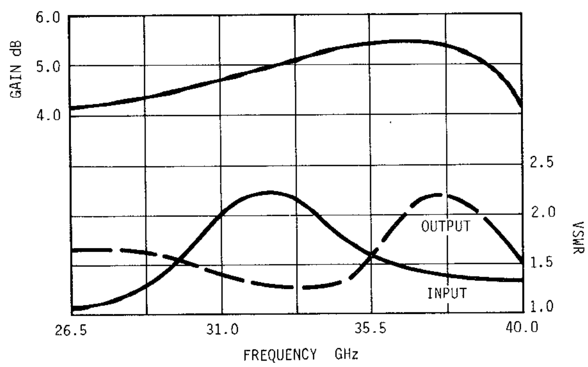

FIGURE 6. Gain, VSWR of balanced 26.5-40.0 GHz amplifier module.

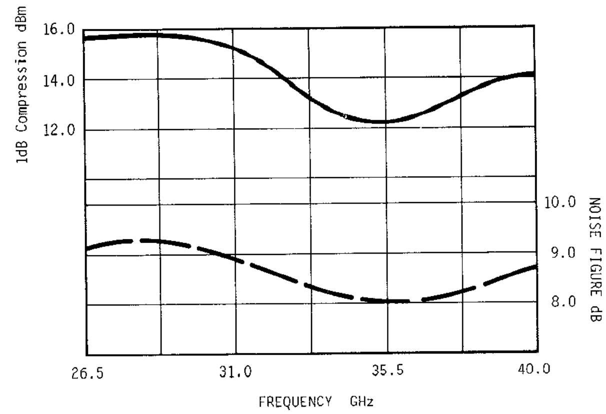

FIGURE 7. 1dB compression, noise figure of 26.5-40.0 GHz amplifier module.

Past experience has dictated that amplifier modules must have a minimum gain performance of approximately 4 dB before they can be effectively cascaded to form high gain amplifiers of 30 to 40 dB. The measured data that has been taken to date on these modules indicates that cascaded modules of this type would have performance which would be very competitive with present 26.5 to 40 GHz TWT's.

SUMMARY

In conclusion sub-half-micron GaAs FET's have been developed which demonstrate performance in wide band (26.5 to 40 GHz) hybrid modules which should be suitable for cascading to make solid state amplifiers capable of replacing 26.5 to 40 GHz low noise TWT's. The same devices tuned narrow band should be even more impressive. Appreciation is extended to R. Podhasky and K. Martin in testing and assembling the modules. This work has been partially supported by the Naval Electronics System Command under NRL contract N00014-81-C-2082.

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