A 2-12 GHz Feedback Amplifier on GaAs

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Abstract: A 2-12 GHz monolithic feedback amplifier has been designed. Initial experiments, made on a semi-monolithic unit, yielded 5.4 dB of minimum gain from 2-12 GHz and 3.8 dB of minimum gain between 2 and 15.3 GHz.

Feedback has proven to be a powerful tool in the design of multi-octave microwave amplifiers. Based on earlier research, a 2-12 GHz monolithic feedback amplifier has been designed [1],[2],[3]. The initial experiments were made on a semi-monolithic unit, i.e., the GaAs MESFET was attached to the GaAs substrate. The latter contains the fully integrated circuitry of the amplifier. The amplifier's dimensions of 1.47 x 2.24 mm included the gate and drain dc biasing lines and the dc blocking capacitor in the feedback line. A minimum gain of 5.4 dB and maximum reflection coefficients of 0.54 for the input and 0.50 for the output port were measured. Compromising gain as well as input and output VSWR, the bandwidth was extended to 2-15.3 GHz.

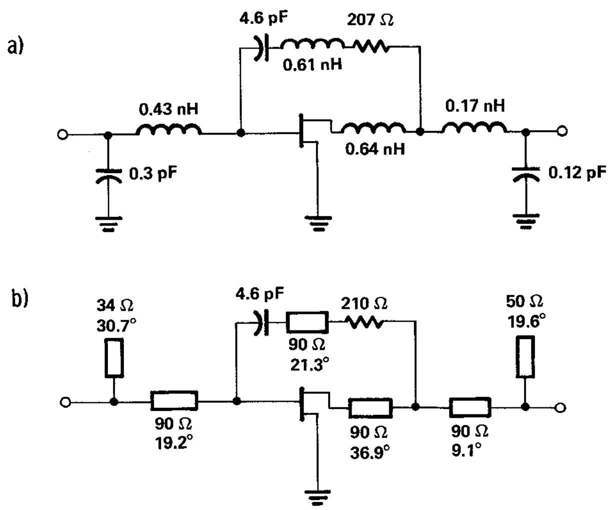

Fig. 1 Schematic of the feedback amplifier using a) lumped circuit elements and b) distributed circuit elements.

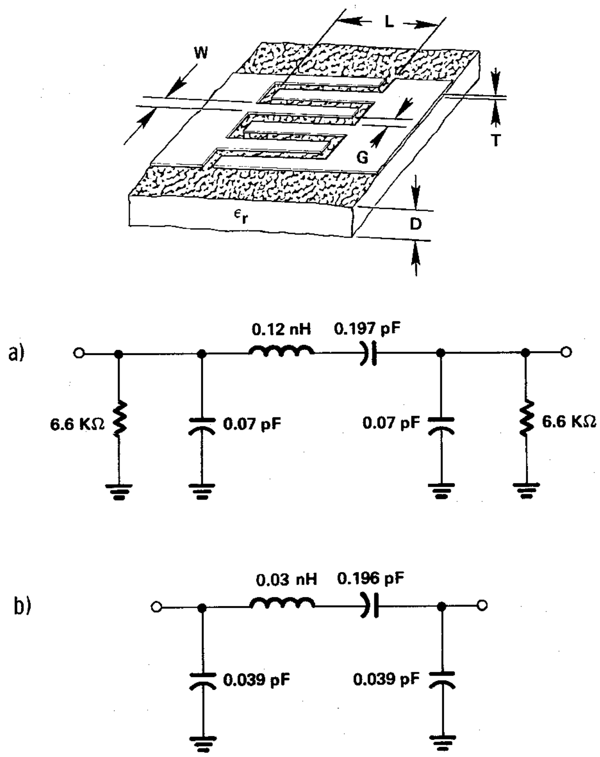

Fig. 2 Equivalent circuit of an interdigital capacitor a) derived from actual measurements and b) derived from computations based on interdigital coupled lines. (D = 115 μm, W = 10 μm, G = 44 μm, L = 200 μm, T = 1.5 μm and N = 12 fingers.)

The amplifier's initial design was based on the use of lumped components such as loop inductors and interdigital capacitors. Its schematic is shown in Fig. 1a. However, extended S-parameter measurements made on a great number of single-loop inductors and interdigital capacitors between 3 and 15 GHz clearly demonstrated characteristics more typical of distributed rather than lumped circuit elements. The actual performance of single-loop inductors was found to be in good agreement with the results computed for a microstrip line of identical dimensions. Similarly, the measured S-parameters of interdigital capacitors revealed a more complicated equivalent circuit in our band of interest than that of a lumped element capacitor. Especially at higher frequencies it showed the behavior of interdigitated coupled lines [4].

Fig. 2 compares the equivalent circuit of a twelve-finger interdigital capacitor (Fig. 2a) derived from actual measurements with that derived from computations based on a lossless interdigitated coupled lines model of identical dimensions (Fig. 2b). The comparison shows a remarkable agreement between the series capacitances of the two models. The agreement between the series inductances, as well as the parallel capacitances, is rather poor. The discrepancies are believed to be due in part to the inductance and the capacitance of the bonding pads, bonding wires and connections to the fingers.

The described observation that "lumped" components very much behaved like distributed elements persuaded us to switch from lumped to distributed element design techniques. A closer examination of the circuit elements

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showed that they could easily be realized by using transmission line elements. The resulting circuit diagram is shown in Fig. 1b. A comparison of the computed electrical characteristics of the two design approaches is made in Fig. 3. The dashed curves (a) represent the electrical behavior of the amplifier using lumped components, while solid curves (b) show the results for the amplifier employing distributed elements. Except for the input reflection coefficient and to a much lesser extent for the reverse isolation, the distributed approach exhibits better performance. In addition, replacement of the interdigital capacitors with simple short-circuited shunt stubs constitutes a significant simplification in the processing of monolithic amplifiers.

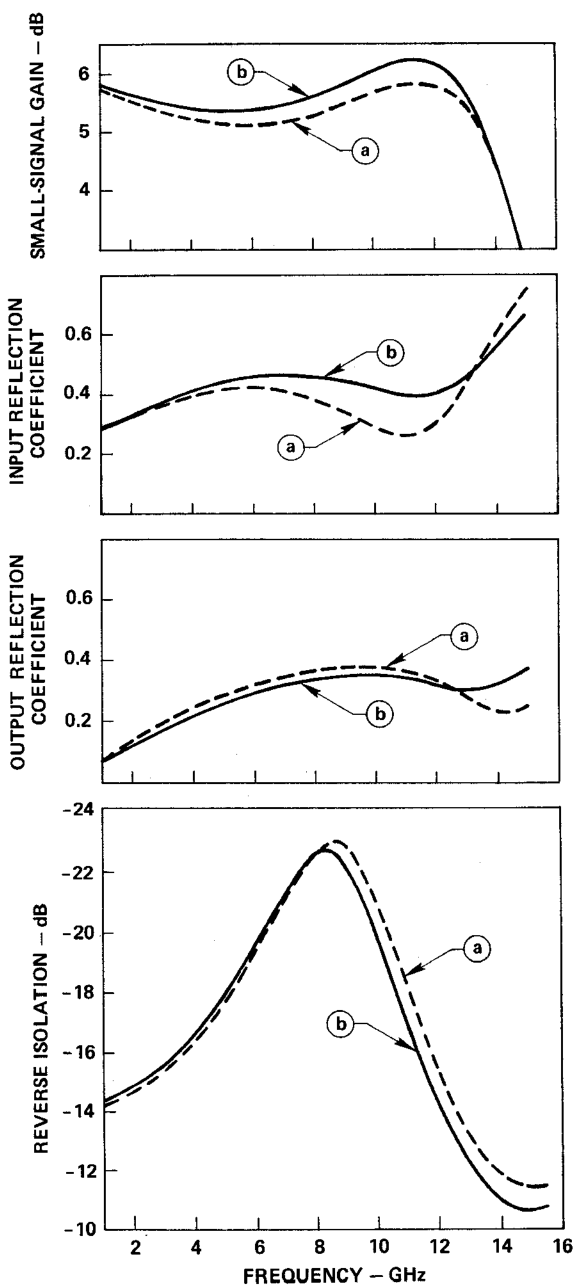

Fig. 3 Computed performance characteristics of the feedback amplifier using a) lumped circuit elements and b) distributed circuit elements.

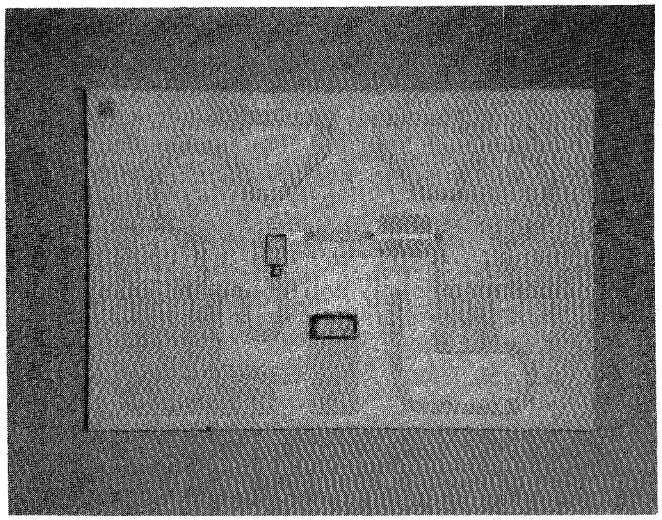

Fig. 4 Photograph of the GaAs substrate containing the circuit elements.

Initial experiments were made on a semi-insulating GaAs substrate incorporating all circuit elements except for the GaAs MESFET (Fig. 4). The latter was attached to the substrate with gold epoxy and connections were made with very short wire bonds. A photograph of the amplifier module is shown in Fig. 5. The circuits were processed on GaAs which was lapped to 115 μm thickness. The circuit metal was plated gold 1.5 μm thick. The dc blocking capacitor (C_{FB} = 4.6 pF) in the feedback line was a metal/Si_3N_4/metal structure with the top metal connected to the circuit by a plated gold air bridge. The resistors were vapor deposited Ti metal covered with Si_3N_4.

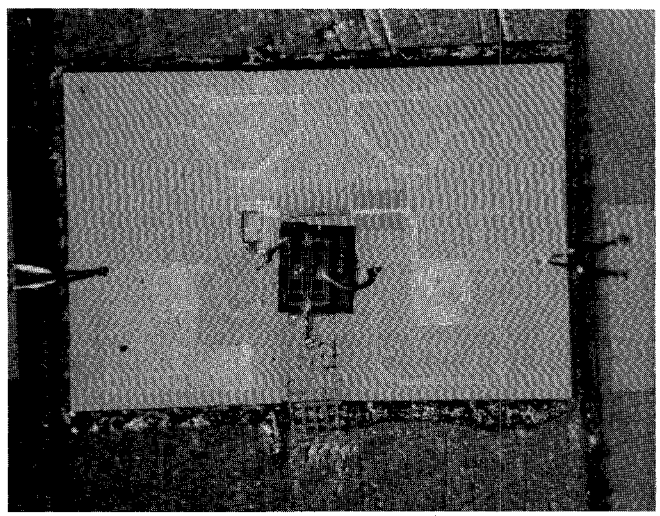

Fig. 5 Photograph of the amplifier module with the GaAs MESFET attached to the GaAs circuit of Fig. 4.

The GaAs circuit was intentionally designed to fit the repeat pattern of our FET mask. This technique required a mask which blocks out the unwanted FET patterns, leaving one FET for each circuit. It allows for a most cost effective and time saving mask procurement for the circuits with the sacrifice of some flexibility. The GaAs MESFET used in our experiments is the

WJ-F810 which has been described in the Literature [1].

Measured gain and reflection coefficients are plotted in Fig. 6 by line segments connecting the measuring points. The feedback resistor in this first amplifier was R_{FB} = 350 ohms, rather than the design value of 210 ohms. This resulted in somewhat degraded reflection coefficients in exchange for higher gain performance, especially in the lower half of the band. Minimum reverse isolation was -9 dB occurring at the upper band edge, while maximum reverse isolation was -24 dB measured at approximately 7 GHz. The computed gain and reflection coefficients of the amplifier whose schematic is shown in Fig. 1b with R_{FB} = 350 ohms are also plotted in Fig. 6 (smooth curves). The comparison shows a relatively good agreement between the measured and the computed characteristics. Decreasing the drain inductance extended the frequency band to 15.3 GHz with a measured minimum gain of 3.8 dB and a maximum gain of 7.4 dB. However, in this mode of operation the amplifier showed a potential stability problem between 15.4 GHz and 15.6 GHz.

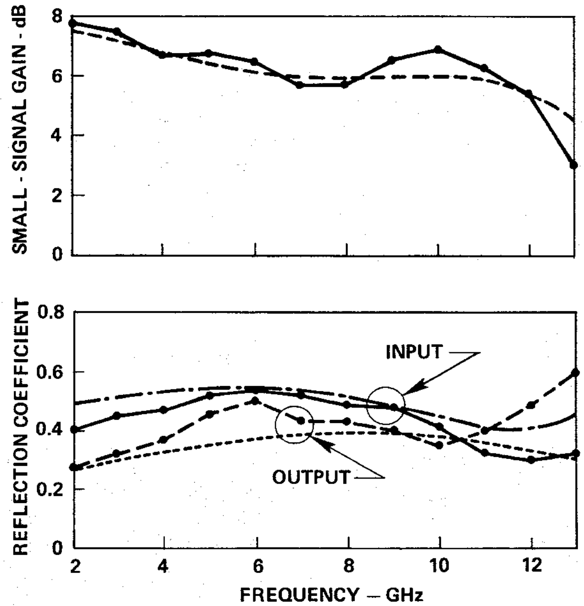

Fig. 6 Measured and computed performance characteristics of the amplifier module with R_{FB} = 350 ohms.

Gain, reflection coefficients and noise figure of an amplifier module with a feedback resistor of R_{FB} = 185 ohms are plotted in Fig. 7. As expected the gain flatness improved significantly. The amplifier's minimum reverse isolation was -8 dB at 12 GHz. Its maximum of -22 dB was measured at approximately 8 GHz.

Based on these preliminary, however very encouraging results, we are presently integrating the GaAs MESFET with the GaAs circuit to a fully monolithic unit.

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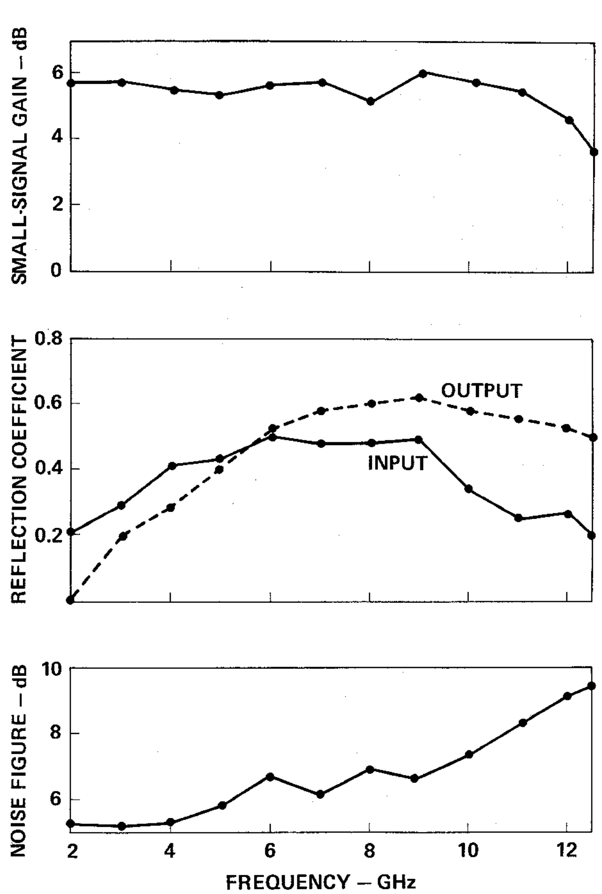

Fig. 7 Measured performance characteristics of the amplifier module with R_{FB} = 185 Ω.

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