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23-GHz Band GaAs MESFET Reflection-Type Amplifier

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***Abstract*—A new method is presented for applying a packaged GaAs MESFET to an amplifier in the frequency region above 20 GHz, using package resonance as a positive feedback element and operating GaAs MESFET as a negative resistance two-terminal device in a reflection-type amplifier. Experimentally, a 6-dB noise figure in the 23-GHz band and a 8-dB noise figure in the 27-GHz band have been achieved.**

I. Introduction

The GaAs MESFET, as the only three-terminal device available in the frequency region above X band, is evolving into the higher frequency region. Several amplifiers using the GaAs MESFET in a 20-GHz band have been reported [1]–[3]. When developing a low-noise preamplifier in the higher frequency region, conventional MIC technology encounters difficulties because the loss in the input/interstage/output matching networks increases as the frequency goes higher than 20 GHz. In addition, the available gain per single stage in those high-frequency regions is not so high as to be insensitive to the noise and loss characteristics of the following stages. Because of these factors, the required number of cascaded stages for an amplifier increases, causing overall noise-figure degradation by interstage loss accumulation. The circuit loss problem can be overcome by using a waveguide circuit and directly coupling the waveguide and GaAs MESFET. The GaAs MESFET, a three-terminal device, can be operated as a negative resistance two-terminal device by properly terminating the gate–source port [2]. Thus the gain problem can be overcome by employing the resulting two-terminal device in a reflection-type amplifier. This paper describes the feasibility of a low-noise amplifier operating at frequencies higher than 20 GHz by employing a packaged GaAs MESFET in a waveguide as a reflection-type amplifier.

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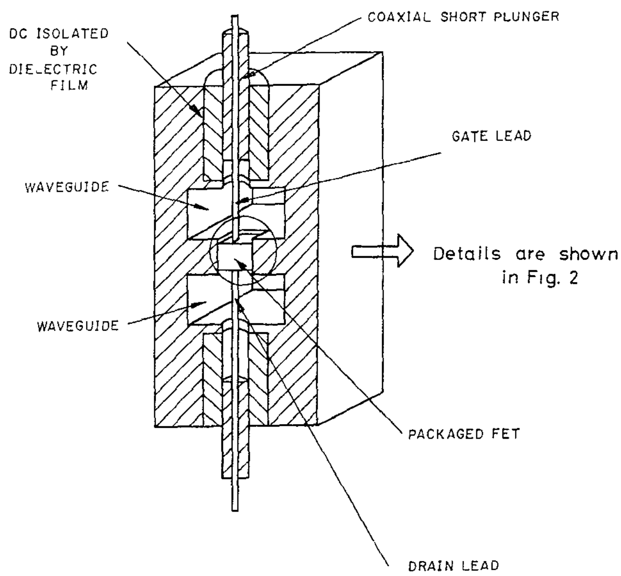

Fig. 1. Waveguide mount structure.

II. Experimental Work

A. GaAs MESFET Mounting

The waveguide mount shown in Fig. 1 was constructed to couple the GaAs MESFET and waveguides directly. The mount is composed of stacked waveguides, FET housing section (a form of through-hole between the stacked waveguides), and two transducers (gate/waveguide and drain/waveguide). Each transducer consists of a waveguide short plunger and a coaxial short plunger whose center conductor is soldered to gate/drain

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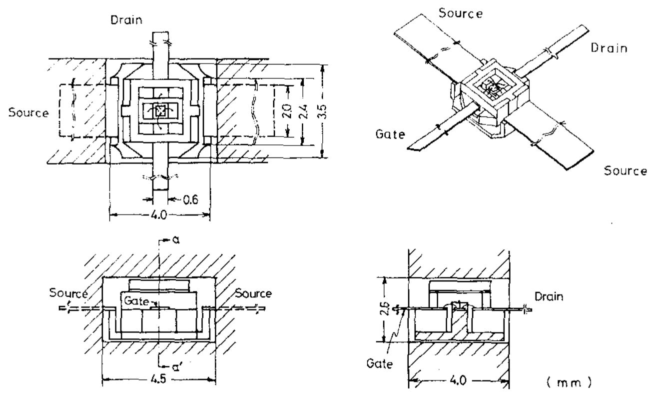

Fig. 2. Structural details of the FET housing section and the GaAs MESFET package.

lead. Thus each lead of the packaged GaAs MESFET forms a portion of each transducer. DC bias is supplied through the coaxial line center conductor.

Fig. 2 shows the structural details of the FET housing section. The GaAs MESFET used in the study is a 0.5-μm gate-length device (NE388, NEC) sealed in a stripline-type ceramic package whose structural details are also shown in Fig. 2. The ceramic package and the lid are soldered. The metallized portion for soldering is in the form of a ring resonator whose dimensions suggest a resonance at around 20 GHz. The metallized ring is so located as to cross over just above the gate and the drain leads. This unique structure, when mounted in the FET housing as shown in Fig. 2, causes an electrical coupling between gate and drain in the frequency region around the resonance which is determined by the dimensions of the metallized ring structure and the FET housing.

B. Impedance Measurement

Impedance characteristics of a GaAs MESFET operated as a two-terminal device were measured. The drain/waveguide transducer was adjusted to transform waveguide impedance to a 50-Ω system, while the gate/waveguide transducer was removed and the gate was connected to a 50-Ω coaxial line which was shorted at a distance of L mm from the gate. Fig. 3 shows the measured impedance looking into the drain–source port of the waveguide mounted GaAs MESFET. Fig. 4 shows the associated reflection-coefficient properties in the form of $1/\Gamma$ (Γ = reflection coefficient) as a function of frequency. Negative resistance characteristics were obtained at frequencies of 23.0–24.6 GHz. The frequency region where the negative resistance appears could be changed by adjusting the dimensions of the FET housing section. Fig. 5 is an example where the negative resistance characteristics were obtained in the 27-GHz region by slightly reducing the FET housing dimensions.

C. Reflection-Type Amplifier

A reflection-type amplifier was constructed using the waveguide mount shown in Figs. 1 and 2. Fig. 6 shows the amplifier schematic. Input and output power were separated by a circulator. Coinciding with the negative resistance properties shown in Fig. 4, a reflection-type amplifier in the 23-GHz band was realized. Fig. 7 shows the amplifier gain as a function of frequency. A gain of 8 ± 1 dB was obtained from 23.3 to 24.1 GHz by adjusting the coaxial and waveguide short plungers. The associated noise figure was in the 6.0–7.7-dB range. The waveguide used was WR-42. Fig. 8 is another reflection-type amplifier coinciding with the negative resistance properties shown in Fig. 5. The waveguide used in the amplifier was WR-34. A gain of 6 ± 1 dB and the associated noise figure of 8 dB were obtained.

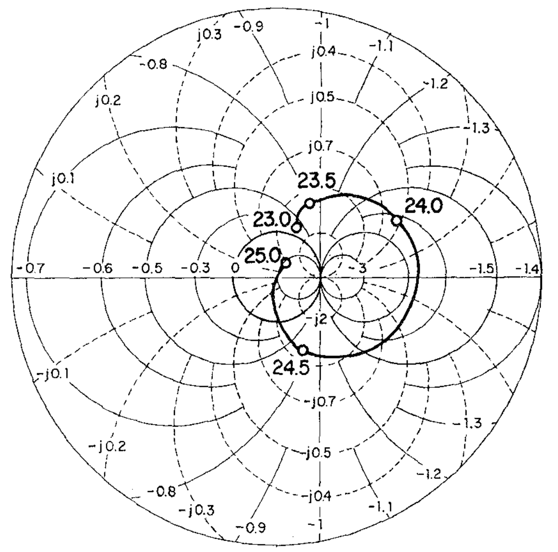

Fig. 3. Measured impedance at the drain–source port.

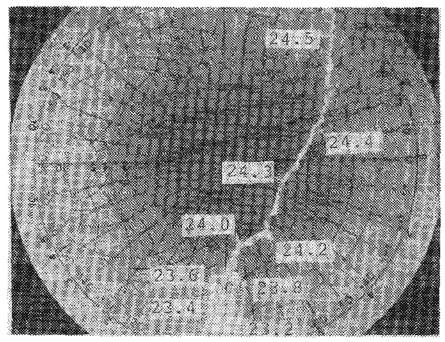

Fig. 4. Reciprocal of the reflection coefficient measured at the drain–source port.

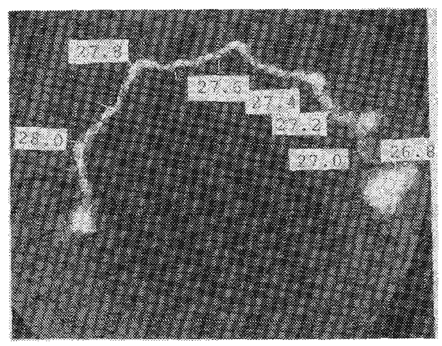

Fig. 5. Reciprocal of the reflection coefficient measured at the drain–source port.

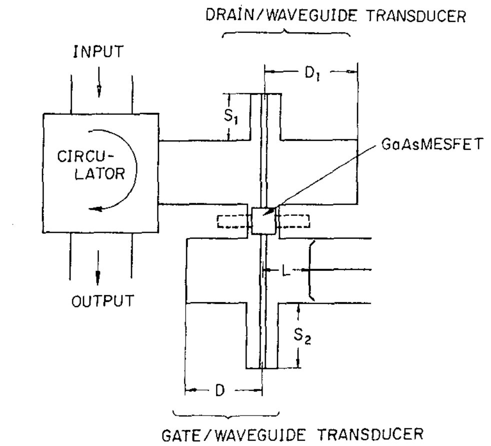

Fig. 6. Reflection-type amplifier schematic.

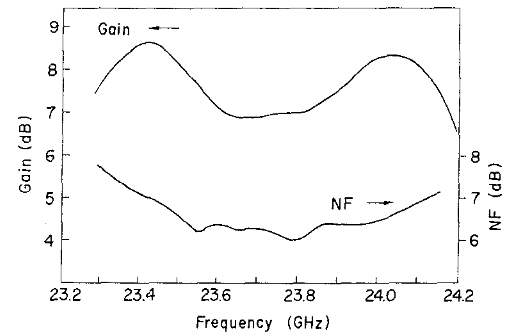

Fig. 7. Gain and noise-figure characteristics of GaAs MESFET reflection-type amplifier in 23-GHz band.

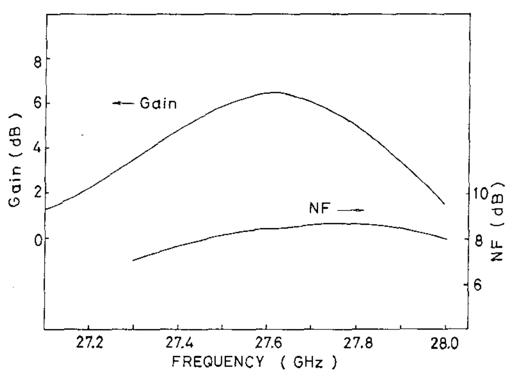

Fig. 8. Gain and noise-figure characteristics of GaAs MESFET reflection-type amplifier in 27-GHz band.

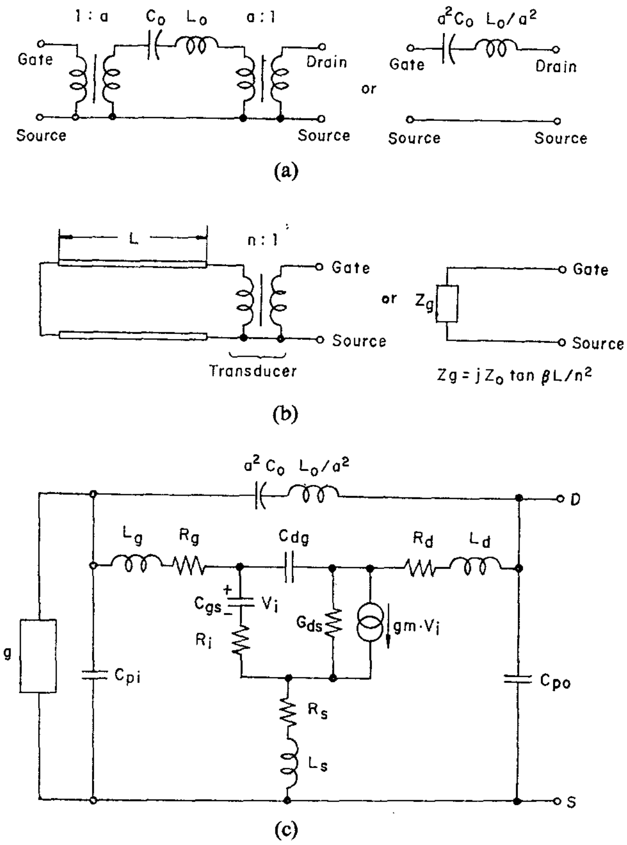

Fig. 9. Two-terminal device model. (a) Feedback structure approximation. (b) Gate terminating circuit approximation. (c) Overall equivalent circuit.

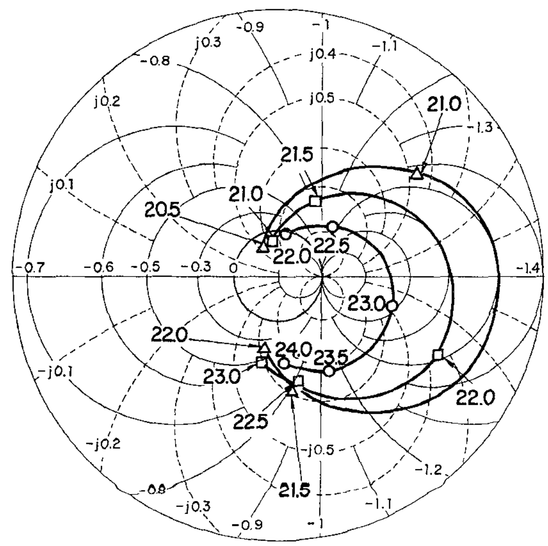

Fig. 10. Calculated impedance characteristics using the model of Fig. 9.

III. Discussions

A. Modeling

A model shown in Fig. 9 was constructed to estimate the impedance characteristics of the GaAs MESFET operated around 20 GHz as a two-terminal device in the waveguide mount. A lumped *LC* series resonant equivalent circuit of the ring resonator in the FET housing described above was used as the first approximation. Parameter "*a*," which stands for the coupling coefficient between the gate–drain and the ring resonator, was incorporated as shown in Fig. 9. The exact value of "*a*," together with values of *L* and *C*, coinciding with the physical structure, could not be determined in a simple form. So calculations were carried out for several combinations of *L*, *C*, and "*a*." Each combination of *L*, *C*, and "*a*" was assumed so as to give 20-GHz resonance frequency, which was roughly estimated from the assumption that the metallized ring structure mounted in the FET housing as in Fig. 2 works as a stripline-type ring resonator. Also, a lumped element equivalent circuit of the GaAs MESFET chip, which is valid at least up to 12 GHz, was used in the study. (Though some quantitative ambiguity remains to be studied, these assumptions could be accepted as the first approximations.) Fig. 9(c) shows the overall model used for the estimations of the impedance characteristics as a two-terminal device looking from the drain- source port.

B. Impedance Calculation

Fig. 10 shows the calculated impedance characteristics of the model as a function of frequency and with coupling factor "a" as a parameter. The result shows that negative resistance properties can be obtained in the frequency region above the resonance of the feedback structure. As the series resonant circuit, whose resonance is of the order of 20–30 GHz, can be easily realized by properly designing the package lid metallized portion and the FET housing structure, the above result indicates the feasibility of high-gain amplifier in the *Ka*-band.

IV. CONCLUSION

An experimentally developed reflection-type amplifier using the GaAs MESFET and some discussions using a simplified model have been described. While the quantitative justification of the lumped element approximation assumption used in the simulation model remains to be studied, the results show prospects for realization of a low-noise preamplifier with high gain using the state-of-the-art GaAs MESFET as a negative resistance two-terminal device in *Ka*-band, where conventional three-terminal operation encounters gain degradation problems.

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Performance of a Dual-Gate GaAs MESFET as a Frequency Multiplier at *Ku*-Band

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***Abstract*—The fabrication and characteristics of a dual-gate GaAs MESFET are briefly described. The feasibility of using a dual-gate GaAs MESFET as a novel frequency multiplier over *Ku*-band with good conversion gain is demonstrated. The multiplier achieved 8-dB conversion gain with frequency doubling at 12.6 GHz and 2.5-dB gain with frequency tripling at 12 GHz. In addition, it possessed a built-in control of conversion gain over a 36-dB dynamic range.**

I. INTRODUCTION

SINCE the advent of the dual-gate GaAs MESFET in 1971 [1], its applications have been successfully expanded into several areas, such as variable-gain microwave amplifiers [2]–[4], mixers with conversion gain [5], RF power limiters [6], phase-shift-keyed (PSK) modulators at subnanosecond rates [7], and low-noise operations [8]. Compared with its counterpart, the single-gate GaAs MESFET, this FET offers higher small-signal gain, better isolation [3], and inherently more nonlinear characteristics due to the addition of the second gate. Recently, further study concerning its nonlinear behavior has evolved a novel application for frequency multiplication [9].

The purpose of this paper is to demonstrate the feasibility of using a dual-gate GaAs MESFET as a frequency multiplier over *Ku*-band with good conversion gain. In addition, the fabrication and electrical characteristics of such a device are briefly described. Finally, the performance comparison between the single- and dual-gate MESFET multipliers will be discussed.

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