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S- and *X*-Band GaAs FET Mixers with Thin-Film Lumped Elements

HIROSHI OHNISHI AND SADAHIKO YAMASHITA, MEMBER, IEEE

***Abstract*—The design and performance of 2- and 11-GHz band mixers with a single-gate GaAs FET are presented in this paper.**

A mixer configuration in which the local oscillator (LO) signal is applied to the source is used. Matching networks are constructed with thin-film lumped elements fabricated on alumina.

An SSB noise figure of 6.2 dB, with an associated conversion gain of 10 dB, has been achieved at the 11-GHz band, and SSB noise figures of less than 6 dB and a conversion gain of more than 8 dB over a 40-percent bandwidth are obtained at the 2-GHz band.

I. Introduction

The operation and experimental results of GaAs MESFET's as microwave mixers have already been reported [1]–[3].

The performance of FET mixers has advantages in terms of conversion gain over Schottky-diode mixers, which makes the mixer nearly insensitive to the IF amplifier noise figure.

FET mixers have already been realized with single-gate or dual-gate FET's. In the dual-gate mixer configuration, the RF and local oscillator (LO) signals are applied to the first and second gate, respectively, offering a high degree of isolation between RF and LO ports.

Two single-gate FET mixer types have been reported. One type is a gate mixer in which the local signal is fed to the gate, and another type is a drain mixer in which the local signal is fed to the drain [3], [5].

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The authors are with the Matsushita Research Institute Tokyo, Inc., Higashimita, Tama-ku, Kawasaki, Japan. 214.

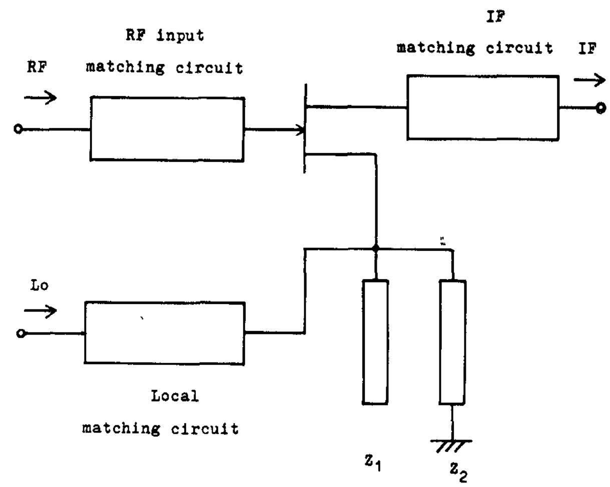

Fig. 1. FET mixer at the *X*-band.

In the case of single-gate FET mixers, one problem is the necessity of introducing both the local and RF input signals into the gate of the FET [2]. Since a coupler with a high coupling ratio is used to provide RF and LO signal isolation, the use of a high LO power level, therefore, is required.

This paper describes and provides performance data on a mixer circuit in which the RF signal is fed to the gate and the LO signal to the source.

The means of construction using a thin-film inductor and capacitor is discussed.

II. Design Principle

In order that a simple circuit can be realized, a single-gate FET mixer configuration has been adopted. The circuit diagram for an *X*-band circuit is shown in Fig. 1.

In the circuit, the LO signal of frequency F_L and the RF input signal of frequency F_{RF} are applied to the source and the gate of the FET, respectively, where mixing takes place in the FET by means of the nonlinearity of the transconductance and drain resistance of the FET.

The mixing product is the IF signal of frequency $|F_L - F_{RF}|$ which is amplified in the FET. The single-gate FET mixer has a simple structure, and does not require couplers or combiners.

To minimize the noise figure in single-gate *X*-band mixers, the RF input frequencies are terminated in a short circuit with a quarter-wavelength open stub (Z_1) at the source of the FET, and the drain is terminated in a short circuit at the RF input frequencies and local signal frequencies. To obtain low-noise performance of the IF amplifier and efficient injection of LO signal into the FET, the source is terminated in a quarter-wavelength short stub (Z_2) for local frequencies. Consequently, the impedance between the source and the common terminal is approximately shorted at the IF frequencies and open at the local frequencies.

Fig. 2 shows a circuit diagram designed for an *S*-band mixer. To obtain wide-band low-noise mixer performance, the source of the FET is terminated in a parallel circuit consisting of a resistor and a quarter-wavelength short stub in the highest local frequencies. Therefore, the impedance of the source at wide-band local

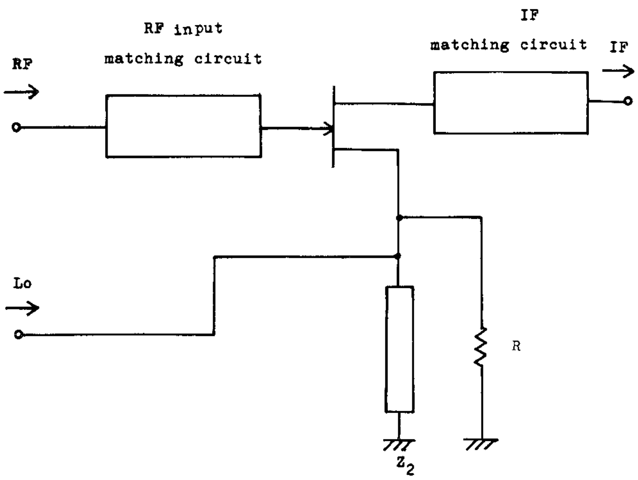

Fig. 2. FET mixer at the S-band.

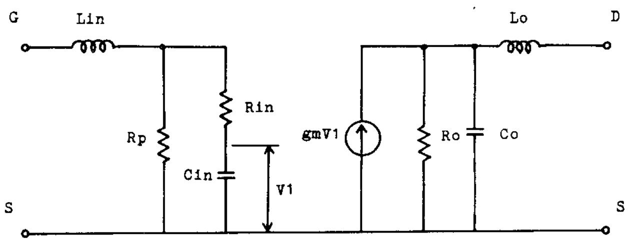

Fig. 3. Unilateral equivalent circuit for a packaged FET device.

signal frequencies is approximately resistive and the local signal is fed into the source of the FET efficiently. In addition, the FET can also operate as a low-noise IF amplifier.

Such a configuration of the FET mixer has an advantage in the independence between the RF signal port and a local signal port, with the result being that an RF input matching circuit can be designed without requiring the impedance of the LO port be taken into consideration.

III. Circuit Design

The unilateral equivalent circuit for a packaged device is shown in Fig. 3 [7]. The element values have been calculated from S-parameter measurements using computer optimization.

The element values obtained at the X-band for a 0.5-μm gate packaged device are as follows:

$$R_{in} = 10\ \Omega$$
$$R_p = \infty$$
$$C_{in} = 0.4\ \text{pF}$$
$$L_{in} = 0.44\ \text{nH}.$$

The element values at the output frequencies for the drain of the equivalent circuit are as follows:

$$R_o = 178\ \Omega$$
$$C_o = 0.4\ \text{pF}$$
$$L_o = 0.4\ \text{nH}.$$

The input and output matching circuits are independently designed, using the equivalent circuit.

Fig. 4. shows the RF input matching circuit for the gate and output matching circuit for the drain at the 11-GHz band for a

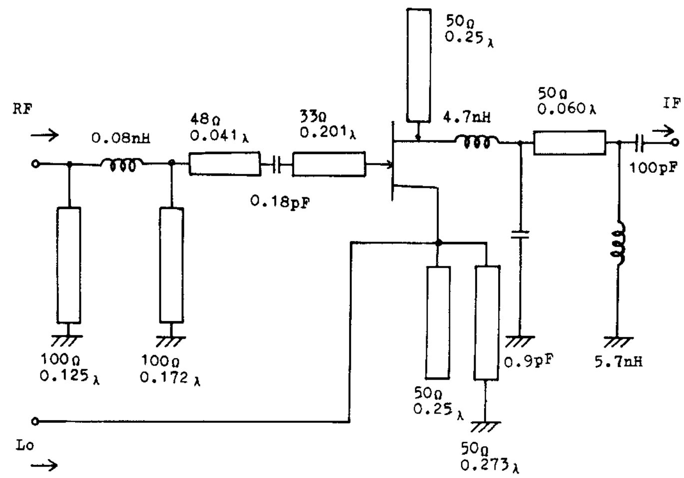

Fig. 4. Input and output matching circuits for 11-GHz band mixer. The transmission lines are defined by their characteristic impedances and lengths, which are expressed as fractions of a wavelength at 11.7 GHz.

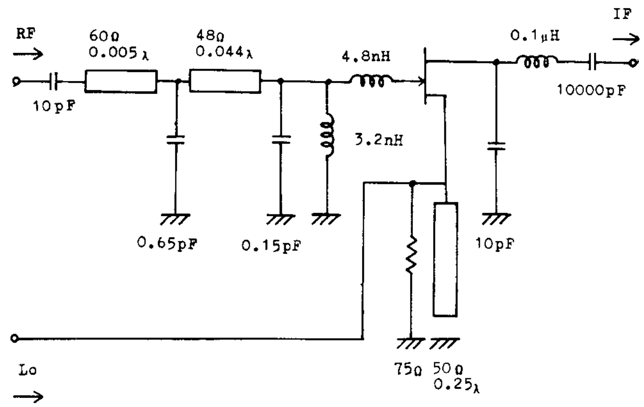

Fig. 5. Input and output matching circuit for a 2-GHz band mixer.

mixer with an IF frequency ranging from 800 to 1200 MHz. In order to provide low-noise mixer performance, the input matching circuit used is of the high-pass filter type, and consequently the gate of the FET is terminated in a short circuit at the IF frequencies. Fig. 5 shows the S-band mixer circuit. For wide-band operation of the mixer, a wide-band matching technique utilizing parallel L and C circuits is used. The element values of the equivalent circuit are optimized in the S-band with an 0.7-μm gate packaged device as follows:

$$R_{in} = 10\ \Omega$$
$$R_p = 400\ \Omega$$
$$C_{in} = 0.65\ \text{pF}$$
$$L_{in} = 0.55\ \text{nH}.$$

IV. Mixer Fabrication

The basic building block uses the circuits described in the previous sections. The 11-GHz band mixer and 2-GHz band mixer, with the exception of the IF matching circuit at 90 MHz, are shown in Figs. 6 and Fig. 7, respectively. These mixers are compact with substrate dimensions of 12×8 mm.

The circuits, with interdigital capacitors, meander line inductors, and transmission lines, are fabricated on 0.635-mm-thick alumina substrates. The substrates are soldered onto a ground plate, and the packaged FET device and RF bypass capacitors

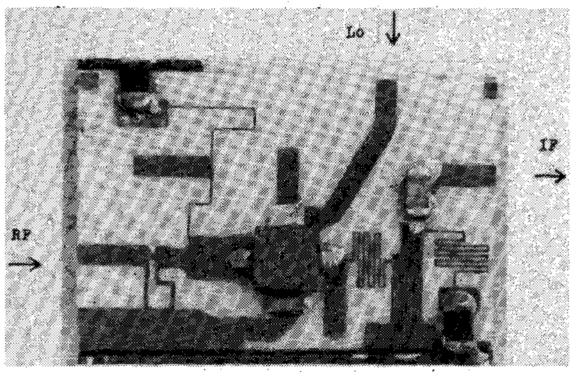

Fig. 6. An 11-GHz band mixer.

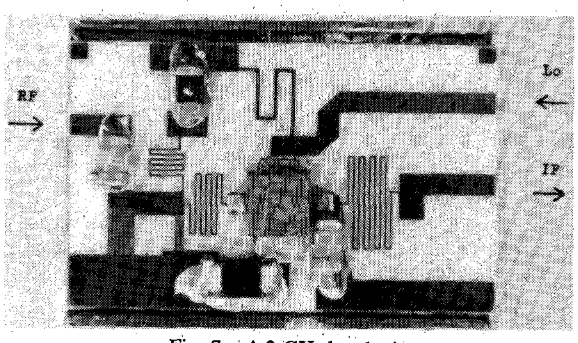

Fig. 7. A 2-GHz band mixer.

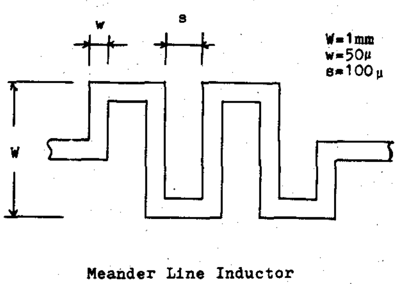

Fig. 8. An inductor pattern.

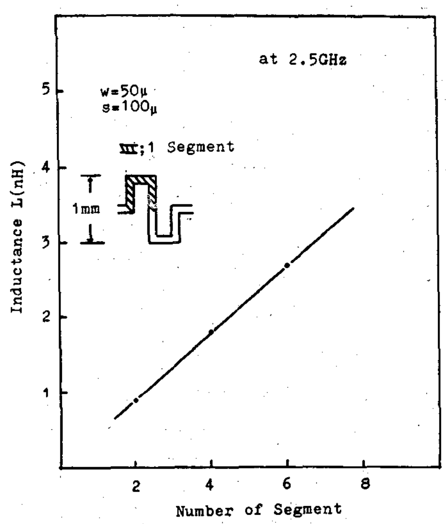

Fig. 9. Measured inductance.

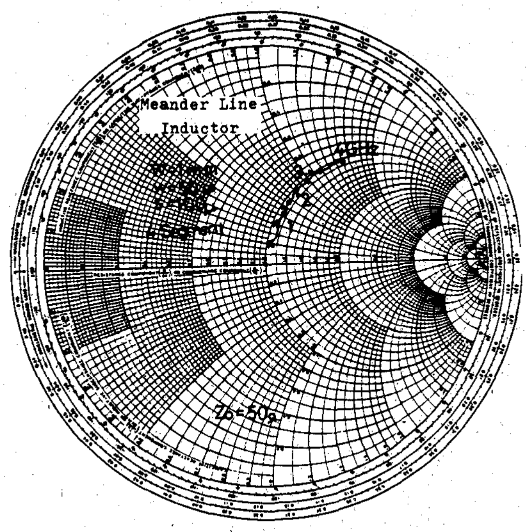

Fig. 10. Frequency locus of an inductance.

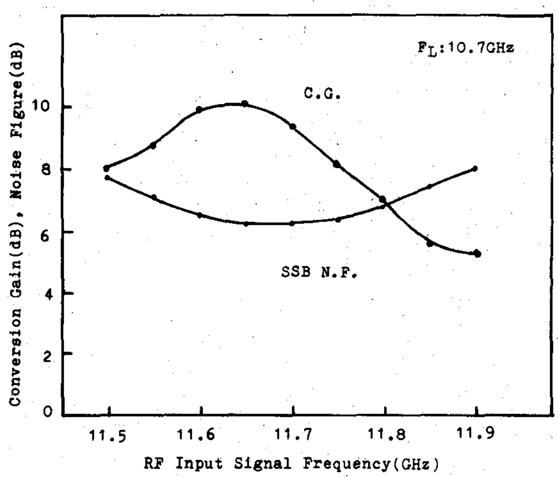

Fig. 11. Conversion gain and SSB noise figure of the 11-GHz band mixer.

are soldered onto the substrates. Fig. 8 illustrates the pattern of the meander line inductor. The inductor can be fabricated by a photoetching process after evaporating Cr–Cu metal on an alumina substrate. The line width is 50 μm and the gap is 100 μm. Fig. 9 shows the measured values of the inductor. The frequency characteristics, up to 4 GHz, are shown in Fig. 10 in the form of a Smith chart. The inductor size must be less than a small fraction of a wavelength (λ), approximately $\lambda/20$.

V. Mixer Performance

A. X-Band Mixer

Fig. 11 shows the conversion gain and SSB noise figure of the *X*-band FET mixer using a 0.5-μm gate packaged device with no LO port matching. The circuit operates with an 11-GHz band signal source and 1-GHz band IF output at a LO signal frequency of 10.7 GHz and a power level of 8 dBm.

A minimum noise figure of 6.2 dB, with an associated conversion gain of 10 dB, are obtained at an RF input signal frequency of 11.65 GHz. From 11.5–11.9 GHz, an SSB noise figure of 7.1 ± 0.9 dB is obtained, at a drain current of 4 mA.

Fig. 12 shows the image rejection ratio, which registers values of greater than 12 dB for the designed band. Image rejection is achieved by an input matching network and a quarter-wavelength

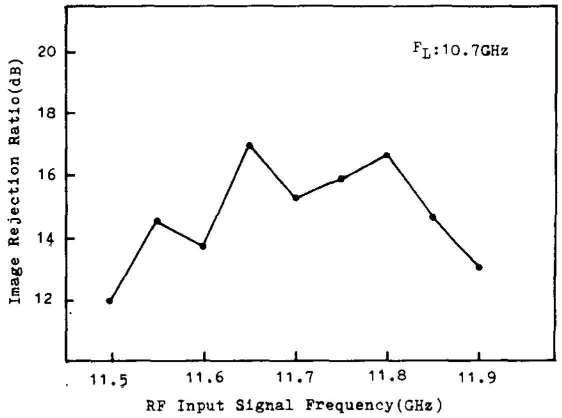

Fig. 12. Image rejection ratio versus frequency.

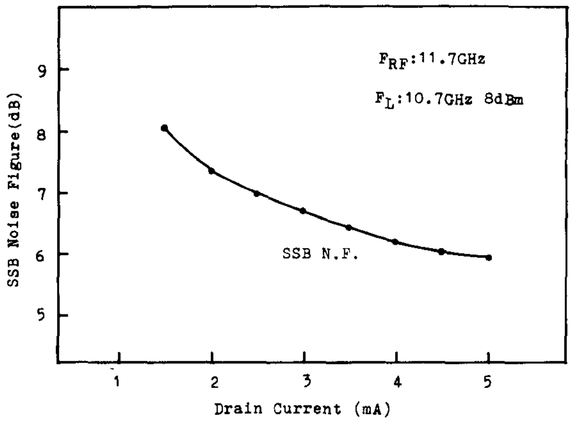

Fig. 13. SSB noise figure versus drain current for the 11-GHz band FET mixer.

open stub in RF input frequencies at the source of the FET. Fig. 13 shows the relationship between the noise figure and the drain current at a LO signal power of 8 dBm. At a drain current of 5 mA, a minimum SSB noise figure of 5.9 dB is obtained.

B. S-Band Mixer

Fig. 14 shows the conversion gain and SSB noise figure of the *S*-band FET mixer using a 0.7-μm gate packaged device. SSB noise figures of less than 6 dB, and a conversion gain of more than 8 dB, have been achieved over RF input frequencies ranging from 2–3 GHz at an IF frequency of 90 MHz. A minimum noise figure of 5.0 dB associated with a conversion gain of 9.5 dB is obtained.

VI. Conclusion

A simple circuit configuration of a mixer for a single-gate GaAs FET is presented. Compact GaAs FET mixers at *S*- and *X*-bands can be achieved using thin-film lumped elements of

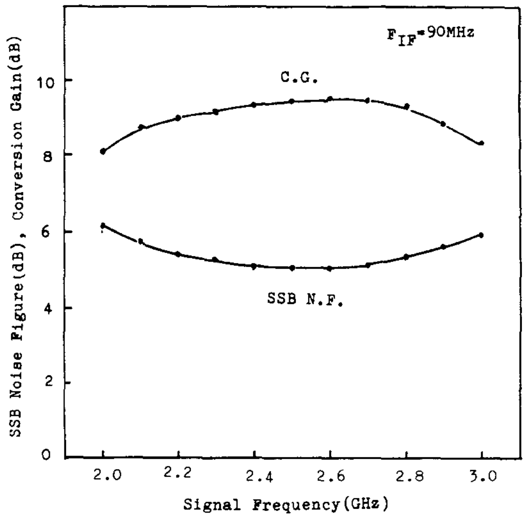

Fig. 14. Conversion gain and SSB noise figure of the 2-GHz band FET mixer

interdigital capacitors and meander line inductors. The following performance values were obtained:

1) an SSB noise figure of 6.2 dB and conversion gain of 10.0 dB at *X*-band, and

2) at *S*-band, an SSB noise figure of 5.0 dB and conversion gain of 9.5 dB.

It is considerated that this mixer is useful for the compact design of a microwave receiver front end.

Acknowledgment

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