AN EXPERIMENTAL EVALUATION OF X-BAND GaAs FET MIXERS USING SINGLE AND DUAL-GATE DEVICES

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Abstract

Experimental results are presented for X-band GaAs FET mixers.

Two circuits using commercially available single-gate devices have yielded good conversion gains at 10 GHz, and a specially developed dual-gate device in a simple microwave circuit has yielded 11 dB conversion gain and 6.5 dB noise figure (D.S.B.), at 10 GHz.

Introduction

The use of a GaAs FET as a microwave mixer which can combine low noise performance and conversion gain has been an attractive possibility since the first appearance of the device. Unlike low-noise amplifier applications, however, the FET mixer has a well established solid-state competitor in the Schottky diode mixer, which forms a standard against which results must be compared. It is important, however, in making such comparisons of electrical performance, that due account is taken of other factors such as circuit complexity and size.

This paper will begin with an assessment of suitable devices and circuit configurations for mixer applications, and then present experimental results from different circuit configurations using commercially available 1 micron single-gate devices. A dual-gate 1 micron FET will then be described, which has been specifically developed for mixer applications. Experimental results are presented for this device in a simple microwave circuit which has yielded 11 dB conversion gain with an associated DSB noise figure of 6.5 dB at 10 GHz, using a 30 MHz I.F.

Device Selection

In order to use a FET as a mixing element, it is necessary to cause the local oscillator signal to modulate the transconductance in a linear manner and with the greatest possible swing. Early FET devices, which were fabricated on unbuffered epilayers, had a substantial square-law region, over which the transconductance varied in a linear manner, over a significant range (fig. 1a). These devices had poor noise and gain characteristics, however, and it has been shown[1] that much improved performance can be obtained using devices fabricated on material with a semi-insulating buffer layer, with an abrupt transition to the n-type active layer. These devices have a distinctive D.C. characteristic, in which the transconductance remains nearly constant with applied gate voltage right down to pinch-off, as shown in fig. 1b. However, it is clear that these devices would give poor mixer conversion gain, unless operated in a 'switching' mode, whereby the device is D.C. biased to a point near, or just beyond, pinch-off, and the local oscillator voltage swings the operating point into the constant transconductance region.

Such a 'switching mode' mixer suffers from the drawback that the transconductance variation with time is non-sinusoidal, and ideal second order mixing is not achievable. The dual-gate device, described in a later section, offers a way of utilising the desirable low-noise properties of a device displaying this very linear gm characteristic, without need to operate in a switching mode, thereby reducing local oscillator power requirements and improving both noise performance and mixing linearity.

Single Gate Mixer Circuits

The initial problem in designing a mixer circuit around a single gate device is the requirement to excite the gate with both signal and local oscillator voltages. One convenient way to overcome this problem is to use a balanced arrangement, as shown in Fig. 2. The 90° 3 dB hybrid was of the interdigital Lange type, which had been previously developed for balanced amplifier applications. The I.F. signals appearing in the drain circuits are in antiphase, and were combined using a centre-tapped tuned transformer with a bifilar wound primary. Fig. 3 shows a picture of the practical circuit, which used commercial Plessey GAT5 devices. The low-pass filters in the drain circuit were realised with networks of high impedance lines and circular capacitive elements. The signal frequencies at the drain were terminated with a 50 ohm load in an attempt to improve overall stability. The correct terminations of the devices at signal frequencies has been found to be a critical factor in achieving good mixer performance.

All results to date have been obtained using an I.F. of 30 MHz, since this appears to be the most useful in potential systems applications. Similar circuits are, however, being constructed for a 1 GHz I.F., in an attempt to resolve the question as to whether I/F noise at 30 MHz causes degraded noise figure performance from FET mixers, as suggested by other works.[2,3]

The circuit shown in Fig. 3 has given 6 dB of conversion gain with a signal frequency of 10 GHz, using simple 'disc' tuning on the input lines to achieve a good match at the signal frequency. The associated noise figure was 8.5 dB (D.S.B.) which includes a contribution from a 3 dB noise figure I.F. amplifier. These results were obtained using 10 dBm L.O. power, obtained from a Gunn diode source.

An alternative circuit has also been evaluated in which two devices are connected in series, L.O. power being applied to one gate and signal to the other. This arrangement has yielded high conversion gains (12 dB at 10 GHz) but inferior noise figures (14 dB).

Dual-Gate FET

Fig. 4 shows the structure of a new Plessey dual-gate GaAs FET. The structure of source and drain is similar to that of the GAT4/5 series, but the source drain spacing has been increased to allow two 1 micron gates to be deposited over the channel region. The bonding pads for the two gates are in a convenient symmetrical arrangement.

The action of a second gate is to control the transconductance of the first gate, and D.C. characteristics of this device shown that this variation is linear over nearly the whole range of gm.

Thus by applying a local oscillator signal to the second gate, which is D.C. biased to a mid-point in the gm range, very linear mixing action can be obtained. (Fig. 5).

A 10 GHz Dual-gate FET mixer has been evaluated experimentally, using a very simple microwave circuit, with matching at each gate input, and a similar LPF arrangement in the drain as used in the single-gate circuits, with the exception that no bifilar transformer is necessary (Fig. 6). This circuit has given 11 dB of conversion gain, with 6.5 dB noise figure (DSB). L.O. power was 10 mW.

The simplicity and compactness of the circuit are particularly significant, since to obtain a comparable noise figure using a Schottky diode mixer would usually require a complicated double-balanced arrangement, using several hybrids.

An image concellation circuit is presently being constructed, using two dual-gate FETs, which will hopefully give a significant improvement in performance.

Measurements of dynamic range and intermodulation performance for the dual-gate mixer compare very favourably with Schottky diode mixers.

Conclusions

In this paper, it is shown that modern low-noise single-gate FETs are not well suited to mixer applications unless used in switching mode circuits. Two such circuits have yielded good conversion gains at 10 GHz, but the best results have been obtained from a dual-gate 1 micron device which has been developed for mixer applications. This device, in a simple microwave circuit, has given considerably better conversion gain and noise figure at 10 GHz than any other GaAs FET mixer results reported to date.

References

1. R.S. Butlin, et al., Proc. 1976 European. Microw. Conf., p606.

2. Pucel et al., IEEE Trans., MTT-24, p351, 1976.

3. B. Loriou, J.C. Leost, Elect. Lett., 12, p373, 1976.

FIG. 1

GaAs F.E.T. TRANSFER CHARACTERISTICS

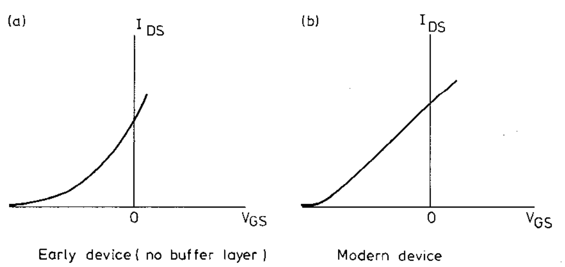


FIG. 2

BALANCED F.E.T. MIXER.

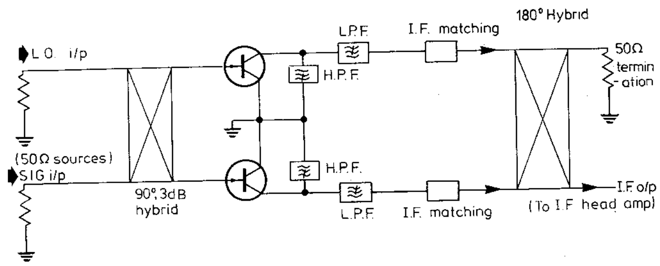


FIG. 3

DUAL-GATE MIXER CIRCUIT

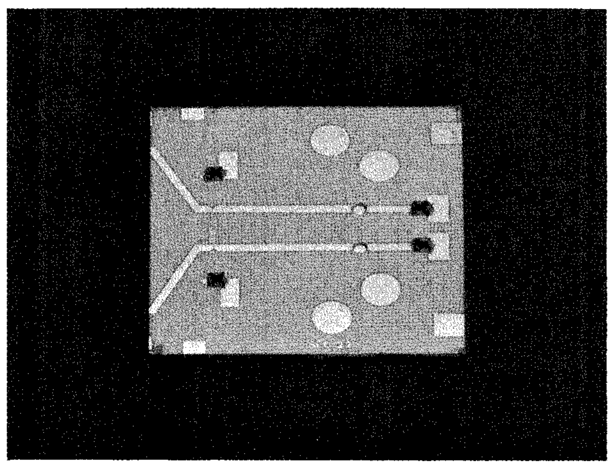


FIG 4

PLESSEY DUAL GATE DEVICE

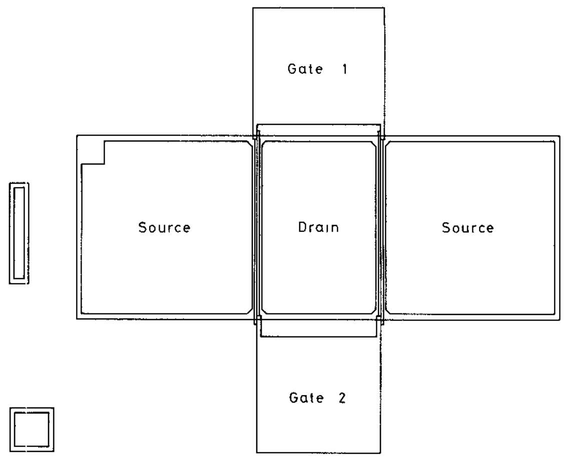
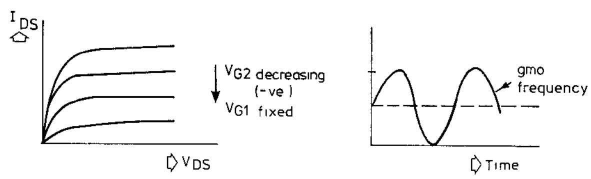


FIG 5

DUAL GATE FET



(a) Dual gate FET D.C. characteristics

(b) Modulation of signal-gate gm by local oscillator voltage on gate 2

FIG 6

DUAL-GATE FET. MIXER