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A DISTRIBUTED 1-12 GHz DUAL-GATE FET MIXER

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ABSTRACT

A novel broadband mixer topology, which can be implemented using either monolithic or discrete microwave integrated circuit methods, has been developed using distributed design techniques. The mixer exhibits excellent conversion gain and frequency response characteristics with signal handling capabilities and LO drive requirements similar to conventional diode double-balanced mixers.

INTRODUCTION

In recent years the need has developed for extremely compact, wideband microwave mixers which have reproducible performance for amplitude/phase tracking systems. A hybrid or monolithic mixer, using GaAs FETs as the mixing elements, would achieve this goal. The distributed mixer offers wideband performance with low VSWR and flat conversion gain characteristics.

THEORY OF OPERATION

The distributed, or traveling-wave mixer uses the same techniques developed for distributed amplification. The distributed amplifier uses the input capacitance of the FET (Cgs) to construct a low pass filter with lengths of transmission line forming the series inductance. Several FETs can be cascaded in this manner, and the input and output lines are terminated by resistors equal to the characteristic impedance of the L-C transmission line. The drain node of the FETs contain an extra series transmission line to adjust the output phase shift between FET stages to equal the input phase shift. By achieving equal phase shift between the FETs on the input and output lines, the gain contribution of each FET is summed in phase along the output line. The input and output VSWRs are low over an extremely broad bandwidth with this configuration. Several distributed amplifiers have been built using monolithic techniques and exhibited excellent performance (1, 2, 3).

The wideband distributed mixer requires two broadband inputs for the LO and RF sources. These two signals can be combined into the same input by using an external coupler as was done by Tang and Aitchison (4). This approach is not practical in many systems because the size of the broadband coupler outweighs any size reduction obtained by the mixer. This approach also requires more LO power to overcome coupling losses and exhibits degraded LO to RF isolation performance compared to other designs.

As an alternate approach, dual-gate FETs can be used with the RF input coupled to gate 1 and the LO input coupled to gate 2 as shown in Figure 1. Using dual-gate FETs as the active device allows independent matching of the LO and RF ports and achieves isolation between RF and LO signals. The two gate inputs on the dual-gate device allow two L-C transmission lines to be formed to provide the broadband matched inputs for the LO and RF signals. These transmission lines must have equal phase shifts between the FET stages when the mixer is operating as a downconverter with a low IF frequency. Equal phase shifts yields a constant phase offset at the IF frequency which allows the IF power to be summed by connecting the drain node of the dual-gate FETs together. Higher IF frequencies, or use of this mixer as an upconverter, would require that the drains of the FETs also be connected with a traveling-wave structure.

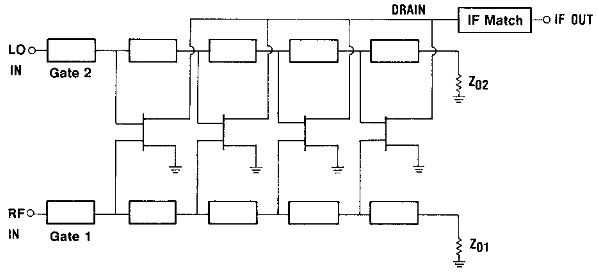


Figure 1. Schematic diagram of a four stage distributed mixer using dual-gate GaAs FETs.

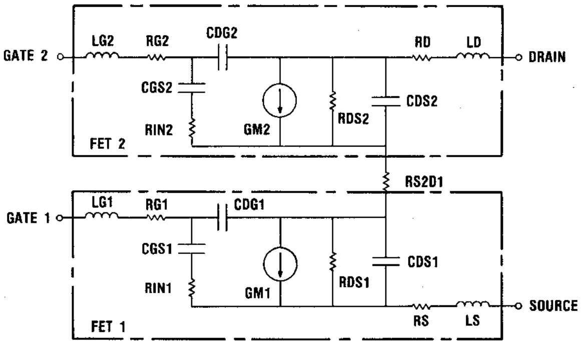
A variety of design considerations were analyzed which affect the bandwidth and conversion gain of the mixer. Some of these considerations were:

1. Number of FETs - cascading more FETs will increase the conversion gain but sacrifice bandwidth by lowering the

cutoff frequency of the low pass input structure,

2. Size of the FET - the gate width of the FET (along with the DC bias voltage) determines the shunt capacitance of the low pass line and therefore the cutoff frequency of the mixer,
3. Gate resistance - the gate resistance of the FET causes signal loss as the wave propagates down the line; hence, a point is reached where adding another FET yields an incremental loss rather than gain,
4. LO power - the LO drive level needed to achieve the same conversion gain is proportional to gate width.

After analysis of these variables, four dual-gate 150 μm GaAs FETs with gate lengths of 0.5 μm were used in the design of the distributed mixer. The small-signal equivalent model of this FET is shown in Figure 2.



CGS1 : 0.22 pF
CGS2 : 0.33 pF
CDS1 : 0.04 pF
CDS2 : 0.09 pF
CDG1 : 0.015 pF
CDG2 : 0.015 pF
RG1 : 4.6 Ω
RG2 : 4.6 Ω
RIN1 : 3.0 Ω
RIN2 : 3.0 Ω
RDS1 : 210 Ω
RDS2 : 980 Ω
GM1 : 8.5 mS
GM2 : 15 mS
LG1 : 0.06 nH
LG2 : 0.06 nH
RS : 2.2 Ω
RD : 2.3 Ω
LS : 0.015 nH
LD : 0.03 nH
RS2D1 : 3.3 Ω

Figure 2. Small-signal equivalent model of a 150 μm dual-gate GaAs FET with 0.5 μm gate lengths.

The circuit was designed using both linear and nonlinear analysis programs. A commercially available, linear analysis program was used to optimize the two gate input structures. A major design goal was to equalize the voltages seen at the gate of each FET in order to achieve efficient mixing action. After the RF input line was modeled, the phase shift between FETs on the LO line was matched to the RF line. A modified version of the nonlinear analysis program described in (5) by Peterson et al., has been developed which describes dual-gate FETs. The inputs to the program include the small-signal model and the I-V curves shown in Figure 3. This program was used to predict the performance of the FET as a mixing element and to determine the optimum bias condition. The DC bias voltage on gate 2 of the dual-gate FET strongly influences the conversion efficiency of the mixer. As shown in Figure 4, the optimum bias point for gate 2 is approximately -0.5 volts. This bias point places the FET near the low noise mixer operating region as defined by C. Tsironis, et al. (6).

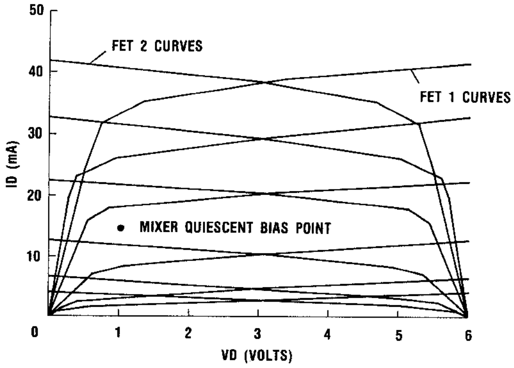


Figure 3. I-V transfer characteristics of a 150 μm dual-gate FET.

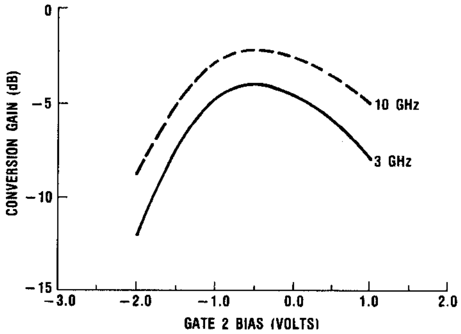


Figure 4. Conversion gain of the distributed mixer as a function of gate 2 bias.

CONSTRUCTION

The assembled hybrid mixer, shown in Figure 5, was constructed on .38 mm thick alumina substrate with thin-film tantalum nitride resistors using four discrete 150 by 0.5 μm FETs. Bond wires were used to attach the 150 μm FET gate inputs to the transmission lines and their drain outputs to the output line. No attempt was made to match the drain port at the low IF frequencies.

RESULTS

The mixer exhibited excellent conversion gain of -1 dB ± 1 dB over the 1 to 12 GHz band as shown in Figure 6 with an IF frequency of 400 MHz and the LO level of 11 dBm. The four FET mixer was analyzed using the nonlinear program described above to predict the conversion gain shown. With reactive IF matching at the drain port the conversion could be increased by 7 dB as indicated in this figure. The input return loss of the RF port is better than -10 dB across the 1 to 12 GHz band (Figure 7). Above 12 GHz the bond wires introduce excessive inductance and cause a reduction in mixer bandwidth. The conversion gain versus local oscillator power, as seen in Figure 8, indicates that LO drive levels above 13 dBm do not contribute much to increased conversion gain. As shown in Figure 9, the conversion gain, as a function of IF frequency, is flat out to 2 GHz when the IF port is terminated in 50 ohms. The conversion gain as a function of RF signal applied is shown in Figure 10 with an indicated 1 dB compression point of 8 dBm at an RF frequency of 3 GHz. The measured two-tone third-order intercept point was 12 dBm which is comparable to a four diode mixer with a similar amount of LO drive power.

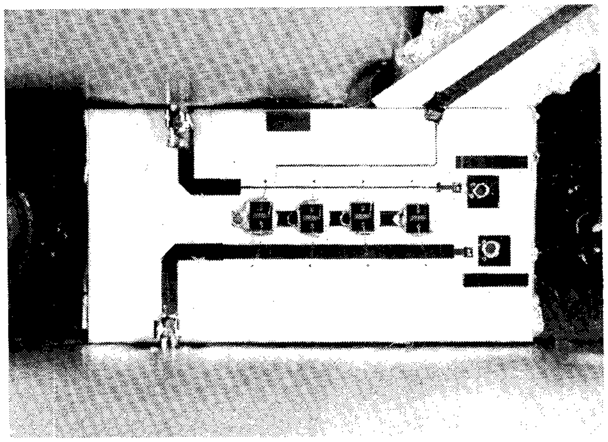


Figure 5. Photograph of assembled four stage distributed mixer.

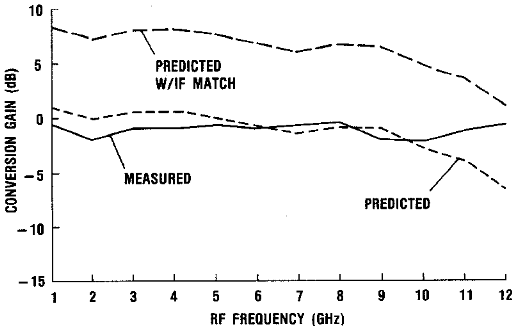


Figure 6. Conversion gain of the mixer.

CONCLUSION

A hybrid distributed mixer was developed which obtained -1 dB conversion gain and excellent input return loss throughout the 1 to 12 GHz frequency range with moderate LO power. The design is very compact and is suitable for monolithic implementation.

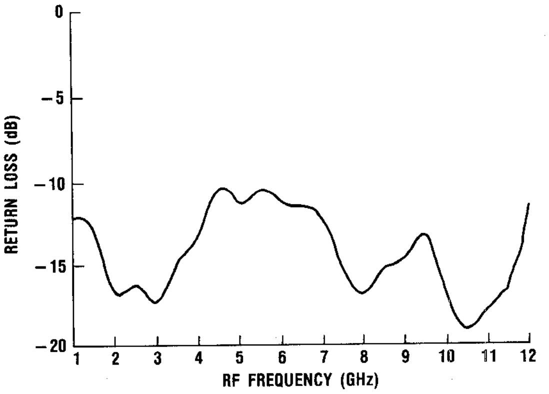


Figure 7. RF port input return loss.

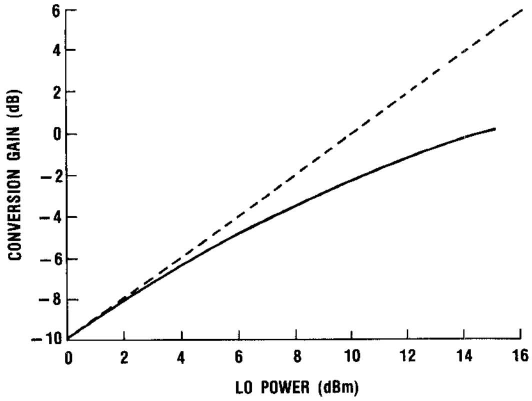


Figure 8. Mixer conversion gain as a function of applied LO power.

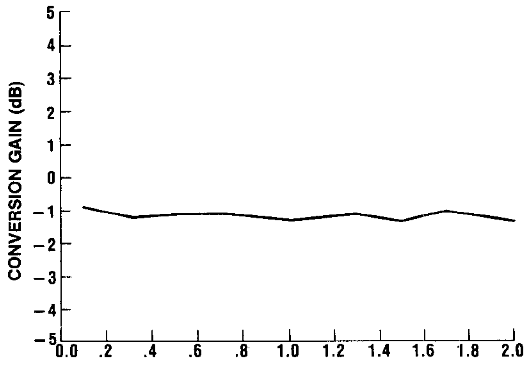


Figure 9. Conversion gain of the mixer over a 2 GHz IF band.

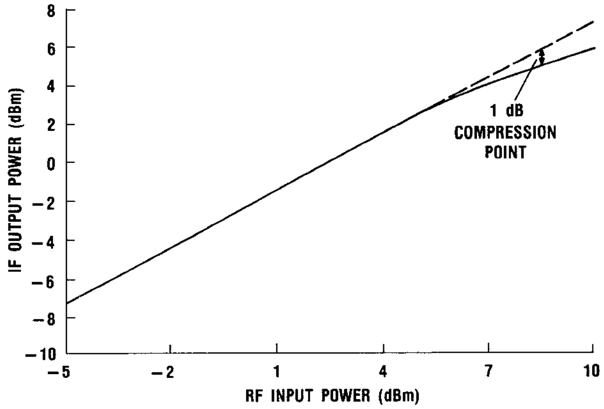


Figure 10. Compression of the IF output at 3 GHz.

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