STATE OF THE ART S-BAND RESISTIVE FET MIXER DESIGN

Matthew M. Radmanesh*
Nader A. Barakat**

*California State University, Northridge, CA
Department of Electrical and Computer Engineering
&
**California Amplifier, Inc., Camarillo, CA

ABSTRACT

The design of an S-band resistive MESFET mixer is presented. Contrary to other types of mixers where the predominant mixing element is a nonlinear device parameter, resistive FET mixers utilize the linear resistive channel of a device as the mixing element.

The intermediate frequency(IF) is extracted at the drain with adequate filtering and impedance matching. With proper termination of all three ports of the device, an overall superior mixer performance was achieved compared to the Schottky barrier diode mixer. This state-of-the-art S-band resistive FET mixer with its low noise and high dynamic range finds wide applications in the wireless TV industry.

INTRODUCTION

In today's modern communication systems, the performance of receivers rely heavily on the mixer operation in terms of its conversion loss(gain), noise figure, port-to-port isolation, port matching and most importantly dynamic range. The inherent nonlinear characteristics of most frequency mixing elements such as the popular Schottky barrier diode produces a number of signals harmonically related to a specific input signal in the presence of a strong local oscillator(LO) signal. Except for the desired down converted IF frequency which is the difference between an incoming small signal and the LO frequency, all other harmonics and spurious products are undesired intermodulation distortion (IMD) output. These products can degrade the overall performance of the system. Most important of these distortion signals are the two-tone third order intermodulation products [1-6].

The need for a low noise, high dynamic range mixer to be used in an S-band downconverter for the wireless TV industry recognized as Multichannel microwave distribution systems(MMDS) is well known. Mixers which would downconvert an input radio frequency(RF) band to a lower IF band when mixed with a fixed LO frequency have been investigated in literature[7,8]. Our present work constitutes a major improvement in the performance of resistive FET mixers and contributes greatly to the state-of-the-art of these mixers.

In this paper a novel design of an S-band resistive FET mixer is presented. Theory and design considerations of a resistive FET mixer, along with experimental work, comparative analysis and a brief conclusion is delineated in the following sections.

MIXER ANALYSIS

The Schottky barrier diode has been used in most microwave mixers. However, its highly nonlinear junction conductance yields a relatively poor performance in spurious signal and intermodulation(IM) products. In order to optimize these parameters , designers have opted to increase the LO power. Increasing the LO power beyond an optimum level usually increases mixer noise figure [9]. Other methods employed to improve the intermodulation performance took on the use of single and double balanced configuration approach [10].

The GaAs MESFET transistor when biased at a very low or no drain voltage is said to be operating in its linear or triode region of the DC I-V curve. This region is also called the ohmic or resistive region because of its linear characteristics as a function of the applied voltage [11]. The FET channel resistance can be varied from almost an open impedance to a low impedance of a few ohms. This can easily be achieved by varying the gate bias from below the pinch-off voltage to a slightly positive value. Figure 1 shows the linear region of the DC I-V characteristics of an NEC,NE72084, GaAs MESFET simulated on the nonlinear "LIBRA" CAD program [12]. The switching voltage mechanism is provided by a rela-

CH3389-4/94/0000-1435$01.00 © 1994 IEEE

1994 IEEE MTT-S Digest

tively large LO signal applied to the gate of the FET in conjunction with a fixed negative DC bias.

The small RF signal is applied to the drain with adequate port matching for maximum power transfer thus enabling good conversion loss and noise figure. The IF signal is filtered at the drain with proper diplexing of both RF and IF signals for an optimum mixer performance of minimum conversion loss and respectable port-to-port isolation.

The device in this linear mode is operated in its common source configuration where the source is grounded. An equivalent circuit of the GaAs MESFET can be derived under this bias condition [5]. Figure 2a shows the FET mixer circuit block diagram. Figure 2b shows the device model, where Rg, Rs and Rd are the gate, source and drain ohmic contact resistances respectively.

EXPERIMENTAL RESULTS

The design of the resistive FET mixer was subdivided into several stages where important decisions such as device selection, nonlinear device models and proper circuit configuration had to be made. Following that and using mixer CAD simulation techniques, the final circuit parameters and element values were obtained and subsequently the circuit was fabricated. The FET mixer circuit layout is shown in figure 3.

The designed circuit is an S-band mixer downconverter where the LO frequency is at 2.3 GHz, the RF bandwidth is at 2.5-2.7 GHz, and the resulting IF bandwidth is 0.2-0.4 GHz. Several performance evaluation tests were performed. These tests included RF BPF test, port match test, noise figure evaluation, IMD evaluation & port isolation test, image rejection test and finally conversion loss test which is tabulated in table 1. The results of these tests are shown in figure 4.

Further experimental work was carried out which clearly demonstrated superior performance of this mixer circuit. The designed mixer circuit finds wide applications in the wireless TV industry where the demands for low noise and large handling of multichannel loads are great.

COMPARATIVE ANALYSIS

This work delineated a FET mixer design approach utilizing an unbiased drain-source channel of a GaAs MESFET device. The nonlinear channel resistance causes frequency mixing in the device. Because of its resistive switching nature, this FET mixer is reasonably lossy. However it possesses a superior IM distortion response. In contrast, a Schottky barrier diode mixer has a highly nonlinear junction conductance which causes a poor IM distortion response.

For comparison, a single balanced(SB) Schottky barrier diode mixer with the same RF and LO frequency bands was also fabricated. In this circuit, the RF & LO signals were combined using a two-section branch line quadrature hybrid. An identical series of performance tests were carried out. A summary of the test results of the diode mixer compared with that of the resistive MESFET mixer is shown in table 2. Also included in this table is the measured data of a commercially available Watkins-Johnson double-balanced mixer (WJ-M1G).

From this table, it is worth noting that the input 1-dB compression point(CP) of the resistive FET mixer is +4 dB higher than the LO power required; whereas the diode mixer 1-dB CP is -8 dB lower. Also the output third order intercept(TOI) point of the FET mixer is noticeably higher (by +8 dBm) than that of the diode mixer. The superiority of the FET mixer conversion loss and noise figure is also evident. The FET mixer, unlike the Schottky barrier diode mixer has noise figure that is almost equal to the conversion loss. This is an evidence of almost purely thermal noise source dominance in the FET mixer noise figure. In short, the resistive FET mixer clearly outperforms its Schottky barrier diode counterpart by a good margin and with less LO power.

CONCLUSIONS

State-of-the-art linear and nonlinear Computer Aided design (CAD) software was used to simulate and optimize the design of the mixer. A prototype circuit was fabricated and tested to evaluate theoretical as well as simulated results. Good agreement between mixer's simulation and experimental results was demonstrated.

A MESFET resistive mixer with a conversion loss of 9 dB (including an RF bandpass filter), a 1-dB input compression point of +12 dBm and an output third order intercept point of +18 dBm has been achieved. This FET mixer was found to be superior to the Schottky barrier diode single-balanced mixer.

REFERENCES

[1] S.A. Maas,"A Low Distortion GaAs MESFET Resistive Mixer," Microwave Journal, pp.213-220

[2] S.A. Maas,"A GaAs MESFET Balanced Mixer with Very Low Intermodulation," IEEE MTT-S Digest, Vol. 11, pp. 895-898, 1987.

[3] S.A. Maas,"A GaAs MESFET Mixer with Very Low Intermodulation," IEEE Trans. MW Theory & Tech.,Vol.35,No.4,pp.425-429,1987.

[4] K.W. Chang,et al,"Zero Bias GaAs MESFET Mixers,"IEEE MTT-S Digest,pp.1027-1030,1989.

[5] R.S. Tucker,"Third Order Intermodulation Distortion and Gain Compression in GaAs FETs," IEEE Trans. Microwave Theory & tech., Vol. 27, pp.400-408 May 1979.

[6] S. Weiner, et al,"2 to 8 GHz Double Balanced MESFET Mixer with +30 dBm Input 3rd Order Intercept," IEEE MTT-S Digest,Vol. 11, pp. 1097-1100, 1988.

[7] M. Sango, et al,"A GaAs MESFET Large-Signal Circuit Model for Nonlinear Analysis," IEEE MTT-S Digest, pp. 1053-1056, 1988.

[8] W.R. Curtice,"GaAs MESFET Modeling and Nonlinear CAD," IEEE Trans. Microwave Theory & Tech., Vol. 36, pp.220-230, Feb. 1988.

[9] R.J. Trew,"MESFET Models for Microwave Computer Aided Design," Microwave Journal, pp.164-171, May 1990.

[10] George Vendelin, et al, Microwave Circuit Design, using Linear and Nonlinear Techniques, John Wiley, 1990.

[11] R. Kruse,"Microwave Design Using Standard SPICE," Microwave Journal, pp.164-171,Nov. 1988

[12] W.R. Curtice,"Nonlinear of GaAs MESFET Amplifiers, Mixers, and Distributed Amplifiers Using the Harmonic Balance Technique," IEEE Trans. Microwave Theory & Tech.,Vol. 35, No. 4,pp.441-447, April 1987.

Table 1. FET mixer conversion loss as a function of V_{GS} and LO power.

RF Freq. (GHz)	IF Freq. (GHz)	Conversion Loss (dB) At +8 dBm LO Power		
		VGS= -0.5V	VGS= -1.0V	VGS = -1.5V
2.5	0.2	9.8	9.0	10.0
2.6	0.3	9.5	8.8	10.2
2.7	0.4	10.8	9.2	11.5

Table 2. FET mixer parameter comparison with a single balanced diode mixer and a WJ-M1G Watkins-Johnson mixer.

Mixer Type	Lo power (dBm)	Conversion Loss (dB)	N.F (dB)	Pin@ 1dB CP(dBm)	IP3O (dBm)
MESFET Mixer	+8	9	9.2	+12	+18
SB Diode Mixer	+13	10.5	11.0	+5	+10
WJ-M1G	+8	9	9.5	+3	+6

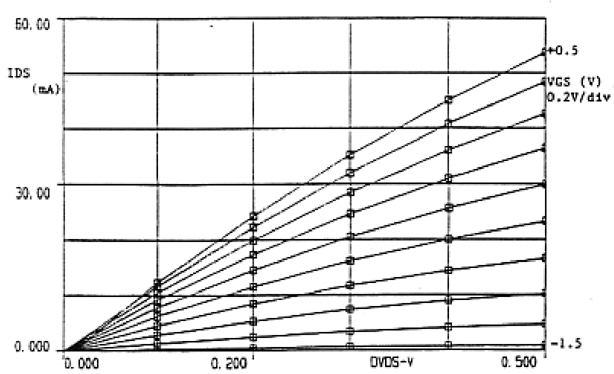
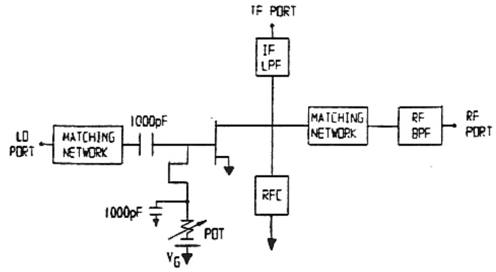


Figure 1. Linear Region of NE72084 GaAs MESFET DC I-V Curves Simulated using LIBRA



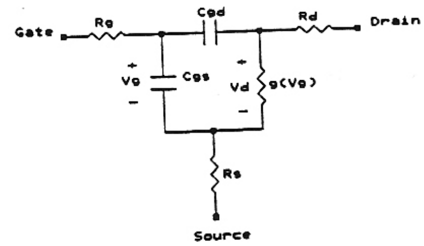


Figure 2a. FET Mixer Circuit Block Diagram **Figure 2b Equivalent Circuit of a GaAs MESFET Operated at Zero DC Drain Voltage**

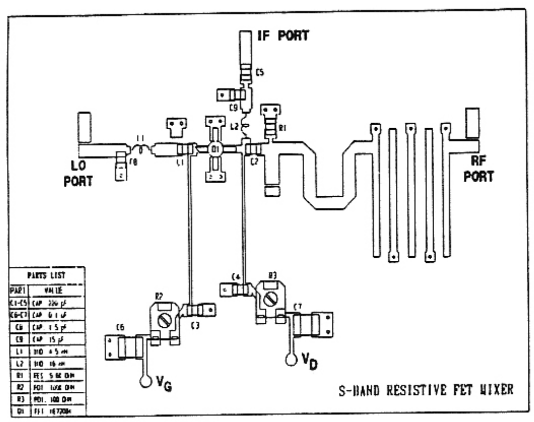


Figure 3. FET Mixer layout

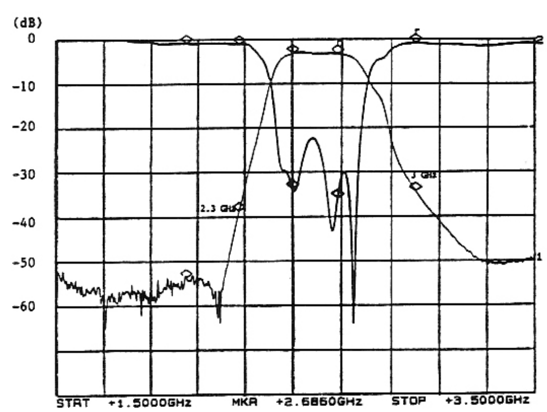


Figure 4. RF BPF Insertion Loss and Return Loss Measurement.