PERFORMANCE OF A 2-18 GHz ULTRA LOW-NOISE AMPLIFIER MODULE

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Abstract: The performance of two-tier matrix amplifiers optimized for best noise figure across the 2-18 GHz band will be discussed. An average noise figure of NF = 2.95 dB with an associated average gain of G = 19.2 dB has been measured in a single-stage module using MESFET's.

I. INTRODUCTION

The noise performance of an amplifier can be improved by optimizing its circuit parameters to achieve the lowest possible noise figure across a given bandwidth. This optimization process, however, results in a degradation of the other performance parameters such as input VSWR and gain variation, especially when ultra-wideband operation is required. The subject of noise optimization of the two-tier matrix amplifier and initial experimental results have been recently discussed in the literature [1]. This paper reports on the continuation of these efforts, which, primarily through the use of a frequency-dependent gate termination, resulted in significant improvements of the data reported earlier. In addition, the main factors leading to the wideband low-noise performance and the ensuing trade-offs will be discussed.

II. DEVICE AND CIRCUIT

The following noise studies were conducted on a two-tier matrix amplifier, a device that integrates the principles of additive and multiplicative amplification in one and the same unit. As shown in Figure 1, the circuit consists of a grid-like network of direct-coupled active and passive elements. The active devices are positioned very much like the mathematical elements in the rectangular array of a matrix, which is the underlying reason for the amplifier's name.

The MESFET's used in the experiments have a recessed gate with the dimensions 0.35 x 200 μm. They are fabricated on MBE substrate material whose active layer is 0.25 μm deep with a carrier concentration of approximately 4.5 x 10^{17} cm^{-3}. The equivalent circuit parameters under normal operating conditions

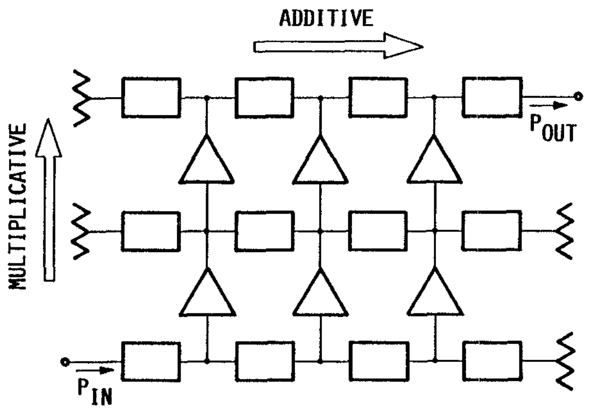

Figure 1 Block Diagram of the Two-Tier Matrix Amplifier

FREQU GHZ	FMIN DB	|GAMMA|	<GAMMA	F DB
2.0	0.21	0.87	12.0	2.85
3.0	0.42	0.81	17.0	2.75
4.0	0.61	0.76	22.0	2.68
5.0	0.79	0.72	26.0	2.65
6.0	0.96	0.68	31.0	2.65
7.0	1.11	0.66	35.0	2.68
8.0	1.23	0.63	40.0	2.73
9.0	1.33	0.60	44.0	2.78
10.0	1.41	0.58	49.0	2.80
11.0	1.47	0.55	53.0	2.85
12.0	1.52	0.53	58.0	2.90
13.0	1.56	0.51	62.0	2.98
14.0	1.59	0.49	67.0	3.05
15.0	1.62	0.47	71.0	3.10
16.0	1.65	0.46	76.0	3.15
17.0	1.67	0.44	80.0	3.25
18.0	1.70	0.43	85.0	3.33

Table I Characteristic Noise Parameters of the MESFET

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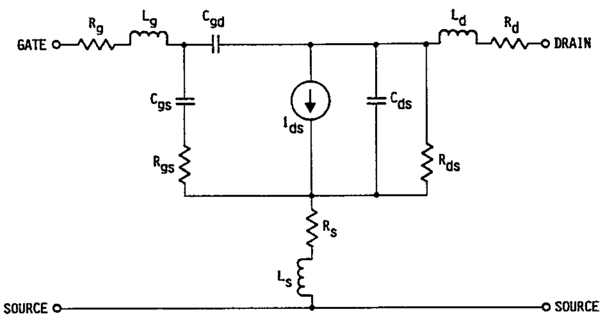
are presented in Figure 2. The devices' optimum noise figure is 0.2 dB at 2 GHz and 1.7 dB at 18 GHz, while their equivalent noise resistances R_n are located between 40Ω and 57Ω across the 2-18 GHz frequency band. The noise data characterizing the transistor is presented in Table I.



INTRINSIC ELEMENTS			EXTRINSIC ELEMENTS		
gm	=	32.8 mS	R_g	=	3.1 ohm
τ_o	=	2.1 psec	L_g	=	0.157 nH
C_{gs}	=	0.156 pF	R_s	=	1.35 ohm
C_{gd}	=	0.0188 pF	L_s	=	0.065 nH
R_{gs}	=	5.9 ohm	C_{ds}	=	0.056 pF
R_{ds}	=	322 ohm	R_d	=	1.3 ohm
			L_d	=	0.625 nH

Figure 2 Equivalent Circuit Parameters of the MESFET

Figure 3 shows the schematic of the 2 x 4 matrix amplifier, which is the subject of our analysis. The actual circuit is fabricated on 10 mil thick substrate material. All circuit elements have been optimized for noise figure, gain, gain flatness and, to a lesser degree, for reflection loss. Special emphasis has been given to the reduction of the gate termination's noise contribution by replacing the commonly used resistor with an impedance consisting of a resistor shunted by a reactance. The latter has been realized in the form of a high impedance shorted transmission line T_G and, as shown in Figure 3, was added in parallel to the termination resistor R_G. While such a measure reduces the noise contribution of the gate termination at low frequencies it simultaneously degrades the amplifier's input match and gain flatness across the same band over which it improves the noise figure. The influence of the termination's reactance is easily discernible from the computed curves of Figure 4, which compares the influence of the shorted transmission line, T_G (W_G = 1.6 mils), for three different line lengths with the case of a simple resistive termination of R_G = 42Ω on noise figure, small-signal gain and return loss. The performance curves in Figure 4 were computed for a circuit identical to that of Figure 3 after the circuit's optimization. At that point all circuit parameters were held constant, except for the electrical length of the shorted transmission line Θ_G, which was changed to the values indicated. The graphs clearly reveal the trade-offs that exist between noise figure and input match, as well as small-signal gain variation at the low end of the frequency band. As one would expect, an improvement in overall noise figure compromises other important performance parameters such as input return loss and gain variation.

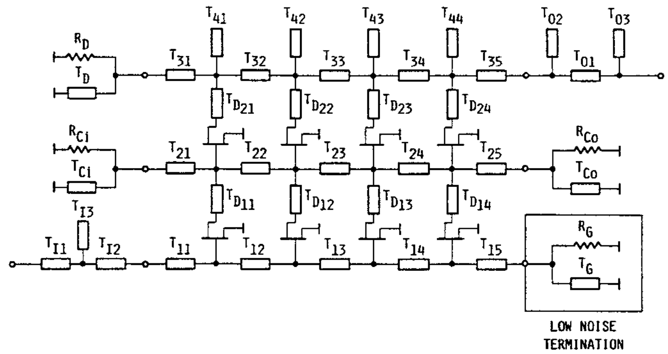


Figure 3 Schematic of the Two-Tier Matrix Amplifier

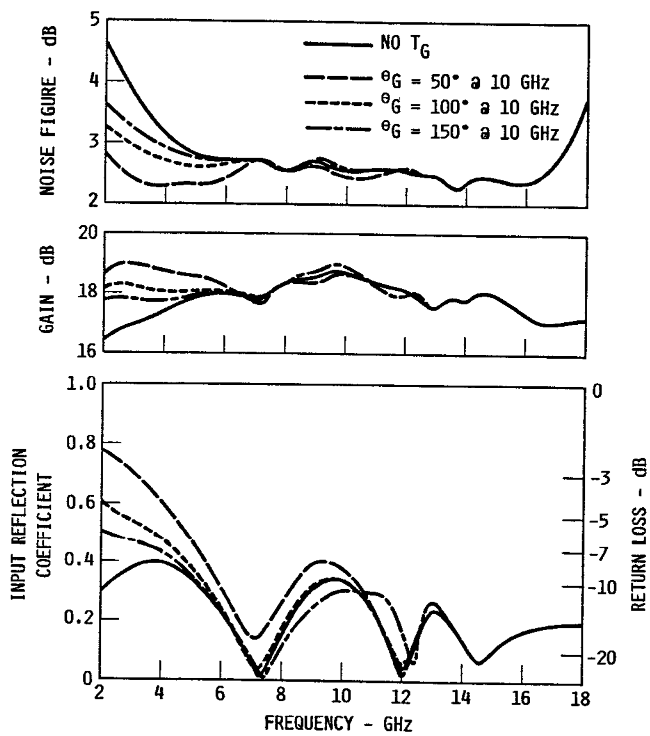


Figure 4 Computed Performance for Various Gate Terminations

III. EXPERIMENTAL RESULTS

Based on the data gained in our computer studies, a number of amplifiers were assembled, tuned and tested. However, for reasons of convenience, the termination reactances of the experimental amplifiers were realized with 0.7 mil thick bondwire rather than the 1.6 mil wide transmission line used in the earlier computations. Due to the wire's partial suspension in air and its small diameter, the actual transmission line's impedance was higher and its physical length had to be increased over that of the computed values, which assumed a 10 mil thick substrate made of fused silica. As shown in the graphs of Figure 5, noise figures of NF = 3.45 ± 0.8 dB and associated gains of G = 18.65 ± 0.65 dB at input VSWR's $\leq$ 2.2:1 (RL $\leq$ -8.5 dB) have been measured in a single-stage module across the 2-18 GHz frequency band when employing only a resistor as the gate termination. The resistor values of this amplifier were R_G = 65Ω, R_{Ci} = 21Ω, R_{Co} = 43Ω and R_D = 43Ω. Adding a reactance in the form of the above mentioned bondwire of the electrical length Θ_G = 96° at 10 GHz in parallel to the gate termination R_G = 65Ω of the same module in accordance with Figure 3 resulted in noise figures of NF = 3.0 ± 0.75 dB and gains of G = 18.7 ± 0.75 dB over the same frequency band (Figure 6). The maximum input VSWR, however, degraded to 3.6:1 (RL $\leq$ -5.0 dB). In a second module (R_G = 52Ω, R_{Ci} = 17Ω, R_{Co} = 42Ω, and R_D = 42Ω), a compromise between noise figure, gain variation and input VSWR was achieved. Its performance parameters, namely, G = 19.2 ± 0.65 dB, NF = 3.2 ± 0.6 dB and input VSWR $\leq$ 2.55:1 (RL $\leq$ -7.2 dB) are plotted in Figure 7. In this case, the electrical length of the bondwire was Θ_G = 110° at 10 GHz.

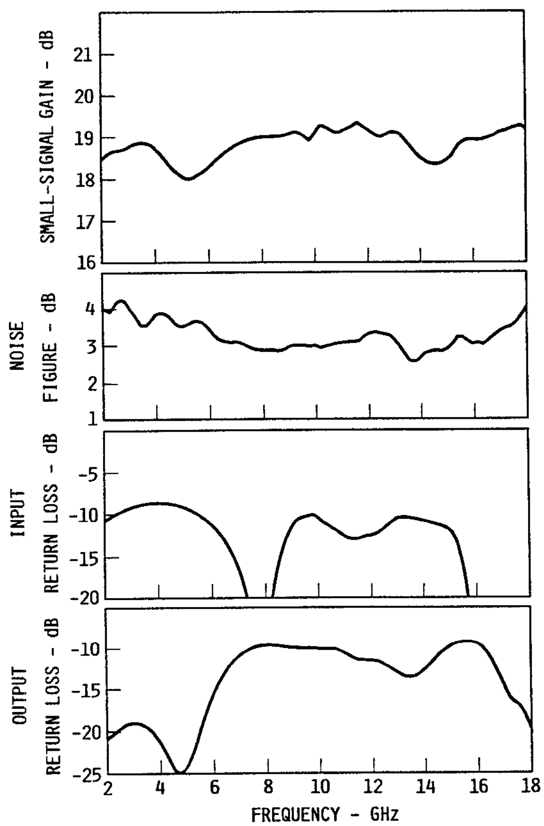


Figure 5 Measured Performance with Ohmic Gate Termination, R_G = 65Ω

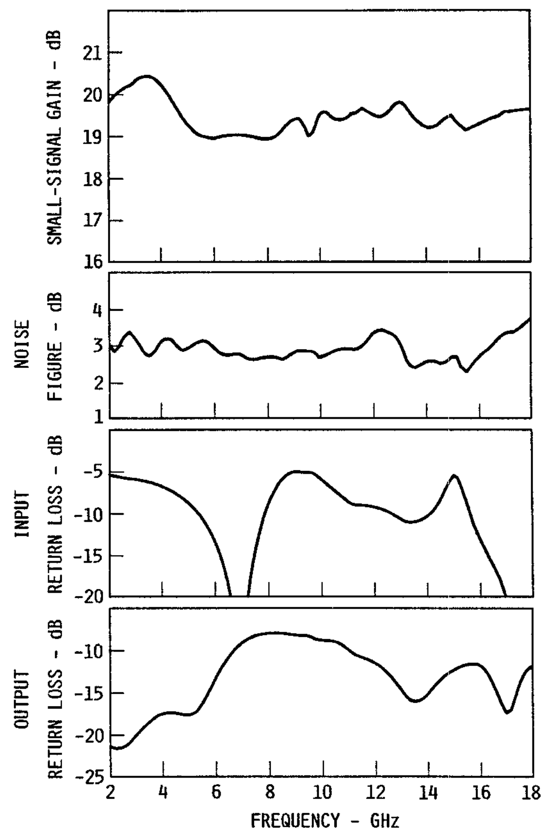


Figure 6 Measured Performance with Complex Gate Termination, R_G = 65Ω, Θ_G = 96° at 10 GHz

Allowing a larger gain variation of G = ±1.8 dB and a maximum input VSWR of 3.0:1 (RL = -6.0 dB), the noise figures of yet another module ranged from a maximum of NF = 3.35 dB to a minimum of NF = 2.55 dB for NF = 2.95 ± 0.4 dB at an average gain of G = 19.15 dB. The curves of this unit's performance parameters are plotted in Figure 8 and were obtained at R_G = 53Ω, R_{Ci} = 22Ω, R_{Co} = 52Ω, R_D = 50Ω and Θ_G = 70° at 10 GHz.

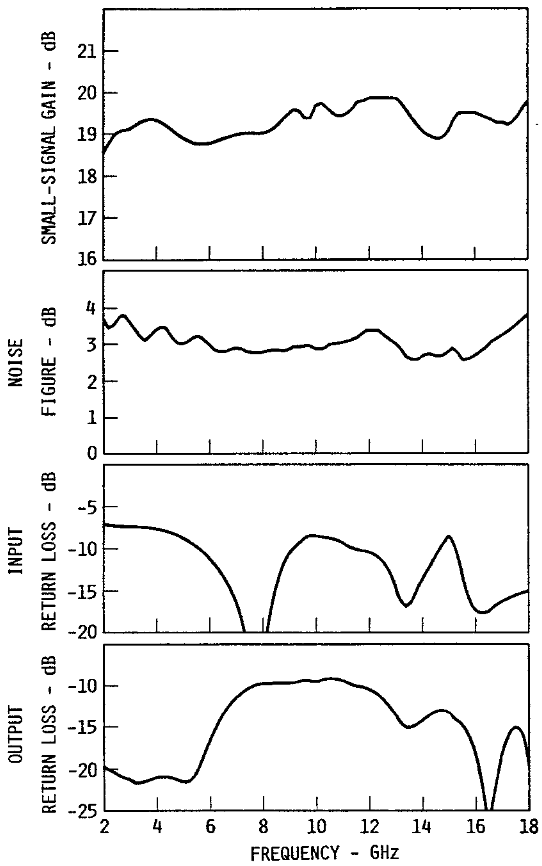


Figure 7 Measured Performance with Complex Gate Termination, R_G = 52Ω, Θ_G = 110° at 10 GHz

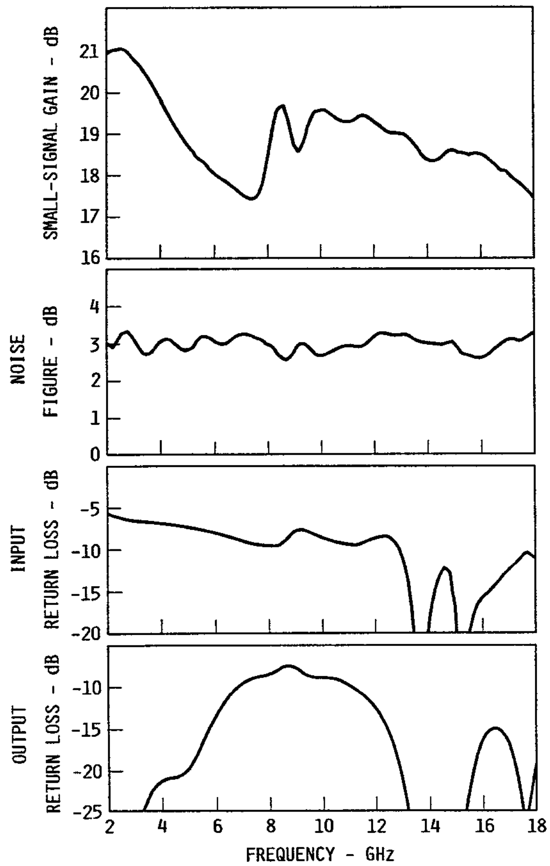


Figure 8 Measured Performance with Complex Gate Termination, R_G = 53Ω , Θ_G = 70° at 10 GHz

IV. CONCLUSION

The above data to the best of our knowledge represent the lowest noise figures and highest associated gains reported to date over the 2-18 GHz frequency band. The measured results gain even more in importance when considering the fact that they were achieved with MESFET's rather than the inherently lower noise HEMT devices. According to our computations, further significant improvements in noise figure and gain (NF $\leq$ 2.75 dB, G $\geq$ 20.5 dB) can be expected when using commercially available HEMT's.

V. REFERENCE

[1] K. B. Niclas, R. R. Pereira and A. P. Chang, "A 2-18 GHz Low-Noise/High Gain Amplifier Module," IEEE Trans. Microwave Theory Tech., vol. MTT-37, pp. 198-207.