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REFLECTIVE MATCH, LOSSY MATCH, FEEDBACK AND DISTRIBUTED AMPLIFIERS: A COMPARISON OF MULTI-OCTAVE PERFORMANCE CHARACTERISTICS

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Abstract - The performance of multi-stage single-ended GaAs MESFET amplifiers are compared when employing one and the same transistor type. Supporting experimental results include those of a 3-17.5 GHz reflective match module, a two-stage 2-18 GHz feedback amplifier, a two-stage 2-20 GHz, as well as a four-stage 2-18 GHz distributed amplifier.

Three circuit design principles exhibiting excellent ultra-wide band characteristics are now challenging the concept of the balanced reflective match amplifier. These are [1] - [9]:

1. the lossy match amplifier,
2. the feedback amplifier, and
3. the distributed amplifier.

Characterized by their simplicity, compact size and low cost, they represent attractive options whenever an economical solution to wide-band amplification is of primary concern.

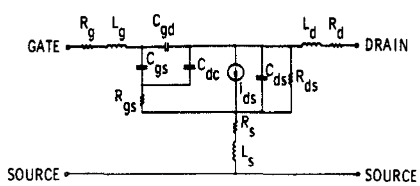
Finding the optimum solution from these four circuit types poses, however, a difficult problem and has no simple answer. In an attempt to compare the performance characteristics of these alternatives, one needs to establish certain conditions to arrive at a meaningful solution. To keep matters simple, we chose only the following two:

1. all amplifiers use identical active devices independent of the circuit type employed
2. the frequency band of interest is 2-18 GHz.

In the following we compare the performance characteristics of the reflective match (RM), the lossy match (LM), the feedback (FB) and the distributed amplifier (DA) based on computed results. The individual circuits are optimized for gain, gain flatness and reflection coefficients. The transistor's model and its element values are presented in Fig. 1. The latter have been obtained from the measured S-parameters of a GaAs MESFET with a 0.5 x 300 μm gate and a $2 \cdot 10^{17}$ cm^{-3} carrier concentration.

The topologies of the amplifier modules and the values of their components are presented in Fig. 2. The values of all passive circuit components have been optimized for best gain performance and do not represent the optimum conditions for noise figure. The positions of the active device in both the lossy match and the feedback amplifier are occupied by two GaAs MESFETs in parallel. This is due to the insufficient gain produced by the single device for these types of circuits. In order to achieve an equivalent gain with the distributed amplifier, three links are required. [9]

In the following we will show that similar gain performance may be obtained with the four circuits



INTRINSIC ELEMENTS	EXTRINSIC ELEMENTS
gm = 28 mS	R_g = 1 ohm
τ_o = 5.2 psec	L_g = .085 nH
C_{gs} = .25 pF	R_s = .44 ohm
C_{gd} = .012 pF	L_s = .041 nH
C_{dc} = .014 pF	C_{ds} = .066 pF
R_{gs} = 5.2 ohm	R_d = 1 ohm
R_{ds} = 272 ohm	L_d = .346 nH

Fig. 1 FET Model

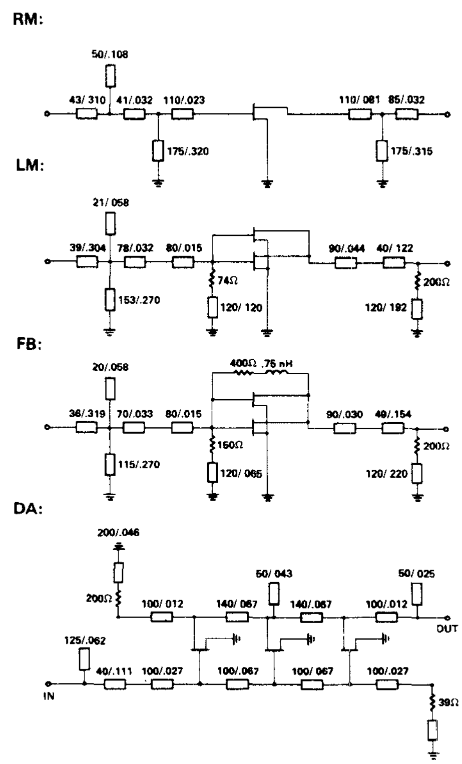


Fig. 2 Circuit Topologies

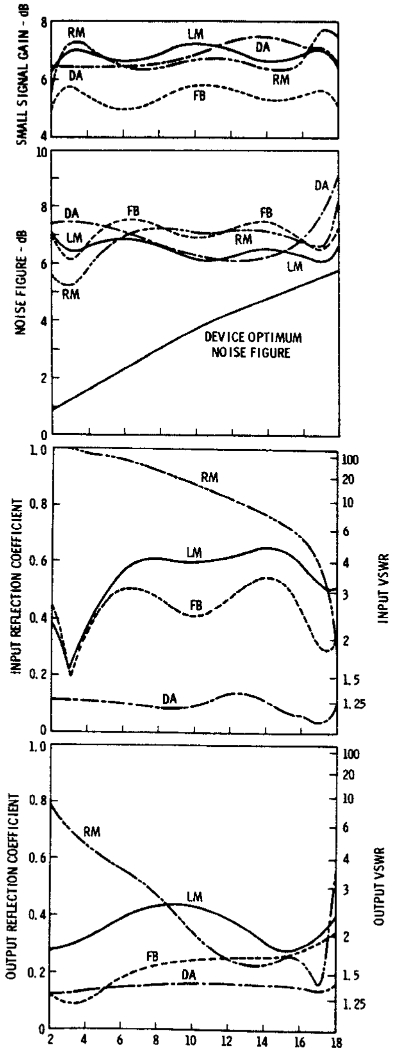


Fig. 3 Computed Characteristics

MULTI-STAGE AMPLIFIER PERFORMANCE					
STAGES	TYPE	SS GAIN dB	MAX. VSWR		MIN. K-FACT.
			INPUT	OUTPUT	
1	RM	6.6 ± 1.0	∞	7.3	0.21
	LM	6.8 ± 0.5	4.7	2.6	1.74
	FB	5.4 ± 0.5	3.4	2.0	2.80
	DA	7.0 ± 0.5	1.3	1.4	2.75
2	RM	15.5 ± 5.6	–	–	-23.8
	LM	14.3 ± 1.7	6.9	2.7	5.50
	FB	11.2 ± 1.0	3.4	2.1	18.1
	DA	14.6 ± 1.0	1.5	1.6	13.5
3	RM	–	–	–	–
	LM	20.9 ± 3.0	7.5	2.7	18.8
	FB	17.2 ± 1.8	3.4	2.1	108.8
	DA	21.8 ± 1.5	1.5	1.6	75.7
4	RM	–	–	–	–
	LM	27.9 ± 4.6	7.6	2.7	64.6
	FB	22.7 ± 3.0	3.4	2.1	672.7
	DA	29.0 ± 2.0	1.5	1.6	408.2
6	RM	–	–	–	–
	LM	43.8 ± 9.8	7.6	2.7	–
	FB	34.1 ± 5.0	3.4	2.1	–
	DA	43.5 ± 3.0	1.5	1.6	–

Table I

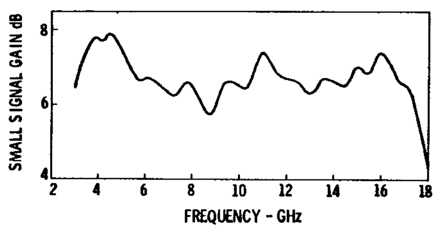


Fig. 4 3-17.5 Reflective Match Module

illustrated in Fig. 2. Their computed small signal gains, noise figures and reflection coefficients are plotted in Fig. 3 across the band of interest. While the average gains of all four amplifier types remain within 1.6 dB of each other, the reflection coefficients exhibit vast differences. The latter, more than any other parameter, dictate the feasibility of the design principle in case of multi-stage operation. The average noise figures of the four types stay within 1.1 dB of each other. Comparing the data, the distributed amplifier demonstrates the best gain flatness, the lowest reflection coefficients and the highest stability factors. Its maximum noise figure, however, exceeds those of the other modules. The lossy match amplifier shows the best overall noise figure in addition to excellent gain performance. The feedback amplifier trails both the lossy match and the distributed amplifier in gain, but has the advantage of lower reflection coefficients over the LM unit. In contrast, the RM module is unstable at frequencies below 9 GHz and therefore not very well suited for cascading.

As already pointed out, the choice of the circuit type is mostly dictated by the reflection coefficients for they represent the most critical parameters. The importance of the modules' input and output VSWR becomes very much apparent when cascading several units. The impact on gain, gain flatness, maximum VSWR and stability factor is summarized in Table I. While the gain characteristics of both the feedback and the distributed amplifier may be acceptable up to three stages, as long as gain flatness is of concern, only the distributed amplifier principle appears to be usable above three stages.

A number of multi-octave single-ended solid-state amplifiers employing lossy-match, feedback or distributed circuits have been described in the literature. [3] [9] [12] Here we shall present experimental data obtained from a 3-17.5 GHz reflective match module, a two-stage 2-18 GHz feedback amplifier and a two-stage as well as a four-stage 2-18 GHz distributed amplifier. While the results support what has been discussed so far, they are not meant to represent the exact experimental proof to the computed results of the circuits in Fig. 2.

While no attempt was made to design a 2-18 GHz reflective match amplifier, we have studied the feasibility of a 4-18 GHz module using the GaAs MESFET described in Fig. 1. The rather limited effort was confined to the design of a single-stage module and was terminated with the measurements of its gain and reflection coefficients. The gain performance is plotted in Fig. 4, demonstrating G = 6.8 ± 1.1 dB between 3 GHz and 17.5 GHz.

Encouraged by the computed results shown in Fig. 3 and the multi-stage characteristics of Table I it was decided to study the feasibility of a two-stage feedback amplifier. Since, however, the use of two parallel transistors in a feedback amplifier is somewhat impractical, the decision was made to replace the two devices with a single sub-half micron gate GaAs MESFET of matching characteristics.

Fig. 5 shows the curves of the small-signal gain, the noise figure and the return loss between 2 and 18.5 GHz. A gain of G = 10.8 ±.7 dB and maximum return loss of -4.4 dB (VSWR of 4:1) for the input port and -9.5 dB (VSWR of 2:1) for the output port were measured between 2 and 18 GHz. Across the same frequency band a maximum noise figure of NF = 7.1 dB was recorded.

The data measured on our distributed amplifiers was taken on a two-stage and a four-stage unit whose individual stages were essentially built to the schematic of Fig. 2 (DA) with the exception of the drain bias circuitry and the resistance of the drain termination. The gain, the noise figure and the return loss of the two-stage unit are plotted in Fig. 6. A gain of G = 12.3 ±.55 dB and a maximum return loss of -8 dB (VSWR of 2.3:1) for the input and -7 dB (VSWR of 2.6:1) for the output terminal were measured from 2.0-20.0 GHz while the maximum noise figure was NF = 9.6 dB between 2 and 18 GHz. The curves for gain and return loss of the 4-stage amplifier are shown in Fig. 7. This unit exhibits a gain of G = 19.4 ±.9 dB while a maximum input return loss of -7.5 dB (VSWR of 2.5:1) and output return loss of -6 dB (VSWR of 3.0:1) were achieved between 2.0 and 18.0 GHz.

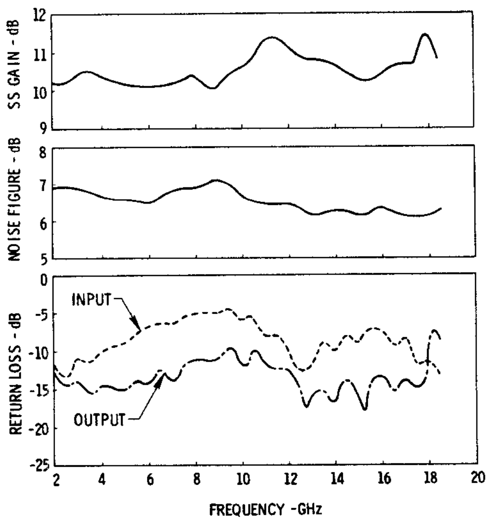


Fig. 5 Measured Characteristics of Two-Stage Feedback Amplifier

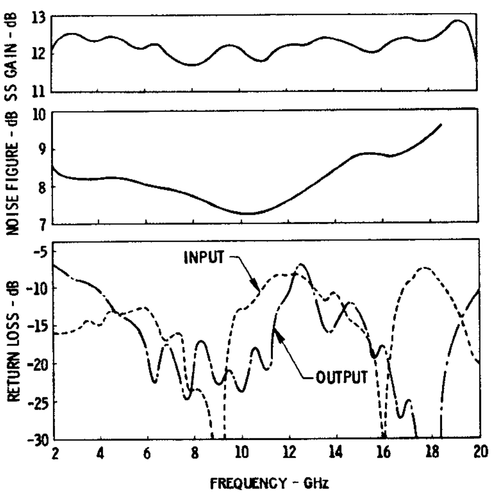


Fig. 6 Measured Characteristics of Two-Stage Distributed Amplifier

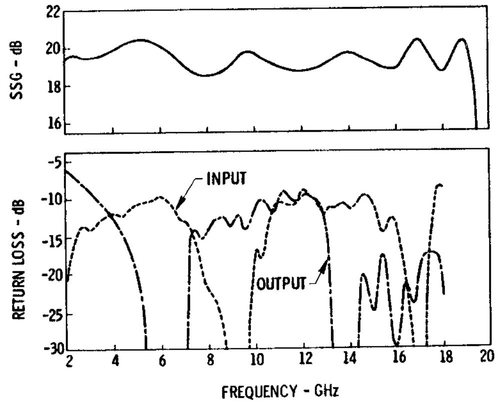


Fig. 7 Measured Characteristics of Four-Stage Distributed Amplifier

In conclusion, when utilizing one and the same type of active device in all four circuit types, the computed results reveal gain and noise figure characteristics that make it difficult to favor one concept over the others. However, when the gain specifications require the cascading of two or more gain modules, as is the case in most practical applications, the reflection coefficients of the input and output ports become of major significance and the choices narrow down with the number of cascaded stages. As demonstrated in Table I, for more than three stages the distributed amplifier is clearly the favorite option. In order to support some of the computed results, a number of amplifiers were built and test results presented.

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