# THE DUAL-FED DISTRIBUTED AMPLIFIER

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## ABSTRACT

This paper describes a novel microwave distributed** amplifier technique which results in a significant improvement in gain and reduction of noise figure in comparison with the conventional distributed amplifier, provided that the novel amplifier uses a small number of MESFETs.

Both theory and practice are described.

## INTRODUCTION

The conventional distributed amplifier consists essentially of a gate artificial transmission line and a drain artificial transmission line which have common active components in the form of MESFETs which provide the gate and drain line shunt capacitances. Such amplifiers have an input port to the gate line and an output port from the drain line. The unused gate and drain ports are terminated in the appropriate characteristic impedances.

The gain and noise performance of this arrangement is well documented both in theory and practice.

This paper presents a method whereby, for a distributed amplifier with a small number of MESFETs, the gain of the amplifier can be significantly increased and the noise figure significantly reduced.

## THE DUAL-FED DISTRIBUTED AMPLIFIER

The principle of the novel distributed amplifier is to feed the signal power into both gate line ports. For this reason the amplifier is described as the dual-fed distributed amplifier.

Provided the distributed amplifier operates under small signal and therefore linear conditions super-position will apply to its operation and it follows that the output due to forward gain from the left to right gate input signal will appear at the right hand drain port and similarly the output due to forward gain from the right to left gate input signal will appear at the left hand gain port. These two output signals can then be combined to give the total output power. A convenient way to feed the gate line and combine the drain line outputs is with a pair of hybrids as shown in Fig.1.

** This is the subject of patent applications in many countries throughout the world.

This argument applies to the forward gain of the distributed amplifier. We have to take into account the reverse gain and, if the phase of the hybrids is appropriate the currents due to reverse gain flow out of the same output hybrid port and add, vectorally to the forward gain.

Thus, this arrangement can result in an increase in available gain from the distributed amplifier in comparison with its conventional mode of operation.

There are corresponding noise figure benefits. In the conventional distributed amplifier the noise sources which contribute to the noise figure are, apart from the source resistance at the standard temperature:

(a) the gate line idle termination
(b) the drain line idle termination
(c) the gate noise generator associated with the MESFETs
(d) the drain noise generator associated with the MESFETs

In the dual-fed amplifier the gate line idle termination and the drain line idle termination vanish and are replaced respectively by the terminations on the fourth port of the input and output hybrids. However, it can be shown that the noise from the fourth port termination of the gate line hybrid is dissipated in the fourth port termination of the drain line hybrid. Furthermore, no noise from the fourth port termination of the drain line hybrid is dissipated in the drain line hybrid output port. Thus, in the dual-fed distributed amplifier the contribution to the noise figure of the first two noise sources in the list above vanish.

Additionally, the gain of the dual-fed distributed amplifier is higher than its conventional equivalent so the noise figure is further reduced.

We conclude that the noise figure of the dual-fed distributed amplifier will be significantly lower than that of its conventional equivalent distributed amplifier.

## SUMMARY OF ANALYSIS

### Gain

Analysis of the configuration shown in Fig.1 shows that the expressions for forward and reverse current through the drain load are given by:



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$$I_{df} = \frac{1}{2} V_{in}\, n g_m\, e^{-j(n-1)\beta}$$

$$I_{dr} = \frac{1}{2} V_{in}\, g_m\, e^{-j(n-1)\beta} \times \left( \frac{\sin n\beta}{\sin\beta} \right)$$

when $\beta_g = \beta_d = \beta$

This illustrates that $I_{df}$ and $I_{dr}$ are always in phase but change sign when $\frac{\sin n\beta}{\sin\beta}$ changes sign.

These expressions can be used to calculate the total available gain, $G_{f+r}$ in the dual-fed amplifier configuration using 180° hybrids as shown in Fig.1:

$$G_{f+r} = \frac{n^2 g_m^{\ 2} Z_{\pi d} Z_{\pi g}}{4} \left( 1 + \frac{\sin n\beta}{n \sin\beta} \right)^2$$

It has been shown (Ref.1) that the corresponding forward gain for the conventional distributed amplifier is given by:

$$G_f = \frac{n^2 g_m^{\ 2} Z_{\pi d} Z_{\pi g}}{4}$$

Thus, the dual-fed distributed amplifier has a 6 dB increase in available power gain compared with the conventional amplifier either when $\beta$ is sufficiently small or, alternatively when n is unity.

Noise Figure

It is convenient to compare the theoretical noise figure for the dual-fed and conventional amplifier configurations in the loss-free configurations using the techniques of Ref.1.

In both configurations the noise figure, F, can be written as:

$$F = 1 + \frac{1}{G_{av}} \Big( \sum i_g \text{ contribution} + \sum i_d \text{ contribution} + \text{gate termination contribution} + \text{drain termination contribution} \Big)$$

These contributions are listed in Table 1.

Figure 2 shows the theoretical noise figure as a function of the normalised cut-off frequencies for the conventional D.A. and the dual-fed D.A. for n equal to one and two. It can be seen that there is an improvement close to 5 dB in noise figure for n equal to unity and an improvement of between 2 dB and 3½ dB at frequencies below half the cut-off frequency for n equal to two.

Figure 3 plots the theoretical gain of the dual-fed D.A. normalised to that of the conventional D.A. for n equal to one, two and four which illustrates a 6 dB improvement in gain for n equal to one, a 6 dB improvement in gain falling to 0 dB improvement at 70% of the cut-off frequency for n equal to two and a fluctuating improvement for n equal to four.

## PRACTICAL PERFORMANCE

The dual-fed D.A. has been evaluated in practice for n equal to one and two with commercially available broad band 180° hybrids. Figure 4 illustrates the measured gain using a single NEC 710 device for both dual-fed and conventional D.As. It can be seen that there is an average gain improvement of about 4 dB compared with the predicted 6 dB. However, in the case of the dual-fed D.A. the measured gain includes the loss of the two hybrids and associated connectors.

The noise performance of the one stage amplifier has also been assessed and the measured results are shown in Fig.5 and show an improvement of approximately 3 dB over the band 2 to 16 GHz with a dual-fed noise figure minimum of 5 dB. This figure has not been corrected for hybrid or connector losses.

The gain performance of a two stage dual-fed D.A. using two NEC 710 devices is shown in Fig.6 both for the dual-fed and the conventional D.A. This shows the expected improvements in gain at the lower end of the band and a gain benefit up to 70% of the cut-off frequency for the dual-fed D.A. in accordance with the theory outlined above.

The noise figure comparison is made in Fig.7 and shows a noise figure improvement of 2 dB at the low frequency end of the band. This improvement diminishes until at about 8 GHz the gains become equal.

It should be noted that the measured noise figure for the dual-fed D.A. again includes the losses of the hybrids and interconnections. These are 0.25 dB at 2 GHz rising to 1 dB at 15 GHz.

## CONCLUSIONS

It is concluded that the dual-fed D.A. is a viable form of distributed amplifier which gives a useful improvement in gain and reduction in noise figure for amplifiers containing a small number of MESFETs.

In particular, the gain and noise figure obtained from a single stage dual-fed distributed amplifier are similar to those obtained from the conventional distributed amplifiers containing four MESFETs.

## REFERENCE


(1) C.S. Aitchison, "The Intrinsic Noise Figure of the MESFET Distributed Amplifier", IEEE MTT-33, No.6, pp.460-466 : June 1985.

| NOISE SOURCE | CONVENTIONAL D.A. | DUAL-FED D.A. |
|---|---|---|
| MESFET DRAIN | $\dfrac{4P}{n g_m Z_{\pi g}}$ | $\dfrac{8P\,h(r,\beta)}{n^2 g_m Z_{\pi g}\left(1+\frac{\sin n\beta}{n\sin\beta}\right)^2}$ |
| MESFET GATE | $\dfrac{Z_{\pi g}\,\omega^2 C_{gs}^{\,2} R \sum_r f(r,\beta)}{n^2 g_m}$ | $\dfrac{Z_{\pi g}\,\omega^2 C_{gs} R \sum_r g(r,\beta)}{2n^2 g_m \left(1+\frac{\sin n\beta}{n\sin\beta}\right)^2}$ |
| GATE LOAD | $\left\lvert\dfrac{\sin n\beta}{n\sin\beta}\right\rvert^2$ | $0$ |
| DRAIN LOAD | $\dfrac{4}{n^2 g_m^{\,2} Z_{\pi g} Z_{\pi d}}$ | $0$ |

$$f(r,\beta) = \left[(n-r+1)\,e^{-j(n-r+1)\beta} + \frac{\sin(r-1)\beta}{\sin\beta}\,e^{-j(n+1)\beta}\right]^2$$

$$g(r,\beta) = \left[(r-1)\,e^{-j(r-1)\beta+\theta} + (n-r+1)\,e^{-j(n-r+1)\beta+\phi} + \frac{\sin(n-r+1)\beta}{\sin\beta}\,e^{-j(n+1)\beta+\theta} + \frac{\sin(r-1)\beta}{\sin\beta}\,e^{-j(1+1)\beta+\phi}\right]^2$$

$$h(r,\beta) = \begin{cases} \displaystyle\sum_{2}^{n}\left(1+\cos(r-1)\beta\right), & n \text{ even} \\ \displaystyle 1+\sum_{3}^{h}\left(1+\cos(r-1)\beta\right), & n \text{ odd} \end{cases}$$

**Legend for Table 1**

| | |
|---|---|
| $g_m$ | mutual conductance |
| $Z_{\pi g}$, $Z_{\pi d}$ | gate and drain characteristic impedance |
| $\beta$ | line phase constant |
| $C_{gs}$ | gate-source capacitance |
| P | Van der Ziel drain noise constant |
| R | Van der Ziel gate noise constant |

Table 1

Noise figure for conventional and dual-fed distributed amplifier

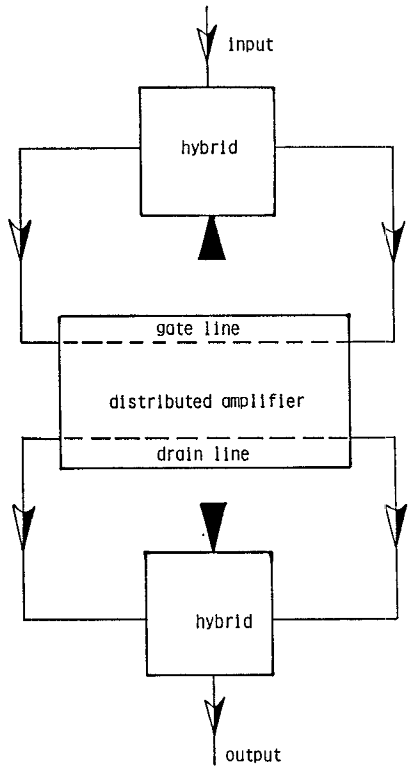


Fig.1: Schematic diagram of distributed amplifier

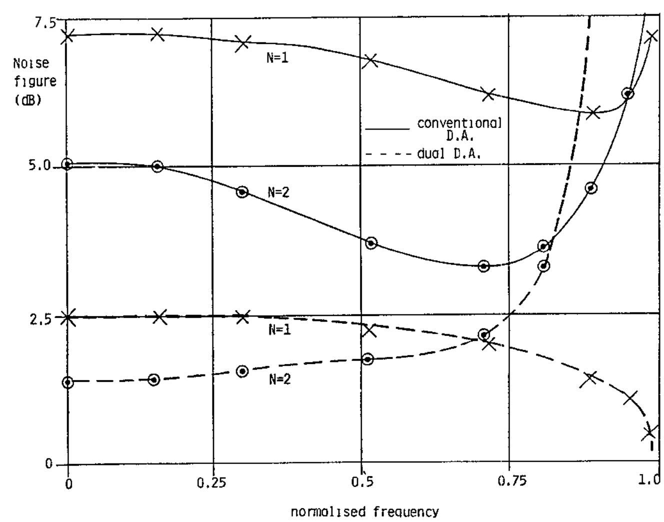


Fig.2: Theoretical noise figure as function of normalised frequency

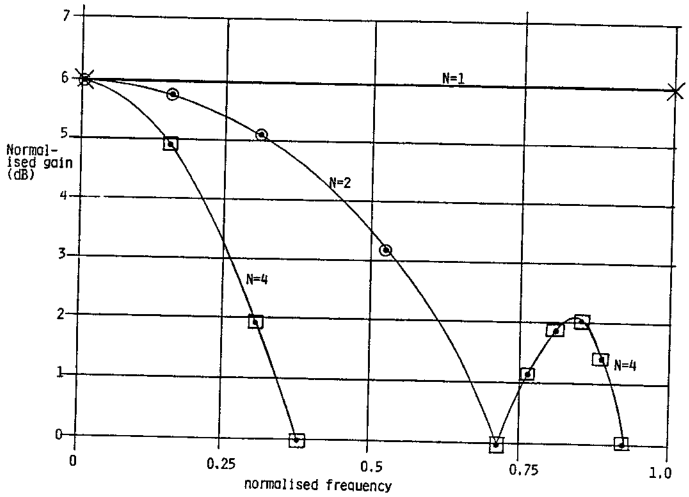


**Fig.3:** Gain of dual-fed D.A. normalised to conventional D.A. as function of normalised frequency

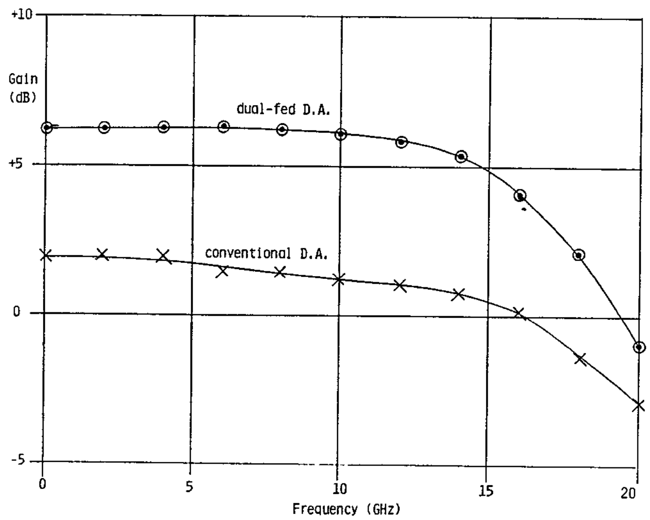


**Fig.4:** Measured gain for dual-fed and conventional single stage D.A. as function of frequency

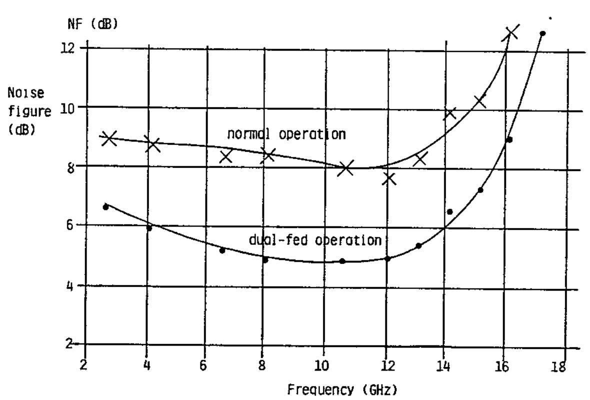


**Fig.5:** Measured noise figure for dual-fed and conventional single stage D.A. as function of frequency for N=1

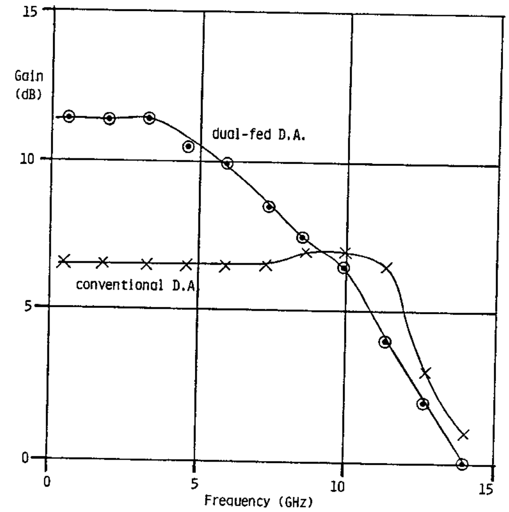


**Fig.6:** Measured gain for dual-fed and conventional double stage D.A. as function of frequency

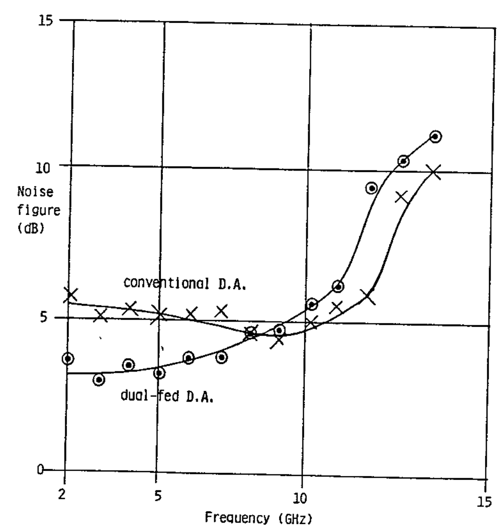


**Fig.7:** Measured noise figure for dual-fed and conventional double stage D.A. as function of frequency