A LOW NOISE MIC GaAsFET AMPLIFIER FOR 4 GHz RADIO

R. H. Knerr and C. D. Swan
Bell Telephone Laboratories, Incorporated
555 Union Boulevard
Allentown, Pennsylvania 18103

Abstract

A low noise amplifier for 4 GHz radio has been designed and is in manufacture. The noise figure is < 2 dB and the gain is typically 10 dB. Input and output return losses are > 25 dB. The insertion loss with failure of either the power supply of the low noise transistor is typically 5 to 8 dB. The amplifier uses a single GaAs Field Effect Transistor in conjunction with a passive failsafe by-pass network utilizing circulators. This approach permits the noise figure and the gain flatness to be optimized for each amplifier without compromising the input and output matches. It is concluded that this single-transistor amplifier design has significant advantages both in performance and in simplicity over the balanced amplifier design.

Introduction

Some of the design considerations for a microwave preamplifier for 4 GHz multi-channel radio service are:

1. Low noise figure over a 12.5 percent bandwidth.
2. Failsafe. (No loss of service for loss of power or transistor failure.)
3. Low 3rd order intermodulation distortion.
4. Input and output return losses > 25 dB.
5. Flat gain (± 0.5 dB desirable over 500 MHz, ± 0.05 over 10 MHz).
6. Low cost.

We have studied both balanced and single ended amplifiers for this application. We realized that meeting the intermodulation and failsafe requirements with a single transistor would allow significant cost savings. The single ended GaAsFET amplifier reported here meets these requirements and has additional performance advantages.

Results and Conclusions

The performance achieved in manufacture is:

Noise Figure	⩽ 2 dB
Gain	8 to 11 dB
Gain Flatness	± 0.5 dB
Unpowered Loss	⩽ 10 dB
Bandwidth	3.7 to 4.2 GHz
2A-B IM Intercept	⩾ 23 dBm
Input Return Loss	⩾ 25 dB
Output Return Loss	⩾ 25 dB

These results are obtained with a single ended GaAsFET amplifier with input and output circulators and a passive signal by-pass circuit. This design is simpler in construction, easier to adjust, and affords better performance than we obtained with a balanced amplifier.

The noise figure degradation due to the input circulator is < 0.2 dB. This is 0.1 dB less than the loss of the corresponding hybrid coupler. The circulator also permits the input circuit of the single GaAsFET to be tuned for best noise without affecting the match presented to the antenna. Ideal minimum noise match, however, is not realizable over a 12.5 percent band. The degradation due to this effect is < 0.3 db from the ideal narrow band noise figure. Thus the total noise figure degradation in manufacture for the completed amplifier is typically < 0.5 dB from that of the transistor. This is significantly better than we achieved in the balanced circuit.

One of the problems with the balanced circuit is the difficulty of individually providing the best noise match over the band for each transistor without unbalancing the inputs and thus causing a poor input match at the hybrid coupler. We found a similar match problem with the output circuit when adjusting for gain flatness. The > 25 dB return losses readily achieved with the single ended amplifier were virtually unattainable in the balanced amplifier without careful laboratory adjustment.

One disadvantage of the single transistor design is the lack of redundancy for transistor failure. In our design, transistor failure changes the amplifier from typically 10 dB gain to 5 to 8 dB loss. The balanced amplifier suffers a gain loss of only 6 dB. Thus the fade margin for the single ended design is significantly lower for this type of emergency.

It should also be pointed out that the 3rd order intercept is typically 3 dB higher for the balanced amplifier and this may be important in some applications. We believe, however, that the cost, noise figure and match advantages of the single ended design with the by-pass circuit override these disadvantages for our application.

Amplifier Circuit Design

Figure 2 shows an open view of the completed amplifier. The GaAsFET is mounted on a carrier plate with microstrip input and output circuits. These microstrip circuits were designed to a first order approximation using BAMP* and a discrete amplifier module. Beam lead MOS capacitors are used for dc blocking. Insulating the carrier plate from the housing permits the common source GaAsFET to be powered with the available negative supply voltage.

*Basic Analysis and Mapping Program (Hewlett Packard)

The amplifier module is embedded in a stripline circuit which provides the signal by-pass circuitry and the waveguide input and output ports.

Failsafe By-pass Circuit

When the GaAsFET is unpowered, both the gate and drain circuits appear approximately as open circuits. The transmission loss typically exceeds 20 dB. If the transistor fails, we expect a short circuit. In either case the input and output return losses at 4 GHz are typically 2 to 4 dB.

The addition of three circulators as shown in Figure 1 provides an effective passive by-pass circuit. In the normal state the relatively small reflected input signal is recombined with the amplifier signal at the output of the transistor. This appears as a small ripple on the gain characteristic which can be compensated by output tuning. In the unpowered or failed state, both the gate and drain circuits are "switched" to open or short circuits. The input signal, with relatively small loss, is then directed to the drain circuit of the GaAsFET where it is reflected to the output circulator and directed to the load. The total insertion loss is typically 5 to 8 dB.

The circulators for the by-pass circuit were designed in air dielectric stripline. This simple technology assures minimum circuit losses, low cost parts and assembly and very high yields. The intermediate circulator is terminated with 50 ohms to provide > 25 dB isolation.

A similar signal by-pass scheme can be used with balanced amplifiers for the unpowered emergency state. In this case a single isolator is connected between the two normally terminated ports of the input and output hybrid couplers.

Power Regulator and Alarm Circuit

The dc operating point for the GaAsFET is a compromise between minimum noise and acceptable linearity. A regulator automatically sets the gate voltage so that I_D = 15 mA and V_{DS} = 4.8 volts. All GaAsFETs are thus powered identically and require no bias adjustment in manufacture. The amplifier operates from a -24 volt supply at 60 mA.

In case of transistor or power supply failure ($I_D < 5$ mA or $I_D > 25$ mA), a contact to ground is provided which energizes a remote alarm.

The Low Noise Transistor

The GaAsFET was developed at the Murray Hill, N. J. Laboratory(1). It is supplied in hermetically sealed packages by Western Electric Company. The gate length and width are 0.8 µm and 500 µm. The typical noise figure is about 1.2 to 1.4 dB at 4 GHz.

Physical Design

The completed amplifier is shown in Figures 2 and 3. The aluminum housing is die cast in two parts. The stripline center conductor is stamped in a single piece from sheet brass. Interlocking molded plastic locating rings are used to locate both the circulator ferrites and the center conductor in the lower housing channel. The printed circuit board with power regulator and alarm circuits is mounted on the bottom side of the lower housing.

Environmental Testing

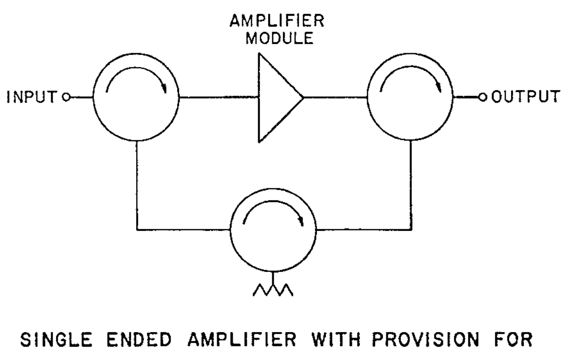
Amplifiers have been temperature cycled over the 4 to 60°C range without appreciable changes. Extended corrosion testing at 85°C/85% relative humidity produced no degradation.

Acknowledgments

We gratefully acknowledge the team efforts of Bell Laboratories and Western Electric engineers in the development of this amplifier. We mention especially the efforts of Messrs. J. J. Kostelnick, G. M. Keltz and G. M. Palmer. The GaAsFET was developed by Messrs. J. V. DiLorenzo and W. O. Schlosser. Mr. L. F. Moose provided essential coordination and technical direction for the program.

References

(1) B. S. Hewett, H. M. Cox, H. Fukui, J. V. DiLorenzo, W. O. Schlosser and D. E. Iglesias, "Low Noise GaAs MESFETs - Fabrication and Performance", 6th International Symposium on GaAs and Related Compounds, Edinburgh, Sept. 19-22, 1976.



SINGLE ENDED AMPLIFIER WITH PROVISION FOR UNPOWERED TRANSMISSION

FIGURE 1

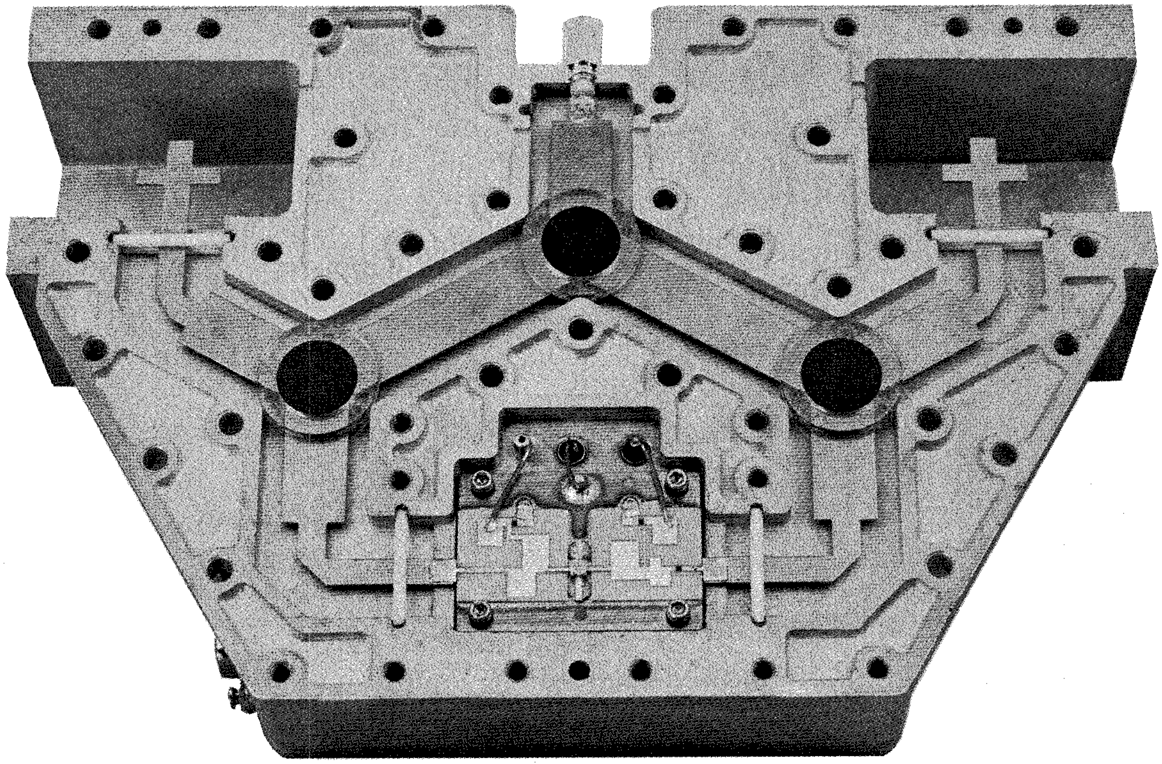


FIGURE 2. 4 GHz LOW NOISE AMPLIFIER WITH TOP COVER REMOVED

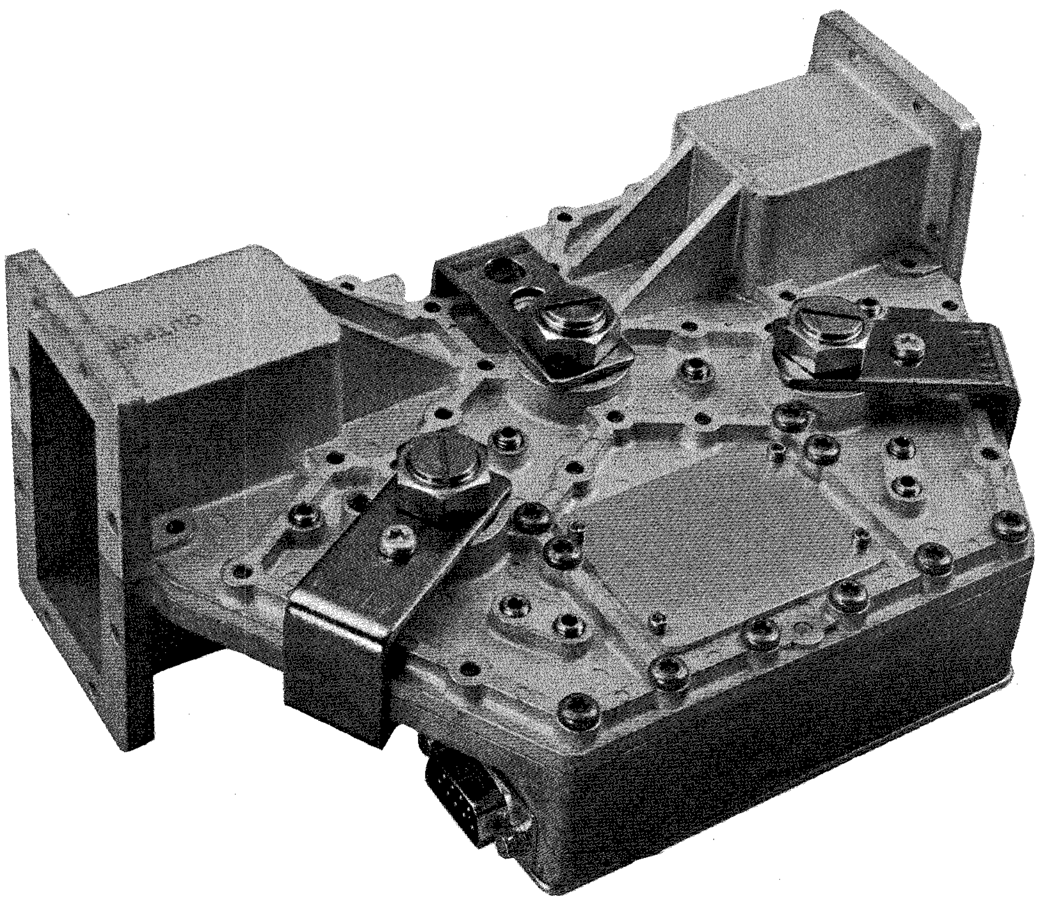


FIGURE 3. 4 GHz LOW NOISE AMPLIFIER