LOW TEMPERATURE PERFORMANCE OF GaAs MESFETS AT L-BAND*

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ABSTRACT

A considerable amount of work[1, 2, 3] has been reported on the use of GaAs MESFET amplifiers at cryogenic temperatures. Most of the applications were for frequencies above 4 GHz. In this paper we discuss a 1.4-GHz GaAs MESFET amplifier cooled to 77 K with a noise temperature of less than 20 Kelvins over a 100-MHz bandwidth. The amplifier serves as an IF amplifier for a millimeter-wave cooled mixer.

Introduction

The ever-growing interest in Earth Science and the origin and makeup of the universe has provided an impetus for the development of extremely low-noise receivers needed for the study of electromagnetic phenomena from terrestrial and cosmic sources. This development has been aided considerably by the advances made in closed-cycle cryogenic refrigerators. Present-day systems are compact, reliable and fairly inexpensive. This progress has spurred a renewed interest in cryogenic receiver components. In this paper we discuss the development of a 1.4-GHz GaAs MESFET amplifier cooled to 77 K. The amplifier (illustrated in Figure 1) serves as an IF amplifier for a cooled millimeter-wave mixer. The noise temperature is less than 20 Kelvins over an operating bandwidth of 100 MHz. We believe this is the lowest noise temperature reported for a transistor amplifier.

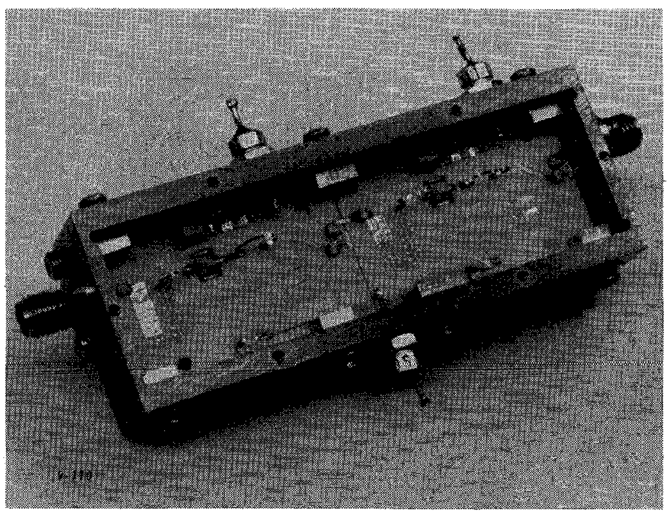

Figure 1. Amplifier, Top View

Design Approach

Use of GaAs MESFETS at L-Band is difficult for several reasons. The impedance levels of the device are rather high, making the design of impedance transformers with significant bandwidth difficult. Transformers must present a noise match to the gate of the FET and a match for power gain to the drain of the FET. Secondly, the device is conditionally stable in this frequency range. Care must be taken to avoid presenting an impedance to the drain of the device which lies within its unstable region. The boundary of this region is calculated from the S-parameters of the FET. Lastly, the frequency range is low enough to preclude the exclusive use of microstrip distributed elements in the matching networks. Lumped elements must be incorporated particularly when high-Q inductors are needed.

The stability problem can be dealt with in two ways. If a lossless output network is used, the circuit designer must take care to see that the impedance presented to the FET always lies outside its unstable region. In this way one would achieve, at most, the maximum stable gain (MSG) of the FET. Accompanying this will be a fairly high output VSWR (typically greater than 4:1). If a lossy output matching network is employed, the stability factor K of the device can be made greater than one while simultaneously providing an output VSWR as close to unity as desired. This is a more desirable situation because it permits easy cascading of gain modules and avoids the necessity of an isolator to condition the output VSWR. However, one must still contend with the high input VSWR that results when one has attained a noise match to the FET. This problem is ameliorated when cascading modules because the output VSWR of the preceeding module can be chosen to be low.

The amplifier we have developed consists of two identical single-ended stages cascaded to provide a minimum of 27 dB with a noise temperature of less than 20 Kelvins from 1.35 to 1.45 GHz. It employs a lossy matching network in the drain circuit and utilizes a mix

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of distributed and lumped elements to implement the matching networks. The active device is the packaged one-micron NEC NE24406. Alumina was chosen as the microstrip medium because of its dimensional stability over the temperature range and its excellent thermal conductivity. Equally important is the fact that the coefficient of contraction of the substrate closely matches that of the Kovar/BeO FET package. This match prevents stress from developing at the solder connections to the FET at cryogenic temperatures.

Noise Temperature Estimate

As discussed[3], if we assume that the FET transconductance exhibits a $T^{-1/2}$ dependence on temperature, then equation 1 can be used to estimate the noise temperature of the MESFET at the cold temperature.

$$T_{e_2} = T_{e_1} \left(\frac{T_2}{T_1} \right)^{3/2} \qquad (1)$$

where

T_{e_2} = FET noise temperature at temperature T_2 (77 K)

T_{e_1} = FET noise temperature at temperature T_1 (300 K for convenience)

With this result and the assumption that the S_{21} of the MESFET varies with temperature in the same manner as the transconductance, we can arrive at an estimate of MESFET noise temperature at the cold temperature. To account for the contributions of circuit dissipation to noise temperature we assume that the noise temperature of a loss is given by:

$$T_e = T_L \, (L-1) \qquad (2)$$

where

T_e = noise temperature of the loss at physical temperature T_{L_1} in Kelvins

L = magnitude of the loss, ratio

At 1.4 GHz, manufacturer's data and data taken by the author indicate that the noise temperature of the NE24406 is approximately 100 Kelvins when the device is operated at 300 K (25°C). With equation 1, we estimate the MESFET noise temperature to be 12 Kelvins at 77 K. Since the MSG of the device is estimated to be in excess of 17 dB at the cold temperature, it is approximately correct to assume that noise generated by the circuitry following the first active device is masked by virtue of the large gain. We estimate this contribution to be in the vicinity of 2 K. However, any loss preceeding the first active device has a greater impact. We can account for this in the following manner:

$$T_{e_{AMP}} = T_L \, (L-1) + L \, T_{e_2} + L \left(\frac{T_{SS}}{G_{MESFET}} \right) \qquad (3)$$

The first term reflects the noise contribution of input loss. The second term is the contribution of the MESFET noise temperature. The final term accounts for noise generated by circuitry following the first active device (~2 K). We estimate the input loss (the loss of the impedance transformer needed for noise match) to be approximately 0.2 dB. Using equation 3 $T_{e_{AMP}}$ is estimated to be 18.2 K.

Circuit Design

Using the 300-K noise and S-parameter data for the device, the circuit shown in Figure 2 was arrived at. Shown here is a single stage of the two-stage amplifier. The inductors needed to resonate the FET were fabricated with 0.025-inch wide, half mil thick, gold ribbon suspended in air. The resistor in the drain was fabricated using the chromium adhesion layer of the substrate. This yielded a resistor with low parasitics. We incorporated an external bias control which permits us to fine-tune the FET bias at the cold temperature to achieve optimum performance.

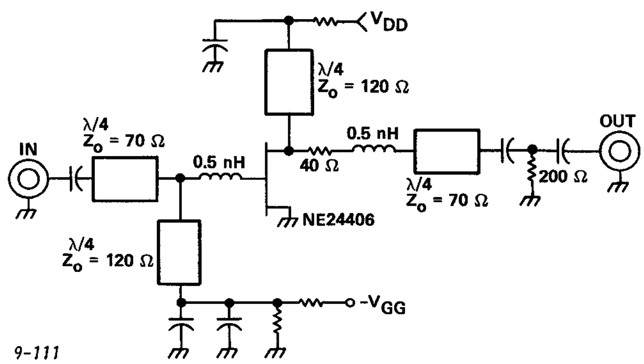

Figure 2. 1.4-GHz Cryogenically Cooled FET Amplifier Schematic Diagram

Measurements

Measurement of noise temperatures in the 20-K range requires considerable care. A hot/cold noise generator must be used which provides, as part of its calibration, a means of accounting for its internal RF losses. To avoid the possibility of gain modulation by the noise source affecting the noise measurements, the reflection coefficients of the hot and cold noise sources must track both in phase and magnitude. Source VSWR's well under 1.05 should be measured. This point is particularly critical when measuring an amplifier with a fairly high input VSWR as in the case here. If the noise measuring setup includes a superheterodyne receiver, a filter must be used after the amplifier under test to reject the image.

Discussion of Results

Figure 3 illustrates the noise temperature of the amplifier as a function of frequency. The total correction to this measurement was approximately 7 K. This contribution was primarily from the coaxial stainless steel cable between the input to the dewar and the amplifier. Figure 4 shows the gain of the amplifier. The input VSWR was approximately 6:1 and the output VSWR was under 1.5:1. The room temperature noise figure was 1.4 dB maximum.

Conclusion

Data indicate that a cooled L-Band GaAs MESFET amplifier can provide extremely low noise temperatures (on the order of 20 Kelvins) at cryogenic temperature. Such an amplifier could serve as an IF to a cooled millimeter-wave mixer.

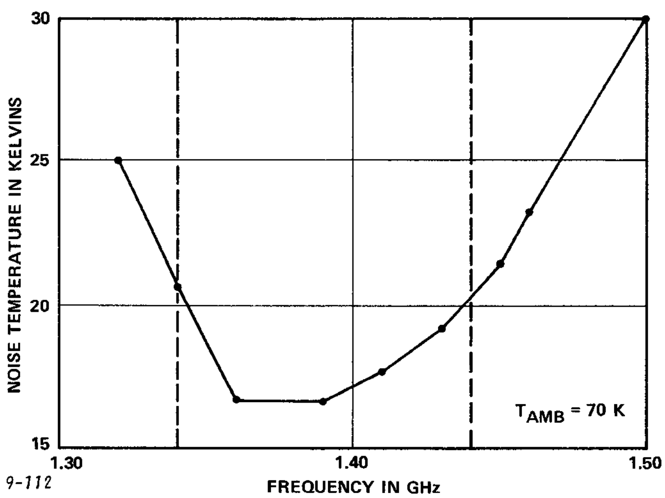

Figure 3. Noise Temperature of 1.4-GHz Cryogenically Cooled FET Amplifier

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Mr. Kenneth Louie is now with Loral Electronics, Yonkers, New York 10704.

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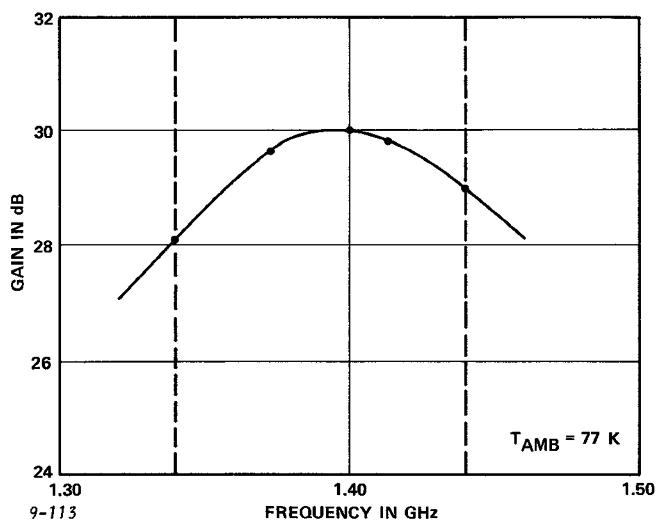

Figure 4. Power Gain of 1.4-GHz Cryogenically Cooled FET Amplifier