GaAs HEMT LOSSY MATCH AMPLIFIERS

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ABSTRACT

A novel design approach of hybrid lossy match amplifiers for the 1 to 13 GHz and 1 to 20 GHz bands using 0.3 micron gate length GaAs HEMT's is described. Two types of the two stage lossy match amplifier have been realized. One amplifier, using 0.3 X 280 micron GaAs HEMT's, exhibits 14.0±0.4 dB gain, better than 10 dB return loss, and less than 7.8 dB noise figure over the 1 to 13 GHz band. The other amplifier, using 0.3 X 200 micron GaAs HEMT's, shows 9.5±0.4 dB gain, better than 10 dB return loss, and less than 7.5 dB noise figure across the 1 to 20 GHz band. These are the unprecedented lossy match amplifiers to achieve high gain-bandwidth product.

INTRODUCTION

Monolithic or hybrid distributed amplifiers covering several octaves have been reported by a number of researchers in the literature [1]-[4]. Distributed amplifiers call for more than 2 FET's as active devices from the circuit design point of view. On the contrary, the concept of the ultra-broadband amplifier which covers decade bandwidth using only 1 FET has been of primary concern. The lossy match amplifier is very attractive for its simplicity, compact size, and low cost [5]-[7]. However previous lossy match amplifiers have been characterized by relatively narrow bandwidth and low gain. It is the purpose of this paper to present a novel design approach to achieve high gain-bandwidth product of the hybrid lossy match amplifier using high performance, 0.3 micron gate length GaAs HEMT's.

CIRCUIT DESIGN

A simplified schematic diagram of the two stage hybrid lossy match amplifier is shown in Fig.1. In this design, there are three features which distinguish it from previous design approaches of the lossy match amplifier.

First feature is that input and output networks are designed to form artificial lossy transmission structures, where high impedance microstrip lines are combined with the gate and drain complex impedances of the FET. Input and output networks show a m-derived low-pass response over decade bandwidth, which are modeled as in Fig.2. This design approach, which can be seen in the distributed amplifier, extends bandwidth and achieves low input and output VSWR's.

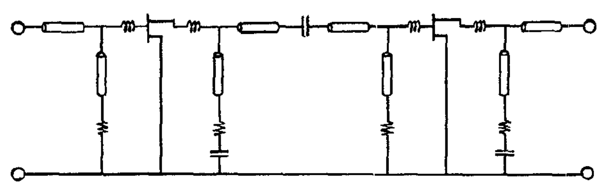
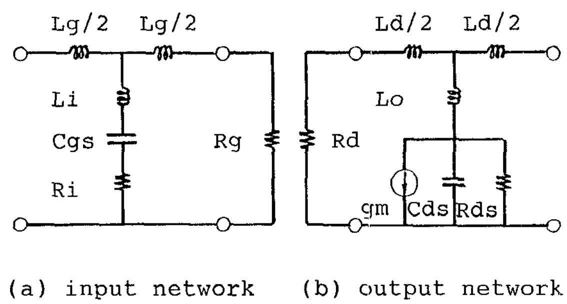


Fig.1 Schematic diagram of the two stage hybrid lossy match amplifier



Li,Lo	bond-wire inductances
Lg,Ld	microstrip inductances
Rg,Rd	terminating resistors
gm	transconductance of the FET
Ri	gate-to-source resistance of the FET
Cgs	gate-to-source capacitance of the FET
Rds	drain-to-source resistance of the FET
Cds	drain-to-source capacitance of the FET

Fig.2 Equivalent circuits of input and output networks

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In the case of hybrid distributed amplifiers, there exists a constraint that microstrip inductances (Lg,Ld) cannot be smaller than 0.4 nH due to the physical size of the FET chip, which limits the upper cutoff frequency and as a result the amplifier's bandwidth [4]. On the contrary, hybrid lossy match amplifiers are free from this constraint and hence much wider bandwidth can be expected.

The second feature is that interstage network is designed to have a impedance of greater than 50 ohms for a high gain. In the case of the two stage amplifier, interstage network has no need to show 50 ohms characteristic impedance. The terminating resistors (Rg,Rd) as shown in Fig.2 are also designed to be greater than 50 ohms for avoiding mismatch. In practice high impedance of greater than 50 ohms may be accomplished by increasing microstrip inductances (Lg,Ld) as shown in Fig.2, however this design approach degrades the amplifier's bandwidth. Therefore the value of these microstrip inductances must be carefully determined to achieve high gain-bandwidth product of the amplifier.

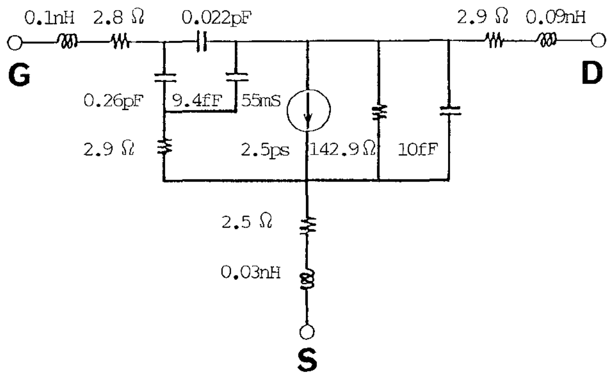

Fig.3 Equivalent circuit and element values of 0.3 X 280 μm GaAs HEMT

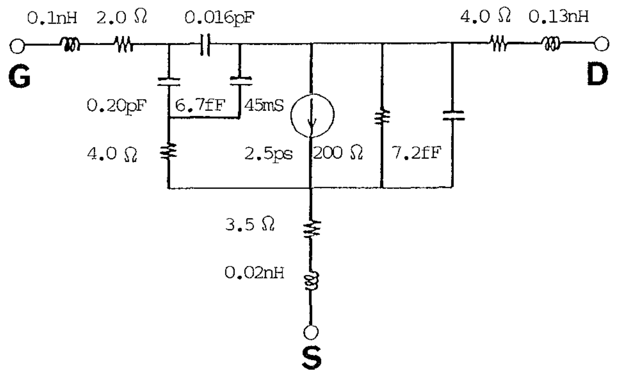

Fig.4 Equivalent circuit and element values of 0.3 X 200 μm GaAs HEMT

And final feature is the FET used. Two types of the FET were used. One type is the HEMT with 0.3 X 280 micron single-gate (NEC NE20300). The other type is also the HEMT with 0.3 X 200 micron single-gate (NEC NE20200). Fig.3 and 4 show the equivalent circuits and element values of both types of GaAs HEMT's which were derived from measured S-parameters. 0.3 X 280 micron GaAs HEMT, which has a large value of gm and Cgs, is appropriate for increasing gain at the expense of bandwidth. In constast to this HEMT, 0.3 X 200 micron GaAs HEMT, which has a small value of gm and Cgs, is suitable for extending bandwidth by sacrificing gain.

AMPLIFIER DESIGN

Using simplified equivalent circuits of Fig.1 and 2, the gain expression for the two stage hybrid lossy match amplifier can be derived as

$$G=\prod_{n=1}^{2}(gm/2)^2 RinRon\cdot\exp(-Agn-Adn)\cdot\frac{(1-\omega^2 LiCgs)^2}{[1+(\omega/\omega g)^2]}\cdot\frac{[1-(\omega/\omega on)^2]^{0.5}}{[1-(\omega/\omega in)^2]^{1.5}} \quad (1)$$

where

$$Rin=(Lg/Cgs)^{0.5} \quad (2)$$

$$Ron=(Ld/Cds)^{0.5} \quad (3)$$

$$\omega in=2[Cgs(Lg+4Li)]^{-0.5} \quad (4)$$

$$\omega on=2[Cds(Ld+4Lo)]^{-0.5} \quad (5)$$

$$Agn \simeq Ri(\omega Cgs)^2 Rin[1-(\omega/\omega in)^2]^{0.5}/2 \quad (6)$$

$$Adn \simeq Ron[1-(\omega/\omega on)^2]^{0.5}/2Rds \quad (7)$$

$$\omega g=1/RiCgs. \quad (8)$$

Rin and Ron, ωin and ωon, Agn and Adn, denote the characteristic resistance, the cutoff frequency, and the attenuation of input and output networks, respectively.

As mentioned above, there exists a tradeoff between gain and bandwidth by increasing interstage network impedance for a high gain. Fig.5 displays computor simulated results of a relation between gain and bandwidth with interstage network impedance as a parameter, which were obtained by using equations (1)-(8) for both types of GaAs HEMT's. In this simulation, bandwidth is defined as the frequency at which the gain obtained from equation (1) falls below the dc gain by 3 dB. It must be noted in this simulation that the first stage input and second stage output networks are also designed to

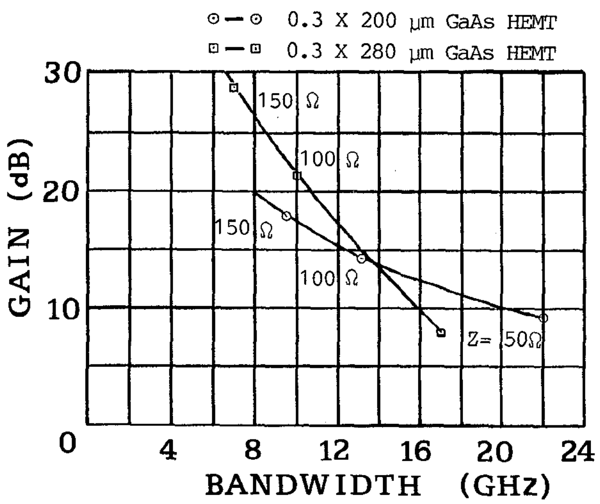

Fig.5 Relation between gain and bandwidth with interstage network impedance as a parameter

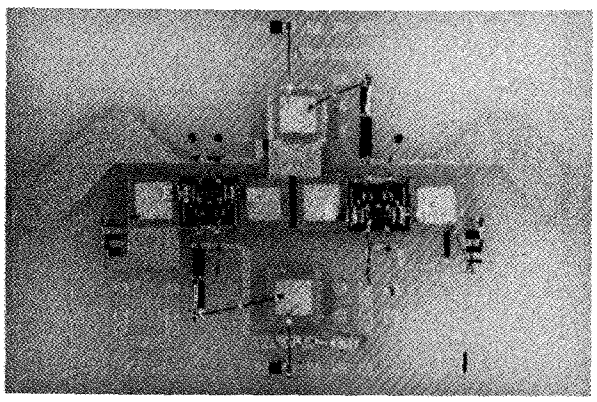

Fig.6 Photograph of the 1 to 13 GHz amplifier

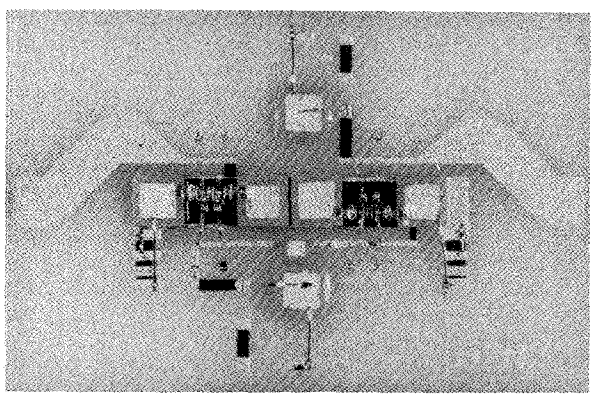

Fig.7 Photograph of the 1 to 20 GHz amplifier

show greater than 50 ohms for a high gain as long as their impedances do not exceed that of interstage network and input and output VSWR's of the amplifier are satisfied to be less than 1.5 : 1.

It can be seen in Fig.5 that higher gain-bandwidth product is achieved by using 0.3 X 280 micron GaAs HEMT's for the frequency below 14 GHz, while by using 0.3 X 200 micron GaAs HEMT's for the frequency above 14 GHz. Therefore two types of the amplifier were designed for the 1 to 13 GHz band by using 0.3 X 280 micron GaAs HEMT's and for the 1 to 20 GHz band by using 0.3 X 200 micron GaAs HEMT's.

CIRCUIT FABRICATION AND PERFORMANCES

Photographs of the two stage hybrid lossy match amplifiers for the 1 to 13 GHz and 1 to 20 GHz bands appear in Fig.6 and 7, respectively. Thin film circuit is fabricated on 0.4 mm thickness alumina substrate with TaNx / Cr / Au microstrip lines. The sheet resistance of tantalum nitride is 50 ohms/square. Plated through holes are used to achieve high-integrity and allow both GaAs FET chips and RF bypass capacitors to be surface-mounted, which are located under all RF bypass capacitors. These circuits measure 2.9 X 4.5 mm. RF bypass capacitors measure 0.4 X 0.4 X 0.15 mm and have a capacitance of approximately 40 pF. A DC blocking capacitor measures 0.1 X 0.1 X 0.15 mm and has a capacitance of approximately 3 pF.

Measured gain and return loss performances of the 1 to 13 GHz and 1 to 20 GHz amplifiers are displayed in Fig.8 and 9, respectively. Predicted gain performances are also plotted in Fig.8 and 9. Measured noise figure performances of both amplifiers are shown in Fig.10 followed by measured 1 dB compressed power in Fig.11.

From Fig.8, 10 and 11, the two stage amplifier with 0.3 X 280 micron GaAs HEMT's exhibits 14.0±0.4 dB gain, better than 10 dB return loss, and less than 7.8 dB noise figure and has a 1 dB compressed power of greater than 11 dBm over the 1 to 13 GHz band. From Fig.9, 10 and 11, the two stage amplifier with 0.3 X 200 micron GaAs HEMT's shows 9.5±0.4 dB gain, better than 10 dB return loss, and less than 7.5 dB noise figure and has a 1 dB compressed power of greater than 10.2 dBm across the 1 to 20 GHz band. Both measured and predicted gain performances are in good agreement. A slight discrepancy between measured and predicted gain performances of the 1 to 20 GHz amplifier is most likely attributed to the error in the modeling of GaAs HEMT. All data presented was measured at VDS~3V and IDS~20 mA.

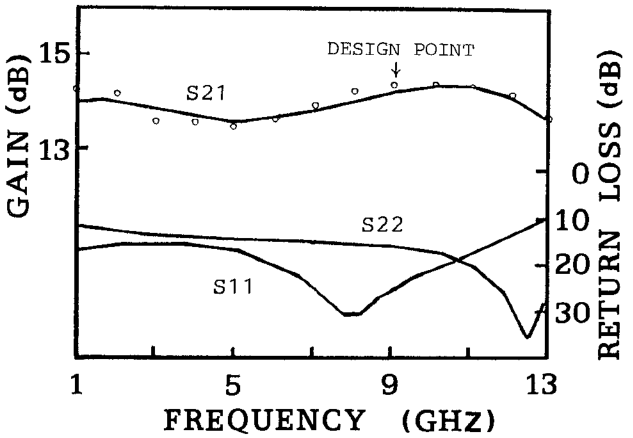

Fig.8 Gain and return loss of the 1 to 13 GHz amplifier

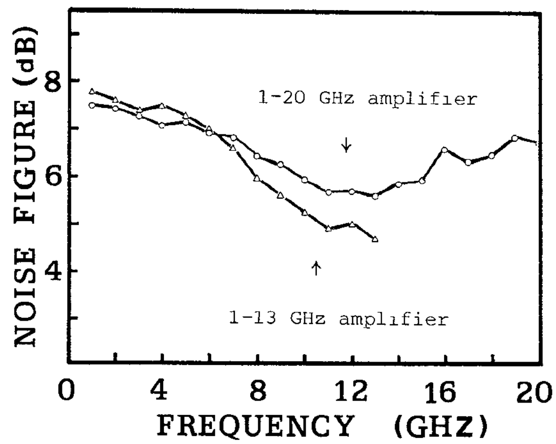

Fig.10 Noise figure

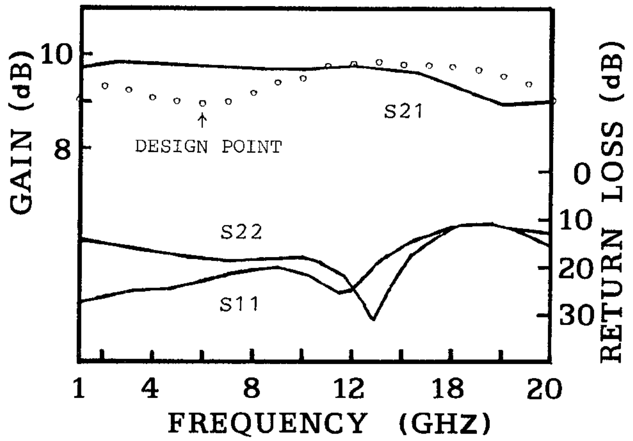

Fig.9 Gain and return loss of the 1 to 20 GHz amplifier

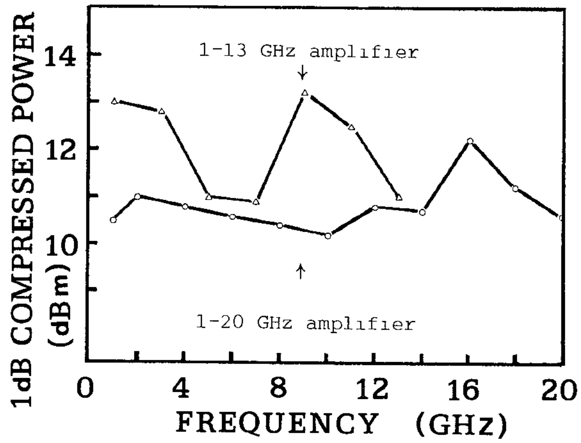

Fig.11 1 dB compressed power

CONCLUSION

Two stage hybrid lossy match amplifiers with 0.3 micron gate length GaAs HEMT's have been designed and fabricated. Using such novel design techniques as input and output networks which show a m-derived low-pass response, interstage network with high impedance, and two types of GaAs HEMT's which have different characteristics, these amplifiers demonstrated high gain-bandwidth product that previous lossy match amplifiers could not achieve. This simple and compact design approach makes it cost effective for a number of applications.

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