ULTRA-BROADBAND LOSSY MATCH AMPLIFIERS

Yasushi Ito, Masayuki Nakajima
Masayuki Kimishima, and Masahito Asa

Aero and Defense Systems Division
Tokyo Keiki Co., Ltd.
2-16 Minamikamata, Ohta-ku, Tokyo 144, JAPAN

ABSTRACT

This paper describes the design, fabrication, and performance of the three stage lossy match amplifier with a gain of 8.0±0.6 dB and return loss of better than 9 dB over the 2 to 32 GHz band. This amplifier uses a novel m-derived low-pass network, and thus shows the widest bandwidth ever reported for a lossy match amplifier.

INTRODUCTION

A lossy match amplification is widely used in both small and large signal devices to absorb the unwanted signals and achieve good input and output matches [1]-[5]. Conventional lossy match amplifiers have been characterized by relatively narrow bandwidth and low gain. This is because the previous design approaches have focused particularly on the synthesis of matching or equalizing network, and have not dealt with the high-gain or ultra-broadband capability of a lossy match amplifier. To address this problem, we introduced a novel design approach to form a m-derived low-pass network by incorporating the intrinsic capacitance of FET's, which makes a broadband matching more difficult, into the design of input and output networks for a wide bandwidth. Furthermore, this approach optimizes the interstage network impedance for a high gain-bandwidth product [6]. However, this design approach had a drawback that there exists a tradeoff between gain and bandwidth when the interstage network impedance is increased.

To overcome this problem, we propose a novel m-derived low-pass network with cutoff frequency of greater than $\sqrt{2}$ times as high as that of a conventional network. The advantage of this novel network is that the gain can be increased without lowering the bandwidth, by increasing the interstage network impedance of a lossy match amplifier.

CIRCUIT DESIGN

A schematic diagram of the three stage hybrid lossy match amplifier is shown in Fig.1, followed by an equivalent circuit of input and output networks in Fig.2. The most significant innovation of this design is to incorporate a novel m-derived low-pass network with cutoff frequency of greater than $\sqrt{2}$ times as high as that of a conventional network, into the design of input and output networks.

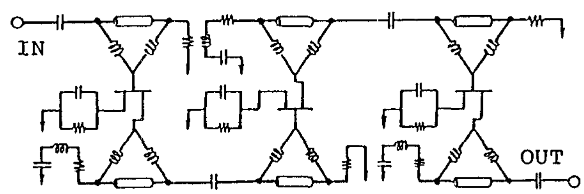
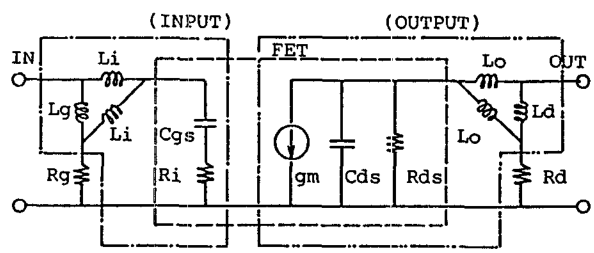


Fig.1. Schematic diagram of the three stage hybrid lossy match amplifier



Lg,Ld -- microstrip inductance
Li,Lo -- bond-wire inductance
Rg,Rd -- terminating resistor

Fig.2. Equivalent circuit of input and output networks

The novel network has two outstanding features when applied to the lossy match amplifier.

First feature is that the cutoff frequency is greater than $\sqrt{2}$ times as high as that of a conventional m-derived low-pass network, though still retaining the same physical dimensions of each circuit element as a conventional network. A theoretical comparison of the conventional and novel m-derived low-pass network is shown in Fig.3 and Table 1. A novel network, as shown in Fig.3(b), is implemented by connecting both ends of a microstrip line and FET through two bond-wires. This can be seen as a parallel connection of FET capacitance (C) and pi-network of microstrip and bond-wire inductances (La,Lb) equivalently. Micro-strip and bond-wire inductances, as well as a cutoff frequency of the novel network are obtained by transforming a novel network to a conventional T-shaped network as shown in Fig. 3(a). The results obtained are listed in Table 1. See Table 1; microstrip inductance values are 0 to La for all the value of Lb, and bond-wire inductance values are less than $\frac{1}{2}$Lb for all the value of La. Therefore, both microstrip and bond-wire inductances can be decreased simultaneously, and as a result, a higher cutoff frequency is achieved. As shown in Table 1, the cutoff frequency of a novel network is greater than $\sqrt{2}$ times as high as that of a conventional network, which improves the bandwidth of a lossy match amplifier significantly.

The second feature is that the gain can be increased without degrading the bandwidth by increasing the interstage network impedance. Using an equivalent circuit as shown in Fig.2, the gain equation for the n-stage hybrid lossy match amplifier can be derived as [6]

$$G = \prod_{k=1}^{n} (gm/2)^2 RgkRdk[1-\omega^2 Cgs(Li^2/(Lg+2Li))]^2 \cdot \frac{\exp(-Agk-Adk)\ [1-(\omega/\omega dk)^2]^{0.5}}{[1+(\omega/\omega o)^2]\ [1-(\omega/\omega gk)^2]^{1.5}} , \qquad (1)$$

where

$$Rgk = [2LgLi/(Lg+2Li)Cgs]^{0.5} \qquad (2)$$

$$Rdk = [2LdLo/(Ld+2Lo)Cds]^{0.5} \qquad (3)$$

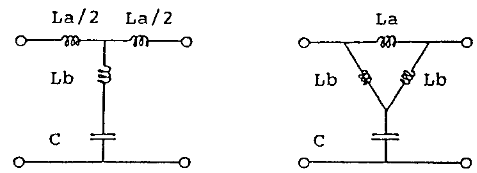
$$\omega gk = (2/LiCgs)^2 \qquad (4)$$

$$\omega dk = (2/LoCds)^2 \qquad (5)$$

$$Agk \simeq Ri(\omega Cgs)^2 Rgk[1-(\omega/\omega gk)^2]^{0.5} \qquad (6)$$

$$Adk \simeq Rdk[1-(\omega/\omega dk)^2]^{0.5}/2Rds \qquad (7)$$

$$\omega o = 1/RiCgs. \qquad (8)$$



La -- microstrip inductance

Lb -- bond-wire inductance

C -- FET capacitance

(a) conventional (b) novel

Fig.3. Conventional and novel m-derived low-pass networks

Table 1. Theoretical comparison of the conventional and novel m-derived low-pass networks

	(a) conventional	(b) novel
MICROSTRIP INDUCTANCE	La	$\frac{2LaLb}{La+2Lb}$
BOND-WIRE INDUCTANCE	Lb	$\frac{Lb^2}{La+2Lb}$
CUTOFF(ωc) FREQUENCY	$\frac{2}{\sqrt{(La+4Lb)C}}$	$\frac{\sqrt{2}}{\sqrt{LbC}}$

Rgk and Rdk, ωgh and ωdk, Agk and Adk denote the characteristic resistance, cutoff frequency, and attenuation of input and output networks, respectively.

As the microstrip inductances (Lg,Ld) of the interstage network are increased, the characteristic resistances (Rgk,Rdk) as shown in equations (2) and (3) increase, and thus, the gain increases. In this case, as shown in equations (4) and (5), the cutoff frequencies (ωgk,ωdk) are not affected by the change of microstrip inductance values (Lg,Ld), therefore bandwidth is not lowered. However, the gain has an upper limit. This maximum value of gain can be obtained by setting microstrip inductance values to infinite, and where the novel network corresponds to a constant-K network.

To demonstrate these features of a novel m-derived low-pass network, the gain performance is obtained by computor simulations for two types of the amplifier with a conventional or novel m-derived low-pass network at different interstage network impedances.

First, the gain performance was obtained for the three stage lossy match amplifier with a novel network as shown in Fig.1, which was designed to show the highest gain and lowest gain ripple over 2 to 32 GHz by increasing interstage network impedances. In this simulation, GaAs FET used is 0.25 X 100 micron GaAs HEMT (SONY SGH5501C), whose equivalent circuit and microphotograph are shown in Figs. 5 and 6, respectively. The result obtained is displayed as Curve (A) in Fig.4. Next, Curve (B) was derived from Curve (A) by decreasing interstage network impedances to 50 ohms. Next, Curve (C) was obtained from Curve (A) by using a conventional m-derived low-pass network with the same length of microstrip lines and bond-wires as a novel network. Finally, Curve (D) was derived from Curve (B) by replacing a novel network with a conventional network in a similar way.

It is clear from Fig.4 that, by using a novel network, bandwidth improvements of greater than $\sqrt{2}$ times can be achieved, and furthermore bandwidth is not lowered by increasing interstage network impedances to attain a high gain. Figs.7 and 8 show the input and output return loss performance for the amplifier with a gain of Curves (A) and (C). It can be seen from these figures that, by using a novel network, a significant improvement can be achieved especially for input return loss. The actual amplifier was designed by using the result of Curve (A).

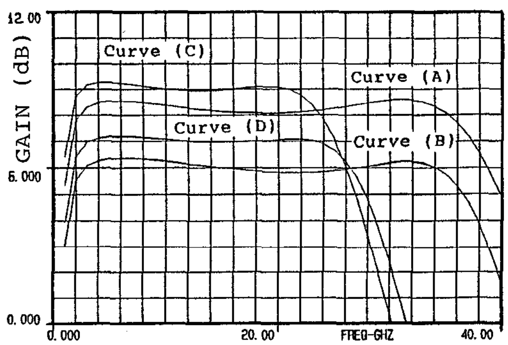


Fig.4. Predicted gain performance of the amplifier with conventional or novel network at different interstage network impedances

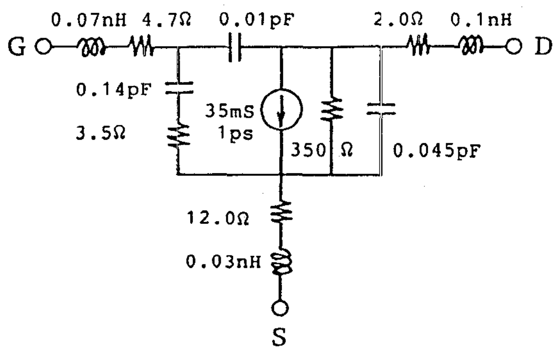


Fig.5. Equivalent circuit of 0.25 X 100 micron GaAs HEMT

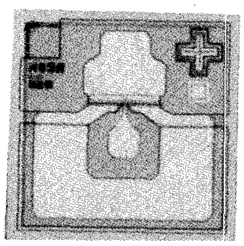


Fig.6. Microphotograph of GaAs HEMT

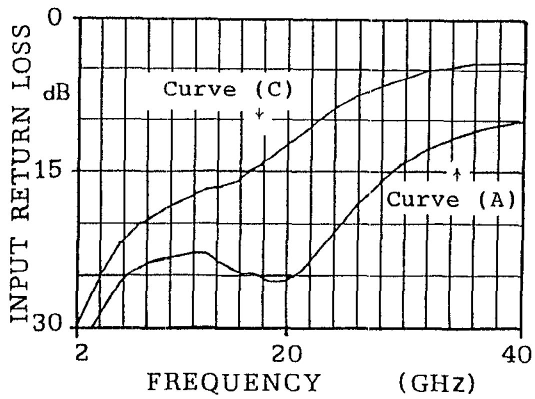


Fig.7. Improvement on input return loss

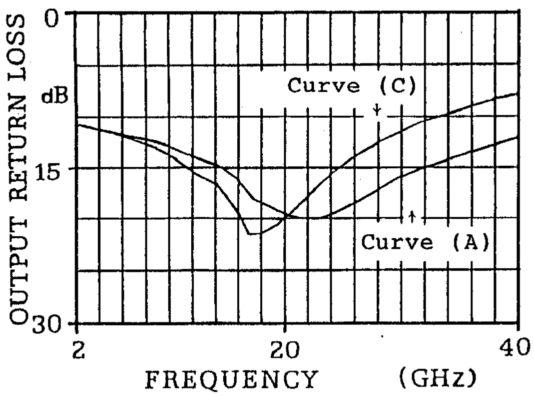


Fig.8. Improvement on output return loss

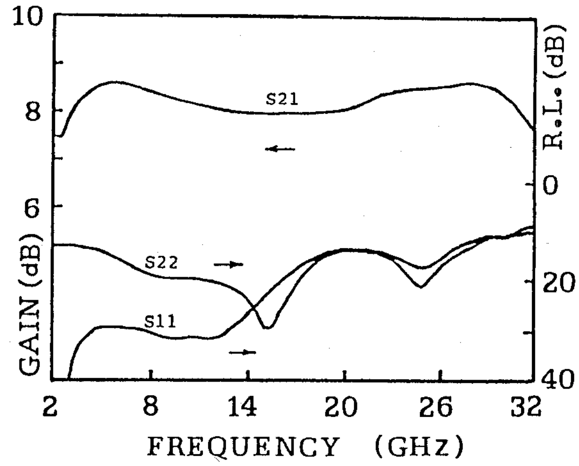


Fig.10. Measured gain and return loss

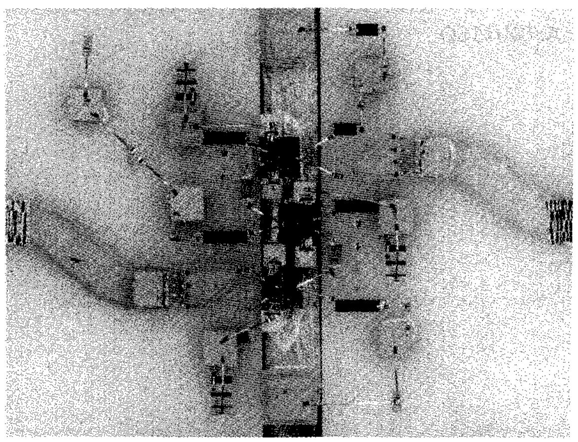


Fig. 9. Photograph of the amplifier

FABRICATION AND PERFORMANCE

A photograph of the three stage hybrid lossy match amplifier with 0.25 X 100 micron GaAs HEMT's appears in Fig. 9. Thin film circuit is fabricated on 0.4 mm thick alumina substrate with TaNx/ Cr / Au microstrip lines. In order to make the length of gate bond-wires as short as possible for a high cutoff frequency, carrier-plates were used to fabricate an amplifier module. Each GaAs FET was die-attached on the input network side of the center rib as well. All RF bypass capacitors have a size of 0.3 X 0.3 X 0.15t mm and capacitance of approximately 22 pF. DC blocking capacitors have a size of 0.1 X 0.1 X 0.15t mm and capacitance of approximately 3 pF. This circuit has a size of 4.0 X 5.4 mm.

The measured gain and return loss performance are shown in Fig.10. Over the 2 to 32 GHz band, this amplifier exhibits a gain of 8.0 ± 0.6 dB and return loss of better than 9 dB. This amplifier shows a measured noise figure of less than 8.8 dB across the 2 to 26.5 GHz band, and has a 1 dB compressed power of greater than 8.2 dBm over the full bandwidth. All data presented was measured at VDS = 2V and IDS = 10 mA. From Figs.4 and 10, a slight discrepancy between measured and predicted gain performance appears at the high end of a design band. This is most likely due to the error in the modeling of GaAs HEMT's at high frequencies.

CONCLUSION

A 2 to 32 GHz three stage hybrid lossy match amplifier has been designed and fabricated. By using a novel m-derived low-pass network with cutoff frequency of greater than $\sqrt{2}$ times as high as a conventional network, the ultra-broadband lossy match amplifier has achieved the unprecedented high gain-bandwidth product.

ACKNOWLEDGMENT

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REFERENCE

[1] K.B.Nicals, "On design and performance of lossy match GaAs MESFET amplifiers, " IEEE Trans. MTT, vol.MTT-30, pp. 1900-1907, Nov. 1982.

[2] K.Honjo, T.Tsuji, and T.Ozawa, " Low-noise, low - power - dissipation GaAs monolithic broadband amplifiers," IEEE GaAs IC Symp., pp.87-90, 1982.

[3] S.Watanabe, K.Nakayama, M.Tatematsu, S.Hori, and K.Kamei," A 1 to 11 GHz broadband monolithic GaAs MMIC amplifier," IEICE Japan NTCV, 805, pp.3-242, Mar. 1986.

[4] D.P.Hornbuckle et al,"Broadband medium power amplification in the 2-12.4-GHz range with GaAs MESFET's," IEEE Trans. MTT, vol.MTT-24, pp.338-342, June 1976.

[5] M.Maoz, H.Badawi, J.Faguet, and R.S. Pengelly,"A fully-integrated, 0.5 W, 2 to 6 GHz MMIC amplifier,"in Proceeding 17th European Microwave Conference, pp.261-266, Sep. 1987.

[6] Y.Ito et al,"GaAs HEMT lossy match amplifiers," IEEE MTT-Symp. Digest, pp. 347-350, May 1988.