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A 4.5 GHZ 40 WATT GaAs FET AMPLIFIER

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Abstract

A high power GaAs FET amplifier with an output power of 40 watts at 4.5 GHz has been developed. Power conbining loss of 1.1 dB was investigated and cooling system using heat pipe was developed.

Introduction

Increase of GaAs FET output power is still remarkable and amplifier output power using these devices also increases, that is, GaAs FET devices with 7 watt output at 10 GHz and 25 watt output at 6 GHz were reported and 6 GHz 20 watt amplifier was also reported. 1), 2), 3)

In this paper, the design philosophy and performance of high power amplifier with a 40 watt output will be described.

The important items of the design for high output power amplifier are power combining technique and cooling system. The combining loss was investigated in detail. As the result, the loss of 1.1 dB was obtained. The cooling system using heat pipes was developed and the thermal resistance was 0.092 degrees C/W.

By using these technique, higher output power amplifier with 40 watt output, a gain of 48 dB and a 3rd order intercept point of 55 dBm over the operating frequency range from 4.4 GHz to 4.6 GHz has been developed.

Power Combining Technique

In order to get 40 watt power output at 4.5 GHz, we have to combine several FET devices, because the biggest device, which was developed at Fujitsu, has an output power of 6 watts with 7 dB gain. It is FLM4450-6. This device has the prematching circuit and also has gate width of 20.8 millimeters and an Idss of 3.6 amperes.

In the final stage of the 40 watt amplifier, 8 pieces of FLM4450-6 are combined using seven branch type 3 dB hybrids and 4 pieces are used in the driver stages. The chip devices are used in the low power stages up to an output power of 1 watt with 30 dB gain shown in figure 1. The regions enclosed with broken-line are four 12 watt amplifier units.

The total combining loss for the final stage of the 40 watt amplifier is estimated as follows. The summarized saturated output power delivered from four 12 watt amplifier units is 47.1 dBm. The estimated output power after combining was 46.4 dBm, that is, power level discounted the combiner dead loss of 0.7 dB from the summarized power. The actual output power of 46dBm (40 watts) for the final stage amplifier was obtained as the experimental result. Therefore the combining loss due to difference between the phases of four 12 watt amplifier units is 0.4 dB. The total combining loss is 1.1 dB.

Developement of Good Heat Sink

High power amplifiers using FETs require a thermal design that can cope with problems of reliability and heat loss can not be solved by conventional means of heat dissipation because of the 260 watt power consumption.

First, the standard aluminum heat sink used for power devices was examined as a means of cooling of a 12 watt amplifier. The amplifier including the series regulator of dc input voltage dissipates a power of 65 watts. If ambient temperature Ta = 50 degrees C, thermal resistance of the FET = 5 degrees C/W and thermal resistance through the intermadiate pass = 0.1 degrees C/W, heat sink must satisfy thermal rise of 6.5 degrees C, and have thermal resistance Rhs of 0.1 degrees C/W to maintain Tch = 150 degrees C as the channel temperature of the FET.

Such a heat sink is not practical, however, and if the figure is increased to Tch = 175 degrees C and Rhs = 0.48 degrees C/W, the resultant fin size is 300 x 200 x 80 in millimeters. Obviously the size is too large to get 40 watts by combining four 12 watt amplifiers because the larger size makes the combining loss larger because of micro strip line length.

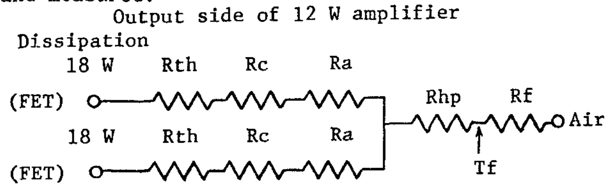
The heat sink must be put apart from the amplifier section. Because of that, the heat pipes are used to transfer large amount of heat from amplifier section to the other place.

In order to use heat pipes effectively, cooling system was designed by some simulations using a computer. To decide the position attaching heat pipe in the amplifier section, a computer program NASTRAN for general-purpose structure analysis was used.

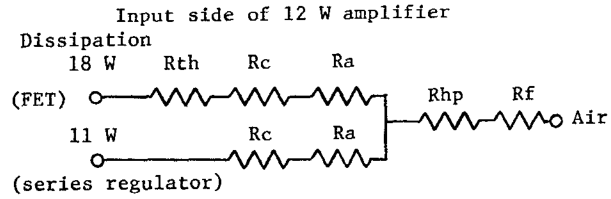
Figure 2 shows thermal distribution of the base plate of the 12 watt amplifier unit obtained by simulation. From the result, two finned heat pipe are attached to the base plate of 12 watt amplifier unit.

The heat circuits shown below was formed for the thermal analysis of the 12 watt amplifier with two finned heat pipes and each value was calculated and measured.

Output side of 12 W amplifier



Input side of 12 W amplifier



Where Rth is thermal resistance of the FET (5 degs C/W),

Rc is thermal resistance of 12 W amp case (0.075 degs C/W),

Ra is thermal resistance of attachment of heat pipe (0.075 degs C/W),

Rhp is thermal resistance of heat pipe (0.106 degs C/W) and
Rf is thermal resistance of fin.

To determine optimum fin shape, first, temperature rise Tf of the fin which is approximated by a circular shape was calculated by following equations.

$$T_f = Q \times \alpha \times \phi \times A_f \qquad (1)$$

Where Q is the value of power dissipation.
Heat transfer efficiency α given by T.Aihara(Tohoku Univ.) is follows.

$$\alpha = \frac{S^3 A}{24}\left[1 - e^{-\left(\frac{32.4}{S^4 A}\right)^{3/4}}\right] \qquad (2)$$

Fin efficiency ϕ given by Japan Society of Mechanical Engineers is follows.

$$\phi = \frac{2}{u_b\left[1 - \left(\frac{u_e}{u_b}\right)^2\right]}\left[\frac{I_1(u_b) - K_1(u_b)}{I_0(u_b) + K_0(u_b)}\right] \qquad (3)$$

A is the area of fin surface. Next, thermal distribution of fins with various shapes was calculated by computer program NASTRAN. As the result, heat radiation structure of the 40 watt amplifier is shown in figure 3 where the shape of the heat pipe is 15 diameter and 315 length and fin shape is 91.5 x 64 x 0.5 in millimeters. Number of the fins attached to one heat pipe is 34 peaces and fin pitch is 6.5 millimeters.

Table 1 shows measured value of temperature rise and differences between measured and calculated value in the structure shown in figure 3. The temperature rise measured at all points agreed well with the design value. As the result, the thermal resistance of the finned heat pipe was 0.092 degrees C/W.

Amplifier Performance

Figure 4 shows frequency responses of output power, output versus input power characteristics and AM-to-PM converson of a 40 watt amplifier with temperature as a parameter. The power consumption of the amplifier section is 246 watts, so the efficiency is 16.3 %. Over all efficiency of the amplifier including the power consumption of dc power supply is 11.8 %. In the dc power supply, switching regulators are used. Figure 5 shows a photograph of the amplifier.

Reference

1). I. Nagasako et al. "Broadband, Pulsed Power Achieved with X-band FET Modules" MSN 11-9 1981 pp 88 - 94
2). A. Higashisaka et al. "A 6 GHz 25 W GaAs MESFET with an experimentally optimized pattern" IEEE MTT-S 1980
3). K. Honjo et al. "15 Watts Internally Matched GaAs FETs and 20 Watts Amplifier Operating at 6 GHz" IEEE MTT-S 1979

Fig. 1 Level and Block Diagram of 40 W Amplifier

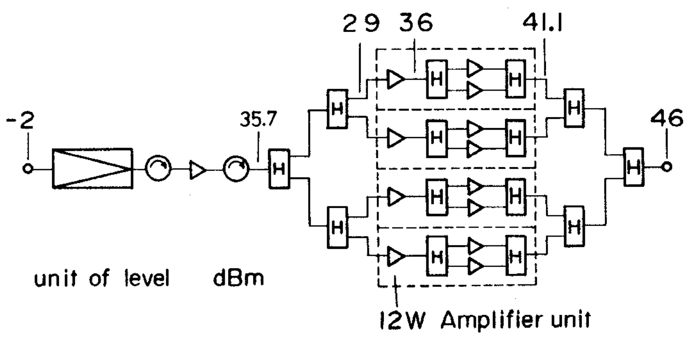
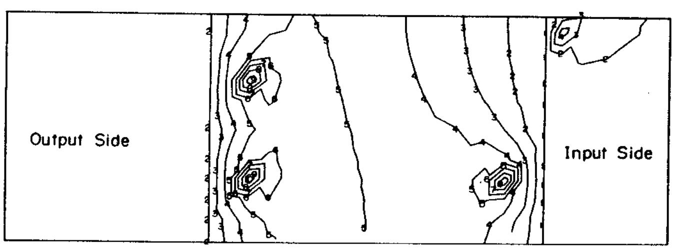


Fig. 2 Thermal Distribution of 12 W Amplifier Unit by Calculation



Symbol	Temperature	Symbol	Temperature
1	41.3°C	6	43.7°C
2	41.7°C	7	44.2°C
3	42.2°C	8	44.7°C
4	42.7°C	9	45.2°C
5	43.2°C	10	45.6°C

Table 1 Temperature Rise for a 40 W Amplifier

Thermal path (measured point)	Measured value	Difference between Measured and Calculated Value
Ambient temperature T_{air}	24.0°C	-
Top amplifier module		
• Fins output side	Δ 19.0°C	ΔΔ 0.8°C
input side	Δ 17.0°C	ΔΔ 2.3°C
• Attachment output side	Δ 24.0°C	ΔΔ 0.7°C
input side	Δ 20.0°C	ΔΔ 0.9°C
• Maximum module temperature	Δ 28.5°C	ΔΔ 3.8°C
• Channel temperature	Δ118.5°C (T_{ch} = 143.5°C)	ΔΔ 3.8°C
Second amplifier module		
• Maximum module temperature	Δ 26.5°C	ΔΔ 1.8°C
• Channel temperature	Δ116.5°C (T_{ch} = 141.5°C)	ΔΔ 1.8°C
Third amplifier module		
• Maximum module temperature	Δ 26.5°C	ΔΔ 1.8°C
• Channel temperature	Δ116.5°C (T_{ch} = 141.5°C)	ΔΔ 1.8°C
Bottom amplifier module		
• Maximum module temperature	Δ17.5°C	-ΔΔ7.2°C
• Channel temperature	Δ107.5°C (T_{ch} = 132.5°C)	-ΔΔ7.2°C

Fig. 3 Heat Radiation Structure of a 40 W Amplifier

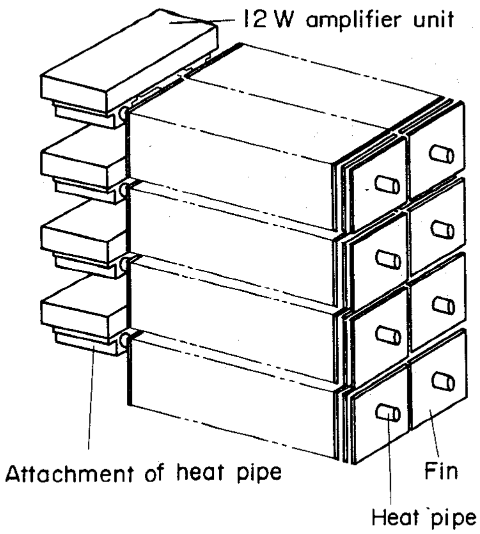


Fig. 4 Characteristics of a 40 W Amplifier

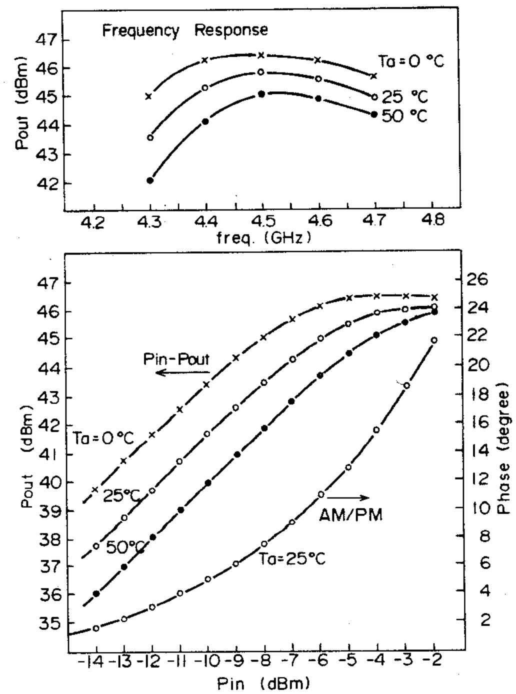


Fig. 5 Photograph of a 40 Watt Amplifier