PP-17

Direct Measurement of the Optimum Source impedance for Minimum Noise Figure

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ABSTRACT

A new measurement system and method measuring the optimum source impedance for the minimum noise figure of the transistor on the wafer has been developed by using the microwave wafer prober system.

The new measurement system is constructed from four blocks: 1)network analyzer 2)noise meter 3) microwave wafer probers 4) coaxial switches that connect the 1) ~ 3) blocks. After tuning to the minimum noise point by connecting the noise meter and microwave probers, these probers are turned to the network analyzer by coaxial switches, and then source (or load) impedance is measured continuously.

The optimum source impedance is measured by two different methods: ("REAL-TIME method" and "50-SHORT-OPEN method"). Two measurement methods showed a little phase difference.

Using this system and methods, we have designed the low noise MMIC amplifier operating at 12GHz and evaluated. It showed the the minimum noise figure without another tuning.

INTRODUCTION

The most important thing to design the low noise Microwave Monolithic IC (MMIC) is to connect the optimum source impedance for the minimum noise figure to the input of the transistor. [1-3] However, there were no such simple system and method to measure the optimum source impedance of the intrinsic transistor because of the difficulty to measure the noise characteristics on the wafer. It isn't so difficult to measure the optimum source impedance of the packaged transistor. The measured impedance data of the packaged transistor include the inductance of the bonding wire and capacitance of the package. In designing the low noise MMIC amplifier, the intrinsic impedance data of the transistor is needed. To solve these problem, we have developed the new measurement system and methods.

MEASUREMENT SYSTEM

Figure 1 and 2 show the photograph and the block diagram of the measurement system that we developed, respectively. One pair of the microwave wafer prober and slide screw tuner is connected to the network analyzer and noise meter by using the coaxial switches.

After tuning to the minimum noise point, the probes are turned to the network analyzer and then source (or load) impedance is measured. In this system, the noise and gain characteristics of the intrinsic transistor on the wafer can be measured continuously and automatically.

The measured impedance data can be used for designing the matching circuit of the MMICs directly, because it doesn't include the inductance of the bonding wire and the capacitance related to the package.

MEASUREMENT METHOD

Two measurement methods of the optimum source impedance are shown in Fig. 3. The first one is "50-SHORT-OPEN method", and the second is "REAL-TIME method".

In the "50-SHORT-OPEN method", three terminations (50 ohm, short and open) are connected to the tip of the microwave wafer prober after tuning to the minimum noise point. The source impedance is calculated by using three impedance data as shown in Fig.4. The optimum source impedance is calculated as E_{22} in this method.

In the "REAL-TIME method", source impedance is measured directly from the tip of the prober by the another prober(output side probe in the through condition), connecting the two probes with the through pattern made on the sapphire or another substrate.

Two measurement method is compared in Fig.5. The phase of "REAL-TIME method" is larger than that of the "50-SHORT-OPEN method" because the through pattern is used in the "REAL-TIME method". We used the length of 150µm as the through pattern. Although there is the phase difference about 10 or 15 degree between two method, "REAL-TIME method" is convenient and speedy method and "50-SHORT-OPEN method" is correct one to measure the source impedance in this system.

Matching area of the impedance at f=12GHz measured from the tip of the prober is shown in Fig.6. It is equal to the impedance seen from the transistor side. The area is measured in the condition that the 50 ohm termination is connected to the another side of the tuner. Because of the prober loss about 1.2 dB at 12 GHz, the matching area becomes small. If the minimum noise point is located outside the slashed area shown in Fig.6 , this system cannot match to it. It is the limitation of this system. The matching area depend on the prober loss.

MEASUREMENT OF THE OPTIMUM SOURCE IMPEDANCE

Figure 7 shows the noise characteristics of the FET on the wafer before and after tuning. The noise figure after tuning is still very large, because it includes the cable loss and prober loss in the input and output of the system. However, FET is tuned to the minimum noise point. After tuning, the system is switched to the network analyzer and the optimum source impedance is measured. Figure 8 shows the minimum noise point and the constant noise circle measured in this system. The minimum noise figure of this measurement is 6.5dB and the constant noise circle of 6.8dB with intentionally off-tuning from the minimum noise point is shown in Fig.8.

DESIGN AND EVALUATION OF THE MMIC

Using the optimum source impedance data that has been measured in this system and method, we have designed the one stage MMIC amplifiers operating at 12 GHz and evaluated its characteristics. The input side of the matching circuit is designed to meet the measured optimum source impedance and the output side is designed to give the maximum gain. In the design of the matching circuit, we consider the inductance of the bonding wire.

Figure 9 is the photograph of the MMIC amplifier mounted in the package. The noise characteristics of the one stage MMIC amplifier is shown in Fig.10. Three kinds of the noise figures are plotted in Fig.10, which are the data before tuning (through in Fig.10), after tuning (tune in Fig.10) and after calibration (calib. in Fig.10). there's no need using the tuners to minimize the noise figure, because the data before tuning (through) and the data after tuning (tune) are all the same, as shown in Fig.10 . It means that measured source impedance using this system and method is correct or very close to the optimum source impedance that gives minimum noise figure. The minimum noise figure of 2.8 dB has been obtained from the MMIC amplifier mounted in the package.

[S] parameter of the low noise MMIC amplifier is shown in Fig.11. The return loss of the input side is very bad, because the matching circuit of the input side is designed to match the optimum source impedance for minimum noise figure. The gain of this MMIC amplifier is 5.4dB at 12 GHz.

CONCLUSION

The measurement system and method of the optimum source impedance for minimum noise figure has been developed. Using this system and method, we have design the low noise MMIC amplifier operating at 12GHz and evaluated successfully. It showed the the minimum noise figure without another tuning.

This system and methods are very powerful tools in designing the low noise MMIC amplifiers.

ACKNOWLEDGMENT

The authors would like to thank Dr. H. Mizuno, Dr. S. Horiuchi and Dr. T. Kaziwara for their encouragement throughout this work.

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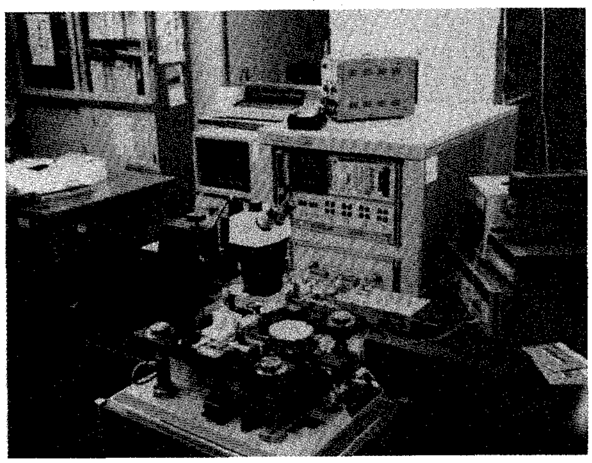


Fig. 1 Photograph of the measurement system

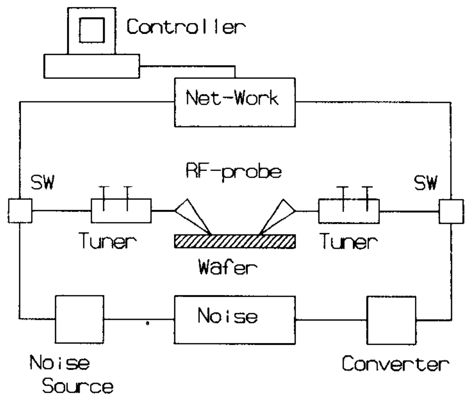


Fig. 2 Block diagram of the measurement system Network analyzer and noise meter are connected to the probe, using coaxial switches.

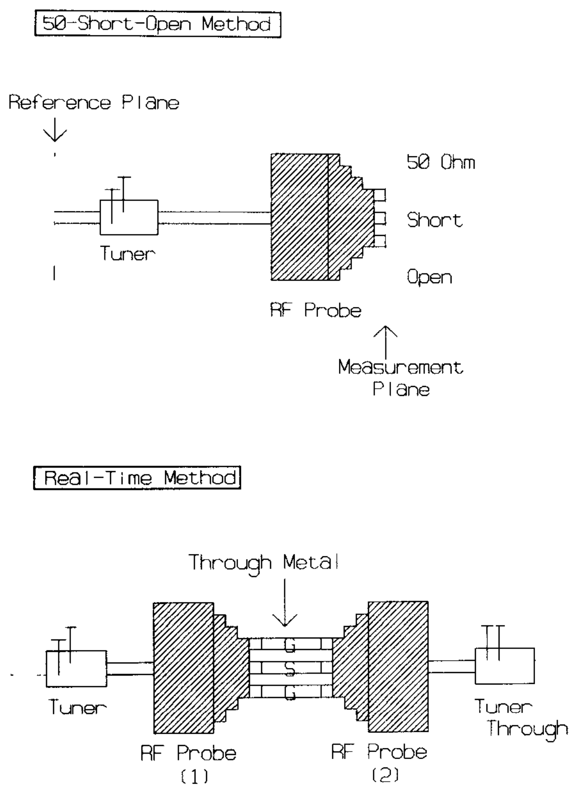
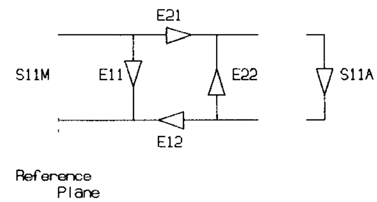


Fig. 3 Two measurement methods of the optimum source impedance
a) "50-SHORT-OPEN method"
b) "REAL-TIME method"

<< 50-Short-Open Method >>



$$S_{11M} = E_{11} + \frac{S_{11A} * E_{21} * E_{12}}{1 - E_{22} * S_{11A}}$$

1) SHORT

$$S_{11S} = E_{11} + \frac{(-1) * E_{21} * E_{12}}{1 - E_{22} * (-1)}$$

2) OPEN

$$S_{11O} = E_{11} + \frac{(+1) * E_{21} * E_{12}}{1 - E_{22} * (+1)}$$

3) LOAD

$$S_{11L} = E_{11}$$

Optimum Source Impedance

$$E_{22} = \frac{S_{11S} - S_{11L} - (S_{11L} - S_{11O}) / S_{OPEN}}{S_{11O} - S_{11S}}$$

Fig. 4 Calculation of the source impedance in the "50-SHORT-OPEN method"

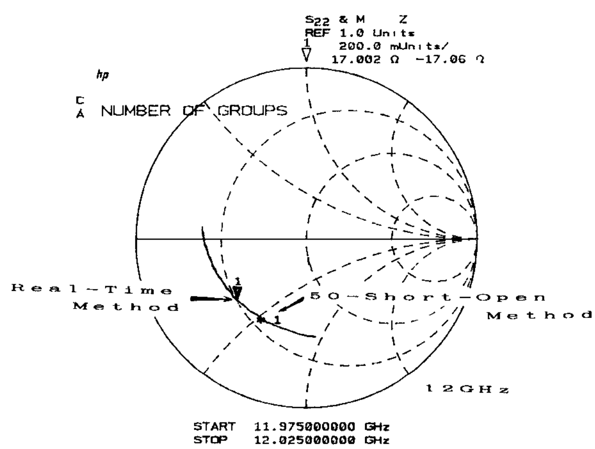


Fig. 5 Comparison of the measured source impedance

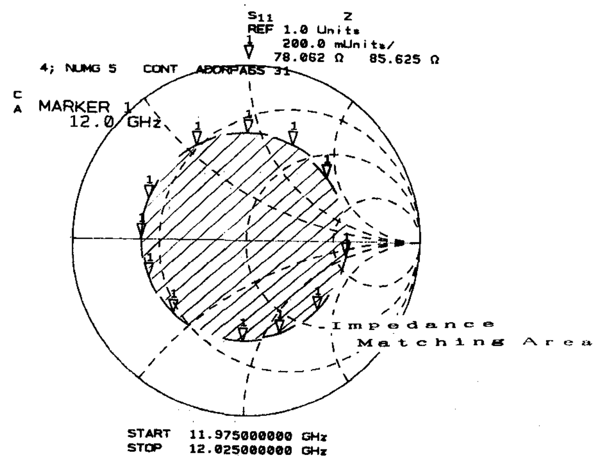


Fig. 6 Matching area of this system, measured from the tip of the microwave wafer prober

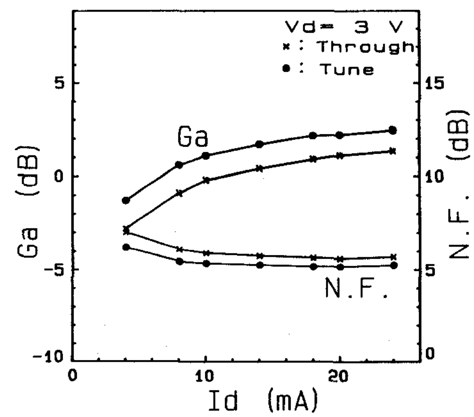


Fig. 7 Noise characteristics of the MESFET on the wafer

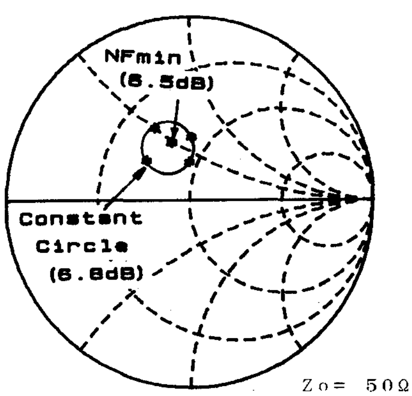
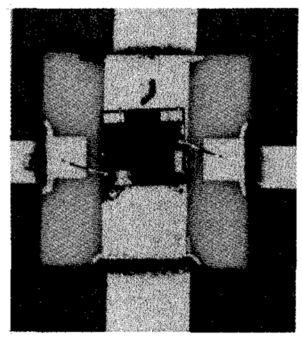


Fig. 8 Minimum noise point and constant noise circle



Chip Size: 0.9mm * 1.0mm

PKG Size: 2.54mm* 2.54mm

Fig. 9 Microphotograph of the one stage MMIC amplifier mounted in the package

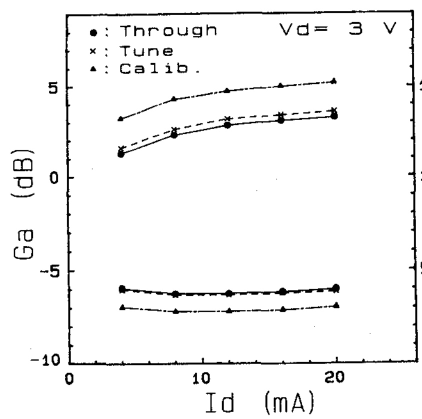


Fig. 10 Noise characteristics of the one stage amplifier The amplifier showed the minimum noise figure without another tuning.

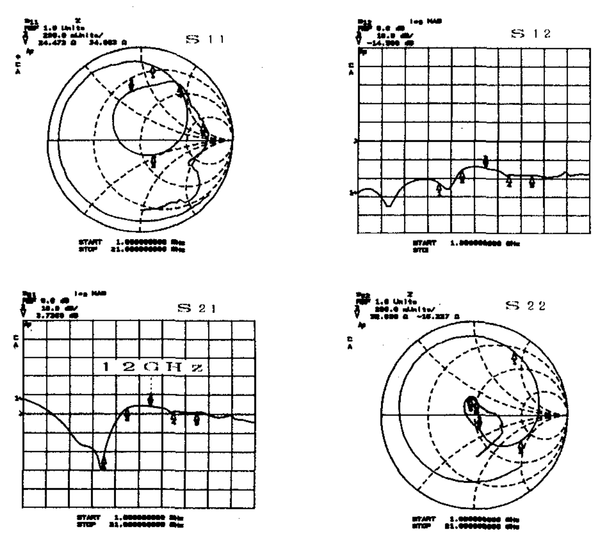


Fig. 11 [S] parameter of the one stage MMIC amplifier