A TECHNIQUE FOR DERIVING NOISE-PARAMETERS OF MILLIMETER-WAVE LOW-NOISE HEMTs AND ITS APPLICATION TO MMIC LNA DESIGN

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ABSTRACT

An on-wafer tuning method has been applied to derive noise parameters of pseudomorphic HEMTs measured at W-band and K-band. As an application of the method, a K-band MMIC LNA with 1.6 dB NF and greater than 32 dB gain has been successfully developed.

I. Introduction

Automatic noise parameter measurement equipments with electrical or mechanical tuners are commonly used for characterizing low-noise HEMT and FET devices. However, measurable frequency range of the equipments are still limited up to 40 GHz or less. This is because the optimum source impedances can not be realized with these measurement equipments due to their losses at higher frequency range.

In this paper, a simple method has been introduced for deriving noise parameters of HEMT and FET devices at millimeter-wave frequencies. The on-wafer tuning method introduced by Schmukler[1] has been used to vary source impedances. Noise equivalent circuit parameters have been derived from on-wafer measurements at W- and K-band. The method has been successfully applied to the design of a K-band 3-stage MMIC LNA.

II. HEMT device with tuning section

Figure 1 shows a pattern layout of a HEMT test element used for our noise parameter extraction at W-band. This is a 0.1 μ m×50 μ m gate HEMT with a coplanar input tuning section and output pads. The coplanar on-wafer probes are used for the input/output interfaces in the following whole measurements.

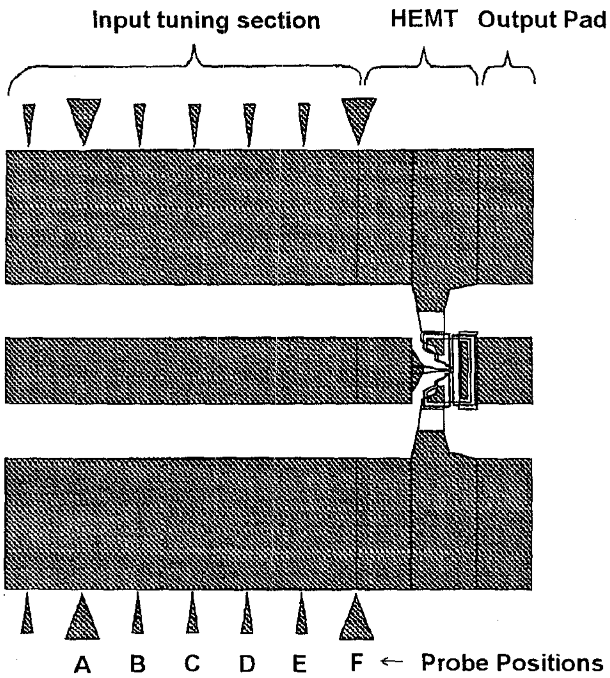

Fig. 1 Pattern layout of HEMT test element.

The input tuning section is an extended input coplanar pad that enables tuning of source impedances. By moving the contact position of the on-wafer probe, the source impedance can be varied continuously without any additional losses. The input tuning section should be designed so as to give the optimum source impedance (Γ opt) when the on-wafer probe is attached to a suitable position. The length of the tuning section has been determined to be 320 μ m. Triangular markers named A to F are arranged at 50 μ m intervals along the input tuning section to distinguish the probe contact position. A

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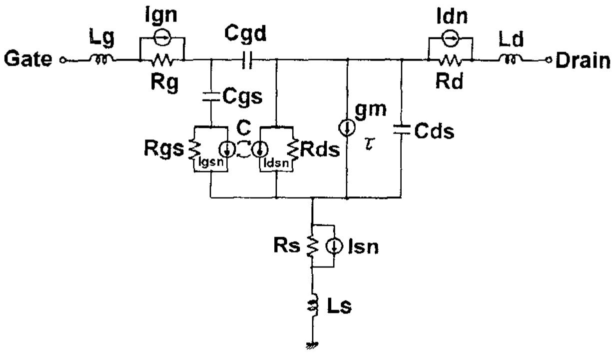

Fig. 5 Noise equivalent circuit.

Table 1 Equivalent circuit parameters of 0.1 μm×50 μm gate P-HEMT derived from W-band measurements.

gm (mS)	29	Rgs (Ω)	0.4	Lg (pH)	54
Cgs (fF)	51	τ (ps)	0.4	Ld (pH)	45
Rds (Ω)	240	Rg (Ω)	4.0	Ls (pH)	3.3
Cgd (fF)	16	Rs (Ω)	4.4	|C|	1.0
Cds (fF)	18	Rd (Ω)	4.2	∠C(deg)	-6
Ign (pA/√Hz)	17	Isn (pA/√Hz)	82	Idn (pA/√Hz)	16
Igsn (pA/√Hz)	400	Idsn (pA/√Hz)	20		

and correlation factor by fitting the measured noise figures of the test element and calculated noise figures of the equivalent circuit at respective probe positions.

IV. Results

Table 1 lists the obtained parameters for the noise equivalent circuit. From these parameters, the minimum noise figures have been calculated as a function of frequency assuming that the correlation factor and noise currents are constant for all frequencies.

Figure 6 presents the calculated minimum NF with measured data for our previously manufactured discrete P-HEMT chips. The measured data were taken at 30, 42, 60 and 94 GHz, respectively, for different P-HEMT chips. Good agreement is found between measured and calculated data.

Table 2 shows an example of the noise parameters calculated from the equivalent circuit. This is the first data obtained at W-band measurements.

K-band measurements have been made for

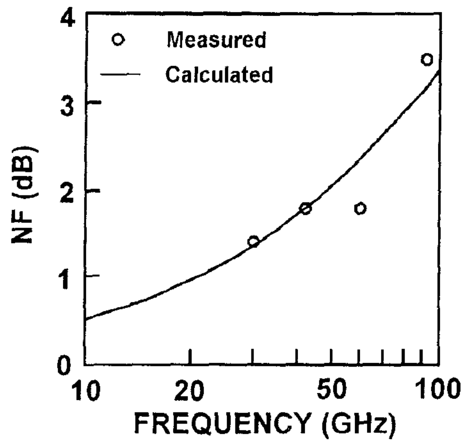

Fig. 6 Calculated Fmin vs. frequency and measured minimum NF of 0.1 μm × 50 μm gate P-HEMT.

Table 2 Derived noise parameters of 0.1 μm ×50 μm gate P-HEMT at 91.8 GHz

Γ opt	0.61∠ -168°
Rn (Ω)	6.5
Fmin (dB)	3.2

Table 3 Equivalent circuit parameters of 0.1 μm×100 μm gate P-HEMT derived from K-band measurements.

gm (mS)	65	Rgs (Ω)	4.8	Lg (pH)	33
Cgs (fF)	92	τ (ps)	0.1	Ld (pH)	40
Rds (Ω)	143	Rg (Ω)	5.5	Ls (pH)	0
Cgd (fF)	19	Rs (Ω)	3.6	|C|	0.05
Cds (fF)	19	Rd (Ω)	1.8	∠C(deg)	-65
Ign (pA/√Hz)	28	Isn (pA/√Hz)	90	Idn (pA/√Hz)	5
Igsn (pA/√Hz)	28	Idsn (pA/√Hz)	29		

a 100 μm gate width device fabricated on the other wafer. Table 3 and 4 show the equivalent circuit parameters and noise parameters derived from the K-band measurements. Discrepancies between table 1 and 3 can be found in noise currents and parasitic resistances when the scaling of gate

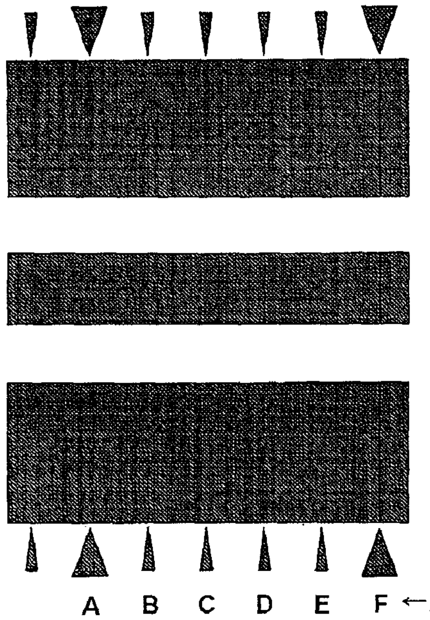

Fig. 2 Pattern layout of tuning section test element.

tuning section test element as shown in Fig. 2 has been formed on the same wafer to measure the source impedances independently.

III. Parameter extraction procedure

The first step to derive the noise equivalent circuit parameters is to measure the NF and S-parameters of the HEMT test element and S-parameters of the tuning section test element with moving the probe contact position. Figure 3 shows the measured NF characteristics of the HEMT test element for several source impedances. Figure 4 presents plots of measured impedance loci of the tuning section test element. These impedance loci correspond to the source impedances referred to the gate input of the HEMT test element. It is seen that the probe position E gives the minimum NF at 91.8 GHz, and hence, the impedance locus E seems to be the closest to the optimum source impedance. The same measurements were made for more than 20 samples of HEMT test elements in the same wafer. These measurements have shown that each HEMT test element gives the minimum NF at the same contact position. The minimum NF values have straggled within ±0.5 dB.

The next step is to derive the equivalent circuit parameters of the HEMT except for the

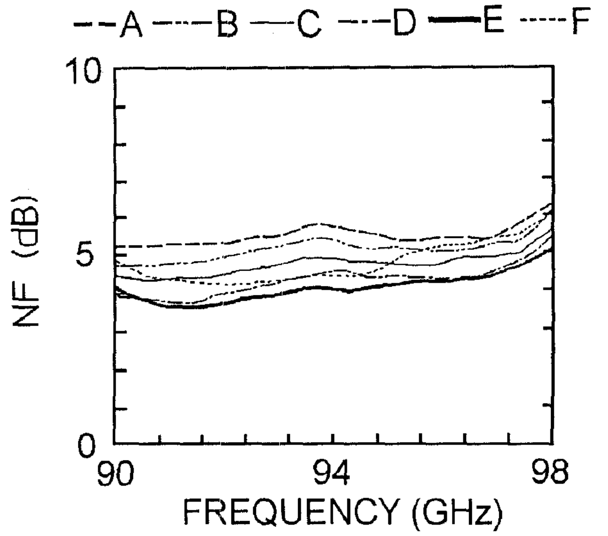

Fig. 3 NF of HEMT test element measured at various probe positions.

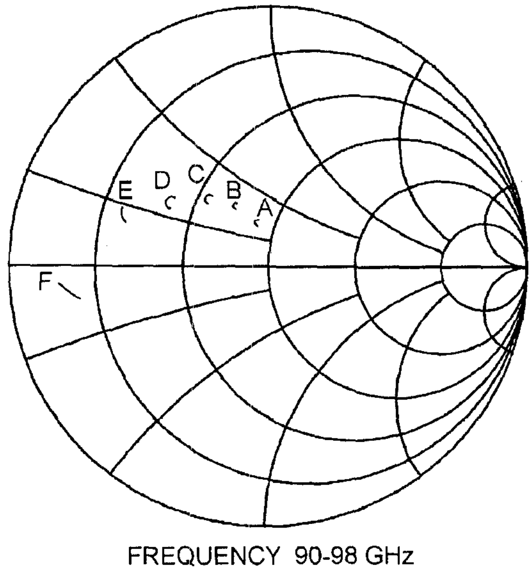

Fig. 4 Measured impedance loci of tuning section test element. A~F correspond to the positions shown in Fig. 1

noise related parameters, such as the noise current sources and the correlation factor. Figure 5 shows the equivalent circuit used in this work. The measured S-parameters of the test element and the tuning section are used in this step for fitting the measured and calculated S-parameters.

The final step is to derive noise currents width is taken into consideration. These may be due to the fact that the equivalent circuit parameters are derived from narrow band measurements. The accuracy will be improved, if the bandwidth of the measurements are increased.

V. Application to MMIC LNA design

This method is applied to the design of a K-band MMIC LNA in order to confirm the validity of the method. Figure 7 shows a top view of a 3-stage P-HEMT K-band LNA (Low Noise Amplifier) chip. The chip size is 3.5 mm x 1.5 mm. The gate width of the HEMTs is 100 μm. The measured and calculated gain and NF characteristics are depicted in Fig. 8. The calculated and measured curves agree well as expected. An NF of less than 1.6 dB and a gain of greater than 32 dB have been obtained between 19 and 21 GHz. The slight discrepancy in gain may be attributed to the varieties of the transcondactance (gm) of the HEMT.

VI. Conclusion

The noise parameters of P-HEMT have been derived from W- and K-band measurements by using the on-wafer tuning method. The K-band 3-stage MMIC LNA designed from the derived noise parameters shows good agreement between the measured and calculated characteristics. This result clearly indicates that the on-wafer tuning method is useful for deriving accurate noise parameters.

Acknowledgment

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Reference

(1) B. C. Schmukler, "Coplanar on-wafer matching structures tunable by RF-probe position," in 1994 IEEE International Microwave Symposium Digest, vol. 3, pp. 1481-1484.

Table 4 Derived noise parameters of 0.1 μm × 100 μm gate P-HEMT at 21 GHz

Γ opt	0.58$\angle$ 67°
Rn (Ω)	12.7
Fmin (dB)	0.91

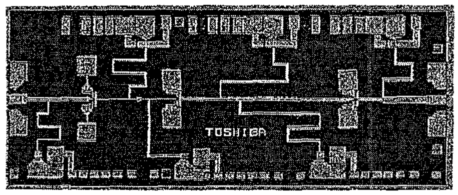

Fig. 7 Top view of K-band 3-stage MMIC LNA

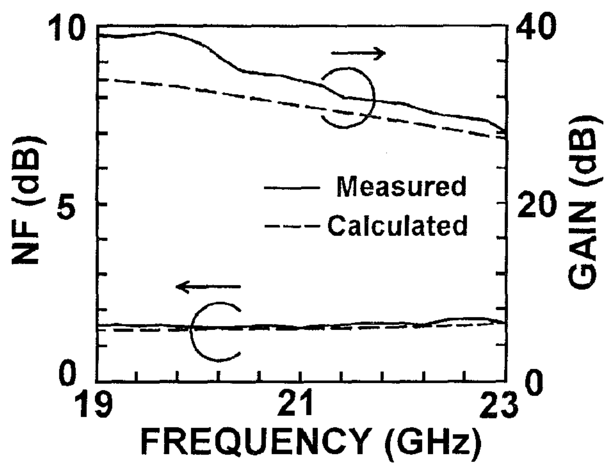

Fig. 8 NF/Gain of K-band 3-stage MMIC LNA.