MILLIMETER-WAVE NOISE PARAMETERS OF HIGH PERFORMANCE HEMT'S AT 300 K AND 17 K

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ABSTRACT

Measurements at 43 GHz of the four noise parameters of very low-noise HEMT's fabricated at several laboratories are reported. The measurements are facilitated by tunable waveguide-to-microstrip transitions which present known, variable generator and load impedances to the device under test and are operable over a wide range of temperature.

The measurement of the noise parameters of very low-noise devices at very high frequencies remains one of the most difficult microwave metrology problems for the following reasons:

1) The noise contributed by circuit losses are often comparable to the noise contributed by the device and thus must be accurately known.

2) The noise contributed by the thermal noise of the generator impedance is larger than the noise of the device. Thus, a given percentage error of measurement of the total noise power produces a larger percentage error in the device noise.

3) The devices often have low gain (of the order of 3 to 9 dB) and the second stage noise contribution is often high and further contributes to error multiplication.

4) While having low gain at the test frequencies, the high performance devices have very high gain at lower frequencies, are potentially unstable, and will oscillate unless special precautions are taken.

5) The device is usually in chip form and there is difficulty in defining the measurement plane and in making a temporary contact to the chip.

6) The required generator and load impedances are usually far from 50 ohms which is central to both calibration standards and to the range of transmission line characteristic impedances.

7) If semiconductor devices are used to vary the generator impedance, unknown noise may be contributed. (This is not the case for varactors which should exhibit only thermal noise.)

Our approach to these problems is to use a tunable, calibrated transition from waveguide to microstrip at both the input and output of the device under test. A photograph of two tuners connected to a chip carrier is shown in Figure 1 and a cross-section drawing of the configuration is shown in Figure 2. Non-contacting waveguide movable shorts provide repeatable and low-loss variation of impedance at the device measurement plane; the position of each short is measured with a miniature linear position sensor which is accurate to 0.2 mm and repeatable to .02 mm even at cryogenic temperatures. Each tuner includes a microstrip substrate as shown in Figure 3 which provides DC bias, termination of low frequencies, and impedance transformation.

The tuner is fully analyzed and calibrated in the thesis of Rothman [1]. The analysis utilizes well-proven theoretical analyses of the waveguide E-plane T-junction and microstrip substrate and 10.2 times scale model measurements of the waveguide-to-microstrip probe transition; these results were partially checked by scaler analyzer measurements of back-to-back tuners. A 43 GHz network analyzer well calibrated at the microstrip reference plane was not available for direct calibration of the tuner.

A block diagram of the noise measurement system is shown in Figure 4. The device under test, including its associated tuners, is driven by a 10 db waveguide attenuator which provides a known, matched impedance and also provides a low generator noise temperature and, hence, reduces error multiplication when it is cooled along with the device under test. The excess noise temperature of a noise diode at the reference plane of the attenuator output was determined by substituting hot and cold terminations at this plane in the form of a small horn with beam emersed in foam absorber material which is either at room temperature or saturated with liquid nitrogen.

The input tuner is adjusted to provide four or more generator impedances which may or may not include the optimum noise impedance, Z_{opt}, and the output tuner is adjusted for maximum gain. A least-square error computer analysis using the method of Caruso and Sannino [2] gives the four noise parameters and also the sensitivity of each noise parameter to error in each measurement. Results are shown in Table I for four very high performance AlGaAs HEMT devices. The table includes references to papers describing device structure and for both 300 K and 17 K, optimum bias conditions, transconductance, and noise parameters. The optimum source reactance parameter, X_{opt}, includes the bond wire reactance, estimated to be 30 ± 10 ohms as part of the device. The noise parameter, N , determines the sensitivity to noise match, is equal to $R_{opt}*g_n$ where g_n is the noise conductance, and is chosen because it is independent, along with T_{min}, of additional reactances (such as produced by packaging) in input and output networks of the device. The parameter T_{casc} is the noise temperature of an infinite cascade of identical devices assuming interstage noise match; it is given by $T_{min}/(1-G_a^{-1})$ where G_a is the associated gain and is also the noise measure times 290 K.

The error limits quoted in Table I are a measure of the sensitivity of the noise parameters to the measurements and are a function of Z_{opt} relative to the generator impedances of the set of

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measurements; the quoted values are the errors which would be produced by a ± 10% noise temperature error of the most error-sensitive measurement. To this error we must add systematic errors due to calibration of the tuner and noise source; we estimate these to be ± 10% for T_{min}, ± 2 ohms for R_{opt}, and ± 4 ohms for X_{opt}. However, the relative error from one device to another for T_{min} should be smaller and we believe this measurement of devices from different manufacturers in the same optimizable set-up provides a fair comparison of performance.

REFERENCES

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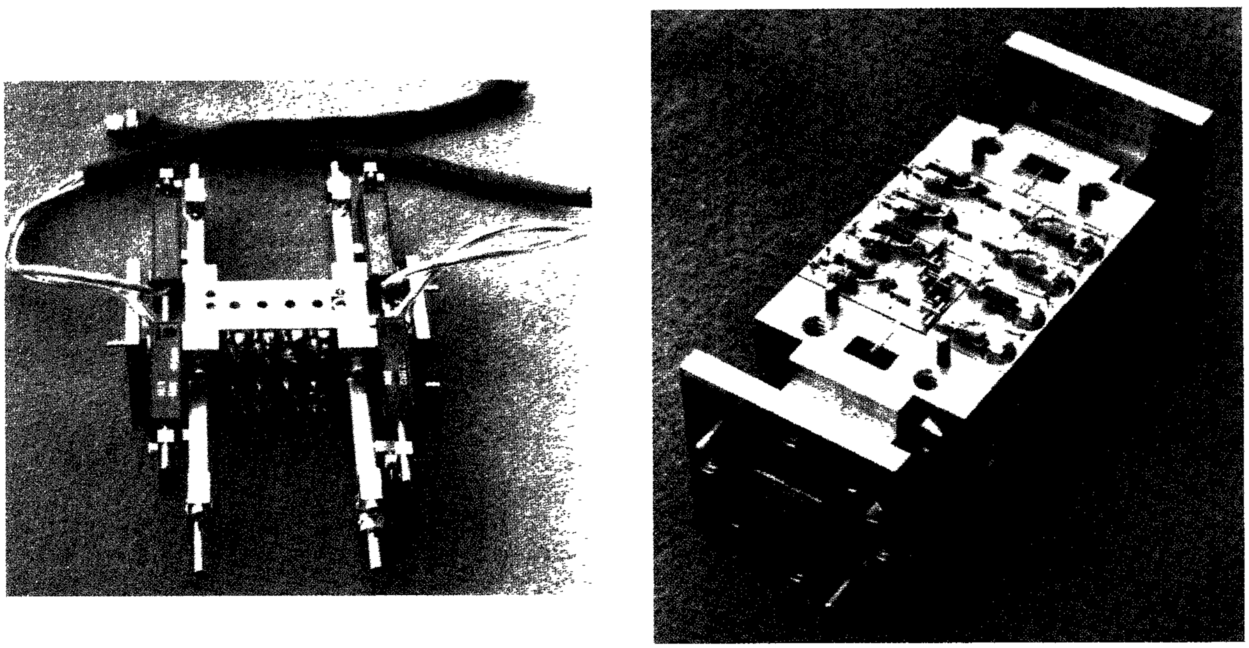

Fig. 1. Photograph of four-stage amplifier with input and output tuner-transitions including position readouts is shown at left while the amplifier with backshorts removed is shown at right.

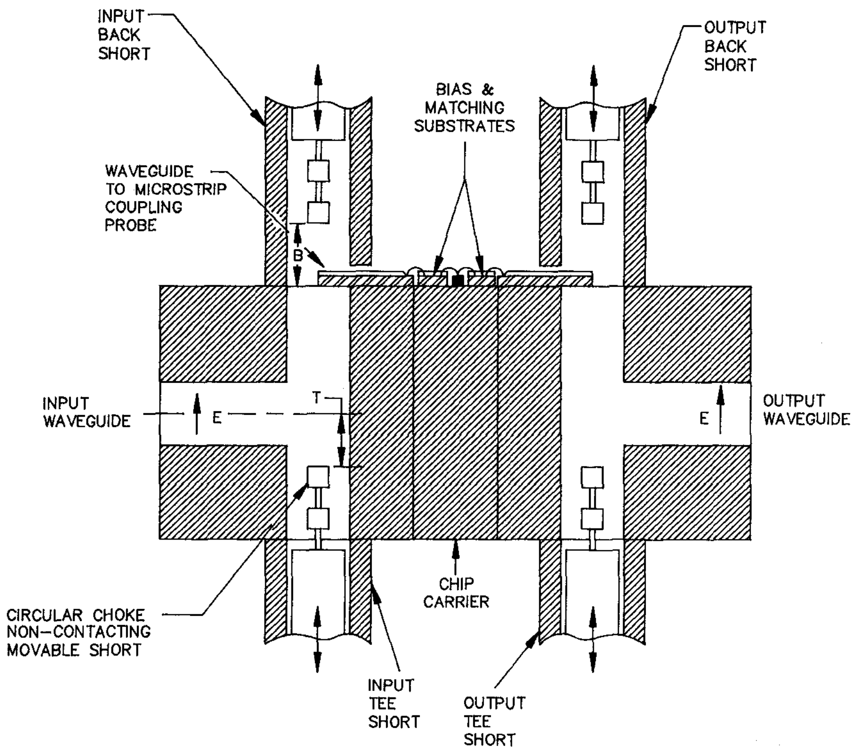

Fig. 2. Cross-section view of two calibrated tuner-transitions and a chip carrier block. The microstrip substrates are .125 mm thick crystalline quartz.

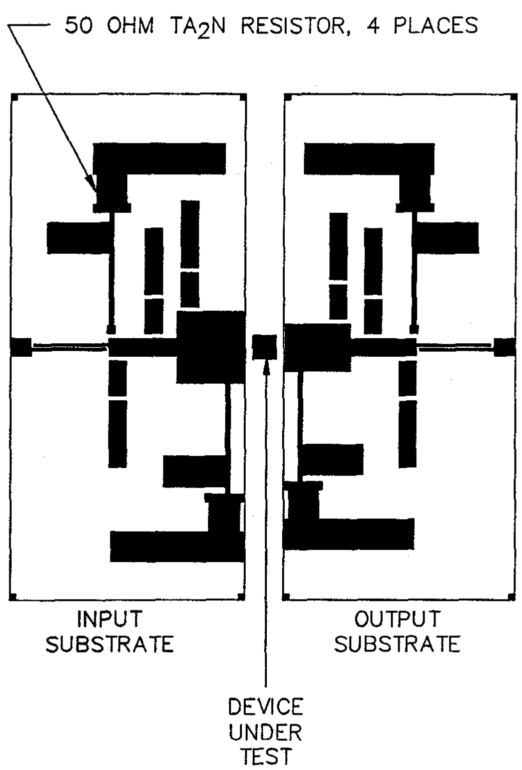

Fig. 3. Crystalline quartz microstrip substrates, .125 mm thick, used in the test configuration.

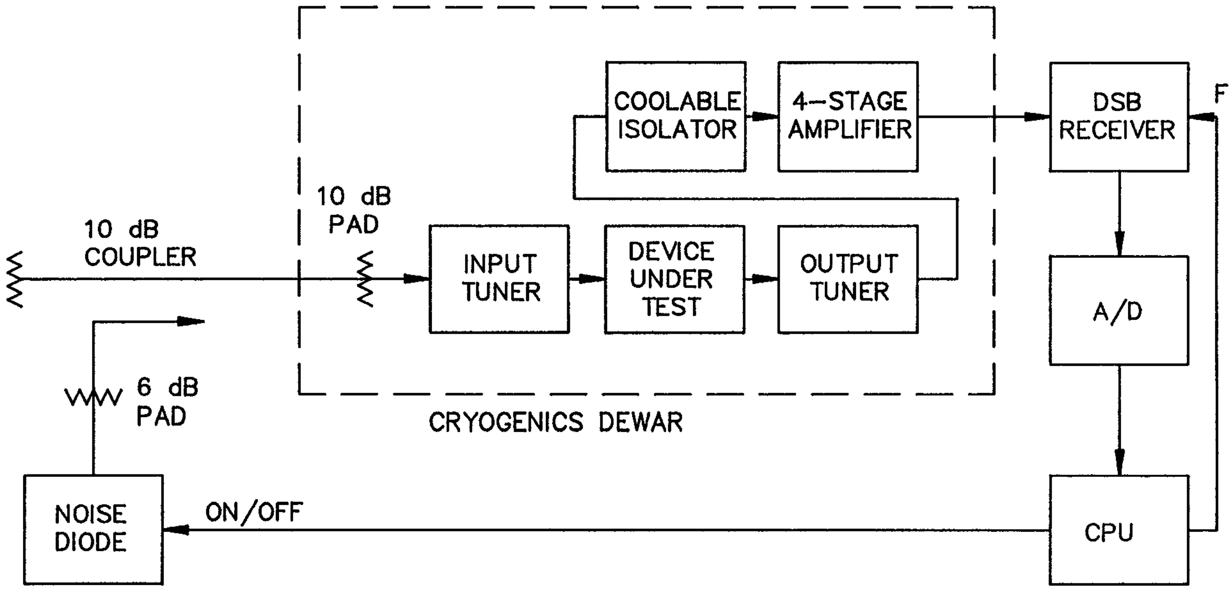

Fig. 4. Noise measurement system. The items within the dashed-line box can be cooled to 17 K by a closed-cycle refrigerator.

TABLE I. HEMT 43 GHZ NOISE PARAMETER SUMMARY - DECEMBER 6, 1988

MFG	GE	FUJITSU	LIN MONO	LIN MONO
TYPE #	391	FHR10X	HCF502	HCF1006
REFERENCE	[3]	-	[4]	[4]
GATE DIM	.25 x 75	.25 x 100	.1 x 50	.1 x 100
300 K DATA				
V_D, I_D OPT	1.4, 6	2, 7	1.3, 7	1, 10
V_g, G_m	-.039, 27	-.332, 33	-.572, 20	-.580, 42
T_{min}	120 ± 15	277 ± 30	195 ± 66	103 ± 8
R_{opt}	5.2 ± 0.7	13 ± 6	10 ± 3	4.9 ± 2.4
X_{opt}	8.0 ± 0.8	1 ± 6	24 ± 6	8.7 ± 1.1
N	.39 ± .08	-	.22 ± .1	.13 ± .06
G_a (dB)	5.0	3.7	6 ± 1	6.7
T_{casc}	175 ± 22	483 ± 50	259 ± 90	131 ± 10
17 K DATA				
V_D, I_D OPT	1.35, 1.5	2.5, 5	0.8, 2	1.8, 2
V_g, G_m	-.135, 24	-.479,39	-.736, 16	-.896, 30
T_{min}	27 ± 2	36 ± 8	34 ± 7	25 ± 1.0
R_{opt}	6.5 ± 1	14 ± 6	8 ± 5	5.3 ± 0.3
X_{opt}	4.3 ± 0.6	-3 ± 6	21 ± 4	3.7 ± 0.4
N	.07 ± .03	-	.03 ± .02	.04 ± .003
G_a (dB)	5 ± .5	5.6	6 ± 1	6.9
T_{casc}	39 ± 5	50 ± 12	45 ± 15	31 ± 1