BROADBAND, LOW-NOISE, CRYOGENICALLY-COOLABLE AMPLIFIERS IN 1 TO 40 GHZ RANGE

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ABSTRACT

A design technique for very broadband, low-noise amplifiers is described. It is based on a wideband noise model of a MODFET. The computer-aided design and realization of L-, K-, K_a-band and wideband 8-18 GHz cryogenically-coolable amplifiers with optimal noise performance are described. A uniqueness of results presented in this paper rest in the demonstration that a single frequency measurement of noise parameters provides sufficient information for a design of a number of wideband amplifiers in the 1-40 GHz range.

INTRODUCTION

A simple, wideband noise model of a microwave FET introduced in recent papers [1], [2] allows for a simple and effective design of broadband, low-noise amplifiers. It also allows for better insight into a broadband noise "matching" problem. A uniqueness of results presented in this paper rest in the demonstration that a single frequency measurement of noise parameters provides sufficient information for a design of a number of wideband amplifiers in the 1-40 GHz range.

A noise model for FHR02X and FHR10X Fujitsu devices [3], both for room and cryogenic temperatures, is introduced in Section II. Then the noise "matching" problem is briefly discussed (Section III). Finally, in Section IV the design, construction and performance of a family of broadband, low-noise amplifiers are described. The measured results are compared against the theoretical prediction using the noise model for FHR02X and FHR10X devices.

NOISE MODEL

The model for the FHR02 device, both in packaged and chip form, was developed in precisely the same way as described in previous papers [1], [2] for other devices. A single frequency noise parameters measurement and small signal equivalent circuit were used to determine the equivalent temperatures of intrinsic gate resistance and drain conductance, T_g and T_d [1], [2]. A comparison between model prediction and measured results for the FHR02FH (packaged) device at 8.5 GHz is summarized in Table I. The best-fit values of T_g and T_d at room temperature (297 K and 1783 K, respectively) and at a temperature of 12.5 K (16.3 K and 523 K, respectively) were used to predict the noise performance of the frequency range of interest. The results for the FHR02X device are shown in Figure 1A and 1B for ambient temperatures of 297 K and 12.5 K, respectively. As the FHR10 device differs only by the gate width from the FHR02 device, the same values of gate and drain temperatures were assumed.

ON BROADBAND NOISE "MATCHING"

A noise temperature of an amplifier may be expressed as follows:

$$T_n = T_{min}\left(1 + \frac{4NT_o}{T_{min}} \frac{1}{1/\left|\Gamma'_{opt}\right|^2 - 1}\right)$$

where Γ'_{opt} is an optimal source reflection coefficient Γ_{opt} transformed through an input lossless matching network ($4NT_o/T_{min}$ is invariant upon this transformation). It has been shown [1], [2] that for a FET at all frequencies

$$1 \leq \frac{4NT_o}{T_{min}} < 2$$

and that $4NT_o/T_{min}$ is a very weak function of frequency. This is well illustrated by the model data for FHR02X transistors in Figure 1A and 1B.

In most practical situations for FET amplifiers, $4NT_o/T_{min}$ for a bandwidth of around an octave can be considered a constant; therefore, a design of wideband input noise matching network may be reduced to a minimization of $1/\left|\Gamma'_{opt}\right|$ over the same bandwidth. Although similarity to the broadband matching problem of complex load to resistive source is quite apparent, none of the known methods (for instance, [4], [5], [6]) may be applied as Γ_{opt} does not possess Darlington representation [1], [2].

*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under cooperative agreement with the National Science Foundation.

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DESIGN AND PERFORMANCE OF AMPLIFIERS

The concepts outlined in Section I and II were used in the computer-aided design of a number of wideband amplifiers for cryogenic applications: L-band (1-2 GHz, 1.2-1.8 GHz), 8-18 GHz, 22-25 GHz, and 25-35 GHz. The first three were built with commercially-available FHR02X and the fourth with FHR10X MODFET's. The circuits of the first two stages were computer-optimized to yield minimum noise over a given bandwidth at the ambient temperature of 12.5 K, while the circuits of subsequent stages were optimized for gain flatness. In all cases, these networks were realized using soft substrate microstrip technology.

The noise performance of cryogenically-cooled 8-18 GHz, 22-25 GHz and 25-35 GHz amplifiers is plotted in Figure 2 against the minimum noise measure at 12.5 K of FHR02 transistors. The example of the 8-18 GHz amplifier illustrates very well the trade-offs between bandwidth and noise performance. The more detailed characteristics of this amplifier at room and cryogenic temperatures are given in Figure 2, and the amplifier is shown in Figure 3. Examples of the characteristics of the L-band amplifier and the 25-35 GHz amplifier are shown in Figures 4 and 5.

COMMENTS AND CONCLUSIONS

The agreement between predicted and measured noise performance of amplifiers was well within the range caused by measurement and realization uncertainties and repeatability of MODFET's. The results demonstrate the usefulness of the model [1], [2] in the design of amplifiers both at room and cryogenic temperatures. The limit of noise performance over given bandwidth is still an open question. It might, however, be only of academic importance as concerns over stability in wideband design would quite often take precedent over noise performance, especially at low frequencies. The noise model coupled with computer-aided design and optimization allows the achievement, within other design constraints, of nearly "optimal" noise bandwidth performance.

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ACKNOWLEDGEMENTS

The authors would like to thank Ronald Harris and Dylon Dillon of NRAO for their suggestions concerning amplifier mechanical design and assembly, and to acknowledge Dillon's expertise in manufacturing amplifier mechanical parts.

TABLE I. NOISE PARAMETERS OF FHR02FH MODFET AT 8.5 GHZ

MEAS. COND.	COMMENTS	T_{min} K	R_{opt} Ω	X_{opt} Ω	g_n mS	T_g K	T_d K
T_a=297 K, V_{ds}=2 V, I_{ds}=10 mA	Measured	51.0	10.7	26.3	5.7	-	-
	Model Best Fit	48.5	11.4	27.7	6.9	297	1783
T_a=12.5 K, V_{ds}=2 V, I_{ds}=5 mA	Measured	7.3	5.3	26.3	1.70	-	-
	Model Best Fit	7.0	5.6	23.4	1.82	16.3	523

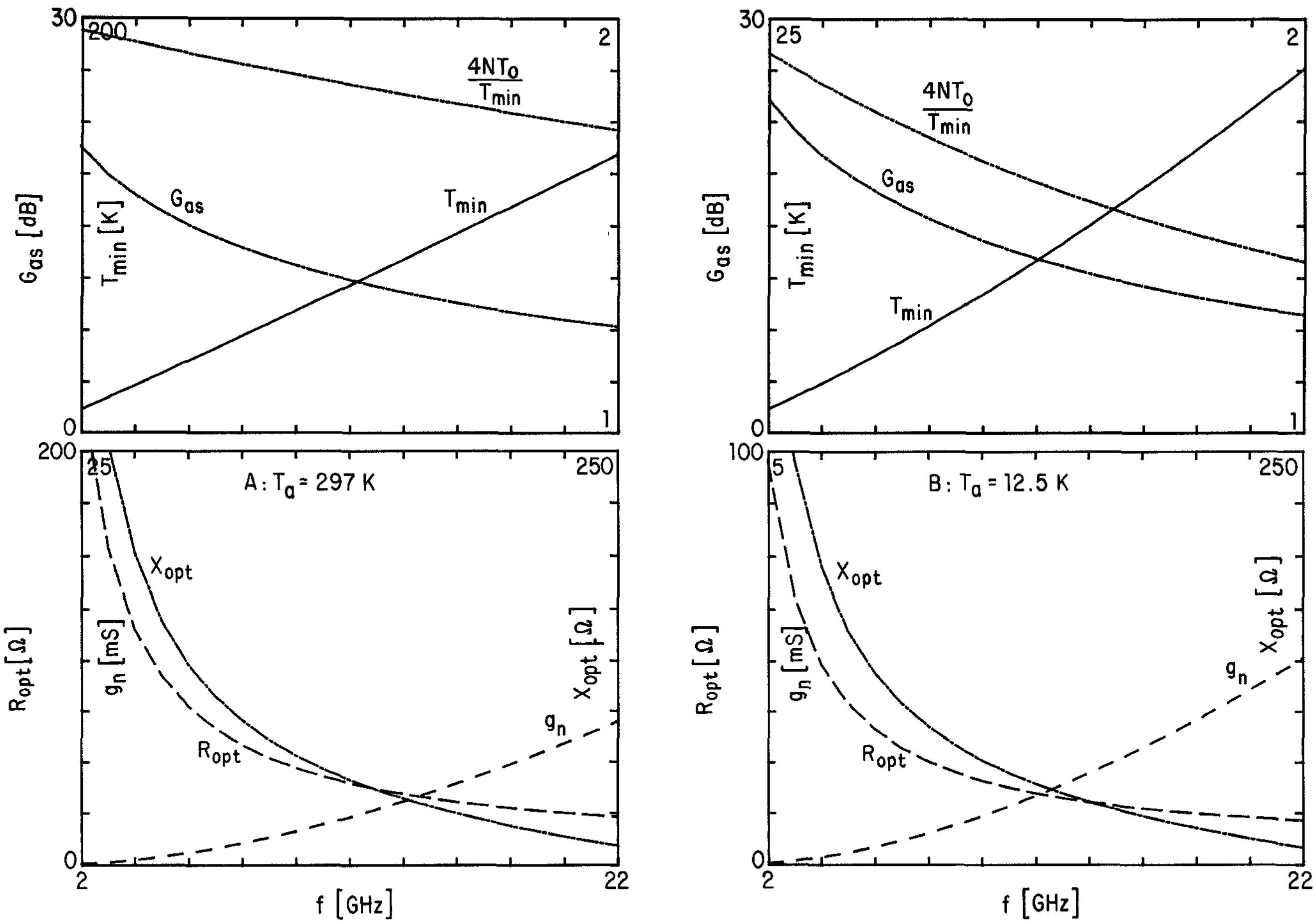

Fig. 1. Noise parameters of FHR02X (chip) MODFET predicted from model with gate and drain temperature values as given in Table I. A) T_a = 297 K. B) T_a = 12.5 K.

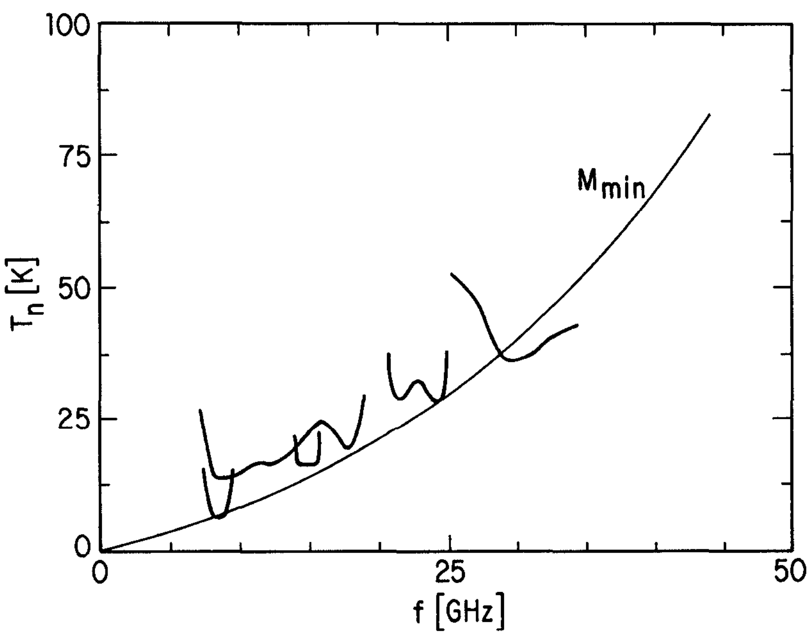

Fig. 2. Noise temperature of different amplifiers and minimum noise measure of FHR02X transistor at T_a = 12.5 K. The performance of 8.4 GHz (GE HEMT [7], [9]) and 14.9 GHz (FHR01FH [8]) narrow band designs are also included for comparison.

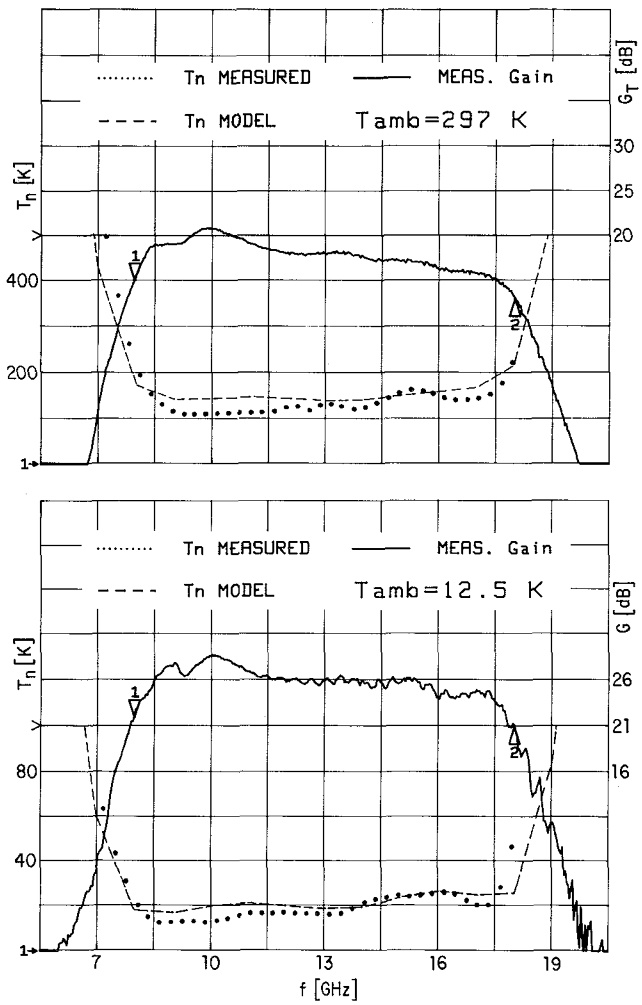

Fig. 3. Measured and predicted characteristics of three-stage, wideband, low-noise amplifier.

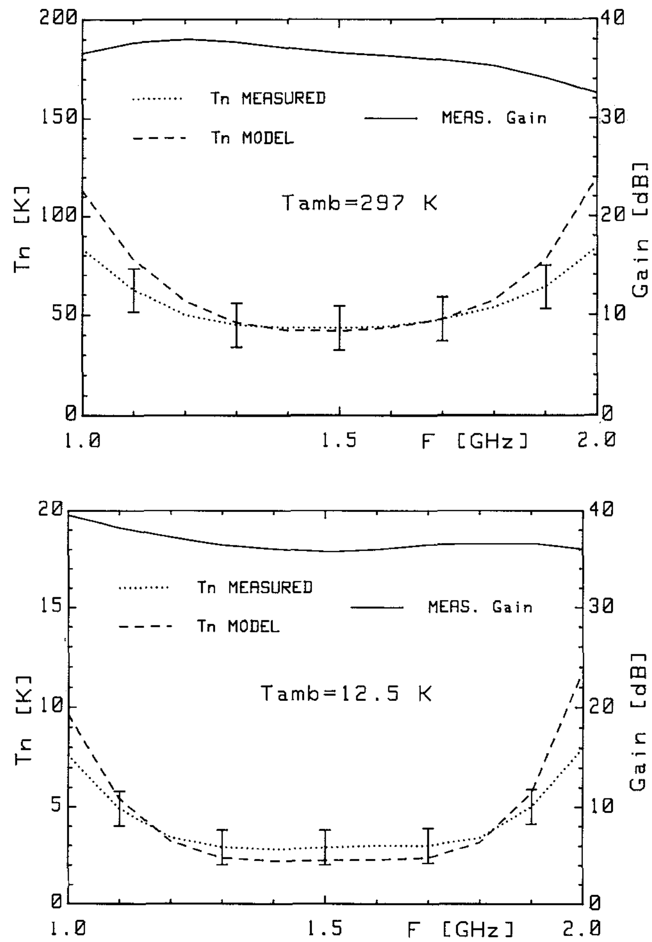

Fig. 5. Measured and predicted characteristics of a three-stage, 1.2-1.8 GHz amplifier.

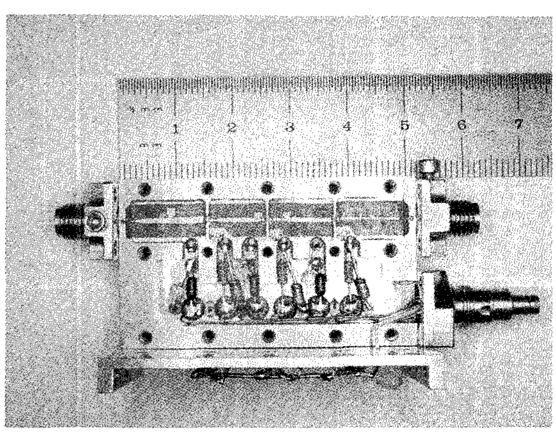

Fig. 4. A photograph of an 8-18 GHz amplifier with the cover plate removed.

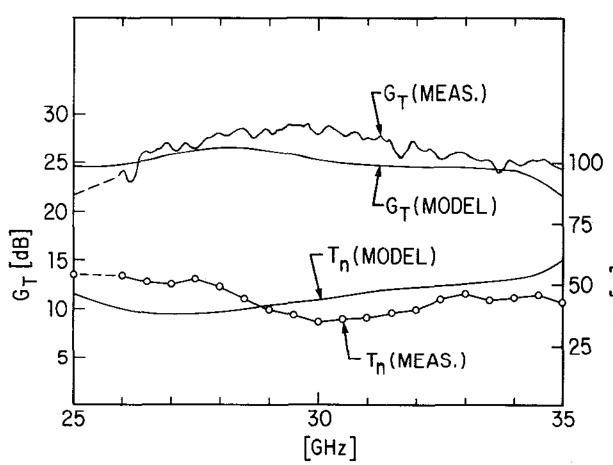

Fig. 6. Measured characteristics of a four-stage, 25-35 GHz amplifier built with FHR10X transistors at the ambient temperature of 12.5 K.