MILLIMETER-WAVE HEMT NOISE MODELS VERIFIED THRU V-BAND

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Abstract

Further enhancements in the HEMT noise modeling procedure described in [1] now enables scaling of bias dependent noise models. This was experimentally verified through V-band using prematched structures utilizing the TRW 0.1um gate length low noise process. With this procedure, it is now possible to scale device noise models obtained at microwave frequencies to millimeter wave frequencies with good correlation. The scaled models are further verified with Q- and V-band low noise amplifiers.

Introduction

Modern millimeter wave receivers demand excellent noise figure performance. This requires the low noise amplifier to be as near to optimum as possible. The successful design of these low noise amplifiers depends heavily on the existence of an accurate device noise model. If the noise model is bias-dependent, the LNA designer can optimize bias along with the matching circuit to improve performance.

At present, millimeter wave low noise amplifiers are designed using scaled and extrapolated HEMT noise models of relatively large periphery devices measured below 26 GHz [2]. Because of the inaccuracies in the noise models and the need to both scale and extrapolate to higher frequencies, the use of the resultant model invariably leads to several design iterations.

In the present paper, we extend our modeling procedure, first reported in [1], to V-band. This procedure significantly improves the accuracy of noise models of HEMT devices at millimeter wave frequencies. In this procedure, prematched noise test structures are designed, fabricated and tested at millimeter wave frequencies (33-50 GHz and 58-64 GHz). On-wafer noise parameters are also obtained on relatively large periphery devices at microwave frequencies (2-26 GHz). We have improved the procedure by including 26-40 GHz noise parameters of smaller device sizes. All data was taken over bias. An accurate, bias-dependent model is developed using the microwave frequency test data and then scaled and verified with millimeter-wave frequency test data. This approach incorporates device scaling and provides a thoroughly verified noise model which can be used to W-band frequencies with confidence.

Bias Dependent Model Development

On-wafer noise parameters were taken on large periphery devices (100 and 200 um) for 2-26 GHz and on smaller devices (40, 60, 80 um) for 26-40 GHz. The noise parameters were taken using ATN noise parameter test sets and an HP8510 network analyzer. In addition, 0-50 GHz S-parameter data was taken on all device sizes. The data was taken using calibrations verified by the procedure outlined in [1]. As shown in [1] and [3], accuracy of calibration is crucial in producing measurements when using the ATN noise test sets.

At each bias, a scaleable small signal model was created to match the S-parameter data for all the device sizes at once. The noise currents were then adjusted to match the noise parameter data while keeping the other model parameters fixed. Data was taken at 50, 75 and 100% of the drain current that produces the peak Gm value (Idp). Fig. 1 shows the model topology and scaling equations. Figures 2 and 3 show the model fit to the S-parameter and noise parameter data for the 60um device. The bias dependent model uses a simple polynomial expressions to fit Cgs, Cds and Cdg and the Curtice model [4] to fit Rds and Gm. The elements Ggn and Gdn vary approximately linearly with the drain current. All other elements can be treated as being independent of bias.

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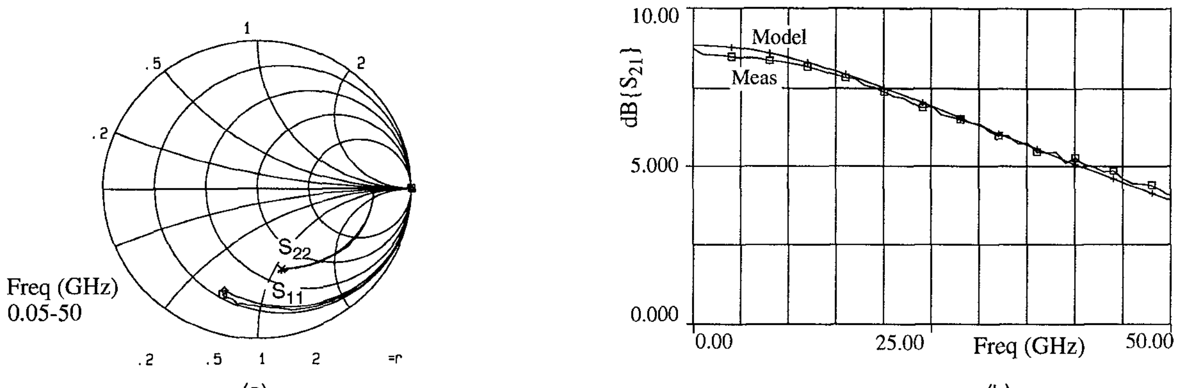


Fig. 2 Measured vs. model 0-50 GHz S-parameters at 2V, 50% Idp for the 60um device (a) S_{11} and S_{22}, (b) S_{21}

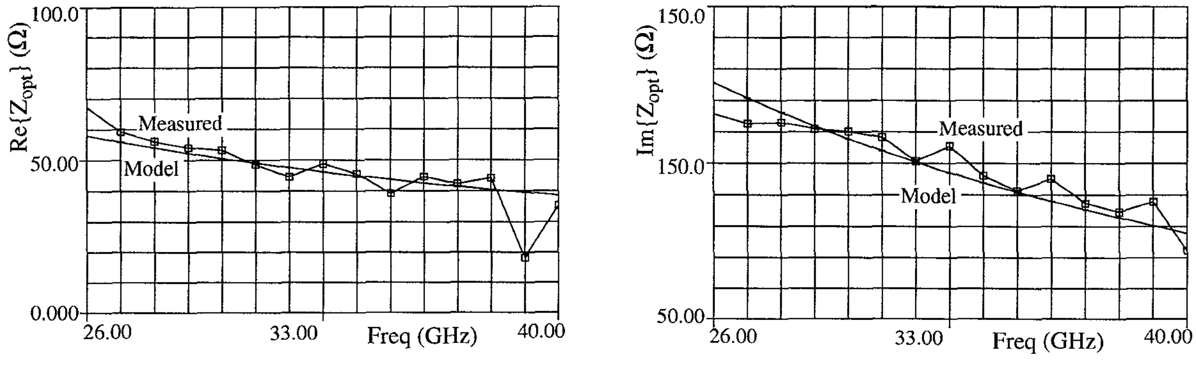
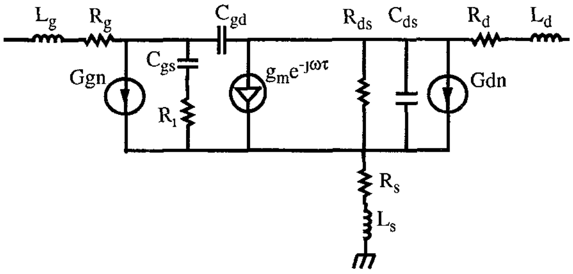


Fig. 3 Measured vs. model 26-40 GHz optimum source impedance at 2V, 50% Idp for the 60um device. (a) Re{Z_{opt}}, (b) Im{Z_{opt}}



Ggn α W	Rds α W^{-1}
Gdn α W	Rd α W^{-1}
Gm α W	Ri α W^{-1}
Cgs=Cgs0*W/W0+Coff	Rg α W/N^2
Cgd=Cgd0*W/W0+Coff	W=periphery
Cds=Cds0*W/W0+Coff	W0=200μm
Coff=(1.5 fF)*N	N=no. fingers

Fig. 1. Device model topology and scaling equations.

Model Verification through Test Structures

On-wafer noise prematched structures were developed to verify noise parameters of 40 and 60 um devices at 60 and 44 GHz respectively. The test structures consist of an input 6 dB pad, an input matching circuit, the HEMT device and an output matching circuit. For each frequency band and device size of interest, five test structures were designed. Each of the five structures has the same input pad and output matching circuit. The input pad serves to reduce the effect of probe VSWR on the source impedance presented to the device and output matching circuit helps raise the gain of the structure. The design of the input matching circuits was based on noise parameters extrapolated in frequency by the above model. One of the structures was designed for minimum noise figure and the others for noise figures going up from the minimum in 0.5 dB steps.

The noise figure of the Q-band test structures was measured from 40 to 48 GHz. The loss of the wafer probes was taken into account by measuring the total loss of both probes with an on-wafer microstrip thru and assuming each probe accounted

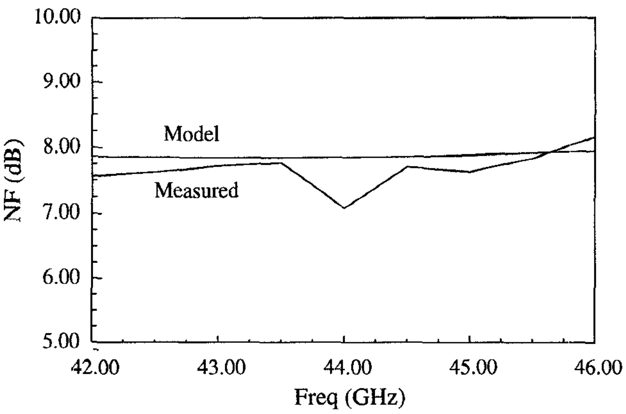


Fig. 4 Typical measured vs. model noise figure for a Q-band noise test structure. Taken at 2V, 50% Idp.

for half the loss. No attempt was made to measure the impedance of the input probe or account for its effect on the noise figure measurements. Fig. 4 shows noise figure vs. frequency for the test structure designed for minimum noise figure. The glitch at 44 GHz is caused by adjacent structures coupling to the probes during calibration. Fig. 5 shows measured and modeled noise figure vs. Rs, the real part of the source impedance. The source impedance Z_S was calculated assuming the input probe presented 50 ohms to the test structure and using Sonnet [5] electromagnetic simulations of the input matching circuits and pad. The noise test structure data indicates that the noise model is fairly accurate through Q-band.

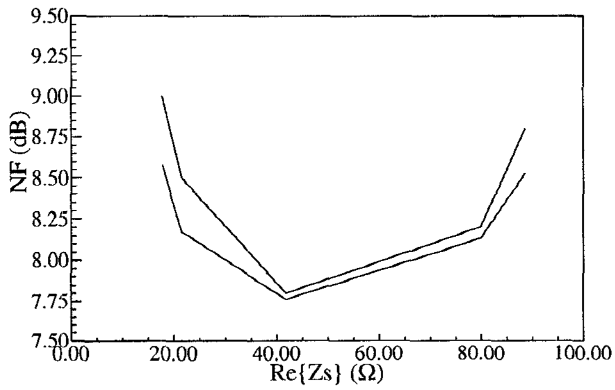


Fig. 5 Noise figure vs. Re{Zs} for the Q-band test structures at 43.5 GHz and 2V, 50% Idp.

The V-band test structures were measured from 58-62 GHz and at Vds=2V, Ids=50, 75 and 100% of the peak gm current (Idp). In an effort to improve our test methodology, the probe loss was measured directly using the embedded calibration technique. The source impedance presented to the test structures was also measured. Fig. 6 shows the measured and modelled dependence of the noise figure on the source impedance presented to the device over bias. These graphs show that the model is about 0.5 dB high in NF_{min}, but is quite close in predicting Re{Z_{opt}} and G_n over bias.

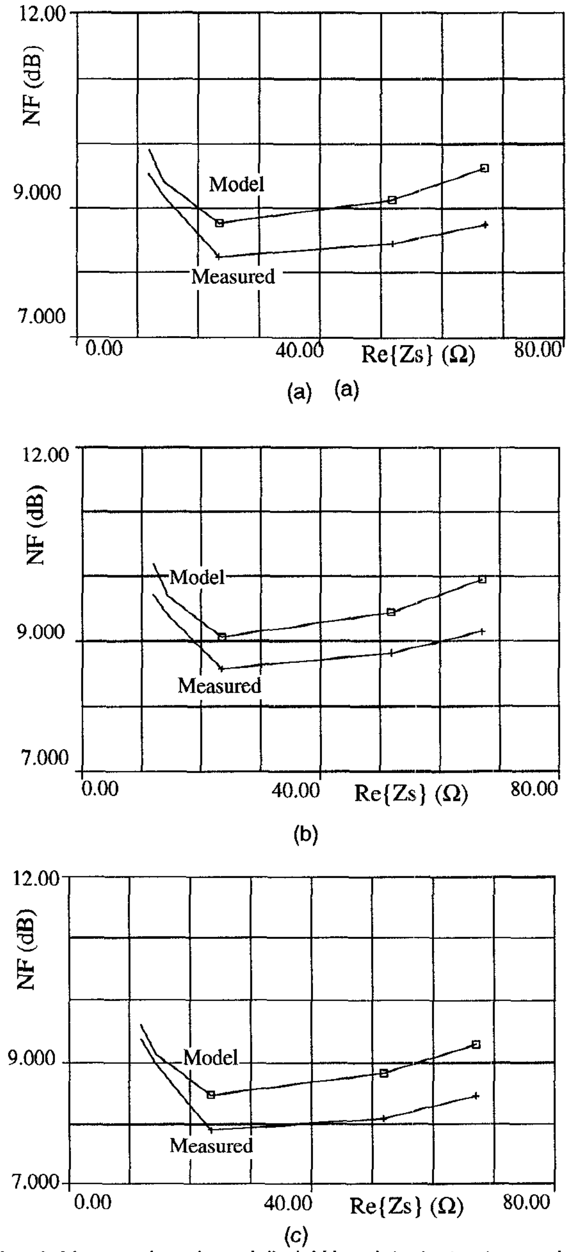


Fig. 6 Measured and modelled V-band test structure noise figure vs. Re{Z_S}. (a) 50% I_{dp}, (b) 75% I_{dp}, (c) 100% I_{dp}

The curves labelled "Model" in Fig. 6 were produced using Libra models for the passive components and assuming the source impedance at the test structure input is 50 Ω.

Low Noise Amplifier Modeling

The model was used to design Q-band low noise amplifiers (LNA). Simulation vs. measurement for a Q-band single-ended low noise amplifier designed for minimum noise figure at 50% Idp will be presented at the symposium. The model was also used to design a 3-stage balanced V-band amplifiers. Simulation vs. measurement for the single-ended version of this amplifier will also be reported at the symposium.

Conclusion

A bias dependent HEMT noise model has been developed through accurate noise and S-parameter measurements at microwave frequencies. The model has been verified at millimeter wave frequencies through measurement of prematched noise test structures. The prematched test structure method has been extended to insure the accuracy of the device model at V-band. The model has successfully predicted the performance of a Q-band LNA, is being compared to a V-band LNA and is being used in the design of W-band LNA's.

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References

[1] M. DuFault, et. al., “A Novel Millimeter-Wave HEMT Noise Modeling Procedure,” 1995 IEEE MTT-S Int. Microwave Sym. Dig., Orlando, Florida, 1995, pp.939-942.

[2] B. Nelson, et. al., “Octave Band InGaAs HEMT MMIC Low Noise Amplifiers to 40 GHz,” 12th Annual IEEE GaAs IC Symposium, New Orleans, LA, Oct. 7-10, 1990, pp.165-168.

[3] J. R. Fenton, “Noise Parameter Data Comparison While Varying the On-Wafer S-parameter Calibration Technique”, 44th ARFTG Conference, Boulder, CO, Dec. 1994, pp. 89-97

[4] Curtice, W.R., “A MESFET Model for Use in the Design of GaAs IC's,” IEEE Trans. Microwave Theory Tech., v. MTT-28, 1980, p.448.

[5] Sonnet Software. Sonnet Software, Inc., Liverpool, NY.