1/*f* NOISE MODELING OF InP HBT-BASED SCHOTTKY DIODES FOR MONOLITHIC MILLIMETER-WAVE MIXERS

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Abstract—**We present a procedure for modeling the low-frequency 1/*f* noise properties of millimeter-wave InP HBT-based Schottky diodes. These noise properties, coupled with the device's small and large-signal characteristics, enable the generation of a comprehensive diode model. The model is particularly useful for analyzing mixer and detector MMIC's. Simulations using this model compare well with W-band mixer measurements.**

I. INTRODUCTION

In recent years, monolithic millimeter-wave integrated circuits (MMIC's) have evolved rapidly. Much of this evolution is the result of vast improvements in solid-state device technology and MMIC design techniques. A very important, yet often overlooked, aspect of MMIC design is an accurate analysis of how the device's low-frequency (1/*f*) noise properties will affect the performance of the circuit. This analysis is especially important for nonlinear components such as mixers and detectors, which convert a high-frequency RF signal to a much lower-frequency signal. In this paper, we present a procedure for modeling the 1/*f* noise properties of millimeter-wave diodes. By combining these noise properties with the device's small-signal and nonlinear performance, we can create a very comprehensive diode model. This model is verified by a favorable comparison against the measured conversion loss and noise performance of a W-band MMIC mixer using InP HBT-based Schottky diodes.

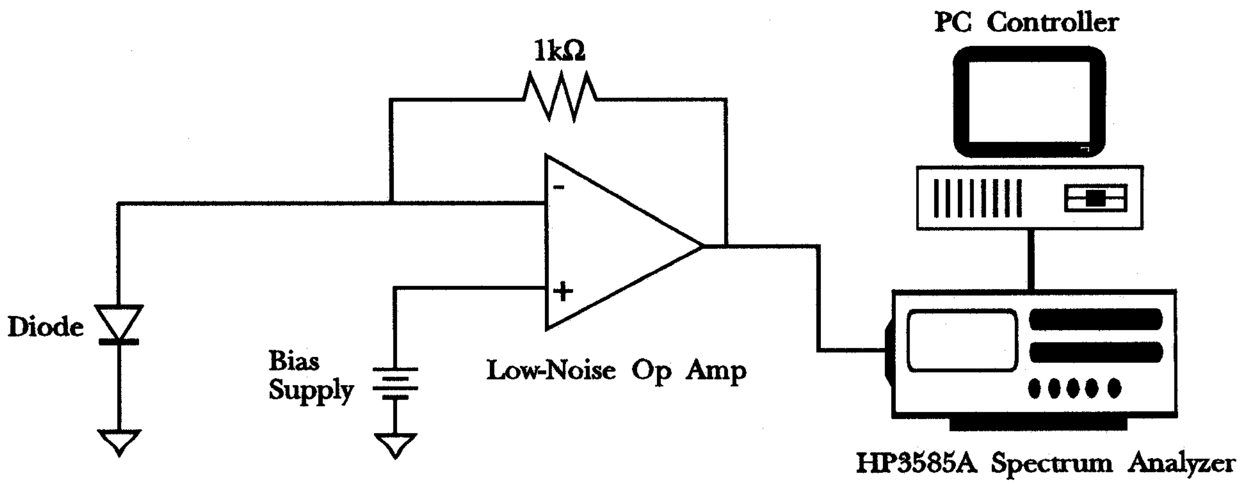

Fig. 1. Simplified schematic of the low-frequency noise measurement system.

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II. Device Description

The Schottky diodes are fabricated using the InP Heterojunction Bipolar Transistor (HBT) process developed by TRW [1]. The device structure is grown using molecular beam epitaxy. The Schottky-barrier diodes are formed in the collector region, with a Schottky p^+ ring guard to provide electrical isolation. The contact area is $5\,\mu$m $\times$ $5\,\mu$m. Compared to planar diodes, this device has lower $1/f$ noise due to its vertical structure, as described in [1].

III. Device Modeling

The comprehensive model for the Schottky diode consists of three separate parts: low-frequency ($1/f$) noise modeling, small-signal modeling, and nonlinear modeling. The $1/f$ noise modeling is performed by first measuring the low-frequency noise properties of individual stand-alone Schottky diodes. This is done using a custom-made noise probing card.

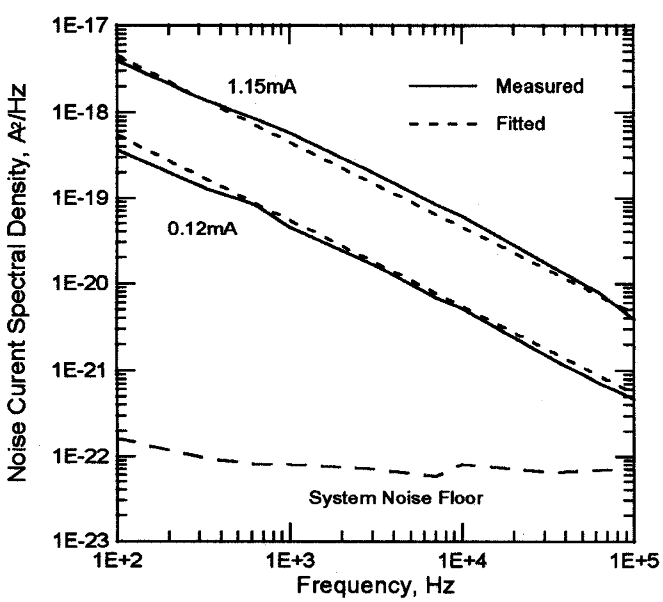

Fig. 2. Typical measured and fitted low-frequency noise spectral density for the InP HBT-based Schottky diode at two different bias points.

A simplified schematic of the measurement setup is shown in Fig. 1. Fig. 2 shows a typical result for an InP HBT Schottky diode at two different bias currents. The noise floor of the measurement system prevents measuring noise currents below $1 \times 10^{-22}\,\mathrm{A}^2/\mathrm{Hz}$. The $1/f$ component is clearly dominant. Next, a $1/f$ noise model is extracted from this data. The $1/f$ noise will have a spectral density of the form [2]:

$$\overline{i^2} = K_f \frac{I_o^\alpha}{f}, \tag{1}$$

where $\overline{i^2}$ is the noise current spectral density, I_o is the diode bias current, and K_f and α are constants. These constants can be determined by fitting the measured noise current spectral density curves at several bias points. For this particular diode, a good fit is obtained using $K_f = 2.5 \times 10^{-13}$ and $\alpha = 0.9$. If necessary, a burst noise term with a Lorenzian power spectral density may be added to (1) to improve the fit.

A small-signal model for the device is generated from measured scattering parameters. A millimeter-wave Hewlett-Packard 85109B network analyzer with Cascade on-wafer coplanar probes is used to measure the scattering parameters of individual diodes up to 50 GHz. This modeling is useful for obtaining information about the diode's equivalent circuit elements as a function of bias. Small-signal data is used extensively to model return loss and other linear circuit characteristics as well.

Finally, information about the device's large-signal behavior is obtained from the diode's measured DC current-voltage relation. Information from the S-parameter measurements is used to characterize the diode's nonlinear junction capacitance and conductance. The combination of the $1/f$ noise characterization, the small-signal modeling, and the nonlinear modeling enable the generation of a compre-

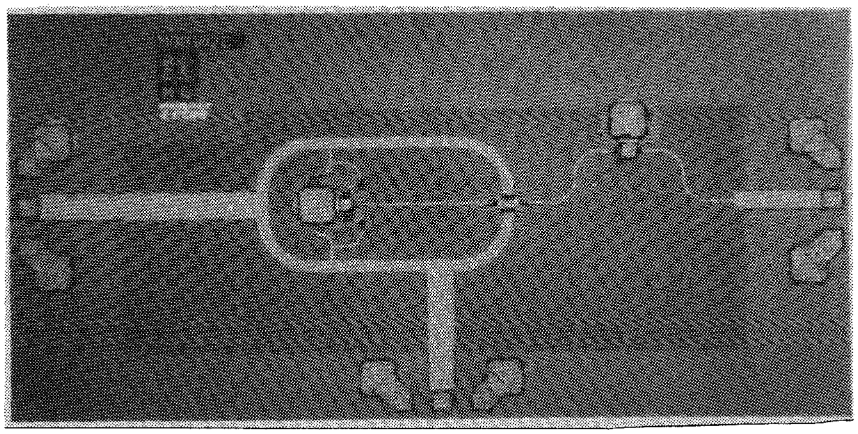

Fig. 3. Photograph of the W-band MMIC single-balanced mixer circuit used to verify the diode modeling.

hensive diode model suitable for mixer and detector design.

IV. Experimental Verification

This modeling was verified by simulating the performance of a single-balanced mixer using two InP HBT-based Schottky diodes as the nonlinear elements. A photograph of the MMIC chip is shown in Fig. 3. A rat-race ring coupler isolates the RF from the LO. The single-ended IF is extracted through a lowpass filter. These W-band MMIC mixers have been previously reported to have excellent noise performance at low IF frequencies, as well as very good conversion loss with low LO drive requirements [3,4]. The theoretical circuit performance was simulated using Hewlett-Packard's MDS CAD package [5].

The mixer conversion loss as a function of LO drive power is shown in Fig. 4. The LO frequency is 94 GHz and the IF frequency is 100 MHz. The simulation is in excellent agreement with the measurement. Fig. 5 plots the double-sideband (DSB) noise figure versus IF frequency. The LO power is 5 dBm at 94 GHz. Again, the simulated curves agree very well with the measurement, especially at low IF frequencies where the $1/f$ noise is dominant. This favorable agreement verifies our

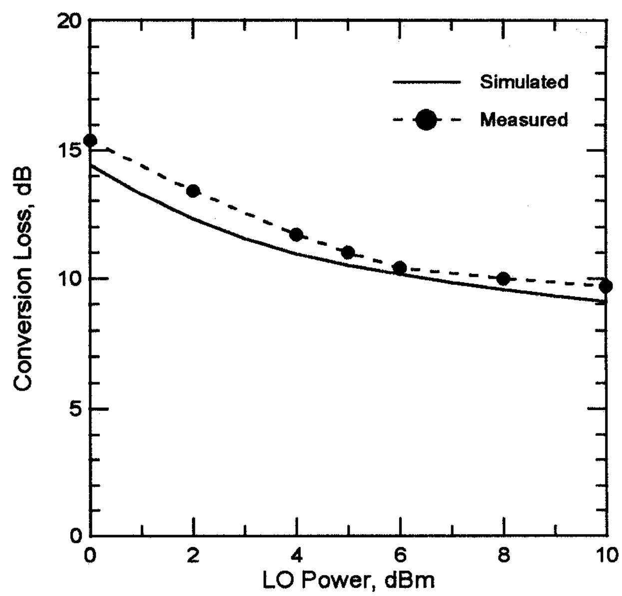

Fig. 4. Measured and simulated conversion loss versus LO drive power for the single-balanced W-band MMIC mixer. The LO frequency is 94 GHz and the IF frequency is 100 MHz.

device modeling and circuit simulation procedure. The minor discrepancies may be attributed to the fact that the diodes used to determine the device properties were not the actual diodes used in the mixer—some device-to-device variation is typical.

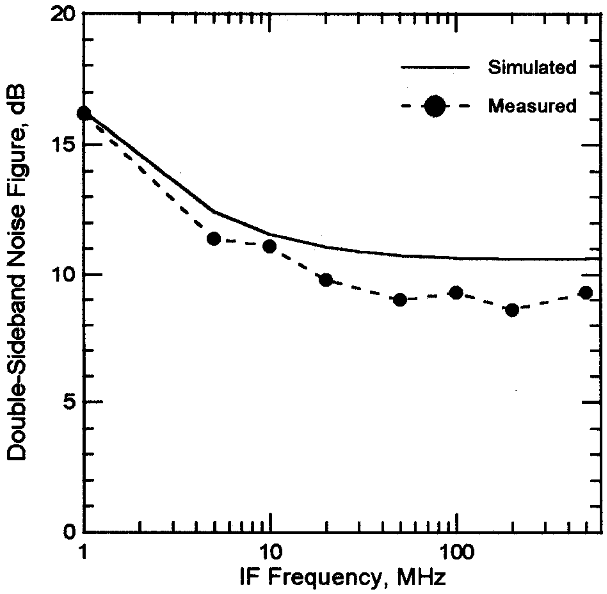

Fig. 5. Measured and simulated double-sideband (DSB) noise figure versus IF frequency for the W-band MMIC mixer. The LO power is 5 dBm at 94 GHz.

V. Conclusion

We have demonstrated a procedure to model the low-frequency noise properties of InP HBT-based Schottky diodes. This technique results in a very comprehensive device model that includes the device's noise, small-signal, and nonlinear behavior. Simulations using this model agree very well with measured results. This technique should be applicable to a wide-range of devices, including GaAs and InP diodes on HBT and HEMT material. Furthermore, this approach can be used to predict the behavior of mixer and detector circuits using these devices.

VI. Acknowledgements

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VII. References

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