NOISE CHARACTERISTICS OF GaAs HBT'S

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Abstract:

A complete characterization of the bias-, area-, and frequency-dependence of GaAs HBT noise characteristics is presented. It is shown that there is an optimum device area (emitter area) and bias condition for achieving a minimum noise figure, which for the M/A-COM process at 2GHz occurs at an area of roughly 120μm^2 and a collector current of 2mA yielding a minimum noise figure of 1.4dB and an associated gain of 13dB. The measured noise characteristics are validated by an extracted equivalent circuit model with associated noise sources.

Introduction:

GaAs HBT's are attractive devices for many low-noise amplifier applications which require high linearity, high dynamic range, and low power dissipation [1,2]. In fact, HBT's have demonstrated a significantly higher Gain/Power figure-of-merit (RF Gain divided by DC Power) than other competing technologies such as MESFET's [2]. There has not been, however, a published comprehensive study of GaAs HBT noise characteristics. This paper analyzes the area-, bias-, and frequency-dependence of GaAs HBT noise characteristics including the minimum noise figure (F_{min}) and the associated gain (G_a). Further, this paper demonstrates that an equivalent circuit model extracted from small-signal data (with the addition of ideal shot- and thermal-noise sources) can be used to quantitatively predict the measured noise characteristics.

Test Conditions:

In order to investigate the noise characteristics of M/A-COM's GaAs HBT process, 0.6-6GHz and 2-26GHz on wafer noise parameter measurements were made for 5 different device sizes at 10 bias conditions for each device. The five devices were chosen to determine the area dependence of the device noise figure and have peripheries which vary from a one-finger 3μm x 10μm HBT to an eight-finger 3μm x 20μm HBT. For all devices, the process and the emitter width are identical with all area scaling occurring in terms of the number of fingers and the finger length. The bias conditions were chosen to determine the variation of the noise parameters with collector voltage (Vc) and collector current (Ic). A list of the device sizes and test conditions are given in Table I. In this paper, the relevant figures-of-merit are F_{min}, G_a, $[F_{min}]_{abs}$, and $[G_a]_{abs}$, which are defined as follows: F_{min} is the minimum noise figure that can be obtained at a given bias condition by appropriately matching the source impedance, yielding an associated gain of G_a when the load is conjugately matched to the device. $[F_{min}]_{abs}$ is defined as the absolute minimum noise figure, and is equal to the minimum value of F_{min} from all of the bias conditions considered, with an associated $[G_a]_{abs}$. The noise parameters were measured using ATN's NP5B noise parameter measurement system which is described in Ref. [3].

Table I - Devices and Bias Conditions for Noise Measurements

Device Name	Finger Number	Finger Geometry	Bias Condition
SACPM	1	3μm x 10μm	Vc(V)=1.5,3.0 Ic(mA)= 0.25,0.5,1.5,4.0,10.0
EAS02	2	3μm x 10μm	Vc(V)=1.5,3.0 Ic(mA)= 0.5,1.0,3.0,8.0,20.0
EMA04	4	3μm x 10μm	Vc(V)=1.5,3.0 Ic(mA)= 1.0,2.0,6.0,16.0,30.0
EQA04	4	3μm x 20μm	Vc(V)=1.5,3.0 Ic(mA)= 2.0,4.0,12.0,32.0,64.0
EQB08	8	3μm x 20μm	Vc(V)=1.5,3.0 Ic(mA)= 4.0,8.0,24.0,64.0

Measurement Results and Discussion:

Bias-dependence:

The bias-dependence of the minimum noise figure (F_{min}) and the associated gain (G_a) is shown in Fig 1 for the EAS02 device. From these results, it is apparent that there is an optimum current which gives a minimum noise figure around Ic = 2mA (Jc=3000 A/cm^2). The minima in noise

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figure is, however, very broad (with roughly 0.1dB increase from Ic=1mA to Ic=4mA). The associated gain, however, increases very rapidly over this current range as it is (to first order) proportional to the device current. The choice of a bias current in this minima is a trade-off between the DC power dissipation and the associated gain. Figure 1 also shows the voltage dependence of F_{min} and G_a. While G_a increases as Vc increases, due to a reduction of the feedback capacitance, F_{min} shows negligible variation with Vc over this bias range. A similar bias-dependence is seen for the other device sizes shown in Table I (see Fig. 2). The location of the F_{min} minima shifts to slightly lower current densities for the larger device areas; the associated gain (G_a) at these current densities remains above 12dB.

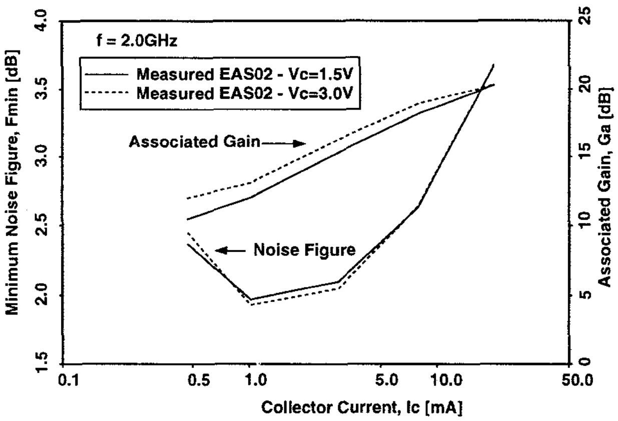

Fig. 1 - The bias dependence of the minimum noise figure F_{min} and associated gain G_a for the EAS02 device.

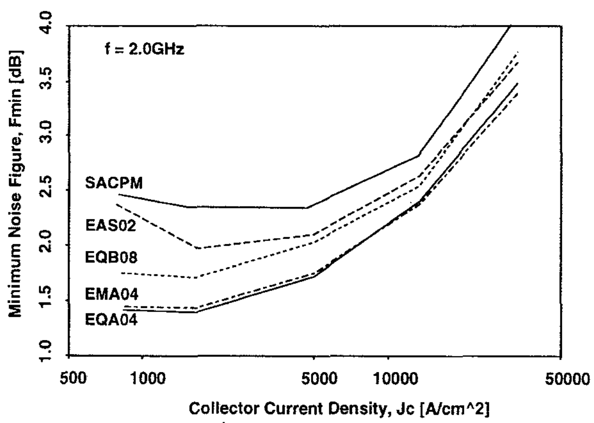

Fig. 2 - Minimum noise figure F_{min} as a function of current density for the devices shown in Table I. The optimum current density shifts to a slightly lower value as the device area is increased.

Area-dependence:

By investigating the bias-dependent noise parameters, one can determine the area dependence of the absolute minimum noise figure $[F_{min}]_{abs}$, as is shown in Fig. 3. From this data, it is apparent that there is an optimum device size, around $120\mu m^2$,which yields a minimum noise figure of 1.4dB at 2GHz with an associated gain of 13dB. The variability in the associated gain with device area is due to the fact that the associated gain is a strong function of bias current (see Fig. 1) and a discrete number of bias conditions was used to generate the data in Fig. 3.

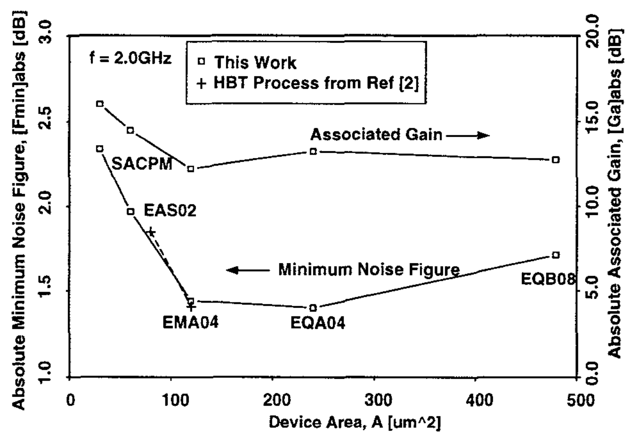

Fig. 3 - Absolute minimum noise figure and associated gain as a function of device area for the M/A-COM HBT process.

As the device area is reduced below the optimum area, the absolute minimum noise figure increases as does the associated gain. As the device area is increased beyond the optimum size, the noise figure increases very slowly, indicating that large power devices can be designed with a reasonably low noise figure, which is important for some system applications which require a high dynamic range. The trajectory of $[\Gamma_s]_{abs}$ and S_{11} as a function of device area is shown in Fig. 4 for f=2.0GHz. As the device area is increased from $30\mu m^2$ to $480\mu m^2$ $[\Gamma_s]_{abs}$ rotates from 0.7<9deg. to 0.5<154deg, while S_{11} rotates in the opposite direction in the lower half-plane. This information is useful for LNA design where one must choose an input match which provides a compromise between minimum insertion loss and minimum noise figure. As a reference, the published minimum noise performance of Ref. [2] are shown on Fig. 3, which displays a similar area-scaling as does the M/A-COM process over the area range considered.

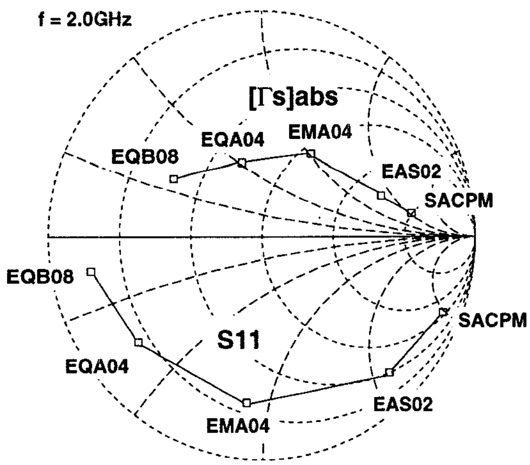

Fig. 4 - Trajectory of the optimum source matching impedances $[\Gamma_s]_{abs}$ and S_{11} as a function of device areas at f=2.0GHz.

Frequency-dependence:

Figure 5 shows the frequency dependence of minimum noise figure F_{min} for the five bias currents of the EMA04 device. At low current densities, the minimum noise figure rises rapidly with frequency while at higher current densities, the noise figure behavior is much less dependent upon frequency. Similar frequency dependent behavior is observed for the other device areas in the 0.6-26GHz frequency range

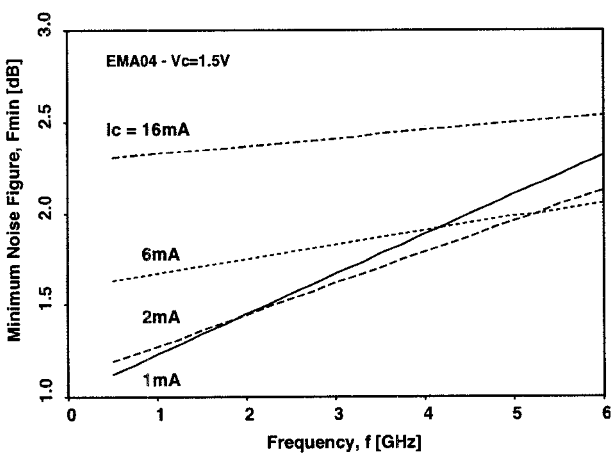

Fig. 5 - Frequency-dependence of the minimum noise figure for the EMA04 device. All the device sizes display a similar trend where F_{min} is less frequency-dependent as Ic is increased.

Noise Modeling:

To understand the measured noise characteristics, an equivalent circuit model has been constructed by adding noise sources to a hybrid-pi HBT small-signal model as shown in Fig. 6. Two correlated current noise sources and three voltage noise sources are used to model the shot noise generated by the device junctions and the thermal noise generated by the parasitic series resistances, respectively.

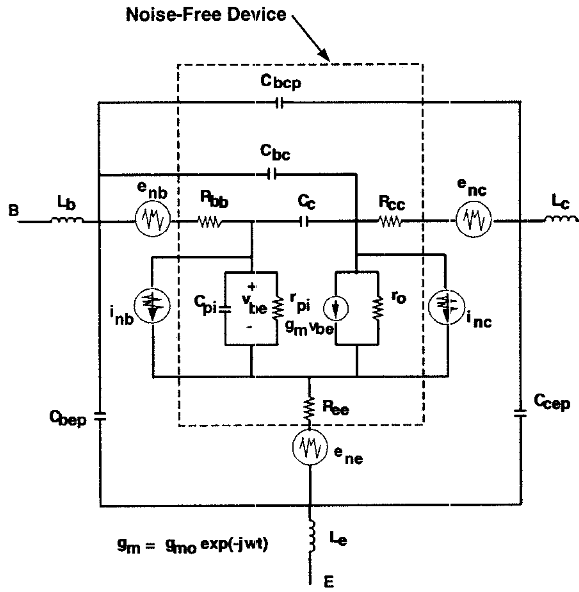

Fig. 6 - Combined small-signal and noise equivalent circuit model used for noise simulations shown in Fig. 6.

A parameter extraction technique has been previously developed to directly extract the element values of the equivalent circuit model from measured S-parameters [4]. Using this approach, all parasitic resistances and intrinsic parameters can be directly extracted from the measured S-parameters without resorting to an optimization process. Using the extracted model for each bias, the noise parameters of the device are calculated (Fig. 7). Excellent agreement is obtained for F_{min} and G_a over a wide bias range. The increased deviation at low bias levels is due to the uncertainty in both the base current and noise measurements at low current levels. To our knowledge, this is the first time the noise behavior of the HBT has been described by direct extraction of the small-signal equivalent circuit model with no optimization of parameters to the measured noise data. The area and frequency dependence are also well described by the extracted models.

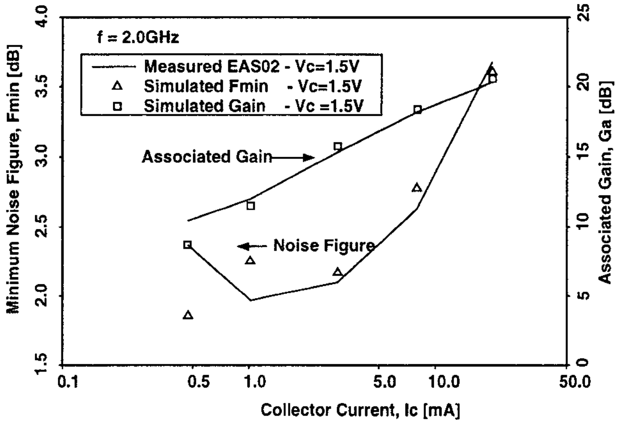

Fig. 7 - Comparison of simulated and measured F_{min} and G_a for the EAS02 device. The small signal model was extracted from S-parameter measurements at each bias point with no optimization of parameters; the simulated noise characteristics are based on the calculation of the shot- and thermal-noise components in this model

Summary:

In conclusion, a complete characterization of the bias-, area-, and frequency-dependence of GaAs HBT noise characteristics has been presented through an analysis of on-wafer noise measurements for a number of device areas and bias conditions. Based on these results, it has been found that there is an optimum device area for achieving the absolute minimum noise figure. For the M/A-COM process, this optimum area at 2GHz is between 120-240μm^2 which yields an $[F_{min}]_{abs}$ of 1.4dB with a $[G_a]_{abs}$ of 13dB at a bias current of roughly 2mA. Further, it has been demonstrated that for all device areas, the minimum noise figure occurs at roughly the same current density and that at low collector current densities F_{min} displays a stronger frequency dependence than at high biases. These results are validated by a directly extracted small-signal equivalent circuit model with associated noise sources.

Using the results described above, one can estimate $[\Gamma_s]_{abs}$, $[G_a]_{abs}$ $[F_{min}]_{abs}$ (and the associated bias conditions) for an arbitrary device area. Further, if one knows the desired collector current, one can use the data presented here to determine the optimum device area which will give the lowest $[F_{min}]_{abs}$ with an acceptable $[G_a]_{abs}$.

References:

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