A Direct Extraction Feature for Scattering Parameters of SiGe-HBTs

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We present a direct approach to obtain intrinsic scattering parameters (S-parameters) of SiGe-HBTs by means of small-signal (AC) simulation. The quality of the results is proven by analytical methods on simplified structures and by comparison with measurements.

Since advanced SiGe techniques allow competitive performance of higher frequency devices in markets that were prior object of other materials, small-signal analysis by means of simulation of these devices becomes more important. S-parameter sets which are widely used for RF circuit design, can be one result of this simulation mode. Basically, normalized incident and reflected waves are used to characterize the operation of a two-port network. Thus, in contrary to the Y-parameters, no short circuit is required, which often cannot be achieved due to parasitics causing unstable devices, thus preventing measurements. The parameters can be straightforwardly converted to other parameter sets, such as Z-, Y- or H-parameters. For example, it is common practice to use the parameter h_{21} to extract the cut-off frequency f_T. Hence, a direct small-signal analysis of complex structures can crucially ease device and circuit development.

Our small-signal analysis mode is based on the S^3A approach presented in [1], which was implemented for the three-dimensional device simulator MINIMOS-NT [2]. After a conventional DC-step, the simulated device is linearized at a given operating point and the simulator is switched to the complex-valued simulation in the frequency domain. In comparison to transient methods [3, 4] performance is better and the results are more accurate since approximations are not required. In addition to this already established small-signal analysis, we have implemented a feature for direct extraction of intrinsic (de-embedded) Y- and S-parameters. As an optional feature these parameters can be transformed to extrinsic parameters.

MINIMOS-NT deals with different complex structures and materials, such as Si, Ge, GaAs, AlAs, InAs, GaP, InP, their alloys and non-ideal dielectrics. All physical effects essential for the simulation of SiGe-HBTs, such as bandgap narrowing, surface recombination, transient trap recombination, impact ionization, self-heating, and hot electron effects, are taken into account. The models are based on experimental or Monte Carlo simulation data and cover the whole material composition range. Thus, we use a combination of advanced SiGe modeling and the feature to simulate directly in the frequency domain.

The investigated 4.8 μm^2 SiGe-HBT device structure is obtained by process simulation [5]. A proper DC-calibration is performed as an important prerequisite for AC-simulation. Fig. 1 shows a comparison of simulated and measured forward Gummel plots at V_{CE}=1 V.

By means of AC-simulation we extracted the intrinsic Y- and S-parameters. The quality of the Y-parameters is proven by calculating the row and column sums of the admittance matrix, which have to be zero according to Kirchhoff's laws. The simulation yields errors of about 10^{-16} A/V for typical matrix entries of 10^{-3} A/V. The transformation to intrinsic S-parameters is completely analytical and, thus, the results can be directly compared to the measurement data. Since the measurement environment accounts for the parasitics, no transformation to extrinsic parameters is necessary.

Figs. 2, 3, and 4 show a comparison of simulated and measured S-parameters at V_{CE} =1 V and current densities J_C = 1.23 kA/cm^2, J_C = 26.9 kA/cm^2, and J_C = 210 kA/cm^2, for the frequency range between 50 MHz and 31 GHz. The agreement in order of the typical curve characteristics with measured and transformed data without tuning proves the efficiency of our new approach.

References

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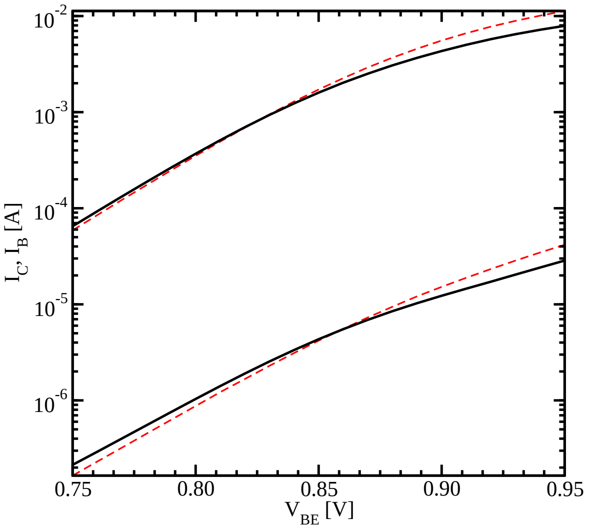

Fig. 1: Comparison of simulated (solid lines) and measured (dashed lines) forward Gummel plots at V_{CE} =1 V.

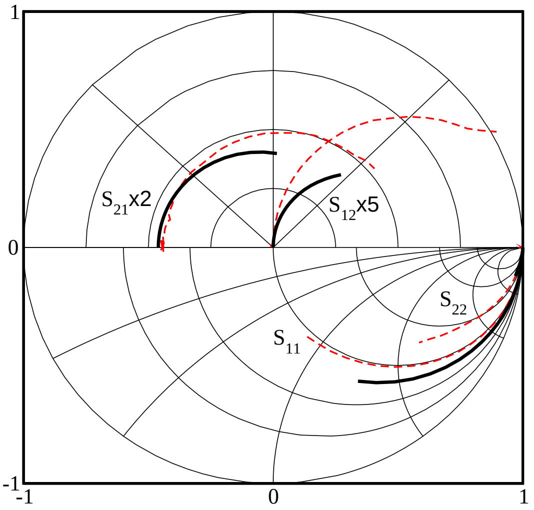

Fig. 2: S-parameters in a combined Smith chart from 50 MHz to 31 GHz at V_{CE} = 1 V and current density $J_C = 1.2\times10^3$ A/cm^2.

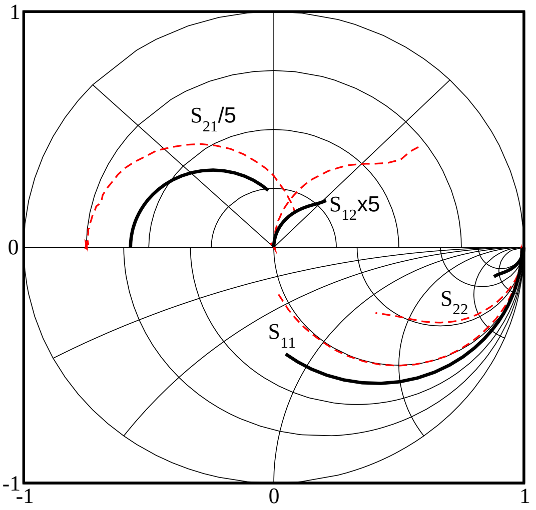

Fig. 3: S-parameters in a combined Smith chart from 50 MHz to 31 GHz at V_{CE} = 1 V and current density $J_C = 2.7\times10^4$ A/cm^2.

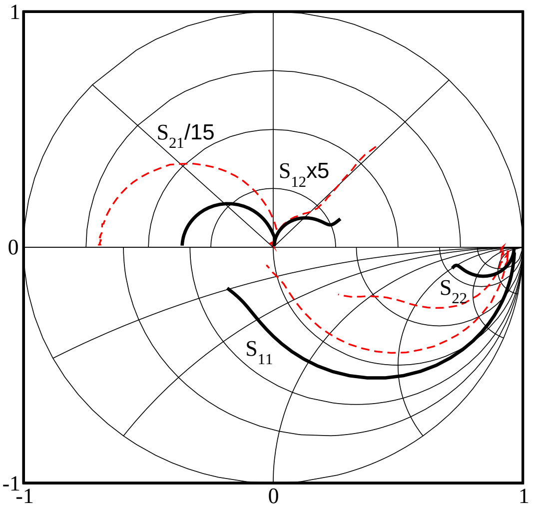

Fig. 4: S-parameters in a combined Smith chart from 50 MHz to 31 GHz at V_{CE} = 1 V and current density $J_C = 2.1\times10^5$ A/cm^2.