A STRAIGHTFORWARD METHOD FOR DETERMINING SiGe HBTs INTRINSIC ELEMENTS OF HIBRID PI AND TEE SMALL-SIGNAL CIRCUIT MODELS FOR MULTIBIAS OPERATION

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ABSTRACT

A new method to simultaneously determine the complete Tee and hybrid Pi equivalent circuit parameters of the SiGe HBT including parasitic intrinsic base resistance, is presented. This approach employs analytically derived expressions and is based on the analysis of measured scattering parameters over an adequate frequency range. This paper shows that a one-to-one correspondence exists between Tee and Pi topologies and very good fit between measured and simulated scattering parameters in the frequency range between 0.05 to 50 GHz is obtained.

INTRODUCTION

Different ways to extract small-signal microwave equivalent circuits of HBT devices from measured data have been proposed in the past. Most of the models that dealt with small signal HBT device performance make use of the Tee model topology, like Wei et al [1], because all the model parameters can be directly tied to the physics of the device. It is not clear which of the two topologies is better to characterize SiGe HBT transistors. This paper demonstrates that a one-to-one correspondence exists between Tee and hybrid Pi models; however some of the Pi model parameters exhibit frequency dependence with respect to the Tee model parameters. This behavior has also been observed in GaAs devices by Teeter and Curtice [2], therefore, it is necessary to optimize the electrical components for both topologies.

In this work a direct comparison between HBT small signal Tee and Pi models is made, taking into account the intrinsic base resistor and feedback capacitors as intrinsic elements (their value varies with bias), splitting the intrinsic part in two: approximate and complete. From the approximate part it is possible to compute the Pi topology of the device using analytical expressions previously developed by us [3], [4]. Tee topology is now computed using a new set of expressions based on the fact that a one-to-one correspondence exists between the two circuit topologies. However, slight variations in Pi model parameters become noticeable at high frequencies. For the devices investigated by us, this effect occurs above 30-40 GHz.

METHODOLOGY FOR THE EXTRACTION OF THE HYBRID PI AND TEE SMALL-SIGNAL MODELS.

Using the techniques previously developed by our group [5], [6], it is possible to compute the parasitic elements from scattering parameter measurements either, at cut-off, DC, or by an optimization process at several bias points. The circuit topology used to determine the parasitic elements is shown in Fig 1(a), and, in our case, cut-off measurements up to 40 GHz were performed. A conventional de-embedding process extracts the intrinsic scattering matrix of the HBT (4), (5). Due to the fact that the complete intrinsic HBT model proposed in this work (Fig 1(b)) has 10 elements, and using the real and imaginary parts of the scattering parameters there are only 8 equations. Therefore, it is necessary to use analytical equations to obtain the intrinsic elements of simplified models as shown in (Fig 1(c) and Fig 1(d)) for both topologies.

This method allows to properly compute the values of $C_{be\pi}$, $R_{be\pi}$, $R_{bc\pi}$, $C_{bc\pi}$, g_m, Tau_π, $R_{ce\pi}$ and $C_{ce\pi}$ for Pi topology, and C_{bet}, R_{bet}, R_{bct}, C_{bct}, α_0, f_α, Tau_{tee}, R_{cet} and C_{cet} for Tee topology. From these values, our approach computes R_{bi} and C_{bcf} for both models, using the following expressions:

$$R_{bi} = \left(\frac{Z_2}{Y_{11} + Y_{12}} - Z_2 Z_3 \right) \cdot \frac{1}{Z_2 + Z_3} \tag{1}$$

$$C_{bcf} = -\mathrm{Im}\left[\frac{1}{\omega} \cdot \left(-Y_{12} - \frac{Z_3}{R_{bi}(Z_2 + Z_3) + Z_2 Z_3} \right) \right] \tag{2}$$

Where Z_2 and Z_3 are given by:

$$Z_2 = \frac{R_{bc}}{1 + j \cdot \omega \cdot R_{bc} \cdot C_{bc}} \tag{3}$$

$$Z_3 = \frac{R_{be}}{1 + j \cdot \omega \cdot R_{be} \cdot C_{be}} \tag{4}$$

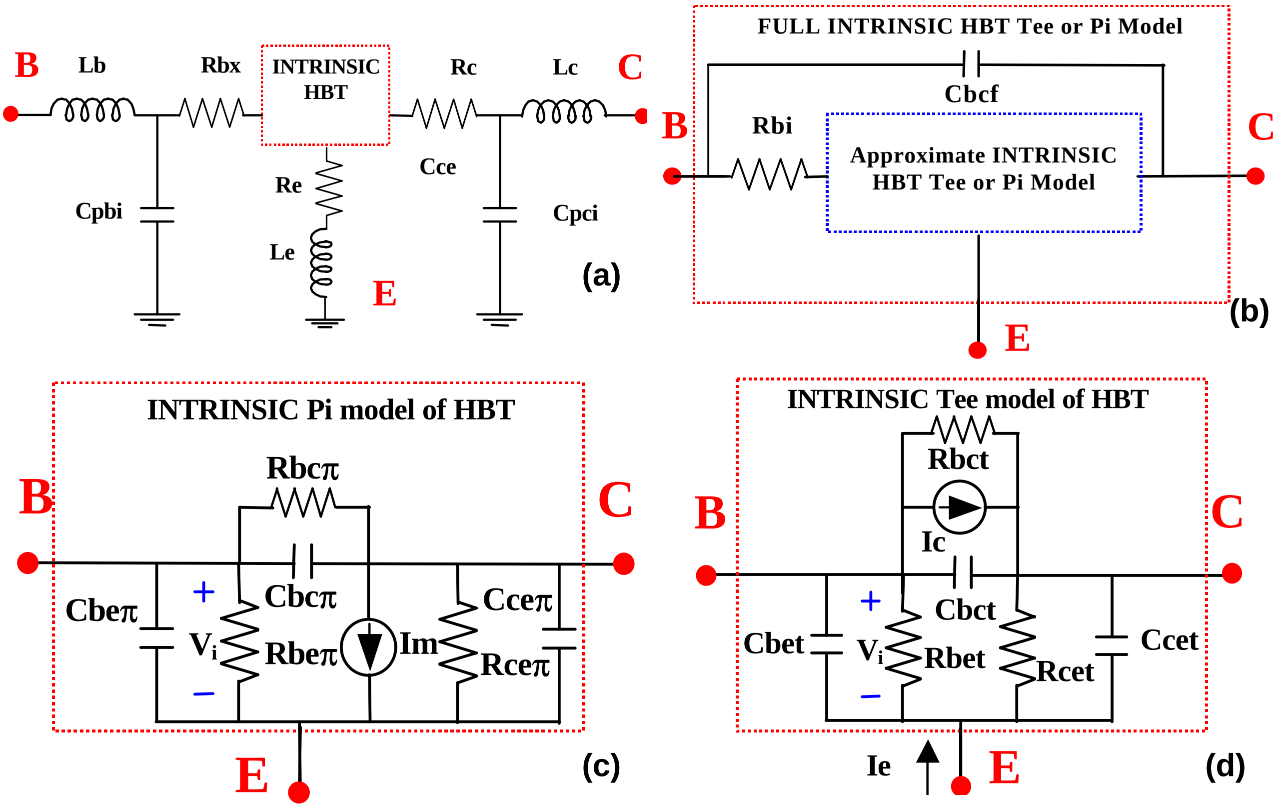

Fig. 1 Small-signal model for SiGe HBT devices.

(a) Parasitic elements. **(b) Complete intrinsic 10 element model.**
(c) Simplified Pi intrinsic HBT model. **(d) Simplified Tee intrinsic HBT model.**

The relationships between the linear current source I_m and the extracted parameters for the hybrid Pi model is giving by:

$$I_m = G_m \cdot V_i \tag{5}$$

Where

$$G_m = g_m \cdot e^{-j\omega\tau_{Pi}} \qquad \textbf{(6)}$$

And for the linear current source I_c and the extracted parameters for the Tee model are given by:

$$I_c = I_e \cdot \alpha \qquad \textbf{(7)}$$

Where

$$\alpha = \frac{\alpha_0 \cdot e^{-j\omega\tau_{Tee}}}{1 + j \cdot \left(f / f_\alpha \right)} \qquad \textbf{(8)}$$

Very good agreement between the complete (Tee and Pi) models and scattering measurements is observed for a six finger device at the bias point I_c= 15mA,V_{ce}=1.5 V, as shown in Fig 2. A microphotograph of this device designated 67 by the Daimler-Chrysler foundry is shown in Fig. 2(d).

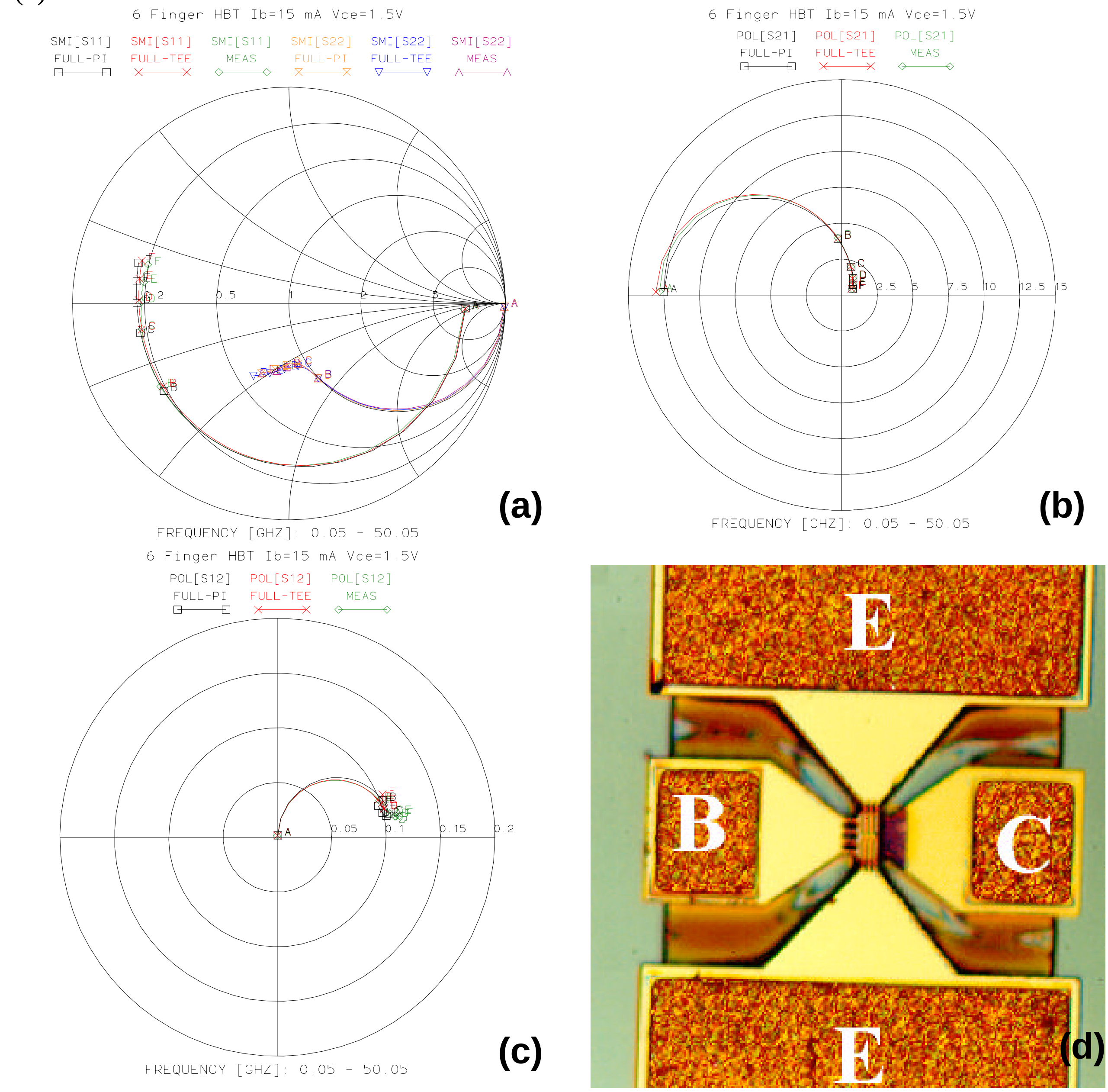

Fig. 2 Measured vs. Modeled [S] parameters (Full Tee and Pi models).
(a) S11&S22 (b) S21 (c)S12. (d) Microphotograph of a 67 device.

CONCLUSIONS

A new technique for the simultaneous extraction of hybrid Pi and Tee topologies of the Daimler-Chrysler SiGe HBT devices, has been presented. Very good agreement for a 67 device between our model (Tee and Pi) and measurements has been observed in the frequency range from 0.05-50 GHz for all bias points studied. Direct comparison between the HBT small signal Tee model and hybrid Pi topology has been made and it is shown that a one-to-one correspondence exists between both topologies. Linear models extracted by this method for another devices have shown satisfactory agreement between measured and simulated data and allowed us to validate the model and encouraged us to use these models in new designs.

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