Chapter 4

MODELLING USING HIGH-FREQUENCY MEASUREMENTS

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Abstract: This chapter focuses on MOSFET modeling methods that are based on high-frequency measurements directly. Modeling approaches that are based on linear and on non-linear measurements are both explained in detail. The different implementations are illustrated by model examples.

Key words: equivalent circuit model; behavioral model; S-parameter measurements; large signal vector measurements; de-embedding.

1. Introduction

The non-linear behavior of MOSFETs has traditionally been described by compact models. This originates from the time that flexible, SPICE compatible, and widely scalable models were required for the silicon based digital designs. Nowadays, the RF performance of silicon CMOS is rapidly increasing and is competing with the III-V compound based devices. As a consequence of which, more and more microwave modeling and design approaches enter the area of silicon analogue circuit design. Whereas most other chapters of this book focus on the latest developments in compact modeling, this and the next two chapters will discuss MOSFET modeling approaches that are based on high-frequency measurements directly. It has to be noted that both the direct high-frequency based and the compact modeling approaches can perform equally well, as recent extensions of compact models are taking special care of high-frequency effects (e.g., gate resistance, substrate network, etc.) [1].
This Chapter is structured as follows. First, the theoretical background of two high-frequency modeling approaches is explained: equivalent circuit and behavioral models. A distinction is made between linear and non-linear vector measurements. Subsequently, examples of the different model representations are presented.

2. HF Non-linear Modelling Approaches

2.1. Linear Versus Non-linear Microwave Measurements

The basic principle of linear and non-linear microwave measurements is depicted in Figure 1. In the linear case, a small incident traveling voltage wave $a_1$ is applied to the device. As response, the device scatters back a scattered traveling voltage wave towards both its port 1 and port 2, which are denoted as $b_1$ and $b_2$. If the response has only one spectral component at the same frequency $f_0$ as the frequency of the excitation signal, then the measurement is linear. In case of microwave measurements, the incident and scattered traveling voltage waves are not measured separately, but only their ratios are characterized. If the non-excited port is loaded by 50 Ohm, we obtain the well-known $S$-parameters that are being measured by vector network analyzers. The definitions are:

$$
\begin{align*}
S_{11} &= \frac{b_1}{a_1} \mid_{a_2=0} & S_{12} &= \frac{b_1}{a_2} \mid_{a_1=0} \\
S_{21} &= \frac{b_2}{a_1} \mid_{a_2=0} & S_{22} &= \frac{b_2}{a_2} \mid_{a_1=0}
\end{align*}
$$

(1)

Figure 1. Schematic representation of microwave linear vector measurements (top) and microwave non-linear vector measurements (bottom).