Chapter 2
Microwave Circuit Design

Gabriel Cormier
Université de Moncton, Canada

Tyler Ross
Carleton University, Canada

ABSTRACT

Circuit models play an important role in the design and optimization of microwave circuits (circuits in the GHz frequency range). These circuit models contain many parameters, including parasitic elements, necessary to correctly model the behavior of transistors at high frequencies. These models are often designed based on a series of measurements. Because of its ability to efficiently locate the global optimum of an objective function, particle swarm optimization (PSO) can be a useful tool when matching a model to its measurements. In this chapter, PSO will be used to calculate a transistor's small-signal model parameters, determine the noise parameters of the transistor, and design a microwave mixer. The mixer is designed at 39.25 GHz, and a comparison between measurements and simulation results shows good agreement.

INTRODUCTION

Particle swarm optimization is very useful technique that can be used when developing models for microwave components. Proper models are important in microwave engineering, as any microwave designer will need to account for the parasitic components of the transistors and passive components used in their design. Good models reduce the number of design/fabrication cycles required to meet a circuit's specifications. This is of considerable benefit to engineers designing microwave circuits, especially monolithic microwave integrated circuits (MMICs), where circuit fabrication is costly and turn-around times are lengthy.

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The first part of this chapter will introduce and explore the subject of small-signal transistor modeling. For the interested reader, references to important background papers treating small-signal transistor modeling in greater detail will be provided.

In many transistor models, it is possible to obtain the same response for different sets of model parameters. As a result, it is very difficult for conventional optimization to converge to a global optimum. In addition, it is difficult to calculate the model parameters accurately using a single frequency or narrowband measurements. Therefore, a method for finding the global optimal solution using broadband measurements is required. The particle swarm algorithm is a suitable method, since it allows the minimization of an objective function with discontinuities, local optima, while not requiring its derivatives. Since the algorithm is less likely to be trapped by local optima, it is usually be more effective than traditional gradient-based algorithms, which often require estimates of model parameters which should be very close to their actual values. Other approaches and the advantages the particle swarm optimization offers are discussed in greater detail in the coming sections.

As a first example of the use of particle swarm optimization in microwave circuit design, we will use a discrete, commercially-available gallium arsenide (GaAs) FET with a 0.3 μm gate length from Excelics Semiconductor (part number EFA018A), and determine the small-signal model and noise parameters. The manufacturer provides S-parameters as well as large and small-signal models for this device.

One use of a small-signal model is for determining noise parameters, required for the design of a low-noise amplifier. Given a transistor's small-signal model parameters, it is possible to calculate the four noise parameters required for low-noise amplifier design: the source resistance needed to achieve the minimum noise figure (R_{opt}), the source reactance needed to achieve the minimum noise figure (X_{opt}), the noise resistance (R_n) and the noise minimum noise figure (F_{min}). As an example, the minimum noise figure will be determined for this transistor, which would be one of the first steps when designing a low-noise amplifier.

Since the algorithm is less likely to be trapped by local optima, it can be more effective than traditional gradient-based algorithms, which often require estimates of model parameters which should be very close to their actual values. Particle swarm optimization can also be helpful in the design of circuits. While the first half of the chapter deals with transistor modeling, in the second half of this chapter, a differential mixer operating at an RF frequency of 39.25 GHz will be optimized to yield maximum conversion gain. The algorithm will be used to determine the optimal transistor size, transmission line lengths and impedances needed to match and stabilize the mixer.

Conventional approaches to this process involve considerable iterations consisting of transistor stabilization, matching and checking the circuit for conformance to design specifications. Using particle swarm optimization allows for all of these goals to be achieved much more quickly and ensures that the *best* circuit is found.

Fitting a Model to S-Parameters

There have been many studies on how to extract a transistor model from a set of data, often measured S-parameters. Most circuits used to model FETs, including MESFETs and HEMTs at microwave frequencies, are similar to the model shown in Figure 1, with somewhere between 12 and 18 circuit parameters (Curtice, 1980; Maas, 1993; Kayali et al., 1996).

Having a set of measurements of a transistor (typically S-parameters), one might be tempted to directly apply particle swarm optimization to the problem to determine all circuit parameters simultaneously. However, the particle swarm

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