Robust Method to Extract Electrical Microwave Packages Models

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Abstract — This paper shows an, accurate-straightforward electrical small signal modeling technique for radifrequency and microwave packaged devices, developed by our group. This method called DICOMPAK can be used for ceramic packaged devices and for low cost plastic encapsulated devices. The technique employs analytically derived expressions and it is based on analysis of the measured scattering parameters over an adequate frequency range. Very good agreement between measured and simulated scattering parameters for different ceramic and plastic packaged devices from several foundries is shown.

1. Introduction

In order to fulfill the ever-increasing demands of communications systems, chip technologies such as silicon FET (including SiGe and GaN) and GaAs are being used. In this way, monolithic microwave GaAs ICs (MMICs) and radio frequency integrated circuits (RFICs) are usually used in wireless, airborne and space applications. A few years ago, only two options were possible for the microwave designer: hybrid circuitry using unpackaged MMICs or RFICs directly bonded to the circuit, or expensive ceramic hermetically packaged devices. Advances in packaging technology in the last decade have made it possible for plastic packages to be used at RF and microwave frequencies, typically at L (0.39-1.55GHz) and S (1.55-5.2GHz) bands, and different authors have studied these applications [1-2].

At higher frequencies, parasitic elements make the use of this type of packaging difficult, and electromagnetic theory, including methods of moments or finite differences, must be applied [3]. For space applications, plastic packages appear as an interesting implementation option given the important associated mass and size reduction, and several authors have studied the effects of operating in space such as out-gassing, thermal effects and reliability [4]. On the other hand, the cost of these plastic packaged MMICs is considerably lower than that of ceramic ones, because they use industrial standard processes to manufacture them. Figure 1 (a) shows a schematic section of a standard hermetic plastic SOT-23 package showing its internal parts. Brown and Hiller [5] have modeled this package for microwave diodes up to 10GHz. However, designing MMICs for use in such packages is difficult because of the poor grounding characteristics of the elevated paddle (MMIC ground), and also to the lack of generally applicable circuit models for the package. This difficulty is exacerbated for designs at frequencies higher than 10GHz, and for packages with elevated number of pins. Figure 1 (b) shows the ceramic package of a MMIC amplifier model MSA-0670 from foundry Agilent characterized in the present Work.

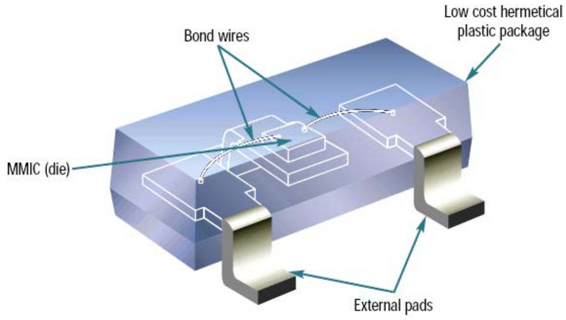

Figure 1.a. Schematic diagram of a SOT-23 low cost plastic package, showing its internal parts.

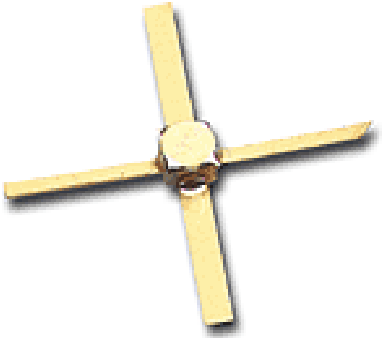

Figure 1.b. Ceramic Packaged MMIC amplifier model MSA-0670 from Agilent Technologies.

The main purpose of this paper is the accurate modeling of the above mentioned effects, and the use of new optimizations algorithms, to extract electrical equivalent circuits in order to use low cost plastic encapsulated microcircuits (PEM) at higher frequencies (up to Ku Band). The results shown in this paper are focused on two types of plastic packaged CFY77-08/10 PHEMT devices from the Infineon (formerly SIEMENS) foundry. These transistors are low noise (0.8 and 1dB respectively) small signal devices, usually used for front end amplifiers up to 20GHz and for DBS down-converters without package. Both devices use the same plastic package, designated by the foundry as MW-4. Figure 2 (a) shows the electrical diagram used to model such package. The same technique has been used for modeling commercial plastic packaged MMIC LNAs from Agilent Technologies and Mini-Circuit manufacturers up to 6GHz with very good results. Table I shows a cross-reference between the different models investigated. Both, companies use the same MSA-0600 chip manufactured by Agilent.

Agilent Part Number	**Mini Circuits Part Number**	**Package Type**	**Package Outline**
MSA-0685	MAR6	Plastic	85 mil[a]
MSA-0686	MAR-6SM	Plastic	86 mil
MSA-0611	VAM-6	Plastic	SOT 143
MSA-0670	---	Ceramic	70 mil
MSA-0600[b]	---	Die	None

a. mil is the acronym of mili-inch.

b. All devices of the table use the same MMIC model MSA-0600 from Agilent

TABLE 1. Cross Reference list of Charaterized Amplifiers

The MODAMP MSA series amplifier is fabricated using a 10GHz of transition frequency (f_T) and 25GHz maximum oscillation frequency (f_{MAX}) silicon bipolar MMIC process which utilizes self-alignment, ion implantation and gold metallization to achieve excellent uniformity and reliability. This characteristic is enough for operation at L and S-bands for this kind of amplifier. The electrical model used in the characterization process for the different devices is shown in Figure 2 (a) and Figure 2 (b).

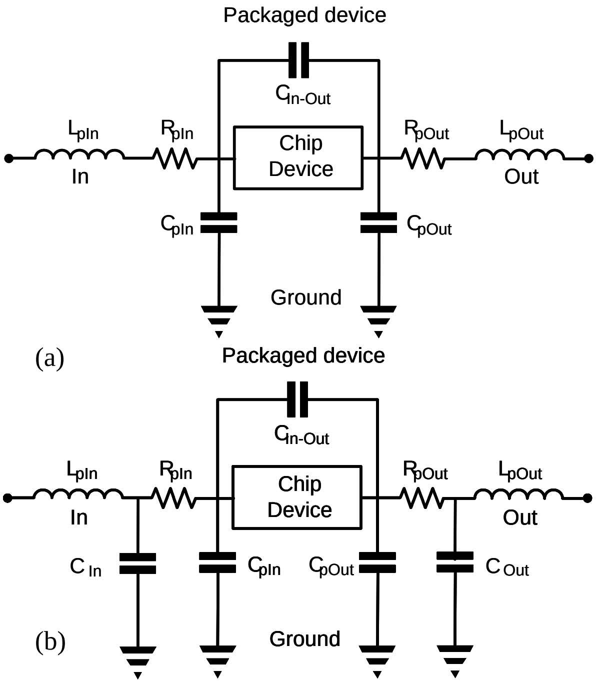

Figure 2. a. Basic electrical model used for characterize the package of active devices (7 elements).

Figure 2. b. Advanced electrical model used for characterize the package of active devices (9 elements)

2. The Dicompak Technique

One of the main objectives in the characterization of MMIC packages involves accurately determining the values of parasitic elements loss resistance, capacitance and inductance for each pad either theoretically or experimentally. This data can be used to describe an equivalent circuit that explains the electrical behavior of PEM devices. At microwave frequencies these parasitic elements mask the electrical characteristics of die devices (without package) and the connections between package pins and chips begin to behave as transmission lines rather than as simple wire connections [6-7]. Parasitic capacitances, inductances and resistances, such as pin-to-pin capacitance, as well as wire inductance and resistance, become significantly higher. For the different plastic and ceramic packaged devices investigated here, parasitic elements are typically of the order of pF, nH, and mΩ for the capacitances, inductances and resistances respectively. In order to summarize, system configurations, as well as the hardware and software used to make laboratory measurements possible, will not be discussed as well as, some high-performance tools (boxes, chip carriers and boards) specially developed to measure the devices under study.

DICOMPAK method uses the scattering parameters measured at different bias points, under the hypothesis that parasitic elements induced by package do not vary with bias. This technique can be applied in two different forms: DICOMPAK-I and DICOMPAK-II. The intrinsic equivalent circuit at each bias point of the active circuits has been computed using conventional techniques reported by Dambrine [8] and later modified by our group [9-10]. The technique presented here differs from previously reported methods [11], mainly in the optimization procedure and the possibility of use another packaged models such us the advanced model shown in Figure 2 (b). Respect the optimizer used here, the Levemberg-Marquard optimization algorithm has bee implemented to get better and fast results instead of Sequential Quadratic Algorithm used in [11]. Both routines are from the Standard Library provided by MATLAB language [12].

2.1. DICOMPAK-I

The DICOMPAK I technique is based on the measurement of the scattering parameters at two or three different bias points for the same type of component, packaged and un-packaged die. It is assumed that both devices are identical during the whole characterization process, and that the plastic package does not vary with the bias point. Parasitic elements at these bias points can be evaluated by a conventional de-embedding process. By comparison between modeled and measured scattering matrix parameters and using, if necessary, Levemberg-Marquard optimization algorithm has been used to minimize the error function, it can be used to finally compute a unique set of parasitic values. To make the electrical characterization of these parasitic elements possible, it is necessary to have the same type of component, either packaged or unpackaged dies, in order to make the necessary scattering measurements of the device under both conditions.

2.2. DICOMPAK-II

The DICOMPAK II technique is quite similar to the above introduced DICOMPAK I. The main difference between the two techniques resides in that DICOMPAK II algorithm uses only the measured scattering matrix from the packaged device, under the assumption that all parasitic elements are all null at the first iteration. After that, using an optimization algorithm and an iterative method, the plastic parasitic extrinsic elements are computed using the variance of the intrinsic elements. Values of the parasitic elements are updated in order to minimize the error vector using the Levemberg-Marquard method. A computer program using the flowchart shown in Figure 3 has been written using MATLAB [12].

3. Results and Validation of the Technique

The 7-element electrical model shown in Figure 2 has been selected in order to characterize the parasitic effects introduced by the plastic package of devices presented in this paper, for simplicity. Table 2 shows the results obtained by the application of the above mentioned techniques to a PHEMT device CFY77-08 from Infineon.

Resistances (Ω)	**Inductances (nH)**	**Capacitances (pF)**
RpIn=3.50	LpIn=0.610	Cpin=0.235
RpOut=5.50	LpOut=5.50	CpOut=0.252
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TABLE 2. DICOMPAK-I Results For CFY77-08 Device.

3.1.Validation for PHEMT device

In order to validate the electrical model developed for the plastic package, measured scattering parameters of the packaged de-vice have been compared with measurements of the same device without packaging and the addition of the electrical model extracted for the package. This comparison offers good agreement for different devices

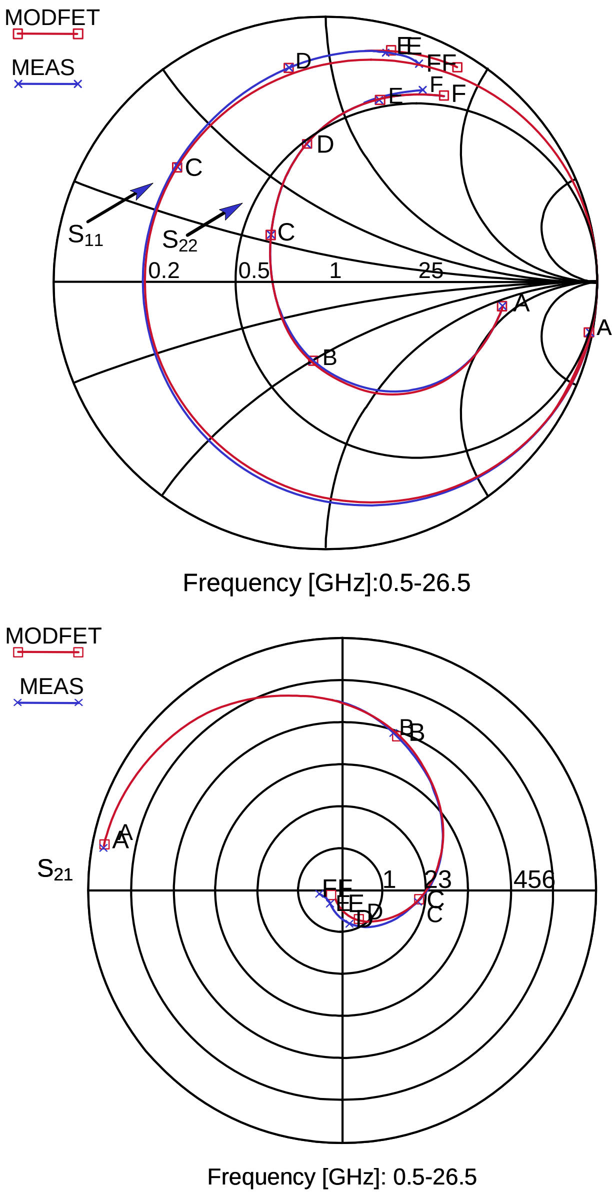

Figure 3. Comparison between measured and modelled Scattering parameters for the PHEMT transistor from Infineon foundry CFY77-08 biased at Vds= 2 V, Id= 15mA.

MEAS ➔ Measured scattering parameters, for packaged device.

MODFET ➔ measured scattering parameters, for chip device + package model extracted used DICOMPAK technique.

(a) S11 and S22. (b) S21

. As an example, Figure 3 (a) and Figure 3 (b) show the results for the CFY77-08 device, biased at Vds=2V, Vgs=-0.1V, and Id=15mA up to 26.5GHz.

3.2.Validation for Agilent and Mini-Circuits amplifiers

In our study we have measured different types of devices such as: die devices, plastic packaged devices and ceramic packaged device model MSA-06070 with the same internal chip in order to verify if the DICOMPAK technique is suitable for application to all type of packaged devices. Table 3 shows the results obtained by the application of the DICOMPAK techniques to these MMIC amplifiers.

Plastic Package			
Model	**Resistances (Ω)**	**Inductances (nH)**	**Capacitances (pF)**
	RpIn=3.38	LpIn=0.934	CpIn=0.053
MSA-0611	RpOut=13.13	LpOut=0.731	CpOut=0.320
	-------------	-------------	CpIn-Out=0.264
	RpIn=5.37	LpIn=0.455	CpIn=0.221
MSA-0685	RpOut=6.52	LpOut=0.485	CpOut=0.116
	-------------	-------------	CpIN.OUT=0.024
	RpIn=4.70	LpIn=1.059	CpIn=0.002
MSA-0686	RpOut=7.64	LpOut=1.047	CpOut=0.116
	-------------	-------------	CpIn-Out=0.192
Ceramic Package			
Model	**Resistances (Ω)**	**Inductances (nH)**	**Capacitances (pF)**
	RpIn=1.78	LpIn=0.328	CpIn=0.291
MSA-0670	RpOut=1.90	LpOut=0.327	CpOut=0.113
	-------------	-------------	CpIn-Out=0.182

TABLE 3. DICOMPAK-II Results For MSA Mmic Amplifiers

Figure 4 shows the comparison between modeled data using the DICOMPAK-II technique and measured S21 scattering parameters for a plastic package MSA-0686 device. In all cases, a reasonable good fit with experimental data is reported.

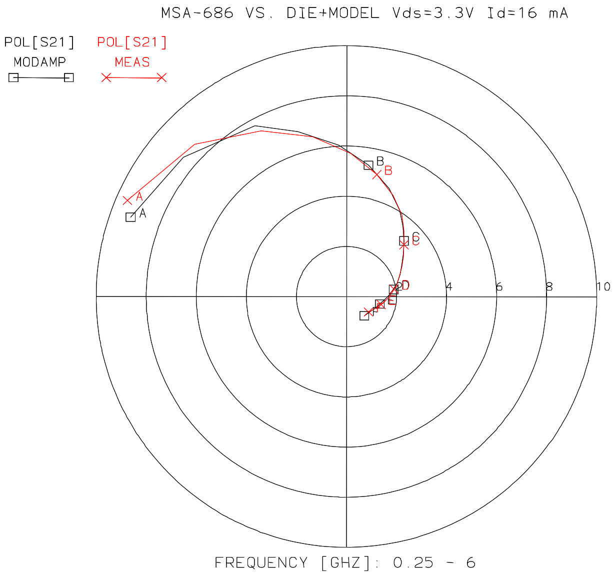

Figure 4. Comparison between measured and modelled S21 parameters for the MSA-0686 device.

MEAS ➔ Measured scattering parameters, for packaged device.

MODAMP ➔ measured scattering parameters, for chip device + package model extracted used DICOMPAK technique.

The package models that have been developed in the present paper, offers a good behavior up to 3 GHz in terms of scattering parameters and figures of merit (FOM), for the ultra-low cost package model SOT-143. For 85/86mil plastic packages, the results are very close to the equivalent 70mil ceramic package up to 6 GHz. For Infineon HEMT devices, the model behavior exhibits very good performance up to the Ku band. As a consequence of this study, it can be established that the electrical model works reasonably well for plastic and ceramic packaged devices. However, the study made here is not comprehensive enough to develop a general purpose model for the plastic packages studied.

In summary, the possible solutions to extend the frequency range of the plastic package electrical models could be the following:

1) Develop a nonlinear model for plastic packages in order to increase the validity bandwidth of the model, using the non-linear techniques developed by us [13].

2) Develop a new model taking into account second order effects like the increase of temperature and moisture level of the plastic package during operation.

3) Repeat this study for another family of compound devices (SiGe, InP and GaN) with similar packages, in order to generalize the models developed within this work, and in order to see if the behavior of these new packaged devices is similar to the behavior presented by the devices studied here.

4. Conclusion

An automatic direct extraction method for extracting the electrical values of parasitic elements from plastic packaged devices has been presented. The method could easily be generalized for other MMIC devices, and has been tested for several different microwave packaged transistors and low noise amplifiers. Furthermore, it has now been extended to MMIC packaged devices with a large number of pins. As a conclusion of this work, several different models for plastic packaged devices have been developed using the 7 or 9 element custom models.

5. Acknowledgments

This work has been partially supported by the Spanish Ministerio de Educación y Ciencia through the project TEC2005-07985-C03-01.

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