PARAMETER EXTRACTION TECHNIQUE FOR NON-LINEAR MESFET MODELS

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ABSTRACT

The non-linear parameter extraction technique proposed in this paper gives both rapid convergence and consistency of the derived model. The computational aspect of the technique is divided into two processes: (i) direct extraction of intrinsic element values by a statistically based routine and (ii) optimisation of intrinsic and extrinsic element values and/or non-linear functions simultaneously at all bias points. The non-linear elements are extracted in two forms: (a) as some analytical functions of bias and (b) as bias-dependent values. The results of the modelling of both chip as well as packaged MESFET devices are presented and very good agreements between measurements and calculations are obtained.

INTRODUCTION

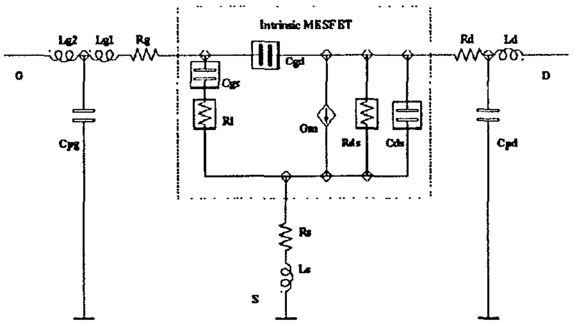
In a typical parameter extraction method for microwave models, optimisation is used which varies model elements until the calculated S-parameters fit the measured S-parameters. Even for linear models, using such an approach presents some well known problems [1,2,4,5], including:

- The results are often inconsistent, i.e. they depend upon the initial element values and the optimisation procedure.
- The results may not be unique, i.e. several almost equally good solutions may exist which have different element values.
- At the point of best fit values of some model elements may be non-physical.

The equivalent circuit elements of a MESFET chip model can be divided into two categories (see Figure 1):

- Intrinsic non-linear elements C_{gs}, R_i, C_{gd}, G_m, R_{ds}, C_{ds}.
- Extrinsic linear elements L_{g1}, L_{g2}, R_g, L_d, R_d, R_s, L_s, C_{pg}, C_{pd}.

FIGURE 1. Circuit model of a MESFET chip (including bond wires)

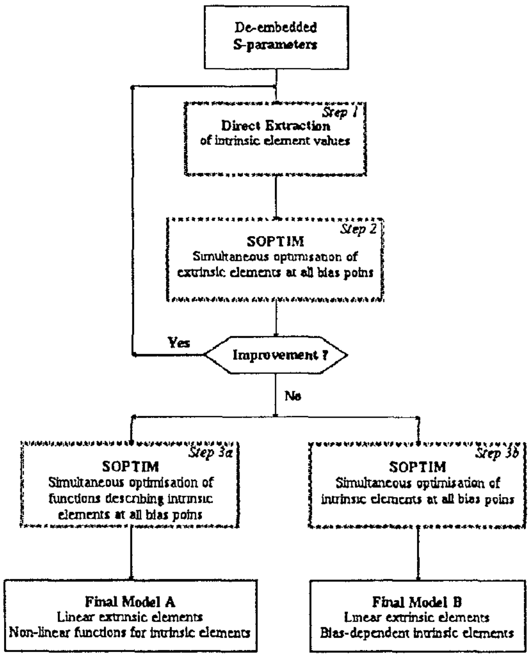


In the case of a packaged device, a model of a package consisting of several linear elements (typically between 7 and 10) also needs to be included. Therefore, the total number of unknown elements is 15, for the chip device in Figure 1, and 22-25 for the packaged device. Such a large number of unknowns is much more than current circuit optimisation procedures can efficiently handle. Therefore, partitioning of the optimisation process into simpler tasks is required.

For non-linear modelling, the problems stated earlier are increased because several linearised models over the range of bias conditions need to be considered. In a typical approach, each linearised model is optimised separately. Analysis performed in [4] shows that this is equivalent to the constrained hierarchical two-level optimisation with a very large number of unknowns and functions. In concept, the values obtained for linear model elements should be the same at all bias points, while the non-linear elements should vary with bias according to their physical behaviour. In practice however this is rarely realized, and at the points of the minimum modelling errors the linear elements will be different for different biases. In order to overcome this problem, a specific optimisation strategy was developed [3,4,5,6]. In this paper this optimisation strategy is used in conjunction with statistically based direct extraction method which improves the convergence and consistency of the parameter extraction process.

NEW PARAMETER EXTRACTION TECHNIQUE

FIGURE 2. Outline of the parameter extraction algorithm



The new parameter extraction technique is illustrated in Figure 2. The computational aspect of the technique is divided into two processes:

- Direct extraction of intrinsic element values by statistically based routine (Step 1).
- Optimisation of model elements and/or non-linear functions using SOPTIM [6] (Steps 2, 3a and 3b).

Assuming that the extrinsic elements are known, then the intrinsic element values can be directly calculated from the measured S-parameters. For each frequency and each bias point, one set of values is obtained. Ideally, the intrinsic elements should be constant with frequency. In practice, however, both the measurement errors and inadequacies of the model structure will cause these elements to vary, even for well optimised models. For each element an appropriate frequency range is chosen and a robust linear regression is performed. Mean values derived from this analysis give a good approximation of intrinsic element values. Statistical analysis of the variation of the intrinsic element values with respect to frequency provides a good indication about consistency and quality of the model. For example, a normalised slope of the regression lines can be used as a figure of merit.

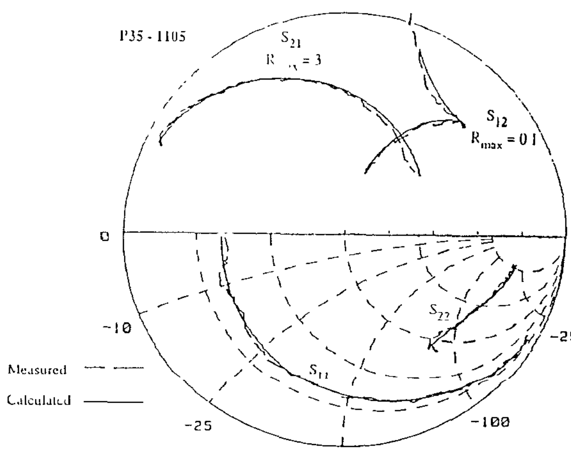
The basic idea behind process (ii) is to optimise the non-linear model simultaneously at all bias points [3,4,5,6]. To help determine the non-linear behaviour of the of the model elements, the intrinsic elements can be defined as bias dependent, with no constraints, whilst the extrinsic elements can be kept the same at all bias point. Alternatively, the non-linear elements can be described by functions which constrain their variation with bias. This reduces the degrees of freedom during optimisation and the probability of finding a global minimum is increased. However, since the existing non-linear functions do not accurately describe variations of model elements, then the quality of the global fit will decrease.

RESULTS

Extraction of non-linear models has been performed for two MESFETs: a Plessey P35-1105 chip device and an NEC71083 packaged device. S-parameters for both devices were obtained using an HP8510 ANA. Both MESFETs were measured at 25 bias points in the resistive and saturation regions. The P35-1105 was measured between 2 and 16GHz and the NEC71083 between 45MHz and 18GHz.

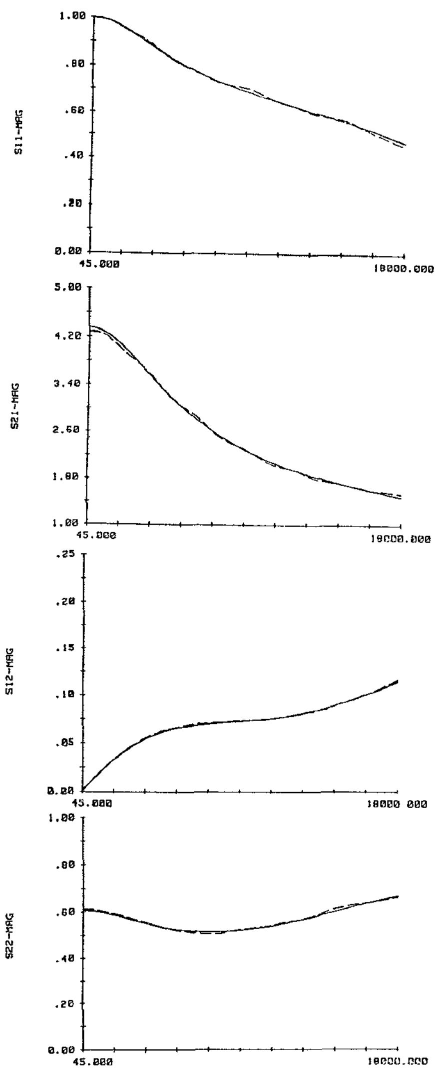
P35-1105 Chip Device

FIGURE 3. Calculated and measured S-parameters for the P35-1105 device at the bias point Vgs=0V, Vds=5V. Frequency range 2-16 GHz.



S-parameters for the P35-1105 device were de-embedded using the TRL technique[1]. The measurements showed some ripples in the magnitudes and phases of S_{11} and S_{22}. Worn microstrip calibration standards were responsible for this behaviour. A comparison of the measured and calculated S-parameters, at one bias point (Vgs=0V, Vds=5V) is shown in Figure 3. It can be observed, that the parameter extraction process has smoothed out the S-parameter errors. Similar quality of the results was obtained for other bias points in the saturation region. In the resistive region of the device operation the fits were acceptable but not as good. This indicates, that the assumed intrinsic model structure is inadequate for this region.

FIGURE 4. Calculated (solid line) and measured (broken line) S-parameters for the NEC71083 device. Linearised model (B), Vds=3V, Ids=20 mA.

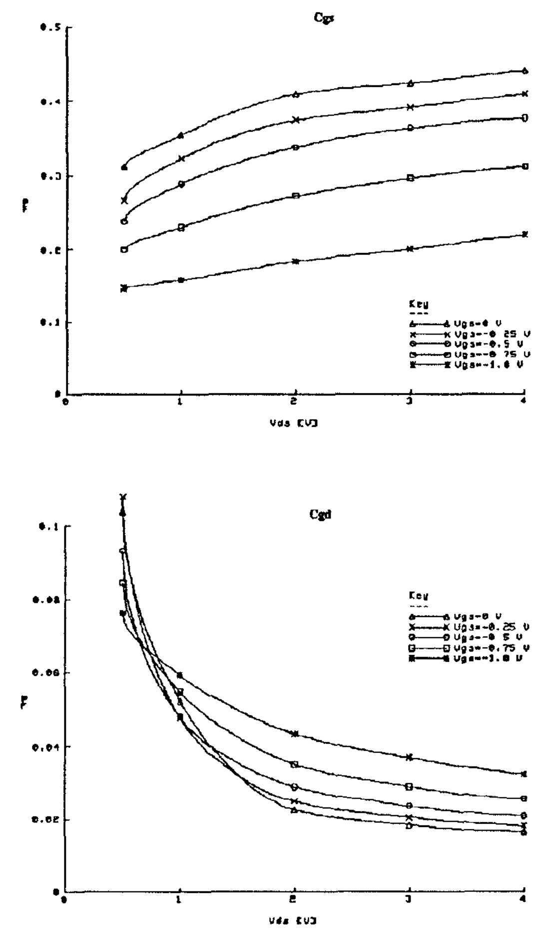


NEC71083 Packaged Device

De-embedded S-parameters for the NEC71083 device were obtained using the Mauri Microwave MT950 Transistor Test Fixture[2]. The equivalent circuit of the package enclosing the chip was determined by performing the extraction algorithm for a number of different topologies. Analysis of the statistical data in Step 1, together with the requirement of a good fit after optimisation, indicated whether or not a particular topology was adequate. Measured and calculated magnitudes of S-parameters for one bias point (Vds=3V, Ids=20mA) are shown in Figure 4. The fit of phases was exact, so the phase plots have been omitted.

Figure 5 shows variations of some of the intrinsic element values as obtained from Step 3b in Figure 2 (no constraints on the element behaviour).

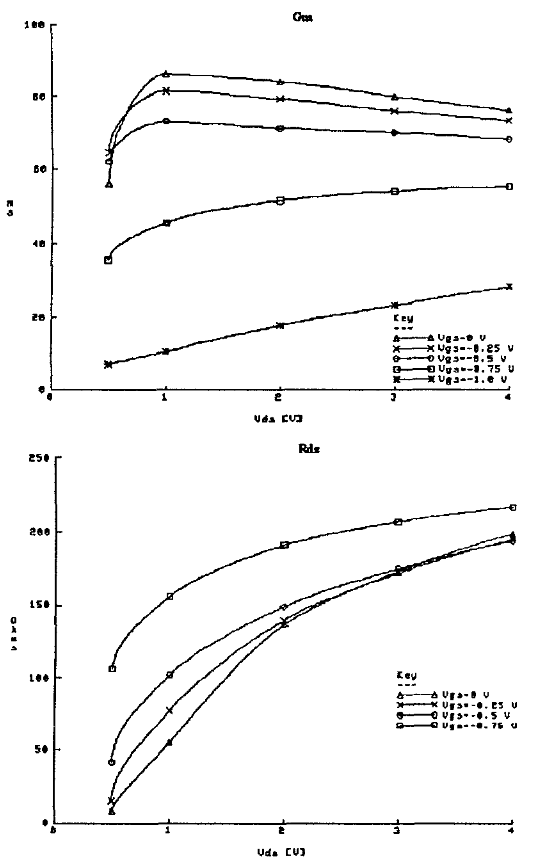
FIGURE 5. Extracted non-linear behaviour of some intrinsic MESFET elements for the NEC71083 device (Model B).



1. The measurements of the P35-1105 device were performed by Dr. O.P.Leisten using facilities at Cossor Electronics Ltd. The resulta were de-embedded at the University of Kent.

2. The measurements of the NEC71083 device were provided by Cossor Electronics, Ltd., Harlow, Essex, England.

FIGURE 5. Continued



A simplified form of the non-linear model [5] has been extracted to simulate the behaviour of the FET in the saturation region (Step 3a in Figure 2). Cgs, Gm and Rds are described by functions currently available in SOPTIM [6]. Cgd, Ri and Cds were fixed as linear elements. The results for one bias point (Vds=3V, Ids=46.5 mA) are shown in Figure 6. Modelling errors of about 3% were obtained for bias points throughout the saturation region.

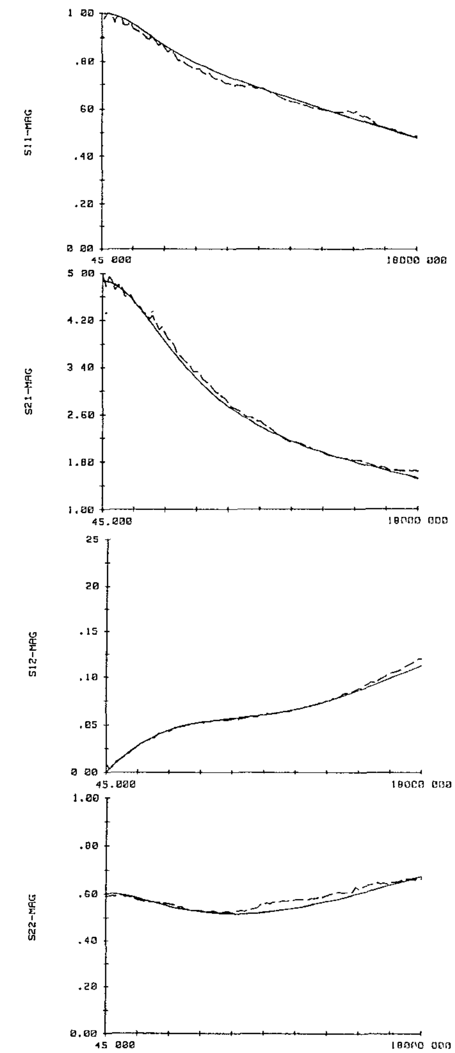
CONCLUSIONS

The non-linear parameter extraction technique proposed in this paper gives both rapid convergence and consistency of the derived model. Therefore, it is well suited for automation of the device modelling task. The technique has already been implemented as an extension to the existing SOPTIM program [6].

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Chris M.D. Raycroft and Mr. Surinder M. Bali from Cossor Electronics Ltd. They also wish to thank Dr. O.P. Leisten.

FIGURE 6. Calculated (solid line) and measured (broken line) S-parameters for the NEC71083 device. Non-linear model (A), Vds=3V, Ids=46.5 mA.



REFERENCES

[1] W.R.Curtice,R.L.Camisa,"Self-Consistent GaAs FET Models for Amplifier Design and Device Diagnostics", IEEE Trans. MTT, Vol. MTT-32,pp.1573 -1578,Dec. 1984.

[2] H.Kondoh, "An Accurate FET Modelling from Measured S-parameters", IEEE MTT-S Digest, pp.377-380, 1986.

[3] A.K. Jastrzebski, "Non-linear MESFET Modelling", 17th European-Microwave Conference, Rome, pp.599-604, 1987.

[4] A.K.Jastrzebski,"Parameter Extraction for Non-Linear MESFET Models", IEE Colloquium on Large Signal Device Models and Parameter Extraction for Circuit Simulation, London, April 1988.

[5] A.K.Jastrzebki,"MESFET Modelling and Parameter Extraction", in D.Haigh, J.Everard (ed.),"GaAs Technology and its Impact on Circuits and Systems", pp.67-121, Peter Peregrinus, 1989.

[6] "SOPTIM User Manual", Sobhy and Jastrzebski Microwave Consultants, Canterbury, Kent, England, 1984-88.