FULL EXTRACTION OF PHEMT STATE FUNCTIONS USING TIME DOMAIN MEASUREMENTS

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Abstract **The large signal state functions of the PHEMT, (Psuedomorphic High Electron Mobility Transistor) are fully extracted for the first time using dynamic measurements only. A novel reverse waveform measurement technique combined with forward waveform measurements yield the intrinsic Current and Charge Surfaces, State Functions. The new reverse extraction results have been verified to be bias and power level independent and the resultant State Functions obtained are confirmed to be unique. The technique provides a direct high frequency curve-tracing tool, and allows for the generation of the parameter surfaces required for dynamic Table-Based models.**

I. INTRODUCTION

Over the last decade the importance of fast, accurate and reliable large signal modeling techniques for high frequency active devices in Computer-Aided Design has become vital. One approach to large signal modeling is to employ the actual measured data in the RF simulator. Measurement based methods provide a direct link from software to device, by manipulating the measured device behavior in the form of a Look-Up table [1]. When implemented in the simulator the Look-Up table should accurately reproduce the complex device operation and performance under the desired stimulus conditions. Usually the Bias Dependant s-parameter approach, [2] is employed to yield the data for the Look-Up table, however this method has two major downfalls. The number of required measurements is high and the measured data is influenced by low frequency trapping issues. A more realistic approach is to use actual non-linear data for the active device model extraction. Recent advances in time domain measurement systems [3] have made the extraction and verification [4] of all large signal parameters from non-linear measurements both achievable and desirable.

In this paper we propose a novel technique for the extraction of PHEMT large signal parameters from time domain waveform measurements, which overcome the problems associated with static based measurement approaches. The technique allows for the direct investigation of high frequency behavior i.e. “RF curve tracing” and the complete extraction of the Current (I) and Charge (Q) surfaces, which are the state functions required by Look-Up table or analytical models.

II. MEASUREMENT SYSTEM DESCRIPTION

The measurement system is based on the HP-MTA, (Microwave Transition Analyzer) [5] a 40GHz bandwidth dual channel sampling scope. The system is identical in both construction and operation to that demonstrated in [6]. On-wafer vector error corrected s-parameters and fully vector error corrected Time Domain Voltage and Current Waveforms can be measured, using the calibrated phase and magnitude information. The measured complex waveforms can thus be reconstructed in software at an accuracy determined by the number of harmonics utilized, typically set between 5 and 10 at a fundamental frequency of 2GHz. Well defined dynamic impedances can be presented to the device input and output terminals by tuning the arbitrary complex loads, at both the fundamental, second and third harmonic components.

III. REVERSE MEASUREMENT EXTRACTION METHODOLOGY

The extraction technique is based on the non-linear Current/Charge generator quasi-static model of [7]. Fig. 1 describes the model in common source mode operation.

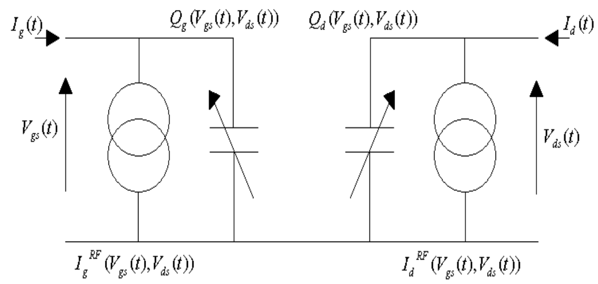

Fig. 1. The Intrinsic Non-Linear Quasi-Static PHEMT Model

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From the model the terminal Time Domain Current waveforms can be expressed in terms of their real (Current), and imaginary (Charge), state functions (1).

$$I_i(t) = I_i^{RF}(V_{gs}(t), V_{ds}(t)) + \frac{dQ_i(V_{gs}(t), V_{ds}(t))}{dt} \quad \text{Where } i = (g, d) \qquad (1)$$

The Charge Based equations can also be expressed in terms of non-linear Capacitances (2).

$$C_{ij}(V_{gs}(t), V_{ds}(t)) = \frac{\partial Q_i(V_{gs}(t), V_{ds}(t))}{\partial V_j(t)} \quad \text{Where } i = (g, d) \text{ and } j = (gs, ds) \qquad (2)$$

Using the terminology of (2) the terminal Time Domain current expression can be rewritten in the from of (3).

$$I_i(t) = I_i^{RF}(V_{gs}(t), V_{ds}(t)) + C_{ij}(V_{gs}(t), V_{ds}(t)) \frac{dV_{gs}(t)}{dt} + \qquad (3)$$

$$C_{ij}(V_{gs}(t), V_{ds}(t)) \frac{dV_{ds}(t)}{dt} \quad \text{Where } i = (g, d) \text{ and } j = (gs, ds)$$

Applying a short circuit dynamic load to the intrinsic Drain terminal yields $V_{ds}(t)=0$, equating the time derivate $dV_{ds}(t)/dt=0$. Hence using (3), fig. 2 illustrates the I_d^{RF} and Q_d^{RF} contour, (constant V_{ds}^{DC} variable V_{gs}^{RF}), that is extracted from such a forward RF waveform measurement using the techniques established in [7]. This is the dynamic equivalent to the Bias Dependant s-parameter "Drain Scan" [8]. It is noted that C_{dgs} consists of both the trans-capacitance and device feedback capacitance terms. Integration with respect to the time derivate $dV_{gs}(t)/dt$ yields Q_d^{RF} as a function of V_{gs}^{RF}.

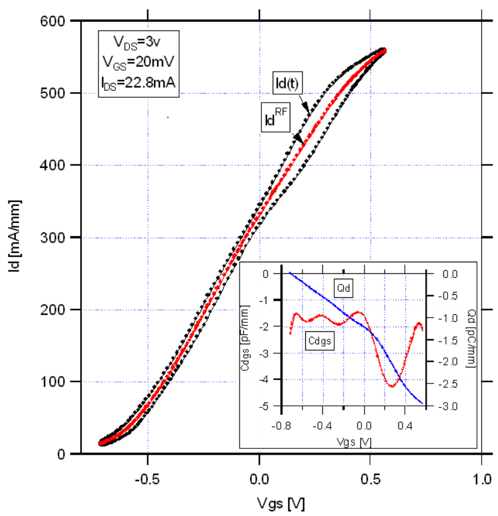

Fig. 2. Extracting I_d^{RF} and Q_d^{RF} from a Forward Measurement

To determine the Id^{RF} and Q_d^{RF} surfaces a number of contour measurements are required. To date, it should be noted that DC or s-parameters data has been used to convert these contours into a surface. This limitation can be overcome by reversing the large signal stimulus signal i.e. exciting the Drain terminal, and thus presenting an input short circuit. Under this condition $V_{gs}(t)=0$, equating the time derivate $dV_{gs}(t)/dt=0$. Hence using (3), fig. 3 illustrates the I_d^{RF} and Q_d^{RF} contour, (constant V_{gs}^{DC} variable V_{ds}^{RF}), that is extracted from such a reverse RF waveform measurement. This is the equivalent to the Bias Dependant S-parameter "Gate Scan" [8].

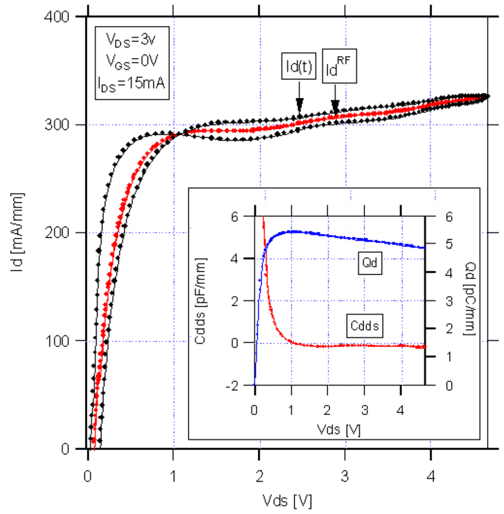

Fig. 3. Extracting I_d^{RF} and Q_d^{RF} from a Reverse Measurement

It is noted that C_{dds} consists of both the output and device feedback capacitance terms. Integration with respect to the time derivate $dV_{ds}(t)/dt$ yields Q_d^{RF} as a function of V_{ds}^{RF}. Fig. 4 illustrates that the extracted state functions from reverse waveform measurements are DC bias and RF power level independent. Previous investigations produced similar results when extracting the state functions from forward waveform measurements [9].

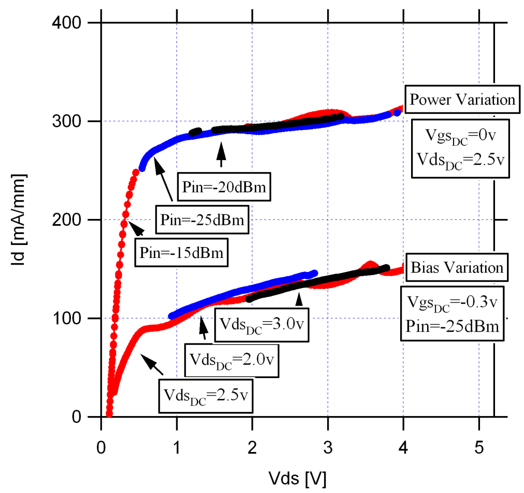

Fig. 4. Reverse Measurement Power and Bias Independence

Hence a combination of these conventional forward and novel reverse dynamic RF waveform measurements allows for the full dynamic extraction of the I_d^{RF} and Q_d^{RF} non-linear surfaces independent of DC or s-parameter data, for the first time.

IV. Surface Extraction And Validation

The extraction technique is demonstrated using a 2x40um PHEMT, fabricated through the H40p 0.2um Power Process at Marconi Caswell Ltd. Parasitic extraction is undertaken using traditional s-parameter techniques [10]-[11], and parasitic de-embedding is completed using the large signal method of [12]. The extracted I_d^{RF} and Q_d^{RF} surfaces can be observed in Fig. 5 and Fig. 6 respectively at a fundamental RF frequency of 2GHz, with 11 harmonic components. These surfaces were determined by aligning a sequence of reverse I_d^{RF} and Q_d^{RF} contours at swept V_{gs}^{DC} values using a single forward I_d^{RF} and Q_d^{RF} contour measured at V_{ds}^{DC} of 3 volts (Solid Circle Markers). In order to determine if these surfaces are unique, forward contours (Open Circle Markers) measured at other constant values of V_{ds}^{DC}, are compared to those predicted by the extracted surfaces. After the removal of the static bias component it is observed that the aligned surface and contours converge within experimental error, indicating that the extracted parameter surfaces are unique and are independent of dynamic load. Some divergence is observed with increasing static bias power. This is most likely due to increased thermal power dissipation. At the 4v V_{ds}^{DC} forward measurement there is approximately 100% more static bias power than at the 0.5v V_{gs}^{DC} aligned reverse measurement. Likewise with Bias Dependant s-parameter techniques, a thermal heatsink system could be implemented to allow for isothermal characterization.

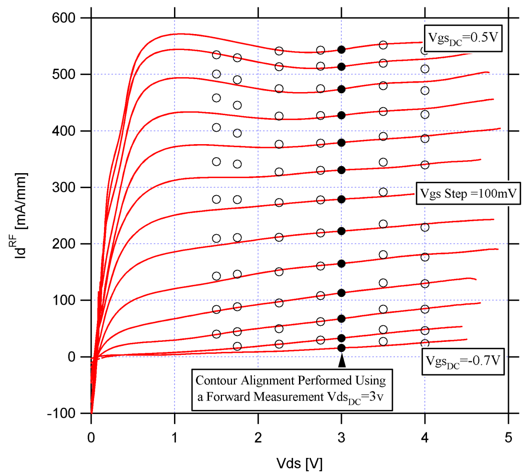

Fig. 5. Dynamically Extracted I_d^{RF} state function

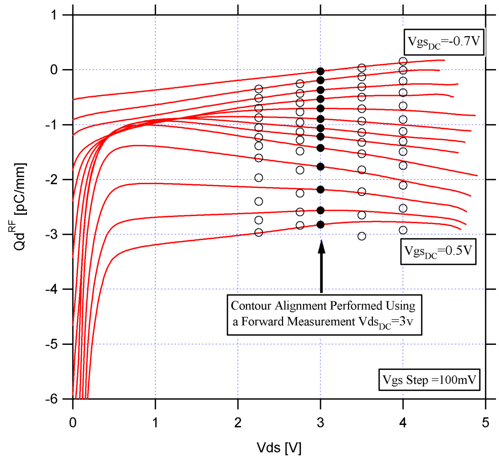

Fig. 6. Dynamically Extracted Q_d^{RF} state function

It should be noted that I_g^{RF} and Q_g^{RF} surfaces, state functions, are also extracted in the same manner from the measured RF input waveforms, and have been verified to be unique.

V. Static-Dynamic Comparison

Fig 7. Demonstrates the Drain terminal DC-IV and the directly extracted intrinsic 2GHz RF-IV comparison.

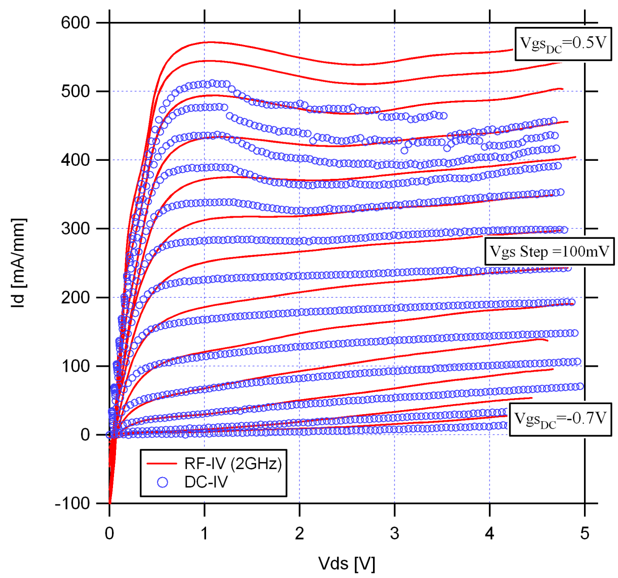

Fig. 7. Extracted I_d^{RF} (2GHz) comparison to DC-IV

From inspection of the DC-IV measurement, it can be noted that the 'Kink Effect', [13] is observed at V_{gs}^{DC} levels that are greater than 0v. Bias Dependant S-Parameter measurements would not allow the characterization of this region, due to the inherent dc instability. Clearly the proposed technique is most advantageous in this case, since by carefully selecting the static bias conditions, the ability to directly obtain the true dynamic behavior in all regions of the plane is realizable.

VI. CONCLUSIONS

A novel reverse time domain RF waveform measurement technique for the extraction of large signal PHEMT parameters has been presented. The resultant measurements have been validated to be bias, power and dynamic load independent. The technique provides a fast and robust high frequency curve tracer, which overcomes the difficulties and inherent low frequency dispersion problems of static approaches. A combination of the novel reverse waveform measurements with the conventional forward large signal waveform measurements allows for the extraction of the I and Q surfaces, state functions, needed for Table Based Models and analytical models, from dynamic data alone.

ACKNOWLEDGMENTS

The authors would like to thank Marconi Caswell Ltd for funding, co-operation and for providing the devices used in the study.

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