Analyses of the Optimal Power Load Impedances Measured in MMIC and Hybrid Configuration in the *Ka* Band

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***Abstract*—This letter deals with the main different behaviors of the optimal power load impedances for two devices (PHEMT) studied in two configurations (called "probing" or "hybrid") in power condition with an active load pull bench in Ka band (26–40 GHz). Contrary to what could be expected, the difference is not only a phase shift, which is usually the case at lower frequencies, but a gap in phase and magnitude between the optimal impedances. This behavior will be presented. A linear electrical simulation has been achieved in order to explain these behaviors.**

I. Introduction

THE FIRST step to design a circuit is to choose between an hybrid or MMIC circuit. In general, the hybrid circuit implementation is used for applications requiring a good efficiency (matching circuit exhibits lower losses) [1]. This solution is suitable for power application requiring a low-volume production. However, the MMIC's solution is preferred for applications requiring small-size low-cost production in moderate to high volume and/or excellent repeatability.

In this framework, two devices (one coplanar and the other microstrip) have been measured in power condition with an active load pull system in the 26–40-GHz band. The methods used for the power vectorial calibration and the impedance vectorial calibration of the active bench are fully described in [2]. These measurements have been performed in two configurations: first, with a microwave probe system (called "probing" configuration, it is simply a device with coplanar input/output probing structures); secondly, the bench has been modified in order to study these same devices mounted in a test fixture (called a "hybrid" configuration in this case, we study the device associated with the bondings mounted in a specific cell, named K cell). These two configurations are summarized in Fig. 1.

The aim of this analysis is, for the first time to our knowledge at these frequencies, to compare the optimal load impedance from the power measurements in test fixture or with the probe system in Ka band. The question is to know if it is possible to determine the optimal load impedance for the two configurations with just one bench topology (test fixture or probe). The following section describes the measurements performed on two devices and compares the optimal load impedances. The link between the impedances in the two configurations is done using the MDS software and demonstrates that the difference between the two impedances is not only a phase shift.

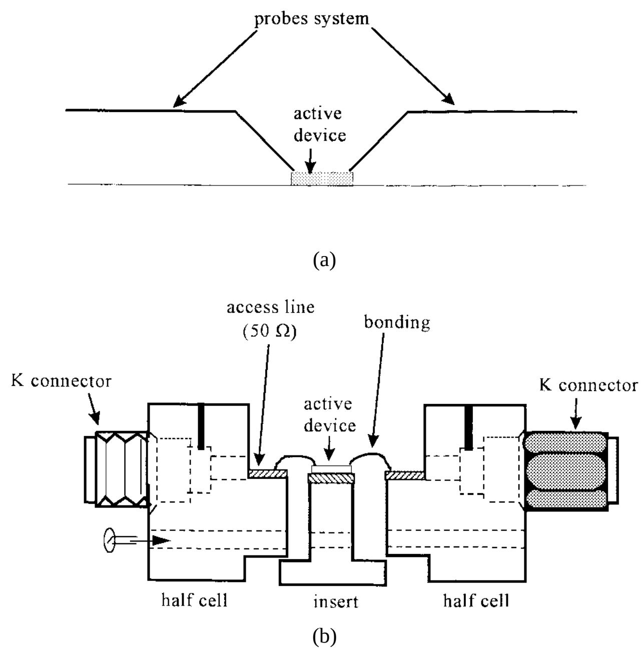

Fig. 1. Main differences between the two configurations. (a) "Probing" configuration. (b) "Hybrid" configuration.

II. Measurements

The first device is a PHEMT ($4 * 50 * 0.25\ \mu m^2$) in coplanar configuration studied in the two configurations at 26 GHz. In this case, the change from the "probing" to "hybrid" configuration requires in addition to the gate and drain bondings a source bonding (which gives rise to a fall down of the microwave performances) to connect the device to the K cell [3]. As we could expect, a strong discrepancy has been established from the "probing" consideration to "hybrid" one, whatever the small- or large-signal consideration. In these conditions, the optimal power load impedance obtained in the two configurations (probing or test fixture) is not the same in phase but also in magnitude (Fig. 2).

The second device studied is a PHEMT ($4 * 50 * 0.15\ \mu m^2$) in microstrip configuration (with via holes). Measurements are

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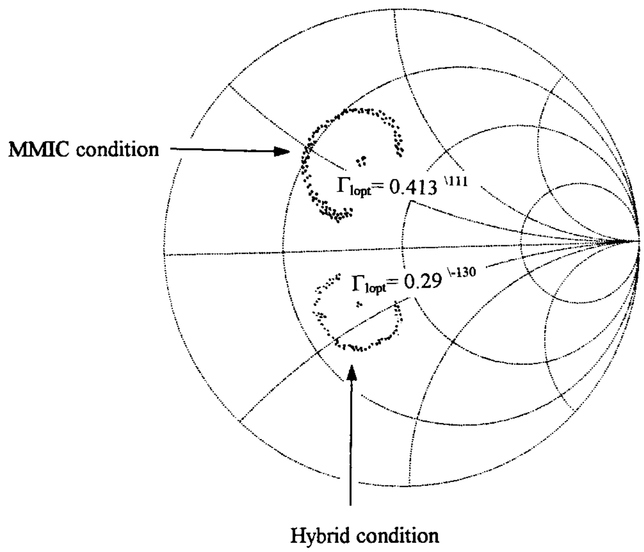

Fig. 2. Optimal power load impedances for the coplanar PHEMT in the two configurations (probing and hybrid) at 26 GHz in linear behavior at a constant injected power level.

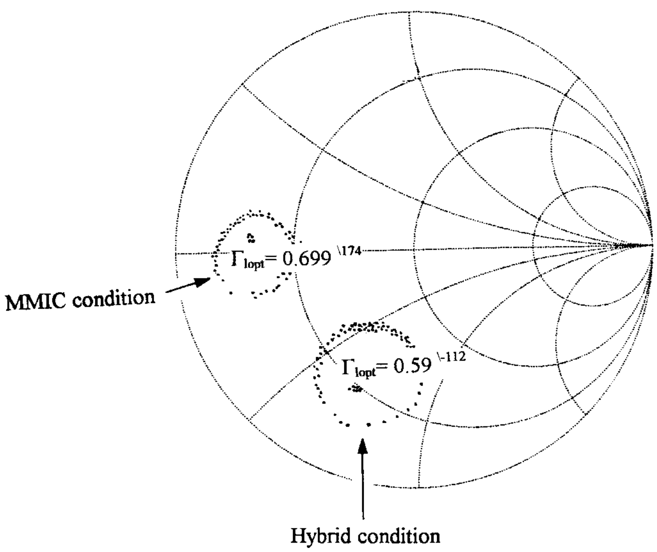

Fig. 3. Optimal power load impedances for the microstrip PHEMT in the two configurations (probing and hybrid) at 38 GHz in linear behavior at a constant injected power level.

performed at 38 GHz. In this configuration, only the gate and drain bondings are added to compare to the probing and hybrid configuration, thanks to the via holes. In this condition, it has been checked that the microwave performances, such as the Maximum Available Gain, for example, are not degraded. But we can note from Fig. 3 that the optimal load impedances are not identical in phase but also in *magnitude*, although no source inductance has been added. This means that at this frequency it will be very difficult to deduce the optimal load impedance in the probing configuration with measurements performed in the hybrid configuration (or vice versa).

Our active load pull bench allows to determine the evolution of the optimal power load impedance versus the injected power level (from small to large signal). In this case, the evolution of the optimal load impedance versus the injected power level

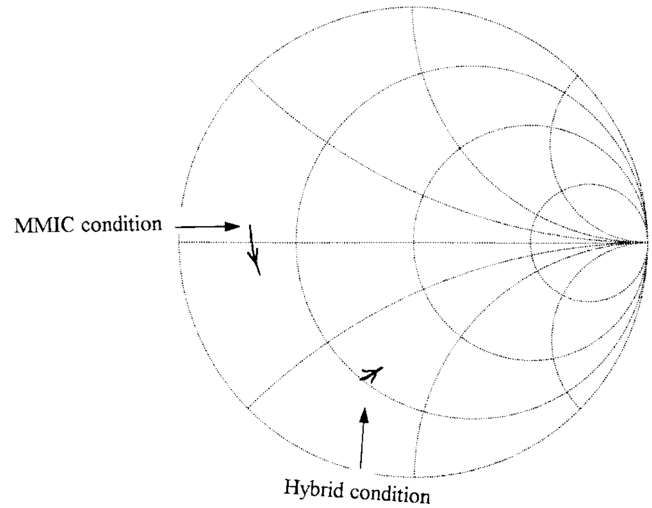

Fig. 4. Behavior of the optimal load impedances versus the injected power level in the two configurations (probing and hybrid) at 38 GHz.

TABLE I
SUMMARY OF THE LOAD IMPEDANCES PRESENTED AT THE OUTPUT AND AT THE INTRINSIC CURRENT GENERATOR OF THE SECOND DEVICE (VIA HOLES) IN THE TWO CONFIGURATIONS (PROBING AND HYBRID)

F = 38 GHz	Small Signal condition	
Hybrid configuration	Zload = 0.62 ∠-112 Zintri = 0.98 ∠0	Ls = 20 pH Ld = 265 pH Lg = 200pH
probing configuration	Zload = 0.71 ∠173 Zintri = 0.98 ∠1	Ls = 20 pH Ld = 90 pH Lg = 95pH

is different between the two configurations. The evolution in "hybrid" configuration is 14% in magnitude and 7% in phase, whereas in the "probing" configuration the shift is 5% in magnitude and 14% in phase for the second device (Fig. 4).

So, even with an accurate determination of the gate and drain bonding values and a precise measurement of the optimal load in one of the two configurations, it will be very difficult to return at the optimal load impedance in the other configuration (perhaps with the using of a three dimensional (3-D) electromagnetic simulator). This effect is due to the bondings, which induce an impedance transformation. The link between the two impedances obtained in the two configurations will be done using the MDS software.

III. ANALYSES

In order to understand the bonding effects on the internal device behavior, an electrical linear simulation has been performed. For this, an equivalent scheme has been deduced for the second device (with via holes) from the scattering parameters [4]. The intrinsic scheme has been kept constant. The bonding values, hence the output load impedances (Z load), measured have been changed as a function of the configuration. In these conditions, the impedances presented at the intrinsic

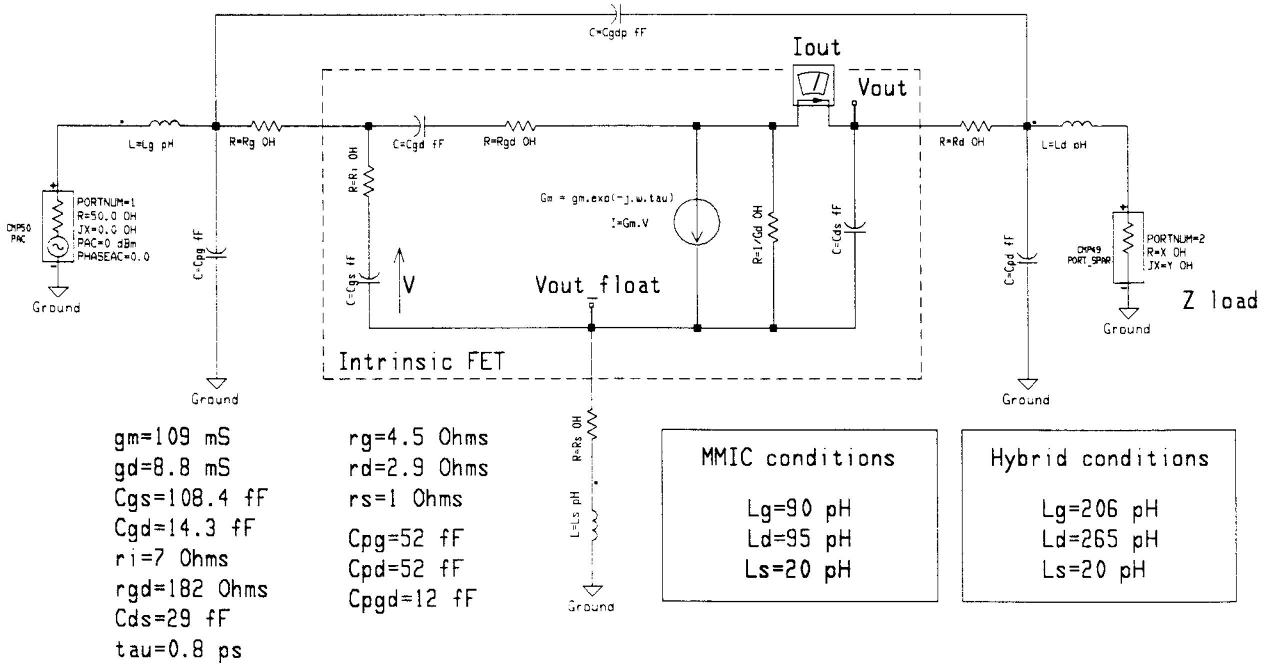

Fig. 5. Lumped linear equivalent circuit in small-signal condition (second device).

current generator (Z intri) have been determined for the two configurations (Fig. 5). This impedance analysis has been achieved in small-signal condition. The results summarized in the Table I are clear: the intrinsic impedance presented at the current generator is the same whatever the configuration. The differences of the output load impedances in the two configurations (probing or hybrid) are due to the bondings and the other extrinsic parameters (pad capacitances and access resistances) which give rise to an impedance transformation.

IV. Conclusion

We have demonstrated that it was impossible to determine simply the optimal power load impedance for a configuration (probing $\Leftrightarrow$ hybrid) from the optimal load impedance measured with the other configuration at these frequencies (26–40 GHz), even if the bonding values are accurately determined. Moreover the behavior of the optimal load impedance versus the injected power level is different following the configuration (probing or hybrid). At these frequencies, a phase shift is not sufficient to correct the optimal load from one configuration to the other. So an MMIC design requires a probing configuration bench whereas a hybrid design requires an hybrid configuration bench.

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