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Employing M1 direct calibration/de-embedding approaches for large signal model validation at mm-wave frequencies

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Abstract—**In this contribution, we employ direct calibration/de-embedding approaches to validate the large signal device model of state-of-the-art HBTs and CMOS technologies operating in the mm-wave frequency band WR6. The capability of placing the first tier calibration reference plane in close proximity to the DUT allows the large signal metric to be directly compared with foundry models.**

I. Introduction

Silicon based technologies (i.e., SiGe HBTs and CMOS SOI) are being proposed as high-performance and complete technology platforms (from the device offering standpoint) to address the needs of beyond 5G and next generation automotive radar systems. Nevertheless, the device parameters as well as the technology metrics which are being advertised to promote the usage of these technologies for upcoming (sub)mm-wave applications, are derived from extraction procedures realized (well) below 100 GHz.

To overcome the frequency limitation of conventional de-embedding approaches [1][2][3] the authors have proposed a direct on-wafer calibration technique allowing to fix the reference plane in close proximity to the intrinsic device [4], thus limiting the error arising from lumped fixture removal [5].

The proposed direct calibration/de-embedding technique (e.g., M1 direct calibration/de-embedding) has been employed to extract the intrinsic device parameters for model validation up to 220GHz [5]. In this contribution, we employ the above mentioned technique in conjunction with large signal device characterization, i.e., mm-wave constant wave (CW) load-pull [6] to extract the intrinsic device large signal metrics and compare them with foundry device models.

II. M1 direct Calibration-De-embedding Fixture

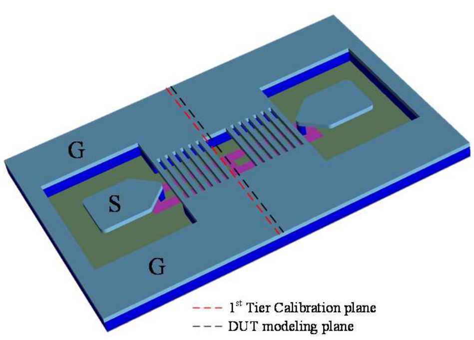

Fig. 1. Example of a device test fixture supporting M1 on-wafer calibration.

In this work, the intrinsic device data is obtained employing 1st tier on wafer calibration, in close proximity to the DUT, employing a fixture design as presented in [4], shown in a simplified 3D drawing in Fig. 1.

The proposed calibration approach allows absorbing the pad-line parasitic provided by the fixture in the 1st tier calibration enabling to extract accurate intrinsic device-level performance at mm-wave frequencies (i.e., above 110GHz). This allows extending the classical device model extraction/validation range which would otherwise be limited by the resonance frequency of the lumped fixture model required in the final de-embedding process.

III. Mm-wave load-pull

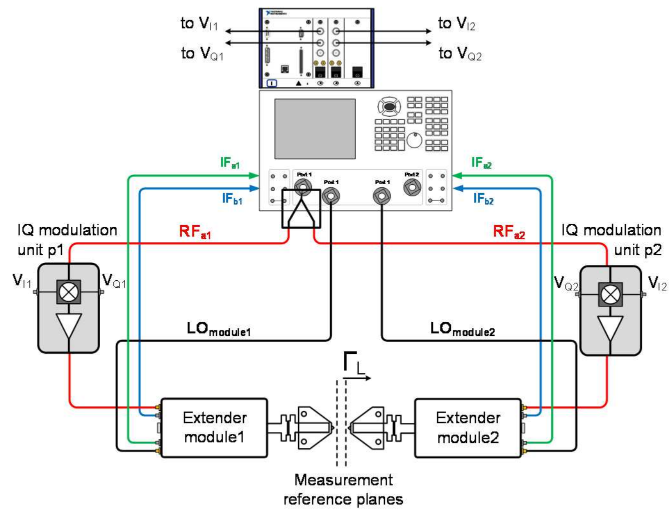

Fig. 2. Frequency scalable (sub)mm-wave load-pull architecture, employing IQ modulation.

In order to extend the characterization to the device non-linear behavior the TU Delft/Vertigo Tech. mm-wave active load pull setup is employed. The system is based on high performance VNAs and standard mm-wave extender modules to provide large dynamic range acquisition of the input and output waves (incident and scattered). A high precision (i.e. resolution of 83 nV) and low noise (i.e. voltage noise of 6.3 µV) digital to analog converter provides the DC signals to a broadband RF IQ modulation unit driven by a single synthesizer source.

IV. Preliminary Results

Here we present the large signal metrics (i.e., gain, PAE and Pout) under non-50 Ohm loading conditions for a 130nm SiGe HBT and a 22nm CMOS technology.

In the final paper contribution, the comparison of the experimental data shown in Fig. 3 and Fig. 4 with the large signal response of the foundry models will be provided.

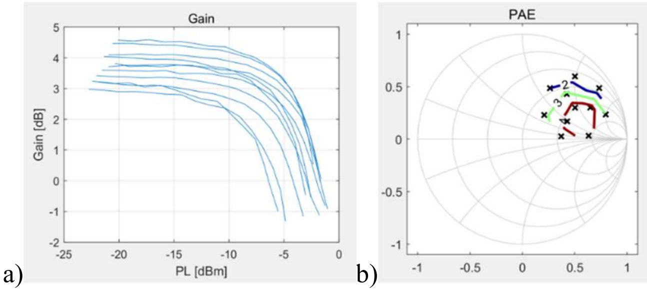

Fig. 3. Measured data at 140GHz of 22nm nMOS, a) Gain versus P_{load}, b) load-contours for optimum PAE at P_{1dB}.

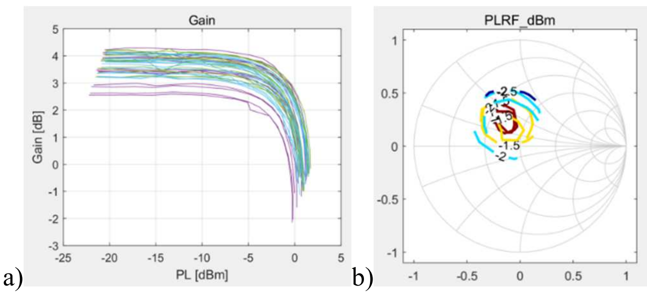

Fig. 4. Measured data at 140GHz of 130nm SiGe HBT, a) Gain versus P_{load}, b) load-contours for P_{load} at P1dB.

V. Conclusions

In this paper, we employ direct on-wave calibration/de-embedding approaches which enable to extend the model validation range to mm-wave frequencies (i.e., above 100GHz) for the validation of the large signal metrics in non-50 Ohm conditions of foundry level compact models.

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