MM-wave on-wafer characterization of electro-optic devices: a new, simple approach

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ABSTRACT

A new simple experimental set-up both for on-wafer and in-package electrical and electro-optic characterization of electro-optic devices up to 40 GHz is presented. The technique makes only use of a conventional network vector analyzer (NVA) and of a calibrated high-speed photodetector. The electro-optic transmission coefficient is simply deembedded from the electrical S_{21} *using the detector calibrated responsivity. The RF calibration of the set-up implements the RSOL technique. The results obtained are shown to be comparable with the ones given by commercially available instrumentation, both in terms of accuracy and repeatability. The frequency bandwidth is only determined by the NVA bandwidth provided that the photodetector RF output is well above the NVA noise floor. Firstly some comparison with commercially available instrumentation up to 40 GHz on in-package device will be shown to validate the technique, after that, results concerning both in-package and on-wafer devices up to 40 GHz will be reported.*

I. INTRODUCTION

The accurate characterization of electro-optic devices at increasingly high frequency is a field of growing relevance. This is the case, for instance, for electro-optic modulators with modulation bandwidth exceeding 40 GHz, whose development places a heavy demand on reliable and accurate experimental characterization tools. This kind of measurements poses some challenges, especially if they are required on-wafer, rather than on a packaged device. The approaches proposed to this aim, are based on the so-called Electro-Optic Network Analyzer concept [1,2], which makes use of a bilateral e/o network [3,4]. This solution is able to deal with the problem, but the implementation is quite complex and the setup calibration procedure, on which the system relies, although based on the classical, well tested algorithms usually employed for RF measurements (e.g. TRL), must make use of exotic optical calibration standards. However, the main limitation of this solution is the frequency range; in fact, the published results are limited to 10 GHz. Similar limitations were found when resorting to commercially available instrumentation for electro-optic transmission measurements (e.g. HP8703A), whose maximum frequency is 20 GHz. Only recently HP, demonstrating the growing importance of this kind of measurements, has presented a new, rather expensive, electro-optic NVA able to cover the millimeter range, whose maximum frequency is 50 GHz.

In this work, we present a new, straightforward technique to characterize an electro-optic two-ports with the RF input classically on a coax connector, or even directly on wafer (i.e. accessible through coplanar probes), and the optical (modulated) output on fiber. The target was to develop a measurement system based, as far as possible, on traditional RF measurement techniques, so as to exploit the corresponding advantages in terms of accuracy, repeatability and reliability. To this aim the RF AM modulated optical signal exiting from the modulator is sent to the photodetctor that takes care of the demodulation process making available the RF signal at its coaxial connector. The input reflection coefficient together with the electrical transmission coefficient between the RF modulating signal and the RF photodector ouput can be then easily measured using the NVA. The electro-optical transmission coefficient S_{21}, the most important parameter to define the modulator frequency behaviour, is simply derived deembedding the photodetector responsivity from the measured electrical S_{21}, using the photodiode calibration curve.

Concerning the RF measurements, as usual, the reference planes are correctly placed through the calibration of the system. When the RF input of the set-up is on a coaxial connector the calibration procedure can be carried out using a whatsoever conventional technique (e.g. TRL, LRM, SOLT); some problem arise, instead, for the on-wafer characterization, since in this case the RF input is on a coplanar probe, while the RF output is always on the photodetector coaxial connector. In this case, in fact, all the conventional calibration technique use a well defined two-port standard, usually referred as THRU, to be placed between the two RF ports, during the calibration step. Such a known standard is not available when the two system ports are of different type, as happens in our case, where, for on wafer measurements, the input port is probable and the output on a coaxial connector. The RSOL calibration approach, as explained in next Section, allows to overcome this problem.

The more relevant advantages of the presented approach are its simplicity, compared to other electro-optic instrumentations and the high accuracy that can be obtained using a classical RF calibration procedure, rather then the ones based on optical standards or cumbersome deembedding procedure. It is also to be remarked the extremely low cost of the system, being its main parts an ordinary VNA and a simple photodetector. Besides, the upper frequency limitation of the set-up is only determined by the bandwidth of the NVA; the only requirement of the detector is to have a responsivity able to ensure, for all the frequency range, a RF signal well above the noise floor of the NVA, while, concerning the diode responsivity frequency behaviour, there are no forcing requirements, since it is deembedded from the electrical S_{21}.

The framework of the paper is the following: Section II describes the measurement set-up and the calibration procedure; Section III is devoted to the presentation of the experimental results: fist of all the validation of the system is carried out through comparison with commercially available HP instrumentation up to 40 GHz; after that, some example of characterization up to 40 GHz on both, on-wafer and in-package device are presented; Section IV is finally devoted to draw some conclusion.

II. THE EXPERIMENTAL SET-UP

The setup, shown in Fig. 1, relies on a high-speed calibrated photodiode, produced by Optospeed (model PD-MH-40A) and characterized by NIST, to detect the optical modulated signal, and on a traditional network analyzer to excite the DUT and measure the photodetector RF output. The system performs S_{11} and electro-optic S_{21} measurements on an electro-optic device with both coax or on-wafer input, implementing the so called RSOL calibration [5], that is the only technique able to deal with two-port devices having different port connectors, as happens in our case for the on wafer characterization. In fact, in this case (see Fig. 1), the two reference planes must be placed at the probe tips (sec. A, port 1), and at the coaxial output of the photodiode (sec. B, port 2). Conventional calibrations are useless (e.g. TRL, SOLT) since they all require a THRU (i.e. an ideal zero length connection) to be placed between the two sections, or at least a cumbersome de-embedding procedure to account for the coplanar probe effect. On the contrary the RSOL calibration [5] only makes use of an undefined two-port network, whose only requirement is to be reciprocal, instead of the fully known THRU standard. During the calibration step, see Fig. 2, simply another probe, cascaded with a coplanar transition, was adopted as the two-port reciprocal junction. To complete the error box extraction procedure, according to the RSOL technique, three one-port known standards, for each of the two ports, are required. We used the traditional one-port standard (short, open and load) on wafer to be connected to port 1, and on coaxial to be connected at port 2. Finally the electro-optic calibration is completed by combining the photodiode response ensured by the NIST (see Fig.3), with the error coefficients given by the calibration procedure described above.

III. RESULTS AND VALIDATION

To test and validate the proposed technique, some Lithium Niobate electro-optic modulators, fabricated by Pirelli Componenti Ottici were measured. To evaluate the repeatability of the set-up several measurements have been carried out with the same calibration and also redoing the calibration step more times. Concerning the input reflection coefficient the spreading of the values obtained were within 8 % while, for the transmission coefficient a maximum difference of 4 % were found; as expected the maximum variations experienced on the reading of S_{11} are due to the presence of frequency with extremely low values of the input reflection coefficient. The validation step was carried out first of all through comparison between our set-up and the conventional electro-optic measurement equipment HP8703A. The results, up–to 20 GHz, that is the maximum frequency affordable by the HP8703A, both concerning the electrical S_{11} and the electro-optic S_{21} are reported in Fig. 4 and Fig. 5 respectively. Since the HP instrumentation only support coaxial RF input, the comparisons were made on a packaged device. The agreement obtained between the HP8703A and the new system concerning S_{11} (Fig. 4) is very good on the whole frequency range, in fact the maximum difference is below 0.2 dB. Fig. 5 reports the elecro-optic transmission $S_{21,}$ normalized, as usual, to the low frequency value. The agreement obtained is still quite good, and any way well within the expected range of ± 1 dB obtained combining the effect of the accuracy of the detector response given by NIST [6], together with the one of the HP8703A measurements [7]. The validation step has been then extended up to 40 GHz comparing the measurements obtained using this set-up and the ones found using the new electro-optic network analyzer, recently presented by HP, and able to go up to 50 GHz. Even in this case the on packaged device is the only configuration that can be measured by the HP set-up. The results concerning the electro-optic S_{21}, up to 40 GHz, are reported in Fig. 6, that shows an excellent agreement between the two approaches, for all the frequency of the measured range.

The last shown results concern measurements on two similar electro-optic modulator: the first one is in-package format, while the second one is in on-wafer configuration. Fig. 7 and Fig. 8 report the electrical S_{11} and the electro-optic S_{21} respectively, up to 40 GHz, relative to the packaged device; Fig. 9 and Fig. 10 report instead the same thing for the on-wafer modulator. Comparing the frequency behaviour exhibited by the electro-optic S_{21} of the two modulators (Fig. 8 and Fig. 10) it is possible to associate the connector and packaging effects to the more irregular response of the packaged modulator.

IV. CONCLUSION

A new simple approach for the characterization of electro-optical devices has been presented and validated. This method makes only use of a conventional NVA and a calibrated photodetector. The experimental results demonstrated that this technique, despite its simplicity, can be effectively used for characterization up to 40 GHz, of both on-package and on-wafer electro-optic devices, ensuring the same degree of accuracy and repeatability that can be obtained using commercially available instrumentations. To resume, the main advantages of the proposed technique are its simplicity, the high calibration accuracy that makes no use of optical standards, the capability to support both in-package and on-wafer devices, the system bandwidth only limited by the NVA and the low cost of the set-up.

ACKNOWLEDGEMENTS: This work was supported by CNR through the MADESS II project.

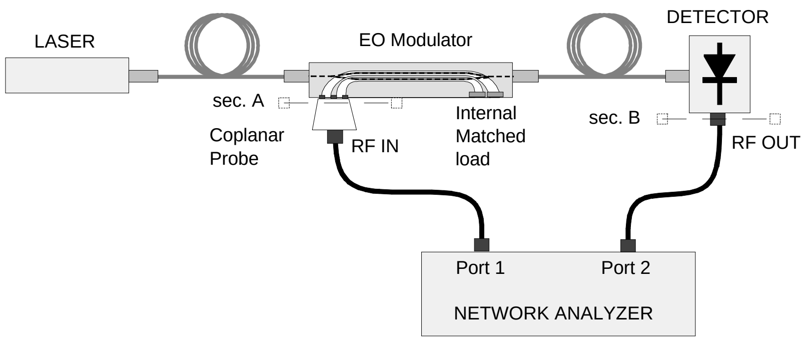

Fig. 1 – Measurement set-up

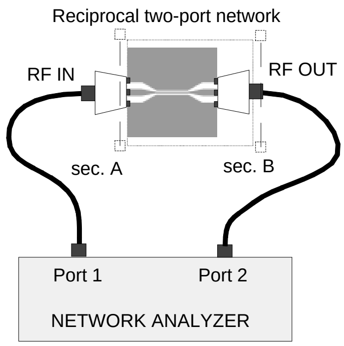

Fig.2 – Calibration procedure

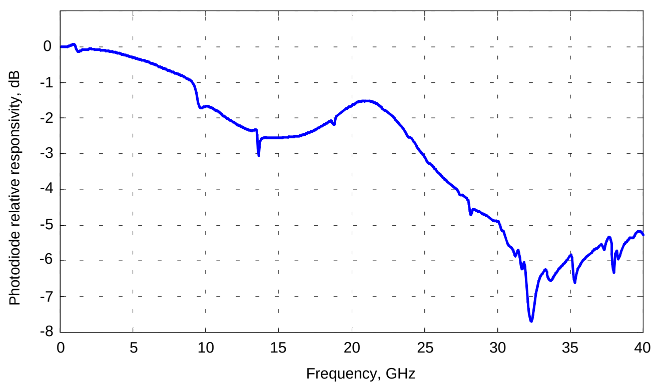

Fig.3 – Optospeed photodiode electro-optical response

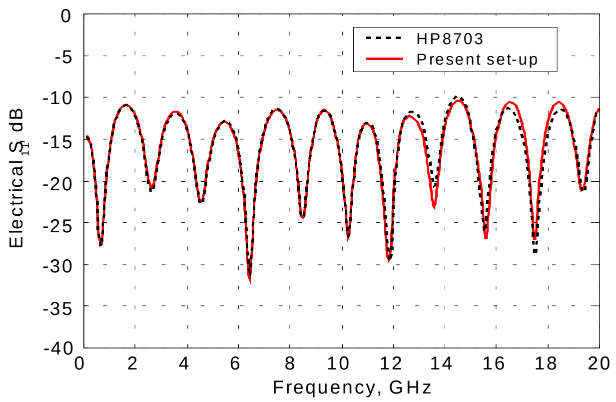

Fig.4 – Comparison between measurements of S_{11} on an electro-optic in-package modulator, up to 20 GHz. Continuous curve: this set-up, dotted curve: HP8703A

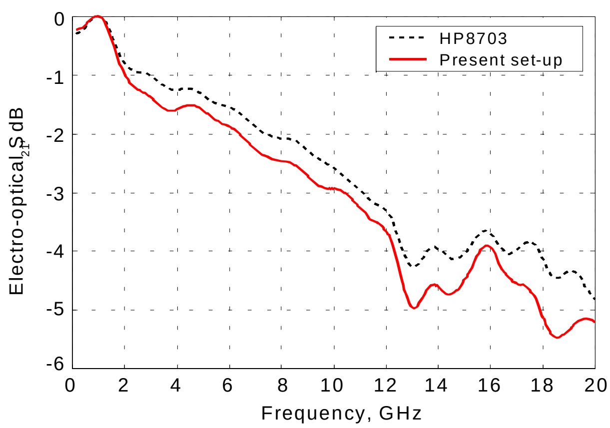

Fig.5 – Comparison between measurements of electro-optic S_{21} on an electro-optic in-package modulator up to 20 GHz. Continuous curve: this set-up, dotted curve: HP8703A

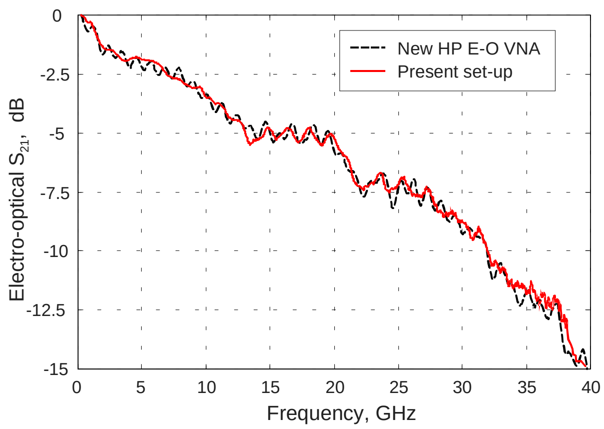

Fig.6 – Comparison between measurements of electro-optic S_{21} on an electro-optic in-package modulator up to 40 GHz. Continuous curve: this set-up, dotted curve: new HP instrumentation

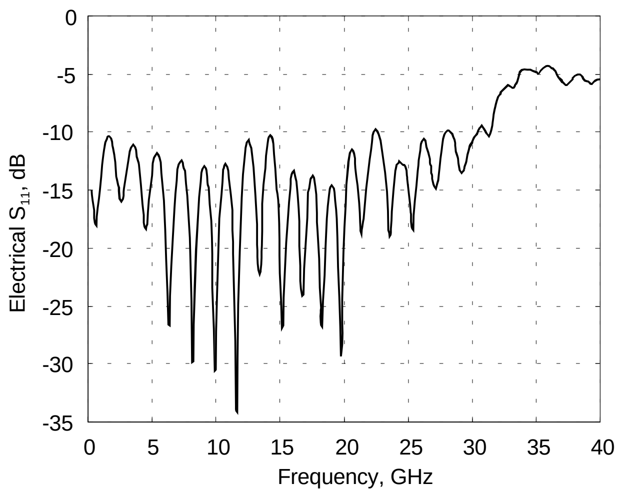

Fig.7 – Measurements of S_{11} on an in-package electro-optic modulator up to 40 GHz.

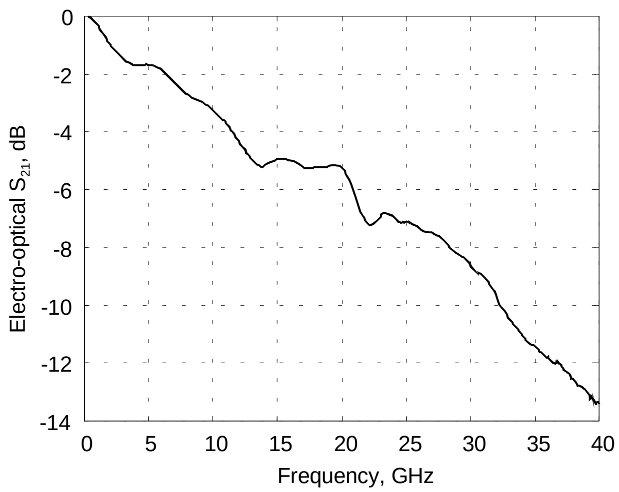

Fig.8 – Measurements of electro-optic S_{21} on an in-package electro-optic modulator up to 40 GHz.

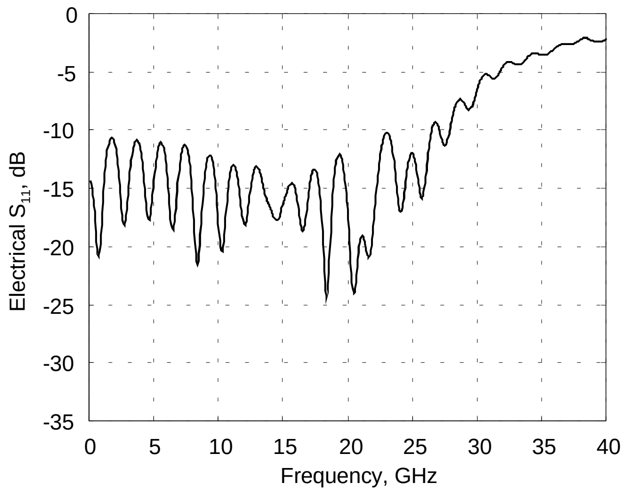

Fig.9 – Measurements of S_{11} on an on-wafer electro-optic modulator up to 40 GHz.

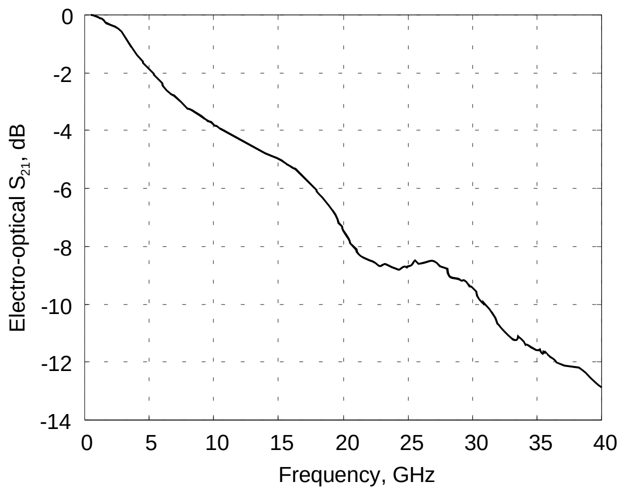

Fig.10 – Measurements of electro-optic S_{21} on an on-wafer electro-optic modulator up to 40 GHz.

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