High-Side Wideband IV Sensor for Characterizing RF PAs at the Supply Terminal

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***Abstract*— The project was dedicated to the design of a high-side wideband voltage and current (IV) sensor for the characterization of supply-modulated power amplifiers. The designed sensing board is capable to measure the frequency response from dc up to more than 100 MHz. It withstands dynamic supply voltages of up to 100 V and currents of more than 1 A, making it suitable for being deployed in experimental test benches for supply modulated GaN RF PA.**

***Index Terms*— Wideband current sensing, RF PA characterization, supply modulation.**

I. Introduction

THE efficiency of radio-frequency (RF) power amplifiers (PAs) represents a key aspect in modern transmitters, as increased power dissipation involves higher operating temperatures, affecting the dynamic behavior of the active devices. The situation is likely to worsen for the wideband modulation foreseen by 5G, as the PA would likely be operated in inefficient classes to guarantee wideband linearity, unless custom solutions for pushing the linearity-efficiency trade-off (e.g., supply modulation) are implemented. In this context, a key aspect concerns measuring the dynamic voltage applied to the supply terminal, and the supply current dynamically drained by the PA (Fig. 1). These measured quantities allow for monitoring the dynamic power dissipated by the device, and, at the same time, can be post-processed for synthesizing optimal RF signal and supply inputs. This project was focused on the design of a high-side wideband current and voltage sensor by means of commercial high-speed opamps.

II. Sensor Design and Board Layout

Since most PAs do not allow to access the transistor source terminal, the current sensing is performed by introducing a high-side 1-Ω shunt resistor, which should have a relatively low value in order to minimize insertion loss and not heat up during operation. The current sensor must operate with relatively high voltages, so an attenuator network (R1, R2 in Fig. 2) is used to reduce the common-mode high-side voltages (up to 100 V) and make it compatible with the maximum input ratings of the opamps (i.e., 5 V maximum). Then, the balanced architecture is based on a fully differential opamp (LTC6409) and an output amplifier (LTC6268-10) for the differential-to-single output. The voltage sensing is implemented as unity gain buffer amplifier (ADA4857) with a 1/25 attenuator network (R1, R2), chosen to guarantee the maximum ratings of the opamp and its stability. As shown in Fig. 3, the PCB layout consists of a 78 mm x 50 mm FR4 board with four layers. The top layer is used for routing, the second and bottom layers for ground planes, and the third layer for a power supply plane. Voltage regulators and decoupling capacitors are added to the PCB circuitry to regulate the supply voltages. In order to minimize noise, linear voltage regulators (LT3065 and LT1964), instead of switching ones, were used. The shunt resistor is connected to the attenuator networks using Kelvin-connection technique to avoid measurement errors due to series resistance between the power supply and the load. The decoupling capacitors are placed as close as possible to the supply terminal to compensate for the inductance of the trace. The differential traces were designed as

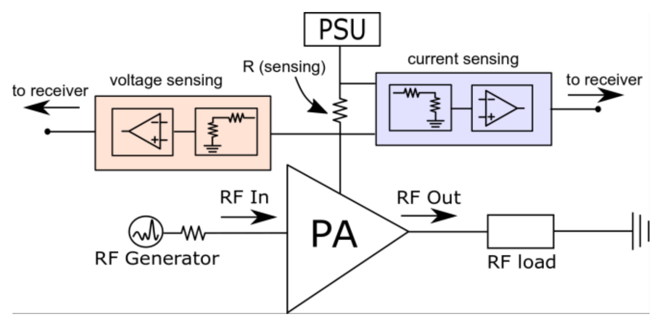

Fig. 1. IV sensor within an RF PA characterization bench.

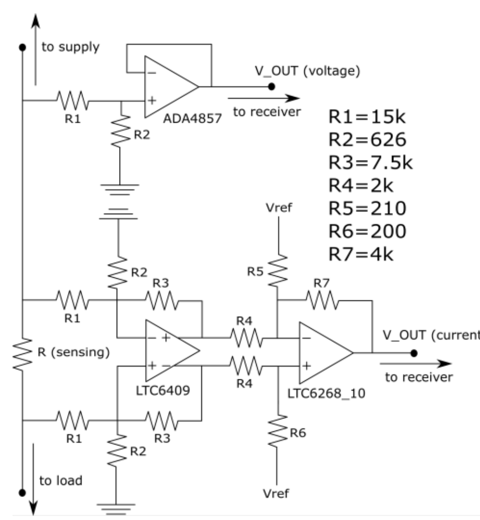

Fig. 2. Topology of the current/voltage sensor.

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short as possible, and of the same length to avoid any differential noise. Finally, the trace at the input of the opamp is as short as possible to minimize stray capacitance at the input.

III. Empirical Characterization of the Sensor

The manufactured sensor was characterized with the set-up in Fig. 4. An Arbitrary Waveform Generator (AWG) was used to generate sine waves between 10 kHz up to a few hundred MHz. An 8-bit oscilloscope with 350 MHz bandwidth (BW) and sampling rate of 4 GSa/s is used to measure the voltage output of the sensors, while the Precision Supply Unit (PSU) applies the supply voltages or a static input voltage. A static characterization was performed by applying different dc voltages at the input of the sensor, while placing different loads. As from Fig. 5, both the current and voltage sensors are linear in the measurable range. A small-signal characterization (Fig. 6) performed by placing a 50 Ω load shows a 220 MHz cut-off frequency for the current sensor, despite the presence of gain peaking probably due to spurious zeroes/poles introduced by the opamp feedback network, or by the parasitic capacitances of the layout. The voltage sensor shows a 90 MHz cut-off frequency. Nevertheless, by means of standard calibration methods (e.g., short-open-load), the performance of the IV sensor has been improved, reaching a flat frequency response beyond 100 MHz. Large-signal evaluation was done by exploiting input voltage pulses generated by a supply modulator device (ADA4870) featuring 52-MHz large-signal BW voltage amplitude between up to 37 V, with a rise-time of 100 ns. As shown in Fig. 7, the IV sensor can reproduce the input without introducing any particular ringing or distortion.

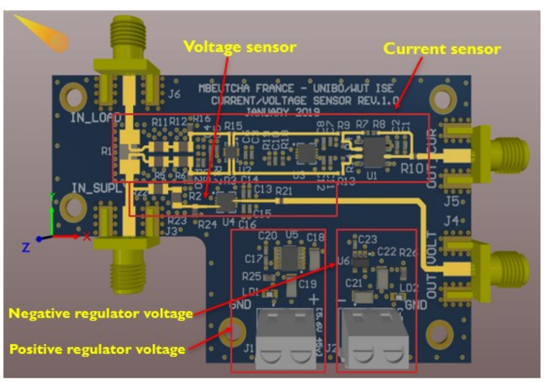

Fig. 3. PCB layout of the sensing board.

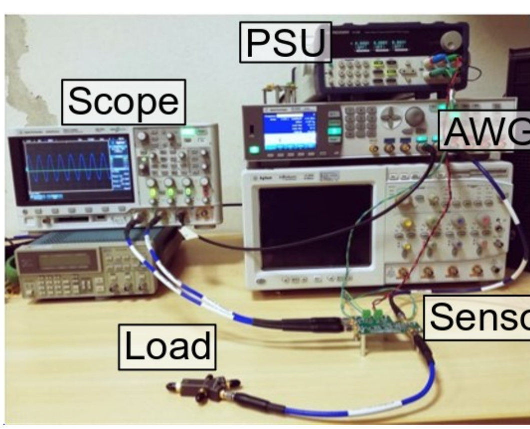

Fig. 4. Measurement set-up for sensor characterization.

IV. Conclusions and Future Developments

An IV sensor was designed, manufactured, and characterized, obtaining a usable BW of more than 100 MHz, current rating >1 A, and voltage rating of 100 V, suitable for high-side sensing at the supply terminal for Gallium Nitride (GaN) PAs. As a further development, the sensor will be introduced in an RF PA characterization set-up.

Acknowledgment

It has been an honor to be a recipient of the IEEE MTT-S undergraduate fellowship. It has helped me defraying the expenses for manufacturing the board and for sustaining my period at the Warsaw University of Technology (Poland) as an exchange master's thesist. In addition, it gave me a special motivation for embracing research in the field of microwave electronics. Finally, it will allow me to attend the European Microwave Conference in Paris, France. After graduation, I started working for the industry.

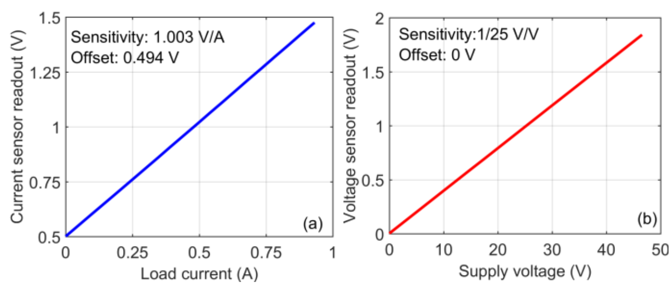

Fig. 5. Static characterization of the sensor.

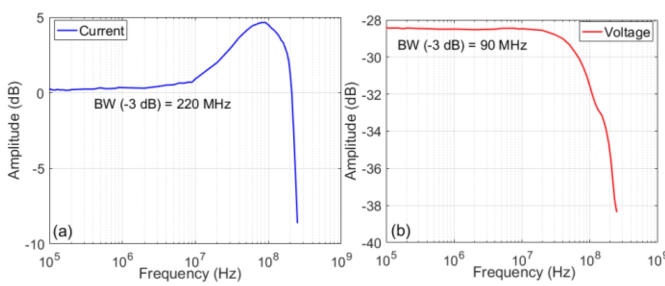

Fig. 6. Frequency response of the IV sensor with an input sine wave of 15-dBm power.

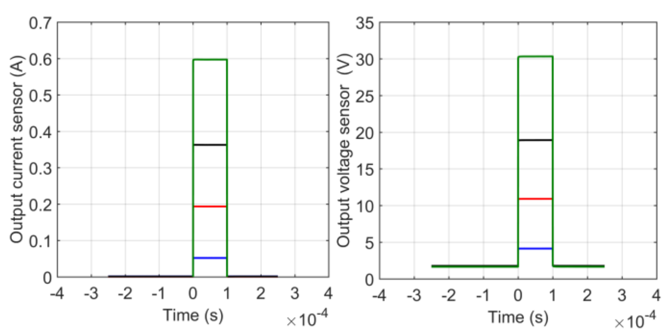

Fig. 7. Time-domain response of the IV sensor with input pulse amplitudes 3.5 V, 10.5 V, 18.6 V, 30.2 V (pulse width: 1 ms, rise-time: 100 ns).