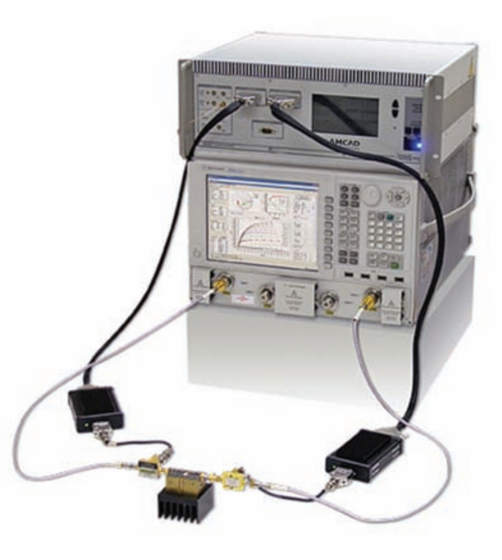

Pulsed IV, Pulsed S-Parameters and Compact Transistor Models

GaN devices have expanded into several markets offering several performance advantages. It has lead to a new generation of high-power transistors as well as a wide product offering of high-power amplifier modules and systems. Compared with GaAs, GaN has a higher breakdown voltage offering a higher load-line dynamic resistance, higher power density, lower thermal resistance and higher gain performances.

But with these great advantages come disadvantages. Despite its improved thermal dissipation capabilities, GaN's large output power density offers higher integration that can lead to significant thermal dissipation challenges resulting in self-heating and performance degradation with time. GaN transistors can suffer from trapping effects in the surface passivation along the gate width, leading to a decrease in threshold voltage and an increase in gate leakage current. The question becomes, how does one accurately characterize a technology that suffers from self-heating and trapping, and how does one develop accurate linear and nonlinear transistor models? The answer lies in the BILT/IVCAD Pulsed IV, Pulsed S-Parameter and Compact Transistor Modeling system.

PULSED IV, PULSED S-PARAMETER AND COMPACT TRANSISTOR MODELING SYSTEM

The BILT/IVCAD pulsed characterization system is a joint development between AMCAD Engineering and Maury Microwave Corp. It consists of three parts: a mainframe, input and output pulsers, and IVCAD measurement and modeling characterization software.

Mainframe

The BILT mainframe is the backbone of the pulsed characterization system and includes five embedded DC power supplies, hardware synchronization/triggering to control external instruments, GPIB/LAN communication and internal calibration standards. The mainframe is designed to fit a standard 19" rack.

Maury Microwave
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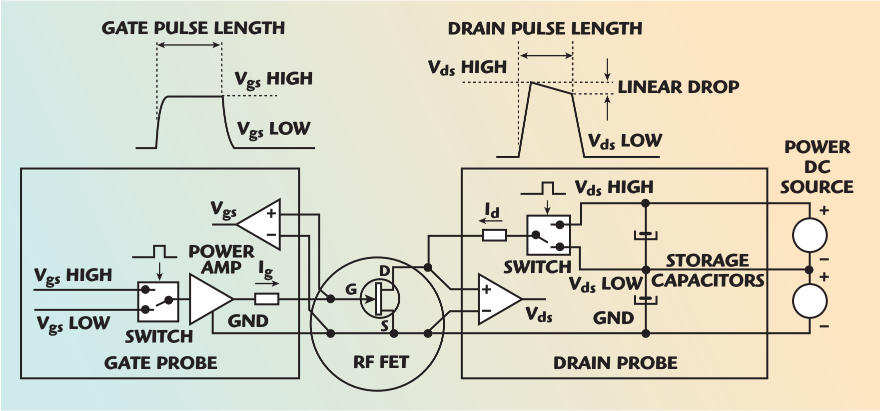

▲ *Fig. 1 Pulser block diagram.*

Pulsers

Input and output pulsers (also referred to as probes or pulse heads) are available in four models. The AM211 has been specifically designed for pulsing the input (gate) of the transistor, while the AM221, AM222 and AM223 have been designed for pulsing the output (drain) of the transistor (see ***Table 1***).

TABLE I

PULSER MODELS AND SPECIFICATIONS

	AM211	AM221	AM222	AM223
Max Voltage	± 15 V	250 V	120 V	-5/+15 V
Max Current (pulsed)	± 200 mA	10 A	30 A	± 200 mA
Max Current (DC)	200 mA	3 A	4 A	200 mA
Peak Power	3 W	2 kW	2 kW	3 W
Avg Power (pulsed)	3 W	50 W	50 W	3 W
Avg Power (DC)	3 W	80 W	80 W	3 W
Min Pulse Width	200 nS	200 nS	400 ns	200 nS
Max Pulse Width	1 ms/DC	1 ms/DC	1 ms/DC	1 ms/DC
Min Duty Cycle	0%	0%	0%	0%
Max Duty Cycle*	100%	100%	100%	100%

* The duty cycle must respect maximum stated average powers for each pulser

Each drain pulser is capable of independently controlling both quiescent and hot voltages, allowing for full flexibility in Pulsed IV configuration. This is achieved by using several separate DC sources, large storage capacitors, a pulse amplifier for the gate and extremely fast MOSFET switching for the drain as shown in ***Figure 1***.

The embedded acquisition and measurement hardware contained within each pulser is actually comprised of two separate A/D converters; one used for low current measurements and the other for high current measurements. Each A/D converter has 16-bit measurement capability, resulting in both fast and accurate voltage and current measurements with a typical measurement accuracy of 0.1 percent. When comparing with an oscilloscope, the embedded measurement system offers the equivalent of 50 Msamples/s and 10 MHz bandwidth for pulse monitoring. Each pulser is equipped with an electronic fuse for system protection. The fast-switching circuitry activates within 70 nS, thereby offering protection to the transistor, probes, components and test system.

IVCAD Measurement and Modeling Characterization Software

IVCAD is a comprehensive software suite that offers a wide array of measurement and modeling device characterization tools including: DC-IV and S-Parameters, Pulsed IV and Pulsed S-Parameters, Harmonic Load Pull, Compact Transistor Modeling, Behavioral Modeling, advanced visualization and data analysis and more.

With regard to GaN technology, the development of linear and nonlinear models first stems from Pulsed IV and Pulsed S-Parameter measurements. Current-Voltage (IV) measurements are used to describe the rela-

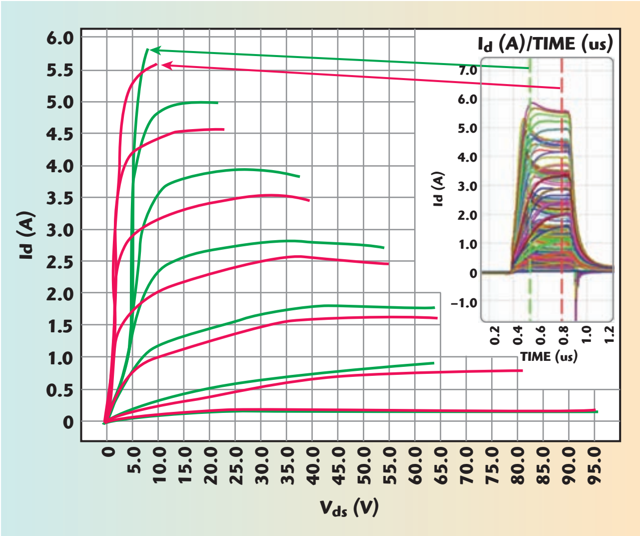

Fig. 2 Example IV plot.

tionship between input and output currents and voltages. For a typical GaN field effect transistor (FET), characterization is achieved by measuring output currents as a function of output voltages for a set of input voltages. Because of self-heating and trapping phenomena, it is critical to pulse the voltages between quiescent and hot states thereby reducing average DC power and achieving quasi-isothermal performance. Pulse widths must be carefully selected in order to reach a steady state but not to the extent of self-heating: too short and undershoots/overshoots will invalidate the measured currents, too long and self-heating will lead to current degradation. IVCAD offers full flexibility on the pulse timing including pulse widths, pulse periods, duty cycles, delays and full synchronization and timing between gate and drain pulses. Enabling time domain measurements allows a user-defined number of IV acquisitions within each pulse and can be used to study the IV curves at user-selected traces within each pulse, including during the rise-time, overshoot, steady state and fall-time (see ***Figure 2***).

S-Parameters are used to define the electrical behavior of an n-port device. With regards to two-port transistors, S-Parameters are used to quantify return loss, isolation and gain, and are essential in developing a transistor model. S-Parameters, however, are only valid under those specific conditions at which they were measured, including bias and temperature. Because a transistor's performance changes as a function of bias (both DC and Pulsed quiescent and hot voltages), its S-Parameters must be recorded for each set of bias conditions. When adding a vector network analyzer (VNA) with pulsed capabilities, such as a PNA-X, to the setup, IVCAD can measure fully synchronized Pulsed IV and Pulsed S-Parameter measurements, with complete flexibility on the measurement sequence and timing within each pulse.

Compact transistor modeling is achieved using Pulsed IV and Pulsed S-Parameter measurements to create linear, nonlinear and electro-thermal models. Pulsed S-Parameters are used to determine the transistor's extrinsic parasitic elements, from which intrinsic elements can be calculated. These elements are then used with the nonlinear modeling engine. Pulsed IV measurements are used to determine input and output current models, as well as gate-lag and drain-lag trapping effects. Synchronized Pulsed IV and Pulsed S-Parameters are used to determine one-dimensional input and output capacitance models C_{gd} and C_{gs}. Electro-thermal models are achieved by calculating the thermal resistances and capacitances through a controlled set of pulsed IV measurements, and are used to model the transistor's temperature dependence.

The BILT/IVCAD pulsed characterization system is the first to allow engineers and transistor designers to characterize and model GaN FETs by performing synchronized Pulsed IV and Pulsed S-Parameter measurements and developing Compact Transistor Models from the comfort of their labs.

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