High Voltage Pulsed IV measurements

AMCAD ENGINEERING

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1KV PIV

Agenda

• Overview
• Pulsed IV measurement concept
• Main Specifications
• Integration with instruments
• Measurement Examples
• Q&A
Overview

High Power Transistors

*For use in switching circuit applications*

- Solar Inverters
- High Voltage DC/DC Converters
- Motor Drives

**Key Parameters:**

- $I_{dss}$ (output current saturation)
- $V_{ds} \text{Max}$ (Avalanche Ruggedness)
- $R_{DS \text{ (ON)}}$ (System Efficiency and reducing cooling requirement)
- $Q_g$ (Low capacitance for max Switching speed)

- Measurement of these parameters in pulsed mode (close to switching operating conditions)
- Influence of quiescent bias (evaluation of parasitic effects)
1KV PIV

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Pulsed IV measurement concept

Short pulses are provided from a quiescent bias point

The IV Family of curve is measured in pulsed mode
Pulsed IV measurement concept

Avoid Thermal Heating

- Device self-heating distorts data and prevents accurate device characterization when pulses are too long.

- Devices designed to target low conduction loss, which result in lower voltages across the device.

- Test equipment must be capable of generating high current and measuring low voltages in short time period.

- Pulsed measurements with short pulse width (~μs) is required to avoid device self heating especially for medium current at high voltage bias.

- The aim is to limit the maximum power using pulse stimulus to limit the maximum power applied to the device.
Pulsed IV measurement concept

Quantify parasitic effects

Some technologies such as GaN transistors have some parasitic effects such as trapping effects.

They can be highlighted by pulsed measurements. The quiescent bias point can influence the Ron characteristic for example.

Pulsed measurements can be used to evaluate Ron as a function of the quiescent bias (Ids=3A)

\[
\begin{align*}
\text{Ron (Vgsq=0, Vdsq=0)} &= 78 \text{ mOhms} \\
\text{Ron (Vgsq=-2V, Vdsq=0)} &= 107 \text{ mOhms} \\
\text{Ron (Vgsq=0, Vdsq=25)} &= 234 \text{ mOhms} \\
\text{Ron (Vgsq=0, Vdsq=50)} &= 387 \text{ mOhms}
\end{align*}
\]

\(\text{RDS(ON)}\) depends on QP
The aim is to highlight the influence of the quiescent bias point under pulsed measurements on key parameters:

- $I_{dss}$
- $V_{dss}$ Max
- $R_{DS \ (ON)}$

**Pulsed IV measurement concept**

**Determine breakdown voltage**

- Because of the high voltage capabilities, this system can be used to determine the breakdown voltage of device under tests.

- Quiescent point can be varied

The aim is to highlight the influence of the quiescent bias point under pulsed measurements on key parameters:

- $I_{dss}$
- $V_{dss}$ Max
- $R_{DS \ (ON)}$

Breakdown voltage (safer in pulsed mode + Electronic fuse)
Pulsed IV measurement concept

Switching speed

- AM241 probe has lower rise and fall time than many of the transistors available on the market!

Necessary feature to evaluate:

Qg (switching speed)

Open conditions:
Rise & Fall time \( \sim 130\text{ns} \) @ 1000V

Gate and Drain pulse width & delay can be customized
1KV PIV

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### Main specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>AM241</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage DC</td>
<td>1000V</td>
</tr>
<tr>
<td>Voltage Peak</td>
<td>1000V</td>
</tr>
<tr>
<td>Current DC</td>
<td>4A (with Power Limits)</td>
</tr>
<tr>
<td>Current Peak</td>
<td>33A (with Power Limits)</td>
</tr>
<tr>
<td>Max Power</td>
<td>90W</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>0% → 100% (including DC)</td>
</tr>
<tr>
<td>Max Pulse Frequency</td>
<td>250 KHz @ 100V</td>
</tr>
<tr>
<td></td>
<td>10 KHz @ 1000V</td>
</tr>
<tr>
<td>Max rise time (95%)</td>
<td>1KV/1A -&gt; 250ns</td>
</tr>
<tr>
<td></td>
<td>10V/30A -&gt; 100ns</td>
</tr>
<tr>
<td>Max fall time (95%)</td>
<td>1KV/1A -&gt; 250ns</td>
</tr>
<tr>
<td></td>
<td>10V/30A -&gt; 100ns</td>
</tr>
<tr>
<td>Package Size</td>
<td>2.87&quot; H x 4.84&quot; W x 6.55&quot; D</td>
</tr>
</tbody>
</table>
Main specifications

- Up to four channels with 16 bits measurement units
- Measurement bandwidth up to 16MHz

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>1000V</th>
<th>200V</th>
<th>40V</th>
<th>30A</th>
<th>3A</th>
<th>300mA</th>
<th>30mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>15 bit + sign</td>
<td>20mV</td>
<td>4mV</td>
<td>0,8mV</td>
<td>580μA</td>
<td>58μA</td>
<td>5,7μA</td>
<td>0,57μA</td>
</tr>
<tr>
<td>Settling time</td>
<td>to 99%</td>
<td>360ns(1)</td>
<td></td>
<td></td>
<td>200ns(2)</td>
<td>220ns(2)</td>
<td>340ns(2)</td>
<td>340ns(2)</td>
</tr>
<tr>
<td></td>
<td>to 99,9%</td>
<td>1,3μs(1)</td>
<td></td>
<td></td>
<td>300ns(2)</td>
<td>300ns(2)</td>
<td>460ns(2)</td>
<td>460ns(2)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>-3dB</td>
<td>4MHz</td>
<td></td>
<td>6MHz</td>
<td>6MHz</td>
<td>3MHz</td>
<td>3MHz</td>
<td></td>
</tr>
<tr>
<td>Absolute accuracy</td>
<td>% of the range(3)</td>
<td>0,2%</td>
<td>0,2%</td>
<td>0,2%</td>
<td>0,5%</td>
<td>0,4%</td>
<td>0,4%</td>
<td>0,4%</td>
</tr>
<tr>
<td>Noise(4)</td>
<td>single pulse</td>
<td>±60mV</td>
<td>±24mV</td>
<td>±22mV</td>
<td>±2,3mA</td>
<td>±1,1mA</td>
<td>±34μA</td>
<td>±70μA</td>
</tr>
<tr>
<td></td>
<td>averaging (240 samples)</td>
<td>±4mV</td>
<td>±2mV</td>
<td>±1mV</td>
<td>±200μA</td>
<td>±240μA</td>
<td>±5μA</td>
<td>±5μA</td>
</tr>
<tr>
<td>Recovery delay</td>
<td></td>
<td>-</td>
<td>2μs(5)</td>
<td>2μs(5)</td>
<td>-</td>
<td>1μs(6)</td>
<td>1μs(6)</td>
<td>1μs(6)</td>
</tr>
</tbody>
</table>
• Overview
• Pulsed IV measurement concept
• Main Specifications
• Integration with instruments
• Measurement Examples
• Q&A
Integration with instruments

Test Fixture for packaged transistors (TO-247) equipped with Kelvin sensors & interlock connection

SHV coaxial connector

High Voltage Banana plug
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Some data sheet info for High voltage transistor

### Silicon Carbide Power MOSFET

#### CMF10120D

- **N-Channel Enhancement Mode**
- **TO-247-3**

### Electrical Characteristics

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{DSS} )</td>
<td>Drain-Source Breakdown Voltage</td>
<td>1200</td>
<td></td>
<td></td>
<td>V</td>
<td>( V_{GD} = -5V ), ( I_D = 50\mu A )</td>
</tr>
<tr>
<td>( V_{GS(ON)} )</td>
<td>Gate Threshold Voltage</td>
<td>2.5</td>
<td>4</td>
<td></td>
<td>V</td>
<td>( V_{GD} = V_{GS} ), ( I_D = 500\mu A ), ( T_J = 25^\circ C )</td>
</tr>
<tr>
<td>( I_{DS} )</td>
<td>Zero Gate Voltage Drain Current</td>
<td>0.5</td>
<td>50</td>
<td></td>
<td>( \mu A )</td>
<td>( V_{GD} = 1200V ), ( V_{GS} = 0V ), ( T_J = 25^\circ C )</td>
</tr>
<tr>
<td>( I_{DS} )</td>
<td>Gate-Source Leakage Current</td>
<td>5</td>
<td>125</td>
<td></td>
<td>( \mu A )</td>
<td>( V_{GD} = 1200V ), ( V_{GS} = 0V ), ( T_J = 125^\circ C )</td>
</tr>
<tr>
<td>( R_{DS(on)} )</td>
<td>Drain-Source On-State Resistance</td>
<td>160</td>
<td>220</td>
<td></td>
<td>( \Omega )</td>
<td>( V_{GD} = 20V ), ( I_D = 10A ), ( T_J = 25^\circ C )</td>
</tr>
<tr>
<td>( g_m )</td>
<td>Transconductance</td>
<td>3.7</td>
<td></td>
<td></td>
<td>S</td>
<td>( V_{GD} = 20V ), ( I_{DS} = 10A ), ( T_J = 25^\circ C )</td>
</tr>
<tr>
<td>( C_{iss} )</td>
<td>Input Capacitance</td>
<td>928</td>
<td></td>
<td></td>
<td>( pF )</td>
<td>( V_{GS} = 0V )</td>
</tr>
<tr>
<td>( C_{oss} )</td>
<td>Output Capacitance</td>
<td>63</td>
<td></td>
<td></td>
<td>( pF )</td>
<td>( V_{GD} = 800V )</td>
</tr>
<tr>
<td>( C_{rss} )</td>
<td>Reverse Transfer Capacitance</td>
<td>7.45</td>
<td></td>
<td></td>
<td>( pF )</td>
<td>( f = 1MHz ), ( V_{SC} = 25mV )</td>
</tr>
<tr>
<td>( t_{rr} )</td>
<td>Turn-On Delay Time</td>
<td>7</td>
<td></td>
<td></td>
<td>ns</td>
<td>( V_{DD} = 800V )</td>
</tr>
<tr>
<td>( t_{r} )</td>
<td>Rise Time</td>
<td>14</td>
<td></td>
<td></td>
<td>ns</td>
<td>( V_{GD} = +2/20V )</td>
</tr>
<tr>
<td>( t_{off} )</td>
<td>Turn-Off Delay Time</td>
<td>46</td>
<td></td>
<td></td>
<td>ns</td>
<td>( I_D = 10A )</td>
</tr>
<tr>
<td>( t_{f} )</td>
<td>Fall Time</td>
<td>37</td>
<td></td>
<td></td>
<td>ns</td>
<td>( R_C = 6.8\Omega )</td>
</tr>
<tr>
<td>( E_{on} )</td>
<td>Turn-On Switching Loss</td>
<td>261</td>
<td></td>
<td></td>
<td>( \mu J )</td>
<td>( L = 856\mu H )</td>
</tr>
<tr>
<td>( E_{off} )</td>
<td>Turn-Off Switching Loss</td>
<td>120</td>
<td></td>
<td></td>
<td>( \mu J )</td>
<td>Per JEDEC24 Page 27</td>
</tr>
<tr>
<td>( R_{G} )</td>
<td>Internal Gate Resistance</td>
<td>13.6</td>
<td></td>
<td></td>
<td>( \Omega )</td>
<td>( V_{GS} = 0V ), ( f = 1MHz ), ( V_{SC} = 25mV )</td>
</tr>
</tbody>
</table>
1. Rdson measurements

**Electrical Characteristics**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
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<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{ds(on)}$</td>
<td>Drain-Source On-State Resistance</td>
<td>160</td>
<td>220</td>
<td>190</td>
<td>260</td>
</tr>
</tbody>
</table>

Test Conditions:
- $V_{GS} = 20V, I_{D} = 10A, T_{j} = 25^\circ C$
- $V_{GS} = 20V, I_{D} = 10A, T_{j} = 125^\circ C$

**Rdson measured** = 152mΩ

From QP1=0V_0V
From QP2=600V_0A

Pulse width = 12us,
Duty cycle = 12%
2. Input Characteristic

**VGS(th) Gate Threshold voltage**

<table>
<thead>
<tr>
<th>Symbol</th>
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<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VGS(th)</td>
<td>Gate Threshold Voltage</td>
<td>2.5</td>
<td>4</td>
<td>1.8</td>
<td>V</td>
</tr>
</tbody>
</table>

**Vgs(th) measured = 2.4V**

From QP1=0V_0V

Pulse width = 12us, Duty cycle = 12%
2. Input Characteristic

**V_{GS(th)}** Gate Threshold voltage

### Electrical Characteristics

<table>
<thead>
<tr>
<th>Symbol</th>
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<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{GS(m)}</td>
<td>Gate Threshold Voltage</td>
<td>2.5</td>
<td>4</td>
<td>1.8</td>
<td>V</td>
<td>V_{DS} = V_{GS}, I_{D} = 500uA, T_{J} = 25°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V_{DS} = V_{GS}, I_{D} = 500uA, T_{J} = 125°C</td>
</tr>
</tbody>
</table>

From QP1=0V_0V

Pulse W= 12us, Duty cycle = 12%
Tchuck=25°C
3. Output characteristic

![Graph showing output characteristic](image)

- **Typical Output Characteristics** $T_J = 25^\circ C$
  - From $QP1=0V\_0V$
  - Pulse width = 12us,
  - Duty cycle = 12%
  - $T_{chuck}=25^\circ C$
3. Output characteristic

Pulse width = 12us, Duty cycle = 12% Tchuck=25°C

Pulse Breakdown area
Peak Power Max = 4.22KW
3. Output characteristic

Pulse width = 12us, Duty cycle = 12%
Tchuck=25°C
3. Output characteristic

Pulse width = 12us, Duty cycle = 12%
Tchuck=25°C

Influence of Quiescent bias point on transistor characteristics
1KV PIV

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Q&A

- What is the maximum voltage when the maximum current is delivered?
  When 30A are delivered, in pulsed mode, the limitation comes from the max peak power of 3.6KW, the max voltage will be close to ~120V!

- What is the maximum current when the maximum voltage is delivered?
  When 1000V are delivered, in pulsed mode, the limitation is also linked to the max peak power of 3.6KW, the max current will be close to ~3.6A!

- What are the resolution and measurement accuracy needed as a function of the voltage and current ranges?
  We especially need small current range with fine resolution for low current measurements. For Range of 30mA, Absolute accuracy is about 120µA (Resolution of 1µA).
  For voltage, 40V range is available with an absolute accuracy of 80mV (1mV resolution).

- Why do we need to get the pulse as short as possible?
  To investigate more deeply into current collapse phenomenon, like other companies and universities, we also test our device on several conditions to learn how electron acts according to applied voltage.

- Our system is equipped with
  - Kelvin voltage measurement capabilities
  - Interlock safety system
  - 20ns horizontal measurement resolution & 16bit vertical resolution
  - Internal calibration
  - Electronic fuse