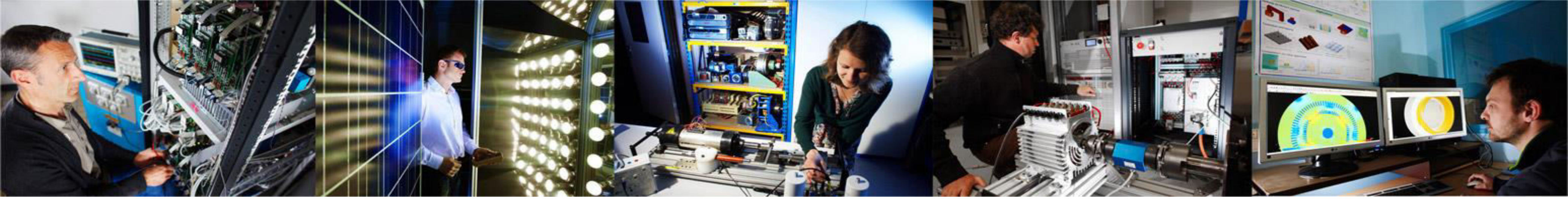

June 20th 2019

A Method to Determine Wide Bandgap (WBG) Power Devices Packaging Interconnections

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HEI

Context

High frequency power conversion enables to reduce size and weight of power converters :

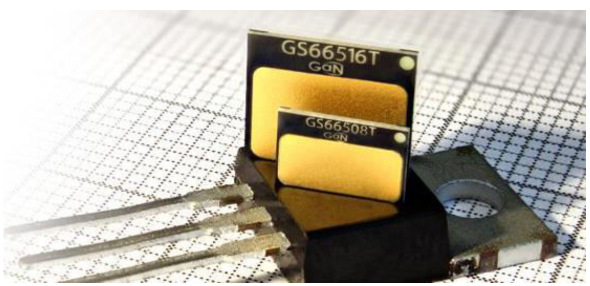
LITTLE BOX CHALLENGE

Google | IEEE

$2\ kW$
$150\ W/in^3$

High power density of WBG devices enables to optimize packagings :

GaN Systems



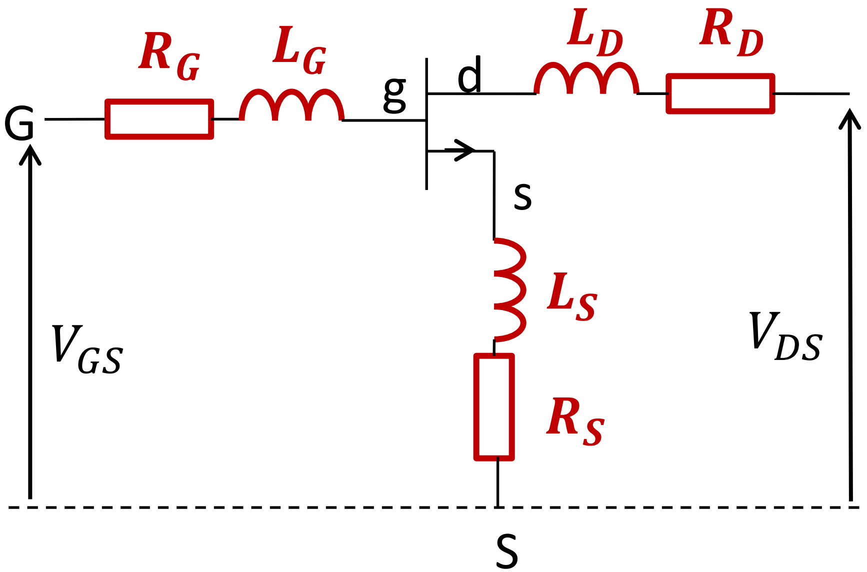
High Johnson FoM of GaN and SiC shows their abilities to operate in high power and high frequency converters :

	Si	SiC	GaN
Johnson FoM	1	410	790

$$JFM = \left(\frac{E_c v_{sat}}{2\pi}\right)^2$$

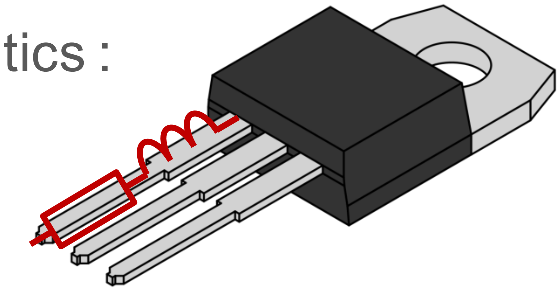
→ **Accurate WBG device models including packaging characteristics are required to better predict high frequency operation of power converters**

Influence of packaging interconnections for a 3-terminals transistor :



Origins of parasitics :

- Bondings
- Vias
- Pins/Pads

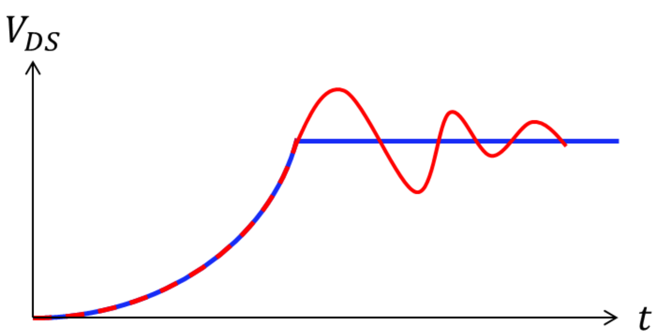


R_G, R_D and R_S :

- Increase conduction power losses
- Slow down switchings
- Damp voltages ringings

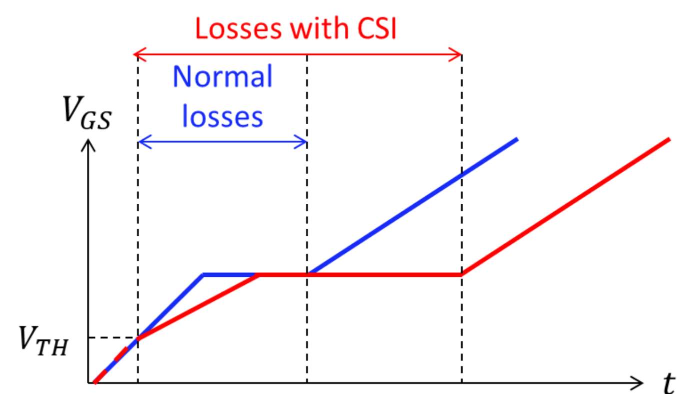
L_G and L_D :

- Gate and Drain overvoltages
- Gate and Drain voltage ringings



L_S :

- Drastically increases turn on and off times



Outline

I. Calibration Procedure for S-Parameter Characterization
   1. Characterization Fixtures for the WBG Devices Under Test
   2. Open-Short Calibration
   3. Characteristics of the Calibration Fixtures

II. Access Parasitics Determination of Packaged WBG Devices
   1. SiC Schottky Diode
   2. GaN HEMT with 3-terminals
   3. GaN HEMT with 4-terminals

Conclusion

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Conclusion

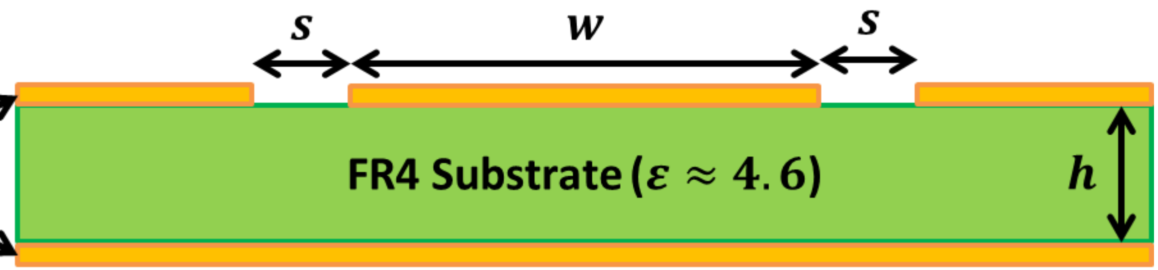
- Transmission lines on PCB :

On-board SMA connectors
18 GHz 500 V

Ground plane

$w = 3\ mm$
$s = 1.5\ mm$
$h = 1.6\ mm$

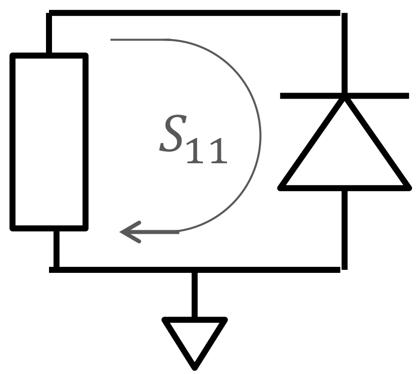
Ground planes



- 1-Port S-parameter characterization for 2-terminals devices :

SiC Schottky Diode
IDDDD04G65C6XTMA1
650V / 8A

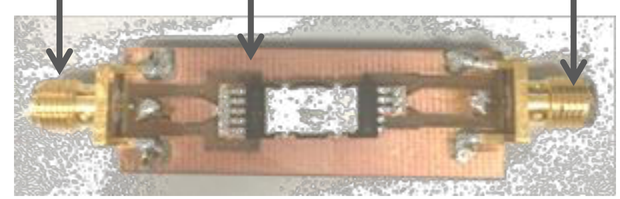
VNA
Port 1



Cathode Port 1

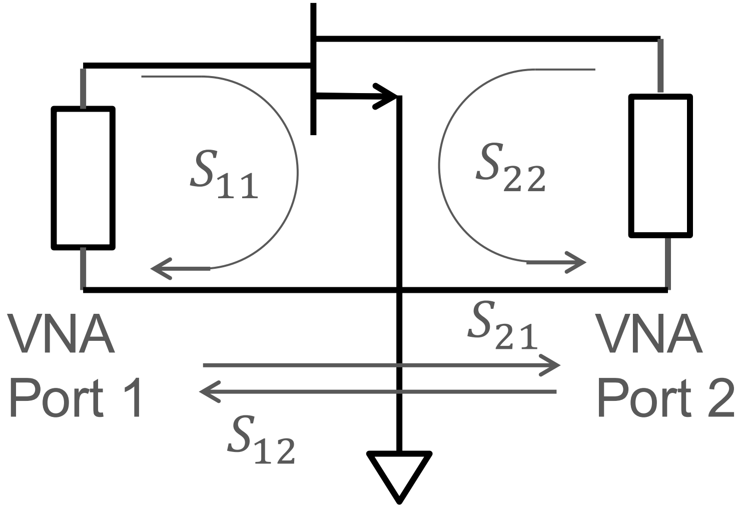
Ground Plane

Anode to Ground

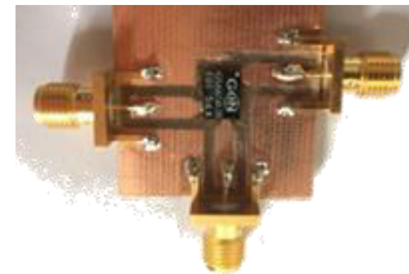


- GaN HEMT with 3 terminals :

GaN HEMT
650V / 8A
GS66502B



Gate
Port 1

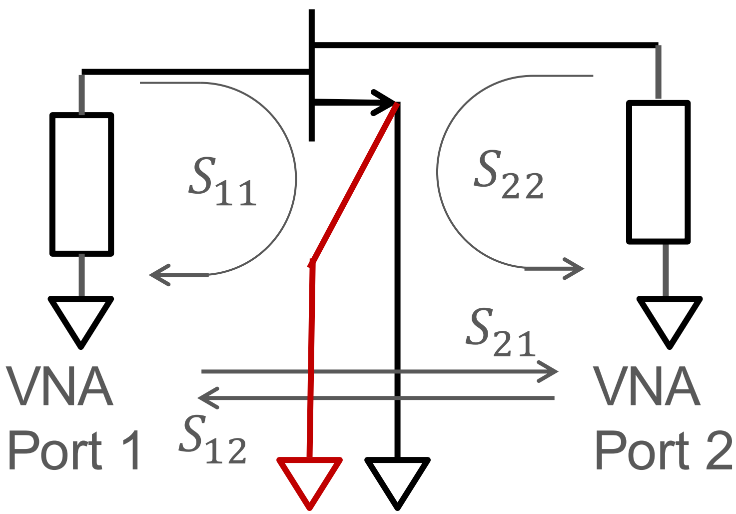


Drain
Port 2

Source to
Ground

- GaN HEMT with additional Kelvin Source :

GaN HEMT
650V / 30A
GS66508B



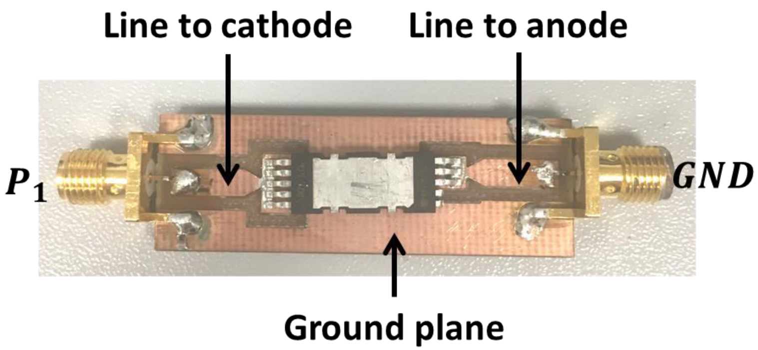
Drain
Port 2

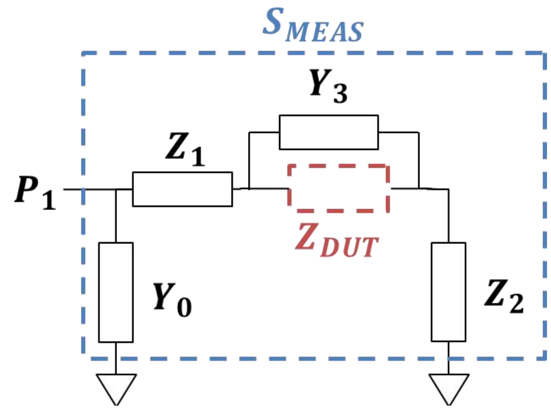
Source
to GND

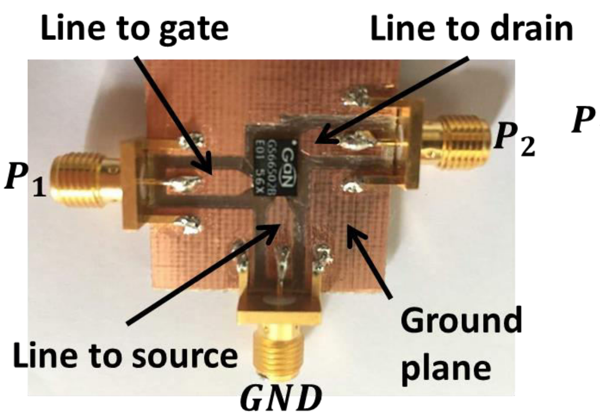
Gate
Port 1

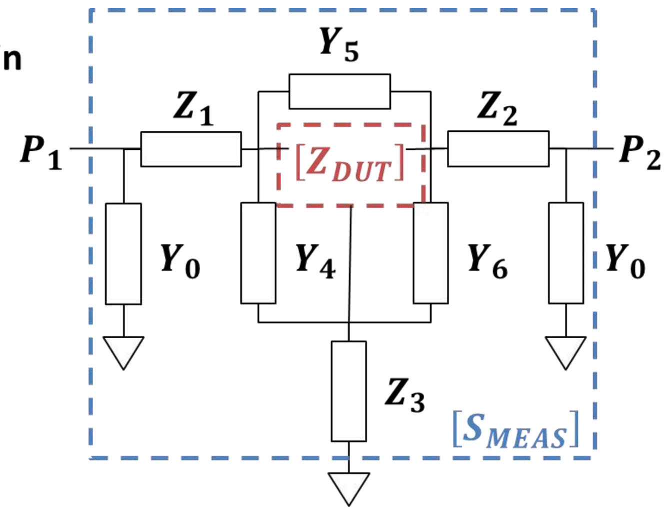
Kelvin Source to GND

I.2. Open-Short Calibration









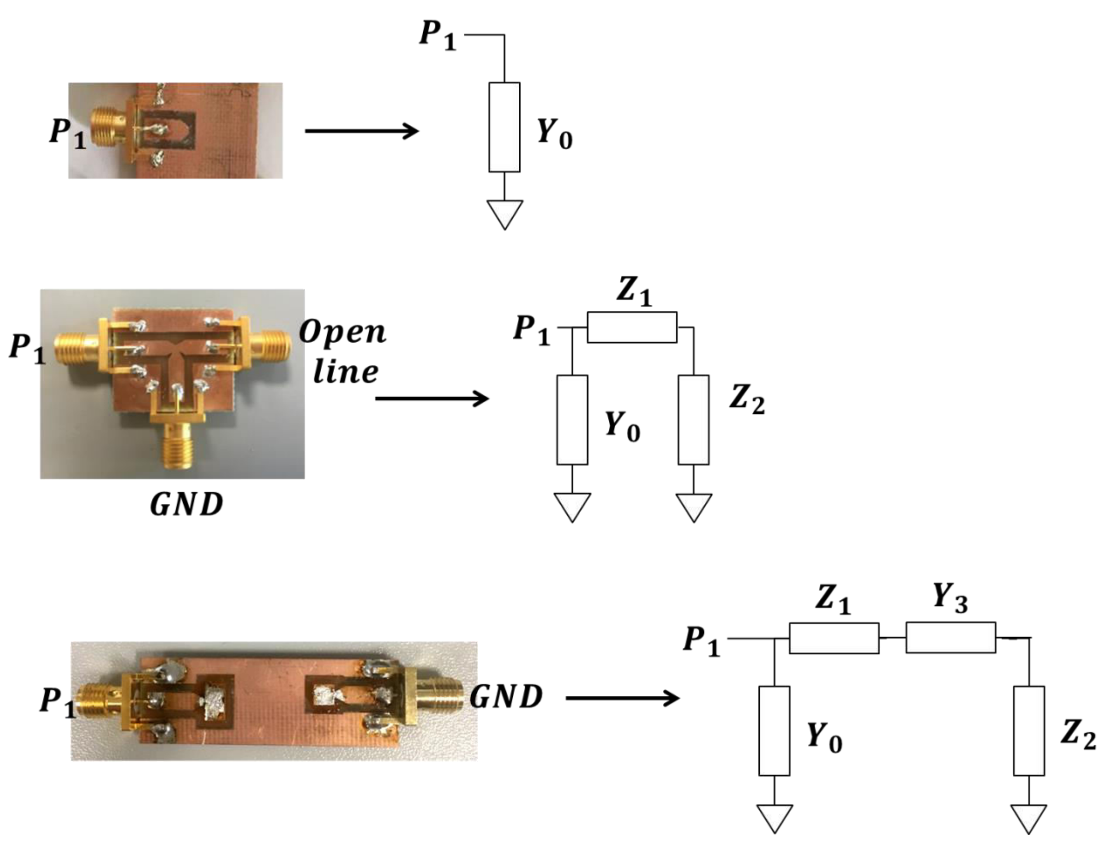
Y_0 : Coupling between line and ground plane

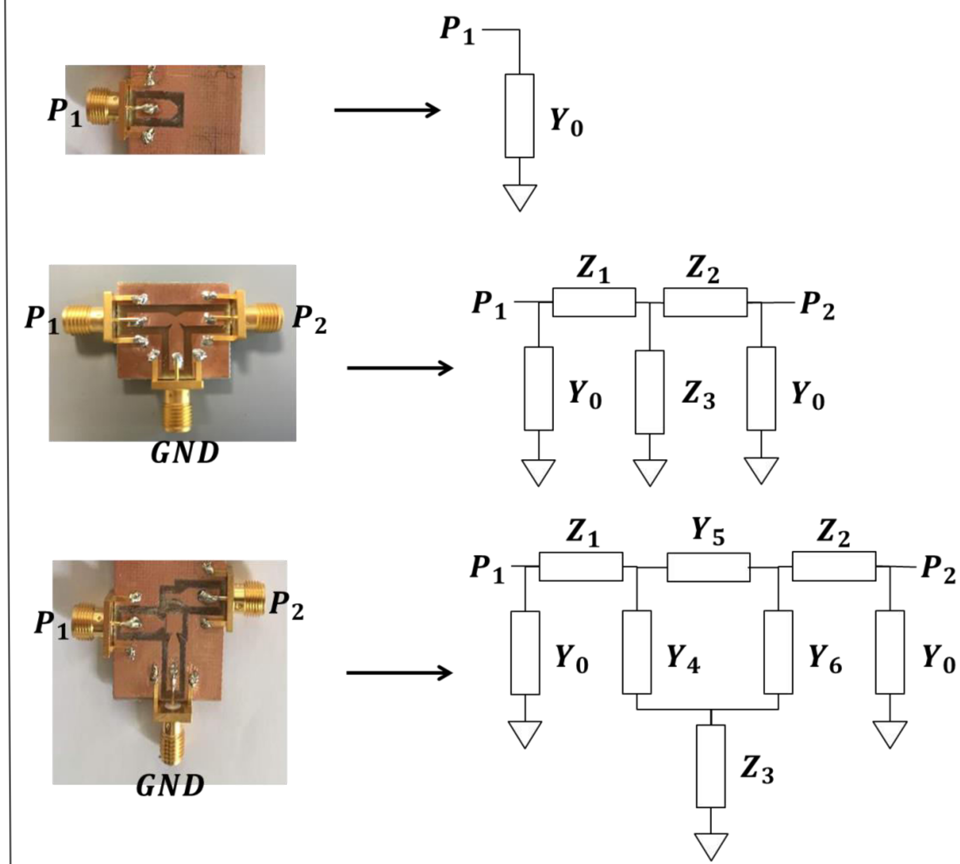
Z_1, Z_2 and Z_3 : transmission lines impedances

Y_3, Y_4, Y_5 and Y_6 : Coupling between transmission lines

→ **Calibration standards are required in order to get Z parameters of the DUT**

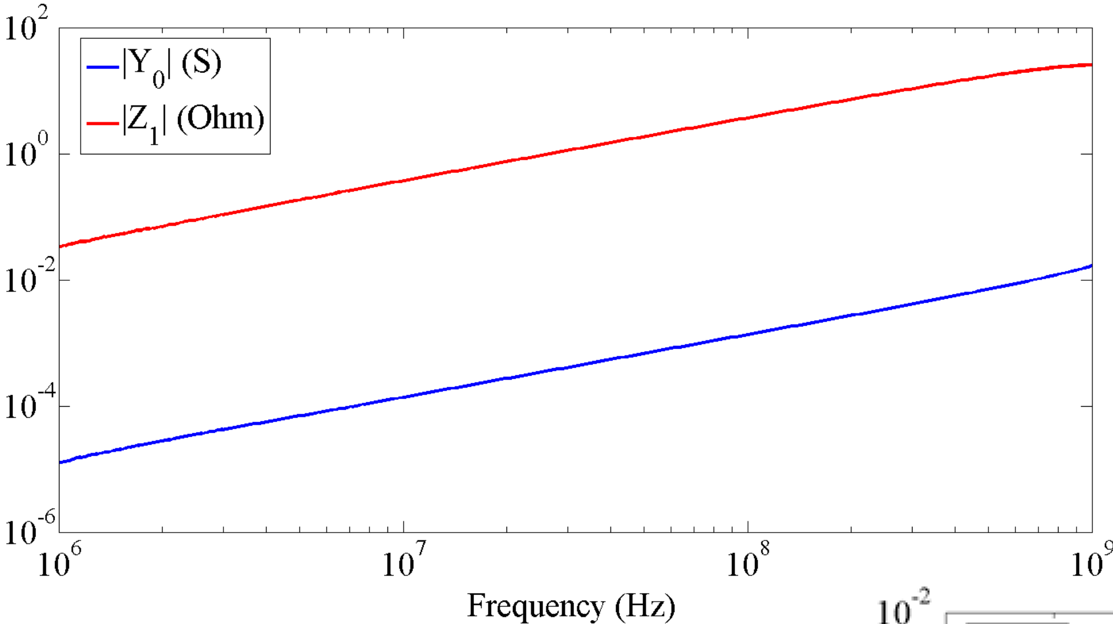
I.2. Open-Short Calibration





→ Simple impedance calculations to get the Z parameter of the SiC Schottky diode

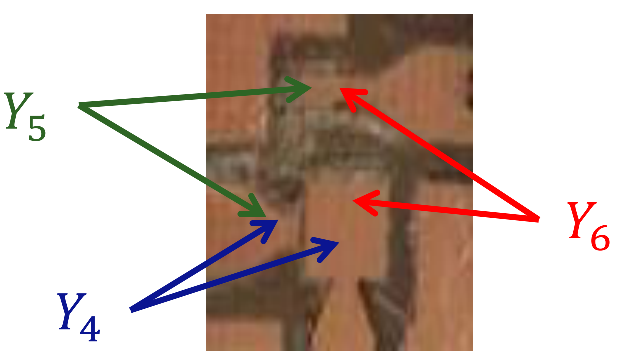
→ Matrix calculations to get the Z parameter of the GaN HEMT



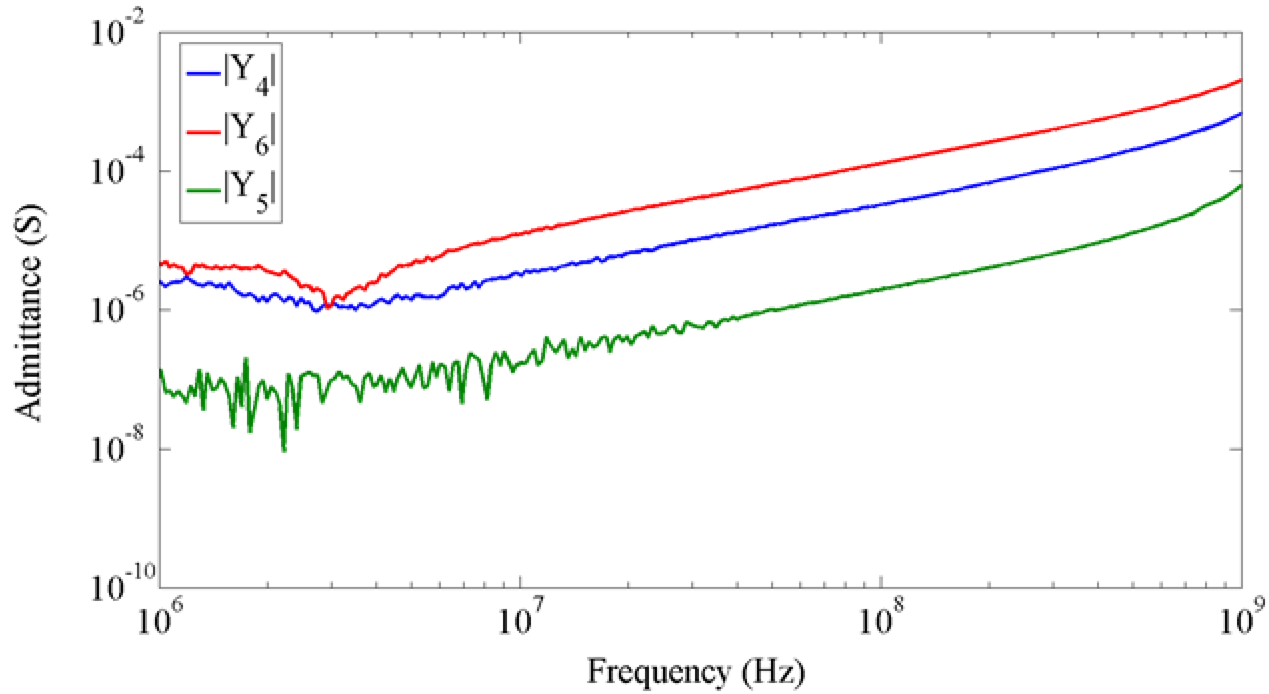
Transmission line parameters :

$$L_{TL} = 5.95\ nH$$
$$C_{TL} = 2.17\ pF$$

$$Z_{C_{TL}} \approx \sqrt{\frac{L_{TL}}{C_{TL}}} = 52.4\ \Omega$$



$C_4\ (fF)$	$C_5\ (fF)$	$C_6\ (fF)$
52.1	3.09	203



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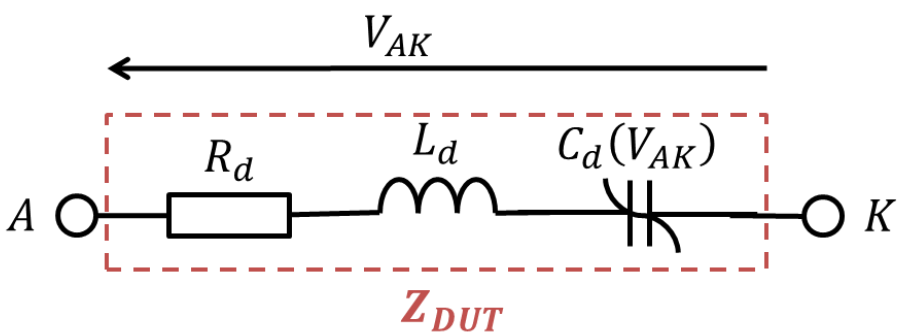
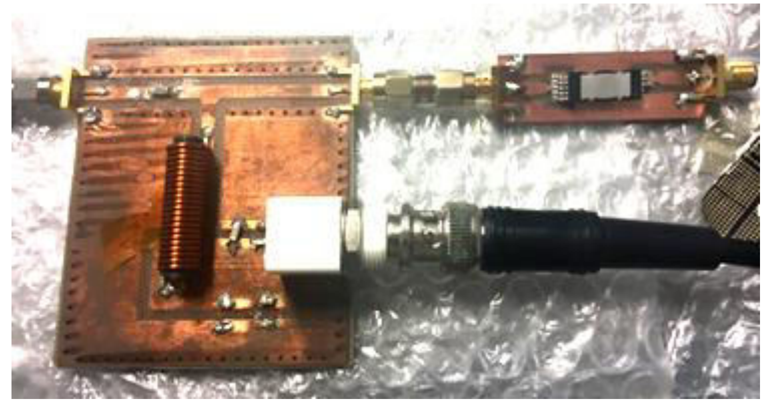
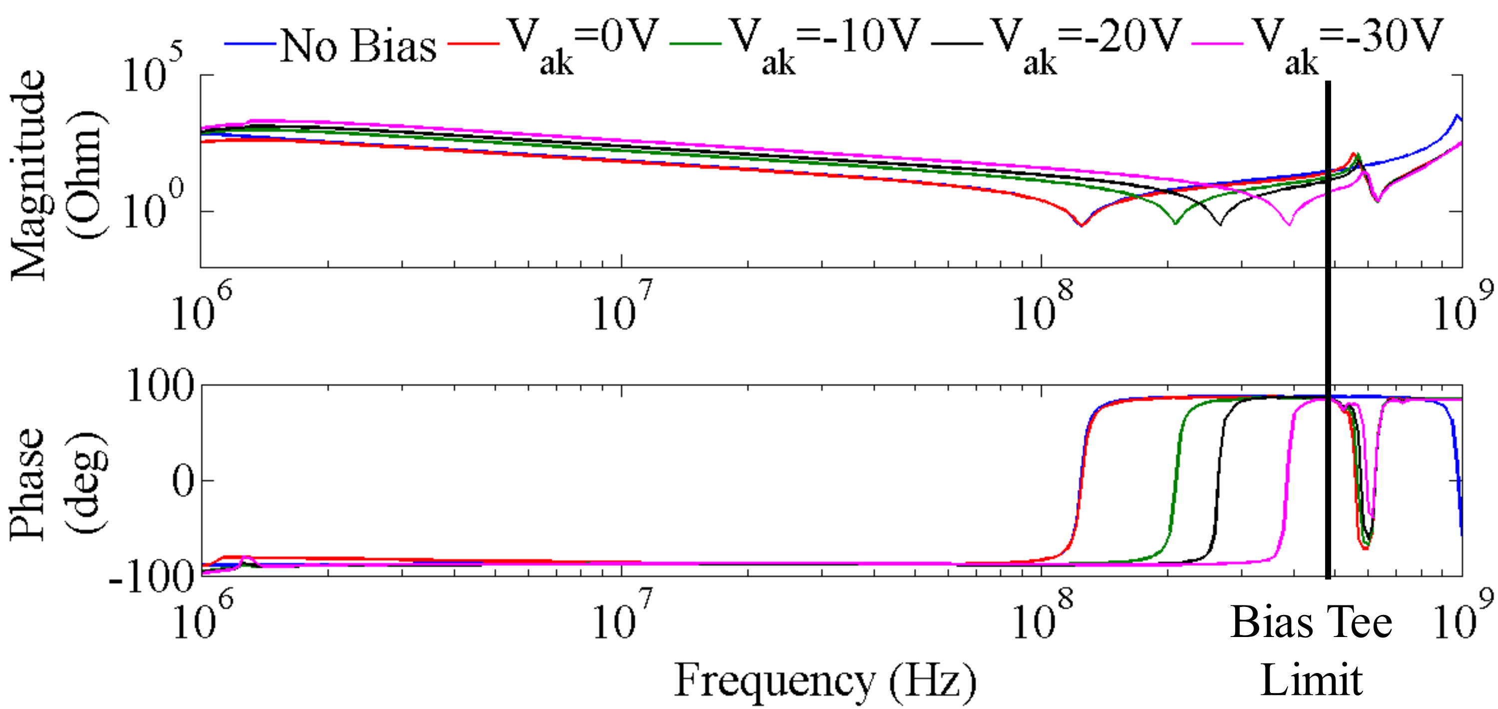
Conclusion

Equivalent circuit in off-state and reverse bias :

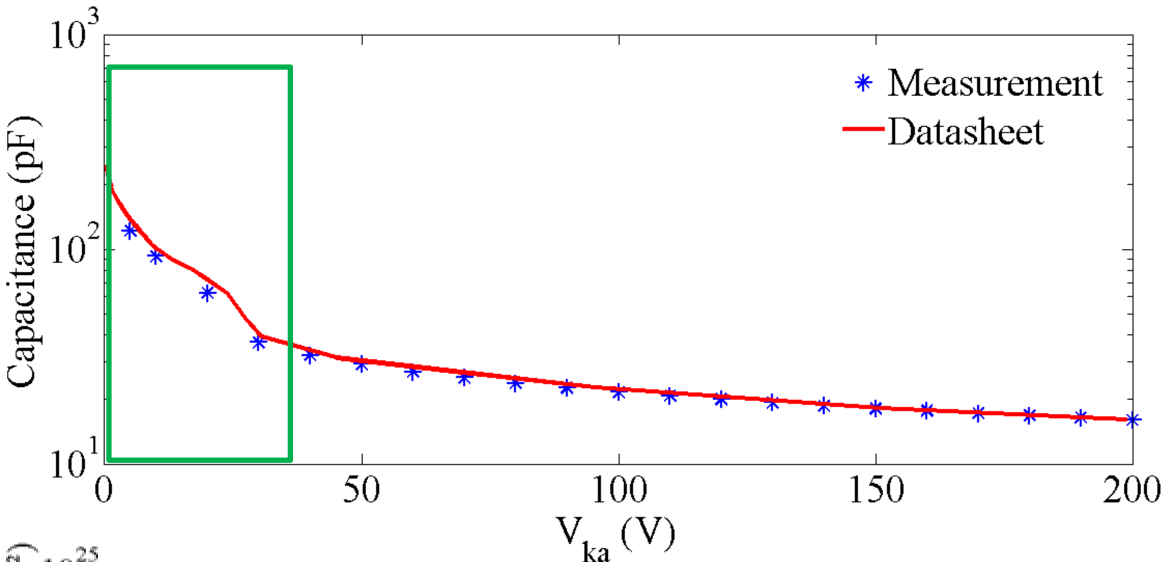


Biasing system :

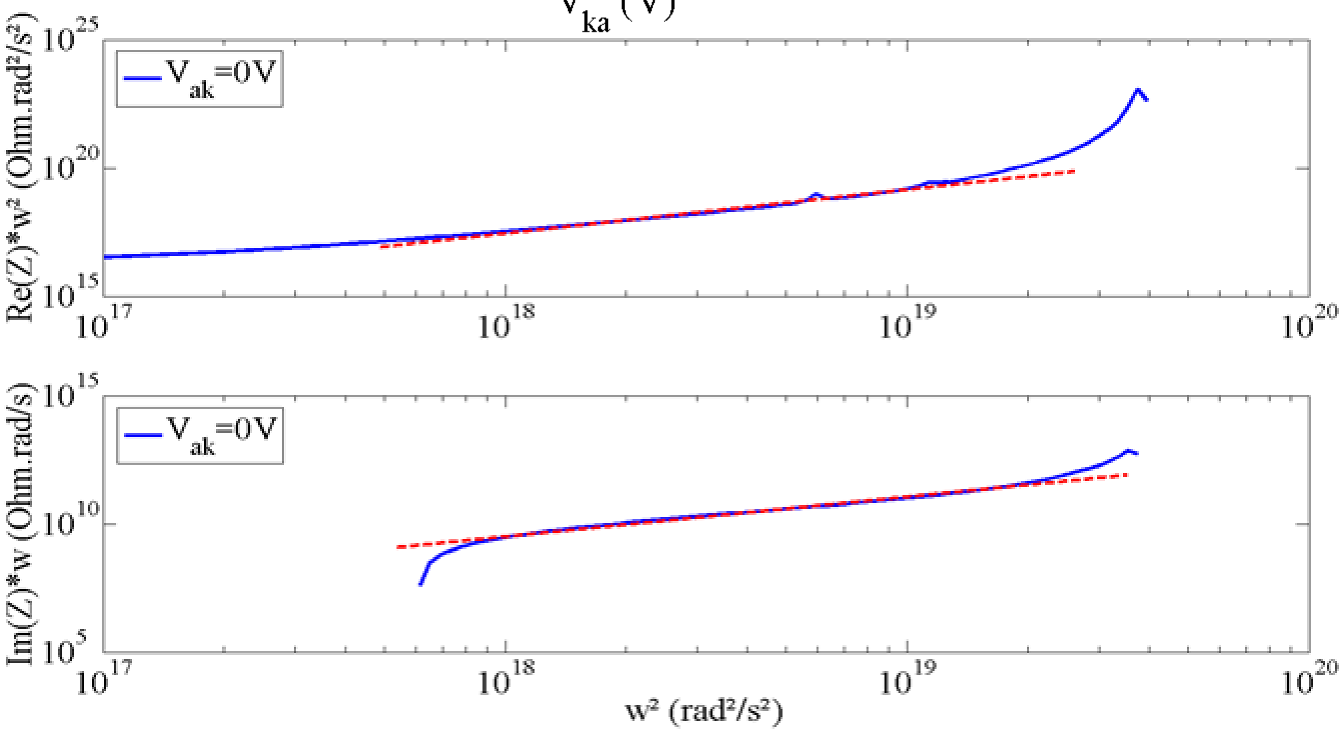




II.1. SiC Schottky Diode



- Diode capacitance is characterized with this method up to 200 V
- Good accuracy for the capacitance extraction



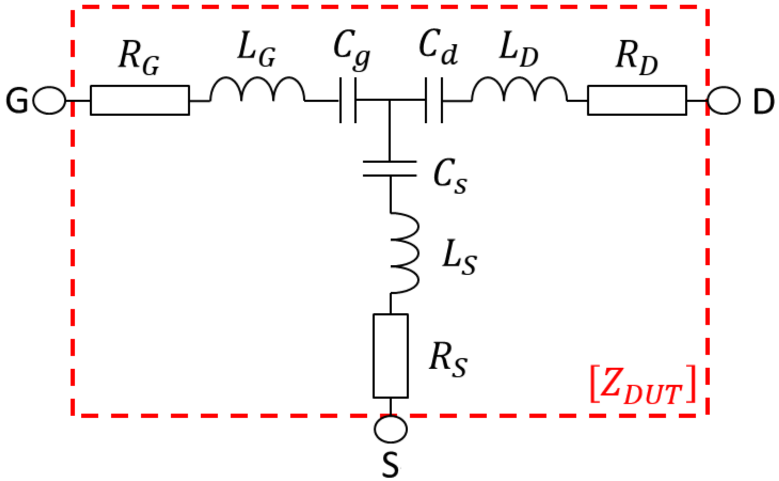
Extraction of parameters :

$$Re(Z_d)\omega^2 = f(\omega^2) \rightarrow R_d$$
$$Im(Z_d)\omega^2 = f(\omega^2) \rightarrow L_d$$

Extracted parameters without bias :

R_d (mΩ)	L_d (nH)	C_d (pF)
442	7.4	237

Equivalent circuit in off-state $(V_{GS} = 0V, V_{DS} = 0V)$:



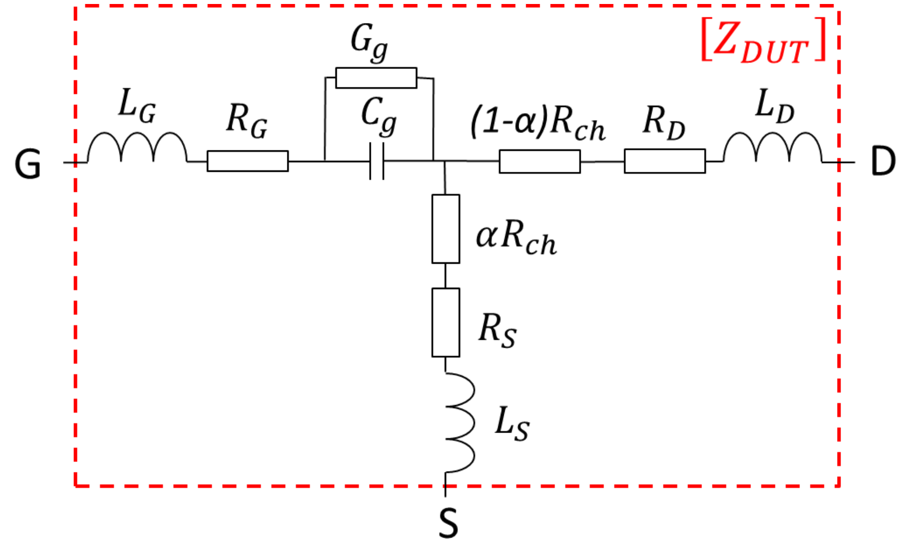
Inductances extraction :

$$Im(Z_{11} - Z_{12})\omega = L_G\omega^2 - \frac{1}{C_g}$$

$$Im(Z_{22} - Z_{12})\omega = L_D\omega^2 - \frac{1}{C_d}$$

$$Im(Z_{12})\omega = L_S\omega^2 - \frac{1}{C_s}$$

Equivalent circuit in Cold FET $(V_{GS} > V_{TH}, V_{DS} = 0V)$:



Inductances extraction :

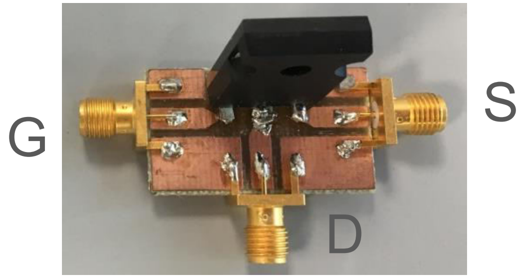
$$Im(Z_{11} - Z_{12})\omega \approx L_G\omega^2 - \frac{1}{C_g}$$

$$Im(Z_{22} - Z_{12})\omega = L_D\omega^2$$

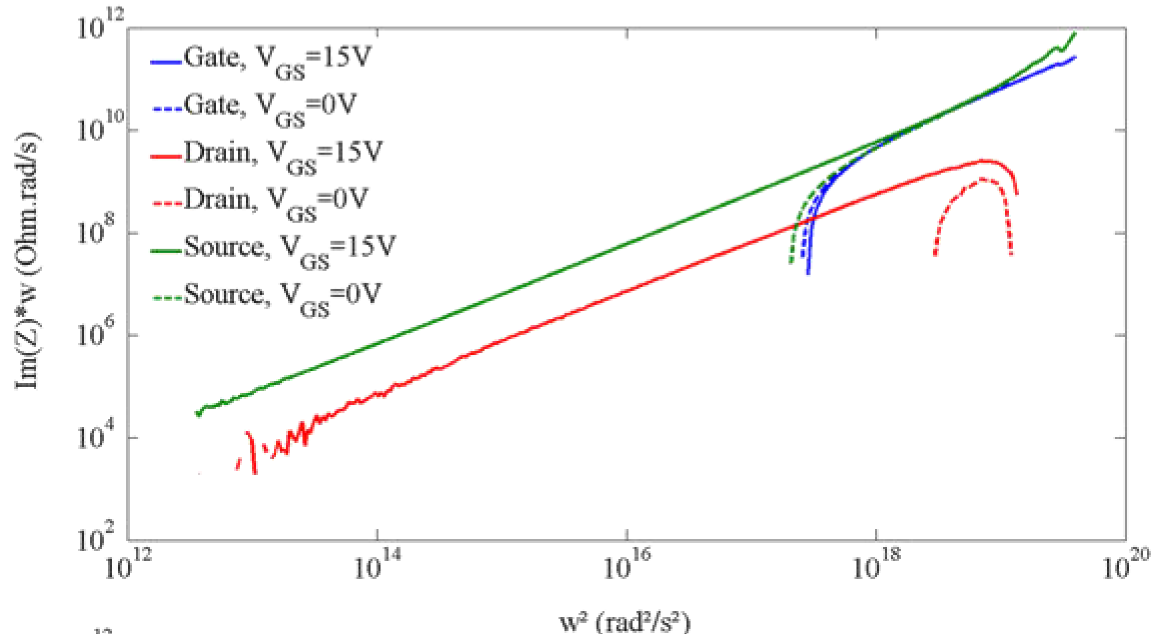
$$Im(Z_{12})\omega = L_S\omega^2$$

II.2. 3-Terminals WBG Power Devices

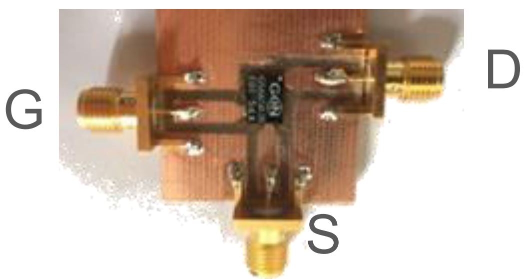
- Characterization of a SiC MOSFET in TO-247 package :



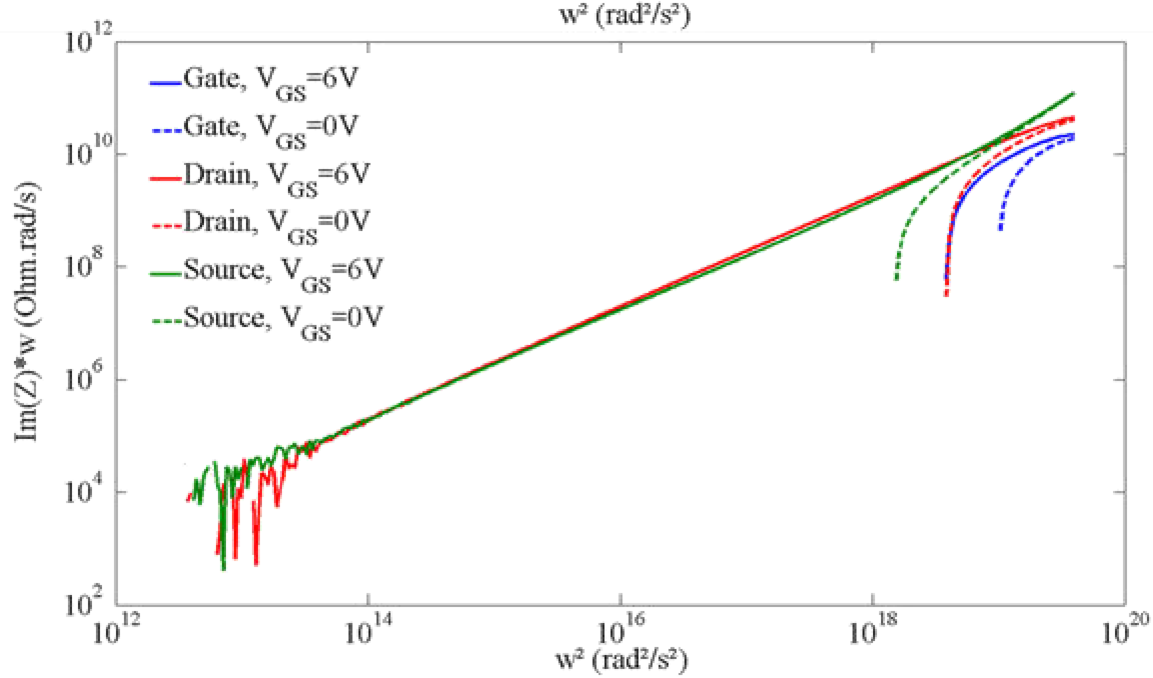
L_G (nH)	L_D (nH)	L_S (nH)
6.96	0.61	5.82



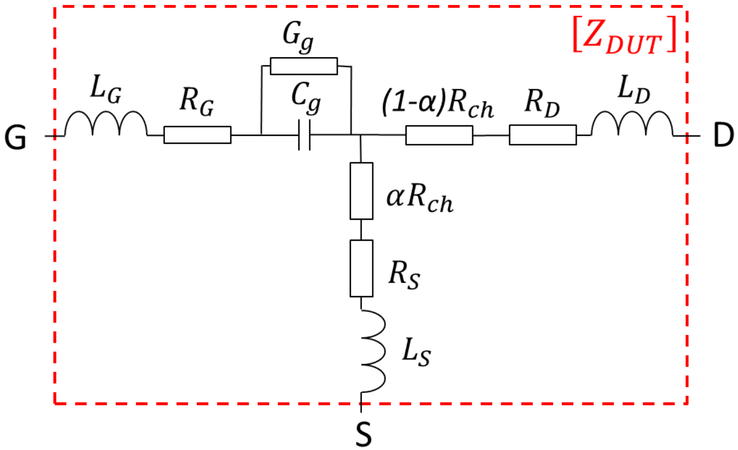
- Characterization of the GaN HEMT G66502B :

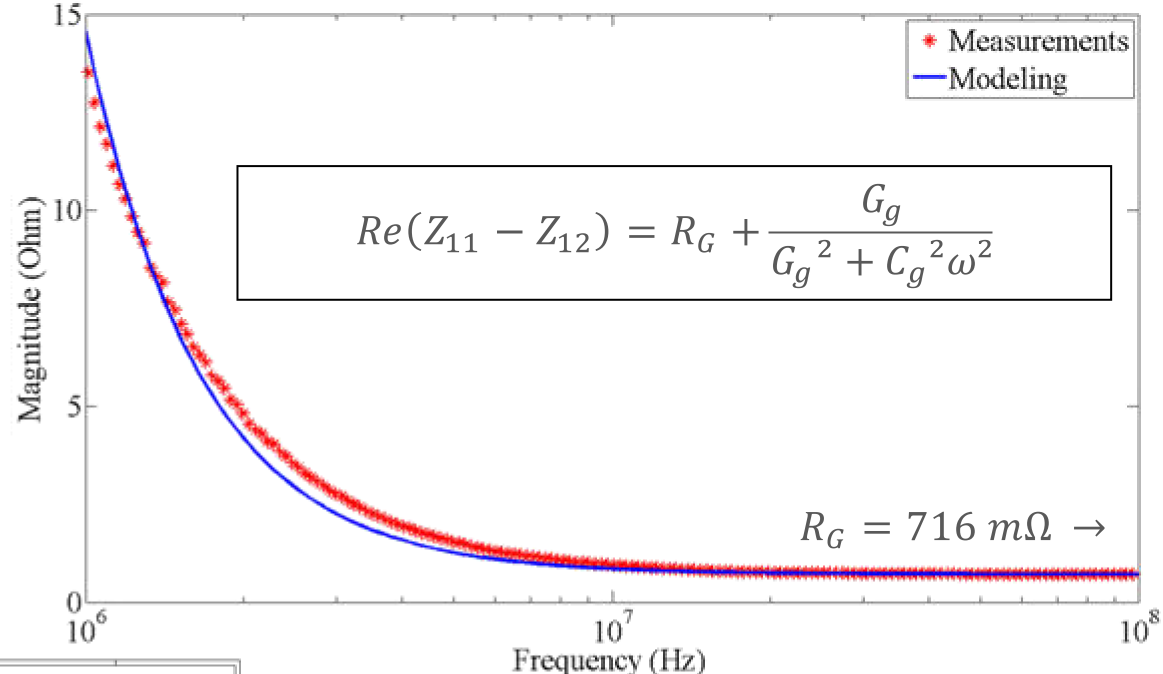


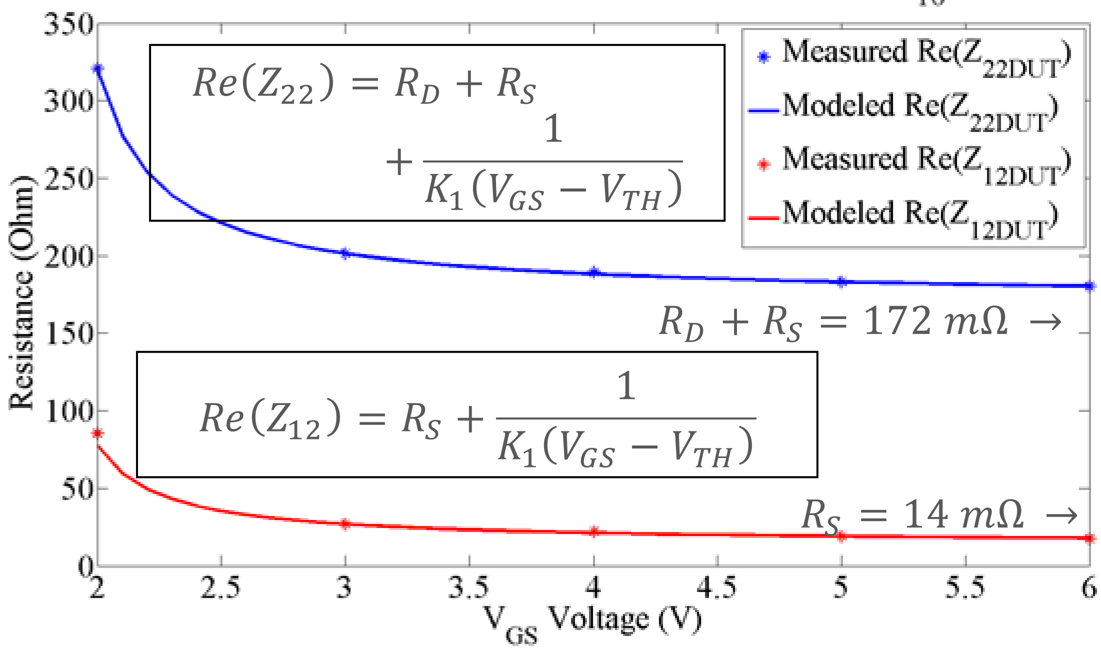
L_G (nH)	L_D (nH)	L_S (nH)
0.56	1.88	0.94



Access resistances extraction with the Cold FET technique :

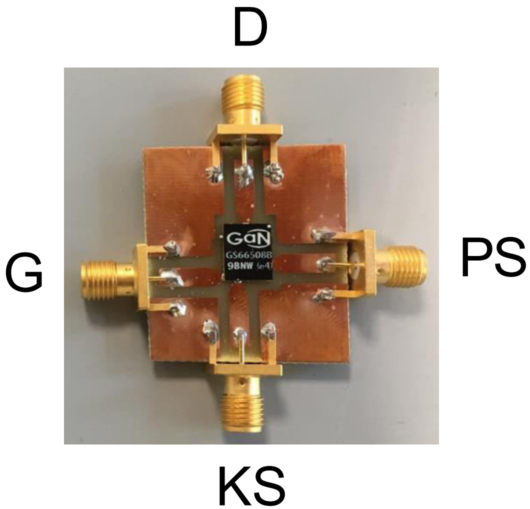


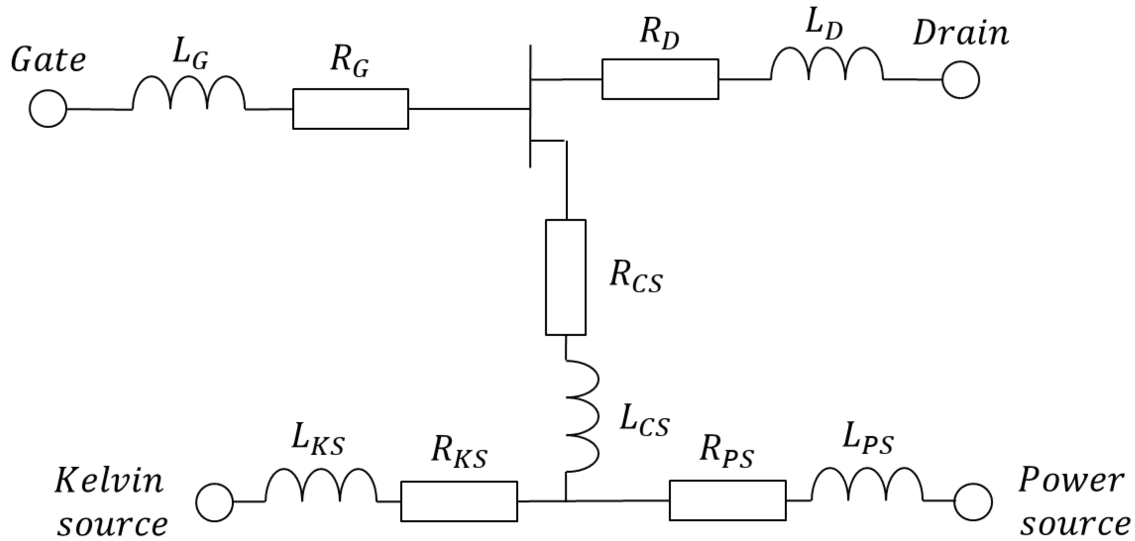




Extracted values :

	R_G (mΩ)	R_D (mΩ)	R_S (mΩ)
Off-State	557	227	124
Cold FET	716	158	14
Manu-facturer	2300	180	10

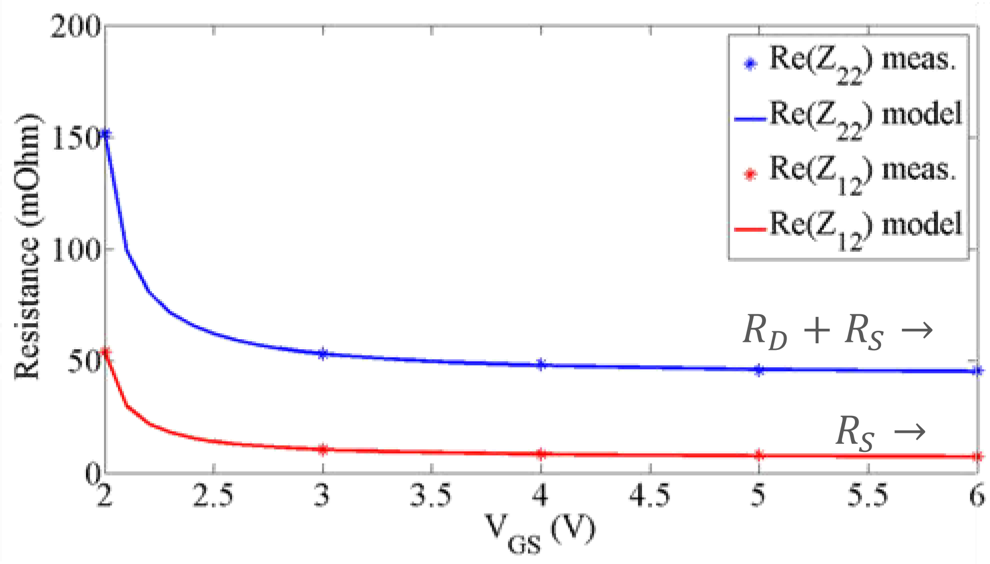


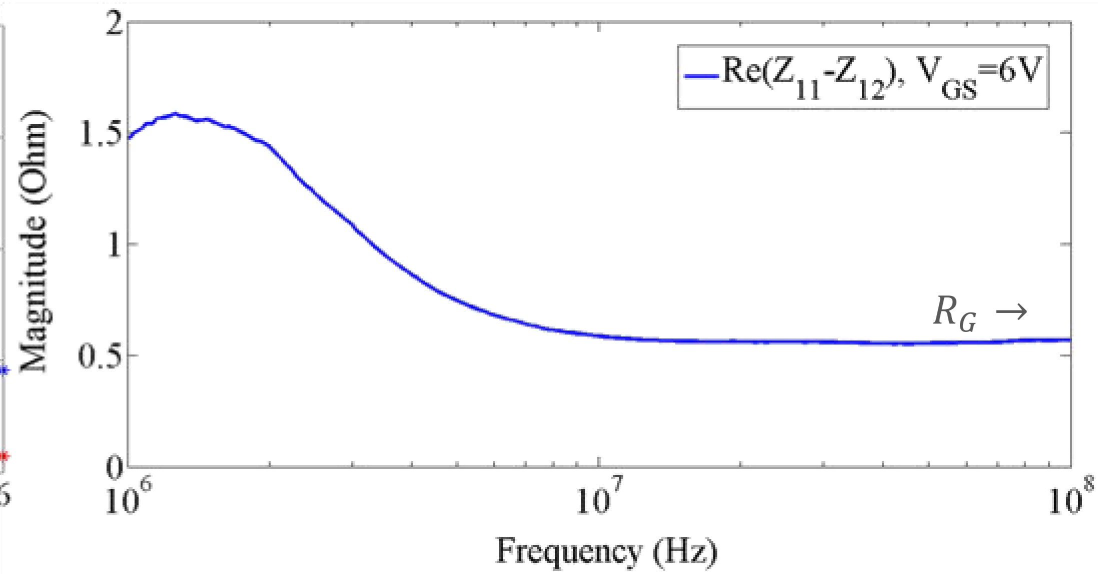


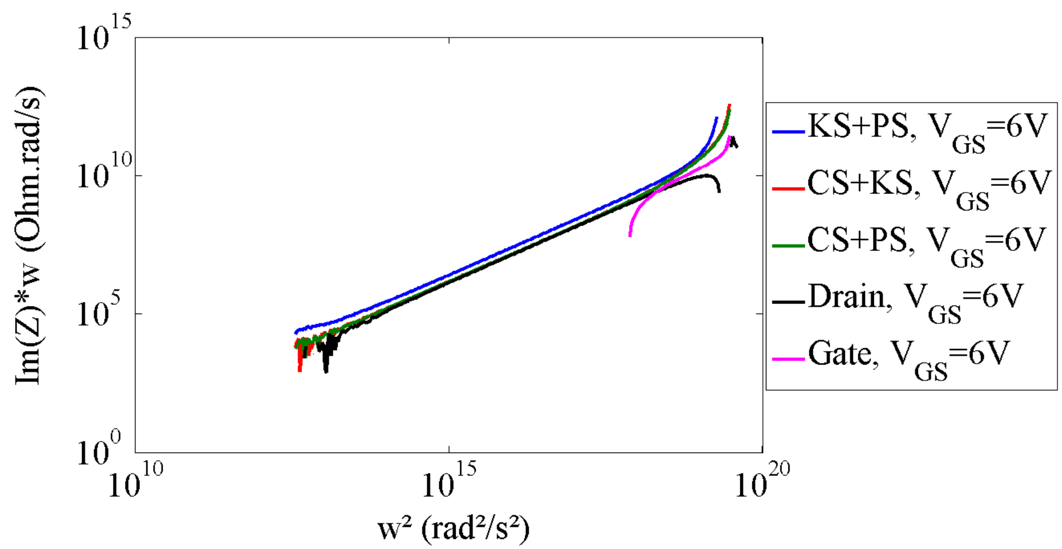
Proposed characterization method :

- Resistances : Cold FET 2-Port S-parameter measurement between G-D-PS

- Inductances :
  - 2-Port S-parameter measurement at $V_{GS} = 6V$ between G-D-PS
  - 2-Port S-parameter measurement at $V_{GS} = 6V$ between G-D-KS
  - 1-Port S-parameter measurement at $V_{GS} = 0V$ between KS-PS







R_G (mΩ)	R_D (mΩ)	R_S (mΩ)
560	42.4	6.1

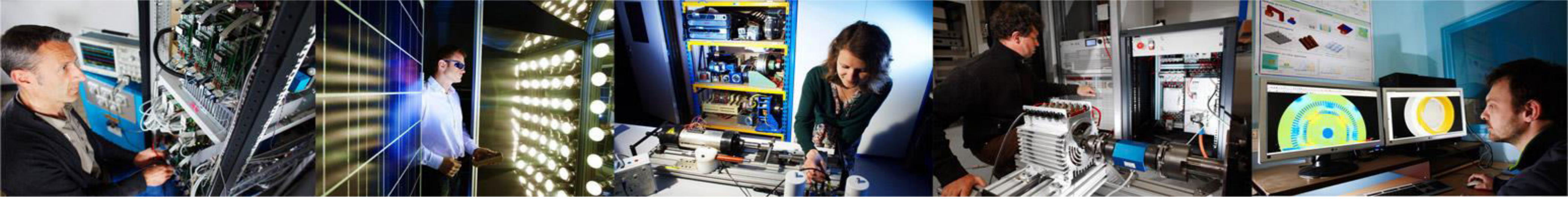
L_G (nH)	L_D (nH)	L_{CS} (nH)	L_{PS} (nH)	L_{KS} (nH)
2.0	1.3	0.2	1.2	1.2

Conclusion of the talk :

- Test fixtures and adapted calibration technique for wideband characterization
- Better accuracy of Cold FET than Off-State measurements for devices prasistics extraction
- Innovative method to characterize packaged transistors including Kelvin Source

Future work :

- Improvement on the short calibration to separate packaging from PCB connections parasitic effects
- Use of ADS software for advanced validation of the characterization method



Thank you for your attention

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