



Università degli Studi di Catania



*Dottorato di Ricerca in Ingegneria dei Sistemi, Energetica,  
Informatica e delle Telecomunicazioni  
XXXIII ciclo*

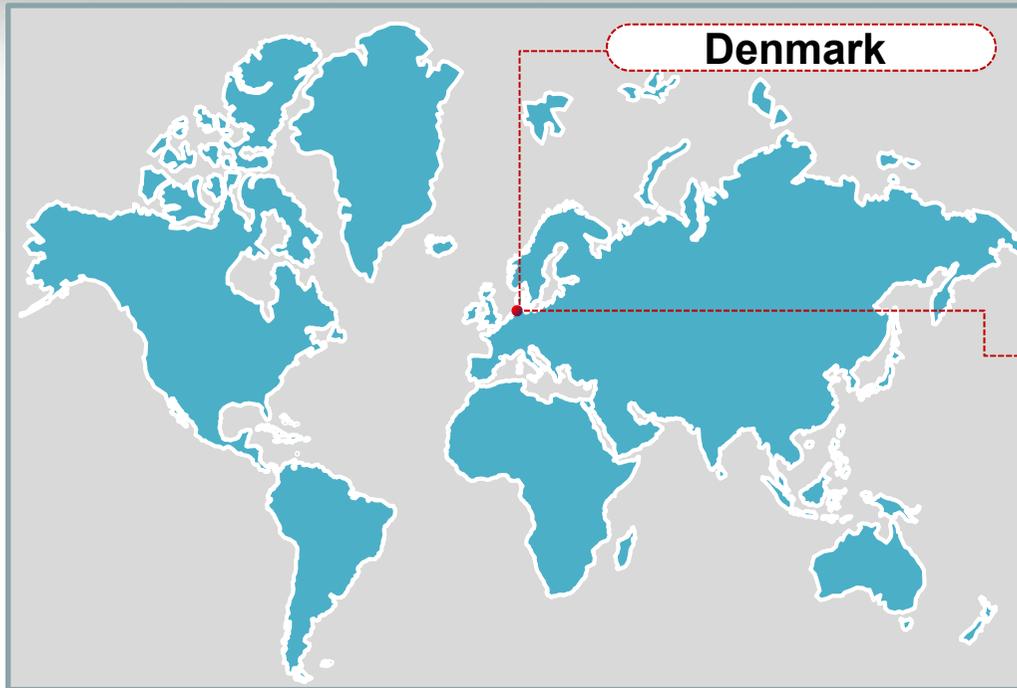
Dipartimento di Ingegneria Elettrica, Elettronica e Informatica

**Innovative semiconductor devices for power  
electronics applications**

**Ph.D. Brainstorming Day  
Catania, 29/10/2019**

**Student:** Giovanni Susinni  
**Tutor:** Prof. Angelo Raciti  
**A.Y. 2018/2019**

# Research periods abroad



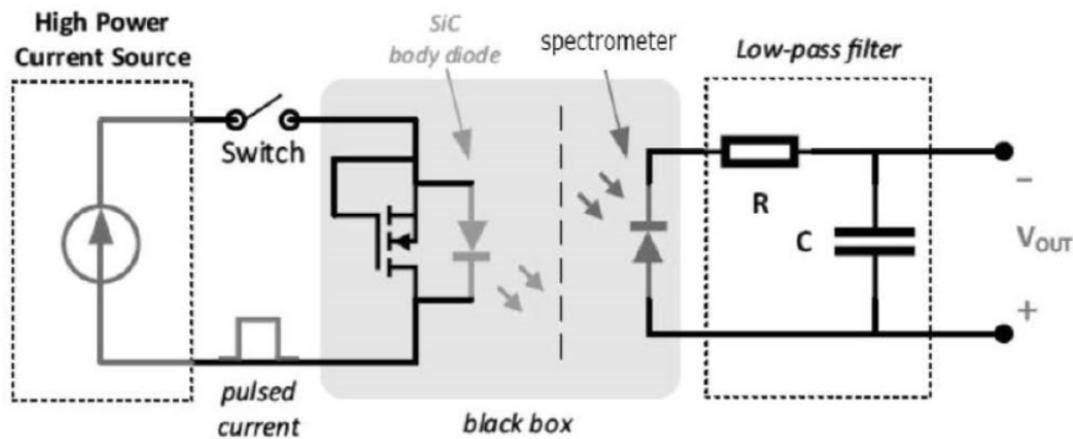
**Energy and technology  
Department**

**From September 2019  
to February 2020**

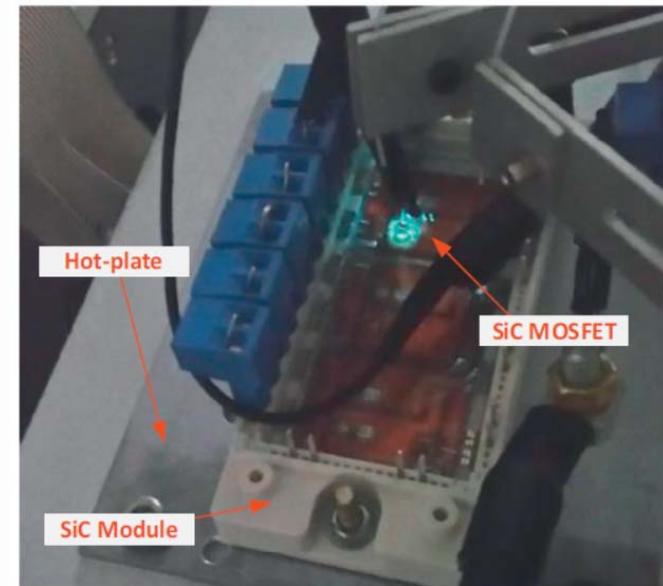


# My project in Aalborg

- The light emission of SiC MOSFETs during reverse conduction, caused by the Light Emission Diode (LED)-like behaviour of the body diode will be studied and investigated.
- SiC MOSFET body diode's light emission is a temperature sensitive electrical parameter

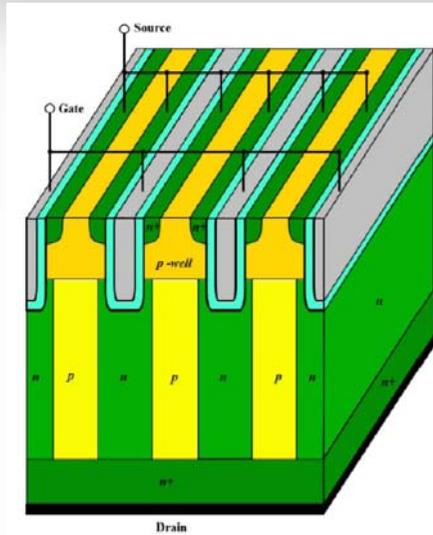


Experimental setup schematic.

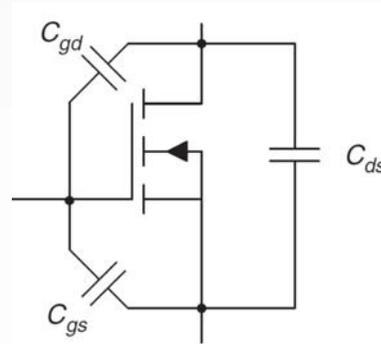


# 1<sup>st</sup> Year Results - Recall

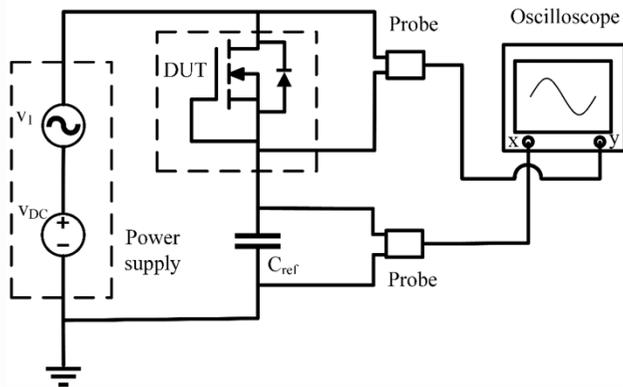
## Superjunction MOSFET



Superjunction MOSFET

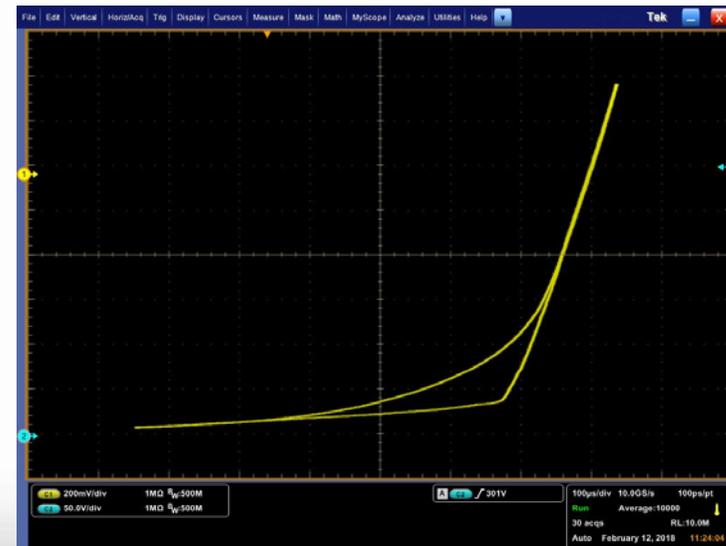


Parasitic Capacitance



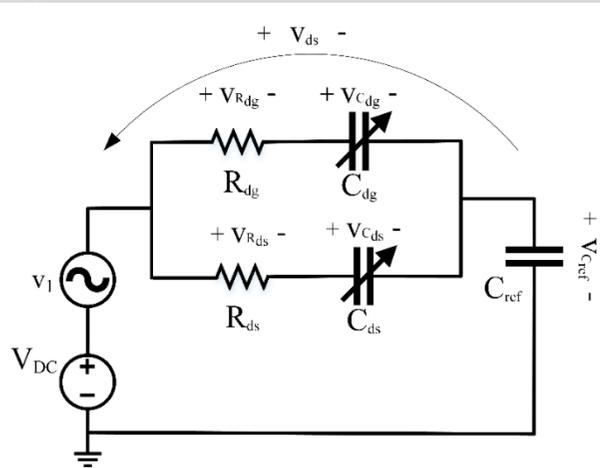
Experimental setup: the Sawyer-Tower circuit

The application of SJ MOSFETs in soft-switching based conversion schemes has revealed unexpected power losses due to the dielectric **hysteresis** phenomenon into the parasitic output capacitance  $C_{oss}$  of the MOSFET



# 1<sup>st</sup> Year Results - Recall

## Superjunction MOSFET



First solution adopted

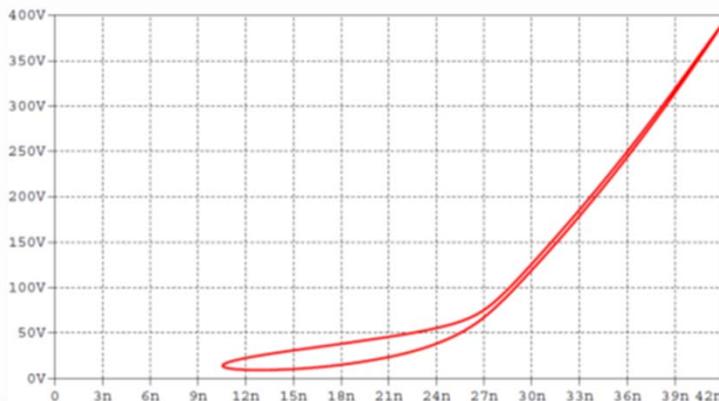
The objective function and the optimization problem are used to estimate the parasitic resistances through a genetic algorithms.

The energy losses,  $E_{LM}$ , is computed from the measurements; the energy losses obtained for a charge/discharge cycle are computed by means of Simulink,  $E_{LS}$ , starting from the simulated trace.

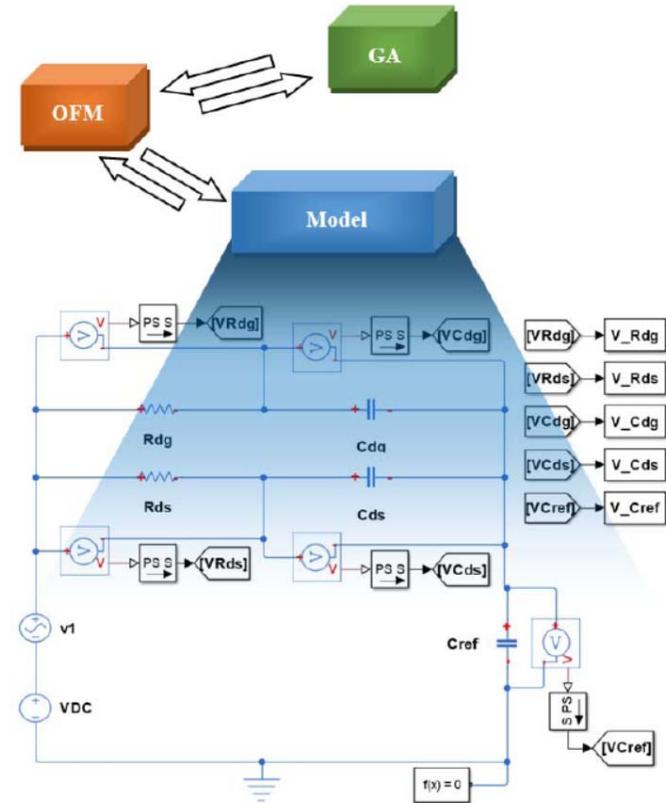
$$OF = |E_{LM} - E_{LS}(R_{dg}, R_{ds})|$$

$$0 \leq R_{dg} \leq R_{m1}$$

$$0 \leq R_{ds} \leq R_{m2}$$

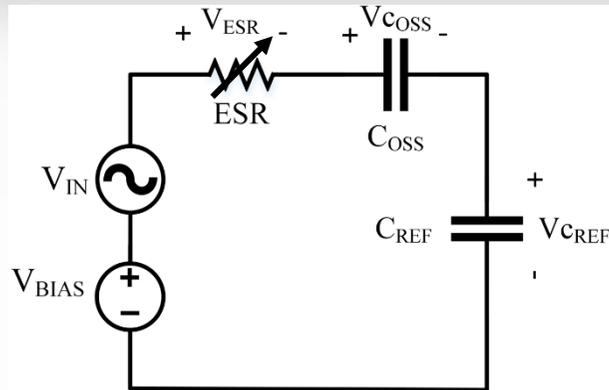


Matlab-Simulink setup for estimating the parasitic resistances by means of the genetic algorithms



# 1<sup>st</sup> Year Results - Recall

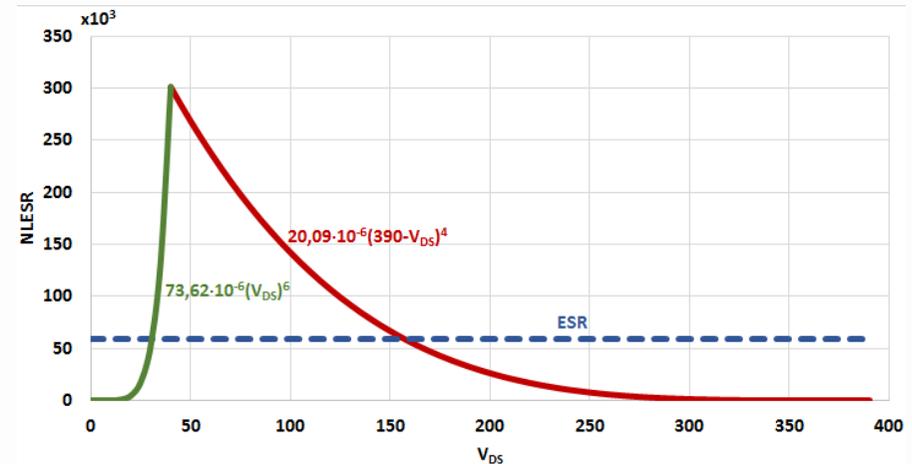
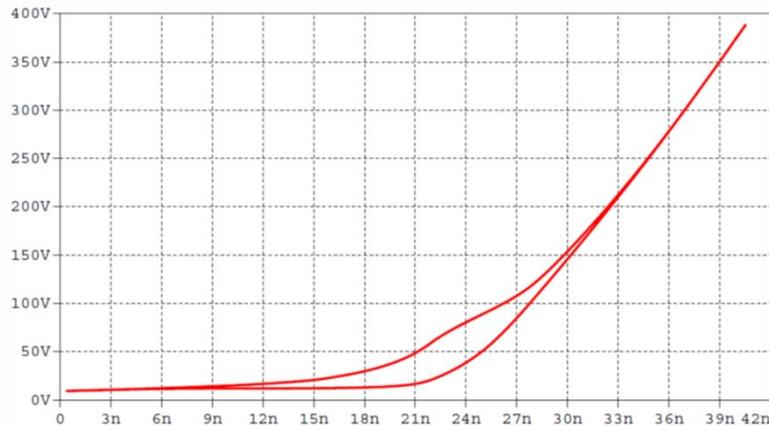
## Superjunction MOSFET



Second solution adopted

The ESR has been represented by means of a nonlinear ESR, NLESR, whose values have been expressed as a function of  $v_{DS}$

$$NLESR = \begin{cases} a v_{DS}^n & v_{DS} \in [0; V_{Rmax}] \\ b (V_{DSmax} - v_{DS})^m & v_{DS} \in [V_{Rmax}; V_{DSmax}] \end{cases}$$

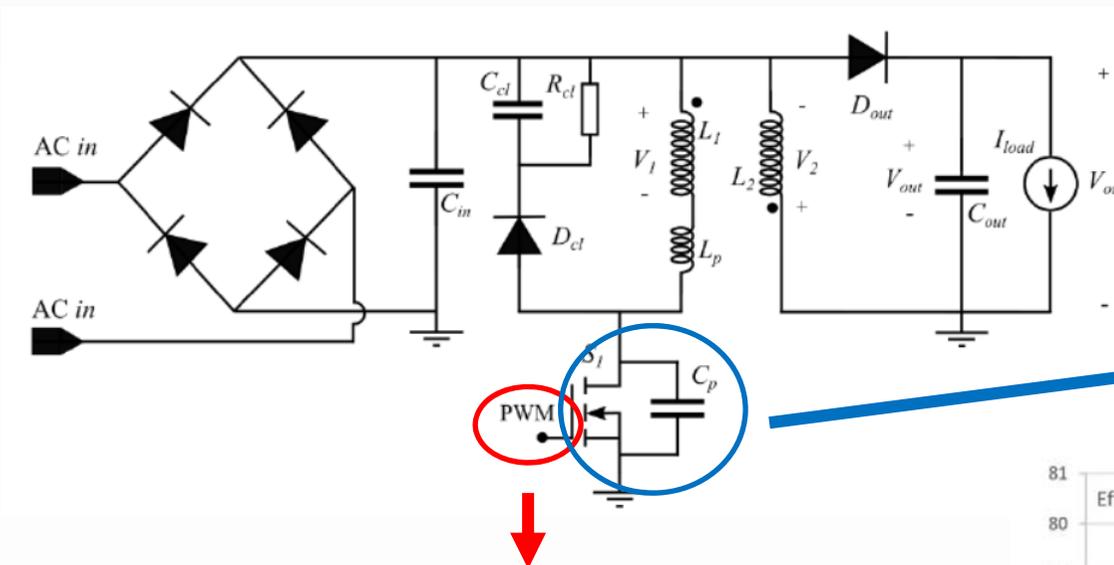


$a$ ,  $b$ ,  $n$  and  $m$  are parameters set to obtain the tuning of the simulated hysteresis to the experimental one. Moreover, the parameter value must avoid discontinuity in the NLESR function, with the additional constraint that the average value of NLESR must be equal to the value of ESR

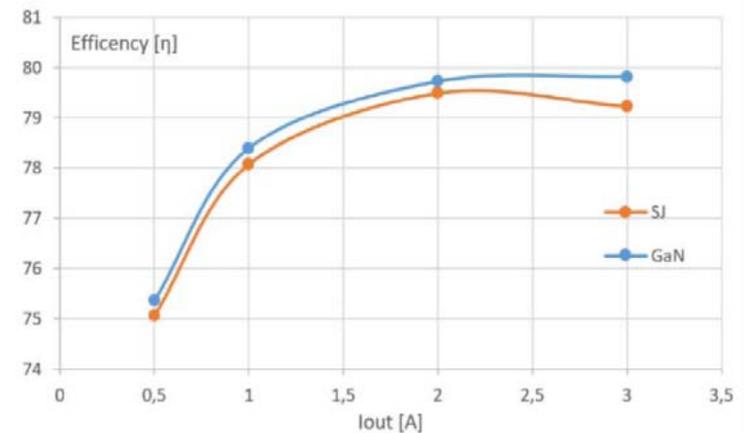
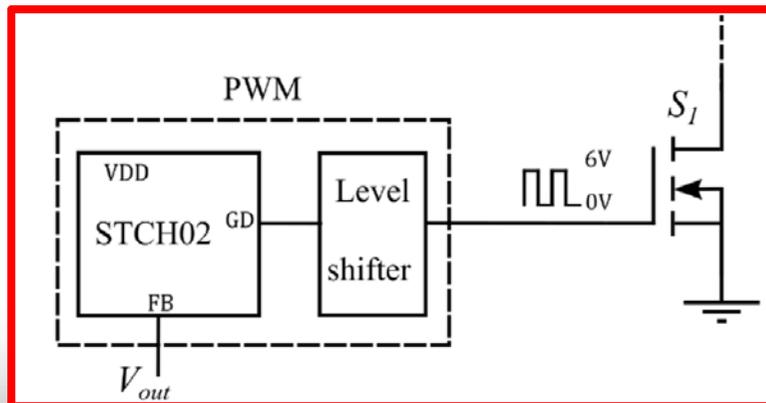
$$a V_{Rmax}^n = b (V_{DSmax} - V_{Rmax})^m$$

# GaN devices applications

- Comparison between Si and GaN devices in Quasi Resonant Flyback for Wall Charger Applications

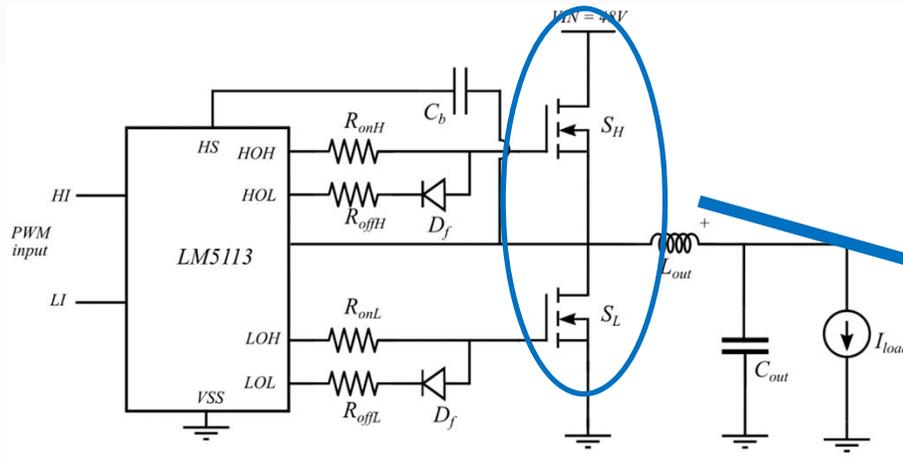


	<i>SJ</i> <i>STF8N65M5</i>	<i>GaN</i> <i>STGT120</i>
$V_{GS(max)}$	25 V	6 V
$V_{GS(th)}$	4 V	1.3 V
$BV_{DSS}$	650 V	650 V
$I_D$	7 A	15 A
$R_{DS(on)}$	0.5 $\Omega$	0.1 $\Omega$
$Q_{Gate}$	15 nC	3 nC

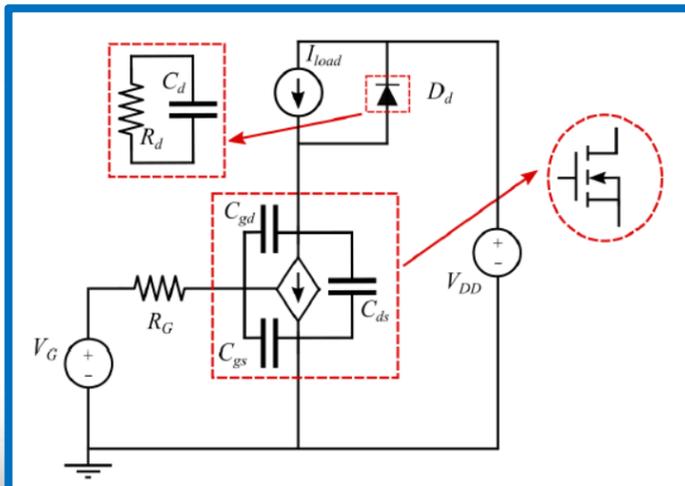


# GaN devices applications

- Efficiency of state-of-the-art GaN devices in a synchronous-rectifier buck converter



Quantity	GaN	Si
$BV_{ass}$ [V] @ 250 $\mu$ A	100	100
$V_{th}$ [V] @ 250 $\mu$ A	1.30	1.45
$R_{on\ typ}$ [m $\Omega$ ] @ $V_{gs}=6$ V @ $I_D=13.5$ A	15	15
$C_{iss}$ @ 50 V [pF]	335	2700
$C_{oss}$ @ 50 V [pF]	130	726
$C_{rss}$ @ 50 V [pF]	5	70

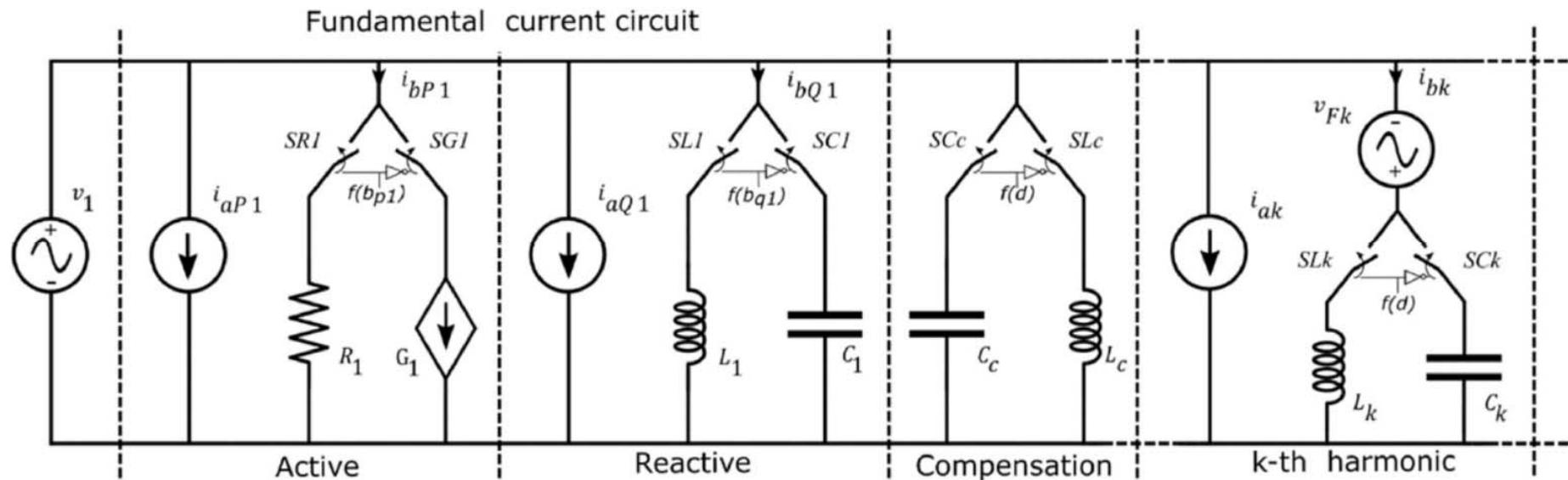


Equivalent circuit model. All the electrical components have been represented, both for turn on and turn off transient

TABLE IV. BUCK EFFICIENCY @ 600 kHz

$I_{load}$	2 A	4 A	5 A	6 A	8 A
GaN	92.8%	94.8%	95.1%	95.5%	95.7%
Si	86.0%	87.8%	88.0%	88.0%	87.6%

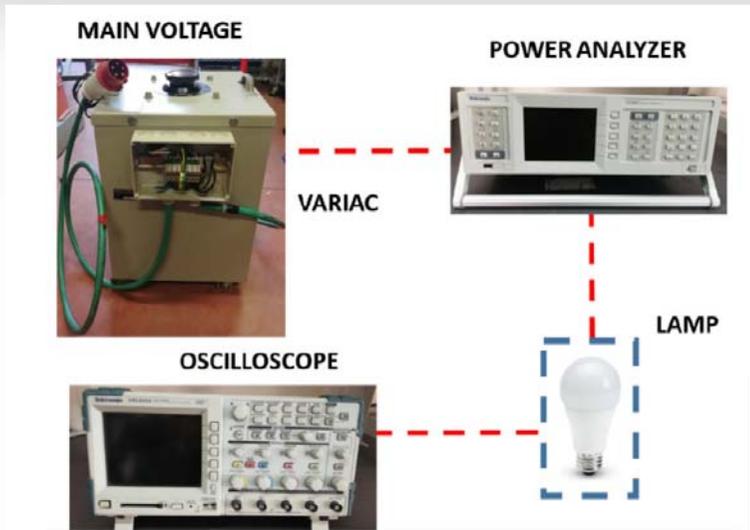
# Modeling of energy saving lamps



Proposed linear equivalent circuit of a generic ESL.

The proposed circuit model is able to foresee the overall current distortion of different lamp configurations. This feature is very useful in the optimal design of lighting systems when a key target is the mitigation of the current distortion due to the power converter inside the energy-saving lamps.

# Modeling of energy saving lamps



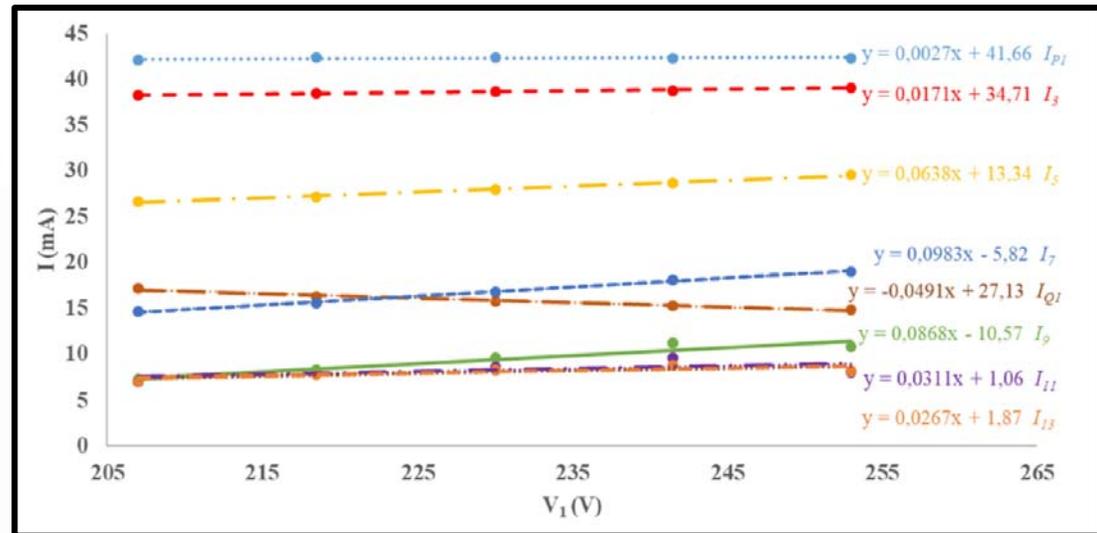
Experimental setup

$$I_{P1} \stackrel{\text{def}}{=} I_{P1}(V_1) = a_{P1} + b_{P1}V_1$$

$$I_{Q1} \stackrel{\text{def}}{=} I_{Q1}(V_1) = a_{Q1} + b_{Q1}V_1$$

$$I_k \stackrel{\text{def}}{=} I_k(V_1) = a_k + b_kV_1$$

$$k = 2, 3, \dots, K$$



A polynomial function representing each current harmonic as a function of  $V_{\text{rms}}$  can be obtained by interpolation of the measured currents amplitudes

# 1<sup>st</sup> - 2<sup>nd</sup> Year Results

# Modeling of energy saving lamps

```
.param freq      50
.param V1       212
.param d        1
.param ron      1u
.param roff     1g
.model swpos    VSWITCH (RON={ron} ROFF={roff} VON= 1 VOFF=-1)
.model swneg    VSWITCH (RON={ron} ROFF={roff} VON=-1 VOFF= 1)
.tran 0 40m 0 10u
.probe
Vsim 1 0      sin(0 {sqrt(2)*V1} {freq} 0 0 90)
Xp1 1 0 2 0   Ip1 PARAMS: freq={freq} a={ap1} b={bp1}
Xq1 1 0 3 0   Iq1 PARAMS: freq={freq} a={aq1} b={bq1}
X1 1 0 4 0    Comp PARAMS: freq={freq} lp={ls} cp={cs} d={d}
X2sim 1 0 4 0  Ik PARAMS: freq={freq} V1={V1} k={2} gammak={gamma2} ak={a2} bk={b2} d={d}
* other current harmonics
X50sim 1 0 4 0  Ik PARAMS: freq={freq} V1={V1} k={50} gammak={gamma50} ak={a50} bk={b50} d={d}
Vbp1 2 0      {sgn(bp1)}
Vbq1 3 0      {sgn(bq1)}
Vd 4 0        {d}
```

. Netlist of the overall lamp circuit.

Pspice Model

# 1<sup>st</sup> - 2<sup>nd</sup> Year Results

# Modeling of energy saving lamps

```
.param freq      50
.param V1       212
.param d        1
.param ron      1u
.param roff     1g
.model swpos    VSWITCH (RON={ron} ROFF={roff} VON= 1 VOFF=-1)
.model swneg    VSWITCH (RON={ron} ROFF={roff} VON=-1 VOFF= 1)
.tran 0 40m 0 10u
.probe
Vsim 1 0        sin(0 {sqrt(2)*V1} {freq} 0 0 90)
Xp1  1 0 2 0    Ip1 PARAMS: freq={freq} a={ap1} b={bp1}
Xq1  1 0 3 0    Iq1 PARAMS: freq={freq} a={aq1} b={bq1}
X1   1 0 4 0    Comp PARAMS: freq={freq} lp={ls} cp={cs} d={d}
X2sim 1 0 4 0   Ik PARAMS: freq={freq} V1={V1} k={2} gammak={gamma2} ak={a2} bk={b2} d={d}
* other current harmonics
X50sim 1 0 4 0  Ik PARAMS: freq={freq} V1={V1} k={50} gammak={gamma50} ak={a50} bk={b50} d={d}
Vbp1 2 0        {sgn(bp1)}
Vbq1 3 0        {sgn(bq1)}
Vd   4 0        {d}
```

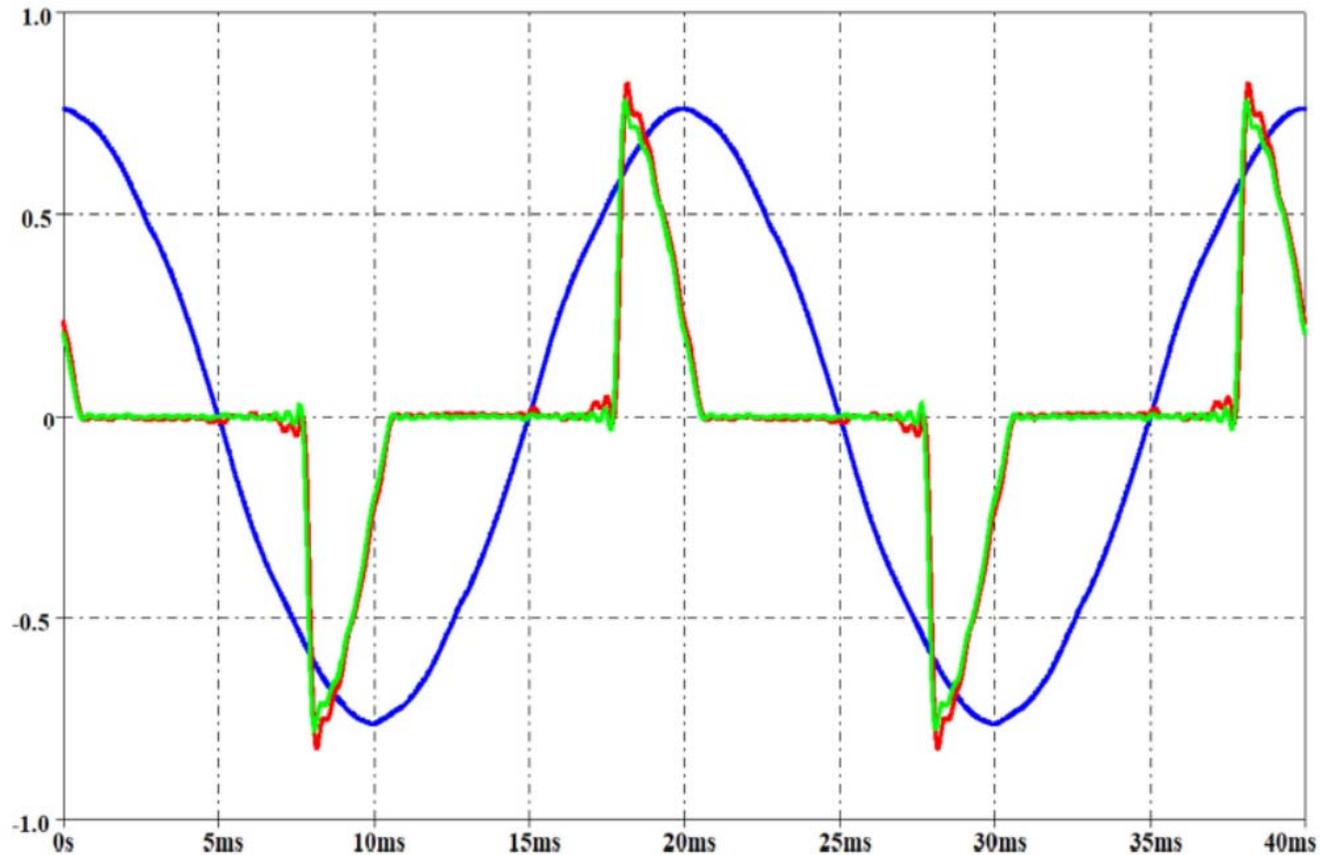
. Netlist of the overall lamp circuit.

## Pspice Model

```
.SUBCKT Ip1 1 2 3 4 PARAMS: freq=50 a=0 b=0
Iap1 1 2        sin(0 {sqrt(2)*a} {freq} 0 0 {0+90})
SR1  1 5 3 4    swpos
ER1  5 6 1 5    {-(sgn(b)+1)/2}
VR0  6 7        0
FR1  1 7        VR0 {-(sgn(b)+1)/2}
R1   7 2        {1/abs(b)}
SG1  1 8 3 4    swneg
G1   8 2 1 2    {b*(-sgn(b)+1)/2}
.ENDS
```

Netlist of the active current circuit.

# Modeling of energy saving lamps



Measured voltage on the mains (blue waveform, rms 212 V), measured current (green waveform) and simulated current (red waveform) for a LED. Per-unit system: base voltage 400 V, base current 250 mA

# International conference



## European PhD School

Power Electronics, Electrical Machines  
Energy Control and Power Systems

1. 21-25 May 2018
  2. 20-24 May 2019
- Gaeta, Italy

Industrial/Ph.D. Course in  
Design of Modern Power  
Semiconductor Components  
30 Oct - 2 Nov 2019

The  
Center of Reliable Power Electronics



[www.corpe.et.aau.dk](http://www.corpe.et.aau.dk)



DEPARTMENT OF ENERGY TECHNOLOGY



20-22 June, Amalfi  
Coast – 2 paper

20-23 October,  
Washington DC – 2 paper



2-5 October,  
Bari – 2 paper

2-4 July,  
Torino - 2 paper



29 September -3 October  
Baltimore (USA) – 1 paper



# Publications

1. S. Di Mauro, A. Raciti, S. A. Rizzo and **G. Susinni**, "LED lamp PSpice circuit emulating first harmonic current absorption as a function of the main voltage," *2018 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*, Amalfi, Italy, 2018, pp. 1101-1106.
2. A. Raciti, S. A. Rizzo, N. Salerno, **G. Susinni**, R. Scollo and A. Scuto, "Modeling the Hysteresis Power Losses of the Output Parasitic Capacitance in Super Junction MOSFETs," *2018 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*, Amalfi, Italy, 2018, pp. 527-532.
3. A. Raciti, S. A. Rizzo and **G. Susinni**, "Drone charging stations over the buildings based on a wireless power transfer system," *2018 IEEE/IAS 54th Industrial and Commercial Power Systems Technical Conference (I&CPS)*, Niagara Falls, ON, 2018, pp. 1-6.
4. S. Conti, S. Di Mauro, A. Raciti, S.A. Rizzo, **G. Susinni**, S. Musumeci, A. Tenconi, "Solar electric vehicles: state-of-the-art and perspectives," AEIT International Annual Conference, Bari, Oct. 3-5, 2018.
5. A. Raciti, S.A. Rizzo, **G. Susinni**, "Steady-state electrical modeling of LED and CF bulb lamps under variable voltage on the main," IEEE IEEEIC - I&CPS Europe, Palermo, June. 12-15, 2018.
6. A. Raciti, S.A. Rizzo, N. Salerno **G. Susinni**, C. Buccella, C. Cecati, M.Tinari, "State of the art and emerging solid-state power devices in the perspective of more electric aircraft" AEIT International Annual Conference, Bari, Oct. 3-5, 2018.
7. A. Dannier, G. Brando, I. Spina, A. Raciti, S.A. Rizzo, **G. Susinni**, "State of the art and emerging solid-state power devices in the perspective of more electric aircraft" AEIT International Annual Conference, Bari, Oct. 3-5, 2018.
8. S. Di Mauro, A. Raciti, S.A. Rizzo, **G. Susinni**, S. Musumeci, "Steady-state equivalent circuit of LED lamps accounting for the current harmonics," 44th Annual Conference of the IEEE Industrial Electronics Society (IECON) , Washington DC, Oct. 21-23, 2018.
9. A. Raciti, S.A. Rizzo, N. Salerno, **G. Susinni**, R. Scollo, A. Scuto, S. Musumeci, "Modeling of the Power Losses due to Coss in SJ MOSFETs Submitted to ZVS: Identification of the Passive Parameters by a Genetic Algorithm," 44th Annual Conference of the IEEE Industrial Electronics Society (IECON) , Washington DC, Oct. 21-23, 2018.
10. **G. Susinni et al.**, "Improvement of SiC power module layout to mitigate the gate-source overvoltage during switching operation," *2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE)*, Torino, Italy, 2019, pp. 1-6.
11. G. Mauromicale, A. Raciti, S. A. Rizzo, **G. Susinni**, G. Parise and L. Parise, "E-mobility: Safety, Service Continuity and Penetration of Charging Systems," *2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE)*, Torino, Italy, 2019,
12. A. Raciti; S. A. Rizzo, **G. Susinni**, "Parametric PSpice Circuit of Energy Saving Lamp Emulating Current Waveform«, *Applied Science* 2019, 9, 152.





UNIVERSITÀ  
degli STUDI  
di CATANIA



# Thank you for your attention

**Ph.D. Brainstorming Day**  
**Catania, 29/10/2019**

**Student:** Giovanni Susinni  
**Tutor:** Prof. Angelo Raciti  
**A.Y. 2018/2019**