Optimization of a 27 MHz Wireless Power Transmitter for an Unknown Receiver

Ghulam Murtaza[(1)], Mazen Shanawani[(1)],
Diego Masotti[(1)], and Alessandra Costanzo[(1)]

(1) Dept. of Electrical, Electronic and Information Engineering "Guglielmo Marconi",
University of Bologna, Italy

Contents of the Presentation

- **Abstract**

ABSTRACT

- Near field Wireless power transfer (WPT) at 27MHz to an unknown receiver.

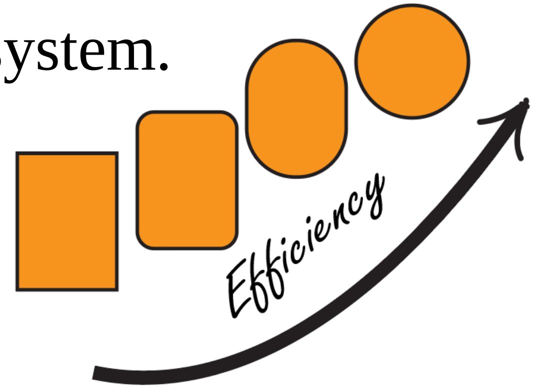
- Class E amplifier as a constant current source
- Optimization and efficiency considerations

- Description of different aspects for the realization of the project

- **Introduction**

Introduction

- **Efficiency** is the primary goal in any WPT system.



- **Switching inverters** have higher efficiencies as compared to Class A , B etc power amplifiers.

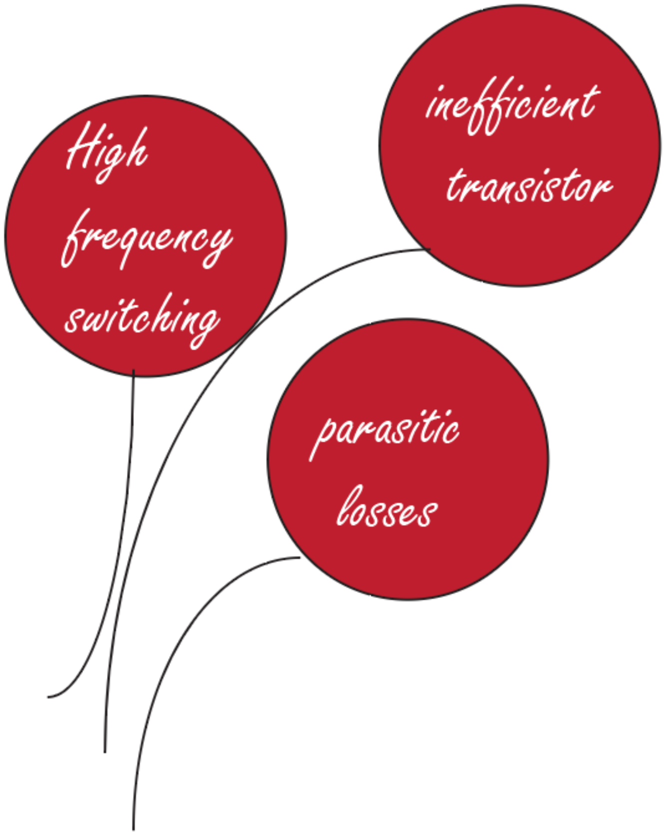
BUT

- Even in the switching inverters there are different aspects to be taken into consideration for better performance of the inverter in terms of efficiency.

Efficiency loss in inverters

Three main reasons of inefficiency:

- At **high frequencies**, the switching losses increase considerably
- **Choice of the switch** also become critical at higher switching frequencies
- **Parasitic losses** contributed by the **lumped elements**



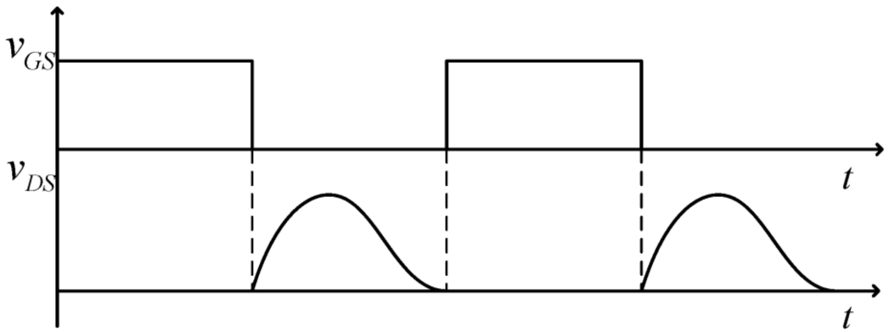
Improvement in Efficiency

Efficiency can be improved by:

- **Soft-switching technique**
- **Using efficient switches**
- **Careful design and selection of coils and lumped elements**

Soft-Switching

- Soft-switching improves efficiency because, at a given instant, the product of the current flowing through the switch and the voltage across it should be zero (or as low as possible), i.e., the power loss in the switch is very small.



Xiao, W.; Shen, R.; Zhang, B.; Qiu, D.; Chen, Y.; Li, T. Effects of Foreign Metal Object on Soft-Switching Conditions of Class-E Inverter in WPT. *Energies* **2018**, *11*, 1926

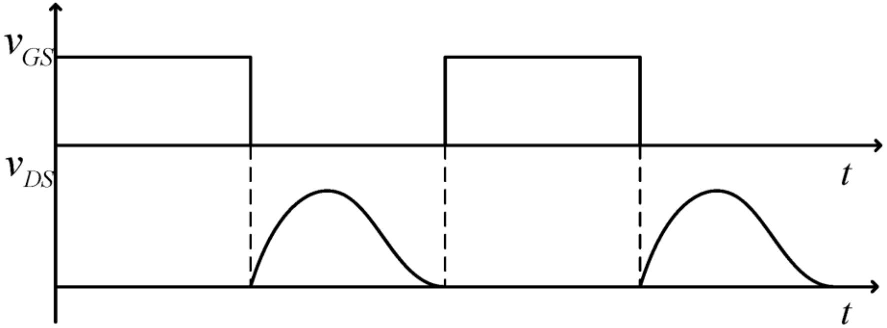
Soft-Switching

- Soft-switching is achieved by ensuring zero voltage switching (ZVS) and Zero Derivative Switching (ZDS)

- Mathematically, it means:

$$\textbf{ZVS}: \quad V_{DS}(\omega t) = 0$$

$$\textbf{ZDS}: \quad \frac{dV_{DS}(\omega t)}{d(\omega t)} = 0$$



Choice of the Switch

- At higher frequencies the choice of the switch is crucial.
- We have adopted the GaN technology for the switching device because of its better performance at higher frequency [7]

Parasitic losses

- Parasitic losses can contribute to the power loss

- A careful selection of the lumped elements is important

- Design of the transmitter coil is also important.

  - A good selection of width, length and the thickness of the coil can reduce its parasitic resistance, hence the losses

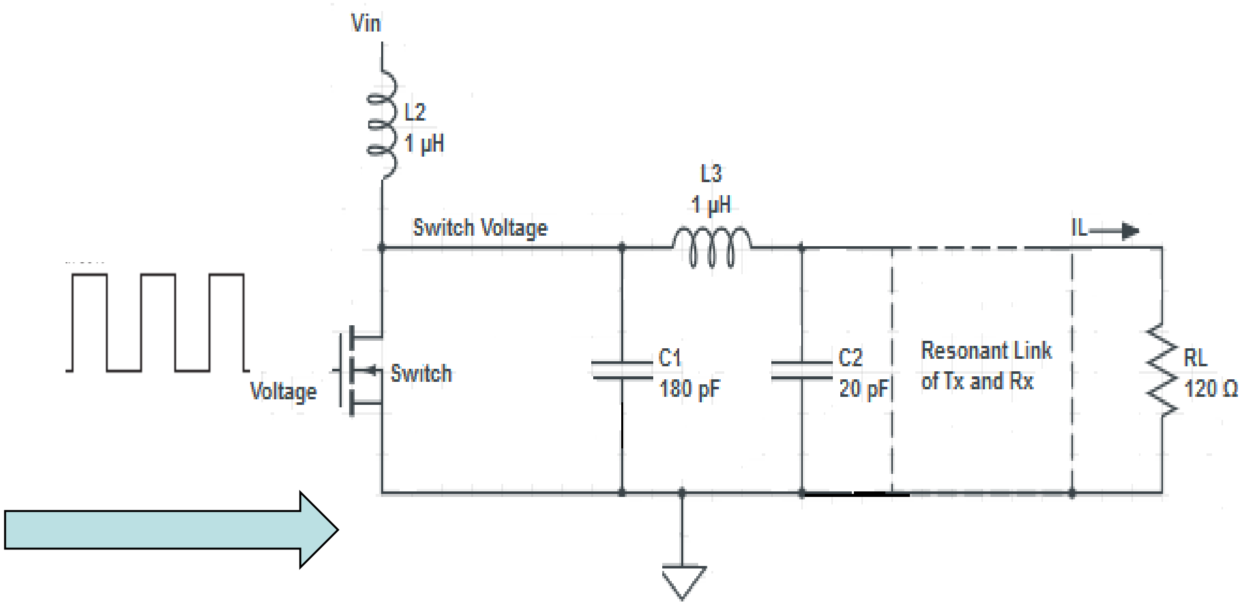
- **Problem Description**

Goals

- Design an amplifier for near field WPT such that
  - 25W power is available at the transmitting coil
  - Load independent operation
  - Working at 27MHz

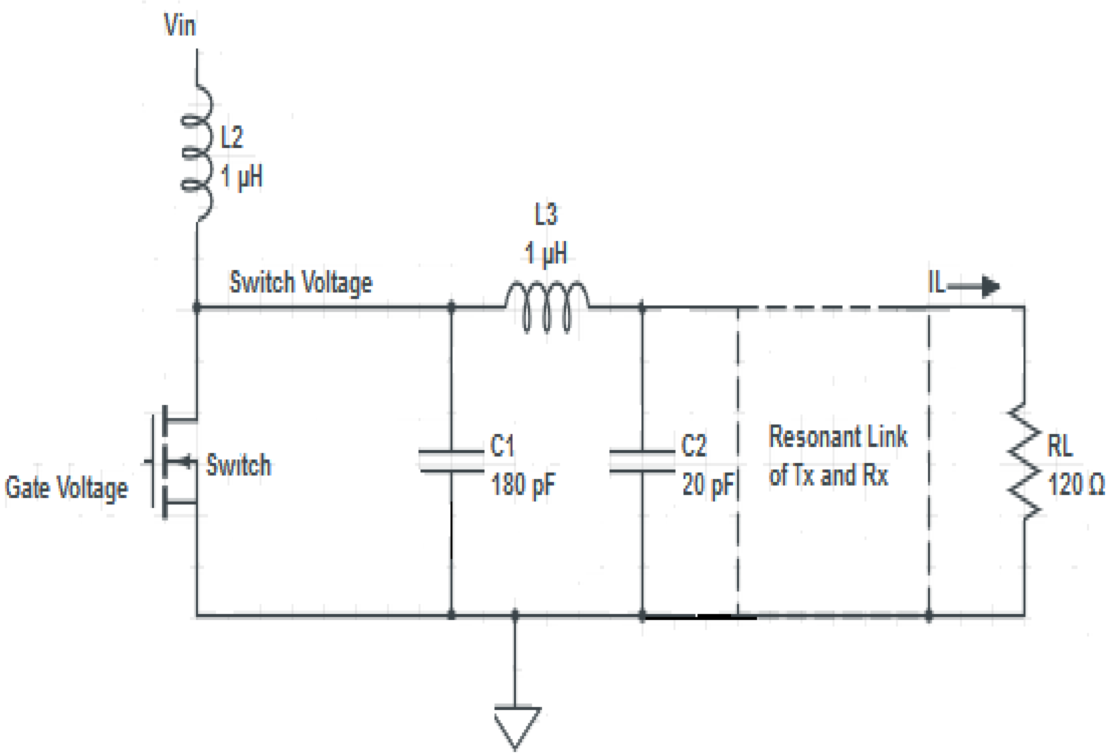
Design of the inverter

- Class E inverter has been adopted for its load independent function
- schematic of class E inverter adopted to provide 25W at the transmitting coil at 27MHz



Design of the inverter (circuit description)

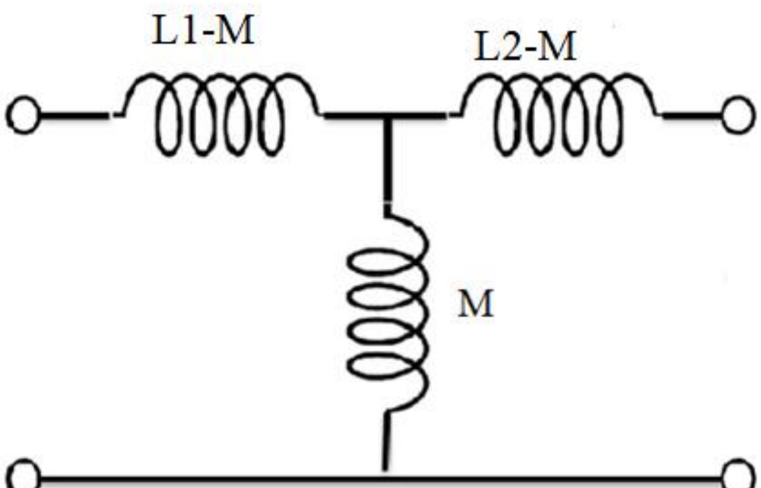
- L2 is a choke, used to provide the constant current and stop any ripples going to the voltage source (DC)
- C1, C2 and L3 form the matching network
- The inverter is loaded by the resonant link of Tx coil and unknown Rx coil (connected to a generic receiver =120Ω)



- **Optimization**

Optimization of the inverter

- To initially represent the inductive link between transmitter and receiver a T network was used.
- L_1 = 1uH represents the inductance of the transmitting coil. L_2 is the inductance of the receiving coil, considered equal to 500 nH.
- M =70 nH is the mutual inductance, evaluated in order to have a 0.1 coupling coefficient (k)

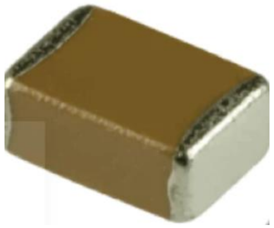


$$M = k\sqrt{L_1 L_2}$$

Component values and operating conditions

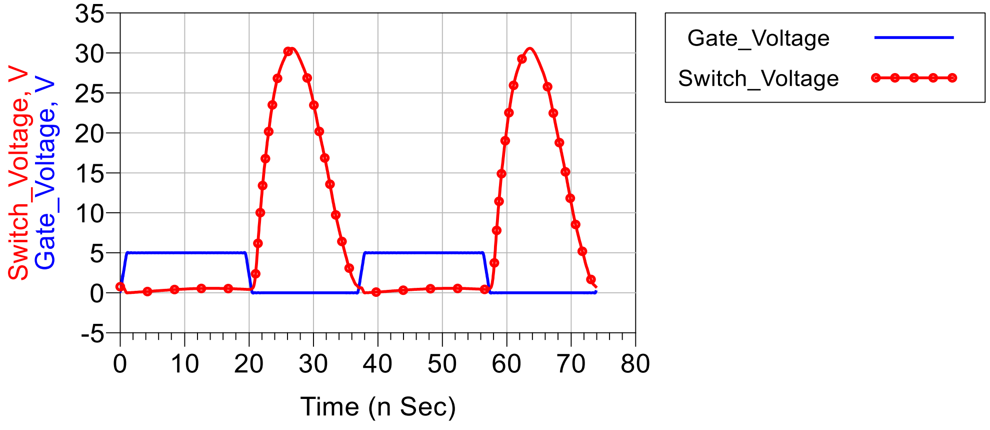
- Optimized Values of the lumped elements are :

  L1=1 uH , C1=180 pF, C2 =20 pF, L3=10 nH
- A square pulse of 27MHz (0V to 5V) and 50% duty cycle is applied at the gate terminal.
- 8.5V dc is chosen as drain biasing voltage
- GaN (GS66508b) is used as a switch

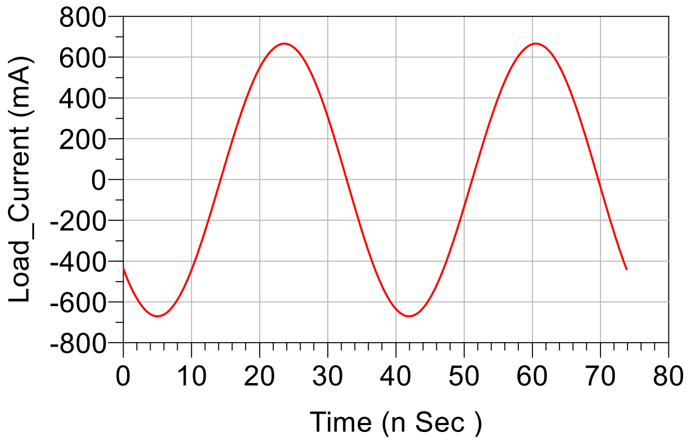


Plots after Optimization of the circuit

- Switch voltage is satisfying the ZVS condition.



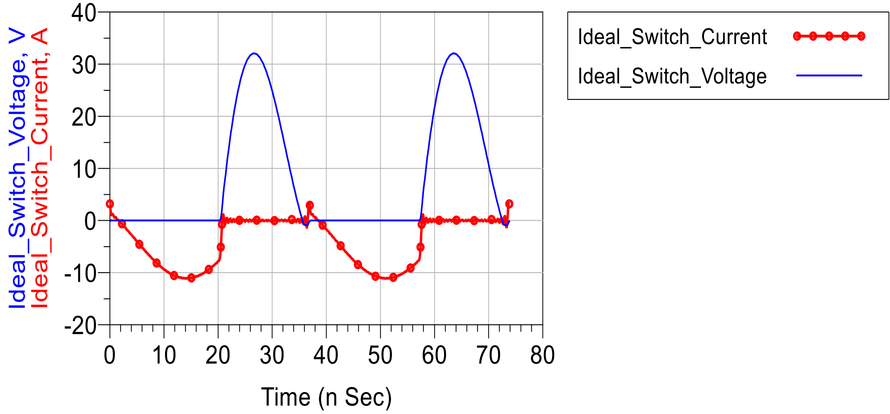
- The pure sinusoidal output current waveform indicates perfect suppression of the higher harmonics



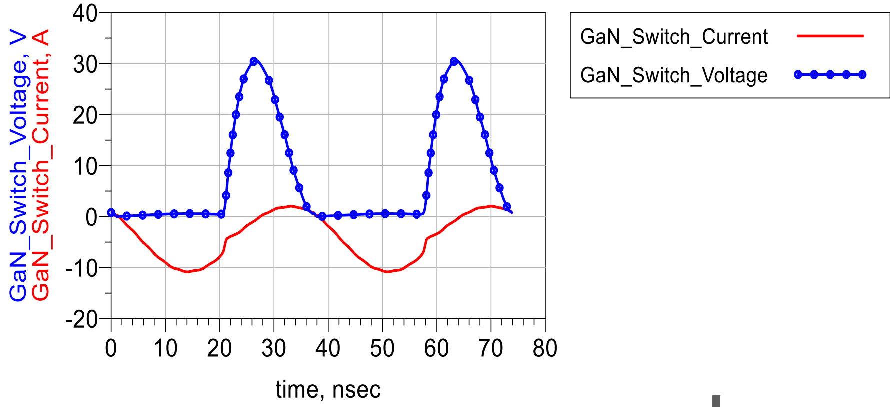
Switching Losses

Comparison between an ideal switch and the GaN device:

- **Ideal switch**: the losses are minima. The efficiency in this ideal case is 90%

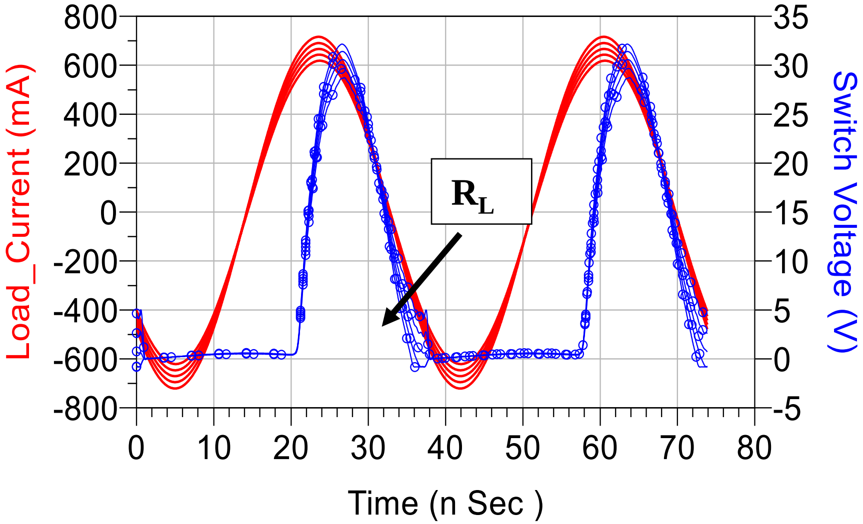


- **Real GaN device**: there are some losses present which reduce the efficiency to 78%



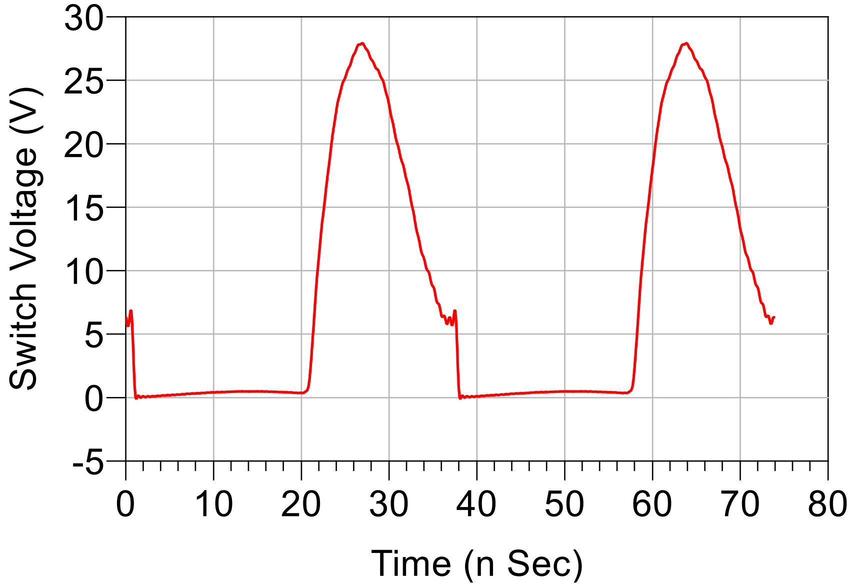
Variation of load

- R_L has been varied from 100Ω to 140Ω
- There is a small degradation in the switch voltage which changes the efficiency from 80% to 75%



Losses in the transmission coil

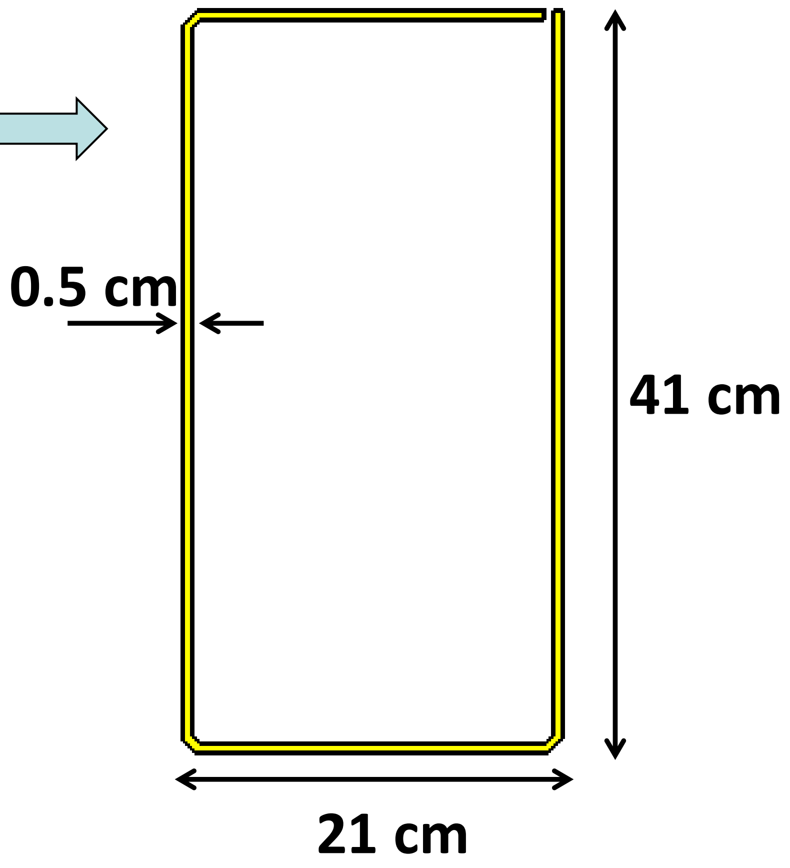
- In the previous evaluation the transmission coil was considered ideal (R_{par}=0).
- The full wave EM simulation of the transmitting coil provides **R_{par}= 0.36 *Ω***: the corresponding switch voltage behavior is worsened
- Efficiency reduces to 62%



- **Realization of the Link**

Choice of the Tx coil

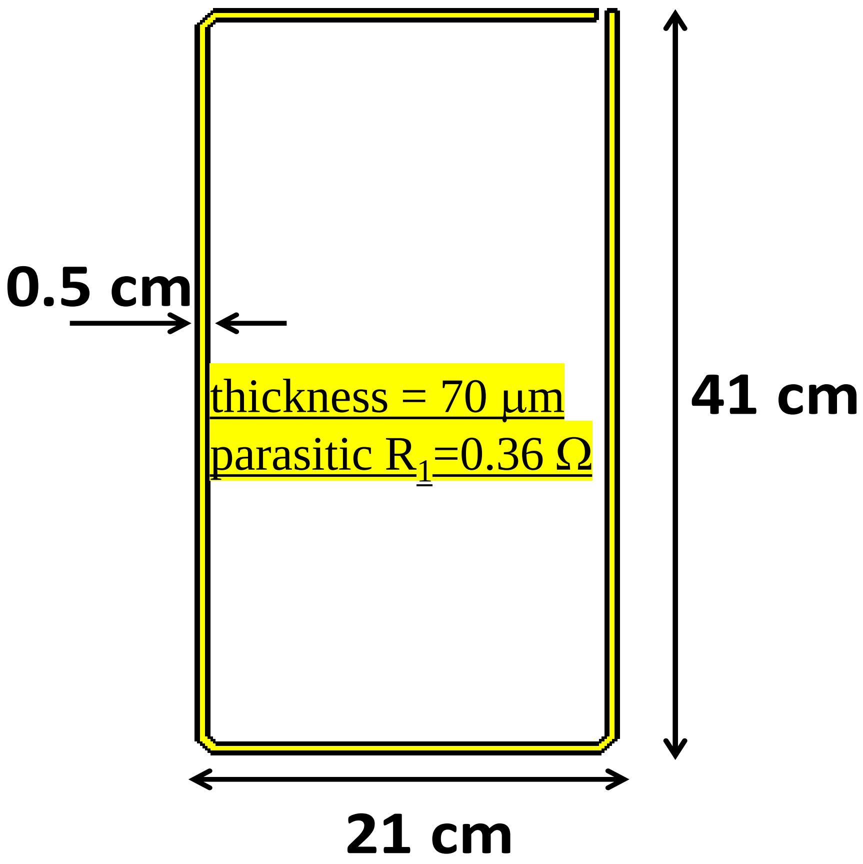
- **Single turn coil** (L1=0.96 uH) is selected
- 2-turn coil is not used because:
  - ☺ would result in higher magnetic flux
  - ☹ would also result in the higher parasitic resistance.
  - ☹ Self resonance phenomenon is to be taken under control



Choice of the coil

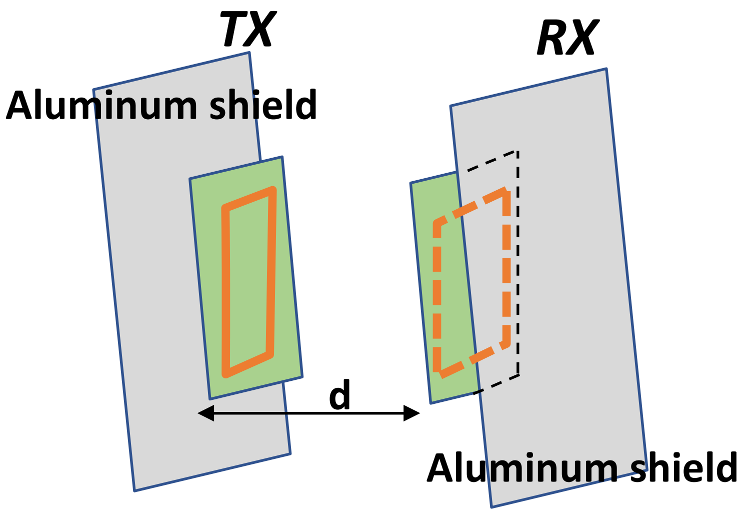
For the **single coil**:

- Area of the coil cannot be reduced greatly as that would reduce the magnetic flux.
- Increasing the thickness of copper would reduce the parasitic losses but that would also increase the cost
- Trade off is needed.



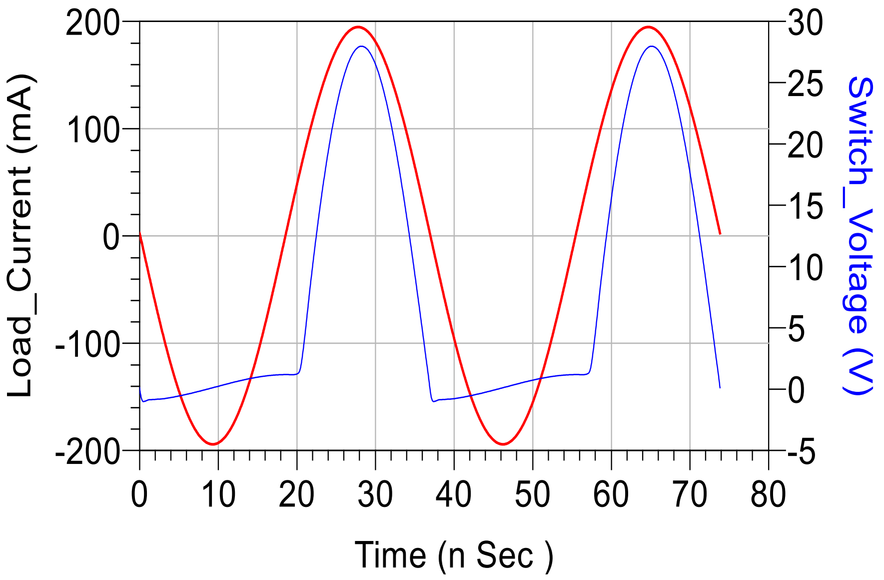
Integrated design of the inverter and the wireless link

- An EM-based link has been established between Tx and Rx and include in the circuit simulation.
- Both transmitter and receiver are shielded by aluminum plates.
- Distance d is 22 cm



Final results with the realistic Link

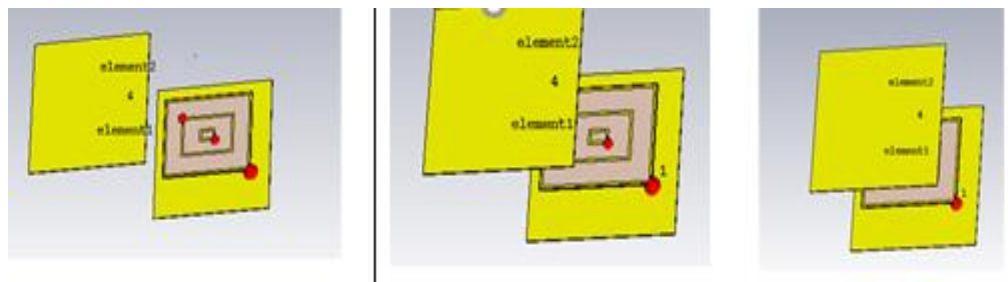
- The current waveform is still a pure sinusoid
- There is a small degradation in the switch voltage because of the change in the loading conditions
- The power delivered to the load (R_L=120Ω) is 2W
- The inverter efficiency is now 60%



- **Conclusion**

Summary

- A detailed study of the 27MHz WPT system is done
- Load independent condition led to the choice of Class E inverter
- GaN device is used for its lower losses at high frequency
- This study will be further extended to the case of unknown **moving receiver**, in a SWIPT application



References

- 1. C. Florian, F. Mastri, R. P. Paganelli, D. Masotti and A. Costanzo, "Theoretical and Numerical Design of a Wireless Power Transmission Link With GaN-Based Transmitter and Adaptive Receiver," in *IEEE Transactions on Microwave Theory and Techniques*, **62**, 4, April 2014, pp. 931-946, doi: 10.1109/TMTT.2014.2303949
- 2. T. Nagashima, X. Wei and H. Sekiya, "Analytical design procedure for resonant inductively coupled wireless power transfer system with class-DE inverter and class-E rectifier," *2014 IEEE Asia Pacific Conference on Circuits and Systems (APCCAS)*, 2014, pp. 288-291, doi: 10.1109/APCCAS.2014.7032776
- 3. D. C. Marian K. Kazimierczuk, Resonant Power Converters, 2nd Edition, Wiley, 2011
- 4. R. S. Pengelly, S. M. Wood, J. W. Milligan, S. T. Sheppard and W. L. Pribble, "A Review of GaN on SiC High Electron-Mobility Power Transistors and MMICs," in *IEEE Transactions on Microwave Theory and Techniques*, **60**, 6, June 2012, pp. 1764-1783, doi: 10.1109/TMTT.2012.2187535

References

- 5. A. Pacini, F. Berra, D. Masotti and A. Costanzo, "Uniform sliding system for Simultaneous WPT and Communication Data Transfer," *2019 IEEE Radio and Wireless Symposium (RWS)*, 2019, pp. 1-3, doi: 10.1109/RWS.2019.8714337
- 6. A. Pacini, F. Mastri, R. Trevisan, D. Masotti and A. Costanzo, "Geometry optimization of sliding inductive links for position-independent wireless power transfer," 2016 IEEE MTT-S International Microwave Symposium (IMS), 2016, pp. 1-4, doi: 10.1109/MWSYM.2016.7540073
- 7. S. Aldhaher, P. D. Mitcheson and D. C. Yates, "Load-independent Class EF inverters for inductive wireless power transfer," *2016 IEEE Wireless Power Transfer Conference (WPTC)*, 2016, pp. 1-4, doi: 10.1109/WPT.2016.7498864
- 8. S. Aldhaher, D. C. Yates and P. D. Mitcheson, "Load-Independent Class E/EF Inverters and Rectifiers for MHz-Switching Applications," in *IEEE Transactions on Power Electronics*, **33**, 10, Oct. 2018, pp. 8270-8287, doi: 10.1109/TPEL.2018.2813760