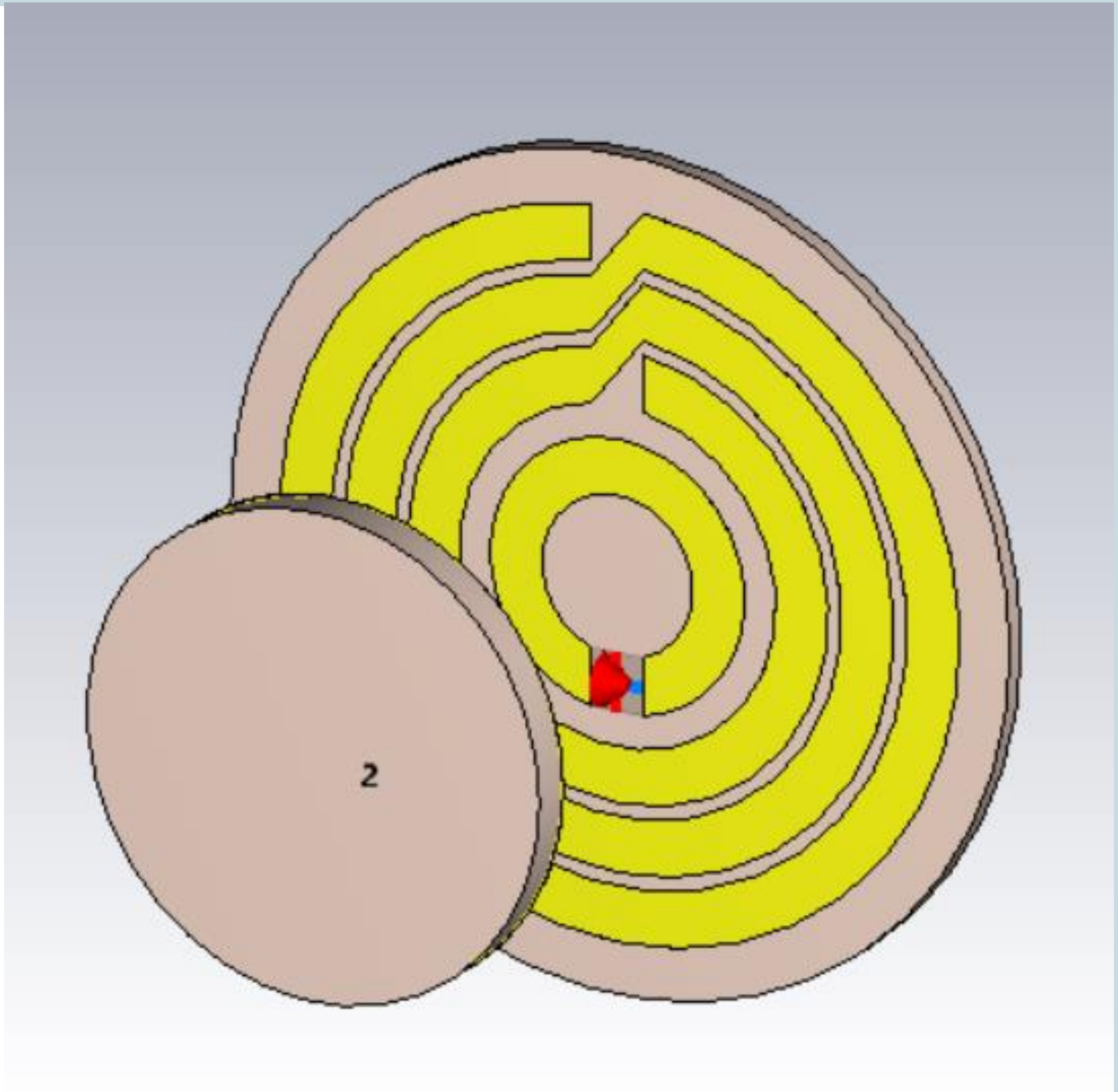
WPT system for medical implanted devices



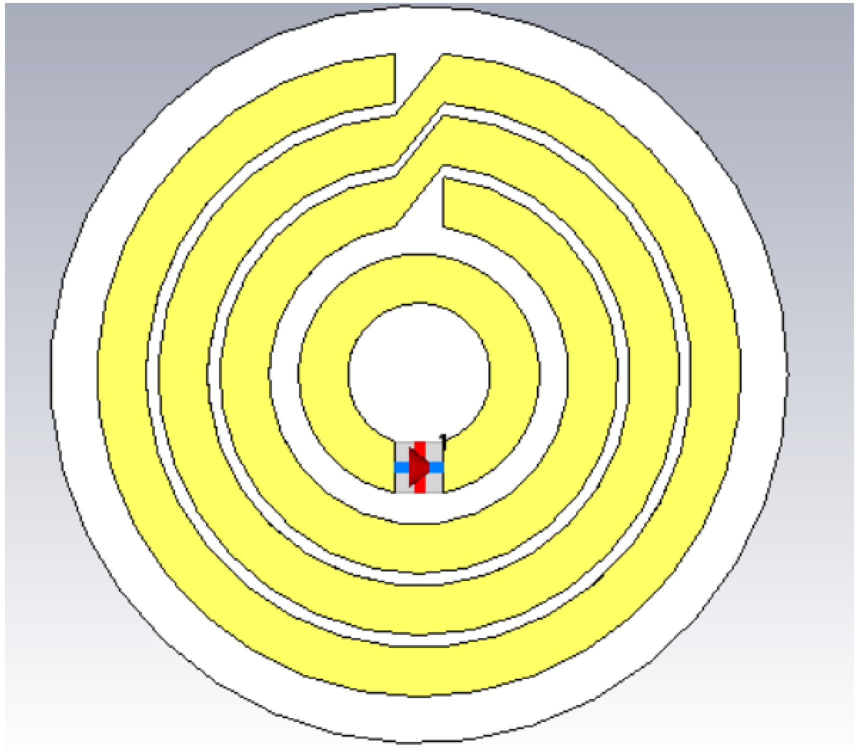
KHALED MOJAHED

AHMAD SAMIR

KAREEM WALID

AGENDA

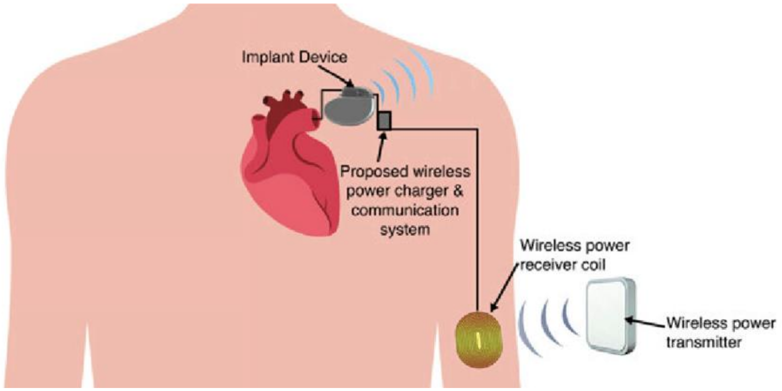
- intro
- survey
- Tx and Rx design
- Rectifier design



INTRODUCTION AND PROBLEM DEFINITION

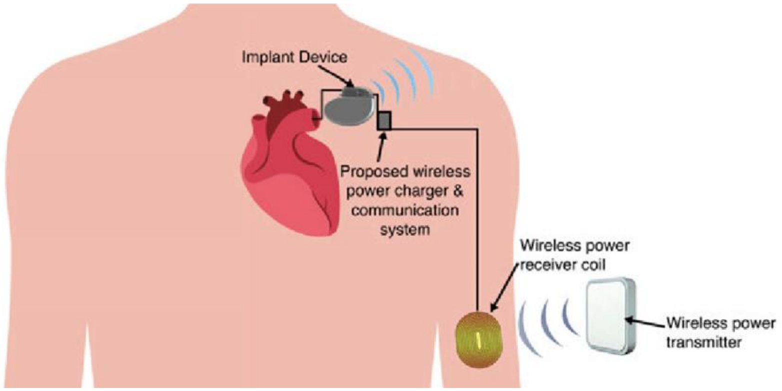
What is a WPT System and why it's needed

WHAT IS THE PROBLEM?



- Many patients require for their treatment to implant some battery-powered electronic medical devices, such devices when the battery in discharged required medicals surgery to replace the battery, and that solution was inconvenient.
- A development in the wireless charging technology will enable the engineers to use a chargeable battery and relay on the wireless charging to avoid any unnecessary surgeries.
- Our project is to develop such system to achieve the maximum power transfer efficiency possible with the smallest dimensions of a Rx and Tx, taking in consideration the SAR limits be under the recommended values

WIRELESS POWER TRANSFER (WPT)



- The WPT system is considered of three main parts: 1- a transmitter 2- a receiver 3- and a rectifier.
- For our application in implanted biomedical devices the receiver and the rectifier will be implanted in the human body, so their dimensions is a top consideration.
- As for the transmitter it can be bigger in size if it help increasing the efficiency.

SURVEY

this survey focus will be with Resonant Inductive Coupling WPT.

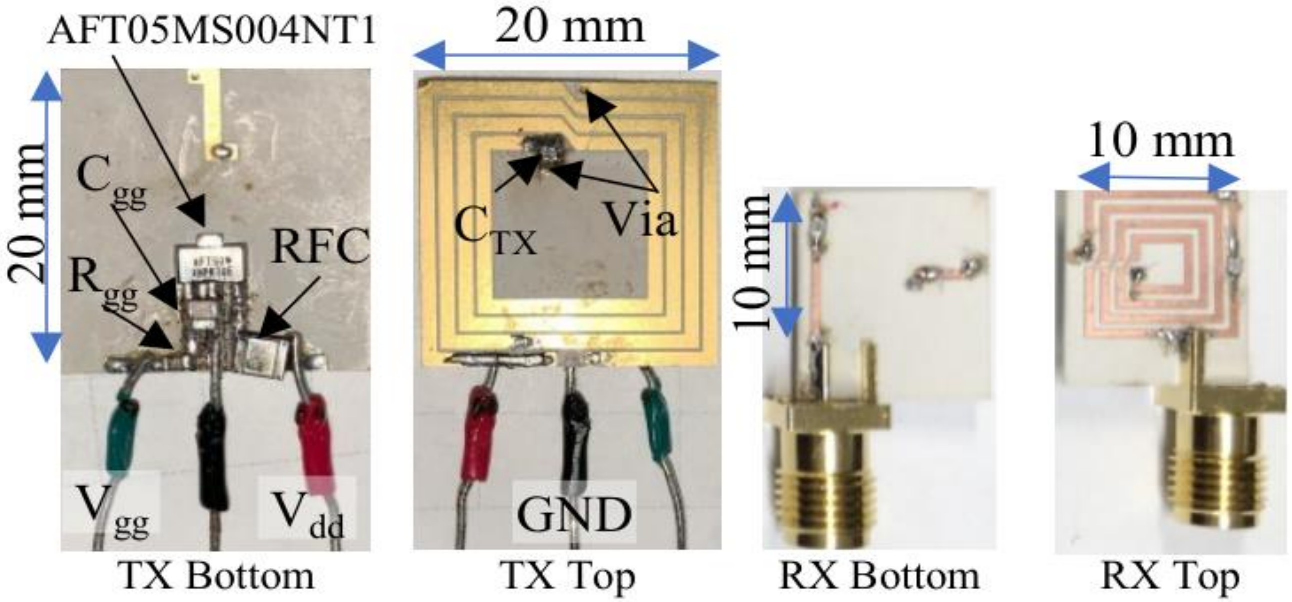


Figure 1: Tx & Rx implementation in [1]

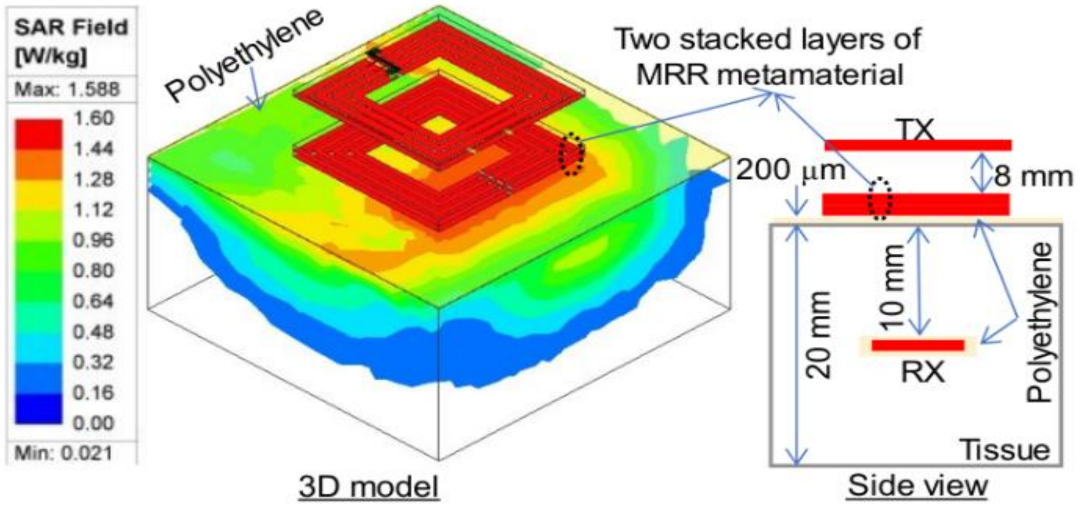


Figure 2: 3D model of [1]

THE FIRST DESIGN

In [1] WPT system with metamaterial operates at 50.3MHz for medical apps with efficiency of 42% at Transfer distance 18 mm

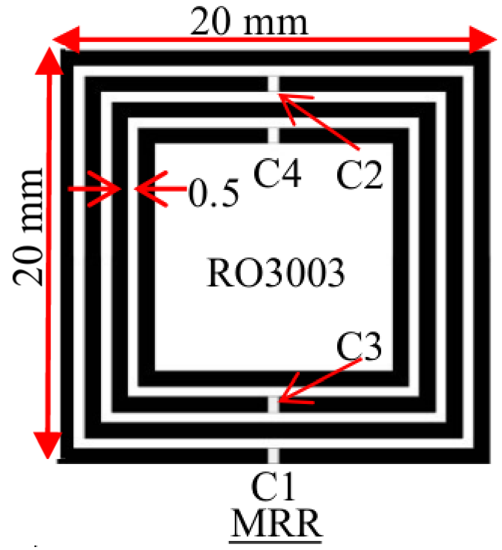
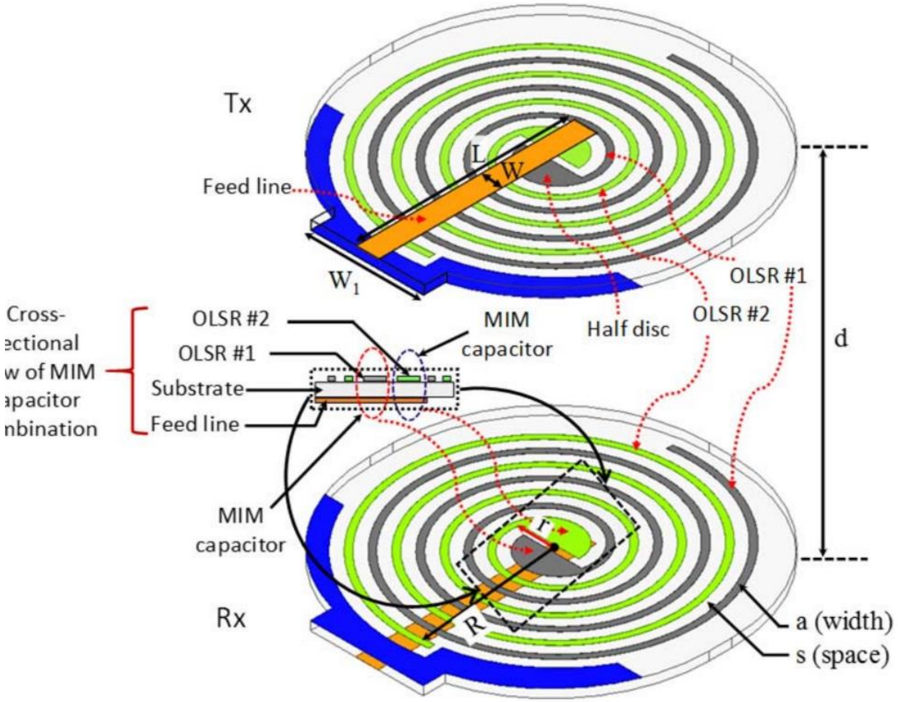


Figure 3 MMR metamaterial dimensions of [1]

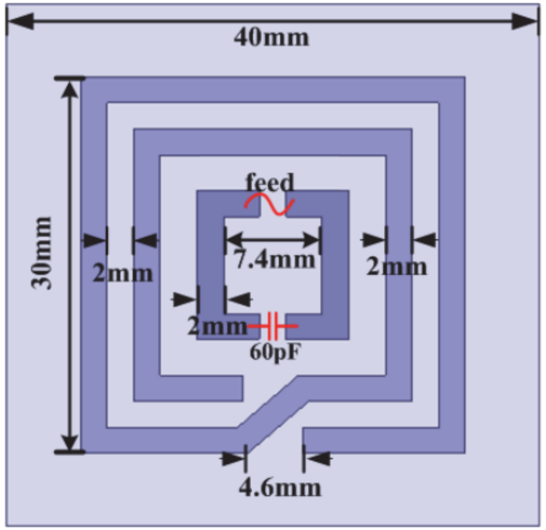
THE SECOND DESIGN

In [2] WPT system operates at 438.5 MHz with a measured power transfer efficiency (PTE) of 70.8% at a transmission distance of 31 mm and a design area of 576 mm^2.

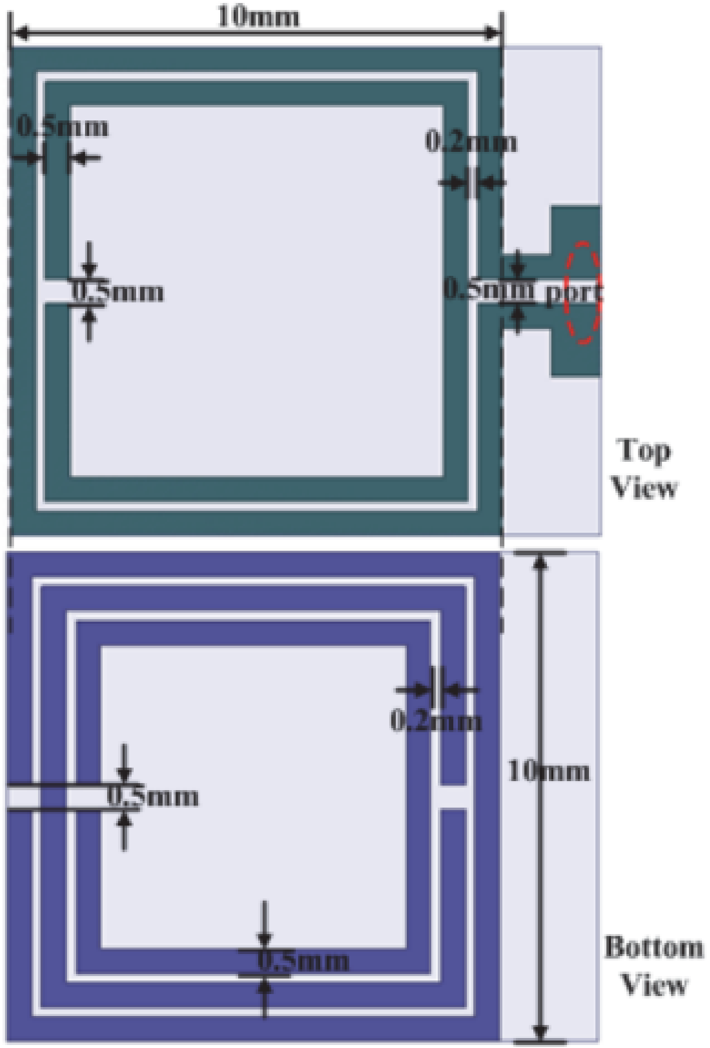


THE THIRD DESIGN

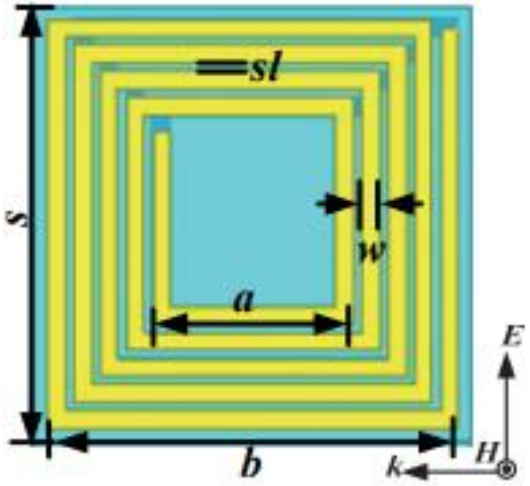
In [3] WPT system operates at 430MHZ for medical apps with S21=-27.9dB at Transfer distance =6cm



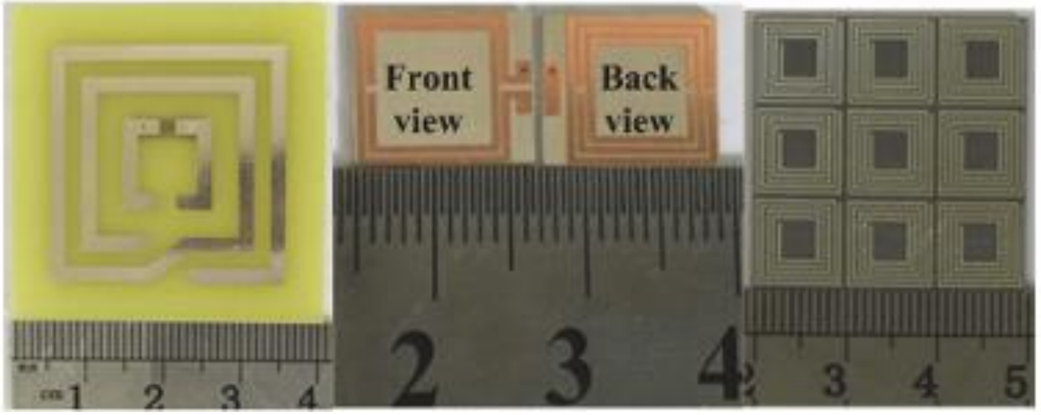
Geometry of the transmitting coil (Tx). The Tx element has the dimensions of 40mm x 40mm x1.6mm



Top and bottom views of the receiving coil (Rx). The Rx element has the dimensions of 10 mm x 12 mm x 1.27 mm



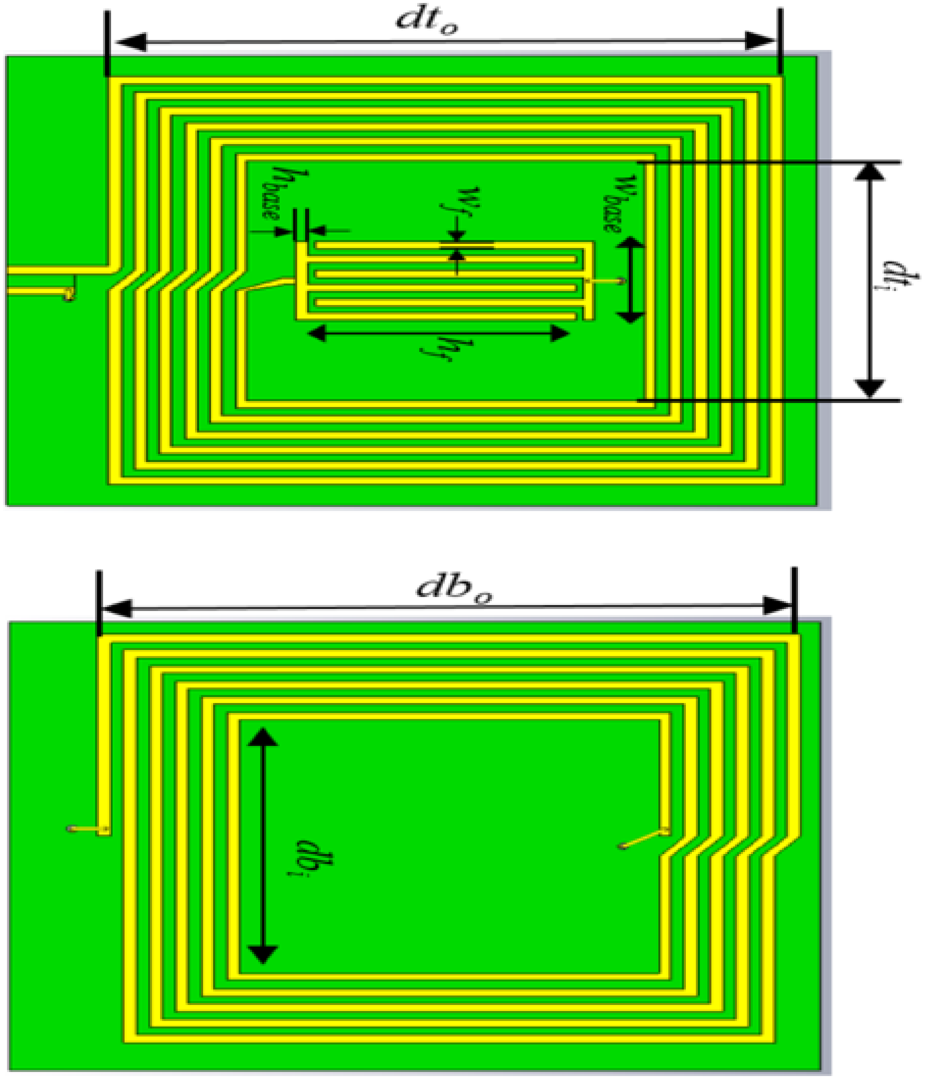
Geometry of double-side five-turn spiral MNG unit cell.
unit cell size= 10 mm x 10 mm x 1mm
The final metasurface dimension is 30 mm x 30 mm by arraying 3x3 unit



Fabricated Rx element, Tx element and metasurface

THE FOURTH DESIGN

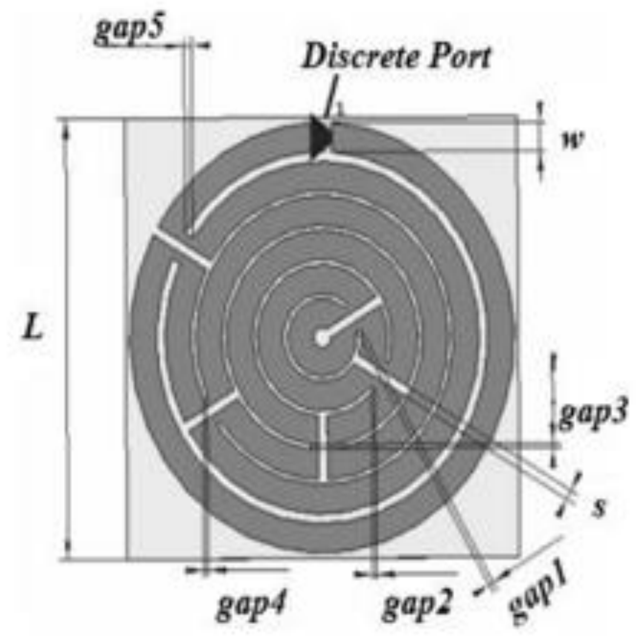
In [4] WPT system operates at 13.56 MHz
The maximum measured power transfer efficiency is 71.84% a distance of 25 mm

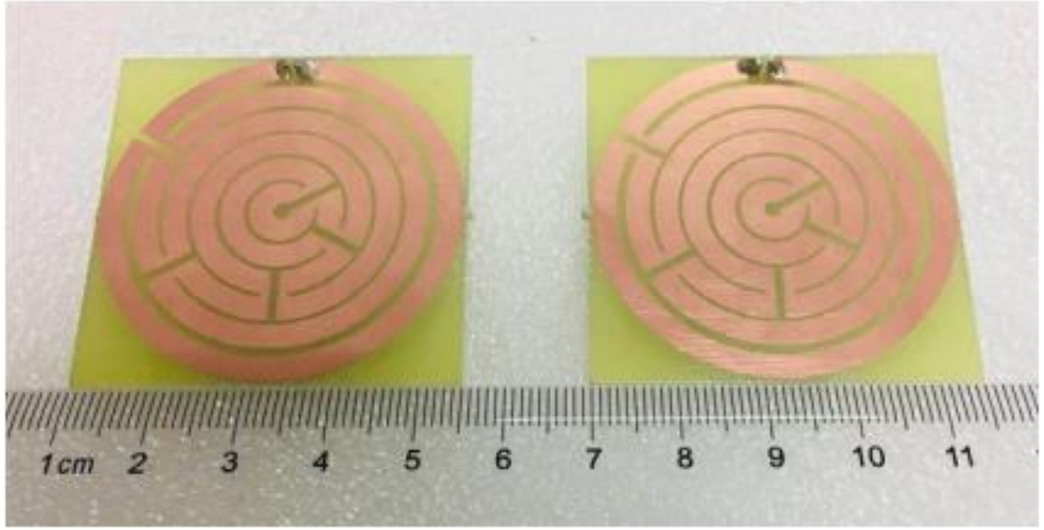


the dimensions of the system is (15 mm x 15 mm x 2 mm) and (10 mm x 10 mm x 2 mm)

THE FIFTH DESIGN

In [5] WPT system operates at 433 MHz, the maximum measured power transfer efficiency is 87.9% at a transfer distance of 22 mm.

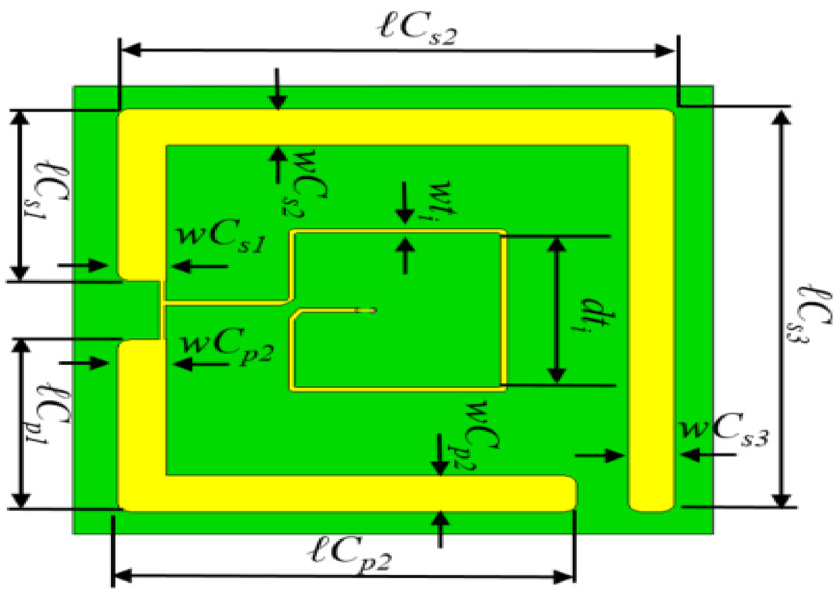


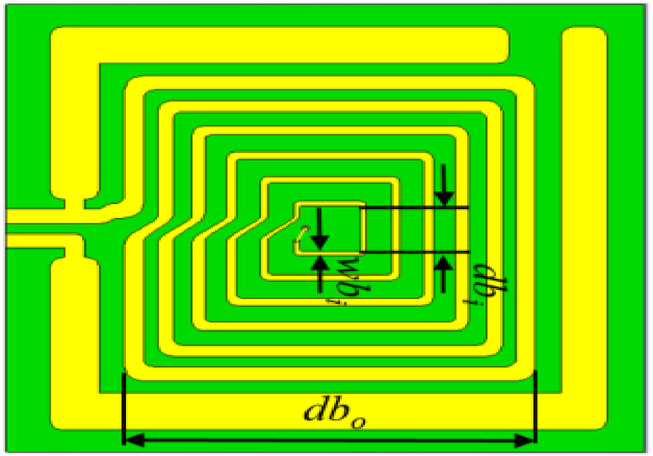


The Rx element and Tx element has the dimensions of 45mm X45mm

THE SIXTH DESIGN

In [6] WPT system operates at 13.56 MHz at a distance of 15 mm with planer shift in z-axis by 180 deg PTE > 70 % , with lateral shift in z-axis =15mm PTE > 60% and with planer and lateral shift (z-axis :180 deg , z-axis :15 mm, z-axis :15mm)PTE > 55 %





Tx dimensions is 15 mm x 15 mm x 2 mm and Rx dimensions is 10 mm x 10 mm x 2 mm.

THE SEVENTH DESIGN

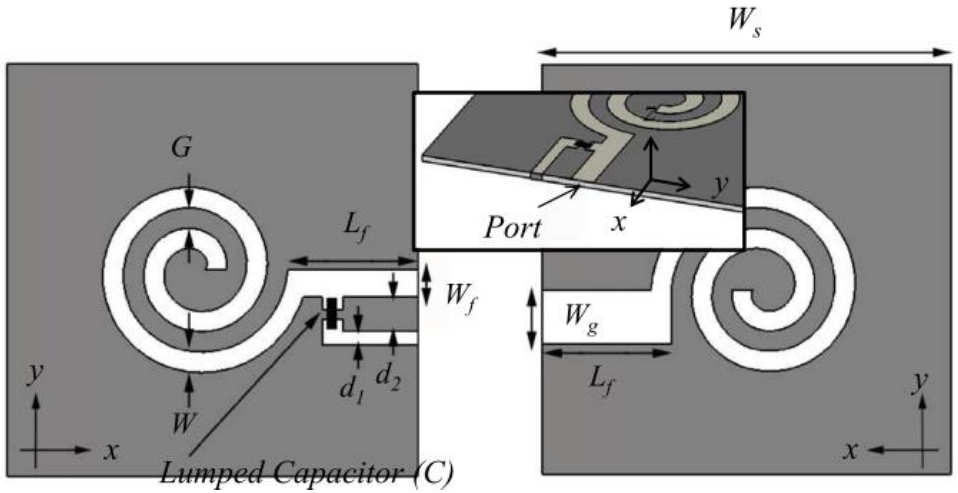
In [7]

. The system operates at 403 MHz a t adistance of 10 mm.

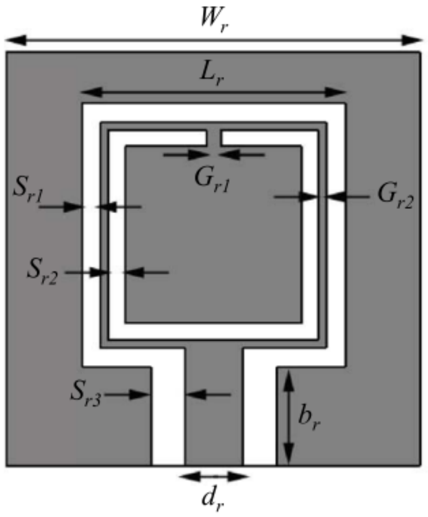
The power transfer efficiency is:

5.24% in experimental data.

7.3% in numerical data..



Front and back view of the transmitter



the receiver

Ref	Scope	Contribution	Specifications
[1]	Compact and dynamic Free running oscillator with stacked metamaterial WPT	dynamically adaptive operating frequency to match the frequency of peak efficiency	Peak efficiency of 51.5% in the air
[2]	Proposing two concentric open-loop spiral resonators	increase the OLSR launched power for higher transmission distance	PTE of 70.8% at 31mm with 576 mm^2 design area
[3]	conformal strongly coupled magnetic resonator coil, with negative permeability (MNG) meta-surface over the human skin surface	dual-band property for transferring power and data telemetry simultaneously	15.7dB coupling enhancement, and S_{21} of -27.9 dB
[4]	integration between the interdigital capacitor and the spiral coil to get a magnetic resonant resonator with high immunity for the misalignment instances	Synthesis between printed spiral coil (PSC) and planar interdigital capacitor (IDC) for near- field Wireless Energy Transfer	At a fixed axial transfer distance of 25 mm, the corresponding maximum simulated and measured transfer efficiency is 73.01% and 71.84% respectively under perfect alignment.
[5]	Planar Split-ring Resonators for UHF-RFID applications	printed conformal split-ring loop with the characteristic of a series LC circuit at its resonance frequency	Measured PTE of 87.9% at 22mm. the best-reported result for such a configuration. At 433MHz
[6]	printed spiral resonator with surface-mount device capacitors to achieve simultaneous conjugate matching	satisfactory tolerance at z-axis plane, lateral at x- and y-axis planes, as well as concurrent planar and lateral displacement	Positioned at perfect alignment with a transfer distance of 15 mm, the measured max PTE achieved are 79.54%
[7]	wireless power link for powering implantable medical devices	deliver up to 1 mW with an induced 10-g average SAR lower than 1.08 W/kg. below the 2-W/kg recommended limit	operates at 403 MHz, with 90 mm^2 area. Achieved Efficiency/Gain of 5.24% @ 1cm

Available material

Type	Model	ε_r	h (in)	h (mm)
Roger	3003	3	0.1	0.254
			0.2	0.508
			0.3	0.762
			0.6	1.527
Roger	3006	6.15	0.2	0.508
			0.3	0.762
			0.6	1.527
Roger	3010	10.2	0.2	0.508
			0.3	0.762
			0.6	1.527
Roger	3210	10.2	0.25	0.635
Roger	4003C	3.38	0.32	0.81
			0.32	0.81
Roger	4350B	3.48	0.133	0.34
			0.166	0.422
			0.2	0.508
Roger	5870	2.33	0.2	0.508
			0.3	0.762
			0.62	1.57
Roger	5880	2.2	0.2	0.508
			0.31	0.787
			0.62	1.57

Available material

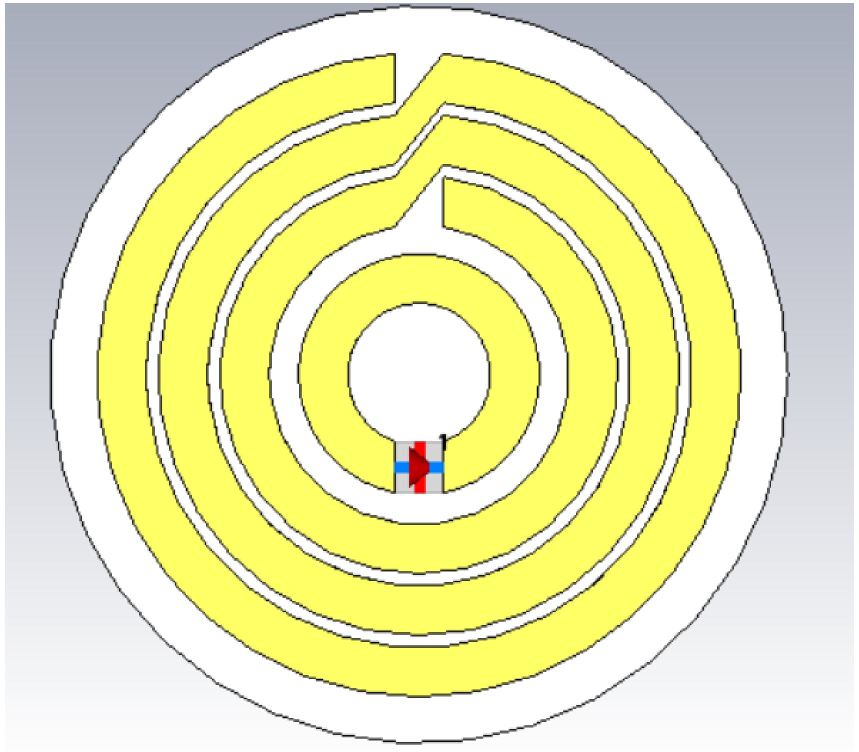
Type	Model	ε_r	h (in)	h (mm)
Roger	**6002**	**2.94**	0.05	0.125
			0.1	0.254
			0.3	0.762
Roger	**6006**	**6.15**	0.25	0.635
			0.5	1.27
Roger	**6010.2LM**	**10.2**	0.1	0.254
			0.5	1.27
Roger	**6010.5LM**	**10.5**	0.25	0.635
			0.5	1.27
PCB	**FR4**	**4.4**	0.32	0.8
	FR4	**4.4**	0.62	1.6

DESING APPROACH: WHAT PARAMETERS TO CONSIDER WHILE DESIGNING

- PTE: power transfer efficiency
- The distance range between Tx & Rx : this app is in mid-range applications (between 1cm and 6cm), as the design dimensions are 1.5 cm and 3 cm
- SAR: specific Absorbtion rate, not to exceed 2.0 W/kg (averaged over 10 grams of tissue, European union standards)
- The operation frequency: this project is designed at 433MHz which is one of the ISM (industrial, Scientific and Medical applications) frequency bands according to the NTRA -National Telecommunications Regulatory Authority
- The dimentions of the receiver considering the area which it will be implanted (the arm, stomach, clavicle) the simulation in this project is at the clavicle area.

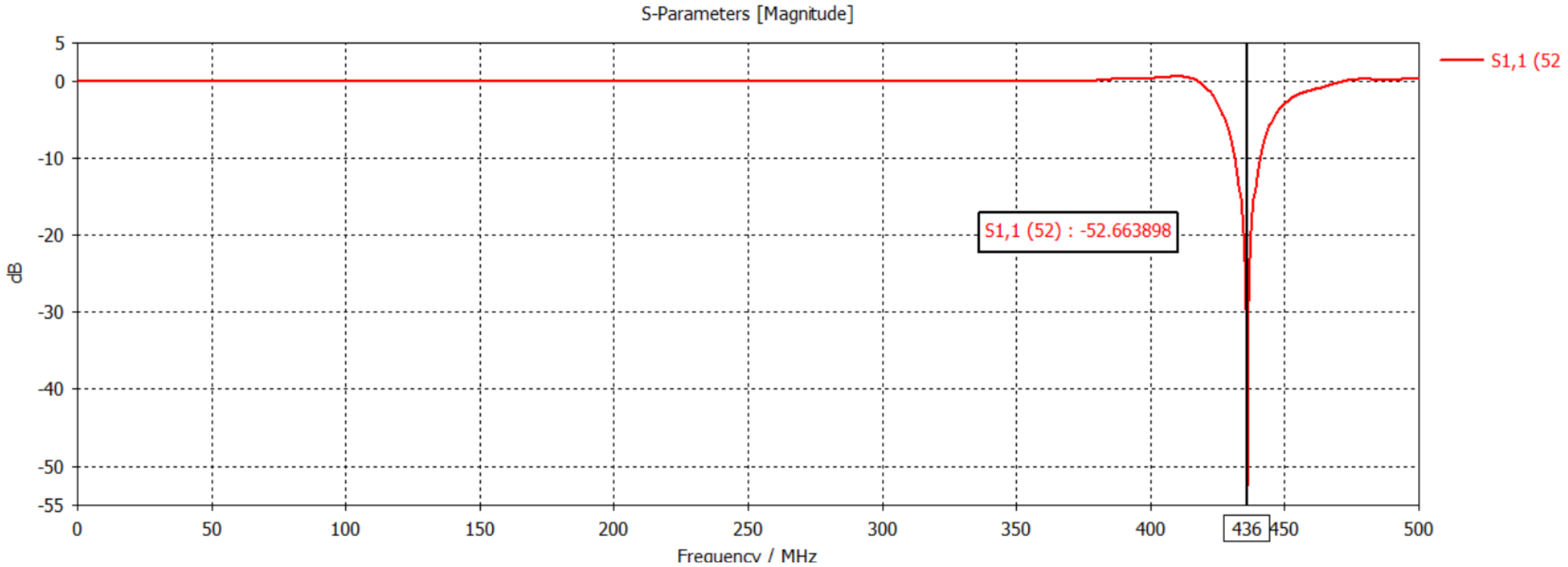
THE TRANSMITTER RESONATOR DESIGN

- The transmitter diameter is 3cm
- It consists of an inner resonator and a mutually coupled outer spiral
- The port is connected to a parallel tuning capacitor.
- The design is matched to the 50-ohm port so it do not need a matching capacitor

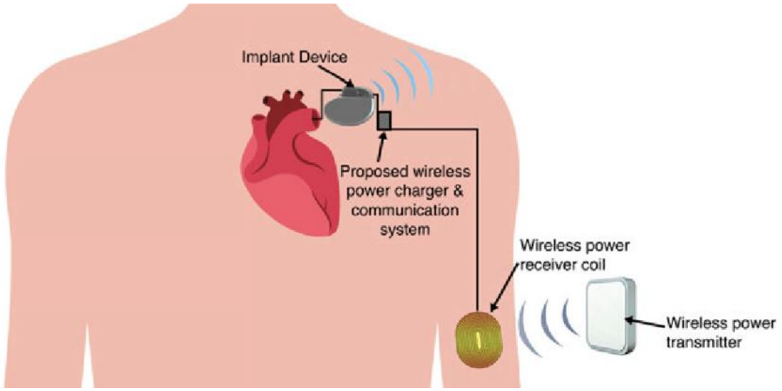


THE TRANSMITTER RESONATOR DESIGN

- S11 parameter for the stand-alone transmitter
- At 436Mhz it reaches –52dB which practically mean the resonator is matched at the port impedance (50-ohm).



THE RECEIVER DESIGN APPROACH



- The size limitations of the receiver depends on where the device is implanted, some places can allow more than 3cm (which is the max size in our case)
- For our application in implanted biomedical devices the receiver and the rectifier will be implanted in the human body, so their dimensions is a top consideration.
- As for the transmitter it can be bigger in size if it help increasing the efficiency.

RECTIFIER

❑ What is Rectifier and Why is it Important?

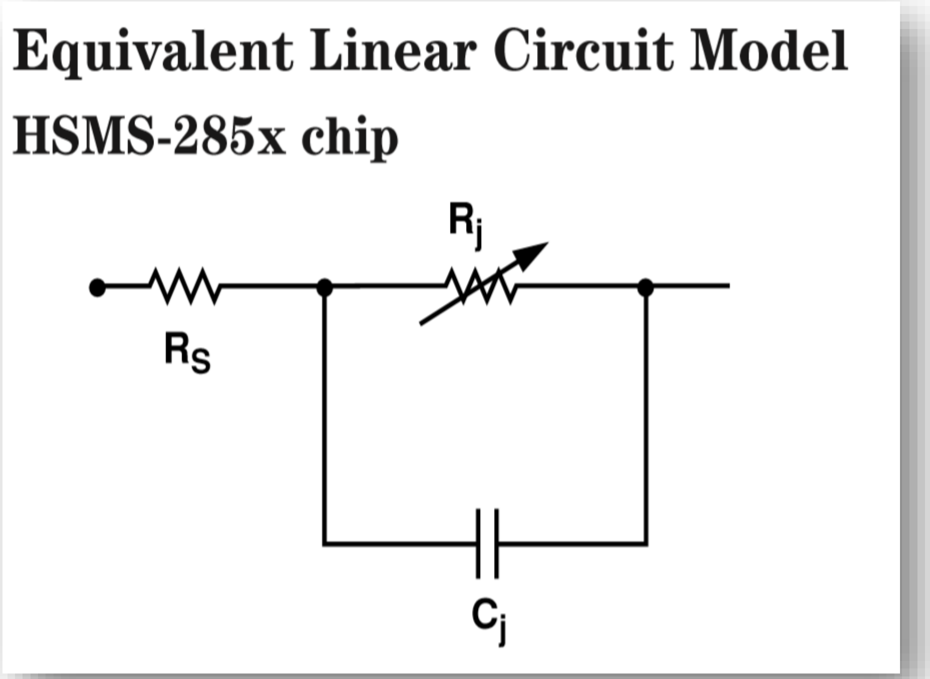
A rectifier is an electrical device that converts **alternating current (AC)** into **direct current (DC)**.

❑ Common Diode types

- **General-Purpose Rectifiers**
- **Zener Diodes**
- **Light-Emitting Diodes (LEDs)**
- **Varactor Diodes (Varicap or Tuning Diodes)**
- **Schottky Diodes**
- **ect…**

❑ Diode Parameters

- Threshold Voltage (Vth)
- Forward Current (If)
- Reverse Breakdown Voltage (Vbr)
- Reverse Leakage Current (Ir)
- Junction Capacitance (Cj)
- Series resistance (Rs)
- Peak Reverse Recovery Time (trr)
- Power Dissipation (Pd)
- Junction Temperature (Tj)
- Maximum Operating Frequency
- ect…



❑ Common Rectifier Topologies

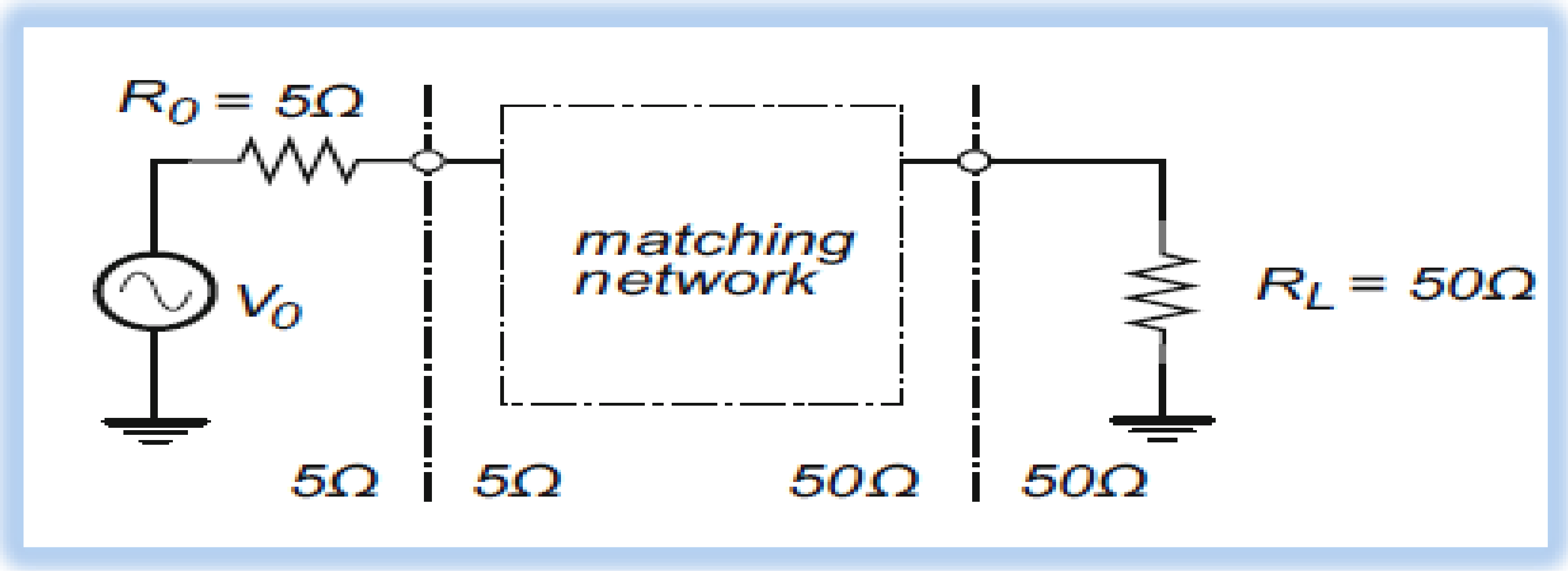
- **Half-Wave Rectifier (series doide)**
- **Full-Wave Rectifier**
- **Voltage Doubler Rectifier**
- **Multiplier Voltage Doubler Rectifier Circuit**
  - **Voltage tripler Rectifier**
  - **Voltage quadrupler Rectifier**
- **Shunt diode Rectifier**
- **Active Rectifier**

❑ Techniques for Enhancing Rectifier Performance in WPT

1) **Choosing the Right Diodes**

   Selecting the appropriate diode is crucial for optimizing the efficiency of Wireless Power Transfer (WPT) rectifiers.

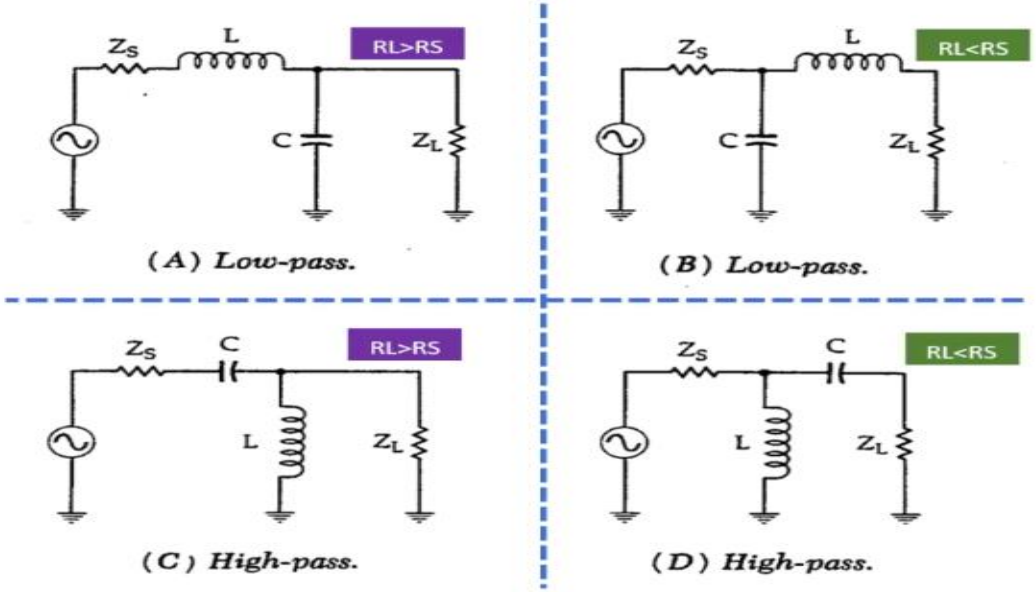
2) **Impedance Matching Networks**

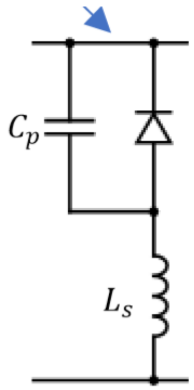


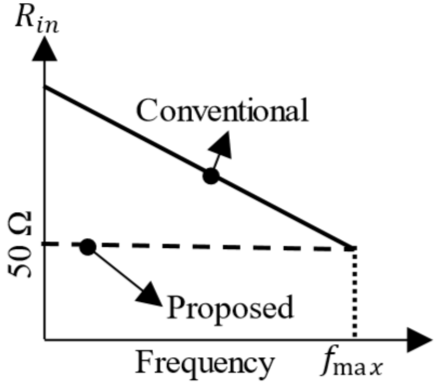
❑ Techniques for Enhancing Rectifier Performance in WPT

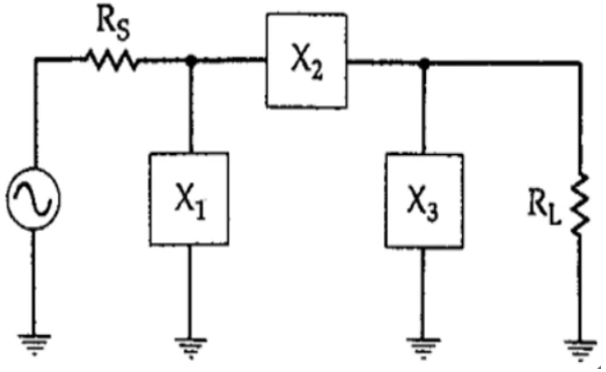
2) Impedance Matching Networks

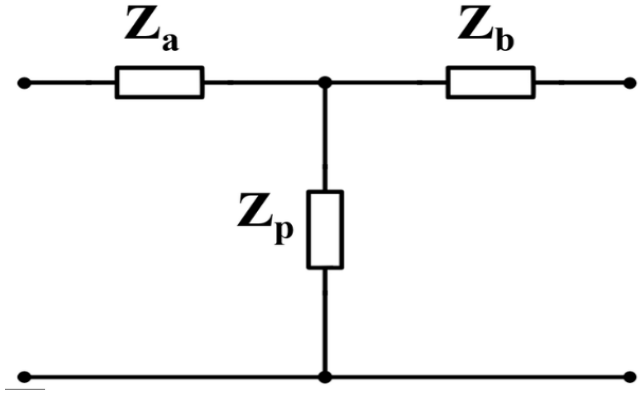
- ❖ **Matching network types**
  - ➢ **L-Matching Network**
  - ➢ **T and π Matching Network**
  - ➢ **Self-Matching Network**











❑ Proposed Topology

1) **We adopt the self-matching rectifier topology as the optimal choice for our design due to the following reasons:**

   - ➢ Self-matching rectifiers eliminate the need for external impedance matching networks by integrating reactive components within the circuit, ensuring high efficiency and minimal power loss.

   - ➢ The proposed design incorporates an inductor-capacitor network to achieve automatic impedance tuning, enhance power transfer and maintaining stable performance across varying frequencies.

   - ➢ This approach simplifies circuit complexity, reduces size, and improves overall rectification efficiency, making it ideal for RF energy harvesting and wireless power transfer applications.

❑ Proposed Topology

2) **The diode which is used (HSMS-2850 Schottky diode) as the optimal choice for our design due to the following reasons:**

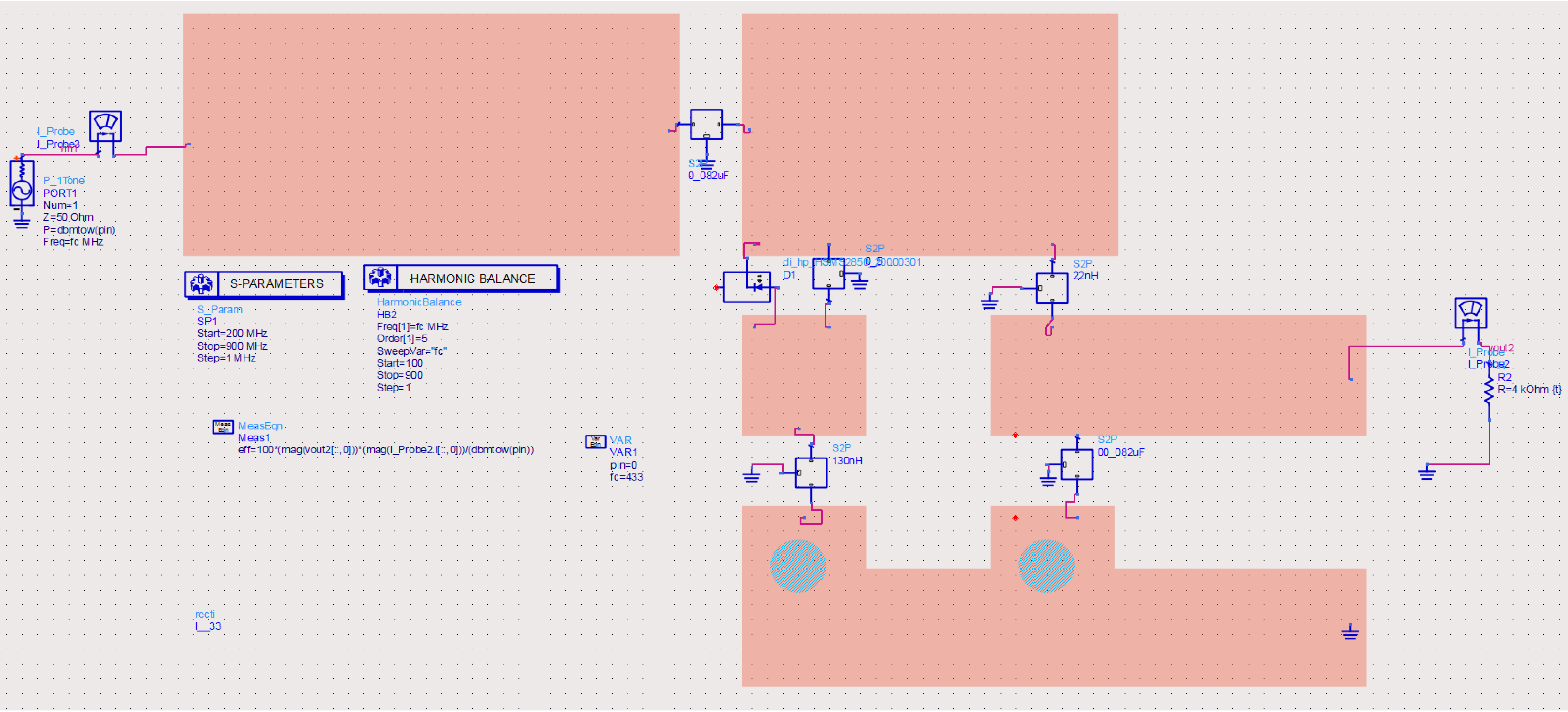
- ➢ **Low turn-on voltage** (typically 150-250 mV) → Minimizes power losses and improves efficiency in low-power applications.

- ➢ **Fast switching speed** → Enhances performance in high-frequency rectification and RF applications.

- ➢ **Low junction capacitance** → Reduces signal distortion and improves impedance matching.

- ➢ **Compact and suitable for integration** → Small SOT-23 package allows for space-efficient circuit designs.

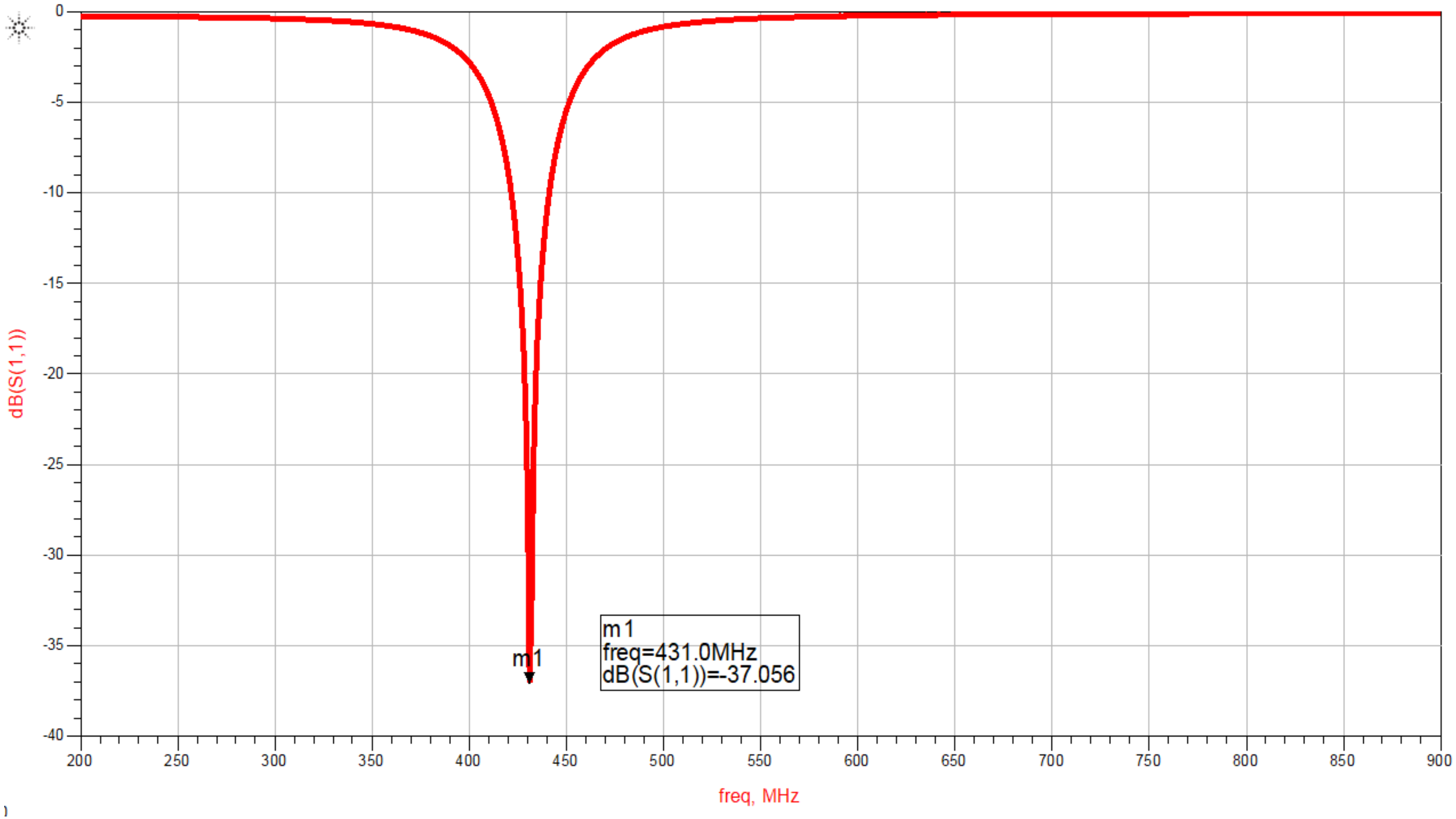
THE DESIGN



I_Probe
I_Probe3
vin
P_1Tone
PORT1
Num=1
Z=50 Ohm
P=dbmtow(pin)
Freq=fc MHz
0_082uF
S-PARAMETERS
S_Param
SP1
Start=200 MHz
Stop=900 MHz
Step=1 MHz
HARMONIC BALANCE
HarmonicBalance
HB2
Freq[1]=fc MHz
Order[1]=5
SweepVar="fc"
Start=100
Stop=900
Step=1
MeasEqn
Meas1
eff=100*(mag(vout2[::,0]))*(mag(I_Probe2.i[::,0]))/(dbmtow(pin))
VAR
VAR1
pin=0
fc=433
recti
L_33
D1
S2P
22nH
S2P
130nH
S2P
00_082uF
I_Probe
I_Probe2
vout2
R2
R=4 kOhm {t}

Features

- Self-matched
- Small size → 9.6mm x 5.7mm
- Efficiency exceed 50%



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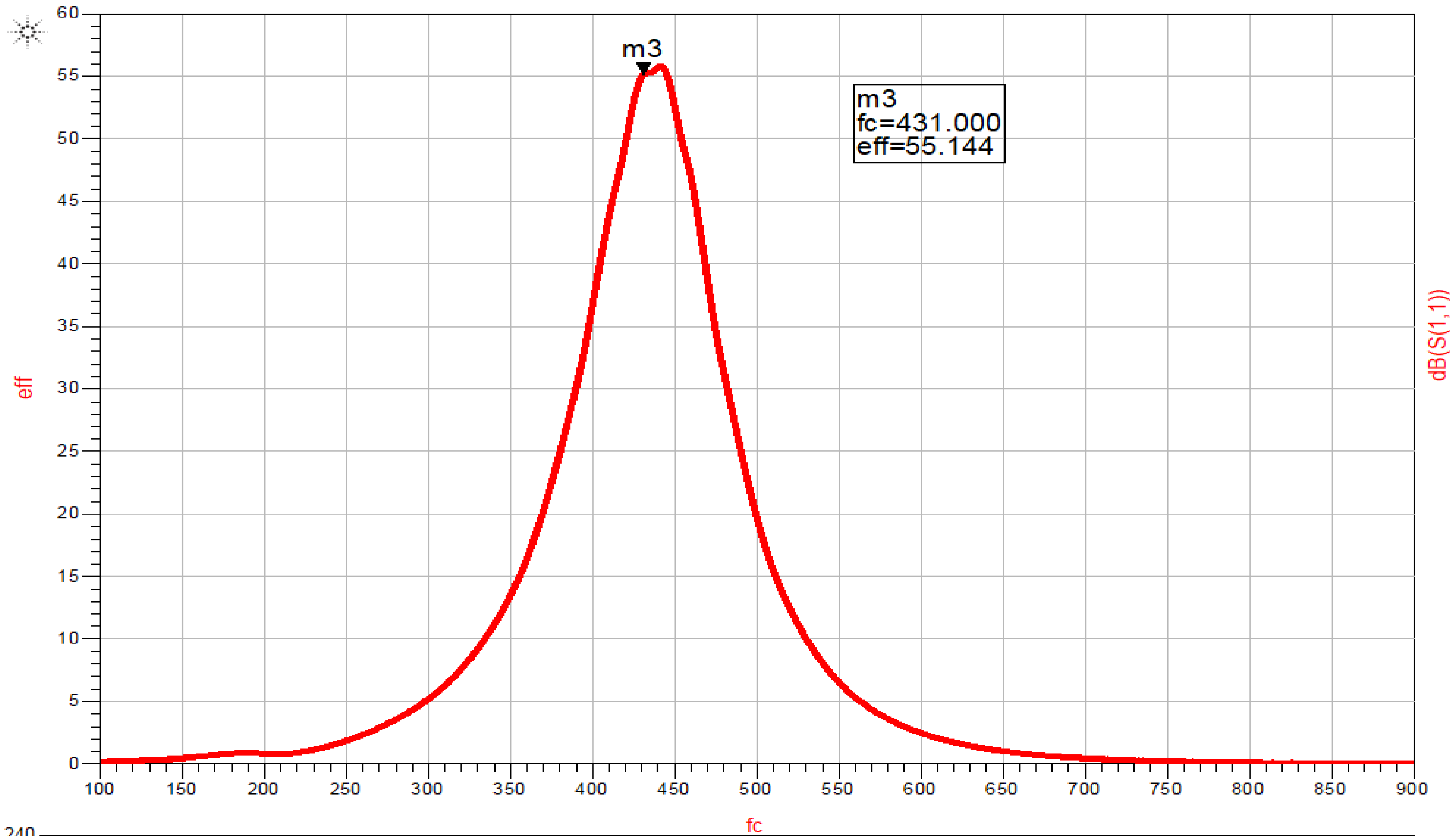

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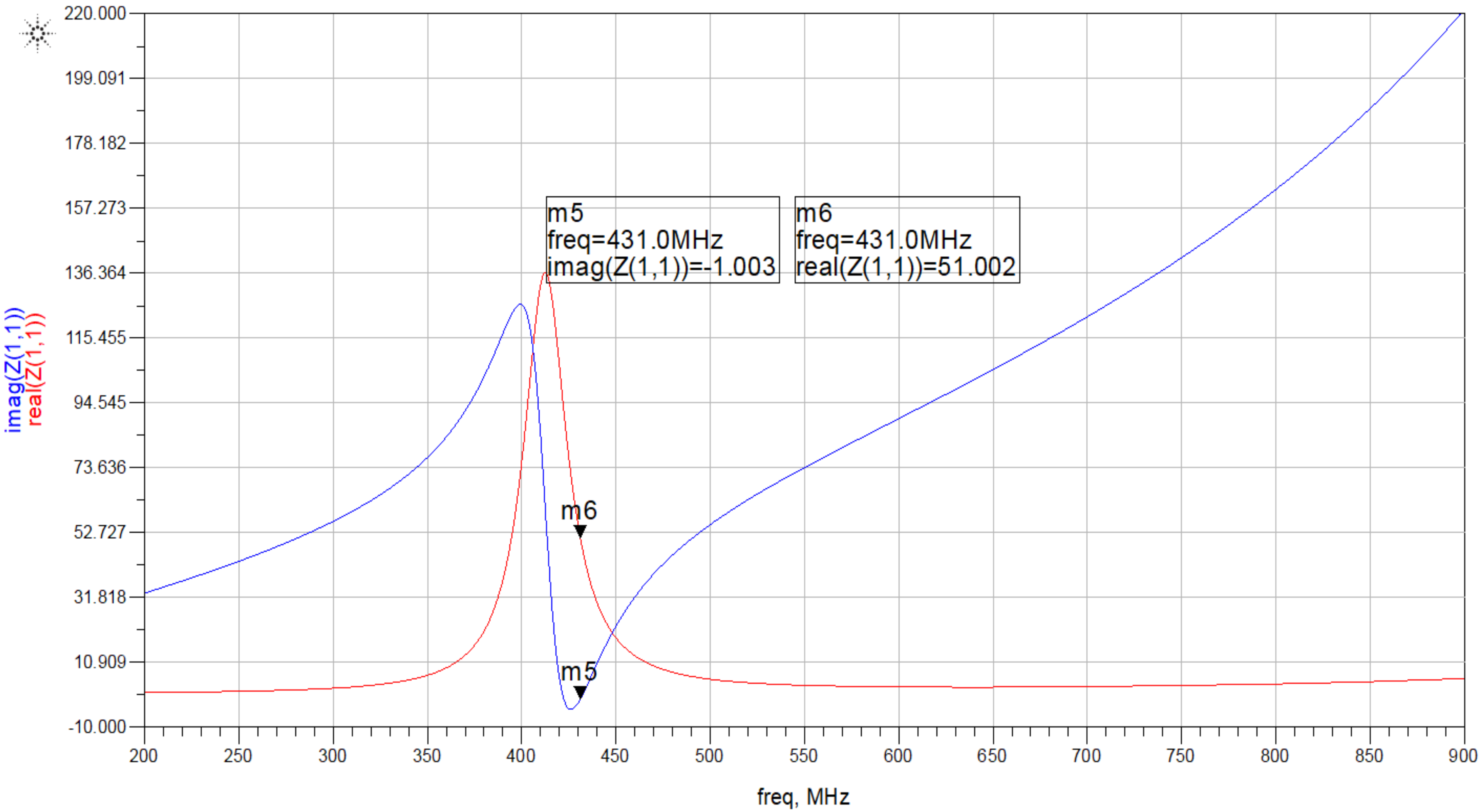

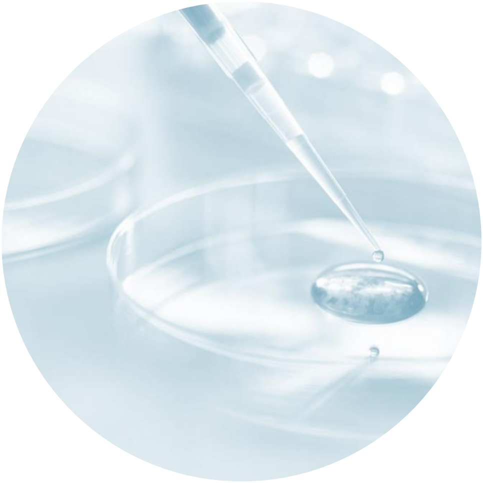

THANK YOU

KHALED MOJAHED & AHMAD SAMIR & KAREEM WALID