

## EEE6012 – Assignment

This assignment is made up of two parts, PART A and PART B. Each part contributes 50% to the required 40% of this module mark. You are required to attempt both parts as satisfactorily as possible.

### PART A

#### 1.1 Task 1: SIMULINK Model of Inductive Link Wireless Power Transfer (WPT) Device

The purposes of task1 of this assignment is to practice MATLAB/SIMULINK basic library blocks to create a full dynamical model of the WPT device. The inductive link has two parts namely transmitter and receiver. The transmitter has class E inverter while the receiver has a class E rectifier. Students need to build a complete state-space mathematical model of the device and use the basic library blocks of SIMULINK to simulate the performance of this device. A handout will be given to the students detailing the circuit parameters and specifications. This will help to understand the basic principles of the above topics and apply the knowledge to electromagnetism.

#### Handout:

### Analysis of Inductive Wireless Power Transfer using class E<sup>2</sup> converter

#### Introduction:

A dynamic response analysis model of a Class E2 converter for wireless power transfer applications is the main task of this assignment. The converter operates at 200 kHz and consists of an induction link with its primary coil driven by a class E inverter and the secondary coil with a voltage-driven class E synchronous rectifier. A state-space model is required to obtain the eigenvalues of the system for the four modes resulting from the operation of the converter switches and to simulate the efficiency of this device using SIMULINK environment. A dynamic analysis needs to be carried out to investigate the effect of changing the separation distance between the two coils, based on converter performance and the changes required of some circuit parameters to achieve optimum efficiency and stability. Figure 1a shows a photograph of the Wireless Power Transfer (WPT) device and the experimental setup that had been used in research.

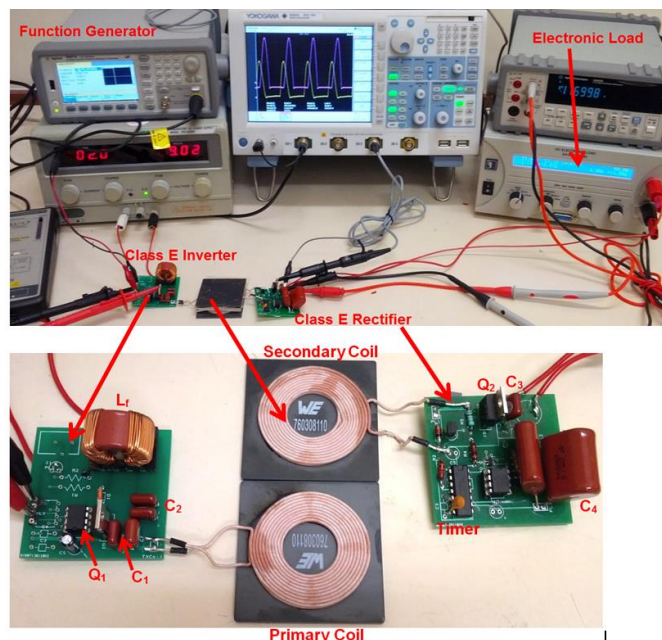


Figure 1.a. Photograph of the experimental setup.

## Aim

To analyse the operation and performance of inductive link wireless power transfer device.

## Objectives

- Explain the operation of WPT device using inductive link and class E<sup>2</sup> converters (10%)
- Prove the correctness of the mathematical model (10%)
- Build a SIMULINK model of the mathematical model given in Figure 2 and test the responses. (20%)
- Tune the capacitors C<sub>1</sub>, C<sub>2</sub>, and C<sub>3</sub> to get at least 75% efficiency and constant output voltage of 11 V for two separation distances: 3mm (equivalent to M=12μH) and 15mm (equivalent to M=8 μH). (60%)

## The circuit diagram (figure 1b):

V is the input Voltage (10 V DC).

L<sub>f</sub> is an inductor.

Q<sub>1</sub> and Q<sub>2</sub> are the switches (MOSFET)

C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, C<sub>4</sub> are capacitors (tuning and smoothing functions)

L<sub>p</sub>, L<sub>s</sub>, and M are the primary leakage inductance, the secondary leakage inductance, and the mutual inductances respectively.

R<sub>L</sub> is the load resistor. You can use the attached parameters.

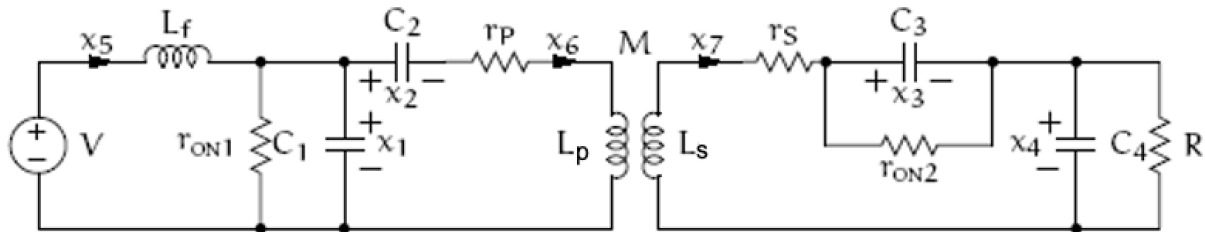


Figure 1.b. The circuit diagram of the Inductive Link Wireless Power Transfer Device

We start first writing the governing equation of the class E<sup>2</sup> converter inductive link wireless power transfer device given in figure 1b.

We use Kirchhoff's current and voltage laws to create these equations where we have seven variables representing the state variables of the system which are:

$x = [v_1 \ v_2 \ v_3 \ v_4 \ i_f \ i_p \ i_s]$ , simply the voltage across C<sub>1</sub>, the voltage across C<sub>2</sub>, the voltage across C<sub>3</sub>, the voltage across C<sub>4</sub> (the output voltage), the inductor L<sub>f</sub> current, the primary current, and the secondary current respectively.

The equations are as follows:

$$\dot{v}_1 = \frac{-v_1}{C_1 r_{Q1}} + \frac{i_f}{C_1} - \frac{i_p}{C_1} \quad (1)$$

$$\dot{v}_2 = \frac{i_p}{C_2} \quad (2)$$

$$\dot{v}_3 = \frac{-v_3}{C_3 r_{Q2}} + \frac{i_s}{C_3} \quad (3)$$

$$\dot{v}_4 = \frac{-v_4}{C_4 R_L} + \frac{i_s}{C_4} \quad (4)$$

$$\frac{di_f}{dt} = \frac{-r_f i_f}{L_f} + \frac{V}{L_f} - \frac{v_1}{L_f} \quad (5)$$

$$\frac{di_p}{dt} = \frac{1}{L_p L_s - M^2} [L_s v_1 - L_s v_2 - M v_3 - M v_4 - r_p L_s i_p - r_s M i_s] \quad (6)$$

$$\frac{di_s}{dt} = \frac{1}{L_p L_s - M^2} [M v_1 - M v_2 - L_p v_3 - L_p v_4 - r_p M i_p - r_s L_p i_s] \quad (7)$$

Figure 2 The device mathematical model

**Parameters:**

$$r_{Q1} = r_{Q2} = 0.15 \text{ Ohm}$$

$$r_p = r_s = 0.18 \text{ Ohm}$$

$$R_L = 10 \text{ Ohms}$$

$$C_1 = 55 \text{ nF}$$

$$C_2 = 45 \text{ nF}$$

$$C_3 = 26 \text{ nF}$$

$$C_4 = 6.6 \text{ } \mu\text{F}$$

$$L_p = L_s = 24 \text{ } \mu\text{H}$$

$$r_f = 1 \text{ mOhm}$$

$$L_f = 1 \text{ mH}$$

Both coils have maximum Q factor of 230 at 200 kHz

Operating frequency= 200 kHz

Duty cycle of  $Q_1=0.5$

Duty cycle of  $Q_2=0.511$

Delay angle of  $Q_1=0$

Delay angle of  $Q_2=229.864^\circ$

For a separation distance of 3mm, the measured mutual inductance is approximately 12  $\mu\text{H}$ , which corresponds to a coupling coefficient (k) value of 0.50.

**Reference:**

Available on moodle page: EEE6012-23-UOB-A

## PART B

### 1. Introduction

In wireless communication systems, antennas are required to transmit electromagnetic waves (signals) from a transmitter to a receiver. These antennas are usually integrated at the Front- End of the transmitter or receiver. Modern communication systems such as Radar Systems, Base Transceiver Stations (BTS), including WiFi, etc. may use more than one antenna by the principle of multiple input multiple output (MIMO) configurations to transmit or receive signals. In the MIMO systems, the antenna elements may be formed into arrays. In this exercise, you are required to design

- a microstrip antenna (which specially transmits signals), and then
- may be used to form an antenna array for a possible  $4 \times N_R$  MIMO system, where  $N_R$  is the number of receiving antennas.

This assignment is designed to enable you understand how to design antennas using MATLAB software. It will also expose you to the design parameters required to achieve the operation of an antenna system at a given frequency. You will need to report the results of antenna design, demonstrate the understanding of interpreting the operational performance of an antenna system and present reproducible results using your report. You are required to provide theoretical evidences that back up your designs including the relevant mathematical models.

### 2. Task

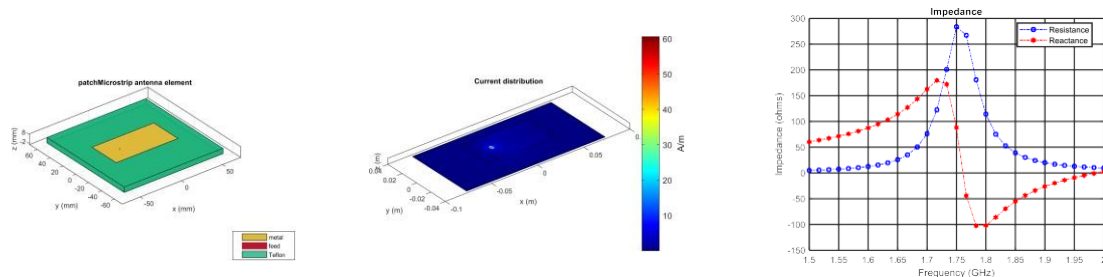
There are two parts involved in this task. The second task depends on the first task. Both tasks involve antenna design, interpretation of the antenna designed, and the application of the knowledge that you acquired from the Engineering Electromagnetism (EEE6012) module.

#### 2.1 Task 1 – Microstrip Antenna Design

Design a microstrip patch antenna with the following properties:

- Length =  $75e-3$  m,
- Width =  $37.5e-3$  m,
- Ground Plane Length =  $120e-3$ ,
- Ground Plane Width =  $120e-3$ ,
- Feed Offset =  $[-18.75e-3 \ 0]$ .

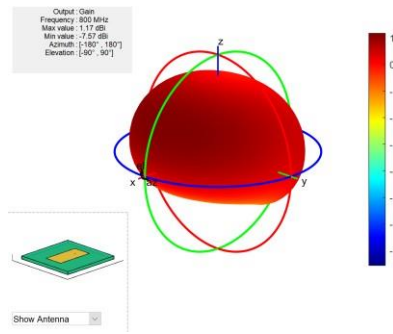
The results you will get should look like the following.



a). Microstrip patch antenna

b). Current distribution

c). Input Impedance of the antenna

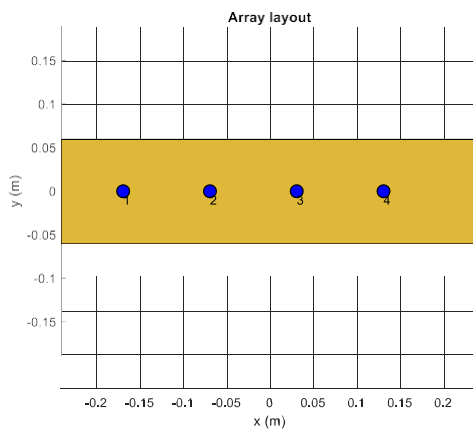


d). Far-field radiation pattern (700 MHz)

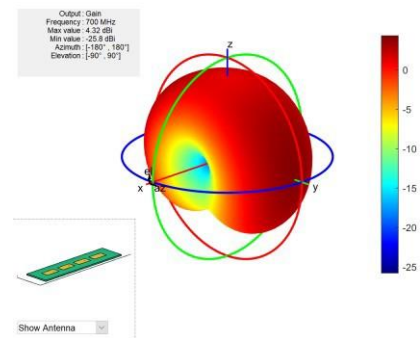
Show the far-field radiation pattern for a BTS operating with antenna on 5G network (700 MHz). Interpret your results.

## 2.2 Task 2 – Antenna Array

Using the microstrip patch antenna that you designed in Task 1, design a linear antenna array of 4 antenna elements with each of the antennas separated from one by another by the necessary antenna spacing that would overcome mutual coupling. The results from your design should be similar to the following.



a). Layout of the antenna array



b). Radiation pattern of the array

Note that the radiation pattern of the antenna array system is realized from the superposition of the individual antenna patterns of the microstrip antenna.

You will need to show

- Far-field radiation pattern of the antenna
- Operating frequency
- Wavelength of operation
- Current distribution
- Layout of the antenna array

From the impedance plot, find the frequency of operation of your antenna. You must submit all the MATLAB codes used to achieve your design. The MATLAB codes used in designing your antenna must be well documented. Discuss the electromagnetism principles governing the operation of linear antenna arrays and their applications.

Supposing that your organisation is a consulting company to MBDA, what professional advice would you give to MBDA regarding your antenna design and the results produced.

By successfully completing this task, you'll acquire practical experience in electromagnetic simulation, deepening your understanding of the subject matter. Good luck!