BIOM1010 LABORATORY
INTRODUCTION TO RADIO FREQUENCY (RF) LINKS

General Introduction:

Many medical implants are powered and controlled by a stream of radio frequency (RF) signals in a configuration known as an *inductive* or *radio frequency* (*RF)* link. An inductive link uses the electromagnetic field generated in an inductor to transfer both power and data to another inductor (and vice versa). In this laboratory, you will gain an understanding of the transmitter's operation.

Part 1 -Introduction to the Transmitting Hardware:

There are several different types of RF amplifiers, typically designated as Class A, Class B, etc. In the transmitting hardware of this lab, the amplifier used is of Class E type, chosen primarily for its efficiency (theoretically 2.3 times more efficient than the others) and also because its operation is quite interesting to observe. The Class E amplifier was invented by the father and son team of Nathan and Alan Sokal and first published in 1975 [1]. Since then it has been used for many RF applications from short-wave radios to biomedical implants.

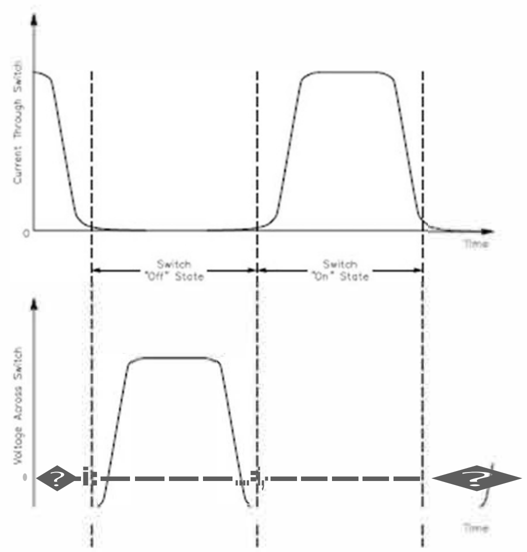


Fig 1-Conceptual "target" wave forms of transistor voltage and current.

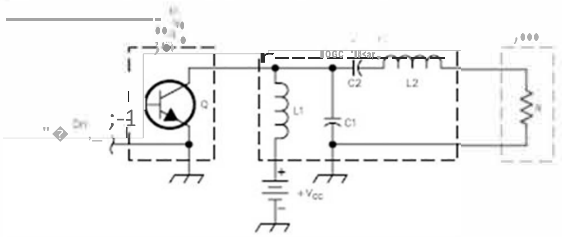


Fig 2—Schematic of a low-order Class-E amplifier.

(SOURCE:QEXJan/Feb2001,pp.9-20)

The concept and the circuit itself are shown in Fig. 2. The primary aim is to save power. The power consumption of the switching transistor is the product of current and voltage (P=VI) passing through the transistor, integrated over the period of the RF cycle. By avoiding having the current and the voltage at high levels simultaneously, the power dissipated in the circuit remains low. First, by tuning the circuit such that the current and the voltage are 180 degrees out of phase from one another (achieved at resonance - V=0 when I=i and I=O when V=v) so that the power is effectively 0, or in reality, only resulting from the resistance within the system.

This is true for any resonant circuit. However, second, and the key to the Class-E's operation is the *timing of switching* which cannot occur instantaneously in a real circuit. By carefully choosing the switching time such that switching occurs when both current and voltage are at their minimum, the power dissipated during switching is substantially reduced (see Fig. 1), and the efficiency of the circuit, and the energy it can emit is maximised. For further details the reader is referred to [1].

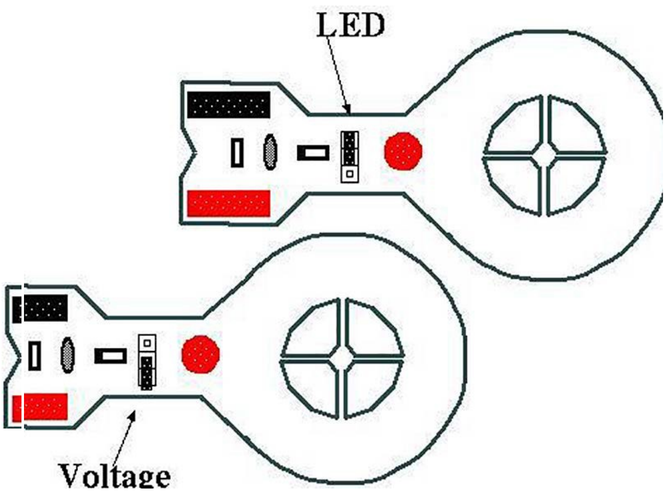
The lab transmitter transmits and receives data via the Class-E circuit, and is controlled by a microcontroller that is attached via USB to a computer. Access to the various signals is available for probing.

For Part 1 of this lab you will need:

1. The RF Transmitter and USB cable {one per group – to be signed out by the lab staff)
2. Multimeter
3. A computer running the custom software "Tera Term" and one free USB port
4. The USS Enterprise Circuit or Simple LED circuit.

Experimental Procedures

In most implants using RF power, the signal will be rectified within the implant and stored in a capacitor to provide a relatively stable voltage supply, from which power to drive the implant may be drawn. It may be regulated for increased stability, or used as-is (unregulated) for higher voltages. Often both are used: high voltage for 'voltage compliance' capabilities during electrical stimulation, and the regulated supply for running microelectronics.



In this task we will use the "USS Enterprise Circuit" or the simple LED circuit as a simulated implant and look at the voltages we can extract from the RF Link as we separate the transmitting coil from the receiving coil, and also as we offset these two coils from their centres. The USS Enterprise circuit has two "modes" which are set by the jumper shown in the figure at left. VOLTAGE mode configures the circuit to be a power supply whereas LED mode configures the circuit to be **a radio** frequency (RF) signal detector where the LED glows in the presence of RF.

Connecting the Transmitter -

The lab Transmitter can be controlled via a USB port using the "TERA TERM" program which is pre-loaded onto the lab computer. Connect your transmitter to the computer using the supplied cable. Using the Windows Device Manager, find the COMM port number that gets allocated to the transmitter. Start the terminal program and choose a new serial connection to the port number that you determined. Then go to Setup>Serial Port on the menu. Change the baud rate to 38400, leave all other values as default and click ok. You are now ready to communicate to the transmitter. A demonstration will be given if this isn't clear.

Simple documentation can be had from the software itself by pressing h for help. Below is similar to what you will see when you do this:

```
> h
> Transmitter Help:
    v:  version        h:  help           i: info
    f:  flash  leds    z: null command
    O:  stop carrier   1: start carrier   L  measure inductance
    s:  set  freq      a: adc             :
                                            F_
    u:  Freq  up       d:  freq  down     I:    INC
```

By the end of today's laboratory, you should be aware of what these commands do.

Searching for Signs of Life -

Once the transmitter is connected, set the USS Enterprise circuit to LED mode (or simply hold the simple LED circuit) and bring its coil near to the transmitter coil. The LED should glow brightly when closely aligned, and should dim when offset or pulled away. Press 'O', then '1', then 'f' and observe the behaviour of the LEDs (both on the USS Enterprise and the lab Transmitter. Next try the 'v' command. Describe in your own words what each of these does.

O: ____

1: ____

f: ____

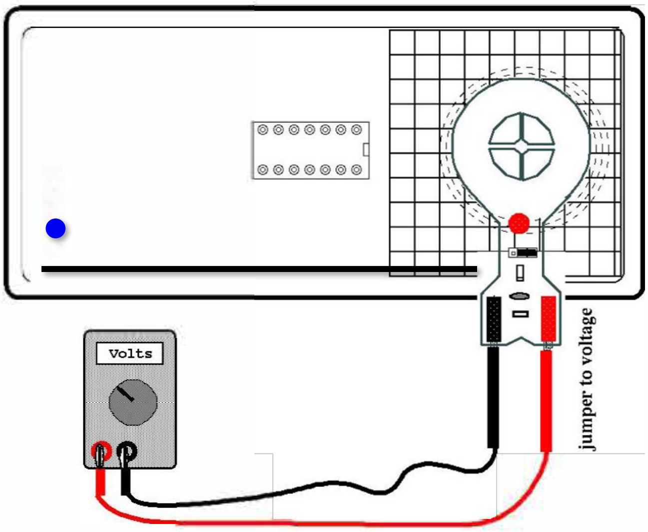
v: ____

Changing the carrier frequency -

The Class-E amplifier is tuned to a frequency of 4 MHz.

Press the 'u' to increase and 'd' to decrease the transmitter's carrier frequency while observing the brightness of the LED on the USS Enterprise circuit. An up arrow '^' appears when you press u (for up), a down arrow 'v' appears when you press d (for down), and '-' appears when you've reached the end of the frequency range. Note your observations, the frequencies where the LED glows the brightest and where it glows the dimmest or not at all. Explain why you are seeing this behaviour (hint: Class-E transmitter).

Extracting Power -



1. Set the USS Enterprise circuit such that it is in voltage mode, and connect the multimeter probes as shown.
2. Centre the USS Enterprise's receiving coil on the transmitter' grid, then measure and record the observed voltage.
3. Move the centre of the USS Enterprise to another location above the grid, carefully locating it when viewing from directly above.
4. Record the observed voltage, and repeat until the voltage at all locations on one quadrant of the grid have been recorded.
5. Place a 3 mm, clear spacer on top of the grid of the transmitter.
6. Re-centre the USS Enterprise onto the grid.
7. Record the observed voltages at all locations on **one quadrant** of the grid.
8. Repeat steps 5 through 7 with a 6 mm spacer by stacking 3 mm spacers.

Interference -

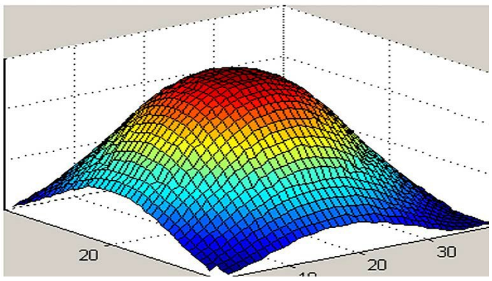
Move the spacers to the side of the grid such that the USS Enterprise circuit is supported only at its edges. Can you observe a clear difference in the voltage measurement when you do this {i.e. plastic -vs- no plastic between the USS Enterprise and the transmitter?

What happens when you place a silver coin (20 or 50c) between the transmitter's grid and the USS Enterprise?

What do you think might happen if the space between the transmitter and the USS Enterprise (the receiver) was replaced with skin as would be the case in a medical device such as a cochlear implant?

Post-Processing

1. Is the USS Enterprise Circuit "tuned?". If yes, to what frequency is it tuned? If not, what should be done to tune it to 4 MHz? What will be the result of doing that on the above tests?
2. Using MATLAB, plot the voltage profile of each position on the full grid for each of the four voltage profiles. Since you have recorded from only one quadrant of data, assume that there is symmetry about the horizontal and vertical bisections of the grid. In MATAB you can construct a 3D plot using the command `surf` with voltage on the Z axis, and position on X and Y (see figure at right which serves as an example - noting that this was done with many more data points than you'll have, and by someone too lazy to add axis titles and units...naughty!).



References:

[1] Lundin, R. (1985) A handbook formula for the inductance of a single-layer circular coil. Proceedings of IEEE. 73(9):1428-1429.