ELEC 3303 - Lab experiment
Inductance and inductive coupling

1 Introduction and report

1.1 Introduction

The purpose of this experiment is to become familiar with the magnetic field generated by a current, the concept of self and mutual inductance, and the magnetic coupling between circuits.

Currents flowing in one circuit generate a magnetic field, and these fields induce an electromotive force in nearby circuits and drive currents – whether this is intended or not. These signals, coupled in a victim circuit, can create problems in a multitude of ways, e.g. they can appear as noise at the input of operational amplifiers, or distort small signals. Designers of electronic devices or system developers must be aware of these effects to avoid signal integrity and electromagnetic compatibility (EMC) problems.

Both experiments are to be conducted in one lab session. The pre-lab questions of section 3 are to be answered BEFORE the lab, and shall be included in the lab report.

Note: This lab experiment is related to the material on pages 33, 34 and 35 in Part 4 of the lecture slides, and to Questions 1 and 3 of Tutorial 9.

Note: The current along a conductor can only be assumed to be uniform if the conductor is electrically short, i.e. much shorter than a wavelength. The wavelength is given as $\lambda = \frac{3 \times 10^8 \left[ms^{-1} \right]}{f}$ (i.e. 6m at 50 MHz, and 0.6m at 500MHz)

1.2 Report

The report shall consist of:

- A signed report cover sheet;
- The completed ELEC3303-LabReport (from the unit website) - tables filled in and Figure P1 added;
- Plots and comments as specified in 2.1.2 and 2.2.2;
- Any material you think necessary for the evaluation of your report.

Reports are to be dropped in the dedicated assignment box by 4pm on the second Monday after your lab session! Reports not submitted within one week after their due date will NOT be marked!

Late submission (less than one week) of the report will incur a 50% penalty!

2 Measurements

2.1 Experiment 1:

2.1.1 The principle idea

In this experiment a signal generator with variable frequency and amplitude is connected via a coaxial cable to a rectangular loop (see Figure 1). The current trough the loop depends on the source voltage and the total impedance of the circuit. This impedance is a series combination of: a) the internal impedance of the signal generator; b) the transfer characteristic of the cable; and c) the impedance of the loop.

The internal impedance of the signal generator is 50Ω (real); the cable could be considered as 2-port network representation for a simple Π-equivalent circuit (capacitance: 2×50pF, inductance: 250nH); the impedance of the loop is determined by its self inductance and the respective frequency.

2.1.2 The measurement

Set the amplitude at the signal generator at 13dBm and measure the current at the centre of side 1 for the following frequencies: 1MHz, 2MHz, 5MHz, 10MHz, 20MHz, 50MHz, 100MHz, 200MHz, 500MHz.

Repeat the current measurements at the centres of sides 2, 3 and 4 for the following frequencies: 5MHz, 50MHz, 500MHz.

Procedure:

a) Set the signal generator and the spectrum analyser to the desired frequency.

b) Record the actual reading from the spectrum analyser in dBμV.

c) Convert the results to dBμA by subtracting the current probe factor (dBμA = dBμV - dBΩ).

d) Convert the current from the logarithmic value in dBμA to a linear scale in mA ($10^{dB\mu A/20}$/1000).

e) Compare the measured results with the prediction from the pre-lab section and comment on differences, if any.

f) plot both currents, calculated for the pre-lab questions and measured during the lab session, as logarithmic values (dBμA) in one diagram with logarithmic frequency axis.

2.2 Experiment 2:

2.2.1 The principle idea

The reference output of the signal generator (10MHz, $2V_{rms}$ with 50Ω internal impedance) is connected via a coaxial cable to a rectangular loop (see Figure 2). The alternating current through the large loop generates a magnetic field, this magnetic field penetrates the area of the small test loop; the time varying flux induces an electromotive force according to Faraday's law which is observed at the input of the oscilloscope.

2.2.2 The measurement

A small test loop is placed at various locations along an observation line, as shown in Figure 2, and the induced electromotive force is measured with an oscilloscope. The test loop is moved in 10mm steps from the centre of the large loop over a distance of 300mm.

Procedure:

   a) Place the small test loop flat on the ruler with its centre at the test points.

   b) Record the voltage for all observation points.

   c) Find the location where the reading of the induced voltage is a minimum.

   d) Along which part of the observation line varies the induced voltage approximately as $1/s$ (where s is the distance from the nearest edge of the large loop)? Explain this behaviour!

   e) Calculate the mutual inductance between the two loops for positions: 0mm, 100mm, 200mm and 300mm.   M=flux though Small / current though large
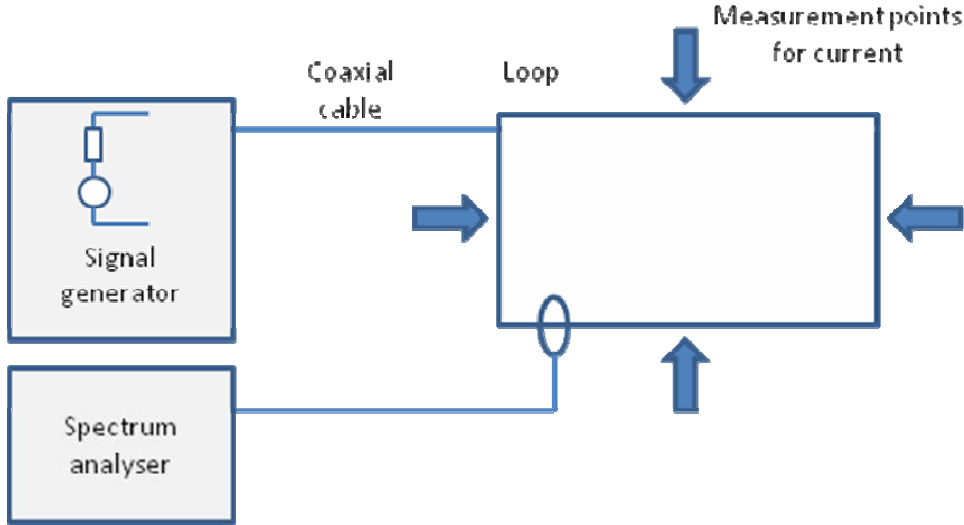
f)

Figure 1: Experiment 1 set up - current in large loop
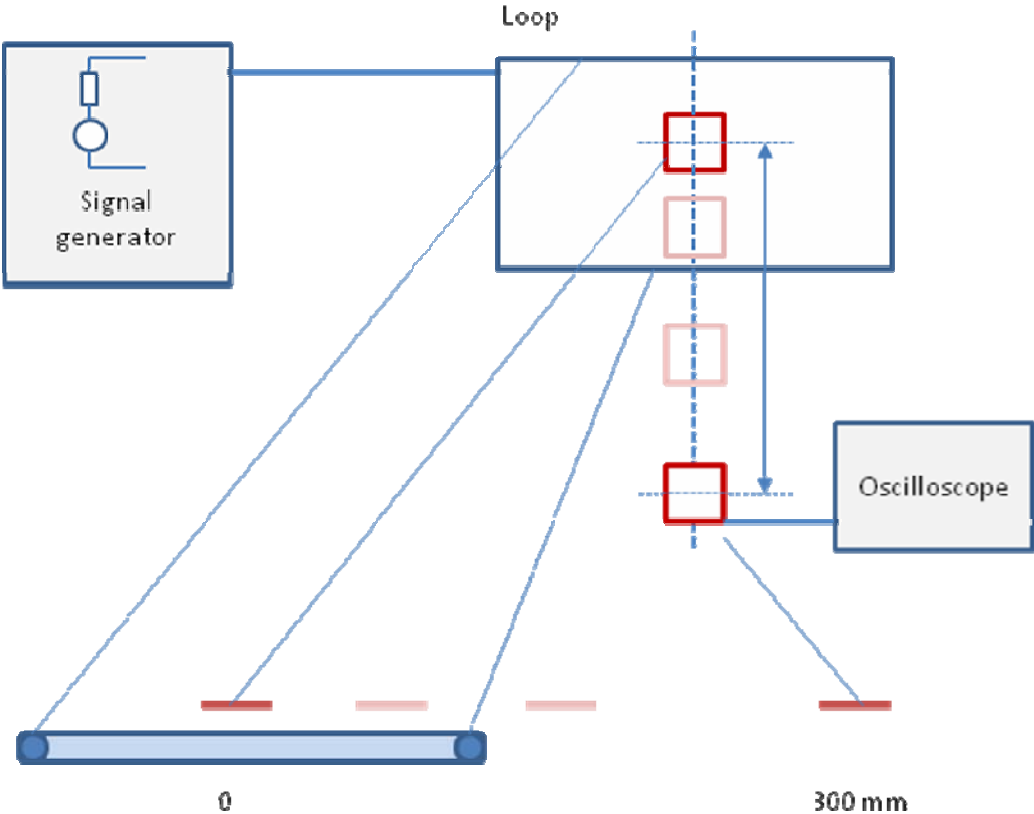

Figure 2: Experiment 2 set up - inductive coupling to test loop

3   Pre-lab questions

3.1   Calculate the self inductance

i)   large loop (150mm × 300mm, radius 0.8mm)

ii)   small loop (30mm × 30mm, radius 0.5mm)

Note: a formula for the self inductance of a rectangular loop can be found at:
http://www.technick.net/public/code/cp_dpage.php?aiocp_dp=util_inductance_calculator

$$L_{rect} \approx N^2 \frac{\mu_0 \mu_r}{\pi} \left[-2(w+h) + 2\sqrt{h^2+W^2} - h\ln\left(\frac{h+\sqrt{h^2+W^2}}{W}\right) - W\ln\left(\frac{W+\sqrt{h^2+W^2}}{h}\right) + h\ln\left(\frac{2h}{a}\right) + W\ln\left(\frac{2W}{a}\right) \right]$$

3.2   Calculate the current in the large loop

The signal generator can be considered as a voltage source with 50Ω internal impedance, and an open circuit amplitude of 2V, when the amplitude is set to 13dBm or 1V$_{rms}$; i.e. the actual generator voltage is twice as large as set - the set voltage would be observed when the generator is terminated with a matching load of 50Ω. The influence of the coaxial cable may be neglected. Calculate the current for the following frequencies:

i)   1MHz

ii)   2MHz

iii)   5MHz

iv)   10MHz

v)   20MHz

vi)   50MHz

vii)   100MHz

viii)   200MHz

ix)   500MHz

I=V/(R+2pi*f*L)

L was calucalted above

V=2U

13dBm=10Log(U^2/2)

U^2=10dBm/10

Defn of decible dB=10Log V

3.3   Predict the induced electromotive force

For 10 MHz and the current in the large loop found at 3.2, determine approximately:

i)   the magnetic field 30mm from the long side of the large loop (consider this side as infinite long, neglect all other sides of the large loop);   H=I/(2*pi*d)

ii)   the magnetic flux through the test loop at his position;   Flux=\int{U_0I/(2*pi*r)W dr

iii)   the electromotive force induced in the test loop as V$_{rms}$;

iv)   draw an equivalent circuit including the self inductance of the test loop and the capacitance of the cable (100pF);

v)   the voltage observed on the oscilloscope (input impedance: 1MΩ) as V$_{pk-pk}$.

Appendix A - Instrumentation

You will be using state of the art test instruments during your lab session. These instruments are sensitive, easily damaged, and expensive to repair. Treat all equipment gentle and ask the lab demonstrator if not sure about something.

Signal Generator: Agilent 8648A

To change settings of the signal generator follow the routine:

1) Select the parameter you want to change

2) key-in the numerical value

3) select the unit
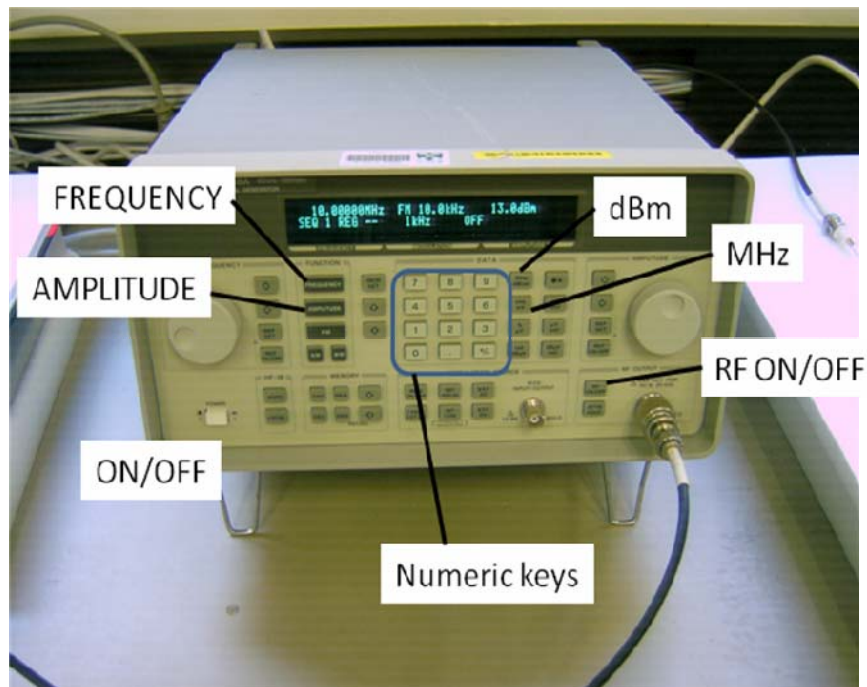
To set the amplitude to 13dBm

press: AMPLITUDE   press: '1' and '3'   press: dBm

To set the frequency to 20MHz

press: FREQUENCY   press '2' and '0'   press MHz

Make sure the RF signal is ON, and the Modulation is turned OFF (indicated in the display area).

Oscilloscope: Agilent 54641A

Switch on the oscilloscope, select Channel (Press CHANNEL 1 key until <u>it is illuminated</u>, press CHANNEL 2 key until <u>it is not illuminated</u>).
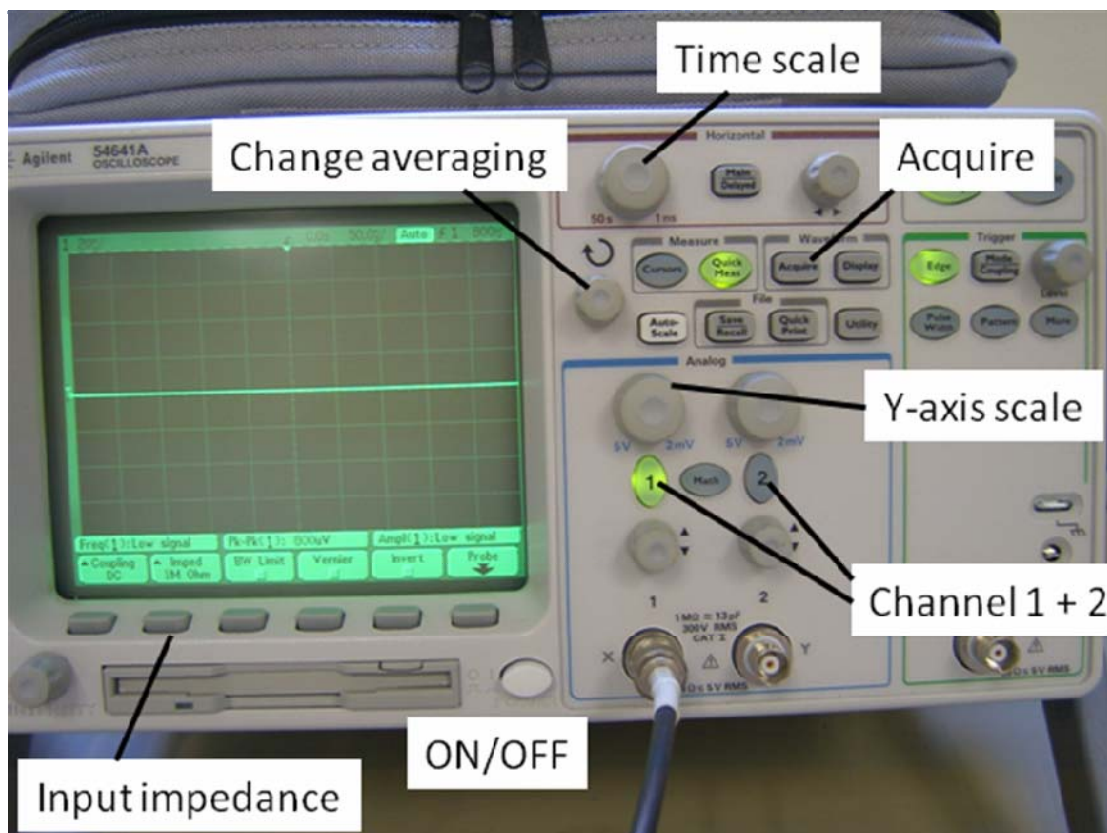
Select input impedance 1MΩ for channel 1 (Press channel 1 key, then press INPUT IMPEDANCE until 1MΩ is selected).

Set Time scale to: 50ns/div.

Set Y-axis scale to 10mV/div (you may have to adjust this setting later).

Press Acquire: select the soft key for 'Average', turn the knob for 'Change averaging' until number of averages reaches 16.

The instrument will show the Pk-Pk voltage.

Spectrum Analyser: Agilent E4411B

Press the PRESET key to bring all settings of the instrument to their default values.

Set the amplitude units to dBμV:

AMPLITUDE   Soft key: More   Soft key: dBμV

Set the span to 100kHz:

SPAN   numericals: '1' '0' '0'   Soft key: kHz

Set the frequency to the same value as the signal generator:

FREQUENCY   CENTRE FREQUENCY: numericals: ... Soft key: MHz

Press: PEAK SEARCH to set the marker to the maximum value, this value is displayed on the top right corner of the screen.

Note: Make sure that START FREQUENCY is positive, or that SPAN is less than twice the CENTRE FREQUENCY!