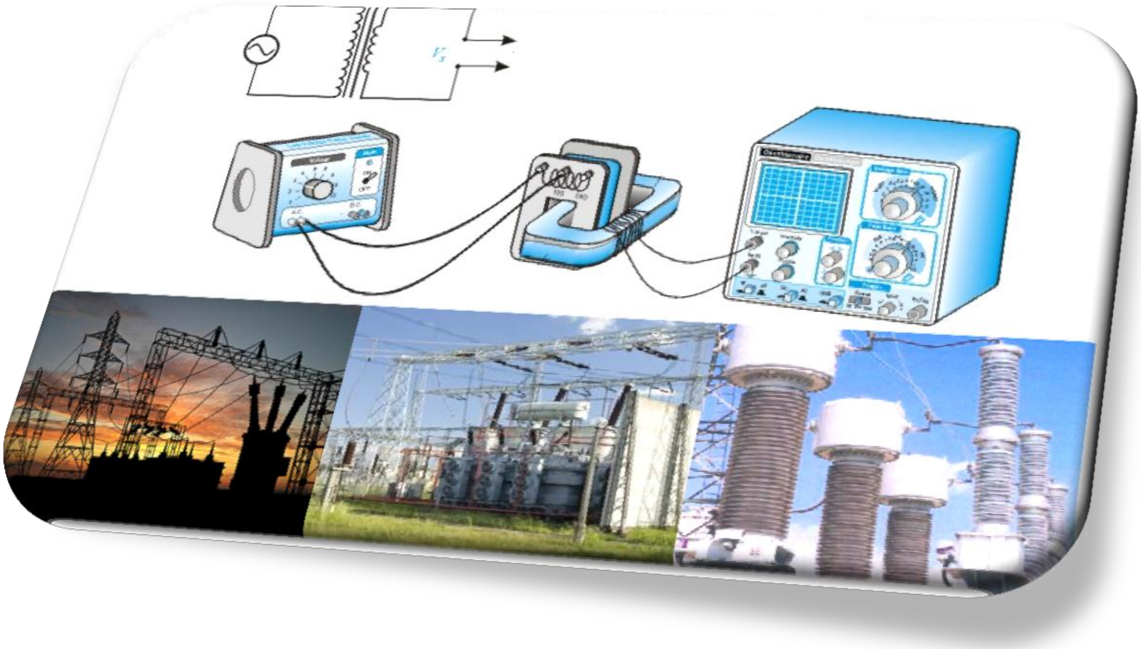
Fall | 2011

Experiment 9

Transformers



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I. OBJECTIVES

In this experiment you will investigate the following:

- Transformer operating characteristics
- Transformer equivalent circuit

II. THEORY

A. IDEAL TRANSFORMER

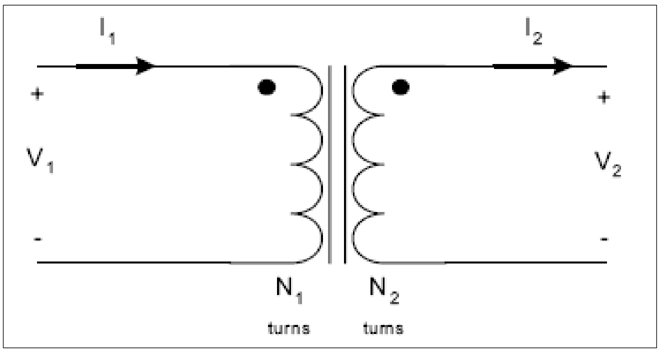

Figure A-1: Ideal Transformer

The primary and secondary AC voltages and currents in an *ideal* transformer are related by (Figure A-1):

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$\frac{I_2}{I_1} = \frac{N_1}{N_2}$$

where N_1 is the number of turns of the primary winding, and N_2 is the number of turns of the secondary winding.

It follows that an impedance Z_2 connected across the secondary terminals will be reflected as an impedance equal to $\left(\frac{N_1}{N_2}\right)^2 Z_2$, connected across the *primary*.

B. REAL TRANSFORMER

B1. EFFECT OF FINITE MAGNETIZING CURRENT

Since the permeability of the magnetic material in the core is not infinite, a certain magnetizing current is required to establish a magnetic flux in the core. The effect of the finite magnetizing current can be modeled by an inductance L_M connected across the primary winding of the ideal transformer, as shown in Figure B-1.

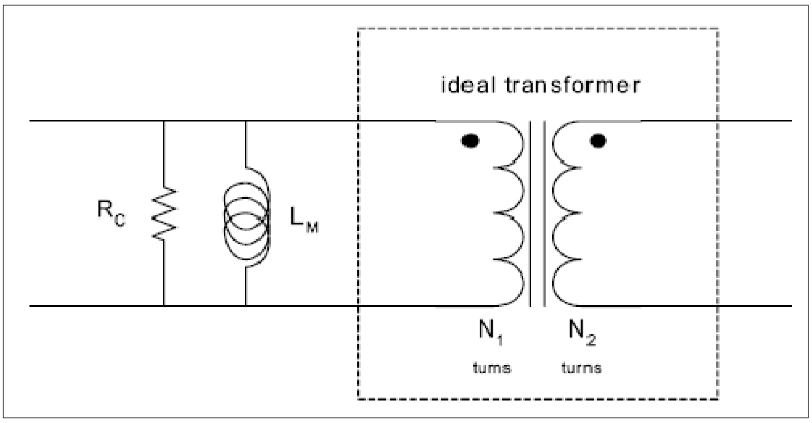

Figure B-1: Real Transformer

B2. EFFECT OF CORE LOSSES

The effect of core losses may be accounted for by adding a resistance R_C in parallel with L_M such that $\frac{{V_1}^2}{R_C}$ = core losses . See the equivalent circuit of a real transformer shown in Figure B-1.

B3. EFFECT OF LEAKAGE FLUX

A primary leakage flux links the primary winding but not the secondary; a leakage flux also exists only at the secondary. Leakage fluxes can be modeled using two inductors L_{L1} and L_{L2} as shown in Figure B-2.

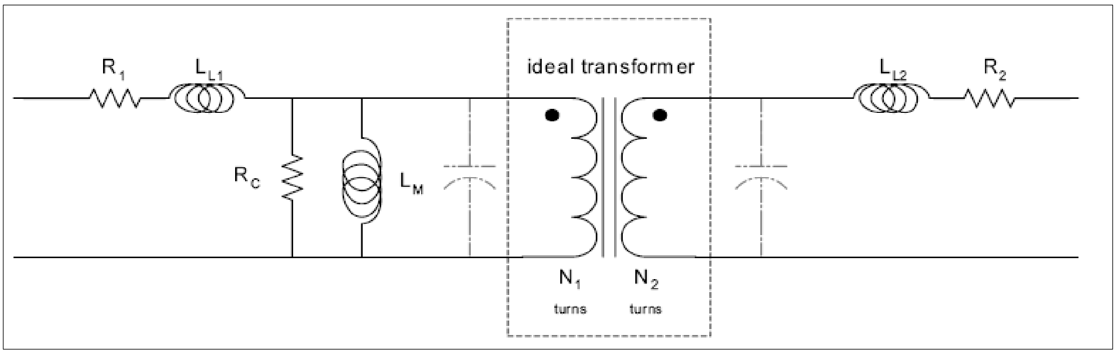

Figure B-2: Real Transformer

B4. EFFECT OF WINDING RESISTANCE

The wire resistance of the windings may be accounted for by adding two resistances R_1 and R_2, in series with L_{L1} and L_{L2}, respectively, as shown in Figure B-2. At low frequencies, these resistances are equal to their values at DC.

B5. HIGH FREQUENCY EFFECTS

At high frequencies, the capacitance of the windings should be included in the equivalent circuit. Refer to the equivalent circuit of a real transformer shown in Figure B-2.

III. MATERIAL AND PROCEDURE

A1. DC RESISTANCE

Using the DMM, measure the DC resistances of the transformer primary and secondary.

Exercise
- Refer to in-lab 9 exercise A-1

A2. POLARITY

Using the oscilloscope, establish the polarity markings of the windings of the transformer.

Exercise
- Refer to in-lab 9 exercise A-2

A3. MAGNETIZING CURRENT

Connect the circuit shown in Figure C, with R_S = 10 Ohms. Apply a sinusoidal voltage of 100 Hz frequency, and observe V_1, V_2, and the voltage drop across R_S. Note that as the voltage is increased, or the frequency is decreased, the waveform of the magnetizing current becomes markedly non-sinusoidal.

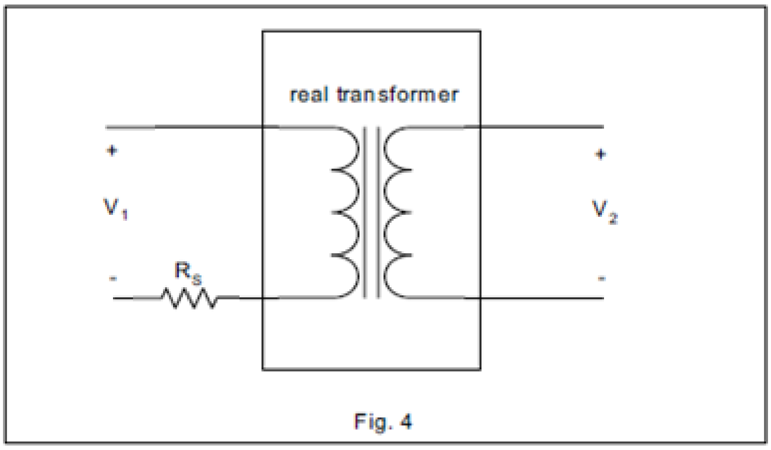

Figure C: Transformer Circuit

Exercise • Refer to in-lab 9 exercise A-3

A4. TRANSFORMER RATIO

Using a voltage level that gives a nearly sinusoidal magnetizing current, accurately measure V_1 and V_2, and determine the turns ratio N_1/N_2.

Exercise • Refer to in-lab 9 exercise A-4

A5. SQUARE WAVE INPUT

Apply a square wave of 100 Hz frequency, and observe V1 and V2. Use first a square wave without a DC component, then a square wave with a DC component.
Explain the behavior of the transformer.

Exercise • Refer to in-lab 9 exercise A-5

A6. OPEN CIRCUIT TEST

Increase the value of R_S to 100 Ohms. Apply a sinusoidal voltage of 100 Hz, adjusting the voltage so that the magnetizing current is nearly sinusoidal. Measure the magnitude and phase shift of this current with respect to V_1.

From these measurements, calculate the values of L_M and RC in Figure B-2. You may neglect the value of L_{L1} compared to L_M.

Exercise • Refer to in-lab 9 exercise A-6

A7. SHORT CIRCUIT TEST

Reduce the magnitude of the applied voltage to about a fifth of its original value, and ***with the help of the Lab Instructor*** short circuit the secondary terminals. Measure the magnitude and phase shift of the primary current with respect to V_1, and from these measurements, calculate the values of $R = R_1 + R_2\left(\frac{N_1}{N_2}\right)^2$ and $L = L_{L1} + L_{L2}\left(\frac{N_1}{N_2}\right)^2$. To calculate L_{L1} and L_{L2}, you may assume that $L_{L1} = L/2$.

Exercise • Refer to in-lab 9 exercise A-7

A8. TRANSFORMER BANDWIDTH

Connect a 100 Ohm resistor at the secondary of the transformer. Determine the bandwidth of the transformer with the load connected: find the lower cutoff frequency f_1 and the upper cutoff frequency f_2. The cutoff frequencies are the frequencies at which the output voltage is 0.7071 times its value at mid frequencies. Make sure that the magnetizing current remains sinusoidal at all frequencies.

Exercise • Refer to in-lab 9 exercise A-8

Discussion on Part A

- What are the values of the circuit elements R_1, L_{L1}, R_C, L_M, R_2, and L_{L2} in the transformer model of Fig. 3?
- What causes the distortion in the current waveform in part 3?
- How can you explain the behavior of the transformer in part 5?
- How does the measured value of R in part 7 compare with the calculated value from R_1, R_2, and the turns ratio N_1/N_2?
- Calculate the transfer function $V_2(s)/V_1(s)$ of the transformer with a load R_L connected at the secondary. Using the transformer model of Fig. 3 and with RL = 100 Ohm, find the the value of the total winding capacitance $C = C_1 + (N_2 / N_1)^2$ from the measured upper cutoff frequency f_2.

IV. OUTCOMES

By the end of Experiment IX, students:

- Are familiar with ideal and real transformer characteristics
- Are able to compute (experimentally and theoretically) the real transformer characteristics