LABORATORY 13: Transformers

Material covered:
- Transformers

Overview Notes:

Transformer Circuit Parameters

The transformer is two physically separated winding circuits which uses magnetic fields to couple the currents (and voltages) between the two windings. By convention the primary side can be considered to have $N_1$ windings and the secondary side has $N_2$ windings, where the source is on the primary side. The winding ratio is then defined as $N = N_2/N_1$. Note, in most transformers, it doesn’t matter physically which side is the primary and which side is the secondary. Therefore, if the winding ratio is some value, $N_a$, then ‘reversing’ the transformer results in a winding ratio $1/N_a$.

Given the winding ratio, the relationship between the primary side current and voltage ($I_1$ and $V_1$) and the secondary side current and voltage ($I_2$ and $V_2$) are

\[
V_2 = N \cdot V_1 \\
I_2 = I_1/N
\]

These relationships are valid for ideal transformers. In practice, transformers are limited by frequency and have internal losses that will affect these expressions. For this lab, we will use ideal the ideal transformer expressions.

In circuit analysis of transformers, we can investigate either the primary side or the secondary side using equivalent circuit models. Considering the primary side, we then need an equivalent impedance that represents the impedance and the load circuit. The technique is called “referring the secondary to the primary” and circuit analysis gives the following equivalent circuit
Referring the Secondary to the Primary

The equivalent load impedance then becomes \( Z_{LEQ} = \frac{Z_L}{N^2} \).

Likewise, we can “refer the primary to the secondary”, where the transformer, the source and the source impedance form the following equivalent circuit

\[
Z_{SEQ} = N^2 \times Z_S
\]

Referring the Primary to the Secondary

The equivalent source is then \( V_{S_{EQ}} = N \times V_S \) and the equivalent source impedance is then becomes \( Z_{S_{EQ}} = N^2 \times Z_S \).

**PSpice**

The transformer component in PSpice is XFRM_LINEAR. In order to set the winding ratio, you need to edit the part itself by double-clicking. The model implements two inductors with a coupling coefficient (which will be discussed in class). The default coupling coefficient is 1 and you should leave that setting for now. You can set the winding ratio by entering values for L1_VALUE and L2_VALUE, such that the winding ratio is \( N = \sqrt{\frac{L_2\_VALUE}{L_1\_VALUE}} \). Additionally, due to the more complete transformer model, the inductor values need to be sufficiently large that they don’t affect the transformer characteristics. For our purposes, you can use integer values.

**Transformers**

The transformers provided have numerous taps. We will use H1-H4 (120) on one side and X1-X3 (120) or X1-X2(60) on the other side. The number in parenthesis can be used to determine the winding ration. For example H1-H4(primary)/X1-X3(secondary) gives a winding ratio of 1, whereas H1-H4(primary)/X1-X2(secondary) gives a winding ratio of \( \frac{1}{2} \) (a step down transformer).
Laboratory:

**Part 1:**

1. Configure the transformer circuit shown above using a 4V amplitude source with a 5kHz frequency. Use a winding ratio of 1. The load is an open circuit. Based on discussion in class, what is the expected measured voltage at V1 and V2? Measure those values using the Oscilloscope on the Discovery Board.

2. Change the winding ratio to 0.5 and measure V1 and V2 again. What do you expect to change? Are your measurements consistent with expectations (or close)?

3. Short circuit the load and measure V1. Again, is your measurement consistent with expectations? Most likely, it is a little bit off. What real circuit properties may explain the difference with expectations?
To implement the above winding ratio, you will need to put the source on the X1-X2 side and the load on the H1-H4 side.

4. Based on ideal transformer equations, calculate V1, V2, I1 and I2.
5. Measure V1, V2, I1 and I2 (note you can get I2 directly from the V2 measurement and I1 by measuring the voltage across RS). Are you measurements close to expectations?

6. Implement a ‘step down’ transformer by changing the winding ratio to 1/2 (reversing the source/load connections on the transformer) and repeat parts 4 and 5.

Extra Credit (2 pts)
Reduce the frequency steadily down to 1 Hz (or lower). At what frequency do the transformer equations start to fail? Explain these phenomena in terms of real transformer characteristics.