Exercise 8: Transformers

Purpose: to investigate basic characteristics of transformers, including voltage and current relationships between primary and secondary coils. Half-wave and full-wave rectifiers will also be examined.

Introduction

Transformers are devices that transfer electrical energy from one circuit through another through a linked magnetic field, where an example is shown in Fig. 1. An alternating current in a primary circuit creates a changing magnetic flux in the primary coil, which is linked to a secondary coil, usually by an iron core. The changing magnetic flux in the secondary coil produces an induced emf. A *perfect* transformer has no magnetic flux leakage between the primary and secondary coils, and no resistance in either the primary or secondary coils. Under these conditions, the magnetic flux change per coil is the same for the primary coils and secondary coils, and Faraday's Law of Induction can be used to obtain the relationship

$$\frac{V_S}{N_S} = \frac{V_P}{N_P}$$

where V_P is the voltage across the primary coil, is N_P the number of loops in the primary coil, is V_S the voltage across the secondary coil, and N_S is the number of loops in the secondary coil.
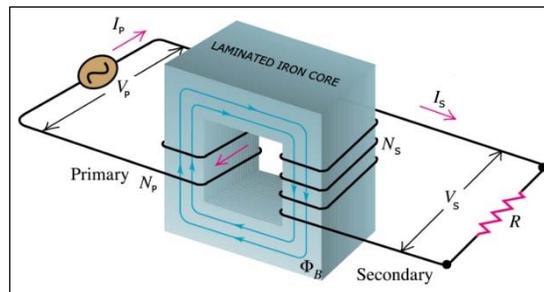

Fig. 1: Schematic diagram of a transformer.

The power delivered to the load resistance must be equal to the power into the secondary coil. For a perfect transformer, the power delivered to the secondary is equal to the power delivered from the primary, which allows us to write

$$I_S N_S = I_P N_P$$

where I_P is the current in the primary coil and I_S is the current in the secondary coil. The average power delivered by the primary circuit is exactly equal to the average power dissipated by the resistor in the secondary circuit,

$$P_{\text{avg},S} = P_{\text{avg},P}$$

Note that real transformers do not perfectly follow these simple equations for many reasons. Most notably, the efficiency of transformers is reduced via Joule heating.

Laboratory assignment

1. Plug one voltage/current sensor into the PowerLink connector. Turn on data Studio software and make sure that the sensor is recognized by the software.
2. Open a scope window and set it to display voltage and current.
3. Build a simple circuit with the frequency generator, current sensor, and 400 turn coil all in series (the coil will be the primary coil of a transformer). Place the voltage sensor to measure the terminal voltage across the coil.
4. With amplitude turned completely off, turn on the frequency generator and set the frequency to 60 Hz.
5. Slowly increase the amplitude and make sure you get both a voltage signal and a current signal in the scope window. The voltage should lead the current; if not, then switch the leads.
6. In a perfect coil, the phase angle between the voltage and current should be 90°. Measure the phase angle. Explain why it is less than 90°.
7. Adjust the frequency generator to give an amplitude of 2 volts.
8. Plug the second voltage/current sensor into PowerLink, make sure it is recognized, and add the second voltage reading to the scope window. Plug the voltage sensor directly into the secondary coil.
9. Place the secondary coil end-to-end with the primary coil. Readjust the primary voltage amplitude to 2 volts if necessary.
10. Use the "smart tool" to measure and record the voltage amplitude in the primary coil V_P, and in the secondary coil, V_S.
11. Place the iron bar through the primary and secondary coils as shown in Fig. 2. Adjust V_P to 2 volts, and measure V_S.
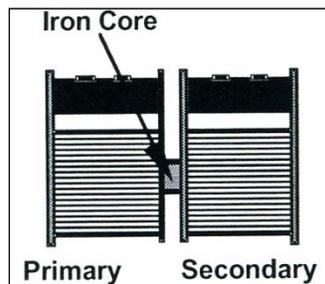
Fig. 2: The experimental setup of the transformer with iron core in step 11.

12. Place the primary and secondary coils on the U-shaped piece of iron as shown in Fig. 3. Adjust V_P to 2 volts, and measure V_S.
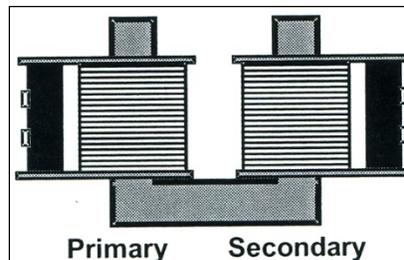
Fig. 3: The experimental setup of the transformer with U-shaped iron core in step 12.

13. Place the iron bar on top of the U-shaped iron and screw it down with the threaded pin as shown in Fig. 4. Adjust V_P 2 volts, and measure V_S.
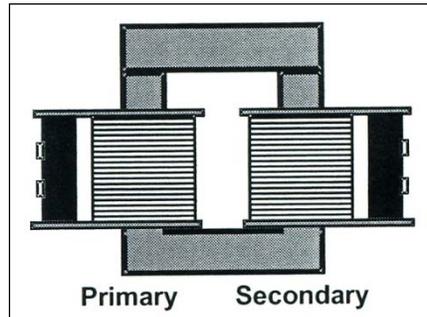

Fig. 4: The experimental setup of the transformer with looped iron core in step 13.

14. Make a table similar to Table I with the data for the four transformer cases.

Table I: terminal voltages of transformer types.

Transformer type	V_P (V)	V_S (V)
No core		
Bar core		
U-shaped core		
Looped core		

15. Using the coil configuration that gave the largest V_S with a primary coil of NP=200 turns, measure V_P, V_S, I_P, and the phase shift information between V_P and I_P (θ_{PP}), and between V_S and I_P (θ_{SP}) for all of the other coils ($N_S = 400, 800, 1600, 3200$). When changing coils, turn the amplitude down completely, and then adjust the amplitude to give a reading of 2 volts on the secondary coil. The primary coil voltage will be less. Also note that the frequency generator should be in series with the primary coil and the current sensor.

16. Make a table similar to Table II with the data for the four transformer cases.

Table II: measurements from step 15.

N_S	V_P (V)	V_S (V)	I_P (mA)	θ_{PP} (°)	θ_{SP} (°)
400					
800					
1600					
3200					

17. Replace the primary coil with the 400 turn coil, $N_P = 400$, and the secondary coil with the 800 turn coil, $N_S = 800$.

18. Add a load resistor of 100 Ω to the secondary coil to complete the secondary circuit as shown in Fig. 5. Use a breadboard for small components like the resistor.
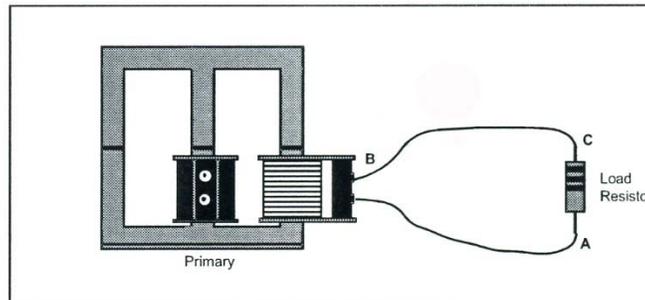

Fig. 5: secondary circuit with load resistor.

19. Open a scope window in Data Studio and add V_P, I_P, and V_S traces. Turn on the frequency generator and adjust V_P to 2 volts.
20. Use the "smart tool" to measure V_P, I_P, and V_S. Save a copy of the scope window.
21. Add a diode in series with the resistor as shown in Fig. 6. The band on the diode should point toward the resistor. Adjust V_P to 2 volts.
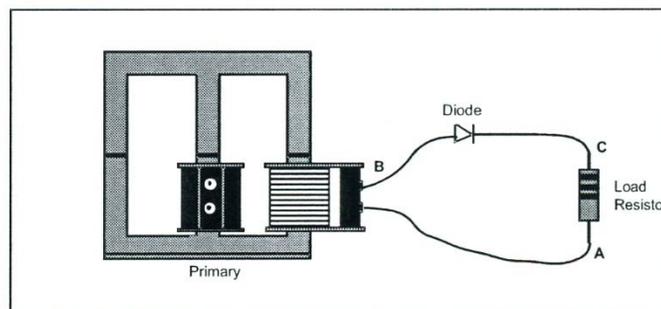

Fig. 6: secondary circuit with load resistor and diode.

22. Measure V_P, I_P, and V_S. Save a copy of the scope window.
23. Add a 100 μF capacitor in parallel with the resistor as shown in Fig. 7. Adjust V_P to 2 volts.

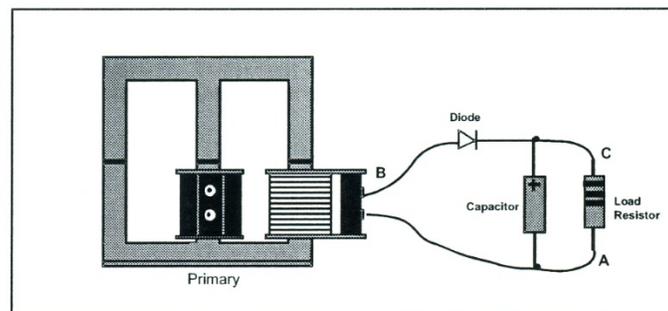*Fig. 7: secondary circuit with load resistor, diode, and capacitor.*

24. Measure V_P, I_P, and V_S. Save a copy of the scope window.
25. Replace the 100 µF parallel capacitor with a 330 µF capacitor. Adjust V_P to 2 volts.
26. Measure V_P, I_P, and V_S. Save a copy of the scope window.
27. Replace the 330 µF parallel capacitor with a 470 µF capacitor. Adjust V_P to 2 volts.
28. Measure V_P, I_P, and V_S. Save a copy of the scope window.
29. Make a table similar to Table III.

Table III: Measurements from steps 20 to 28.

Circuit type	V_P (V)	V_S (V)	I_P (mA)
$R_L = 100\ \Omega$			
R_L & diode			
R_L, diode, & 100 µF			
R_L, diode, & 300 µF			
R_L, diode, & 470 µF			

30. Describe what happens by increasing the capacitance across the load resistance in the half-wave rectifier.
31. Now create a circuit by setting the a primary coil to $N_P = 200$ and use two secondary coils of $N_S = 400$ each, and place them in series on the three-column transformer core. Note that the coiling direction of the two secondary coils must be the same.
32. Set up the secondary circuit for a full wave rectifier with 100 Ω load resistance shown in Fig. 8. Adjust V_P to 2 volts.
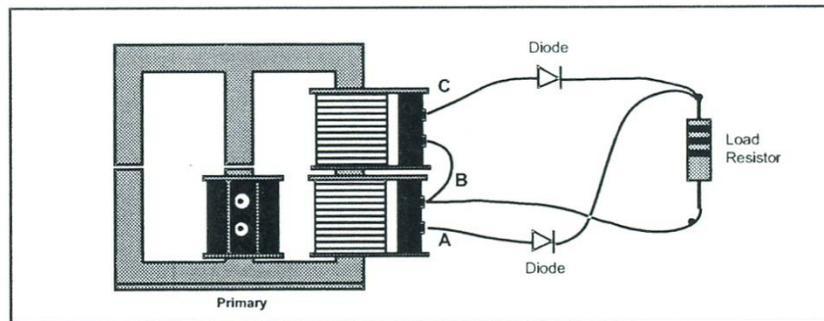

Fig. 8: secondary circuit with load resistor and full-wave rectifier.

33. Measure V_P, I_P, and V_S. Save a copy of the scope window.
34. Add a 100 µF capacitor in parallel with the resistor. Adjust V_P to 2 volts.
35. Measure V_P, I_P, and V_S. Save a copy of the scope window.
36. Replace the 100 µF parallel capacitor with a 330 µF capacitor. Adjust V_P to 2 volts.
37. Measure V_P, I_P, and V_S. Save a copy of the scope window.
38. Replace the 330 µF parallel capacitor with a 470 µF capacitor. Adjust V_P to 2 volts.
39. Measure V_P, I_P, and V_S. Save a copy of the scope window.
40. Replace the 100 Ω resistor with a 10 Ω resistor. Adjust V_P to 2 volts.

41. Measure V_P, I_P, and V_S. Save a copy of the scope window.
42. Replace the 10 Ω resistor with a 1 kΩ resistor. Adjust V_P to 2 volts.
43. Measure V_P, I_P, and V_S. Save a copy of the scope window.
44. Make a table similar to Table IV.

Table IV: Measurements from steps 33 to 43.

Circuit type	V_P (V)	V_S (V)	I_P (mA)
100 Ω, 2 diodes			
100 Ω, 2 diodes, & 100 μF			
100 Ω, 2 diodes, & 330 μF			
100 Ω, 2 diodes, & 470 μF			
10 Ω, 2 diodes, & 470 μF			
1 kΩ, 2 diodes, & 470 μF			

45. Discuss the differences between the half-wave rectifier and full-wave rectifier.
46. Which one, half-wave rectifier or full-wave rectifier, is better suited to produce DC from an AC source?

Equipment list: Laptop computer with Data Studio software, Pasco PasPort Powerlink, Pasco PasPort voltage/current sensor (2), red banana/banana patch cord (6), red banana/alligator adaptors (6), black banana/banana patch cord (6), black banana/alligator adapters (6), Pasco Frequency Generator, Pasco EM8656 electronics laboratory board, Pasco wire kit for electronics laboratory board, Pasco coil kit, 100 μF polarized capacitor, 330 μF polarized capacitor, 470 μF polarized capacitor, pn junction diode (2), decade resistance box.