DOCUMENT RESUME

ED 099 507 CE 002 584

TITLE Module Ten: Transformers; Basic Electricity and Electronics Individualized Learning System.
INSTITUTION Bureau of Naval Personnel, Washington, D.C.
REPORT NO NAVPERS-94558-10a
PUB DATE Jan 72
NOTE 135p.; For other modules in the series, see CE 002 573-589

EDRS PRICE MF-$0.75 HC-$6.60 PLUS POSTAGE
DESCRIPTORS Course Content; *Electricity; *Electronics; Individualized Instruction; Individualized Programs; Industrial Education; Military Training; Post Secondary Education; *Programed Instruction; *Programed Materials; Study Guides; Trade and Industrial Education; Units of Study (Subject Fields)

ABSTRACT

The module introduces a very important electrical device, the transformer. The module is divided into six lessons: transformer construction, transformer theory and operation, turns and voltage ratios, power and current, transformer efficiency, and semiconductor rectifiers. Each lesson consists of an overview, a list of study resources, lesson narratives, programed instructional materials, and lesson summaries. (Author/BP)

NAVPERS 94558-10a

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

MODULE TEN

TRANSFORMERS

Study Booklet

BUREAU OF NAVAL PERSONNEL

January 1972

OVERVIEW

MODULE TEN

TRANSFORMERS

In this module you will be introduced to a very important electrical device, the transformer. As you will learn, without transformer action the practical, economical application of electrical energy would be nearly impossible.

For you to more easily learn the above, this module has been divided into the following six lessons:

TURN TO THE FOLLOWING PAGE AND BEGIN LESSON I.

NAVPERS 94558-10a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE TEN
LESSON I

Transformer Construction

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON I

Transformer Construction

In this lesson you will study and learn about the following:

- -what a transformer is
- -function of transformers
- -inside a transformer
- -the core
- -core construction
- -laminations
- -core shapes
- -coils or windings
- -schematic symbols for transformers

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON I

Transformer Construction

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON 1

Transformer Construction

What a Transformer Is

Look at your power supply and find the largest wired component. You have just identified the transformer. Probably you have observed a similarity between the shape of the transformer and the iron-core inductor in your power supply. Both of these components are capable of inducing a voltage.

Most power supplies have a transformer. From this statement, you can infer that most TV sets, radios, and almost all amplifying equipment contain transformers.

Transformers are of many different sizes. There are small ones like the one in your power supply, but there are also giant transformers in substations of power companies. Whatever the size of a transformer, its purpose is the same.

Function of Transformers

A transformer is a device that transfers electrical energy from one circuit to another via electromagentic induction. The energy is always transferred without a change in frequency but usually involves changes in voltage and current. Because transformers work on the principle of induction, they must have an AC source to supply a continuous output.

What do you think would happen if we put pure DC into a transformer? ________________________

After current had reached the maximum steady value described by the basic Ohm's Law, there would be no change in current, the frequency would be zero, and there would be no inductive reactance. The coil would act like a straight piece of wire; current could become too great and burn out the transformer.

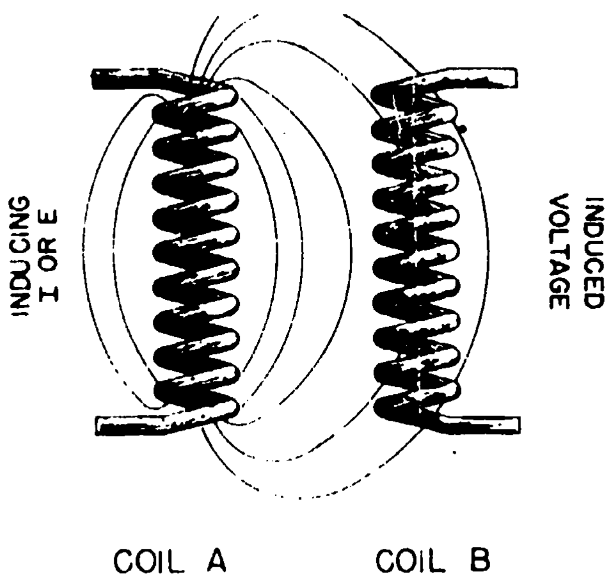
A transformer steps up or steps down AC voltage. For example, the voltage entering the transformer on your power supply is greater than the voltage leaving the transformer. In this manner, your power supply can provide a lower voltage to the load than the wall socket could. The transformer in your power supply is a <u>step-down</u> transformer.

Inside a Transformer

A transformer is a very efficient device because it has no moving mechanical parts that might malfunction, and it requires very little maintenance. If you were to look inside a transformer, you would see at least two coils, maybe more, and a core. The coils and core are the only essential parts of a transformer.

The Core

Just as an inductor has either an iron core or an air core, a transformer usually has either an air core or some form of an iron core. A transformer is actually two or more inductors positioned so that the flux lines of one cut the coils of the other. Generally, air-core transformers are used when the source has a frequency above 20 KHz; however, special ferrite cores may be used at very high frequencies.



Iron-core transformers are usually used when the source frequency is in the audio range (below 20 KHz).

Your power supply operates on a frequency of 60 Hz. What kind of core does the transformer in your power supply have?

____

Your power supply has an iron core to obtain high inductance at low frequencies.

Core Construction

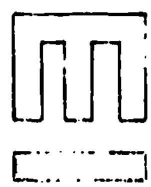
Iron cores in transformers are not solid hunks of iron or steel. If they were, the flux lines cutting them would induce large currents in the core, and thus rob the circuit of power.

Laminations

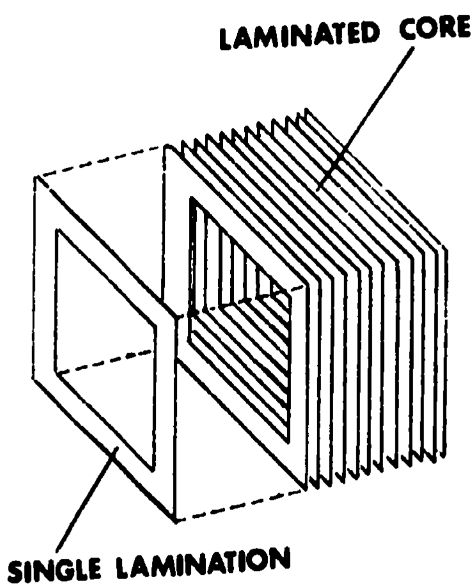
To minimize this loss, cores are made of many thin slices of core material. Each slice is coated with insulating varnish which is a non-conductor. These slices of core are called laminations. After all the laminations are varnished, they are then bonded together to form core shapes.

Core Shapes

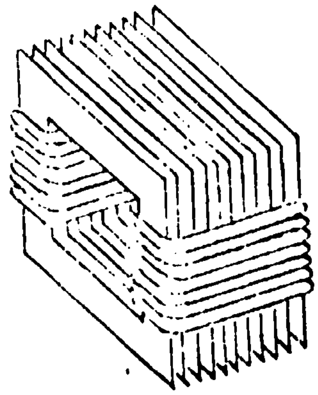
There are two main core shapes used in transformers. One we call the hollow-core type, because it has a hollow square in its center. The other is called either a shell type or E and I type, because it looks like these two letters put together like this:



Hollow Core



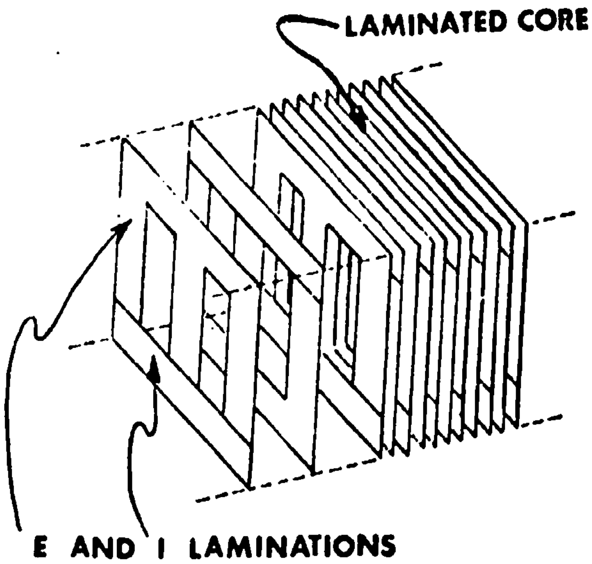
This illustration shows a hollow-core transformer. Notice that it is constructed of many laminated slices of iron or steel. After the laminations have been bonded together, the coils are wrapped around both sides of the core as shown on the next page.

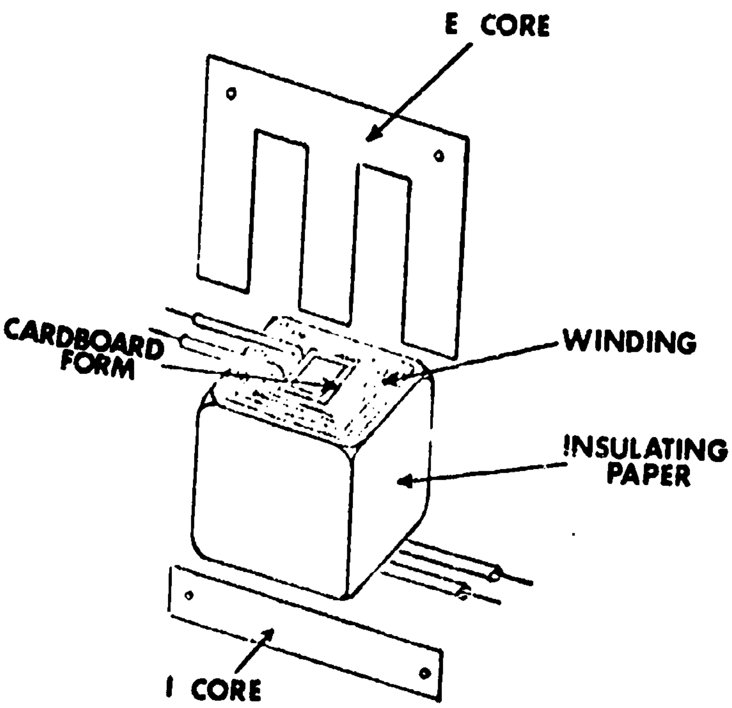


We have learned previously that the closer the coils are without touching, the greater the magnetic coupling. It is apparent that quite a bit of space exists between the two coils in a hollow-core transformer. From this, we can assume that this type of transformer will not have a maximum coefficient of coupling.

Shell Type

The most commonly used and most efficient laminated core is called a shell or E and I Type core. Observe that this core is made of the laminated pieces that resemble E's and I's. The laminations in the shell core are also varnished to provide insulation. For the shell core, the coils are all wound on the same center, and the legs of the E are set down through the coil as shown below.





This design provides a high coefficient of coupling.

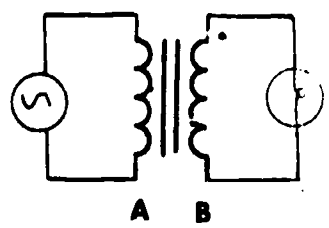
Coils or Windings

The wires or coils in a transformer are referred to as windings. Transformers have a primary winding and one or more secondary windings. Occasionally a transformer will have more than one primary.

The primary winding connects to the source.

The secondary winding connects to the load or loads.

Identify:



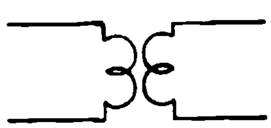
____ 1. Secondary winding

____ 2. Primary winding

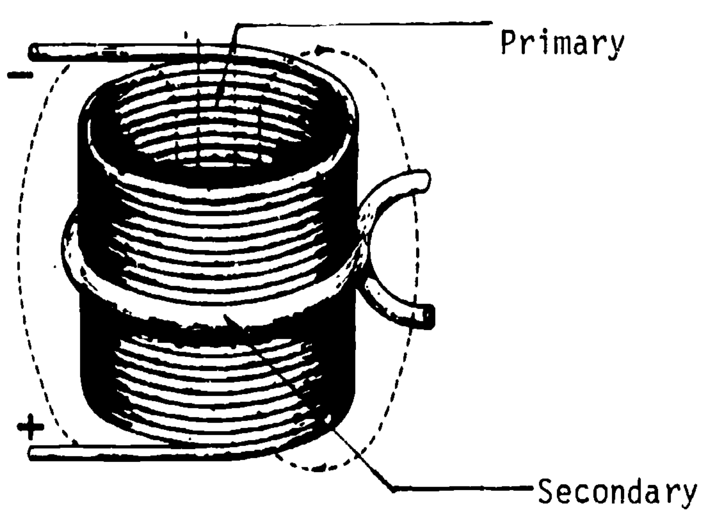
You can see that coil A is connected to the source and therefore is the primary. B is connected to the load, so it is a secondary.

How Coils Are Wound in Shell Type

You recall that windings in the hollow core are placed side by side



This is not the case with windings in a transformer with the shell-type core. To achieve maximum coefficient of coupling and save space, in a shell-type core the secondary winding is wound on top of the primary winding as shown here.



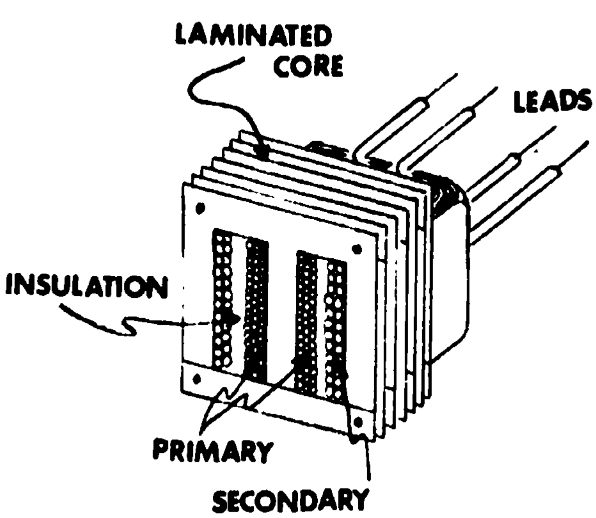
First, the primary winding is wrapped around a cardboard cylinder forming many turns of wire. These turns are placed close together. The wire is coated with insulating material to prevent short circuits between wires. After the primary is completely wound, it is covered with a special insulating material -- usually paper or cloth.

The secondary winding then is wound on top of the primary winding; however, the wires do not touch because they are separated by the insulating material. This material allows magnetic flux lines to pass from one winding to another, so that magnetic induction can take place. Finally, the secondary winding is covered with an insulating material to prevent contact between the winding and the metal transformer case.

Your power supply transformer is constructed with an E and I type core. Will the windings be:

____ a. two coils separated by space.
____ b. two coils, wound one on top of the other.

Answer: b



The core sections are then inserted into the windings and the E and I are butted together.

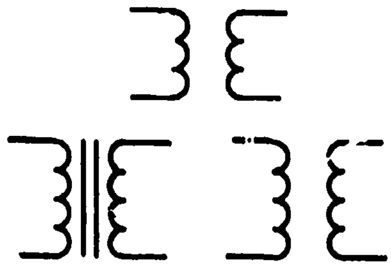
Leads

Notice in the illustration that there are two leads for the primary and two leads for the secondary.

These will be connected to the source and load, respectively.

Schematic Symbols for Transformers

A basic transformer symbol looks like two coils as shown.



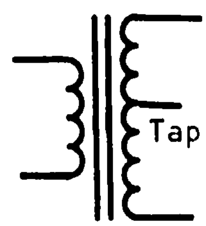
Iron Core Air Core

Bars between the coils indicate an iron core. If there are no bars, the symbol represents an air core.

We mentioned that transformers frequently have more than one secondary winding. This is for the purpose of supplying multiple loads of different voltages. Sometimes a transformer has more than one primary.

Occasionally a winding has taps which allow delivery of different voltages from the same secondary.

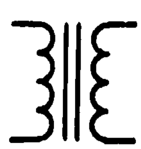
Iron Core
1 Primary
1 Secondary with
a center tap



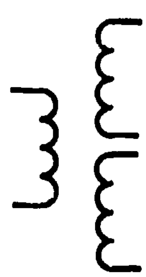
If there is 12v across the entire secondary, and we measure between the top lead and the center tap, what do you think voltage is? ________

Answer: 6 volts.

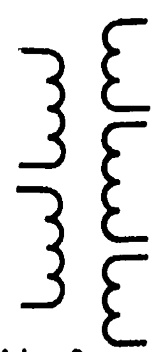
Other schematic representations might be:



Iron Core
1 Primary
1 Secondary



Air Core
1 Primary
2 Secondaries



Air Core
2 Primaries
3 Secondaries

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON I

Transformer Construction

THIS PROGRAM SEQUENCE HAS NO TEST FRAMES.

1. Transformers come in many different sizes, ranging from smaller ones than the one in your power supply to the very large ones used by commercial power companies. Regardless of the size, the function is the same, to transfer electrical energy between two electrically isolated circuits.

   The function of the transformer in your power supply is to:

   ____ a. develop electrical energy to light the lamp.
   ____ b. change alternating current to direct current.
   ____ c. transfer energy from the wall socket to the circuit containing the lamp.

(c) transfer energy from the wall socket to the circuit containing the lamp

---

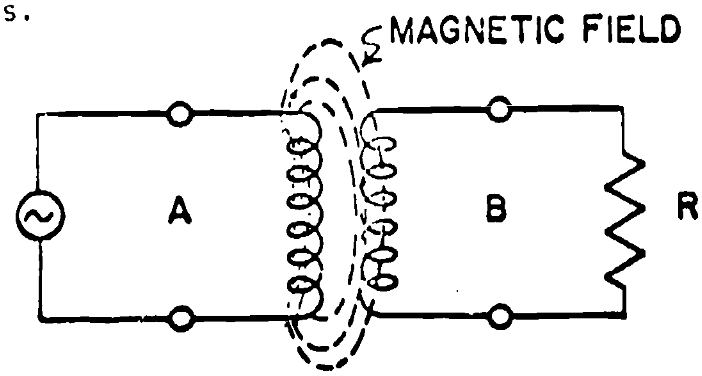
2. The purpose of a transformer is to transfer electrical energy from one circuit to another isolated circuit.

   Can you generate power with a transformer alone?

   ____ a. yes.
   ____ b. no.

(b) no

3. The energy transfer is accomplished by mutual induction between two or more coils.



If a changing current flows through coil A, a changing magnetic field is produced. This varying flux field cuts coil B, inducing a voltage and causing a current to flow through the load (R).

Since neither coil A nor coil B can be moved without both being moved, there is an induced voltage in coil B only as long as:

____ a. the magnetic field is changing.
____ b. a stable magnetic field exists.

- -

(a) the magnetic field is changing

4. Recall that for a stationary coil to continuously induce a voltage (electromagnetic induction), there must be a continuously changing current.

Would a coil be capable of continuously producing electromagnetic induction if placed in a DC circuit?

____ a. yes
____ b. no

- -

(b) no

5. Transformers and coils have some similarities in both construction and operation; both utilize the phenomenon of electromagnetic induction, and therefore induced voltages are associated with transformers and coils. Their uses are different, however.

Would a transformer function in a pure DC circuit?

____ a. yes
____ b. no

- -

(b) no

6. Transformers are useful only in AC circuits because:

(Check the statements that are true.)

____ a. pure DC does not vary in value.
____ b. DC voltages are too high.
____ c. alternating current is constantly changing in direction and magnitude.
____ d. electromagnetic induction depends on a changing magnetic field.
____ e. there is no magnetic field associated with direct current.
____ f. a DC transformer is too large to be practical.

- -

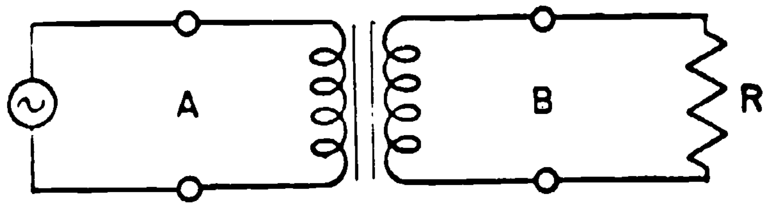
(a. pure DC does not vary in value; c. alternating current is constantly changing in direction and magnitude; d. electromagnetic induction depends on a changing magnetic field.)

7. A transformer is one of the most common electrical devices used. It consists mainly of wire wound into coils about some type of core. Since ____________ have no moving mechanical parts to malfunction, they are very efficient and require very little maintenance.

- -

(transformers)

8. A simple transformer consists of two coils placed so that the flux lines from one cut the turns of the other as shown in the diagram.

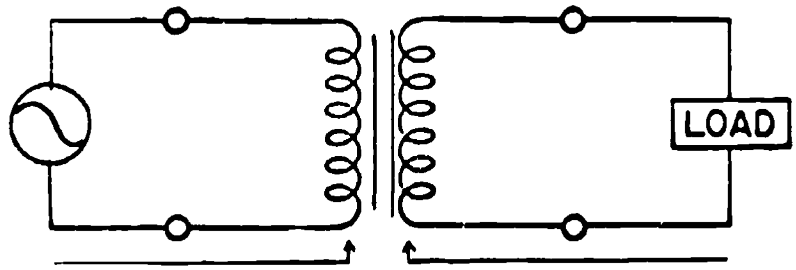


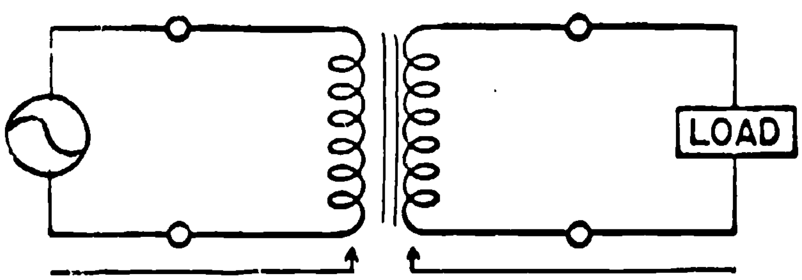
Coil A is known as the primary coil, while coil B is called the secondary.

The primary coil is connected to the ____________ while the secondary is connected to the ___________.

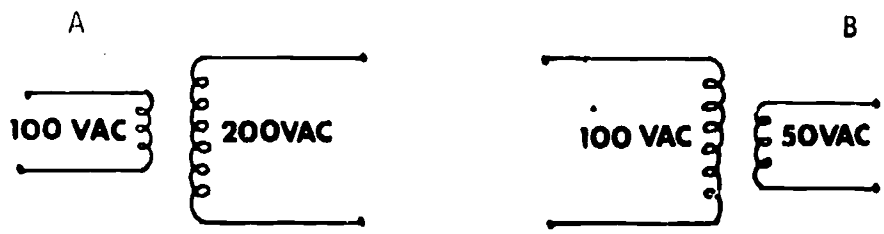
(source or input; load [resistor] or output)

9. Label the primary winding and the secondary winding in the transformer below.





10. Transformers can be used to step-up or step-down voltage. This can be done by increasing or decreasing the number of turns in the secondary winding as compared with the number of turns in the primary winding.

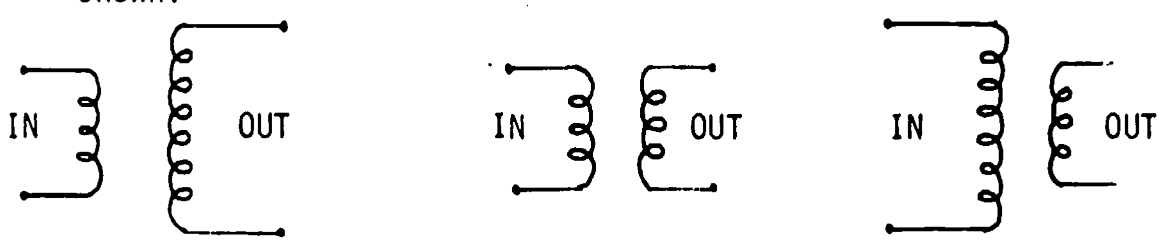


Select the true statement.

____ a. A is a step-down transformer, B is a step-up transformer.
____ b. A is a step-up transformer, B is a step-down transformer.
____ c. Both are step-up.
____ d. Both are step-down.

(b) A is a step-up transformer, B is a step-down transformer

11. Label the step-up transformer and the step-down transformer shown.



a. ____________ b. ____________ c. ____________

(a) step-up; b. neither, one-to-one; c. step-down)

12. Note: You can often tell if a transformer is a step-up or ________ by looking at a drawing. Due to the space limitations on most schematics, the actual turns ratio is seldom drawn, but may be indicated numerically.

(step-down)

13. The transformer in the power supply you built is:

____ a. step-up.
____ b. step-down.
____ c. neither.

- -

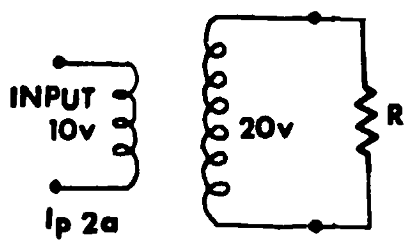
(b) step-down

14. Note that the terms <u>step-up</u> and <u>step-down</u> refer to ____________, <u>not</u> to power.

- -

(voltage)

15. The law of conservation of energy tells us that energy is neither created nor destroyed, but that it can be changed in forms. You cannot expect to get something for nothing. This is also true in transformers. If the secondary voltage is higher than the primary voltage, secondary current will be smaller than primary current in the same proportion. Output power can never be larger than input power, but may be somewhat less because of losses in the transformer itself. For the circuit shown, secondary current equals __________, assuming there are no losses in this transformer.



- -

(1 a)

16. Each transformer characteristic listed below applies to either a step-up or a step-down transformer. Underline your choice at the end of each statement.

a. higher primary current than secondary (step-up/step-down)
b. higher primary voltage than secondary (step-up/step-down)
c. lower secondary current than primary (step-up/step-down)
d. higher secondary voltage than primary (step-up/step-down)
e. lower primary current than secondary (step-up/step-down)

(a. step-up; b. step-down; c. step-up; d. step-up; e. step-down)

17. Energy transfer from primary to secondary is accomplished by mutual induction between two or more coils and usually results in changes in voltage and current but never in frequency.

If the input signal to a step-up transformer is 400 Hz, the output would be:

____ a. 200 Hz.
____ b. 400 Hz.
____ c. greater than 400 Hz.
____ d. (insufficient information)

(b) 400 Hz

18. Check the statements about transformer operations that are true.

____ a. usually involves change in voltage and current
____ b. uses a pure DC source
____ c. involves changes in voltage and frequency
____ d. capable of stepping voltage up or down
____ e. transfers electrical energy from one circuit to another

---

(a. usually involves change in voltage and current; d. capable of stepping voltage up or down; e. transfers electrical energy from one circuit to another)

19. Air core transformers are usually used at high frequencies (above 20 KHz). Due to the high rate of change of current at these frequencies, an iron core is not needed to increase the inductance of the coils. At low frequencies, an iron core is used to concentrate the flux lines and increase mutual inductance.

Your power supply operates at an input frequency of 60 Hz. What kind of core does the transformer have?

____ iron
____ air

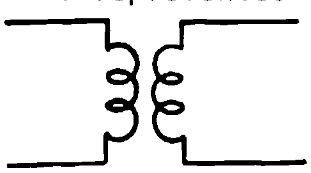
(iron)

20. A transformer is basically two or more coils wound around some type of core. As with inductors, the cores are usually either iron or air.

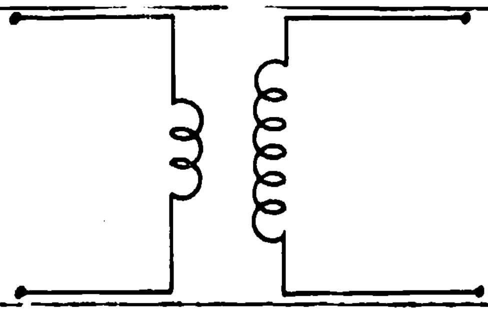
An air-core transformer is used at ________ frequencies.
high/low

(high; usually 20 KHz and above)

21. An air-core transformer is represented schematically like this:

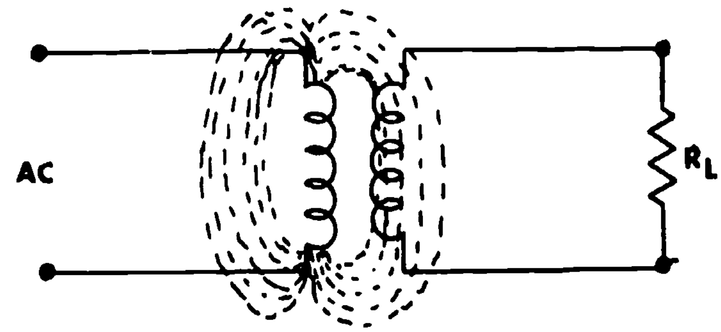


Draw the schematic for an air-core step-up transformer.



22. As stated, transformers work on the principle of mutual induction. This, you remember, occurs when a changing current flow in one coil causes a changing magnetic field which cuts a second coil and induces a voltage in the second coil. This action is also known as transformer action.

Nothing is perfect. As shown in the illustration below, all the lines of flux from the primary are not cutting the secondary.



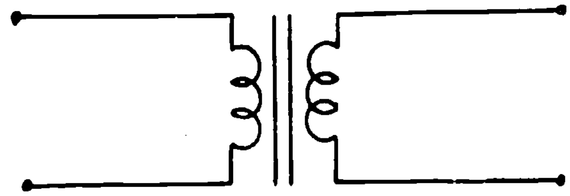
This means that the energy in the secondary is less than what it could have been. There is a magnetic flux leakage when all the lines of flux produced in the primary do not cut the secondary. For that reason, most transformers are constructed with special ferromagnetic (material that can be easily magnetized) cores of high permeability (iron), so that all the lines of flux pass through the core and cut the secondary. In summarizing, most transformers are constructed with ferromagnetic cores of high permeability so that almost all the lines of flux pass through the core and cut the secondary.

An iron core serves to _______________ flux density.
increase/decrease

- -

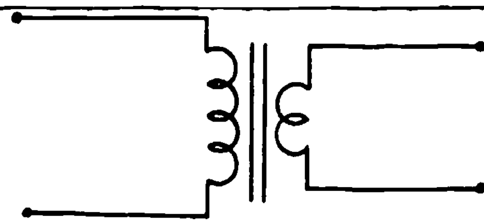
(increase)

23. Iron-core transformers are represented schematically as shown:

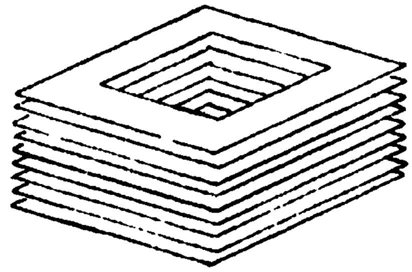


Draw the schematic symbol for a step-down iron-core transformer.

- -

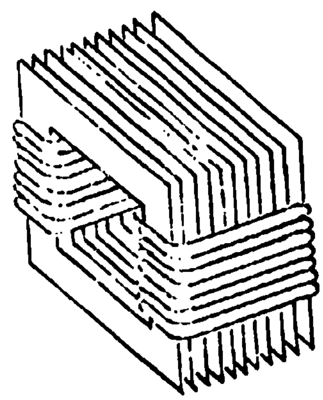


24. There are two types of iron cores in common usage. The hollow box-like core looks like this:



Varnished Laminations

The coils, which are called windings, are wrapped on either side of the core as shown.

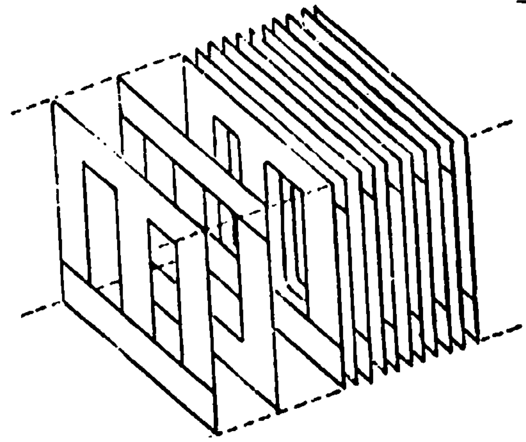


The effect of the core would be to ________________ mutual inductance as compared to air-core transformers.

- -

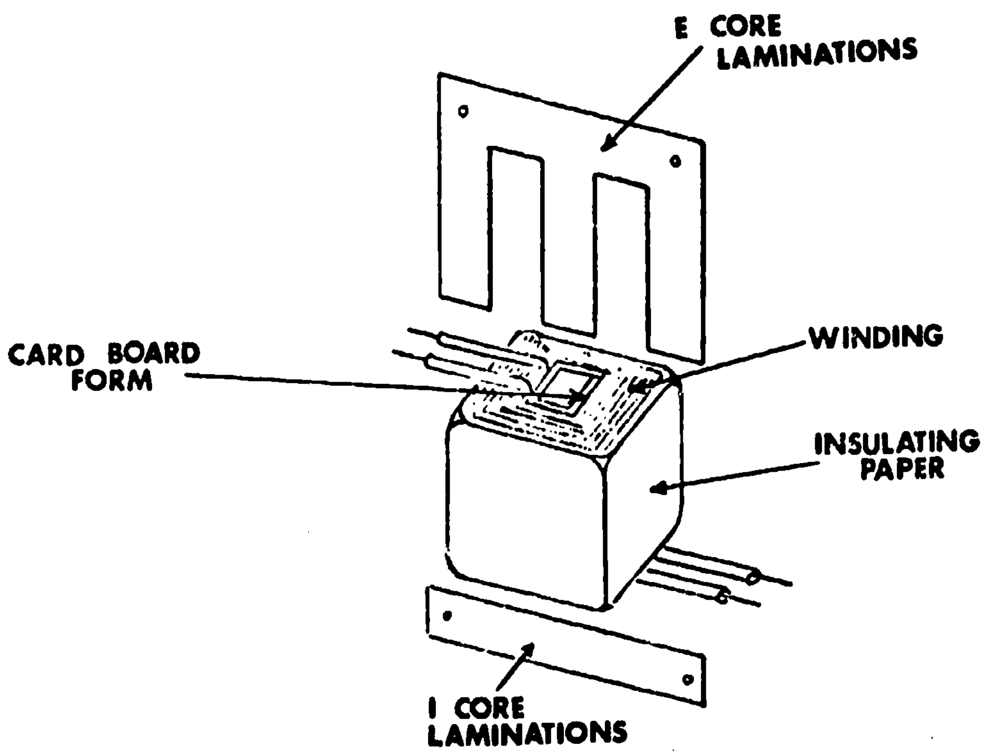
(increase)

25. A more popular type of iron core is called the shell, or E and I, type.



The windings are constructed separately by winding the wires on a cardboard form with the secondary wound on top of the primary and with insulating paper separating the two coils.

The center section of the E is then inserted through the center of the assembled coils.



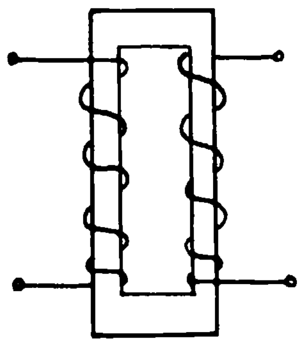
This arrangement gives maximum coefficient of coupling because the coils are wound one on top of the other, and the core surrounds the windings.

This shell-type core provides maximum common flux density.

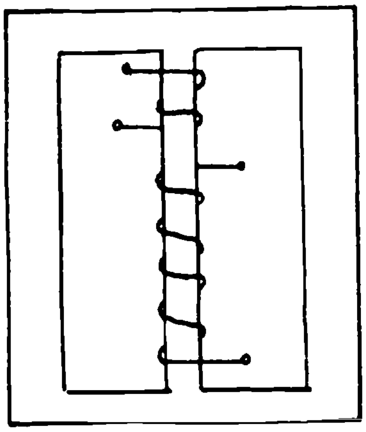
(Go to next frame)

26. The most efficient core is one that offers the best path for the most lines of flux with the least amount of magnetic and electrical energy loss.

Which of the two diagrams below illustrates the more efficient type of core construction?



____ a. HOLLOW CORE



b. SHELL TYPE

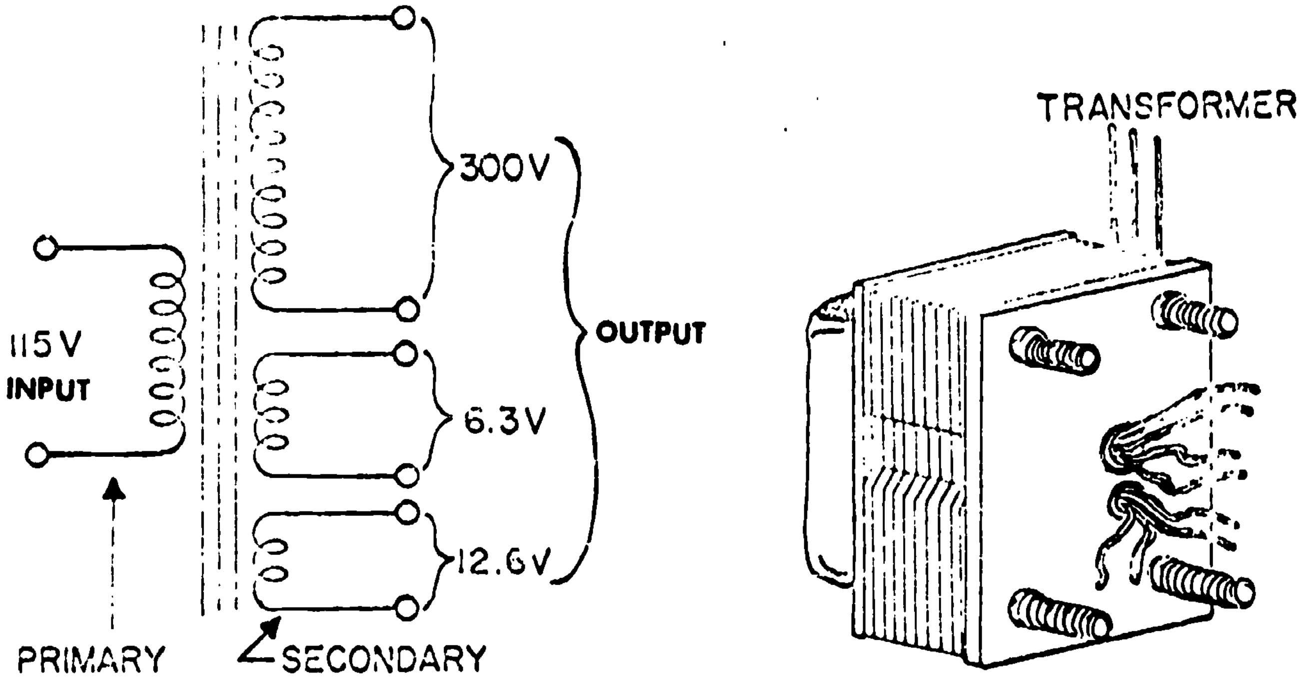
(b) Shell Type

27. Check the statements about an E and I core that are true.

____ a. P winding is separated from S winding by insulating material.
____ b. P winding is separated from S winding by air space.
____ c. Coils are wound side by side.
____ d. Coefficient of coupling is greater than in a hollow core.

(a. P winding is separated from S winding by insulating material; d. Coefficient of coupling is greater than in a hollow core.)

28. A transformer often has more than one secondary winding. This enables one transformer to supply several different values of voltage from one source.



This single transformer takes the place of how many transformers?

_____ a. 1
_____ b. 3
_____ c. 4

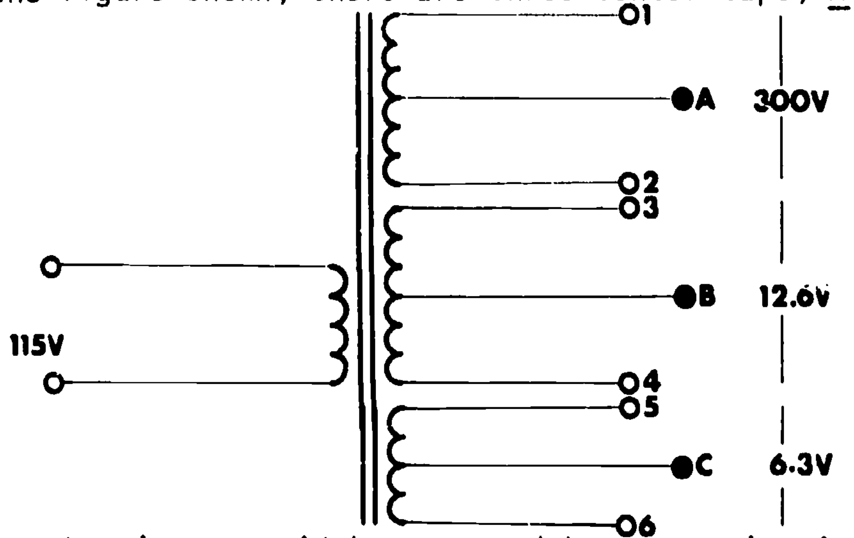
- -

(b) 3

NOTE: In some cases a transformer may have more than one primary winding.

29. To further utilize transformers, a device known as a center tap is used. This allows us to tap off half of the voltage available from each secondary winding.

In the figure shown, there are three center taps, A, B, C.



How much voltage could be measured between point A and output No. 2? ____________

(150 v)

30. Draw the correct schematic symbol below each of these descriptions.

a. 1 primary
3 secondaries
iron core

b. 1 primary
1 secondary
with center tap
iron core

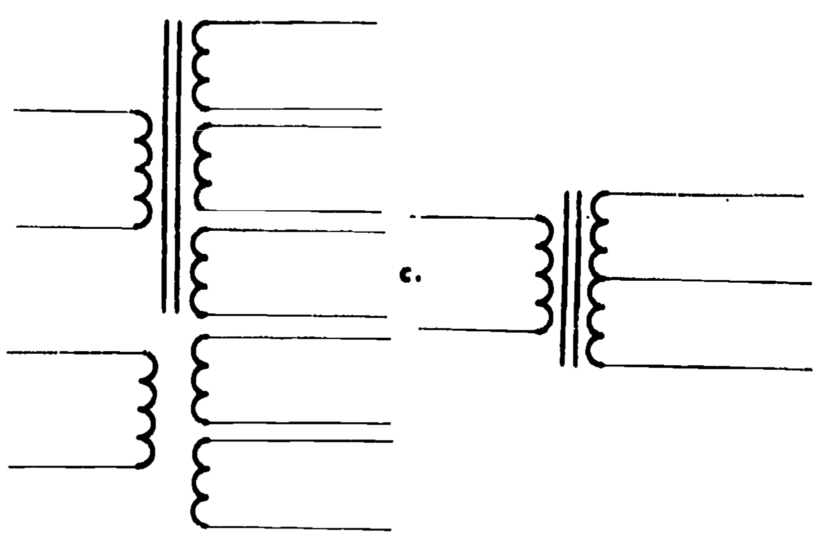
c. 1 primary
2 secondaries
air core

- -

a.

b.

c.



YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY

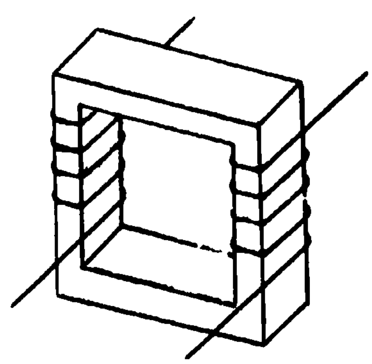
LESSON I

Transformer Construction

A transformer is an electrical device which consists of a primary and a secondary winding linked by a mutual magnetic field. The voltage that is impressed across the primary winding is usually supplied by an external source of EMF: the voltage appearing across the secondary winding is induced by the magnetic flux of the primary coil.

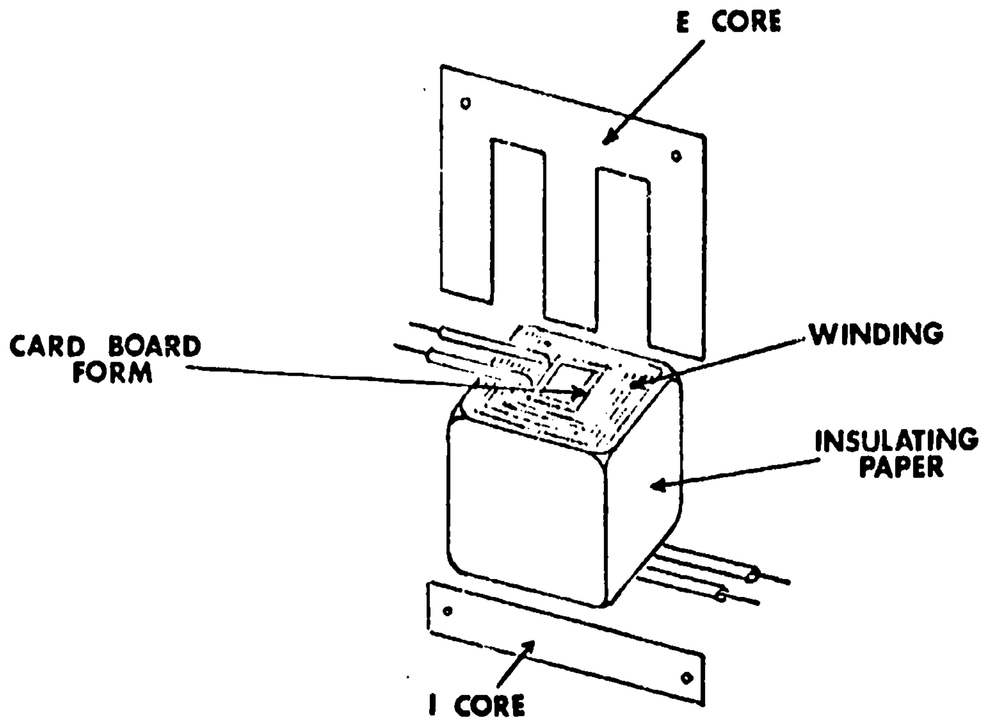
Transformers come in many sizes, ranging from some about the size of a peanut to the very large ones that are used by commercial power companies. Transformers may be used at power-line frequencies (60 Hz, 400Hz, etc.), audio frequencies (20 to 20,000 Hz), ultrasonic frequencies (20,000 to 100,000 Hz), and radio frequencies (over 30 KHz). The design and construction of transformers varies greatly with the application and electrical frequency to be employed. For example, power transformers (as in your power supply) and audio transformers (as in your hi-fi set) are normally built on a core of laminations (or flat pieces stacked together) of silicon steel. At these relatively low frequencies, a very good magnetic interaction between the primary and secondary windings can be produced only by careful design and the utilization of high-quality transformer iron.

There are two main core shapes used in iron-core transformers. One is known as the hollow core and is shaped like this:



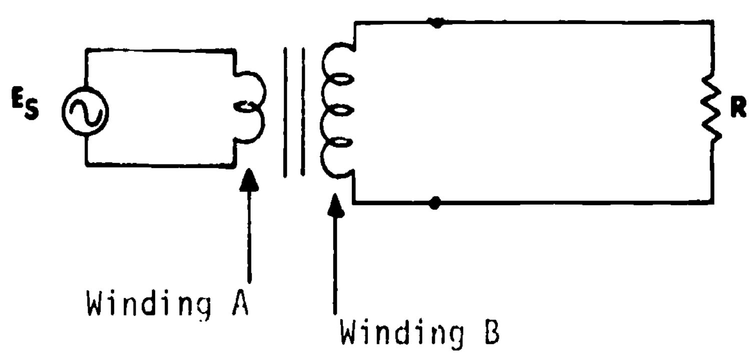
The primary and secondary windings are wound on either side of the core.

The other core shape is the shell or E and I type. Its shape is as shown on the next page.



At the higher frequencies, it is possible to design a transformer in the form of two coils wound end to end on an air core and supported by cardboard. Other transformers are wound on a solid ferromagnetic material for use at higher frequencies.

A simple transformer application is shown schematically below:



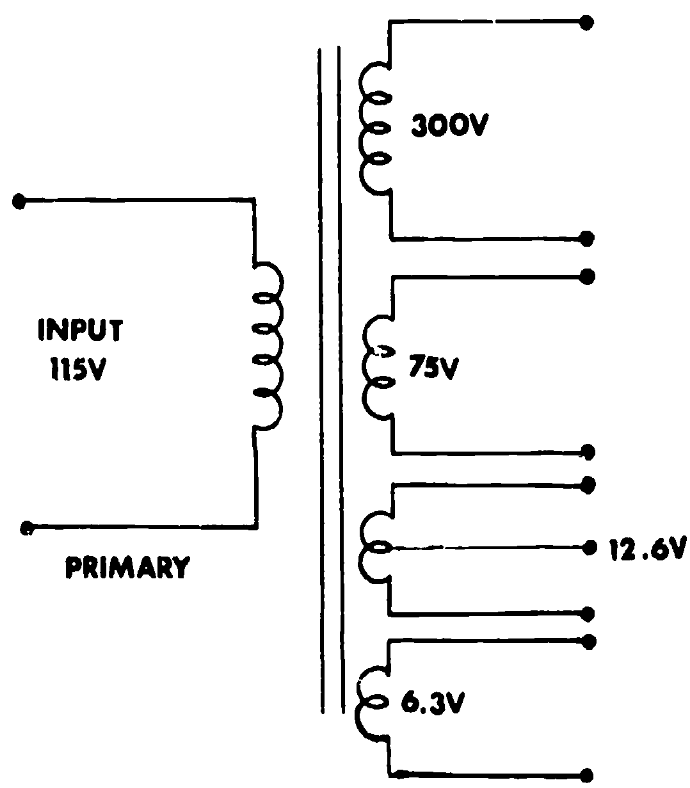
Note: If the vertical lines are not shown between the windings, the symbol represents an air-core transformer.

If secondary winding B has more coil turns than primary winding A, the voltage across load R is higher than E_p (primary voltage). This type of transformer is called a step-up transformer, since it acts to increase the voltage to the load in the secondary circuit. If winding B had fewer turns than winding A, we would have a step-down transformer. The load voltage would be smaller than E_p.

Transformers are normally used on AC, since a changing primary current is needed for operation. The requirement of a periodically changing primary coil flux must always be met for a continuous output of secondary voltage. You should also be aware that unless the rate of change of flux matches the transformer's design specifications, the transformer is likely to overheat and burn out. A transformer operated at frequencies above its design range will only be less efficient, but if operated below the proper frequency, current will be too high and overheating results.

While the secondary coil may produce a higher voltage than E_p, the law of conservation of energy tells us that the total power in the secondary circuit (neglecting transformer losses) must always equal the E_pI_p product (power) at the primary coil. This means that if secondary voltage is higher than primary voltage, secondary current must be lower than primary current.

A transformer may often have more than one secondary winding. This enables one transformer to supply several different values of AC voltage from one input source. In the transformer shown below, there are both step-up and step-down circuits, all in one unit.



The 12.6-volt secondary coil has a center tap connection. Think about some of the possible uses of this configuration.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-10a

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

MODULE TEN

LESSON II

Transformer Theory and Operation

Study Booklet

Bureau of Naval Personnel

January 1972

OVERVIEW
LESSON II

Transformer Theory and Operation

In this lesson you will study and learn about the following:

- no-load conditions
- exciting current in the primary
- producing a CEMF
- inducing a voltage in the secondary
- polarity or sense
- load conditions

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON II

Transformer Theory and Operation

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

Sound/Slide Presentation - "Function of the Transformer."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

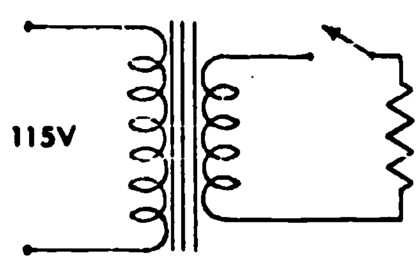
NARRATIVE
LESSON 11

Transformer Theory and Operation

No-Load Condition

We said that a transformer is capable of supplying load voltages which are usually higher or lower than the source voltage. We also know that this is accomplished through mutual induction which takes place when the magnetic fields of the primary winding cut the coils of the secondary. Let's look at what happens in the transformer under no-load conditions.

A no-load condition exists when there is a voltage applied to the primary, but there is no load connected to the secondary.



Exciting Current in the Primary

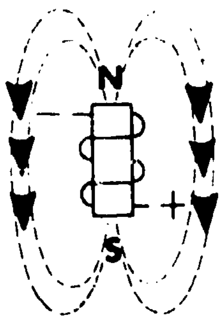
Under no-load conditions, when voltage is applied to the primary, there is a very small amount of current in the primary. This current is called exciting current. Essentially, what the exciting current does is excite the coil to create a magnetic field. The amount of exciting current is determined by three factors: (1) the amount of E_a, (2) the <u>R</u> of the primary coil's wire and core losses, and (3) the X_L which is dependent on the frequency of the exciting current.

This very small amount of exciting current serves two functions.

1. Most of the exciting current is used to support the magnetic field of the coil.
2. A small amount of current is utilized to overcome the resistance of the wire and core, and this is dissipated in the form of heat (power loss).

Producing a CEMF

As alternating current is passed through the primary coil, a magnetic field is established around the coil. As the lines of flux



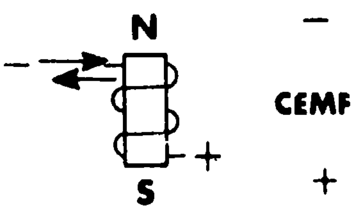
expand outward, relative motion is present, and a CEMF is induced in the coil. Observe that by the left-hand rule for coils, we can determine the N and S poles of the coil. Flux is leaving the coil at the N pole, circling the coil, and entering the core at the S pole.

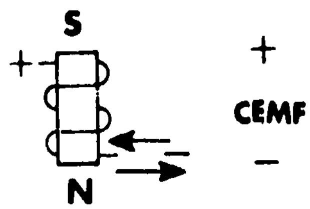
Polarity of CEMF

If we analyze the left half of the coil, we see that flux outside the coil is pointing downward, flux motion is toward the left as the flux expands, and the EMF is induced with a polarity which opposes the applied voltage, thus opposing current flow.

E_a and CEMF are how many degrees out of phase? ______________

The CEMF opposes the applied voltage at an angle of 180°; therefore, CEMF is in direct opposition to E_a. On one half cycle the polarities will look like this:



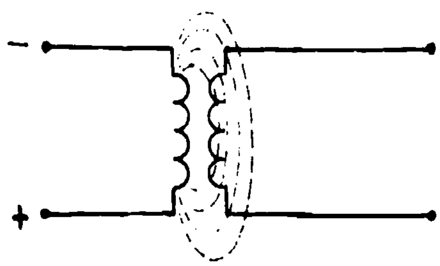


Then on the next half cycle, polarity of the applied voltage reverses. Current flowing through the coil in the opposite direction reverses the N and S poles of the coil and reverses the polarity of the induced voltage.

Thus in either half cycle E_a and CEMF are in direct opposition to each other.

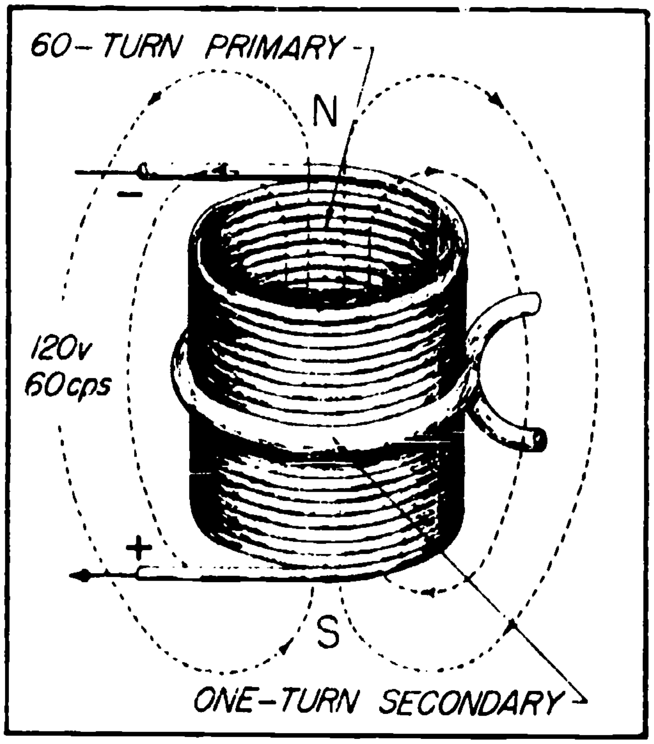
As long as we have an AC voltage applied to the primary coil, the primary is constantly inducing a counter EMF.

Inducing a Voltage in the Secondary



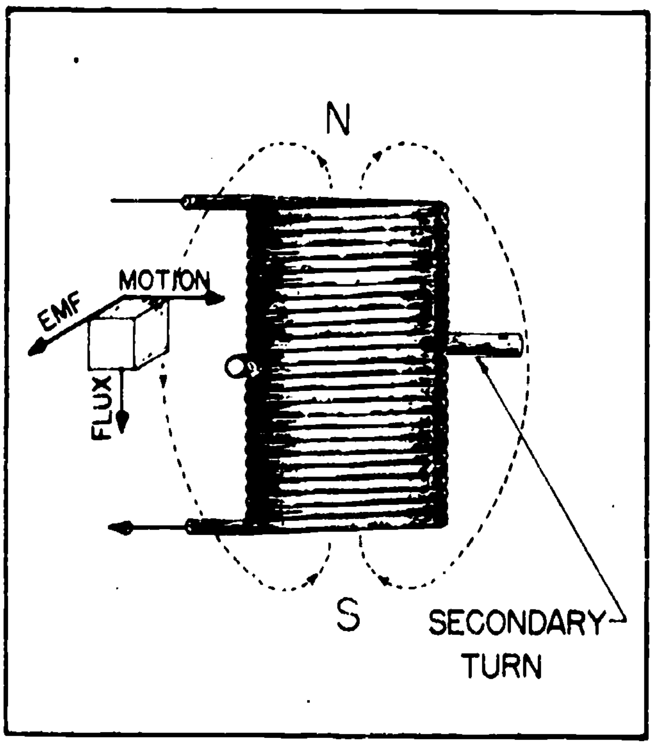
When two coils in electrically isolated circuits are positioned so that flux lines of one cut the coil of the second, we know that mutual induction takes place. A voltage is induced in the secondary.

Direction of Induced Voltage in the Secondary



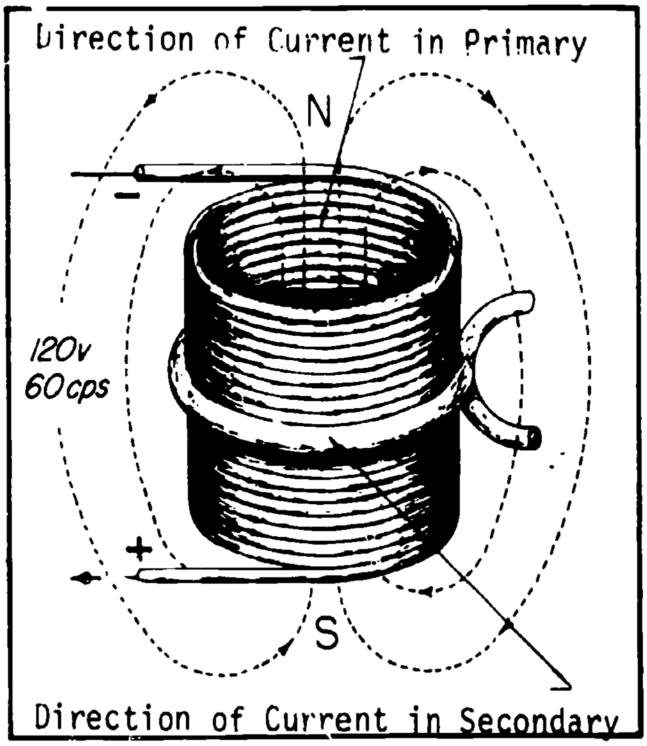
This illustrates a primary and a secondary coil with the secondary wrapped around on top of the primary. In this example, the secondary coil has only one turn. Notice it is wound in the same direction or sense as the primary.

If we could open up the secondary coil, we could see in which direction the voltage would be induced. If we examine the left side of the diagram, observe current flows into the top lead of the primary. Lines of force are generated which produce a N pole at the top of the coil. During the time that primary current is increasing, the flux lines expand outward from the primary and cut the secondary conductor. Thus, the secondary conductor appears to be moving inward, or in this direction →.



Using the left-hand rule, then, a voltage is being induced in the secondary in the direction shown.

The EMF appears to be coming out of the paper on the left side of the coil.

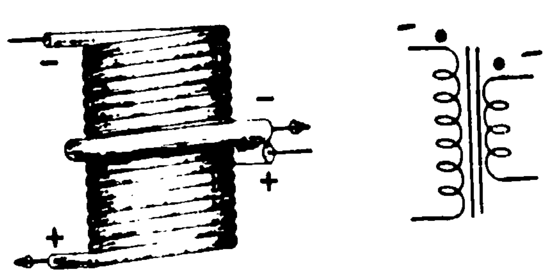


If you were viewing the coil from above, the voltage induced in the secondary tends to force current through the winding in a counterclockwise direction, while the EMF applied to the primary forces current through the primary in a clockwise direction. Therefore, the voltage induced into the <u>secondary</u> is identical to the <u>counter EMF</u> induced into an adjacent <u>primary</u> turn.

<u>Polarity or Sense</u>

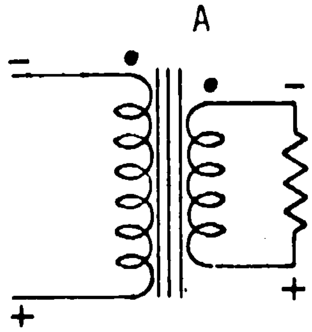
The polarity of the secondary voltage depends on:

1. the direction of the windings.
2. the arrangement of the connections to the external circuit.



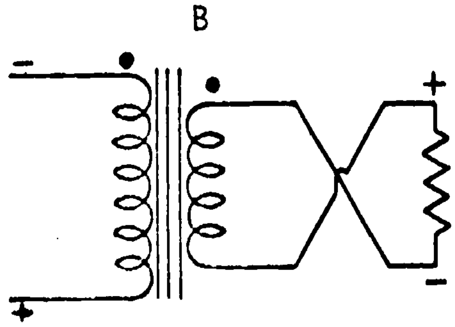
A

In figure A, both the primary and secondary are wound in the same direction. The sense dots (•) on the schematic indicate the ends of the windings which have the same polarity at the same instant.



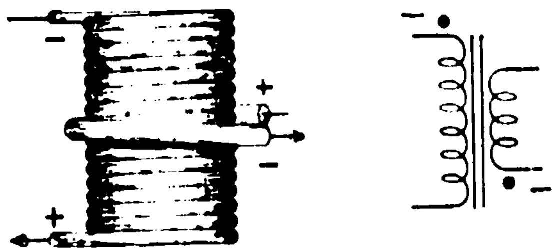
B

If you move the negative lead from its position in figure B so that it is below the positive lead as shown in figure C, the location of the sense dot on the schematic of the secondary does not change; however, polarity to the load reverses.



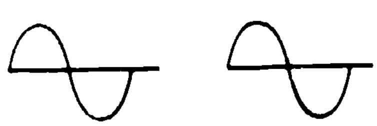
C

The other way to change the polarity of the secondary is to wind the secondary in the opposite direction in which the primary is wound; this also results in reverse phasing as shown in figure D.



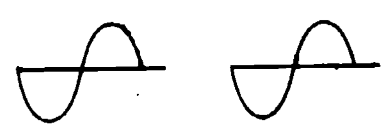
D

If the secondary winding is wound in the same direction as the primary, the sine wave going into the primary is identical in polarity, or sense, to the sine wave coming out of the secondary.

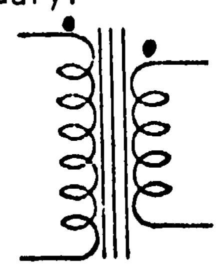


input output

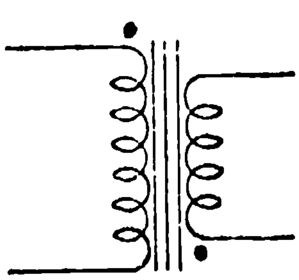
or



input output



However, if the secondary winding is wound in the opposite direction of the primary, the sense is reversed.



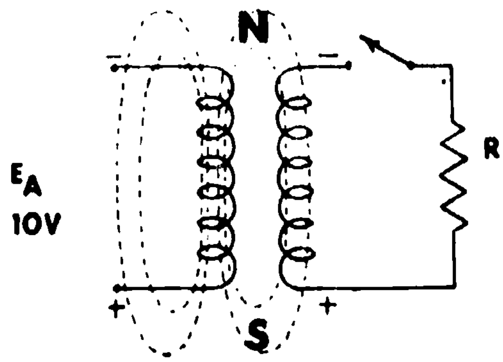
In this example, the sine waves look like this:

input output

The phase has been reversed.

Note that because AC is constantly changing polarity, instead of labeling coils with (-) or (+) we use sense dots to indicate identical phase.

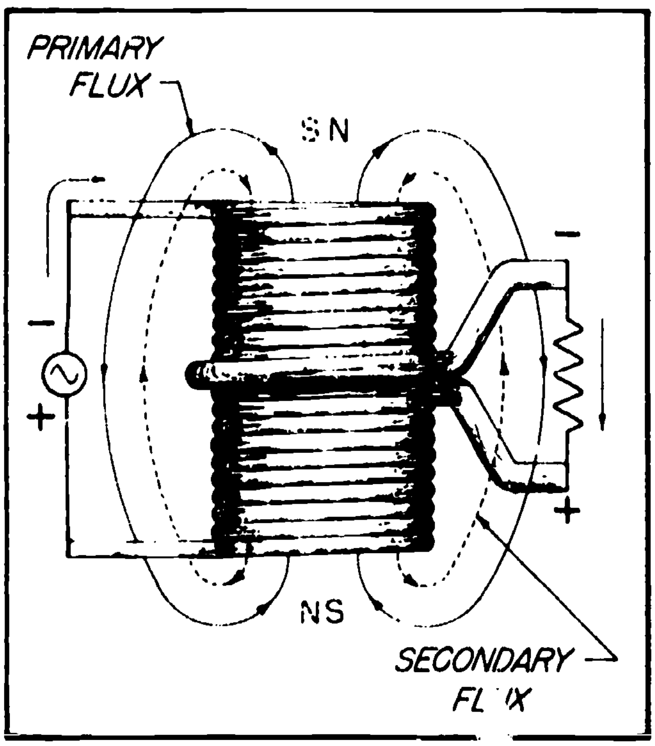
Load Conditions



Under no-load conditions, you know that we have induced a voltage in the secondary winding which has caused a displacement of electrons. However, because there is no complete path, there is no current flow.

If we close SW1 in the above schematic, the load draws current from the secondary. When a secondary is supplying current to a load, the transformer is operating under load conditions.

When a transformer is operating under load conditions, current flows through the secondary and produces a magnetic flux field around the secondary winding. Now the flux field of the secondary interacts with the flux field of the primary. From Lenz's Law we know that the flux field of the secondary is in direct opposition to the flux field of the primary. Thus, the secondary flux cancels out some of the primary flux.



As a result of a reduction of the primary flux field, the CEMF in the primary decreases. As CEMF decreases, current in the primary increases. As current increases, it re-establishes the lines of flux around the primary that were cancelled out.

Any time you go from a no-load to a load condition, for a brief time flux lines interact and cancel each other: CEMF in the primary decreases, current rises in the primary and re-establishes the flux lines. With normal loads applied to the secondary, total flux does not vary more than 2 or 3 percent.

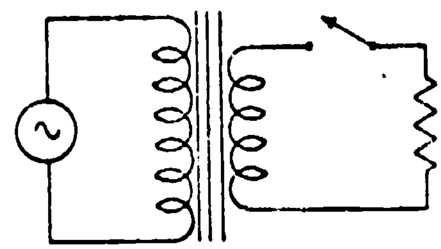
AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON II

Transformer Theory and Operation

THIS PROGRAMMED SEQUENCE HAS NO TEST FRAMES.

1. Recall that a transformer operates by mutual induction between two or more coils; as long as there is a changing voltage applied to the primary, there is a voltage induced in the secondary.



In the schematic shown:

a. Will there be an induced voltage? ________
b. Will there be secondary current? ________

(a. yes; b. no)

2. A no-load condition exists when there is no load attached to the secondary (an open secondary circuit). This results in a nearly pure inductive load on the source.

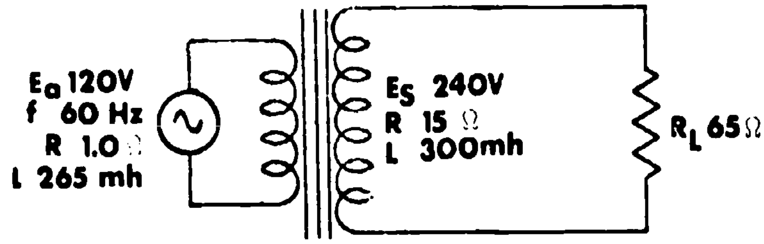
The factors which determine no-load primary current are:

____ a. secondary voltage.
____ b. resistance of attached loads.
____ c. resistance of primary windings.
____ d. primary voltage.
____ e. CEMF of secondary.
____ f. inductive reactance of primary.
____ g. frequency.
____ h. resistance of secondary winding.

(c. resistance of primary winding; d. primary voltage; f. inductive reactance of primary; g. frequency)

3. The small amount of current that flows in the primary in a no-load condition is called exciting current.

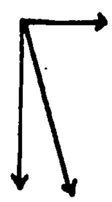
What is the exciting current in this circuit? (Since X_L is much larger than R; neglect R.) ________

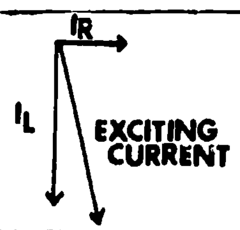


(≐ 1.2a)

4. Exciting current, like current in any inductive circuit, is actually composed of two parts, I_R which overcomes the power loss due to the resistance of the winding, and I_L which supports the magnetic field around the coil.

Label the vector diagram.





5. Exciting current flows in the primary in a no-load condition; it supports the magnetic field around the coil and a small part of it overcomes the resistance of the ____________ and supplies the power for losses due to this resistance.

(winding or coil)

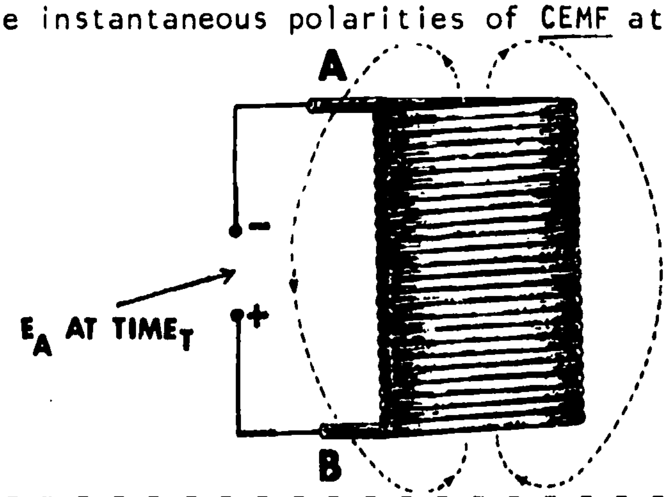
6. Exciting current:

____ a. supplies I to the load.
____ b. supports magnetic field of primary coil.
____ c. is found in the secondary.
____ d. is all dissipated as heat.
____ e. overcomes the R of the winding.

(b. supports magnetic field of primary coil; e. overcomes the R of the winding)

7. Taking one winding at a time, the study of the operation of a transformer should be nothing more than a review. Recall that as the magnetic field around a coil expands, a CEMF is induced which opposes the applied voltage.

Label the instantaneous polarities of CEMF at points A and B.



A. ________
B. ________

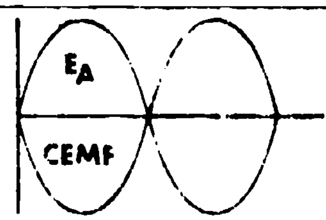
(A. -; B. +)

8. CEMF and applied voltage are ____________ out of phase.

(180°)

9. As long as we have an AC voltage applied to the primary coil, the primary is constantly inducing a counter EMF.

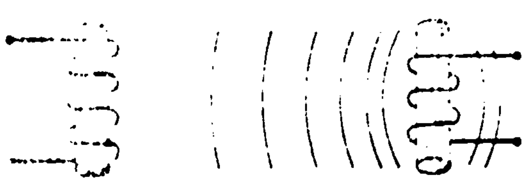
Time-graph and label the phase relationship between E_a and CEMF.



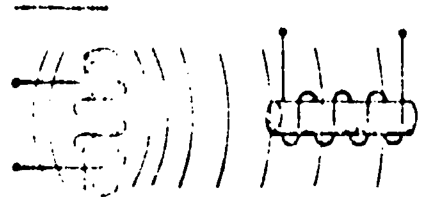
10. When two coils are positioned so that the flux lines of one cut the turns of the other, they are said to be inductively linked and a voltage is induced in the second coil.

In which of the examples shown would the largest voltage be induced in the secondary?

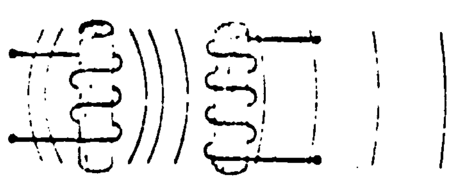
_____ a.



_____ b.



_____ c.



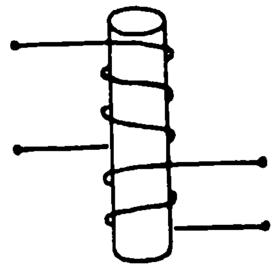
(c)

11. In the majority of transformers, the secondary is wound directly on top of the primary.

Why is this done? ______________________________

(Increase coefficient of coupling, or magnetic coupling between the primary and secondary coils.) (or words to this effect.)

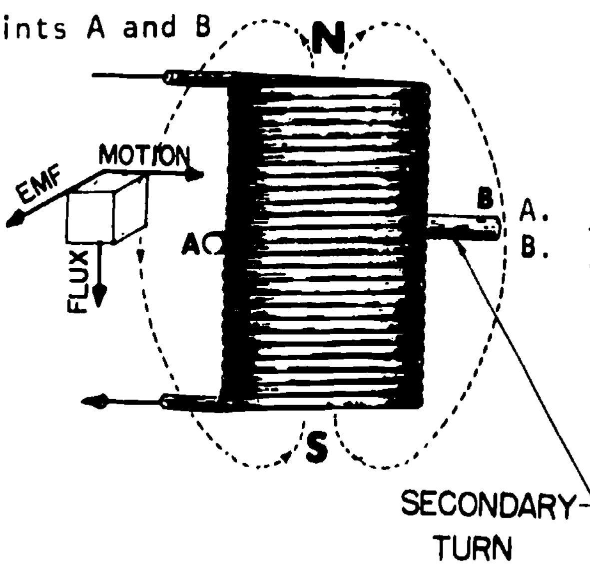
12. As shown in the figure below, the ____________ can be wound on the same iron cylinder.



(coils)

13. As the magnetic field expands outward, an EMF is induced in the secondary. The polarity of the induced voltage can be determined by applying the left-hand rule for generators as shown in the illustration.

Label polarities at points A and B

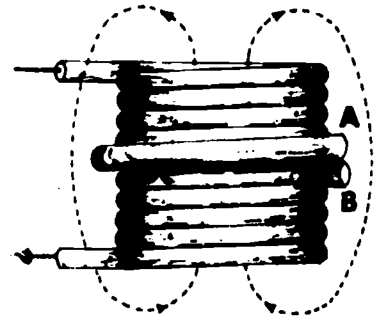


A. ________

B. ________

(A. -; B. +)

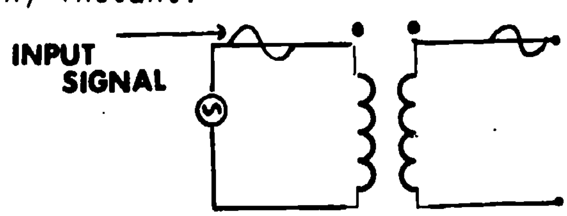
14. Assuming that primary current is increasing, label the secondary polarities at points A and B.



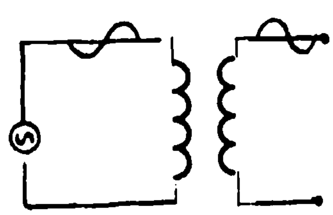
A. ____________
B. ____________

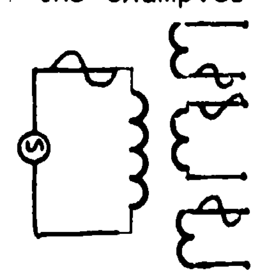
(A. -; B. +)

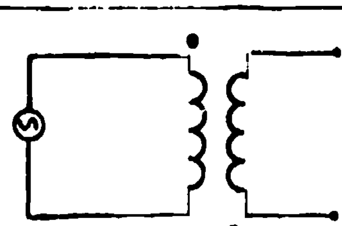
15. The polarity of the secondary winding as compared to primary is indicated by sense dots. The dots indicate points which are of like polarity at any instant.

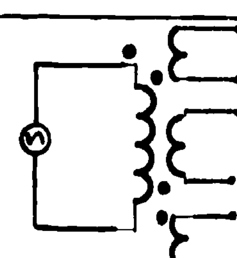


Indicate points of like polarity on the examples below.



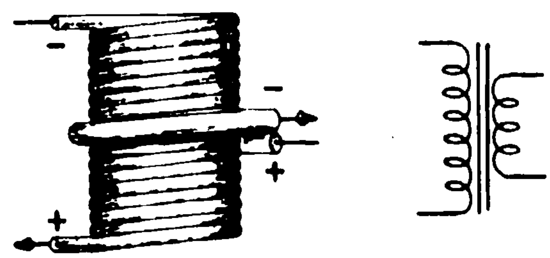




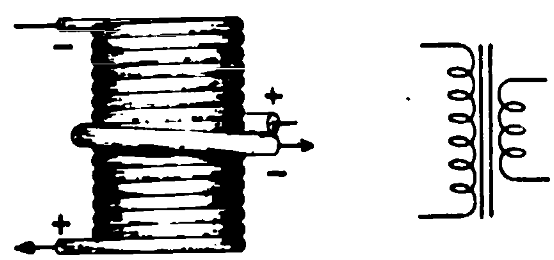


16. There are two factors which determine the polarity of secondary voltage. The first is the direction of winding. If both the primary and secondary windings are wound in the same direction, the polarities (sense) of both are the same. The second is the arrangements of the connections to the external circuit.

Using sense dots, indicate on the schematics points of like polarity for each example.

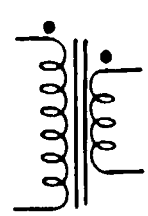
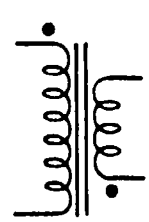


A



B

- -

A  B 

17. Recall that a power transformer is usually used to step voltage up or down. As the magnetic field around the primary expands outward, a counter EMF is induced in the primary; this same magnetic field also cuts the turns of the secondary inducing a voltage there.

Is there any secondary voltage when the magnetic field reverses direction and collapses inward? ____________

- -

(yes)

18. The voltage induced in each turn of the secondary is equal in magnitude to the counter EMF in each turn of the primary.

If there are more turns in the primary than in the secondary it is a ______________ transformer.
step-up/step-down

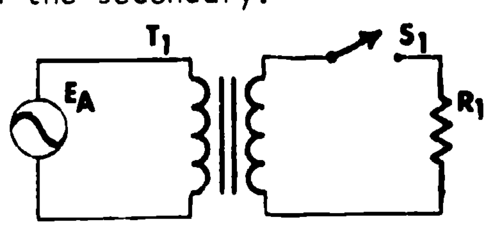
(step-down)

19. Match.

____ 1.	100 volt output and 50 volt input	a.	step-up
____ 2.	E_p of 117 volts; E_s of 24 volts		
____ 3.	primary with 60 turns and secondary with 40 turns	b.	step-down
____ 4.	transformer in your power supply		

(1. a; 2. b; 3. b; 4. b)

20. In the figure below, if switch 1 is closed, there is a current flow in the secondary.



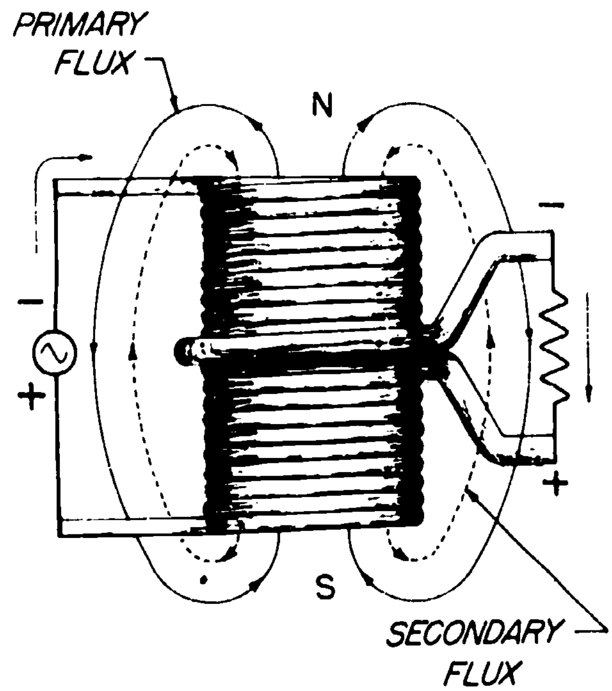
Is there any magnetic field associated with this current flow?

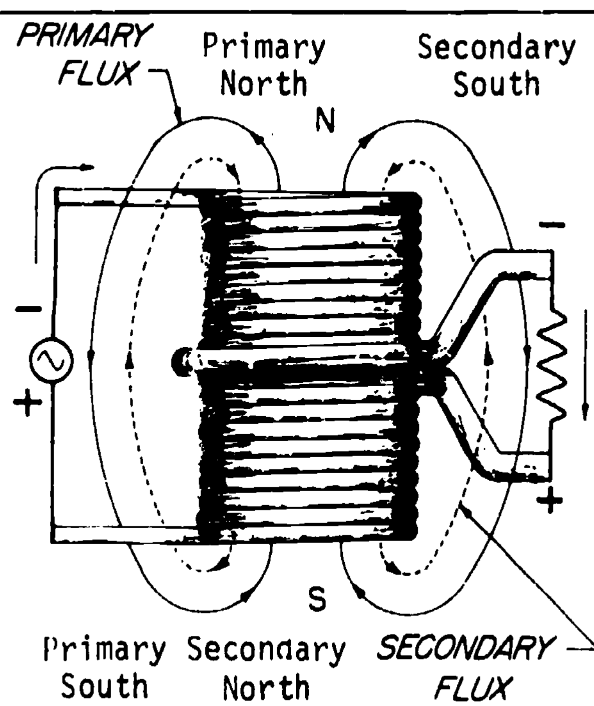
____ a. yes
____ b. no
____ c. insufficient information

(a) yes

41. When a transformer is operating under load conditions, the current flow in the secondary produces a magnetic field which opposes the magnetic field of the primary.

Indicate the polarity of the secondary flux field. (Keep in mind the rules concerning lines of flux.)





22. The opposing magnetic fields cause a decrease in the original primary flux field. This causes secondary voltage to momentarily:

____ a. increase.
____ b. decrease.
____ c. no effect.

(b) decrease

23. The magnetic field produced by the secondary current opposes and consequently reduces the effect of the flux field of the primary. This in turn reduces the counter EMF of the primary coil.

The EMF of the primary, together with the CEMF effects, tends to make the primary current ________________.
increase/decrease

(increase)

24. The increased primary current re-establishes the primary's original magnetic field.

What effect does this have on secondary voltage?

____ a. increase to original value
____ b. decrease further
____ c. no effect

(a) increase to original value

25. Although the magnetic field of the primary momentarily fluctuates to a considerable extent as loads are added to the secondary, the overall effect does not result in a variation of more than 2 or 3 percent from the original flux field.

This results in:

____ a. unstable secondary output.
____ b. stable secondary output.
____ c. limited applications for transformers.

- -

(b) stable secondary output

26. To summarize, any time you go from a ____________ condition to a load condition, or add another load, the induced magnetic field of the secondary opposes the existing primary field. This has the effect of decreasing CEMF (opposition) in the primary coil, allowing primary current to increase, re-establishing the original magnetic field strength, and restoring the secondary output voltage to its original value.

- -

(no-load)

27. Transformers are self-regulating devices. As additional loads are added to the secondary, there is an increase in primary current due to the interaction of the magnetic fields. This increase in primary current supplies the power to operate the additional loads.

How does a transformer compensate for increases in secondary power dissipation.

____ a. increase in secondary resistance.
____ b. increase in source voltage
____ c. decrease in secondary resistance
____ d. decrease in primary opposition

- -

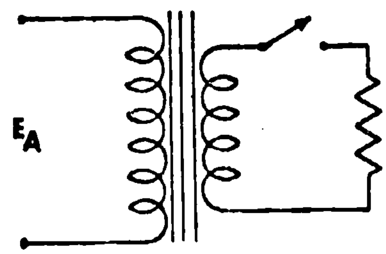
(d) decrease in primary opposition

YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WITH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON 11

Transformer Theory and Operation

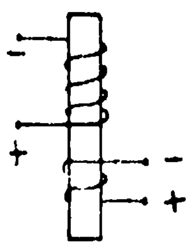
When we studied inductors, we saw that the CEMF produced opposed, or was 180° out of phase with, the applied voltage, E_a. If a transformer operates in a no-load condition, as in the figure, there is no current flow in the load and the situation in the primary resembles that discussed for an iron-core inductor.

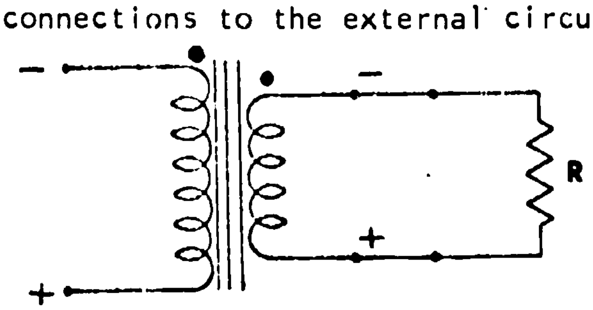


A small amount of current, called the exciting current, flows in the primary. (This current excites the coil to produce the magnetic field in the core.) The amount of exciting current is determined by three factors: (1) E_a, (2) the R value of the primary coil and core losses, and (3) the X_L value which is dependent on the frequency of the exciting current.

We know that a voltage is induced in the secondary coil, however, with the switch open, no current flows through the load. In this lesson we wish to investigate the polarity of the voltage induced in the secondary, with respect to the polarity of the applied voltage. Using the left-hand rule for generators, we find that the relative polarity of the secondary voltage depends on:

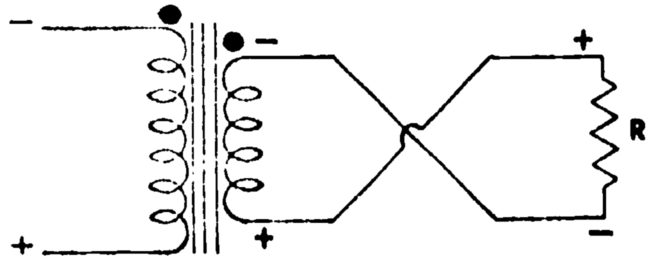
1. the direction of the windings.
2. the arrangement of the connections to the external circuit.





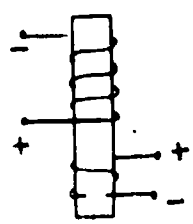
In the above arrangement on an iron cylindrical core (for simplification), we see the primary and secondary coils are both wound in the same direction. The sense dots in the schematic indicate the ends of the windings which have the same polarity at the same instant of time. Note that we can change the polarity to R (with respect to E_a) by reversing the

secondary lead connections:

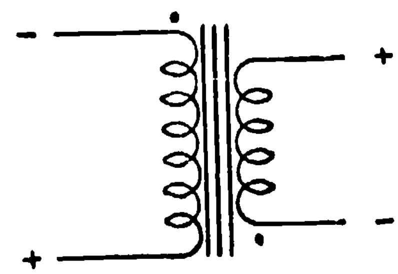


Here, the sense dot on the schematic does not change, since we have not changed the direction of the transformer coil windings.

However, instead of reversing the leads to change polarity, we could have substituted a transformer whose secondary coil was wound in the opposite direction to the primary. Here we have:

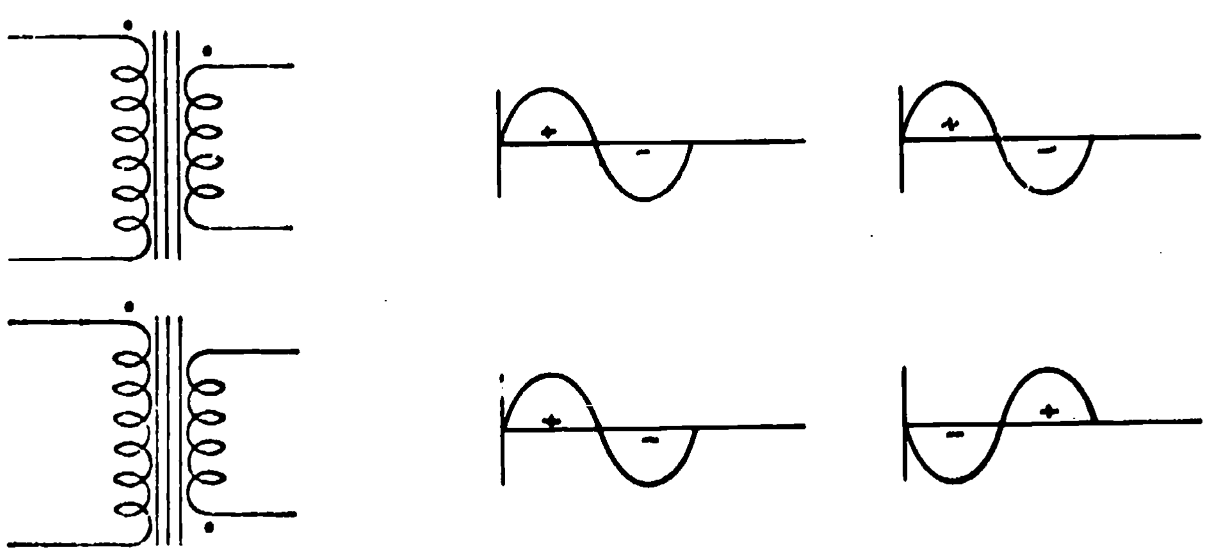


OR



Let us examine the waveforms of the two cases.

Winding Input Output



The above analyses are for steady-state conditions. As we go from a no-load to a load condition (when the switch in the secondary circuit closes) for a brief current build-up time, flux lines interact and, by Lenz's Law, tend to cancel each other. The CEMF in the primary decreases, current rises in the primary, and the more fully developed magnetic field is re-established. With normal loads applied to the secondary, total flux does not vary more than 2 or 3 percent.

YOU MAY NOW TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-10a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE TEN
LESSON III

Turns and Voltage Ratios

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW
LESSON III

Turns and Voltage Ratios

In this lesson, you will study and learn about the following:

- -determining the amount of induced voltage
- -the voltage induced in the secondary coil
- -flux leakage
- -amount of induced voltage in the secondary
- -turns ratio
- -voltage ratio
- -using the turns ratio

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON III

Turns and Voltage Ratios

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400a-2 (Chapter 15) "Basic Electricity, Power Supply and Amplifiers." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

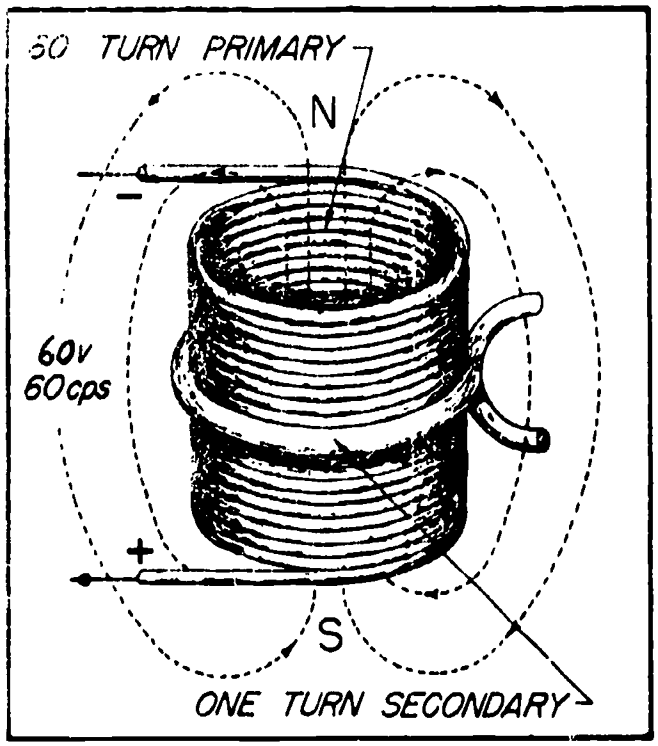
BEST COPY AVAILABLE

NARRATIVE
LESSON III

Turns and Voltage Ratios

Determining the Amount of Induced Voltage

When we induce a voltage in the primary winding, the CEMF is just about equal to the applied voltage. Thus, if the applied voltage is 60 v, for all practical pruposes, the CEMF is also 60 v.



If we have a coil which has 60 turns that means that the wire is wound into 60 loops. These turns can be counted.

If we know the applied voltage is 60 v, then we can assume that the CEMF in the primary will be 60 v. If the primary has 60 turns, then each turn must be producing 1 v of CEMF.

By dividing the E_a by the number of turns, we can determine how many volts of CEMF are induced in each turn.

If the E_a is 120 v, and the primary coil has 60 T (turns), how many volts are being induced in each turn? ________

If E_a is 120 v, then CEMF must be be 120 v. By dividing the amount of CEMF by the number of turns (60 T), we find that 2 v are induced in each turn.

The Voltage Induced in the Secondary Coil

The factors which determine the coefficient of coupling are major factors in determining how much voltage is induced in the

secondary. Ideally, we would want all the flux lines of the primary to cut all the turns of the secondary. This would give us unity coefficient of coupling.

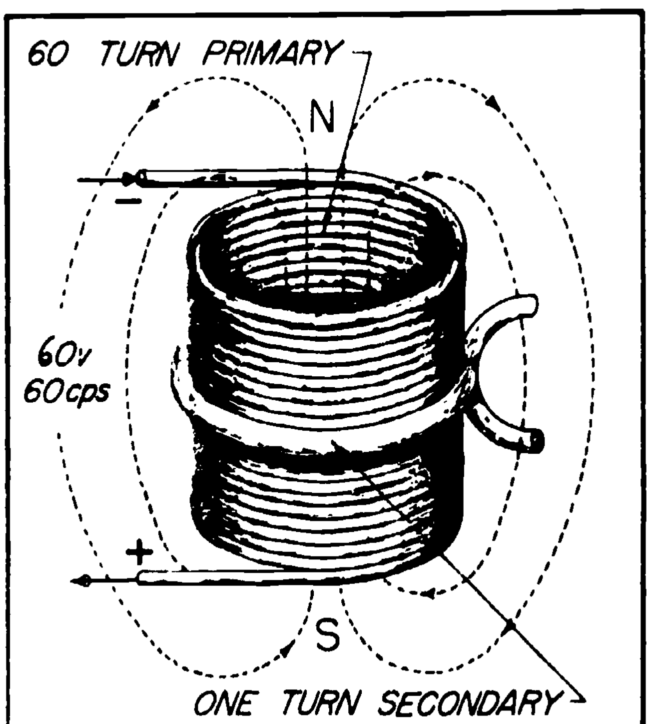
Flux Leakage

Realistically, not all the flux lines of the primary can cut all the turns of the secondary; so a small loss occurs. This loss is called flux leakage, and refers to the flux lines of the primary which do not cut secondary coils.

To minimize flux leakage, a good transformer uses a high-permeability core, and places the windings close together. In this course, we will normally consider transformers to be perfect.

Amount of Induced Voltage in Secondary

The amount of voltage induced in each secondary turn is equal to the amount of CEMF induced in each primary turn when the coefficient of coupling is 1. In this illustration, the primary has 60 T, and the CEMF is 60 v, so 1 v is being induced in each turn of the winding.



Observe that the secondary winding has only one turn. Therefore, the voltage induced in the secondary is only 1 v.

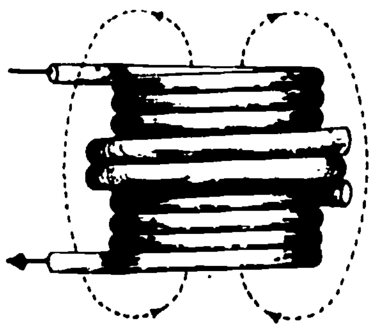
If the secondary had two turns, 2 v would be induced in the secondary (1 v in each turn).

The amount of voltage induced in the secondary is determined by the applied voltage, the coefficient of coupling, and the number of turns in both the primary and the secondary.

If a 10 T primary has an applied voltage of 10 v what is the induced voltage in a secondary winding with 2 T? ____________

Primary = 10 T

10v



Secondary - 2 T

If the E_a is 10 v, CEMF in the primary is 10 v. With a 10 T primary, each turn has 1 v of CEMF induced. Therefore, in a 2 T secondary, we have an induced voltage of 2 v (1 v per turn).

Step-Up and Step-Down Transformers

When a transformer has a secondary winding which has fewer turns than the primary, the output, or induced voltage to the load, is less than the applied voltage. When the output voltage is less than the input, the transformer is a step-down transformer; it steps down the voltage.

On the other hand, if there are more turns on the secondary than there are on the primary, the transformer has a greater secondary voltage than the applied voltage. When the output is greater than the input, the transformer is a step-up transformer. Power companies use step-up transformers to increase voltages to very high values for efficient transmission over long distances. A step-down transformer at a sub-station or on a power pole near your home takes this high voltage and steps it down to the proper voltage (110-220 v) for use in your home.

Because the amount of induced voltage in the secondary winding of a transformer depends largely on the voltage in the primary and the turns ratio of the primary to the secondary, let's think about ratios for a few minutes.

Turns Ratio

A ratio is a comparison of one number to another number. This comparison can be expressed in several ways:

1. in a fraction
2. in ratio form
3. in words

If we want to compare the number of turns in a primary winding of 10 turns with the number of turns in a secondary with one turn, we can express this as:

1. $\frac{10}{1}$

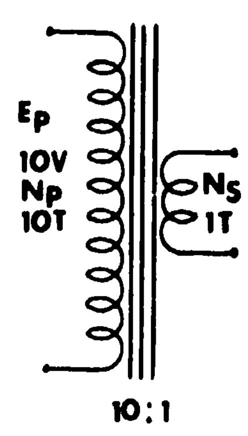
2. 10:1

3. 10 is to 1

A 10:1 turns ratio means that for every 10 turns in the primary, there is one turn in the secondary.

If we have a step-up transformer with five turns in the primary and ten turns in the secondary, this can be expressed as $\frac{5}{10}$ which can be reduced to $\frac{1}{2}$ or a 1:2 ratio. That means that for every turn in the primary, there are two turns in the secondary.

Voltage Ratio



In this transformer, we have a 10:1 turns ratio. We have 10 v applied to the primary (E_p) and 10 turns (T) in the primary. We know, therefore, that the voltage induced in each coil of the primary is 1 v.

The induced voltage in the secondary (E_s) is equal to the amount of induced voltage in each turn of the primary times the number of turns in the secondary (N_s).

Therefore,

$$E_s = (1\ v) \times (1\ T)$$

$$E_s = 1\ v$$

Notice that E_p is 10 v and E_s is 1 v. This volts ratio can be expressed as 10:1.

Observe that the turns ratio and volts ratio are the same.

Volts-Turns Proportion

When two ratios are equal, they can be expressed in a statement of proportionality. This statement says that the two ratios are equivalent.

Proportions can be expressed in these ways:

1. words
2. fractions
3. proportion statement

1. volts ratio equals turns ratio

2. $\frac{E_p}{E_s} = \frac{N_p}{N_s}$ or $\frac{10}{1} = \frac{10}{1}$

$$10 \times 1 = 10$$

$$10 \times 1 = 10$$

$$10 = 10$$

Solving for an Unknown

If you know three numerals of a statement of proportion, you can solve for the fourth by working the equation.

For example, if you know the turns ratio is 5:1 and the applied voltage to the primary is 50 v, you can determine the secondary voltage.

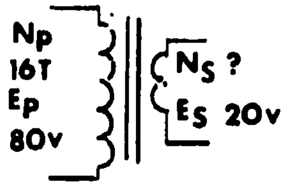
$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \qquad \text{(state the proportion)}$$

$$\frac{50\ v}{E_s} = \frac{5}{1} \qquad \text{(substitute known values)}$$

$$5\,E_s = 50 \times 1$$
$$E_s = 10\ v \qquad \text{(cross multiply and solve)}$$

We have determined that the secondary voltage is 10 v.

Solve for N_s.



N_s = ______

You know that the volts ratio is proportional to the turns ratio; therefore:

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

$$\frac{80\ v}{20\ v} = \frac{16}{N_s}$$

$$80\ N_s = 320$$

$$N_s = 4$$

$$N_s = 4\ T$$

Perhaps you saw that there is a simple way to solve this. If the E_p is 80 v and E_s is 20 v, then:

$$\frac{80\ v}{20\ v} = \text{a ratio of } 4{:}1.$$

$$\text{so} \quad \frac{4}{1} = \frac{16}{N_s}$$

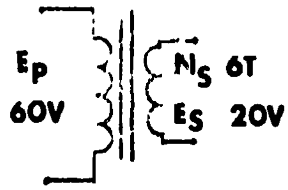
$$4\ N_s = 16$$

$$N_s = 4\ T$$

By using proportions, you can easily solve for an unknown voltage or number of turns in either the primary or secondary.

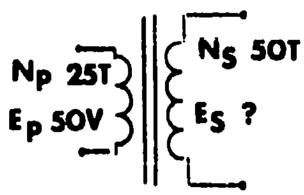
PROBLEMS

1.



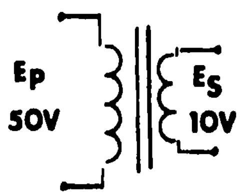
N_p = ______

2.



E_s = ______

3.



What is the turns ratio?

______

Check your answers below:

ANSWERS:

1. N_p = 18 T
2. E_s = 100 v
3. 5:1

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON III

Turns and Voltage Ratios

THIS PROGRAMMED SEQUENCE HAS NO TEST FRAMES.

1. Consider a perfect (100 percent efficient) transformer. Since the working current flows for the same interval in both primary and secondary, and since power is work per second, then $P_{pri} \times t = P_{sec} \times t$. Since the _t_'s are equal, we may cancel them. When this is done, we see that the primary power ____________ the secondary power; this directly follows from the law of conservation of energy.

(equals)

2. In a perfect transformer, if the secondary power consumption is 100 watts, the primary input power must be 100 va.

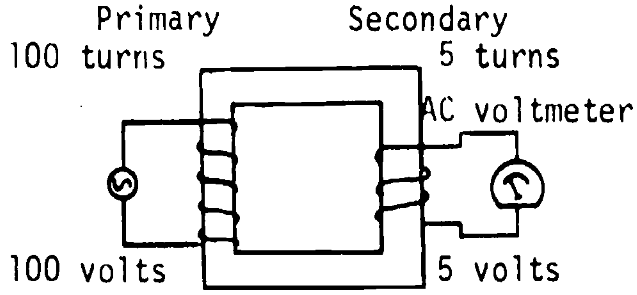
   If conditions change so that the secondary power consumption rises to 250 watts, then the primary power input must automatically change to ____________.

(250 va)

3. In an AC circuit employing a transformer (100 percent efficiency assumed), a 1,000-watt floodlight, connected across the secondary, lights to full brilliance. Thus, the power input to the primary must be _________ va.

(1,000)

4. In the figure shown, the transformer has a primary-to-secondary turns ratio of 20:1 (read 20 to 1). The ratio of primary EMF to secondary EMF is the same as the turns ratio; 100 volts in the primary induces 5 volts in the secondary. If the secondary is now increased to 10 turns (turns ratio now 10:1), the secondary voltage becomes _____ _________.



(10 volts)

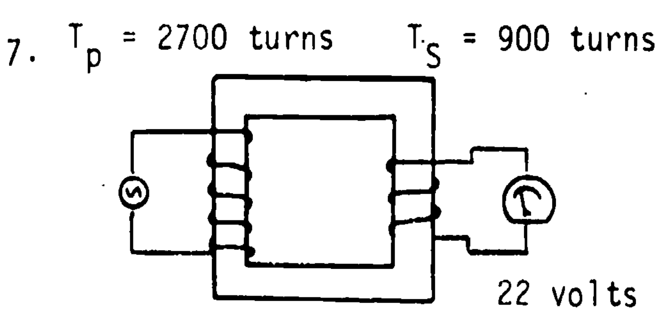
5. In the same transformer, if we increase the secondary turns to 20 turns (ratio 5:1), the secondary voltage becomes _________ volts.

(20)

6. In this step-down transformer, it is apparent that the primary-to-secondary voltage ratio is the same as the primary-to-secondary turns ratio. Thus, if the primary has 500 turns and the secondary 50 turns (ratio 10:1), a primary voltage of 20 volts yields a secondary voltage of _____ _________.

(2 volts)

7. In the transformer shown in this figure, the turns ratio, primary-to-secondary, is _____________.



(3:1)

8. Since the secondary voltage of the transformer in frame 7 is 22 volts, the primary voltage must be ________ volts.

- -

(66)

9. The voltage ratio to the turns ratio relationship is best expressed in a simple equation thus:

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

If a perfect transformer has a primary voltage of 120 volts and a secondary voltage of 20 volts, its turns ratio must be ________.

- -

(6:1)

10. The same equation holds true for <u>step-up</u> transformers in which the secondary voltage is <u>higher</u> than the primary voltage. A transformer has a turns ratio of 1:4 (note that this is one primary to four secondary turns). Thus, a voltage of 25 primary volts produces 100 secondary volts. In the same transformer, 120 volts applied to the primary yields ________ secondary volts.

- -

(480)

11. A certain power transformer (assume 100 percent efficiency) steps up the voltage from 120 primary volts to 120,000 secondary volts. The turns ratio of this transformer, primary to secondary, must be ________.

- -

(1:1,000)

12. A toy train transformer that yields 12 secondary volts from a 120-volt AC source has a turns ratio of ____________.

(10:1)

Calculations for Ideal Transformers

The behavior of ideal (100 percent efficient) transformers can be calculated from the following set of basic equations:

Voltage-turns relationship: $\frac{E_p}{E_s} = \frac{N_p}{N_s}$

Voltage-current relationship: $\frac{E_p}{E_s} = \frac{I_s}{I_p}$

Current-turns relationship: $\frac{N_p}{N_s} = \frac{I_s}{I_p}$

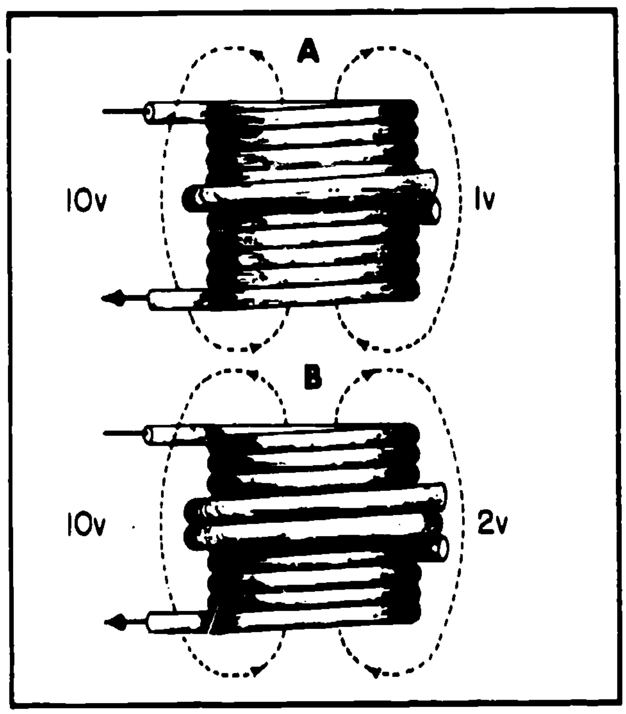
Conservation of energy relationship: $P_{pri} = P_{sec}$ or $E_p I_p = E_s I_s$

YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON III

Turns and Voltage Ratios

The total voltage induced into the secondary winding of a transformer is determined mainly by the ratio of primary to secondary turns and the amount of voltage applied to the primary. This can be explained using the figure below:



Part A of the diagram shows a transformer in which the primary consists of 10 turns of wire and the secondary consists of a single turn of wire. Notice that as the flux generated by the primary expands and collapses, it cuts both the primary turns and the secondary turn. Since the length of the wire in the secondary turn is approximately the same as the length of wire in each primary turn, the voltage induced into the secondary turn is the same as the CEMF induced into each primary turn.

If the voltage applied to the primary winding is 10 volts, the primary CEMF is almost 10 volts. Thus, each primary turn has an induced CEMF of approximately one-tenth of the total primary voltage, or 1 volt. Since the same flux lines cut the secondary as cut the primary, each secondary turn has an induced EMF of 1 volt. The transformer in A of the figure above has only one turn on the secondary; therefore, the secondary voltage is 1 volt.

The transformer in part B of the figure also has a 10-turn primary but the secondary consists of two turns of wire. Since the flux induces 1 volt per turn, the total secondary voltage is 2 volts. Notice that the volts per turn ratio is the same for primary and secondary windings.

This last statement can be used to derive an important relationship between the number of turns of each winding and the voltages across the windings, as follows: The volts per turn (V/T) in the primary is obtained by dividing the voltage across the primary (E_p) by the number of turns on the primary (N_p).

$$V/T = \frac{E_p}{N_p} \qquad (1)$$

Transposing (1) yields:

$$E_p = N_p \times V/T \qquad (2)$$

The volts per turn across the secondary are:

$$V/T = \frac{E_s}{N_s} \qquad (3)$$

Transposing (3) gives:

$$E_s = N_s \times V/T \qquad (4)$$

Where: E_s = total secondary voltage in volts
N_s = number of secondary turns
V/T = secondary volts per turn

Dividing equation (2) by equation (4) gives:

$$\frac{E_p}{E_s} = \frac{N_p \times V/T}{N_s \times V/T} \qquad (5)$$

Since secondary V/T equal primary V/T, they cancel leaving:

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \qquad (6)$$

This important equation shows that the ratio of primary to secondary voltage is the same as the ratio of primary to secondary turns. If any three of the quantities in equation (6) are known, the fourth quantity can be computed.

Example 1

A transformer has 2000 primary turns, 500 secondary turns, and a primary voltage of 120 volts. What is the secondary voltage?

Given: $N_p = 2000$

$N_s = 500$

$E_p = 120$

$E_s = ?$

Solution: $\frac{E_p}{E_s} = \frac{N_p}{N_s}$ (6)

Transposing for E_s:

$$E_s N_p = E_p N_s$$

$$E_s = \frac{E_p N_s}{N_p}$$

Substituting the given values:

$$E_s = \frac{120 \times 500}{2000}$$

$$E_s = 30 \text{ volts}$$

Example 2

A technician has an iron core choke (coil) consisting of 4000 turns. If the existing choke winding is to be used as a primary, how many turns must he wind for a secondary to construct a transformer in which the secondary voltage will be one-fifth the primary voltage?

Given: $N_p = 4000$

$E_p = 5$

$E_s = 1$

$N_s = ?$

Solution:

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \qquad (6)$$

Transposed:

$$N_s = \frac{E_s N_p}{E_p}$$

Substituting the given values:

$$N_s = \frac{1 \times 4000}{5}$$

$$N_s = 800 \text{ turns}$$

The transformers in the two example problems have fewer secondary turns, and as a result, have less secondary voltage than primary voltage (step-down transformers).

In each case, the turns ratio (or voltage ratio) may be expressed numerically. The first number refers to the primary of the transformer and the second number to the secondary.

(Example: 4:1)

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-10a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE TEN
LESSON IV

Power and Current

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON IV

Power and Current

In this lesson, you will study and learn about the following:

- -power in transformers
- -current ratio
- -conservation of energy
- -current and power in multiple secondaries

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON IV.

Power and Current

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Experiment
- Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-2 (Chapter 15) "Basic Electricity, Power Supply and Amplifiers." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

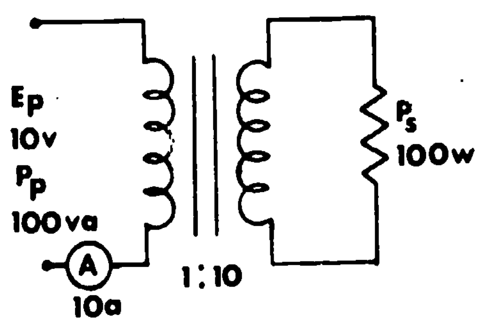
NARRATIVE
LESSON IV

Power and Current

Power in Transformers

To make computations easier, we will assume that a transformer is a device which is 100% efficient. If a transformer is 100% efficient, then power in the primary equals power in the secondary, according to the law of conservation of energy.

We can state this formula as:



$$P_p = P_s$$

Power in Primary = Power in Secondary

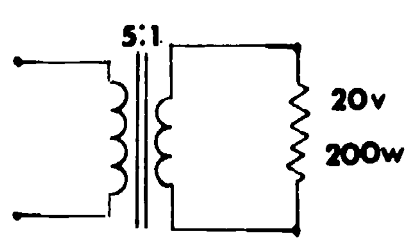
Observe that we have 10 volts in the primary and the turns ratio is 1:10. Therefore, the secondary voltage is 100 volts.

If E_s is 100 v and P_s is 100 va, what is current through the secondary?

By transposing the power formula $P = EI$, then $I = \frac{P}{E}$

$$I = \frac{100\ w}{100\ v} = 1\ a.$$

Observe that the power formula can be a very useful tool to help you solve for other quantities in either the primary or the secondary.



Find current in the primary.

I_p = ____________________

Here you know that E_s = 20 v, and the turns ratio is 5:1; therefore, E_p = 100 v. You also know that $P_s = P_p$; so, if P_s is 200 w, P_p must be 200 w.

$$P = EI$$

$$200 \text{ w} = (100 \text{ v}) \times (?)$$

Therefore, current in the primary must be 2 a.

What is I_s in the circuit above? ____________

Current through the secondary can be determined by dividing watts by volts, so that I_s = 10 amps.

Current Ratio

Notice in the transformer above that current in the primary is only 2 amps, but current in the secondary is 10 amps. In this case, the current ratio is 2:10, better expressed as 1:5. Now recall that the turns ratio for this step-down transformer is 5:1. As voltage was stepped down, current was stepped up by the same proportion.

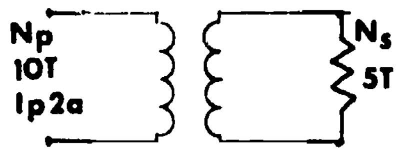
5:1 turns ratio
1:5 current ratio

We can say then that the current ratio is inversely proportional to the turns ratio.

Therefore, these ratios are true:

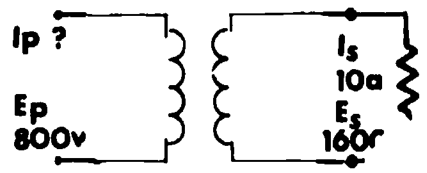
$$\frac{E_p}{E_s} = \frac{I_s}{I_p} \quad \text{or} \quad \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

1\.



$I_s =$ ________

2\.



$I_p =$ ________

By using the proportions shown above, you can solve these accordingly.

1\. $\frac{N_p}{N_s} = \frac{I_s}{I_p}$; $\frac{10}{5} = \frac{I_s}{2}$; $I_s = 4a$

2\. $\frac{E_p}{E_s} = \frac{I_s}{I_p}$; $\frac{800\ v}{1600\ v} = \frac{10\ a}{I_p}$; $I_p = 20\ a$

You Can't Get Something for Nothing.

Another way to look at the relationship between voltage and current in a transformer is this: You can get out of something only what you put into it.

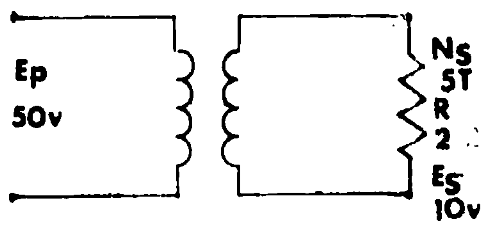
If a transformer steps up voltage, then current decreases proportionally.

If a transformer steps down voltage, then current increases proportionally.

If the turns ratio of a transformer is 10:1, what is the current ratio? ________________

Current will increase by a 1:10 ratio.

Keeping in mind that $P_p = P_s$ and that current increases or decreases inversely to the turns ratio, practice these problems.



Current in secondary, I_s = _____

number of turns in P, N_p = _____

current in primary, I_p = _____

power in primary, P_p = _____

power in secondary, P_s = _____

You know <u>E</u> and <u>R</u> in the secondary, so you can find I_s by Ohm's Law.

$$I = \frac{E}{R}$$

$$I = \frac{10\ v}{2\Omega}$$

$$I_s = 5\ a$$

To find number of turns in primary:

If you have 50 v E_p and 10 v E_s, the step-down ratio is 5:1.

If N_s is 5 turns, 5 x 5 = 25 turns = N_p

$$N_p = \underline{25\ T}$$

or, you could have worked it this way:

$$\frac{E_p}{E_s} :: \frac{N_p}{N_s}$$

$$\frac{50\ v}{10\ v} :: \frac{N_p}{5T} = 10\ N_p = 50 \times 5$$

$$10\ N_p = 250$$

$$N_p = 25\ T$$

$$N_p = \underline{25\ T}$$

To find current through the primary, you know that power in the primary is equal to power in the secondary. So, find the power in the secondary.

$$P = I^2R$$

$$P = (5)^2\ 2$$

$$P = 50\text{ w (true power)}$$

Primary power (P_p) then is 50 va.

$$P = EI$$

We know voltage and power in the primary, so:

$$P_p = 50\text{ va}$$

$$E_p = 50\text{ v}$$

$$P_p = 50\text{ v} \times I_p$$

$$I_p = 1\text{ a}$$

Current through the primary is 1 amp.

For a short-cut method of finding current, use the inverse of the turns ratio.

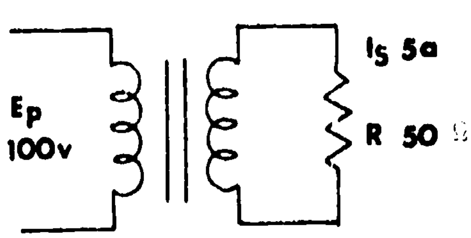
This is a step-down transformer 5:1.

Therefore, current is stepped up 1:5.

If the current in the secondary is 5 amps, current in the primary is 1 amp.

I_p = 1 amp

Solve these problems:

1. 

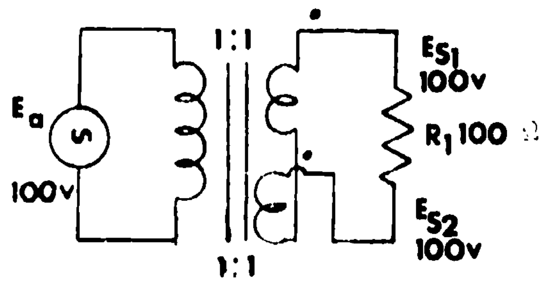
I_p = ______

Is this step-down or up? ______

E_s = ______

Turns ratio = ______

2.



E_R = ______

Answers:

1. I_p = 12.5 amps

   Step-up

   E_s = 250 v

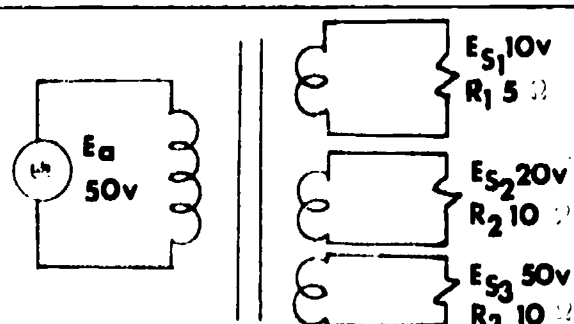
   turns ratio = 1:2.5

2. E_R = 0

   Notice the sense dots indicate points of identical polarity. Trace the circuit and you will discover both ends of the resistor have the same polarity at any given instant; therefore, there will be no difference of potential across the resistor. The secondaries are connected in series opposition.

Current and Power in Multiple Secondaries

When you have more than one secondary circuit, power in all the secondary circuits adds up to equal power in the primary. Therefore, $P_p = P_{s1} + P_{s2} + \ldots + P_{sn}$, where n means any number.



P_p = ______

I_p = ______

Solving for P_p

To find power in the primary, you need to determine the power in each secondary, then add them all together.

If voltage in S1 is 10 v, and R is 5Ω, then Ohm's Law shows that I is 2 amps. Power in S1 can then be determined by either power formula.

$$P = EI \quad \text{or} \quad P = I^2R$$

$$P = 10\text{ v} \times 2\text{ a} \quad \text{or} \quad P = 4\text{ a} \times 5\Omega$$

$$\text{Therefore, } P_{s1} = 20\text{ w}$$

Using Ohm's Law, you can determine that current in S2 is 2 a, and power in S2 is 40 w.

Similarly, current in S3 is 5 amps, and power in S3 is 250 w.

The formula then:

$$P_{s1} + P_{s2} + P_{s3} = P_p$$

$$20\text{ w} + 40\text{ w} + 250\text{ w} = P_p$$

$$P_p = 310\text{ va}$$

Solving for I_p

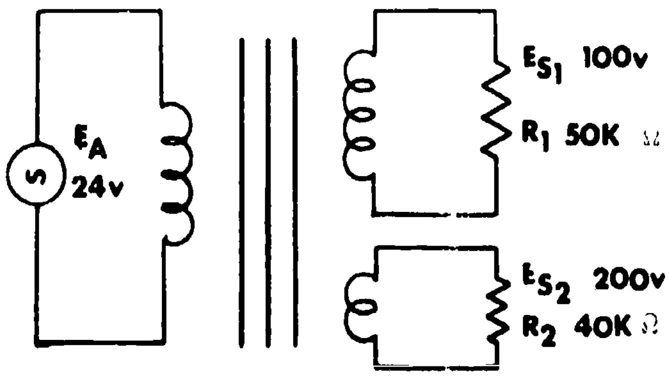
Current in the primary cannot be determined by adding currents in the secondaries. Current can, however, be determined in the primary if you know primary power and primary voltage.

$$P = EI\text{, therefore } I = \frac{P}{E}$$

$$\text{or } I = \frac{310\text{ va}}{50\text{ v}}$$

$$I_p = 6.2\text{ a}$$

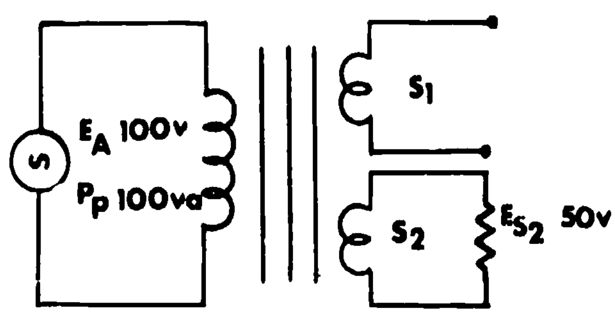
I_p = ______



Current in the primary will be 50 ma.

Solving for I_{s2}

There is a separate ratio of volts and current between the primary and each secondary. Therefore, current and voltage in the secondaries cannot be added to determine current or voltage in the primary. Each One Must Be Calculated Separately.



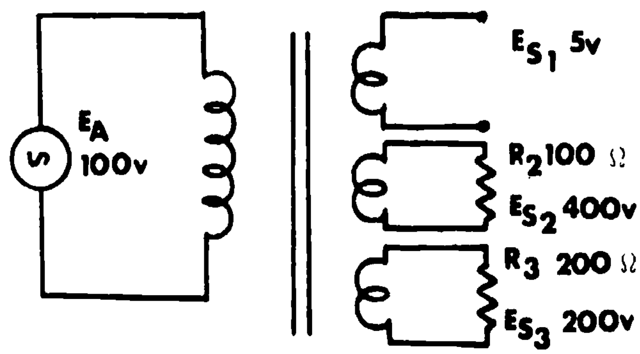
I_{s2} = ______

I_{s1} is zero. This schematic indicates a no-load condition.

The turns ratio between P and S2 is 2:1; therefore, the current ratio for S2 is 1:2. If P_p is 100 va, and E_a is 100 v, then current in the primary is 1a. By using the current ratio, if I_p is 1 a, then I_{s2} is 2 a.

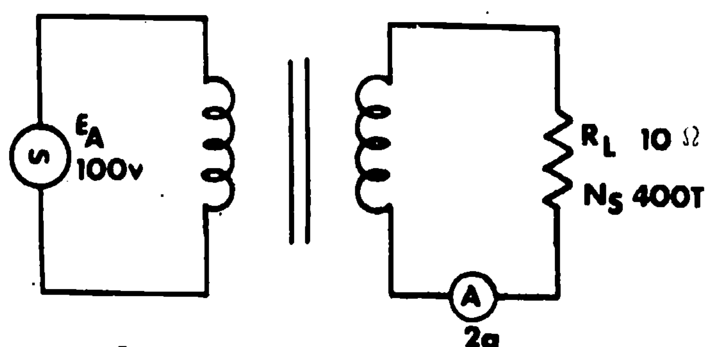
Practice these, then check answers on next page.

1.



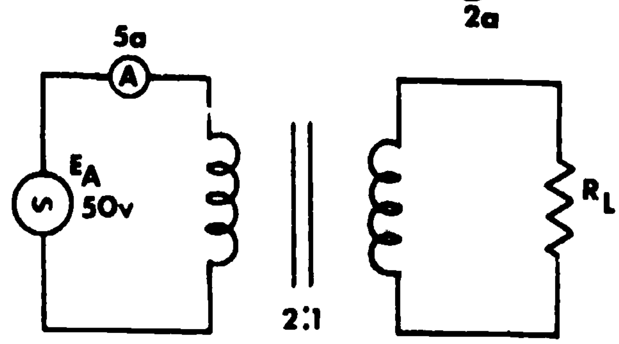
I_p = ______

2.



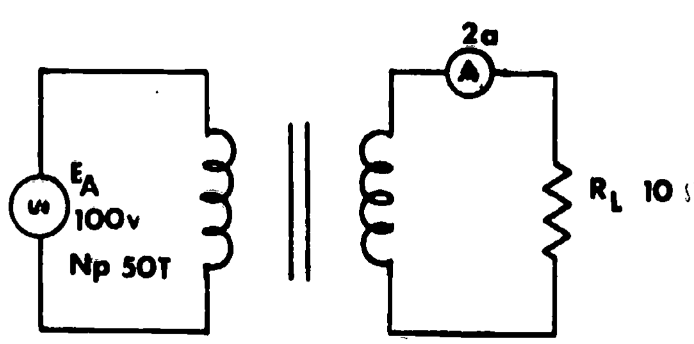
N_p = ______

3.



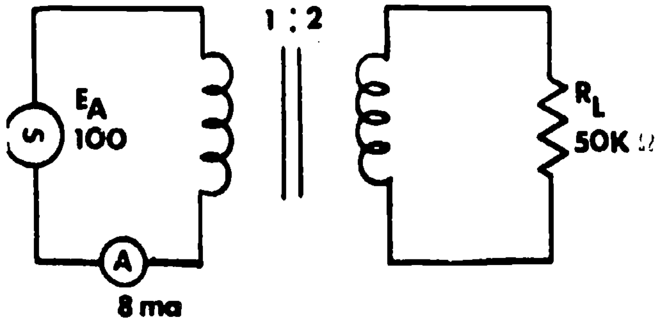
R_L = ______

4.



N_s = ______

5.



I_s = ______

ANSWERS:

1. I_p = 18 a
2. N_p = 2000 T
3. R_L = 2.5 Ω
4. N_s = 10 T
5. I_s = 4 ma

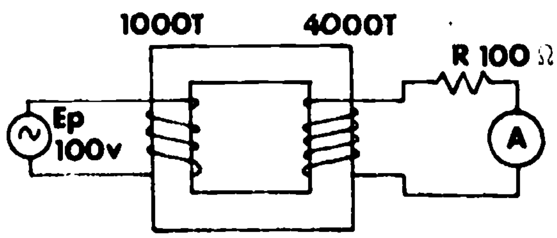
AT THIS POINT, YOU MAY PERFORM THE EXPERIMENT WHICH STARTS ON PAGE 97 PRIOR TO TAKING THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE RESOURCES LISTED. IF YOU DO THE EXPERIMENT, TAKE THE PROGRESS CHECK, AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON IV

Power and Current

THIS PROGRAMMED SEQUENCE HAS NO TEST FRAMES.

1. A perfect transformer having the characteristics shown in the accompanying figure is connected to a 100-volt line. The turns ratio of this transformer is



__________________.

(1:4)

2. The voltage produced across the secondary winding is, therefore, ________________ volts.

(400)

3. Since R is 100 ohms, then the current indicated by the ammeter in the secondary circuit (according to Ohm's Law) is __________ amps.

(4)

4. The power consumed in the secondary circuit, according to the power equation P = EI, must be _______________ kilowatts.

(1.6)

5. According to the law of conservation of energy, if this transformer is perfect, the power fed to the primary circuit must be ______________.

(1.6 kw)

---

6. The voltage across the primary winding is 100 volts. To produce a power input of 1.6 kw, the primary current must be $I_{pri} = P_{pri}/E_{pri}$ or ____________ amps.

---

(16)

---

7. This illustrates the self-regulating action of a transformer wherein the primary current automatically adjusts itself so that the power input equals the power output.

If R in the figure in frame 1 were decreased to 50 ohms, then the secondary current would become ___________ amps.

---

(8)

---

8. This makes the secondary power equal to ___________ kilowatts.

(3.2)

---

9. The primary power (100 percent efficiency) would then have to become ______________ kilowatts to satisfy the law of conservation of energy.

(3.2)

10. This, in turn, means that the primary current would have to rise to __________ amps to produce this power input.

- -

(32)

11. The voltage-current relationship in a transformer is thus dependent upon conservation of energy. Since $P_{pri} = P_{sec}$, then

$E_pI_p = E_sI_s$. Changing this to a pair of ratios, we obtain

$\frac{E_p}{E_s}$ = __________.

- -

$\frac{I_s}{I_p}$

12. In summarizing, we might say that if a transformer steps up the voltage by a factor of x, then it steps the current down by a factor of x. If it steps the voltage down by a factor of z, then it steps the current __________ by a factor of z.

- -

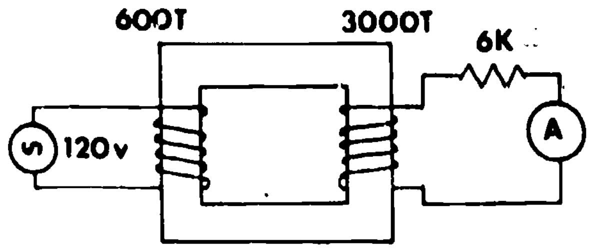
(up)

13. The ratio $E_p/E_s = N_p/N_s$ has been established. Also, the relation $E_p/E_s = I_s/I_p$ has been established. Combining these expresssions, we can obtain the connection between turns ratio and current ratio. Thus, N_p/N_s = __________.

- -

(I_s/I_p)

14. Applying the relationships just established, we can find the secondary voltage, secondary current, and primary current in a perfect transformer such as the one in this figure. First, the turns ratio is 600 to 3000 or __________.



(1:5)

15. The secondary voltage appearing across the transformer terminals must therefore be _____ __________.

(600 volts)

16. Since the resistance in series with the secondary winding is 6 kohms, the secondary current must therefore be _____ __________.

(0.1 ampere)

17. The secondary power is found by multiplying the secondary current by the secondary voltage. Hence, in this example the secondary power is ______________.

(60 watts)

18. From the law of conservation of energy, we may say that the primary power dissipation is _____ ____________, assuming 100 percent efficiency.

(60 watts)

19. Thus, the current flowing in the primary must be _______ _________.

(0.5 amps)

---

20. Using the turns-current relationship established above, we can check this reasoning by determining the primary current in a second way. Thus, $N_p/N_s = I_s/I_p$. Now, substituting the turns ratio of N_p/N_s and 0.1 amps for I_s, we find that I_p again turns out to be _______ _______________.

(0.5 amps)

Go back to page 90 and solve practice problems prior to performing experiment on page 97.

EXPERIMENT
Transformer

Draw #9 Neat Board from resource center. Insure that the Neat Board has a power cord.

Neat Board #9 is a step-down transformer test board with resistive loads connected through switches to several secondaries.

The turns ratio of primary to secondary is not given; however, with either E_p/E_s or I_p/I_s, turns ratio can be determined. Bear in mind that the terms E_p/E_s and I_p/I_s pertain to primary/secondary voltage and primary/secondary current. The symbols will be used frequently. One point to remember, this Neat Board contains dangerous voltages; use caution when handling test probes. Insure all switches are in the off position. Connect power cord to the Neat Board in receptable provided, and plug cord into wall outlet.

Step 1.

Set Simpson 260 Range Switch to the 250-volt range and Function Switch to the AC position; connect test leads to "common and +" jacks.

Step 2.

Touching only the insulated handles of the probes, insert the tips into TP 901 and TP 910. Watching the meter scale of the Simpson 260, turn S1 (located just left of the "power on" indicator lamp, on the Neat Board) to the "on" position. (1) Record voltage reading from TP 901 to TP 910: ______. This is the primary or line voltage. (2) Record the primary current measured by meter M1: ______.

Step 3.

With the meter still connected to TP 901 and TP 910, watch the meter closely while you turn S2 to the "on" position. S3 and S5 should be open and S4 should be in the TP 905 position. Place R2 in the full C.W. position. (3) Record the current flow from M2: ______.

Step 4.

Remove your meter test leads from TP 901 and TP 910 and place them in TP 902 and TP 903. Open S2 and carefully turn the meter Range Switch to the 10-volt position. Close S2. (4) The meter indicates __________ volts.

Step 5.

The load in this circuit is rated at 25 watts; (5) What is the actual power being dissipated by the load? ______ watts. (6) What formula did you use to determine the power dissipated? ________________ Open S2 and remove test leads.

Step 6.

Turn meter Range Switch to the 250-volt position, plug test leads into TP 904 and TP 905, and turn the Range Switch to the 50-volt scale. Turn S4 to TP 905 position. (7) With S3 and S5 open, record voltage reading from TP 904 to TP 905: ____________. (8) Record the current reading indicated on M3 of the Neat Board: ____________.

Step 7.

Notice that under open circuit conditions, E_s (TP 904 to TP 905) is 35.0 volts and I_s is 0 amps. (9) Now turn S3 "on" and record E_s and I_s as indicated by your meters. E_s = ______________. I_s = ______________. (10) Secondary voltage ____________________ by 1 volt. Primary current
increased/decreased
increased by 0.1 amps. Place R4 in full C.W. position.

Step 8.

Take the test lead from TP 904 and move it to TP 906. (11) Record voltage between TP 905 and TP 906: ____________. (12) Record I_s as indicated by M3: __________. Notice current and voltage have not changed, thus indicating a center-tapped secondary. You will see that a 0.5 amp increase in I_s results with a 0.1 amp increase in I_p. This same condition existed across TP 904 and TP 905.

Step 9.

With S4 still in the TP 905 position, open S3, turn the Range Switch on the multimeter to the 250-volt position, and move the test lead from TP 905 to TP 904. This places the meter across the complete center-tapped secondary (13) E_s is ____________ volts under open circuit conditions.

Step 10.

Close S3. I_s = ____________ amps
E_s = ____________ volts

Step 11.

Close S5. I_s = __________ amps
Place R6
fully CCW E_s = __________ volts

Step 12.

Turn S4 to TP 906.

E_s = __________ volts

I_s = __________ amps

E_p = __________ volts

I_p = __________ amps

Step 13.

Open S5.

E_p = __________ volts

I_p = __________ amps

E_s = __________ volts

I_s = __________ amps

Step 14.

Note the relationship between E_p/E_s and I_p/I_s. Open S3, close S5, and record the following readings:

E_p = __________ volts

I_p = __________ amps

E_s = __________ volts

I_s = __________ amps

Step 15.

Again note the distinct relationship between E_p/E_s and I_p/I_s in this particular circuit. <u>Open</u> S5 and S3, close S2. Connect multimeter from TP 901 to TP 910. With S4 in the TP 906

position, close both S5 and S3 and record primary current through M1 and secondary current through M2 and M3.

M1 ____________
M2 ____________
M3 ____________
E_p ____________

Step 16.

Open S3.

M1 ____________
M2 ____________
M3 ____________
E_p ____________

Step 17.

Note that the M2 reading increased as the M1 reading decreased. Open S5.

M1 ____________
M2 ____________
M3 ____________
E_p ____________

M2 current again showed a increase as did E_s, while I_p showed a strong ____________.

You can see from this experiment that as voltage is stepped down, current is stepped (1) ________, as secondary current is increased (more loads added in parallel), primary current will (2) __________.

But as secondary current increases, both primary and secondary voltage will show some decrease. Why do you think this happens?

Answers: (All measured values are approximations and are given to provide guidelines to determine accuracy of your answers.)

Step 2. 115 V AC
Step 3. 0.7 a
Step 4. 7.2 v
Step 5. 5w; P = EI
Step 6. 35 v; 0
Step 7. 34 v; 0.6 a; decreased
Step 8. 35 v; 0.6 a
Step 9. 70 v
Step 10. 0.6 a; 68 v
Step 11. 1.2 a; 66 v
Step 12. 60 v; 2.2 a; 115 v; 1.25 a
Step 13. 120 v; 0.7 a; 65 v; 1.2 a
Step 14. 120 v; 0.7 a; 65 v; 1.2 a

Step 15. 1.35 a; 0.65 a; 2.1 a; 112 v
Step 16. 0.7 a; 0.7 a; 1.2 a; 118 v
Step 17. Minute; 0.725 a; 0; 122 v; decrease
(1) up; (2) increases

Summary. As secondary current flow increases, the magnetic field around the secondary increases, cancelling part of the magnetic line of flux caused by primary current. This reduces the EMF induced in the secondary. The primary voltage is decreased due to the increased voltage drop across the internal resistance.

When you are satisfied with your readings, secure your equipment and return to the resource center.

YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON IV

Power and Current

According to the law of conservation of energy, for an ideal or 100% efficient transformer, the power in the primary circuit equals that in the secondary circuit. Thus:

$$P_p = P_s$$

Using $P = EI$, and

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

you can write other forms of the law. (Try to form them.)

For example:

$$E_s I_s = E_p I_p; \quad \text{But } E_p = E_s \frac{(N_p)}{(N_s)}$$

Therefore:

$$E_s I_s = E_s \frac{N_p}{N_s} I_p.$$

Cancelling E_s, and rearranging, we see:

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

Note that while the ratio voltages are directly proportional to the turns ratio, the current ratio is inversely proportional.

If you feel you have mastered these concepts, try the problems at the end of the narrative.

AT THIS POINT, YOU MAY PERFORM THE EXPERIMENT WHICH STARTS ON PAGE 97 PRIOR TO TAKING THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU DO THE EXPERIMENT, TAKE THE PROGRESS CHECK, AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, SELECT ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-10a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

M O D U L E   T E N
L E S S O N   V

Transformer Efficiency

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON V

Transformer Efficiency

In this lesson you will study and learn about the following:

- -transformer efficiency
- -copper loss or I^2R loss
- -eddy current loss
- -hysteresis loss
- -transformer ratings

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON V
Transformer Efficiency

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-2 (Chapter 15). "Basic Electricity, Power Supply and Amplifiers." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON V

Transformer Efficiency

Transformer Efficiency

As we have learned about transformers, we have considered that they were 100% efficient. Therefore, if the power to the primary was 100 w, then the load connected to the secondary was assumed to dissipate 100 watts. This is an idealized situation and does not take into account losses that occur in transformers.

Losses

We will discuss three major kinds of transformer losses which are:

1. copper or I^2R loss
2. eddy current loss
3. hysteresis loss

Copper Loss or I^2R Loss

Copper loss or I^2R loss occurs as a result of the small amount of resistance present in any coil or wire. This resistance causes a loss of power in the form of heat. If current increases, then the power dissipation by this resistance increases, and power is wasted.

To minimize copper loss, windings are made of low-resistance copper. Another factor which helps minimize copper loss is the selection of the proper size of wire for the windings; for example, transformer windings which carry high current require wire with a larger cross-sectional area than transformers carrying lesser amounts of current.

Eddy Current Loss

Recall that an iron-core transformer has a core which is constructed of a ferromagnetic material. As the magentic field around the coil changes, some of the flux lines cut the core and induce voltages in the core. When you have a conducting material, such as the core, then a small amount of random current flows within the core. This causes a power loss within the core which is called eddy current loss and is lost as heat.

To minimize eddy current loss, transformer cores are made of laminated slices insulated from each other with varnish. This procedure provides greater opposition to current flow in the core, thereby reducing eddy currents.

Hysteresis Loss

When a magnetic field is passed through a core, the core material becomes magnetized. To become magnetized, the domains or magnetic units within the core must align themselves with the external field. If the direction of the field is reversed, the domains must turn so that their poles are aligned with the new direction of the external field. This process takes energy.

Power transformers normally operate from either 60-cycle-per-second or 400-cycle-per-second alternating current. Each tiny domain must realign itself twice each cycle or a total of 120 times a second when 60-cycle alternating current is used. The energy used to turn each domain is dissipated as heat within the iron core. This loss is called hysteresis loss, and can be thought of as resulting from a kind of friction.

When you increase the frequency of the applied voltage, greater motion of the magnetic elements of the core material are caused and thus a greater loss through heat dissipation.

Hysteresis can be minimized by proper core selection. Generally air-core transformers are used for frequencies above audio range - $20KH_z$ - because, with an air core, hysteresis loss is kept to a minimum. You can assume, then, that iron cores are generally used with frequencies in the audio range.

Transformer Ratings

Most transformers have ratings on the nameplates according to their capabilities for handling:

1. voltage
2. current
3. power

Voltage Handling Capacity

The voltage rating depends on the construction of the primary and secondary windings. The type and thickness of the insulation between the windings determines how much voltage the windings can stand before the insulation breaks down and wires short. The thicker (and better) the insulation, the more voltage the transformer can handle.

Frequency

A frequency higher than the rated value can be applied to a transformer without serious damage. For example, a 400-cycle voltage can be applied to a 60-cycle transformer. Transformer efficiency will be seriously reduced, but no damage is likely to occur. However, if you apply a 60-cycle source to a transformer rated at 400 cycles, you may have circuit trouble. Let's see why!

When you increase frequency, X_L increases and current decreases; therefore, a higher frequency source results in less current and a small reduction in power but no damage to the transformer.

Now, if you decrease frequency to 60 cycles for a 400-cycle transformer, then X_L decreases and current increases. If current exceeds the current handling capacity of the transformer, significant damage results.

Current-Handling Capacity

The current-handling capacity is determined largely by the diameter of the wire used for the windings. If current in the windings is excessive, there is too much power dissipated in heat and the insulation on the wires is damaged. If excessive current is permitted to flow for too long a time, the transformer will be permanently damaged.

Power-Handling Capacity

The amount of power a transformer can handle depends on its ability to dissipate heat. Many transformers have louvres in the case which direct cool air to flow across the windings. Large transformers often use an oil-cooling technique to prevent excessive heat build up.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON V

Transformer Efficiency

THIS PROGRAMMED SEQUENCE HAS NO TEST FRAMES.

This lesson deals with transformer efficiency. For ease of computation, we have considered transformers to be 100 percent efficient. In many cases, efficiency is close enough to 100 percent to make no difference. There are, however, some cases where power losses are large enough that they must be considered. In this lesson you will learn what type of losses occur in transformers and how their effects are kept at a minimum.

1. Recall that even good conductors, such as the copper wire used in transformer windings, have some resistance. As current passes through this resistance, some power is lost in the form of heat.

   As secondary and primary currents increase, total power losses ______________.
   increase/decrease

- -

(increase)

2. Losses due to winding resistance are called copper or I^2R losses. Copper losses are minimized by using the proper diameter wire for the current the winding is expected to carry.

   Power losses are reduced by using __________ diameter wire.
   large/small

- -

(large)

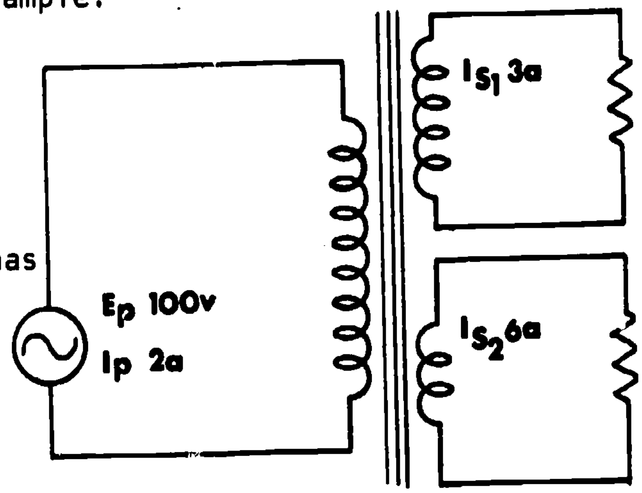
3. In a 10:1 step-down transformer the secondary has a ____________ diameter wire than the primary.
   (larger/smaller)

- -

(larger)

4. Copper losses result in slightly less power being dissipated by the secondary loads than is supplied to the primary ($I_p \cdot E_p$). To compute I^2R losses, determine how much power is being lost in each primary and secondary winding (not the loads), then add them together. For example:

primary winding has 5Ω resistance



S_1 winding 2Ω

S_2 winding 1.5Ω

primary copper loss = I^2R $(2)^2 \cdot 5 = 4 \cdot 5 = 20$ w

S_1 copper loss = $(3)^2 \cdot 2 = 9 \cdot 2 = 18$ w

S_2 copper loss = $(6)^2 \cdot 1.5 = (36)(1.5) = \underline{54\ W}$

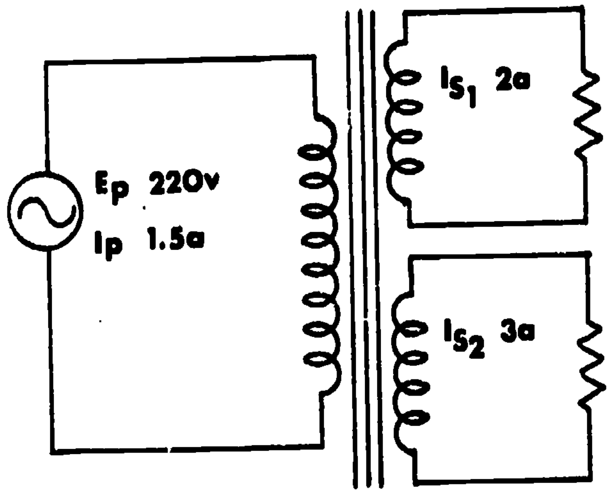
total copper loss 92 w

The total available power in the primary is 200 volt-amps. If 92 watts are lost as copper losses, there are 108 watts to be dissipated by the loads as useful work.

In the example below how much power is actually dissipated by the loads? ________

primary winding has

3.3Ω resistance



S_1 winding 2Ω

S_2 winding 1Ω

(305.57 watts)

NOTE: This is an exaggerated example used only for explanation.

5. Another type of transformer loss occurs in the core material and is due to tiny currents known as <u>eddy currents</u>. When a changing magnetic field passes through the core material, a voltage is induced in the conducting core material which results in a small current in the core. These currents cause the transformer to heat up, with a resultant loss of power.

What effect would an increase in the frequency of primary voltage have on losses due to eddy currents?

____ a. increase
____ b. decrease
____ c. no effect

- -

(a) increase

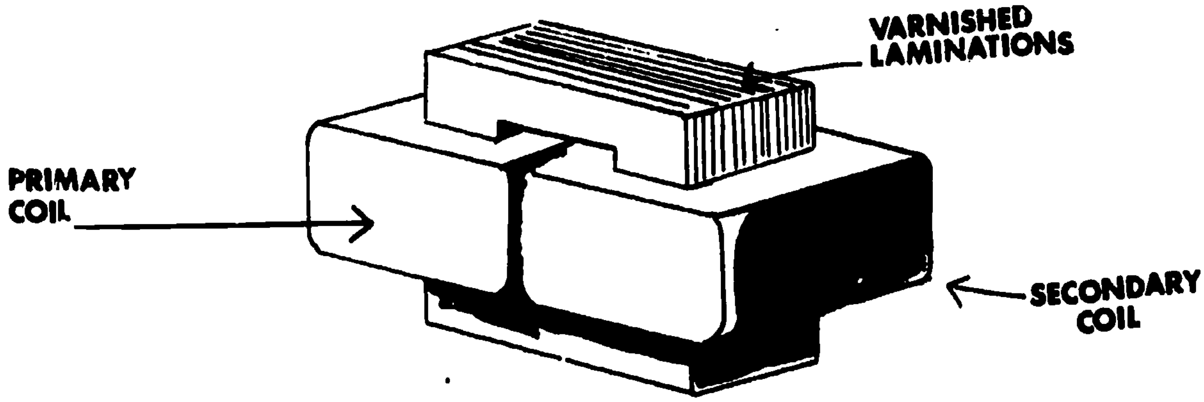
6. Since air is an insulating material, would an air-core transformer be likely to have significant eddy current losses?

____ a. yes
____ b. no

- -

(b) no

7. The effect of eddy currents can be reduced by laminating the core. A laminated core is made up of many thin steel slices insulated from each other with a type of varnish. This increases the resistance of the core, thereby reducing both the eddy currents and the losses they cause.



LAMINATED IRON CORE TRANSFORMER

Lamination of the core material serves to ______________ transformer efficiency.

(increase)

8. Another power loss which occurs in the core is known as hysteresis. Hysteresis is a characteristic of iron or any ferromagnetic material and results from the continuous realignment of the magnetic field in the core as the primary field expands and collapses through it. In oversimplified terms, hysteresis results from a kind of atomic friction caused by reversing the magnetic polarity of the core.

Would hysteresis losses increase or decrease with an increase in frequency? ______________

(increase)

9. Are hysteresis losses a significant factor to consider with air-core transformers?

____ a. yes
____ b. no
____ c. core material irrelevant

(b) no

10. Hysteresis is an inherent characteristic of all ferromagnetic materials. There is not much that can be done to eliminate the effects of hysteresis, but they can be reduced by careful choice of core materials. Soft iron, powdered iron, and silicon steel all have low hysteresis losses.

Two types of core losses are __________ and ______________.

(hysteresis; eddy current)

11. Match each term to its appropriate description.

____ 1. I^2R	a. core loss resulting from friction of particles
____ 2. eddy current	b. loss resulting from flux lines cutting the core
____ 3. hysteresis	c. loss resulting from flux lines not cutting turns of coil
	d. loss resulting from resistance of coil

(1. d; 2. b; 3. a)

12. Transformers are not 100 percent efficient. Because of the losses involved (copper loss and core losses) in transferring energy from the primary to the secondary, the power in the secondary circuit does not quite equal the power in the primary circuit.

To determine the percentage of efficiency of a transformer, we divide the output by the input power.

$$\text{Percentage of efficiency} = \frac{\text{output}}{\text{input}} \times 100$$

A transformer with 220 va in its primary circuit and only 200 w in its secondary circuit has a loss of 20 w. What is the transformer's percentage of efficiency? ____________

(90.9%)

13. A transformer has a 60 va primary and a 55 w secondary. What is the percentage of efficiency of this transformer? ____________

(91.66%)

14. Iron-core transformers are used mainly in the audio frequencies (up to 20 KHz) and are classed as audio-frequency transformers.

Audio-frequency transformers have iron cores to:

____ a. increase ruggedness.
____ b. increase flux leakage.
____ c. increase transformer efficiency.

(c) increase transformer efficiency

15. Transformers used with high frequencies (above 20 KHz) usually have an air core because hysteresis and eddy current losses in an iron-core transformer are too great for use at high frequencies.

The small iron-core transformer used in your power supply is:

____ a. a high-frequency transformer.
____ b. an audio-frequency transformer.

- -

(b) an audio-frequency transformer

16. Match the correct core type to frequency ranges.

____ 1. f below audio range		
____ 2. f above audio range		a. air core
____ 3. f above 20 KHz		b. iron core
____ 4. f below 20 KHz		

- -

(1. b; 2. a; 3. a; 4. b)

17. When a transformer is to be utilized in a circuit, it is necessary to know more than just the turns ratio. The power-handling capability and maximum voltage and current that each winding can safely handle must also be considered.

Three factors to be considered are:

a. ____________________
b. ____________________
c. ____________________

- -

(a. power handling capability; b. maximum voltage; c. maximum current) (in any order)

18. The type and thickness of the insulation between windings determine the maximum voltage that can be safely applied to the windings. The thicker or more efficient the insulation, the higher the voltages that can be safely applied to the transformer.

If a transformer is used at a voltage higher than it is rated for:

____ a. there would be short circuits between the windings.
____ b. nothing would happen.

(a) there would be short circuits between the windings

19. The current handling capability is determined by the diameter of the wire used for the windings. If the wire is not of sufficient diameter there may be excessive heat, possibly resulting in extensive damage.

The greater the diameter the ____________ (higher/lower) the resistance, and the ______________ (greater/smaller) the power waste will be.

(lower - smaller)

20. The power handling capability of a transformer is dependent upon its ability to dissipate heat. There are several methods to increase heat-dissipation capability. Immersion in oil, increasing surface area, and forced cooling systems are some of the ways to increase heat dissipation.

What are two ways to increase heat dissipation? ______________ and ______________.

(increase surface area; forced cooling systems; oil immersion)
(any two)

21. Complete the following statements about transformers by matching the phrases.

____ 1.	voltage handling capability primarily depends on . . .	a.	cross-sectional area of wire
____ 2.	current handling capability primarily depends on . . .	b.	cooling ability
____ 3.	power handling capability primarily depends on . . .	c.	type and thickness of insulation

(1. c; 2. a; 3. b)

22. Transformers are designed to operate within only a limited range of frequencies. If the recommended operating frequency is ignored the result will be either a greatly reduced efficiency or a damaged transformer.

If a frequency below the recommended value were applied to the primary winding, X_L for that winding would be ____________ (greater/less) than desired.

(less)

23. At the lower frequency, X_L of the primary coil will be less than the desired value. This will result in an abnormally ____________ (large/small) primary current which in turn will cause overheating and possible damage.

(large)

24. If, on the other hand, a transformer should be operated at a frequency higher than that for which it was designed, the result would be a/an ________________ (increase/decrease) in X_L, causing a/an ________________ (increase/decrease) in primary current. This would result in decreased efficiency.

(increase - decrease)

25. Match.

____ 1. higher than specified frequency.	a.	damage
____ 2. lower than specified frequency.	b.	poor efficiency

- -

(1. b; 2. a)

YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON V

Transformer Efficiency

Practical transformers, although highly efficient, are not perfect devices. Small power transformers used in electronics equipment range from 80 to 90 percent efficient, while large commercial power-line transformers may have efficiencies exceeding 98 percent.

Transformer losses are confined mainly to the windings and core, and are the result of an undesirable conversion of electrical energy into heat energy. Three major types of losses occur.

Copper Loss

Whenever a current is passed through a conductor, power is dissipated by the conductor in the form of heat. This power loss is due to the resistance of the conductor. We have seen that the amount of power dissipated by the conductor is directly proportional to the resistance of the wire and to the square of the current through it. The greater the value of either resistance or current, the greater is the power dissipated.

The primary and secondary of a transformer are made of low resistance copper wire. The resistance of a given winding is a function of the diameter of the wire and its length. Power transformer windings have resistances ranging from less than 1 ohm to several hundred ohms. The power dissipated by winding resistance is called an (I^2R) loss, or copper loss.

Copper loss is reduced by using the lowest resistance wire practicable.

Eddy Current Loss

The core of a transformer is constructed of a ferromagnetic material. This material may not be a good conductor, but it does have the ability to conduct current.

Whenever the primary of an iron-core transformer is energized by an alternating current source, a fluctuating magnetic field is produced which cuts the conducting core material and induces a voltage into it. The induced voltage causes random currents to flow through the core which dissipates power in the form of heat. These undesirable currents are called eddy currents.

We have seen that to minimize the loss resulting from eddy currents transformer cores are laminated. The laminations are made of thin strips of metal, which are pressed together to form the core. Each lamination is coated with varnish or some other insulating material. Since the thin, insulated laminations do not provide an easy path for current, eddy current loss is greatly reduced.

Hysteresis Loss

When a magnetic field is passed through a core, the core material becomes magnetized. To become magnetized, the domains or magnetic units within the core must align themselves with the external field. If the direction of the field is reversed, the domains must turn so that their poles are aligned with the new direction of the external field. This process takes energy.

Power transformers normally operate from either 60-cycle-per-second or 400-cycle-per-second alternating current. Each tiny domain must realign itself twice each cycle or a total of 120 times a second when 60-cycle alternating current is used. The energy used to turn each domain is dissipated as heat within the iron core. This loss is called hysteresis loss, and can be thought of as resulting from a kind of friction. Hysteresis loss can be held to a small value by proper choice of core materials.

Transformer Efficiency

To compute the efficiency of a transformer, the input and output powers must be known. The input power is equal to the product of primary voltage and primary current. The output power is equal to the product of secondary voltage and secondary current. The difference between the input power and the output power represents the power consumed by the various transformer losses. The efficiency of a transformer is a measure of how well it works. A transformer with high efficiency has low losses.

Transformer Ratings

When a transformer is used in a circuit, more than the simple turns ratio is considered by the designer. The power-handling capacity of the primary and secondary windings must also be considered. The maximum voltage that can be applied

to any winding is controlled by the type and thickness of the insulation. The better (and thicker) the insulation between the windings, the higher the maximum voltage that can be applied to the windings. The current handling capacity of the transformer windings is controlled by the diameter of the wire used for the windings. If the current is excessive in the transformer winding, there is a higher than expected value of power dissipated from the winding in the form of heat. The heat generated inside the transformer may be sufficient to melt the insulation around the wires. If excessive current is permitted to continue, the transformer may be permanently damaged.

The power-handling capacity of a transformer is dependent upon its ability to dissipate heat. If the heat dissipation can safely be increased, the power-handling capacity of the transformer can be increased. This is sometimes accomplished by immersing the transformer in oil or by the use of cooling fins. The power handling capacity of a transformer is measured in either volt-amperes or watts.

Transformers are designed to operate within a specified range of frequencies, and should never be used in circuits which are outside the design range. If they are used outside of specifications, efficiency will be poor and, in extreme cases, the transformer may be damaged.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-10a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE TEN
LESSON VI

Semiconductor Rectifiers

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON VI

Semiconductor Rectifiers

In this lesson, you will study and learn about the following:

- the rectifier
- semiconductor
- the function of a rectifier
- how the rectifier works
- waveforms
- seeing rectification with an oscilloscope

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON VI

Semiconductor Rectifiers

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Experiment

Lesson Summary

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON VI

Semiconductor Rectifiers

The primary winding of your power supply transformer has a voltage rating of 117v. The secondary coil sends out approximately 24v. Therefore, the first operation that takes place in your power supply is stepping down the voltage. After current leaves the secondary of the transformer, it goes through a small component sometimes called a semiconductor rectifier. The rectifier in your power supply looks like a very small resistor with only one color band.

Semiconductor

You know that a conductor is a material which allows current to pass through it easily. Conversely, a non-conductor does not easily let current pass through it. A semiconductor, then, is a material which lets current pass through, not as easily as a conductor, but more easily than a nonconductor.

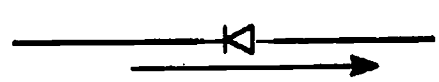
Function of a Rectifier

A rectifier is a device that changes AC to some type of pulsating DC. From this we can assume that after current passes through the semiconductor rectifier in your power supply, it is no longer AC, but has been changed to pulsating DC. Let's see how this happens.

How the Rectifier Works

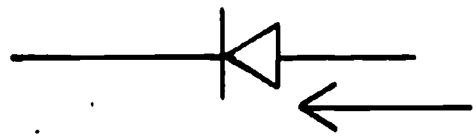
First we will see what the symbol is for a rectifier. It looks like this:

The rectifier is constructed so that it has little resistance to I flowing in this direction.



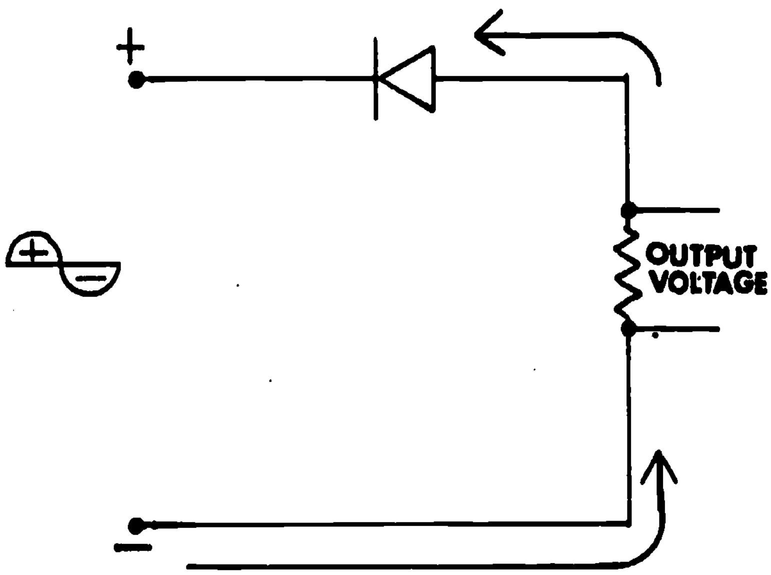
Current can easily flow in this direction as shown by the arrow.

However, a rectifier is constructed so that it has very great resistance to current flow from the other direction.

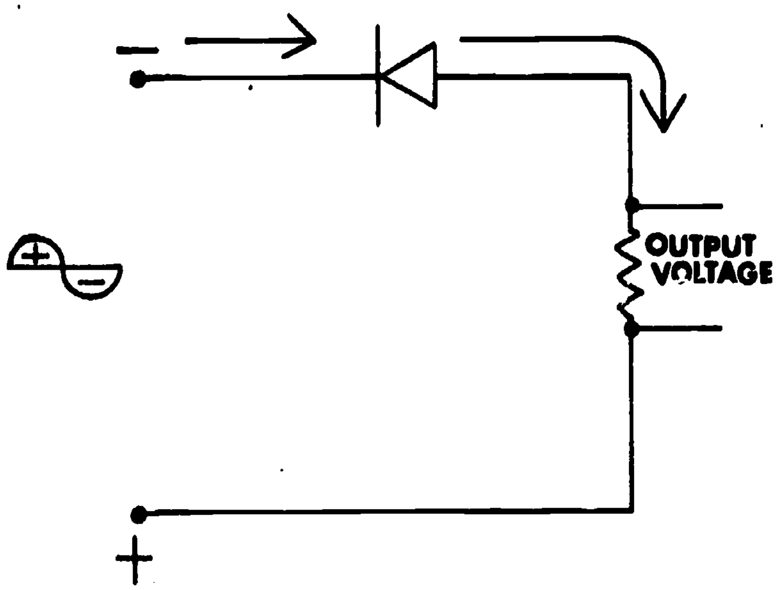


Current cannot readily flow

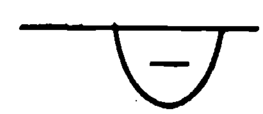
in this direction.



Now if we apply AC to this circuit, current will attempt to flow as indicated by the arrow, from negative to positive, during this first half cycle. However, The rectifier will not let current pass through it in this direction. No current can flow, and there is no voltage drop across the resistor.

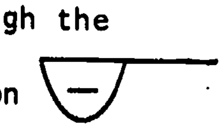


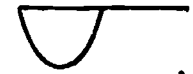
On the next half cycle, polarity reverses and current flows through the rectifier in the other direction. The rectifier now lets current flow and one-half of the waveform passes through like this. Notice, we have eliminated the positive alternation.



Half-Wave Rectification

On the next half cycle, current again attempts to flow in the other direction. Again, no current passes through the rectifier. This makes our waveform look like this with a pause line where the positive alternation is chopped off.



This wave is the equivalent of one cycle of  pulsating DC. Although this accurately shows one cycle, the output of a half-wave rectifier is frequently illustrated as  because it is easier to visualize when a number of cycles are shown. This or  is a wave form for half-wave rectification such as occurs in your power supply.

AT THIS POINT, YOU MAY DO THE EXPERIMENT WHICH STARTS ON PAGE 135 PRIOR TO TAKING THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU DO THE EXPERIMENT, TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, YOU MAY TAKE THE MODULE TEST. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON VI

Semiconductor Rectifiers

THIS PROGRAMMED SEQUENCE HAS NO TEST FRAMES.

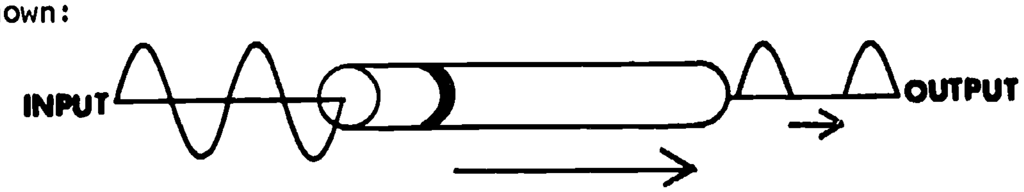
As you've been told, the purpose of a power supply is to provide one or more DC voltages from an AC source. The transformer and the voltage-dropping resistors take care of providing the various values of voltages desired; the device which changes AC to DC is called a rectifier. There are several types of rectifiers available; the one used in your power supply is known as a semiconductor rectifier. In this lesson, only the actual circuit function is covered; the solid-state physics needed to understand operation will be covered as needed in your A School.

1. After current leaves the secondary of the __________, it goes through a small component, the rectifier, which looks like a small resistor with one colored band.

   Locate the rectifier in your power supply.

(transformer)

2. A rectifier is a device that changes AC to what is known as pulsating DC. Graphs of an AC input and a pulsating DC are shown:

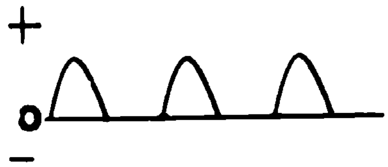


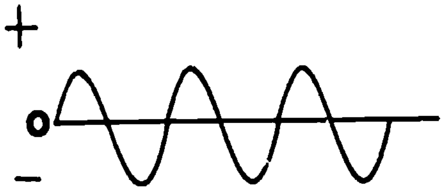
From the illustration, you can see that while current leaving the rectifier still varies somewhat in magnitude, it is now going in __________ direction.

(one)

3. From the illustration, you can see that the bottom of each sine wave has been chopped off; the reason is that the special atomic structure of the materials used in the rectifier permit current to pass through it in only <u>one</u> direction.

Which of these sine waves indicates that current has passed through a rectifier?

___ a 

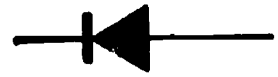
___ b 

(a)

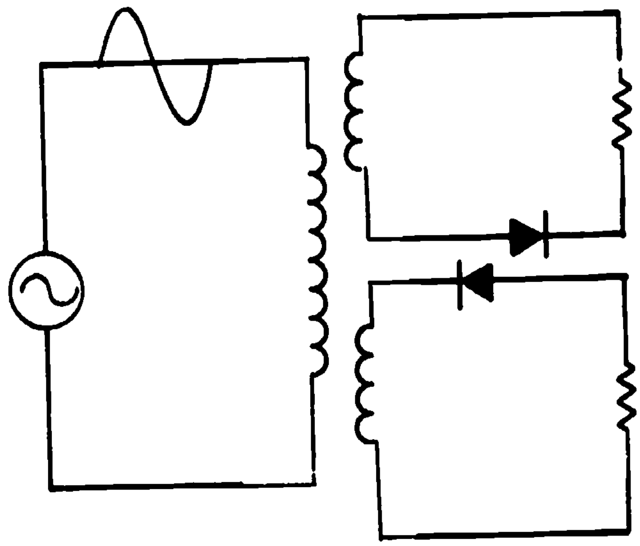
4. A semiconductor rectifier:

____ a. rectifies DC to AC.
____ b. rectifies AC to pulsating DC.
____ c. pulsates AC.

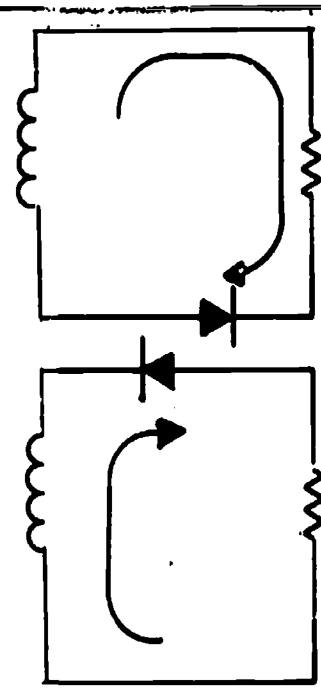
(b) rectifies AC to pulsating DC

5. The schematic symbol for a rectifier looks like this 

Electron current flow is against the arrow making the heavy line negative and the arrow positive. Using arrows, indicate direction of current in each secondary circuit in this schematic.



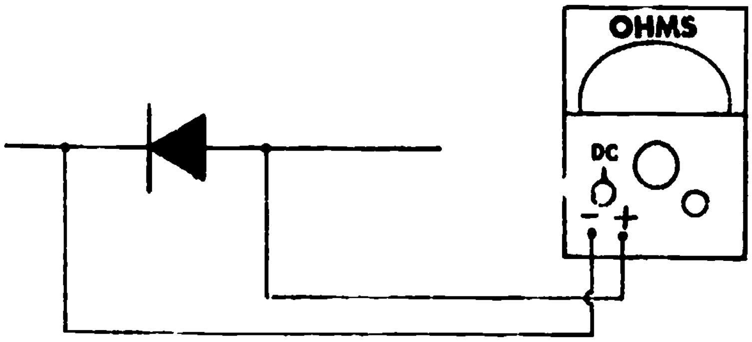
- -



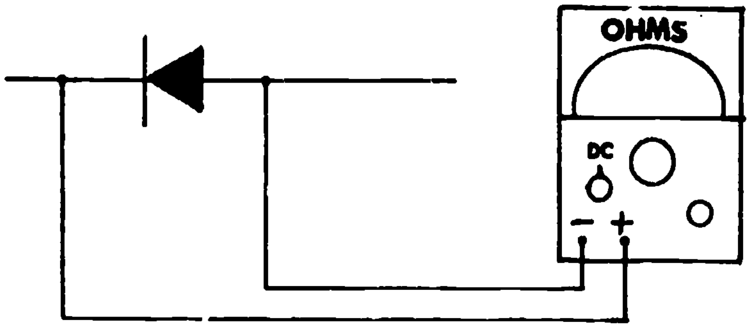
6. A rectifier is constructed so that it has very little resistance to current flow in one direction but a very large resistance to any current flow in the opposite direction.

   In which circuit would the meter indicate the largest value? (The polarity of the voltage supplied by the ohmmeter is opposite to the + and - signs on the meter connectors because of the way the internal battery is connected.)

____ a.



____ b.



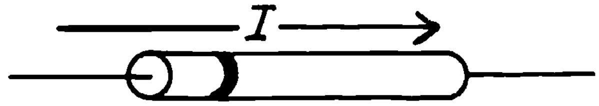
- -

(b)

NOTE: When reading across the rectifier in the high resistance direction, the meter should indicate an infinite value.

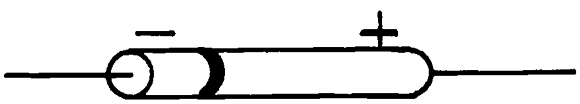
7. On your power supply, disconnect the end of the rectifier closest to the transformer. Then using the multimeter, determine which way current will flow through it.

Using an arrow, indicate direction of electron current through the rectifier.

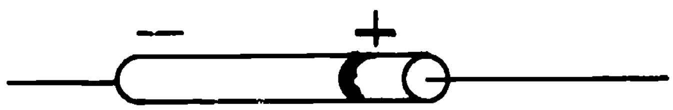


8. Which polarities will permit current flow?

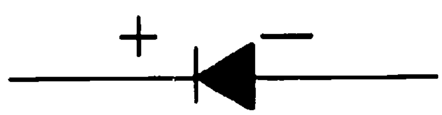
___ 1.



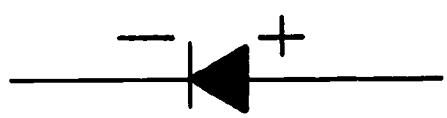
___ 2.



___ 3.

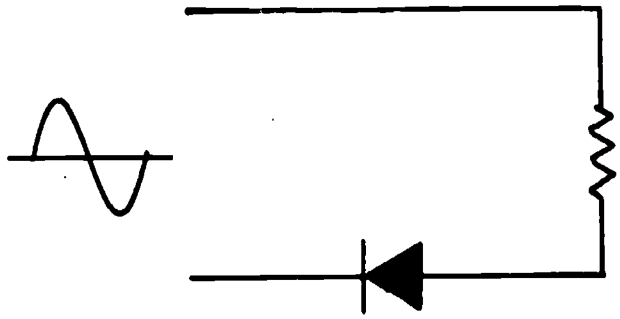


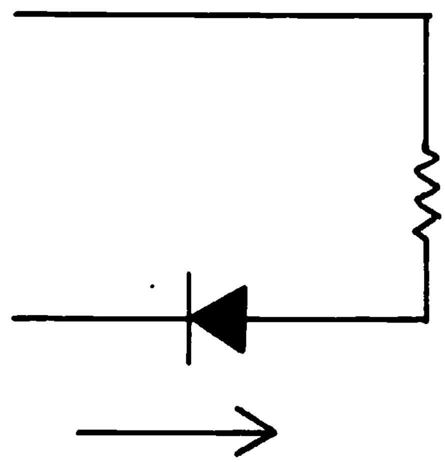
___ 4.



(1; 4)

9. Draw an arrow to show the direction current will flow through the rectifier.





TURN TO THE NEXT PAGE AND PERFORM THE EXPERIMENT.

EXPERIMENT
Diode

Draw an "O" scope from the resources center. Using the oscilloscope in conjunction with a Simpson 260 and your power supply, you will perform a simple experiment with diodes to see how they operate. Plug in the oscilloscope and turn it on for warm up.

Step 1.

With the power supply disconnected, remove one end of the diode from terminal T8. With the test leads connected to the "common and +" terminals of the Simpson 260, set the range switch to the R x 10,000 position. Place test leads across the diode, (Red lead T7, Black lead to disconnected end of diode.) Do you get a resistance reading? How many ohms ______________? Reverse the meter test leads across the diode. How about a reading now? This indicates that current will flow through a diode in only one direction.

Step 2.

Recall the schematic symbol for a diode, 

Current will flow from __________ to __________, hence a diode is said to offer maximum opposition to current in a reverse direction or from __________ to __________.

---

(2) - to +
+ to -

Step 3.

Disconnect the multimeter and reconnect the diode to terminal T8.

Step 4.

With the oscilloscope set up as you learned in Module Nine, connect the black lead of the scope to T8 and the blue lead to T1. Plug in the power supply. Make certain the switch is closed and the lamp glows.

Step 5.

Adjust the SWEEP VERNIER control of the scope to show one steady cycle of a sine wave. If the signal starts to jump or drift, readjust this control.

Step 6.

Vary the SYNC/PHASE control so that the signal begins about half-way between positive and negative peaks. Readjust the SWEEP VERNIER control, if necessary.

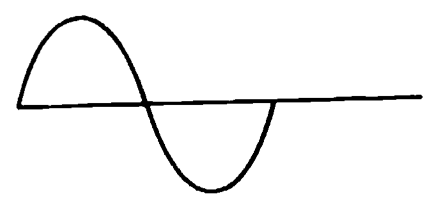
Step 7.

Use the V CAL to bring the signal amplitude just within the vertical limits of the graph.

Step 8.

Draw the signal you see on your oscilloscope. This is the output of the transformer secondary.

The waveform should look about like this:



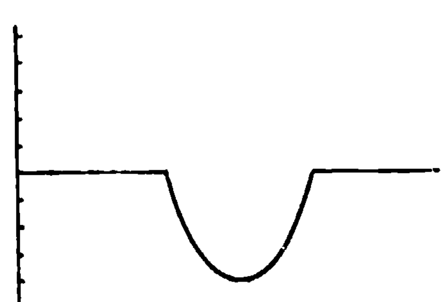
Now let's check on the rectification at the diode.

Step 9.

Unplug the power supply and move the blue lead of the scope from T1 to T7. Plug in the power supply. Adjust the SYNC/PHASE control if the waveform is not stable.

Step 10.

Draw the signal now showing on the scope.



You should see a sine wave with one alternation clipped off by the action of the rectifier.

The output of the rectifier is pulsating DC, and must be smoothed to a (nearly) pure DC. This smoothing process is accomplished by other circuit configurations not covered in this module. These circuits will be covered in a later module.

When you have completed your experiment, properly secure your equipment and turn it into the resource center.

YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

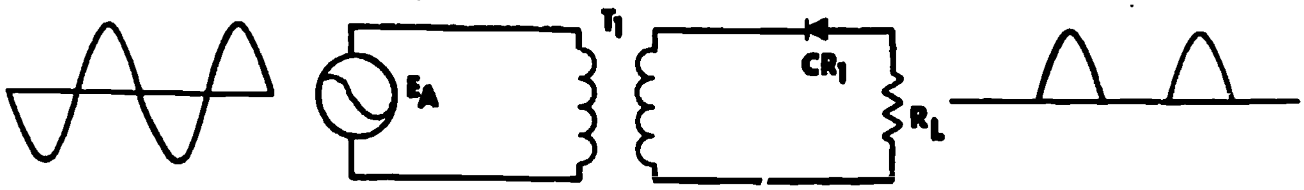
IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR LEARNING SUPERVISOR AND ASK TO TAKE THE MODULE TEST.

SUMMARY
LESSON VI

Semiconductor Rectifiers

A rectifier is a component that allows current to pass in one direction only. There are man-made materials called solidstate crystals which have this property. The symbol for a rectifier is:

Electron current will only flow against the indicated arrow. If a rectifier circuit is supplied by the output of a transformer, the graph of current against time is as shown:



This circuit is called a half-wave rectifier. It converts AC into pulsating DC.

AT THIS POINT, YOU MAY DO THE EXPERIMENT WHICH STARTS ON PAGE 135 PRIOR TO TAKING THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU DO THE EXPERIMENT, TAKE THE PROGRESS CHECK, AND ANSWER ALL OF THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR LEARNING SUPERVISOR AND ASK TO TAKE THE MODULE TEST.