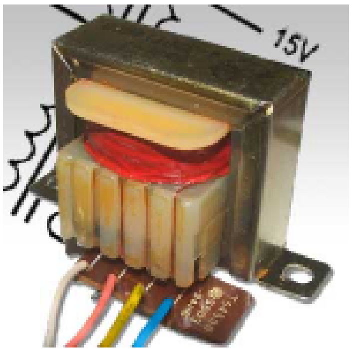
Module

11

AC Theory



Transformers

What you'll learn in Module 11.

- **Section 11.1 Transformer Operation.**
- • Transformer Operation.
- • Transformer Losses.
- • Off Load Current.
- • Volts per Turn.
- **Section 11.2 Magnetic Circuits & Transformer Cores.**
- • Magnetic Circuits & Cores.
- • Magnetic Flux.
- • Reluctance.
- • Permeability.
- • Common Core Types.
- **Section 11.3 Power Transformers.**
- • Tappings.
- • Toroidal Power Transformers.
- • Isolation.
- • Autotransformers.
- • Switch Mode Power Supply Transformers.
- • Transformer Faults.
- **Section 11.4 Audio Transformers.**
- • AF Transformers.
- • Microphone Transformers.
- • 100V Line Transformers.
- • Data/Pulse Transformers.
- **Section 11.5 Radio frequency Transformers.**
- • RF Transformers.
- • VHF Transformers.
- • UHF Transformers.
- • Screening.
- **Section 11.6 Transformers Quiz.**

Introduction

Transformers have been an essential component in electrical and electronic circuits since the 1830s and although new technologies in some electronic circuits have reduced the need for transformers, they are still essential in many applications.

How Transformers work.

This module describes how transformers work, and how the design of both the transformer coils, and the core on which they are wound affects the efficiency of the transformer. Detailed descriptions of many types of transformer are also given together with typical applications.

Isolation

Transformers can allow separate circuits to be physically isolated from each other whilst still allowing current and voltage to pass between the two. They can also be used to reduce or increase the voltage or current that is passed as required.

Impedance Matching

Another common use for transformers can be to match input and output impedances where the output of one circuit needs to pass an AC signal to the input of another. The advantage of this technique is that the transfer can be achieved with practically no loss of power in the transfer.

Transformers of many types.

Transformers are made in a very wide range of sizes and configurations, from the enormous power transformers, weighing many tons that connect the different parts of the public electricity grid together, to tiny transformers consisting of nothing more than a few turns of wire, found in UHF radio equipment.

Module 11.1 Transformer Basics

What you'll learn.

- **After studying this section, you should be able to describe:**

• Basic transformer operation

• Turns ratio.

• Power ratio.

• Transformation ratio.

• Transformer losses: Copper, Hysteresis & Eddy current.

• Transformer efficiency and off load current.

Transformers.

A transformer uses the principles of electromagnetism to change one A.C. voltage level to another. Faraday's work in the 19th century showed that a changing current in a conductor (e.g. a transformer primary winding) sets up a changing magnetic field around the conductor. If another conductor (secondary winding) is placed within this changing magnetic field a voltage will be induced into that winding.

Turns Ratio.

Faraday also calculated that the voltage induced into the secondary winding would have a magnitude that depends on the TURNS RATIO of the transformer. i.e. If the secondary winding has half the number of turns of the primary winding, then the secondary voltage will be half the voltage across the primary winding. Likewise, if the secondary winding has twice the number of turns of the primary winding, the secondary voltage will be double the primary voltage.

Power ratio.

Because the transformer is a passive component, (it has no external power supply) it cannot produce more power out from its secondary than is applied to its primary. Therefore if the secondary voltage is greater than the primary voltage by a particular amount, the secondary current will be smaller than the primary current by a similar amount, i.e. If the voltage is doubled the current will be halved.

Transformation Ratio.

Basic Transformer operation can be described by two formulae relating the transformation ratio to the turns ratio of the transformer windings.

- V_P = the primary voltage.
- I_P = the primary current.
- V_S = the secondary voltage.
- I_S = the secondary current.
- N_P = the number of turns in the primary winding.
- N_S = the number of turns in the secondary winding.

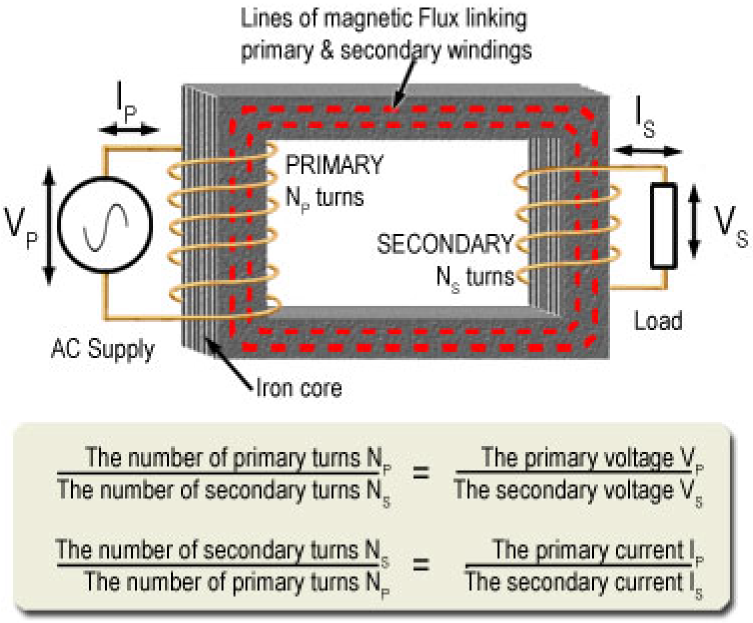


Fig 11.1.1 Basic Transformer Operation.

Transformer Losses.

The formulae in Fig. 11.1.1 relate to an ideal transformer, i.e. a transformer with no power losses, in which, Primary volt amperes = Secondary volt amperes.

While practical transformers can be extremely efficient, some losses will occur because not all of the magnetic flux produced by the primary winding will link with the secondary winding. The power losses that occur in a transformer are of three types:

1. Copper Losses.

These losses can also be called winding losses or I^2R losses, because they can occur in windings made from metals other than copper. The losses become evident as heat, generated in the (copper) wire windings as they dissipate power due to the resistance of the wire.

The power loss in a transformer winding can be calculated by using the current in the winding and its resistance, in formula for power, $P = I^2R$. This formula is the reason copper losses are sometimes called I^2R losses. To minimise the losses the resistance of the winding must be kept low, using wire of suitable cross sectional area and low resistivity.

2. Hysteresis losses.

Each time the alternating current reverses (once each cycle), tiny "magnetic domains" within the core material are reversed. These are physical changes within the core material and take up some energy. The amount of energy used depends on the "reluctance" of the core material; in large cores of power transformers where hysteresis loss maybe a problem it is largely overcome by using special low reluctance "grain oriented" steel as the core material.

3. Eddy Current losses.

Because the iron or steel core is an electrical conductor as well as a magnetic circuit, the changing current in the primary will tend to set up an EMF within the core as well as in the secondary winding. The currents induced into the core will oppose the changes of magnetic field taking place in the core. For this reason these eddy currents must be kept as small as possible. This is achieved by dividing the metal core into thin sheets or "laminations", each one insulated from the others by an insulating coat of lacquer or oxide. Laminated cores greatly reduce the formation of eddy currents without affecting the magnetic properties of the core.

In high frequency transformers eddy current losses are reduced by using a core made of a ceramic material containing a large proportion of tiny metal particles, iron dust or manganese zinc. The ceramic insulates the metal particles from each other, giving a similar effect to laminations, and performing better at high frequencies.

Due to the ways of reducing losses described above, practical transformers closely approach the ideal in performance. In large power transformers, efficiencies of about 98% can be achieved. Therefore for most practical calculations, it can be assumed that a transformer is "Ideal" unless its losses are specified. The actual secondary voltages in a practical transformer will be only slightly less than those calculated using the theoretical transformation ratio.

Off Load Current.

Because the action of a transformer is nearly perfect, the power in both primary and secondary windings is the same, so when no load is put on the secondary, no secondary current flows and the power in the secondary is zero ($V \times I = 0$). Therefore, although a voltage is applied to the primary no current will flow, as the power in the primary must also be zero. In practical transformers the "Off Load Current" in the primary is actually very low.

Volts per Turn.

A transformer with a primary winding of 1000 turns and a secondary winding of 100 turns has a turns ratio of 1000:100 or 10:1. Therefore 100 volts applied to the primary will produce a secondary voltage of 10 volts.

Another way to consider transformer voltages is by volts/turn; if the 100 volts applied to the 1000 turn primary produces $100/1000 = 0.1$ volts per turn, then each single turn on the 100 turn secondary winding will produce 0.1V so the total secondary voltage will be $100 \times 0.1V = 10V$.

Module 11.2 Magnetic Circuits and Transformer Cores.

What you'll learn.

- **After studying this section, you should be able to describe:**

• Magnetic Flux

• Permeability: Relative and absolute.

• Reluctance.

• The Magnetic Circuit.

• Magneto-motive force, m.m.f.

• Common types of transformer cores.

Magnetic Flux and Ampere Turns

The strength of the magnetic field (or amount of flux measured in Webers) in a transformer core is directly proportional to the number of TURNS around the coil that is producing the magnetic flux within the core, and to the amount of CURRENT flowing in the coil. Therefore the amount of flux, Φ (The Greek letter Phi) is proportional to the product of N (number of turns) x I (the current in amperes) or the 'AMPERE TURNS' of the coil. Increasing either the number of turns or the current in the coil produces an increase in flux.

$$\Phi \propto NI$$

Reluctance.

There is a third way to increase the flux. That is to improve the magnetic properties of the core by using a material that has a low Reluctance (R_m), this is the property of a material that is the magnetic equivalent of the electrical property of Resistance. The lower the reluctance, the easier it is for magnetic flux to flow through the core material.

Materials that are easily magnetised have a low reluctance and a high permeability, and none magnetic materials have a high reluctance and a low permeability. The opposite of Reluctance is Permeability, the magnetic equivalent of electrical Conductance.

Fig 11.2.1 Electrical and Magnetic Circuits compared.

Electrical and magnetic circuits are similar in many respects. Fig. 11.2.1 compares a simple electrical and simple magnetic circuit.

In the electrical circuit an e.m.f. produced by a cell or battery drives a current around the circuit, which consists of a length of wire having some resistance R.

The magnetic circuit also has a source of power in the form of a coil, supplied by an AC current. Just as the external electrical source is called an electro motive force, the external magnetic source is called a magneto motive force (m.m.f.), and is measured in ampere turns.

An e.m.f. produces a current (I), which has a strength measured in amperes in the electrical circuit; in the magnetic circuit, the m.m.f. produces a magnetic flux, Φ and is measured in units of webers (Wb).

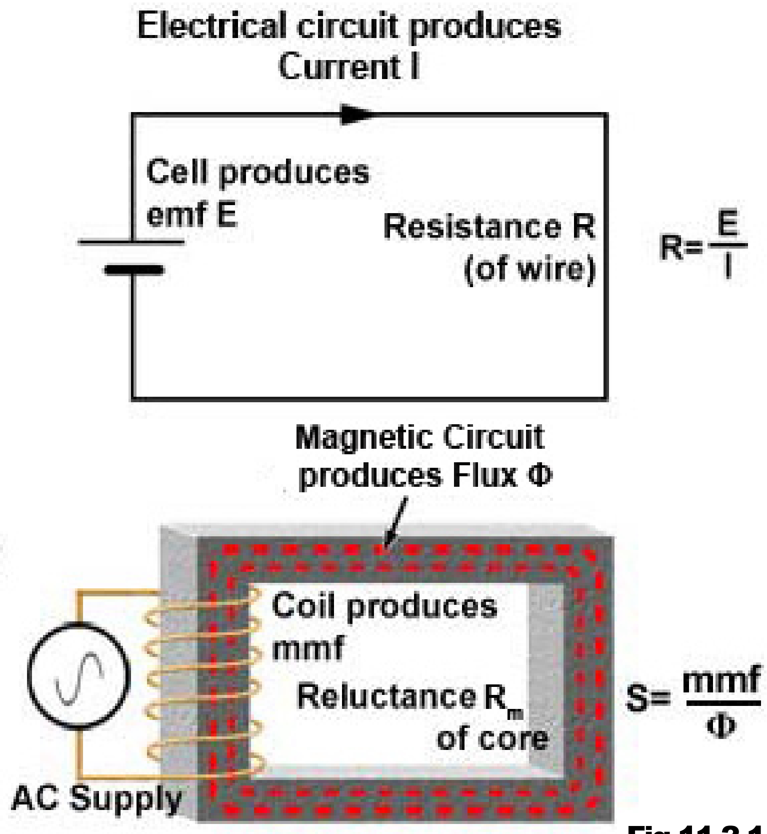


Fig 11.2.1

The resistance to the flow of magnetic flux in the core is called Reluctance (R_m)

Fig 11.2.2 Magnetic Flux linking primary and secondary windings.

Figure 11.2.2 shows a magnetic circuit made from a rectangular shaped iron loop or core. A coil (the primary) supplied with an AC current is wound around one side of the core to provide a source of m.m.f. On the other side of the core, a separate coil (the secondary) is wound which supplies a measuring instrument to measure the amount of current in the coil. The current in this coil will be proportional to the amount of flux flowing in the core. This arrangement therefore provides a means of measuring magnetic flux.

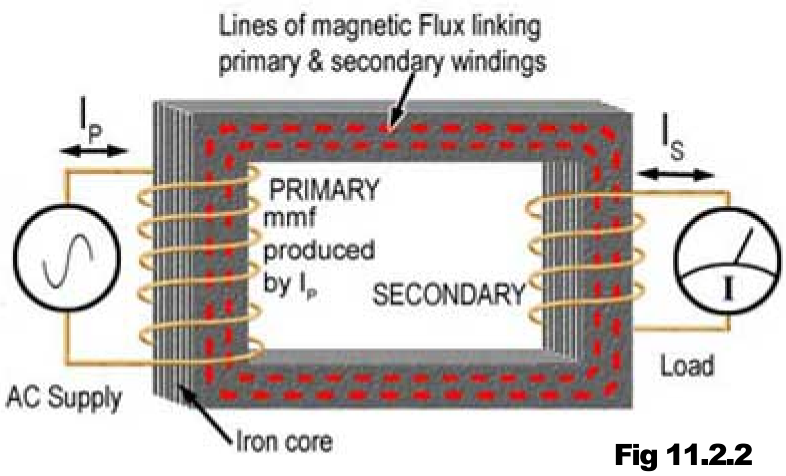


Fig 11.2.2

Fig 11.2.3 Flux is proportional to current and number of turns.

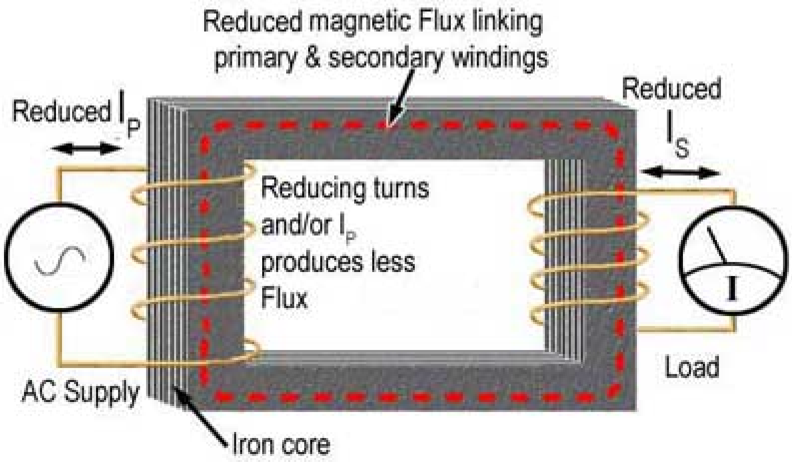


Fig 11.2.3

Figure 11.2.3 shows that by changing the number of turns on the primary coil, or the current through it, a different amount of current will flow in the secondary coil showing that the flux (Φ) is proportional to both the current and the number of turns. $\Phi \propto NI$.

Fig 11.2.4 Flux is also affected by the dimensions of the core.

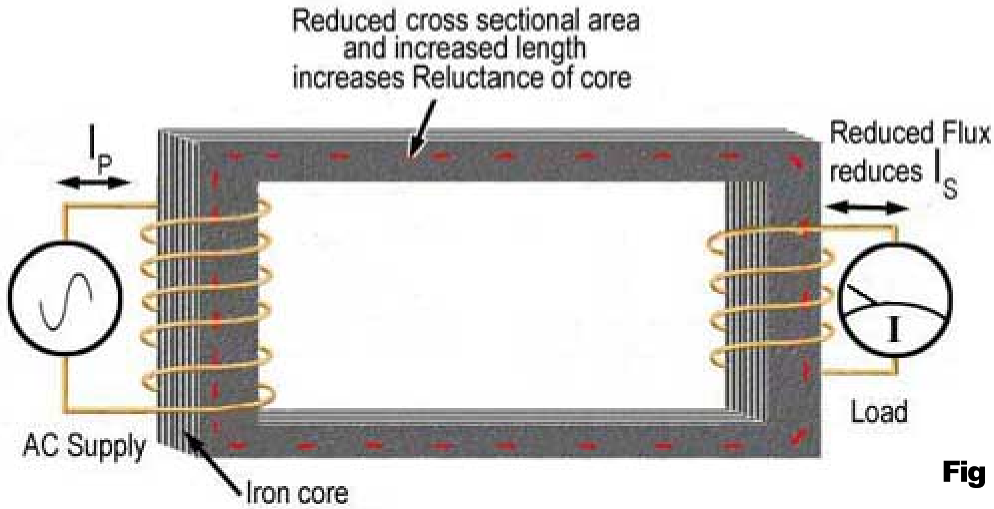


Fig 11.2.4

Figure 11.2.4 shows that if the m.m.f. is kept constant, but the dimensions of the core are altered by changing either the length of the flux path or its cross sectional area, the amount of flux flowing around the core will also change.

Therefore the measured flux (Φ) in the core (and therefore the secondary current) is proportional to the cross sectional area of the core, and inversely proportional to the length of the flux path:

$$\Phi \propto \frac{A}{L}$$

Where:

A is the cross sectional area of the core and

L is the mean length of the flux path around the core.

The magnetic circuit also has some Reluctance R_m (a type of resistance to flux);

$$\text{Reluctance } R_m = \frac{mmf}{\Phi}$$

Reluctance is measured in Amperes per Weber (A/Wb).

Permeability.

Electrical resistance also depends not only on the dimensions of the conductor but also on the material of the conductor and its resistivity. Likewise, in magnetic circuits reluctance depends not only on the length and cross sectional area, but also on the Permeability (μ) of the material.

The higher the value for μ the more flux will flow and the more flux that flows, the lower must be the value of reluctance R_m

Therefore:

$$R_m = \frac{l}{\mu A}$$

So Reluctance increases with the length of the magnetic path (l) and decreases as either the cross sectional area (A) of the core or the Permeability (μ) of the material is increased.

Relative and Absolute Permeability

Permeability is often expressed as:

$$\mu = \mu_0 \mu_r$$

It is normal to find a core material described by its relative permeability (μ_r), i.e. by how many times the absolute permeability (μ) of the material is greater than the absolute permeability of free space (μ_0). The absolute permeability of free space μ_0 has a value of $4\pi \times 10^{-7}$ H/m = $1.256637061 \times 10^{-6}$ H/m where H is in henrys and m is in metres. Quoting the absolute permeability of materials used in cores would involve similarly awkward numbers. If a more convenient figure, the relative permeability of free space (or air), which will be 1 is used, the absolute permeability of a material (μ) will be its relative permeability (μ_r) multiplied by the absolute permeability of free space (μ_0).

Therefore μ is a simple ratio that does not have any units, e.g. if the μ of a material is given as 1000, its permeability is one thousand times greater than the absolute permeability of free space (or air).

The permeability of iron can be many hundreds, so having a magnetic circuit path of iron rather than air greatly increases the flux, which is why iron is a common choice of material for inductor and transformer cores.

Fig. 11.2.5. Common Types of Transformer Cores.

Fig 11.2.5 illustrates some commonly used types of core. The Shell Core is an improvement of the Core type; its magnetic circuit encloses the windings more fully. Notice the centre limb has twice the cross sectional area of the outer limbs, allowing for double the flux within the primary and secondary windings.

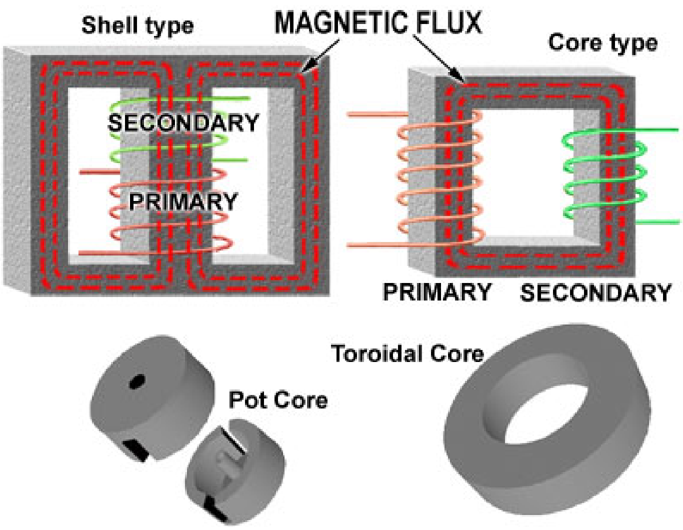


Fig 11.2.5

The Toroidal core gives an even more efficient coupling, and radiates less electromagnetic energy outside the transformer.

The magnetic circuit of the two part Pot Core, used for smaller high frequency transformers and inductors, totally encloses the windings.

Module 11.3 Power Transformers.

What you'll learn.

- **After studying this section, you should be able to describe:**
  - Tappings.
  - Toroidal Power Transformers.
  - Isolation.
  - Autotransformers.
  - Switch Mode Power Supply Transformers.
  - Transformer Faults.

Fig. 11.3.1 Laminated Core Power Transformer.

The job of a Power Transformer in an electronic system is to provide that system with a number of AC supplies of various voltages and suitable values of current, from the high voltage public electricity supply. In addition it may be required to provide electrical isolation between the electronic circuitry and the external public power supply. A typical power transformer construction using a laminated core is shown in Fig 11.3.1

A core of thin steel 'E' and 'I' shaped laminations is used to reduce the effects of eddy currents. These are clamped together and the primary and secondary windings wound on a former placed around the central limb of the core. The windings may be separate as shown, or often, for greater efficiency, wound concentrically in layers (primary, secondary, primary, secondary, etc). Transformers are often made specific to a particular application or equipment in which they are used. Correct identification of windings may therefore require reference to manufacturers data.

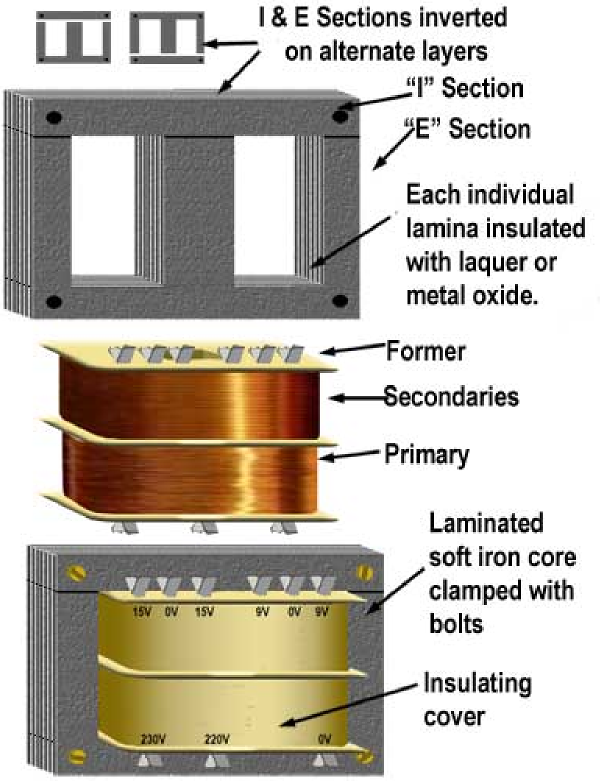


Fig 11.3.1

Tappings.

To enable transformers to supply a range of secondary voltages to different parts of a circuit it is common for power transformers to have "Tapped windings". That is, windings split into various sections by using a number of connections brought out from a single winding, each one at a particular number of turns along the winding, as shown in the schematic symbol diagram Fig 11.3.2.

Fig. 11.3.2 Schematic Diagram of a Tapped Power Transformer.

This provides a selection of different turns ratios between primary and secondary allowing different input voltages to be used and a range of different output voltages to be obtained.

By using a winding with a central tapping, e.g. 9V 0V 9V, a balanced supply can be provided giving two equal voltages (9V) of opposite polarity, or a single 18V supply.

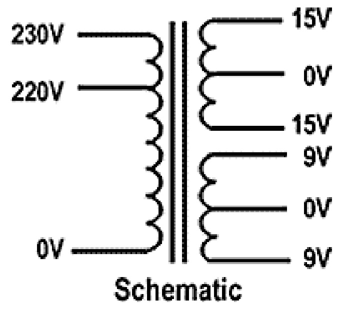


Fig 11.3.2

Fig. 11.3.3 Toroidal Power Transformers.

A popular design for power transformers is based on the toroidal core shown in Fig 11.3.3. This design gives excellent linkage between primary and secondary as both coils are wound on the same ‘donut’ shaped core. Core losses are kept low by the use of high permeability ferrite core material. The toroidal construction, although generally more expensive than laminated core types provides a smaller and lighter transformer than for a given power rating.

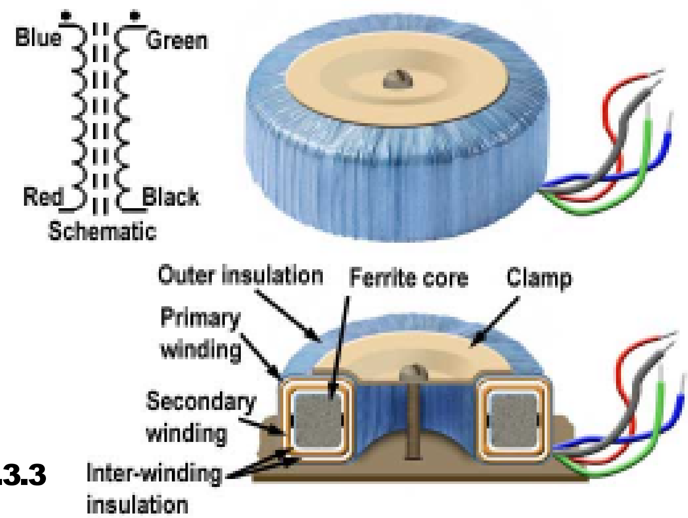
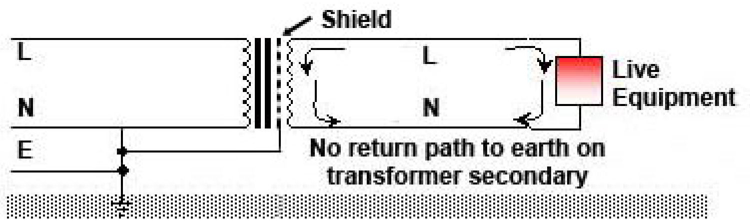


Fig 11.3.3

Isolation.

One advantage of transformers is that there is no electrical connection between the input circuit connected to the primary and the output circuit connected to the secondary; they can therefore be used to electrically isolate two circuits.

Fig. 11.3.4 Mains Isolation Transformer.



Mains (Line) Isolation Transformers are used to give greater safety to users of electrical equipment such as outdoor power tools, and to technicians servicing equipment where live conductors and components may be touched, by providing input and output terminals that are electrically isolated from the main circuit.

Large isolating transformers are typically capable of handling a power output of about 250-500 VA (volt amperes) without being overloaded. Their primary is connected directly to the mains supply, and to give a mains (or line) output voltage their turns ratio is 1:1 as illustrated in Fig. 11.3.4. They also have an earthed metal shield between primary and secondary windings to prevent AC being passed by electrostatic (capacitive) as well as inductive coupling between the two windings.

The use of an isolation transformer greatly reduces the risk of a shock to a person simultaneously touching a live conductor and earth, as the secondary circuit has no earth connection and therefore no continuous circuit for current to flow. The isolation transformer does NOT prevent shock to anyone touching live and neutral at the same time.

Much smaller isolating transformers are used in voice and data communication equipment such as Fax machines and modems, where their task is to safely isolate equipment that may, under fault conditions, allow high voltages to be present at their interface with the public telephone system. These transformers are also used to match the impedance of the equipment inputs and outputs to those of the telephone lines.

Autotransformers.

This is a special type of transformer that has only one winding. It is often used for conversion between different mains (line) voltages, allowing electrical equipment to be used internationally. The single continuous winding is divided into a number of "tappings" as shown in Fig. 11.3.5 to produce different voltages. An appropriate number of turns are provided between each tapping to produce the required voltage, based on the turns ratio between the complete winding and the tapping. A useful method of calculating unknown voltages on an autotransformer, if the number of turns on the various tappings is known, is to use the volts per turn method described on the Basic Transformer Operation page. Unlike a conventional transformer with primary and secondary windings, the autotransformer does not provide any isolation between input and output.

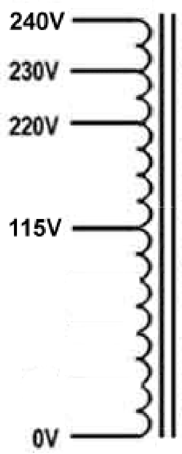


Fig. 11.3.5 Schematic diagram of an Autotransformer.

Autotransformers are also used to provide the very high voltages need for such applications as automobile ignition systems and cathode ray tube drives in CRT TVs and monitors.

The "Auto" part of the name in this case does not mean automatic but has the meaning of:

"One - acting on its own" as in **auto**nomous.

Switch Mode Power Supply Transformers

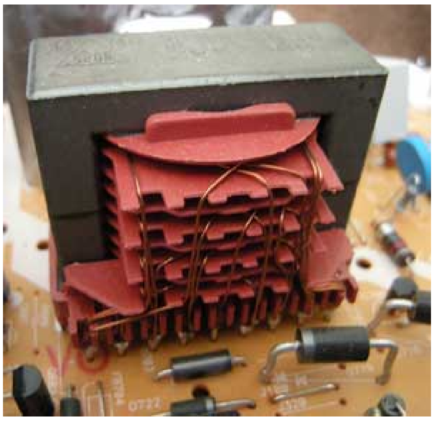


Fig. 11.3.6 Switch Mode Power Supply.

Large laminated core transformers are less common nowadays because of the use of Switch Mode Power Supplies (SMPS). These circuits operate at much higher frequencies than the older 50-60Hz supplies. In addition to being more efficient SMPS have the advantage that many of the components in the power supply circuit can be physically much smaller and lighter, including the transformer. SMPS transformers, working at around 500kHz, like the example in Fig 11.3.6 in a TV receiver, use ferrite instead of laminated core losses in these cores are much less at high frequencies. The waveforms handled by transformers in SMPS, in addition to being high frequency, generally have a square wave shape. Because of this, they will contain many harmonics at event higher frequencies. This creates a problem of skin effect; high frequency currents flowing in wires tend to flow only along the outer skin of the wires, which means that the normal calculations of wire cross sectional area are made more complex. Because the effective cross sectional area changes with frequency, then so will the effective inductance of the winding. Also, the layout of components in relation to SMPS transformers needs careful design, as electromagnetic interference at high frequencies is greater.

Transformer Faults

Transformers are generally highly reliable; their very high efficiency means that under normal conditions little power is dissipated as heat (in many components the biggest killer!). As with any electronic device, it is those that handle the greatest power that are the least reliable, so power transformers, especially those operating with high voltages that are more susceptible than other transformer types, to breakdown.

Overheating, whether caused by an internal fault, or by overloading can lead to dangerous, even complete "meltdown" situations. For this reason many power transformers may be fitted with a temperature operated fuse or cut–out. In the unlikely advent of this device failing it is usual that the primary winding will appear to be open circuit. It is often difficult or impossible to remove and or repair the fuse, which will be buried deep switching the windings. It is also very possibly unwise to do so, as the transformer will have overheated for one of two probable reasons:

1. The transformer has been seriously overloaded for some considerable time; in which case internal damage to the insulation may have occurred. The safest option is to replace the transformer.

2. The transformer has suffered an internal shorted turn. This means that the insulation between two turns of a winding has broken down. The effect of this is to create a winding of a single turn. The transformation ratio is now enormous! Imagine a transformer with a 1000 turns on its primary and 100 turns on it secondary, suffering a shorted turn on the secondary winding. The turns ratio has just changed from 10:1 to 1000:1! The result is very little secondary voltage but enormous current. In this case again the only solution is replacement.

Another problem that can happen, especially on high voltage transformers (some transformers may generate several thousand volts) working or stored for long periods in humid conditions is damp penetrating between the transformer windings. In such cases when high voltage is applied, arcing can occur between the layers of a winding and punch a tiny carbonised hole in the insulation and the transformer immediately suffers a shorted turn.

With any fault where a transformer (whatever type) is suspected, the likelihood of it being the culprit is very low down the list of probabilities.

Module 11.4 Audio Transformers.

What you'll learn.

- **After studying this section, you should be able to describe:**

• AF Transformers

• Microphone Transformers.

• Impedance Matching.

• 100V Line Transformers.

AF Transformers.

Audio Frequency (AF) Transformers work at frequencies between about 20Hz to 20kHz and are used in audio amplifier circuits, they were essential in valve (tube) designs for matching the high impedance outputs of theses amplifiers to low impedance loudspeakers, but transistor amplifiers have much less need for output transformers. AF transformers are still produced however for a range of audio functions; many are similar in construction to the power transformers described in Module 11.3, but are often much smaller, see Fig.11.4.1.

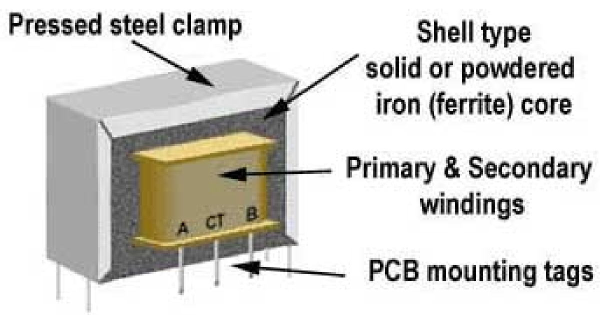


Fig 11.4.1 Small audio transformer.

Some common arrangements of audio transformer windings are shown in Fig 11.4.2.

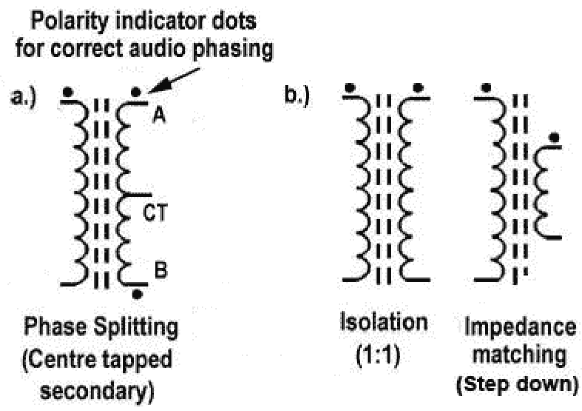


Fig 11.4.2 AF transformer schematic diagrams showing phase indicators.

Example a.) shows a centre tapped secondary winding that can be used to provide a selection of different turns ratios. Some transformers may also have tapped primaries for an even wider range of ratios. In audio amplifiers, the phase/anti phase of signals can be important and phase splitting transformers with centre tapped secondary windings can be used to provide two anti phase signals. The dots near the windings on schematic diagrams indicate the relative polarity of the signals on different windings, and in this example show that the signal from the upper secondary winding (A) will be in phase with the primary signal, while the lower secondary winding (B) will provide a signal in anti phase with the primary signal.

Example b.) shows two output transformers, used to couple the power output stage of an audio amplifier to the loudspeaker. Audio transformers often perform several functions at once:

- Where used, they allow the AC audio signal to reach the loudspeaker whilst preventing any DC from the amplifier affecting the operation of the loudspeaker.
- They provide an isolated external connection for the loudspeakers, improving safety.
- They can match the low input impedance of the loudspeaker (typically a few ohms) to the much higher output impedance of an amplifier, allowing maximum power to be transferred from the amplifier to the speaker

Microphone Transformers.

Audio transformers can also be used for matching microphones to amplifier inputs. The main purpose of a transformer at the amplifier input is matching impedance between microphones, connecting cables and the amplifier input. This is important to ensure that there is no signal reduction due to impedance mismatching.

To prevent electromagnetic interference, often in the form of a low frequency hum, long microphone cables usually use a balanced cable similar to that shown in Fig. 11.4.3. This consists of two conductors twisted together surrounded by a conducting shield made from metal foil or braid. Because the conductors are twisted together, effectively rotating their relative positions to each other, magnetic fields generated by each conductor into the other, tend to cancel out. The surrounding earthed conducting foil helps prevent external magnetic fields from affecting the conductors.

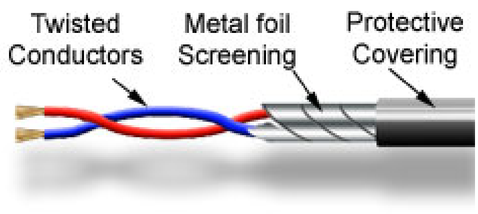


Fig. 11.4.3 Balanced Microphone Cable.

A transformer with a single primary and a centre-tapped secondary is used to connect the microphone (a two wire unbalanced device) to the balanced cable. Because the cable is fed from a centre-tapped transformer, the signals on the two conductors are in anti-phase.

The amplifier input uses the difference between these two signals to produce a signal that is doubled in amplitude. Any noise that has been externally induced into the cable after the transformer will be identical in phase on both conductors, so the subtraction (difference) combination occurring at the amplifier input cancels out these noise signals.

The combination of signals at the amplifier can be carried out either by using a differential amplifier (an amplifier with two anti-phase inputs), or by using a balun (BALanced to UNbalanced) device. This is a type of transformer for matching balanced transmission lines or cables to, or from an unbalanced input or output, (the device is reversible). A simplified Schematic of a balun is shown in Fig. 11.4.4.

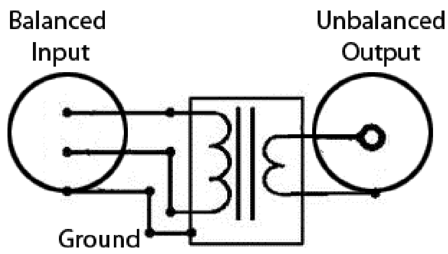


Fig. 11.4.4 A Balun.

Fig. 11.4.5 shows a typical microphone transformer that plugs directly into an unbalanced high impedance amplifier input. The XLR socket at the other end of the device allows a low impedance microphone to be connected via a long lead. The transformer within the metal screening case acts as a balun, an impedance matching device and an input isolator for the microphone.

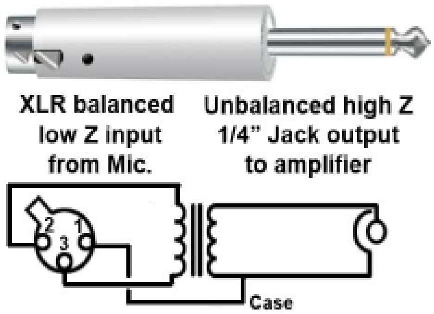


Fig. 11.4.5 A Microphone Matching Transformer.

Impedance Matching.

When the output of one circuit or device is feeding an AC signal to the input of another circuit or device, it is important that the input and output impedances are properly matched. In most case impedance matching requires that the maximum VOLTAGE is transferred from one circuit or device to the next and for the transfer of maximum voltage this is achieved using simple resistance networks.

Where it is required to transfer the maximum amount of AC POWER between the circuits, transformers may be used. This is because a transformer has the ability to "transform" or change the apparent impedance of a circuit input or output. It can make a low impedance appear much higher, or a high impedance much lower.

Suppose a transformer has a primary to secondary ratio of 10:1 and a load impedance Z_L of 8Ω is connected across the secondary winding. If 20 volts is applied to the primary winding the voltage across the load impedance will be:

$$20 \times N_S / N_P = 20\ (1/10) = 2\text{volts}$$

Therefore the current in the load impedance Z_L will be:

$$I_L = V_L / Z_L = 2/8 = 0.25 = 250\text{mA}$$

So the current in the primary must be 1/10 of this amount:

$$I_P = 250\text{mA} \times 0.1 = 25\text{mA}$$

Thus the apparent resistance of the primary winding must be:

$$R_P = V_P / I_P = 20\text{v} / 25\text{mA} = 800 \text{ ohms}$$

Therefore the 10:1 transformer "magnifies" the impedance Z_L of the load so that it appears to the amplifier as though it is feeding a load impedance of 800 ohms instead of the actual impedance of 8Ω. The apparent load on the amplifier has been increased in value by a factor of 100 times by the presence of the transformer. Notice the amount of the apparent increase; 100 times. As the turns ratio of the transformer is 10:1 the increase in apparent resistance (or impedance) is the square of the turns ratio. This relationship is described by the formula;

$$Z_P = Z_S\,(N_P/N_S)^2$$

Ensuring that the output stage of an amplifier is correctly matched to its load.

100V Line Transformer.

Another Audio transformer, used for multi loudspeaker public address systems is the 100V line transformer used for connecting multiple speakers in public address systems to a single amplifier. The word "Line" in the title should not be confused with the United States public electricity supply. In the 100V line speaker system, a transformer steps up the audio output signal voltage to 100V so that the output current for a given power is low. The resistance on long cables between the amplifier and loudspeakers will attenuate this low current signal much less than if the current were left at its normally high level. An impedance matching step down transformer (shown in Fig. 11.4.6) is used at each speaker to reduce the voltage and increase the current again, and to match the line to the low impedance of the loudspeaker. The multiple connections on the primary allow suitable level of power (and therefore sound volume) to be chosen for each loudspeaker, and the secondary has a choice of impedances to match a range of loudspeakers.

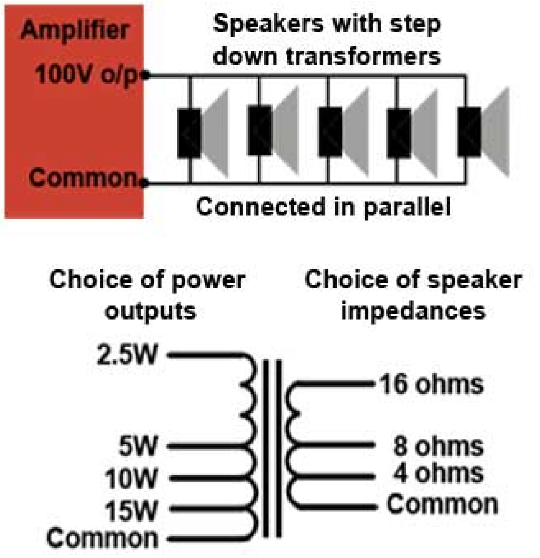


Fig. 11.4.6 100V Line

Module 11.5 RF Transformers.

What you'll learn.

- **After studying this section, you should be able to describe:**

• RF Transformers

• VHF Transformers.

• UHF Line Transformers.

• Screening.

Radio Frequency Transformers.

Radio Frequency transformers describe those used at frequencies including RF VHF and UHF. At each of these frequencies, construction varies considerably.

RF Transformers

RF is considered to be the lowest band of frequencies in this group, and transformers working at frequencies between 30kHz to 30MHz may often have their windings "tuned" to a particular frequency by the addition of a small capacitor to one winding as shown in Fig. 11.5.1. This forms a parallel LC resonant circuit with the transformer primary, and therefore have high impedance at one particular frequency. The inductance of such transformers is often made adjustable and the whole assembly housed inside a metal screening can. The resonant frequency of the circuit can then be fine tuned after assembly. Once adjusted during manufacture, it is normally intended that further adjustment should not be needed.

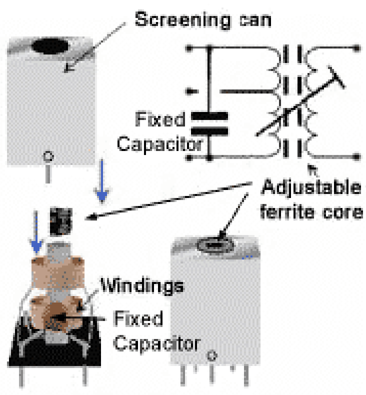


Fig 11.5.1 RF Transformer.

VHF Transformers.

At Very High Frequencies of 30MHz to 300MHz the inductance needed in the windings of transformers is very small and can be achieved by just a few turns of wire. The surface mount transformer shown in Fig. 11.5.2 is wound on a ferrite core only a few millimetres wide.

Fig 11.5.2 Surface Mount VHF Transformer.

UHF Transformers

At Ultra High Frequencies of 300MHz to 3GHz the losses in iron or ferrite cores are too great for these conventional cores to be used, also the amount of inductance needed can be provided by just a few turns of wire or less, as can be seen in the view of a UHF TV tuner (with the outer screening plate removed) in Fig. 11.5.3. Even small coils printed on the circuit board may be used as inductors and transformers. Because signals at UHF and above, predominately flow on the surface of the conductor it is common for inductors working at these frequencies to be plated with a very low resistivity material such as silver.

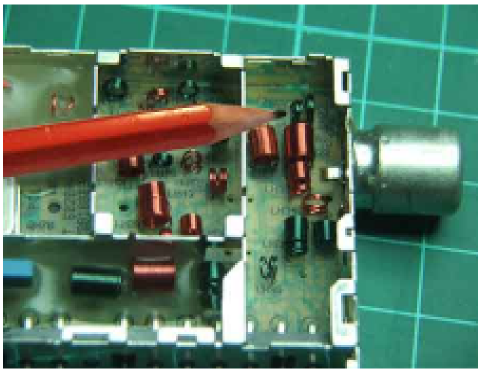


Fig 11.5.3 Inductors and Transformers in a UHF Tuner.

It is essential, when working on circuits operating at VHF and above, that no component or wire is moved from its original position during servicing, as the tiny amounts of inductance and capacitance involved can be greatly influenced by nearby components.

Screening.

Transformers are electromagnetic devices and both produce, and are affected by electromagnetic fields. The problem of electromagnetic interference increases considerably as signal frequencies increase from audio frequencies upwards, becoming most troublesome at radio frequencies where electromagnetic fields radiate particularly well, this makes efficient magnetic screening essential.

Electrostatic interference can also be a problem due to the capacitance between the transformer coils and any nearby components of wiring. Only a tiny amount of capacitance is needed at RF and higher frequencies for electrostatic fields to transfer voltages to or from the transformer.

Fig 11.5.4 How a Screening Can Works.

To reduce interference caused by electromagnetism, especially at high frequencies, transformers working at RF and above are normally completely surrounded by a metal screening can, which provides a preferred low magnetic reluctance path for any external magnetic fields to flow through, rather than flowing through the transformer itself.

To reduce electrostatic effects, screening cans must also have a very low electrical resistivity and are connected to either the equipment ground potential, or to true earth. Any electrostatic fields are then effectively conducted away from the transformer. Metals normally used for conductors or for transformer cores possess one, but not both of these properties, therefore special metal alloys are used for screening cans that combine low resistivity and low reluctance. Two commonly used alloys go under the commercial names of "Mu-metal" and "Permalloy"

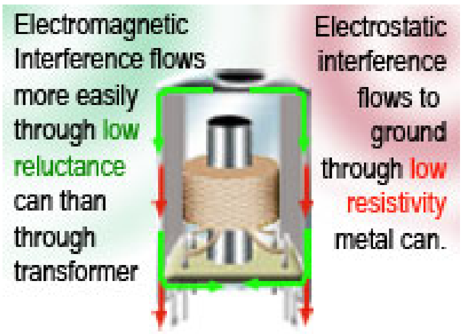


Fig 11.5.4

Module 11.6 Transformers Quiz

What you should know.

- **After studying Module 11, you should:**

• Be able to describe basic transformer operation.

• Be able to describe the operation of transformer cores.

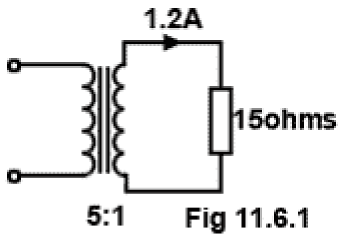
• Be able to carry out calculations transformers, involving turns ratio, reluctance, permeability, transformation ratio, impedance matching and volts per turn.

• Be able to describe practical applications for transformers, involving power, audio and RF transformers.

Try our quiz, based on the information you can find in Module 11. Check your answers on line at http://www.learnabout-electronics.org/ac_theory/transformers06.php

1.

What is the primary voltage applied to the transformer illustrated in Fig 11.6.1?



5:1 Fig 11.6.1

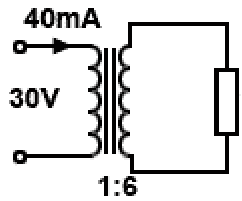
a) 90V b) 18V c) 62.5V d) 0.4V

2.

What is the value of current flowing through the resistor R in Fig 11.6.2?

a) 240mA b) 6.7mA c) 18mA d) 125mA

Fig 11.6.2



3.

Which solution from the following may be used to overcome hysteresis losses in power transformers?

a) Low resistivity copper windings.
b) Low reluctance steel cores.
c) Laminated steel cores.
d) Soft Iron cores.

4.

Flux linkage between primary and secondary windings of a transformer is proportional to which of the following?

a) Cross sectional area of the core and the length of the flux path.
b) Cross sectional area and Permeability of the core.
c) Cross sectional area and Reluctance of the core.
d) Permeability of the core and the length of the flux path.

5.

Refer to the diagram of an autotransformer in Fig. 11.6.3.
If the voltage across A and D is 230V, what will be the voltage across A and B?

a) 20V b) 4.6V c) 9.6V d) 11.5V

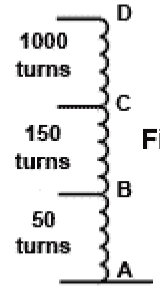


Fig 11.6.3

6.

What will be the approximate turns ratio of a transformer matching a microphone of 60Ω impedance to the 47kΩ input impedance of an amplifier?

a) 1:108 b) 1:78 c) 1:35 d) 1:28

7.

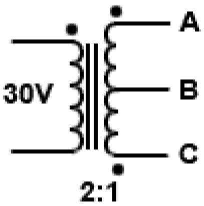
Which of the following would be the most important property of the material, used for an electromagnetic shield around a RF transformer?

- a) Low reluctance.
- b) Low resistivity.
- c) Low conductance.
- d) Low permeability.

8.

Refer to the diagram of a transformer having a continuously wound, centre tapped secondary winding in Fig. 11.6.4: What is the relationship between voltages across AB and BC when B is used as the common terminal?

Fig 11.6.4



- a) AB and BC are equal and in anti phase.
- b) AB is twice BC and in phase.
- c) AB is half BC and in phase.
- d) AB and BC are equal and in phase.

9.

Refer to Fig 11.6.4:
What is the voltage between A and C when B is connected to 0V?

a) 30V b) 15V c) 7.5V d) 0V

10.

How are eddy current losses reduced in AF and RF transformers?

- a) By using air cores.
- b) By using shell cores.
- c) By using laminated cores.
- d) By using ferrite cores.

