



ISTANBUL COMMERCE  
UNIVERSITY

---

Electrical-Electronics Engineering  
EEE202 Electro-technic Laboratory

---

Theory

Part 10

## Contents

|   |          |
|---|----------|
| <b>EXAMINATION OF LC FILTERS .....</b>  | <b>2</b> |
| 10.1 INTRODUCTION.....                  | 2        |
| <b>EXAMINATION OF TRANSFORMER .....</b> | <b>4</b> |
| 10.2 INTRODUCTION.....                  | 4        |
| 10.3 MUTUAL INDUCTION.....              | 4        |
| 10.4 DESIGN LOSSES.....                 | 6        |
| 10.5 WORKING LOSSES .....               | 7        |
| 10.6 EFFICIENCY.....                    | 9        |
| 10.7 TRANSFORMER CALCULATION .....      | 10       |

# EXAMINATION OF LC FILTERS

## 10.1 INTRODUCTION

Filter circuit passes frequencies within a certain range and rejects frequencies outside that range, or vice versa. There are four types of filter circuits:

- 1- Low pass filters
- 2- High pass filters
- 3- Band pass filters
- 4- Band stop filters

Basic components of these filter circuits are capacitors and inductors. As we know, reactances of inductor and capacitor depend on the frequency. As the frequency increases, reactance of inductor also increases but reactance of capacitor decreases. Various types of filter circuits are designed using these properties. Most used types are "T" type and "Π" type. These are shown in figure 10.1

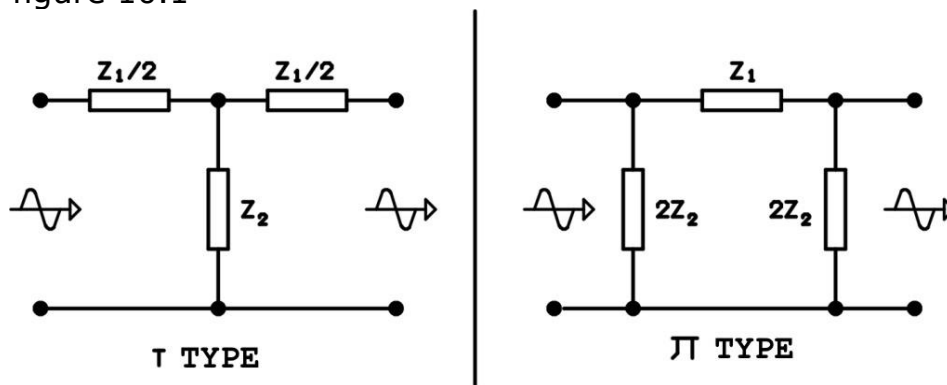


Figure 10.1

Two impedances ( $Z_1$  and  $Z_2$ ) are used in designing filter circuits. One of them is inductive reactance of inductor and the other one is the capacitive reactance of the capacitor. Best result will be reached if the filter circuit designs are made like given in figure 10.1. Output of the circuit must be closed with a resistor. This resistance is called "**R<sub>out</sub>**" or shortly "**Ro**";

$$Ro = \sqrt{\frac{L}{2C}}$$

The frequency on which the filter is expected to stop passing is called "**cut-off frequency**". It is the frequency value at which the output signal amplitude equals "**0,707**" multiple of the input signal amplitude. For example, if the input signal amplitude is 10Volt, cut-off frequency is the frequency at which the output signal amplitude is  $10 \times 0,707 = 7,07$  Volt.

Cut-off frequency at "T" type filter circuits;

$$F_c = \frac{1}{4\pi\sqrt{LC}}$$

Following formula is used in "Π" type filters;

$$F_c = \frac{1}{2\pi\sqrt{LC}}$$

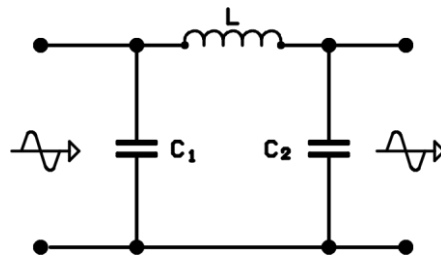
In formulas;

**F<sub>c</sub>** = Cut-off frequency (**Hz**)

**L** = coil inductance (**Henry**)

**C** = capacitance of capacitor (**Farat**)

"Π" type filters are used in our experiment set. Serial component in "Π" type low pass and high pass filters is inductor (L) and the parallel components are capacitors (C<sub>1</sub> and C<sub>2</sub>).

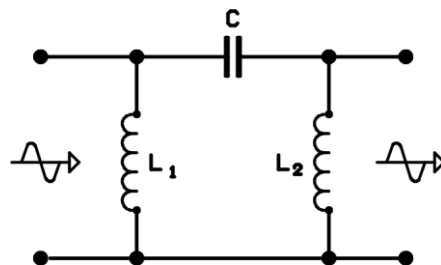


**Figure 10.2**

Low pass "Π" type filter is shown in figure 10.2 In a well-designed filter C<sub>1</sub>=C<sub>2</sub> and the effective capacitor value is equal to C<sub>1</sub>+C<sub>2</sub>.

In low pass filters, Ohmic resistance of inductor decreases the output signal amplitude.

In high pass filters, the serial component is capacitor and the parallel components are inductors.



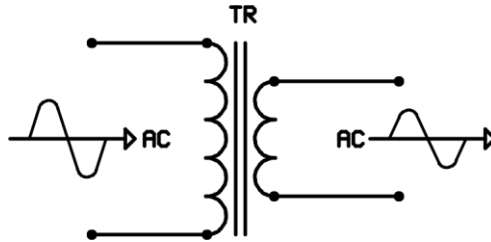
**Figure 10.3**

High pass "Π" type filters are shown in figure 10.3 In a well-designed filter, L<sub>1</sub>=L<sub>2</sub>. And the effective inductor value is L<sub>1</sub>/2 or L<sub>2</sub>/2

# EXAMINATION OF TRANSFORMER

## 10.2 INTRODUCTION

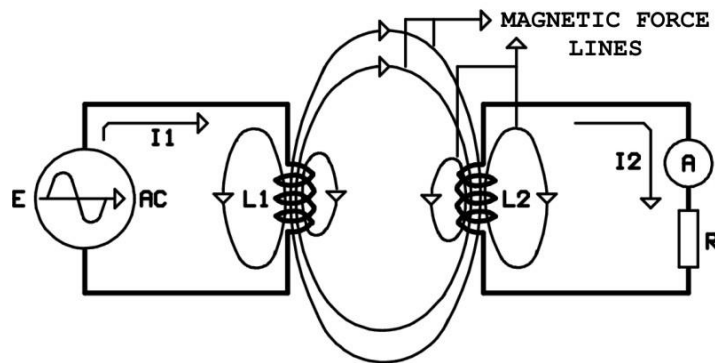
Transformer is the device which transforms the voltage and current values applied as input to the required values of voltage and current with minimum loss in AC.



**Figure 10.4**

The symbol of transformer is shown in figure 10.4

## 10.3 MUTUAL INDUCTION



**Figure 10.5**

If the L1 and L2 inductors are placed like in the figure 10.5 and one of them is connected to the AC supply, it will be observed that a current passes through the other inductor despite there is no electrical connection. The reason for this is that the inductor which is connected to AC supply will generate a variable magnetic field around itself and there will be an EMF generated on the inductors which are in that magnetic field. So, there is a magnetic connection between the inductors. This connection is called "**mutual induction**".

In magnetically connected circuits, the mathematical relation between the inductor inductances and mutual inductance is like in the following.

$$M = k\sqrt{L_1.L_2}$$

**In Formula;**

**M** = Inductance between two inductor (**Henry**)

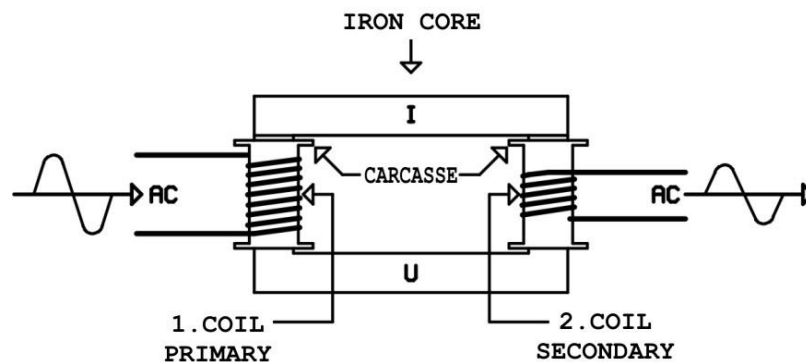
**K** = Magnetic connection coefficient

**L1**= Inductance of first inductor (**Henry**)

**L2**= Inductance of second inductor (**Henry**)

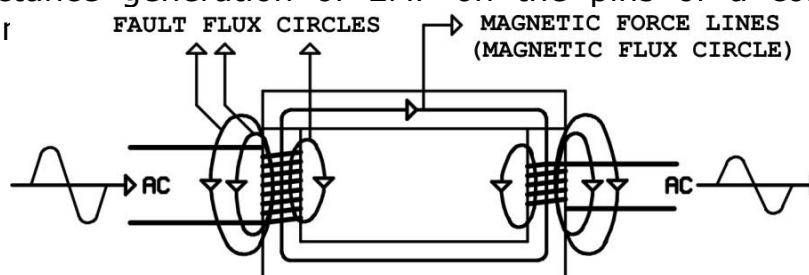
The coefficient of the magnetic connection is "1" if the second inductor contains all the magnetic field of first conductor. Practically,  $k=1$  is impossible, because there is a loss of current in inductors. So, the coefficient is always less than "1".

Transformers work according to the rules of mutual induction. The simplest transformers are made by placing two inductors on an iron core.



**Figure 10.6**

In figure 10.6 the structure of a transformer is shown. Coil conductors are generally circular cross-sectioned copper wires isolated by enamel. Coil wires are placed on the core after wrapping over a carcass. The first coil (the coil to which the input energy is applied) is called **primary** and the second one (the coil of which the output is taken) is called **secondary** coil. There is no electrical connection between two coils. Electrical energy transmittance between them is the mutual inductance. As we know, the mutual inductance generation of EMF on the pins of a coil placed in a variable magr



**Figure 10.7**

In figure 10.7 if AC is applied to the primary inductor there will be a magnetic field around it. Magnetic force lines start changing direction in relation with the AC frequency in the core. AC energy is inducted on the secondary inductor in the core. Ideally, this energy is equal to primary energy. to express the electrical energy in the system as power;

$$P_p = P_s$$

### **In Formula;**

**P<sub>p</sub>**= Primary power (**Watt**)

**P<sub>s</sub>**= Secondary power (**Watt**)

There is always a loss while the energy is transmitted or changed form. Those are design and work losses.

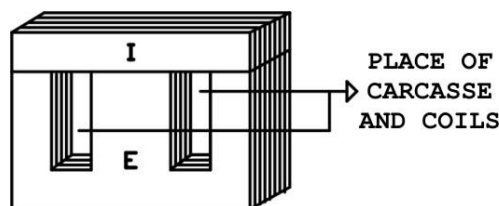
## **10.4 DESIGN LOSSES**

It is required that all the magnetic force lines generated by the primary are intersected by the secondary. As in figure 10.7, the circles that are not intersected increases the power loss. The structure in the figure 10.7 is the one which the transformer theory is most easily explained but also the one which has the most power loss. In this structure, the core is formed by packing the "I" and "U" shaped iron sheets.

Practically, the secondary coil is wrapped over the primary. There is a thin but well non-conductor between the two so that the loss can be decreased.

The material and the shape of the core is important in preventing the power loss. The loss will be decreased if the core is made of thin and soft iron sheets.

The loss will be minimized if the "I" and "E" shaped iron sheets are used. This form of iron sheet is shown in 10.8



**Figure 10.8**

In figure 10.8, carcass is around the "E" shaped iron sheet leg. The primary coil, non-conductor and the secondary coil is wrapped over the carcass respectively.

In sum, design losses are decreased by making the secondary coil intersect the magnetic force lines generated by primary coil.

## 10.5 WORKING LOSSES

There are two types of working losses

**1-** Iron core losses

**A-** Hysteresis losses

**B-** Eddy current losses

**2-** Copper losses

### 1-Iron core losses

#### A-Hysteresis losses

If a coil is wrapped on a magnetic metal and **DC (direct current)** is made pass through, the metal becomes magnetized. Magnet poles are ingenerated depending on the current direction. If another current with a reverse direction passes, then the magnetization will disappear. This time, because of the reverse current, a magnetization with opposite poles will be generated after a short period of time.

If **AC** is applied to coil, magnetic metal becomes a magnet which changes in relation to frequency during the work time. This means the movement of magnetic metal molecules by constantly changing direction. Yet, the change of the poles occurs with a period of delay like in **DC**. This delay results in the decrease of magnetic field for some amount and a loss of energy depending on that. This is called "**hysteresis loss**".

Hysteresis loss appears as heat energy as a result of the magnetic molecules' attrition or bumping into each other. Hysteresis loss varies for every different metal. It varies directly proportionate to the frequency. Hysteresis loss of magnetic metals is shown as slopes in the catalogs of the producer firms.

Hysteresis loss is calculated mathematically with the following formula:

$$Ph = \frac{F.K.B^{1.6}.V}{10^7}$$

#### In Formula;

**Ph**= Hysteresis loss (**Watt/cm<sup>2</sup>**)

**F** = Frequency (**Hz**)

**K** = Hysteresis coefficient of magnetic metal

**B** = Maximum flux density of core (**Gauss**)

**V** = Volume of Core (**cm<sup>2</sup>**)

**Note:** The hysteresis coefficient of widely used core siliceous sheet is K=0,001.

## B-Eddy current losses

Alternating current passing through a working transformer's primary and secondary coils generates a constantly varying magnetic field around the coils and inside the core. Varying magnetic force lines affect the core and cause the valance electrons of the magnetic core atoms to move. The movement of valance electrons results in unwanted electric currents. These are called "**eddy currents**". Eddy currents cause energy loss. This loss appears as heat energy.

Eddy current losses can be decreased by producing the cores from one side isolated thin siliceous sheets.

Eddy current losses can be calculated mathematically by the following formula:

$$Pf = \frac{(\pi.d.F.B)^2}{6.p.10^{14}}$$

### In Formula;

**Pf**= eddy current loss (**Watt/cm<sup>2</sup>**)

**D** = Sheet thickness (**mm**)

**F** = Frequency (**Hz**)

**B** = Maximum flux density of core (**Gauss**)

**P** = Specific resistance of the sheet (**Ohm**)

Core iron losses (sum of hysteresis and Eddy current losses) can be calculated by the following formula:

$$Wd = \frac{P.B^2.F.K}{5.10^9}$$

**Wd**= Total iron core loss (**Watt**)

**P** = Weight of magnetic core (**kg**)

**B** = Maximum flux density of core (**Gauss**)

**F** = Frequency (**Hz**)

**K** = Represents the coefficient of power loss per kg when the magnetic flux density B=10000 Gauss. This coefficient can be obtained from the producer.

**K** = Varies between 1,2-3,6 W/kg. Smaller the coefficient value higher the quality of sheet.

## 2-Copper Losses

The energy loss caused by Ohmic resistances of primary and secondary coils in transformer is called "**copper loss**". Terming this loss as copper loss is because the coil conductors are generally made of copper.

Copper losses can be calculated mathematically by the following formula:

$$P_{cu} = I_p^2 . R_p + I_s^2 . R_s$$

### In Formula;

**P<sub>cu</sub>**= Copper loss (**Watt**)

**I<sub>p</sub>** = Current of Primary (**Amper**)

**R<sub>p</sub>** = Ohmic resistance of Primary (**Ohm**)

**I<sub>s</sub>** = Current of Secondary (**Amper**)

**R<sub>s</sub>** = Ohmic resistance of Secondary (**Ohm**)

Copper losses of transformer increase during the work time because the resistance of metal increases directly proportional with the heat. This increase is %20 of calculated copper loss.

## 10.6 EFFICIENCY

Efficiency is the ratio of sum of obtained power in secondary and power losses to the spared power in primary. It is expressed as per cent.

Efficiency in formula;

$$\% \text{Efficiency} = \frac{P_s + P_k}{P_p}$$

### In Formula;

**P<sub>s</sub>**= Power in Secondary(**Watt**)

**P<sub>k</sub>**= total power loss(**Watt**)

**P<sub>p</sub>**= Power in Primary (**Watt**)

Transformer power is expressed in terms of primary power. Efficiency varies with the power of transformer. Efficiency is %80 in transformers smaller than 50Watt. Efficiency is %85 in transformers between 50Watt and 100Watt. Efficiency is %95 in transformers between 100Watt and 150Watt. So the efficiency is directly proportional to the power of transformer.

## 10.7 TRANSFORMER CALCULATION

Electrical and electronic devices may require more than one source with different voltage and currents. In this situation, secondary coil of transformer consists of electrically isolated (more than one) coils. Power of secondary is the sum of powers of secondary coils. The source of the total power to be acquired from the secondary is the AC supply applied to the primary. This supply is city network. City network is 220Volt/50Hz in our country.

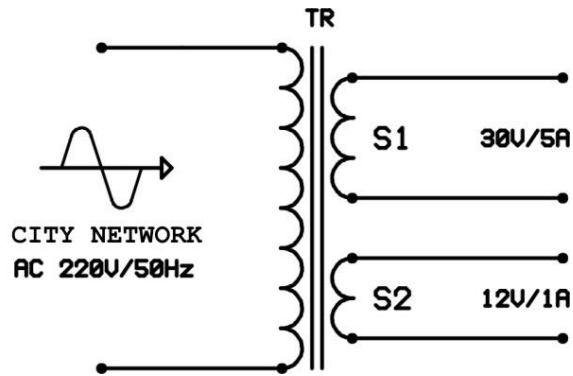
Electrical energy is the multiplication of voltage and current. The determinant factor of current in transformer is diameter of the wire. Voltage is determined by the number of turns.

Absolutely, there will be a loss when carrying the electrical energy. This loss should not be observed on the secondary power. Because of that primary power is greater than the secondary as much as the loss. Practically, two processes are carried out to make sure that the loss is from the primary. First one is making the transformer core bigger for the sake of efficiency. The effect of loss to the secondary is the decrease of voltage. Because of that, secondary voltage is made greater. This is achieved by increasing the number of turns in secondary. The rate of increase in the number of turns varies depending on the power of transformer. The rate of increase in the number of turns is put to a scale by making various experiments.

| POWER OF TRANSFORMER<br>(WATT) | RATE OF INCREASE IN<br>THE NUMBER OF TURNS<br>(%) |
|--------------------------------|---|
| 0-5                            | 20,0  |
| 6-10                           | 17,0  |
| 11-25                          | 15,0  |
| 26-50                          | 12,0  |
| 51-75                          | 10,0  |
| 76-100                         | 9,0   |
| 101-150                        | 8,0   |
| 151-200                        | 7,5   |
| 201-300                        | 7,0   |
| 301-400                        | 6,5   |
| 401-500                        | 6,5   |

**Figure 10.9**

For example, let's make the calculation of a transformer which will work with the city network (**220V/50Hz**) and 30V/5A and 12V/1A will be acquired from its secondary.



**Figure 10.10**

### 1- Power of Secondary( $P_s$ )

$$P_s = P_{s1} + P_{s2}$$

$$P_s = 30,5 + 12,1$$

$$P_s = 150 + 12$$

$$P_s = 162 \text{ Watt.}$$

### 2- Power of Primary ( $P_p$ )

Transformers work with %95 efficiency between 100W and 500W. %5 loss is from iron core and copper losses. In order to prevent this loss observed in secondary, power of Primary ( $P_p$ ) is made %5 more than the secondary.

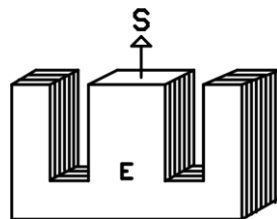
$$P_p = \frac{P_s}{0,95} = \frac{162}{0,95}$$

$$P_p = 170,5 \text{ Watt.}$$

### 3- Selection of Carcass and Core

Nowadays, carcasses and sheets are designed and produced according to the primary power assuming that sheets with  $B=1000$  Gauss magnetic flux density will be used. Core should be in the shape of "E" and "I", siliceous and one side isolated with a material (**lacquer, etc.**)

Core measure in calculations is the cross-section area ( $S$ ) of the part of core in the carcass. Unit of this area is " $\text{cm}^2$ ". Although the carcass and sheet packs are sold according to primary power, calculating the " $S$ " area is the check-up of the process.



**Figure 10.11**

$$S = 1,2\sqrt{Pp} = 1,2\sqrt{170,5}$$

$$S = 13\text{cm}^2$$

The total loss will be lower if this area is in the form of a square. The nearest bigger size should be used if there is not carcass and sheet pack in that size.

#### 4- Number of Turns In Primary And Secondary

Number of primary and secondary turns is calculated after the number of turns required for "**1Volt**" in the core is calculated. Number of turns required for "**1Volt**" is called "**VPT**" (**V**olt **P**er **T**urn). VPT is calculated by the following formula:

$$VPT = \frac{10^8}{4,44.S.B.F}$$

##### In Formula;

**S**=Cross-section of core (**cm<sup>2</sup>**)

**B**=Maximum magnetic flux density of the sheet (**Gauss**)

**F**=Frequency

Maximum magnetic flux densities of widely used sheets are between 8000Gaus and 14000Gaus. This value can be acquired from the catalogs of the producer as well as measuring with the "**Gausmeter**". Assuming that the magnetic flux density of the sheet we used is B=10000Gaus;

$$VPT = \frac{10^8}{4,44.13.10000.50}$$

$$VPT = \frac{10^3}{4,44.13.5}$$

$$VPT = 3,46 \text{ turns.}$$

If we show the primary turn number with "**NP**", number of primary turns is the multiplication of VPT and primary voltage (**Ep=220V**).

$$\mathbf{NP=Ep.VPT}$$

$$\mathbf{NP=220.3,46}$$

$$\mathbf{NP=761 \text{ turns.}}$$

Power of transformer is 170Watt. According to table 19.6, number of secondary turns is %7,5 greater for this power value.

If we symbolize the first secondary with "**NS1**", number of turns in first secondary is %7,5 greater than the multiplication of VPT and its own voltage (**Ep1**).

$$NS1 = Es1.VPT + \frac{Es1.VPT.7,5}{100}$$

$$NS1 = 30.3,46 + \frac{30.3,46.7,5}{100}$$

$$NS1 = 103,3 + 7,7$$

$$NS1 = 111 \text{ turns.}$$

If we symbolize the second secondary with "**NS2**", number of turns in second secondary is %7,5 greater than the multiplication of VPT and its own voltage (**Ep2**).

$$NS2 = Es2.VPT + \frac{Es2.VPT.7,5}{100}$$

$$NS2 = 12.3,46 + \frac{12.3,46.7,5}{100}$$

$$NS2 = 41,5 + 3,1$$

$$NS2 = 44,6 = 45 \text{ turns.}$$

## 5- Wire Diameters of Primary and Secondary

Diameters of the wires used in the transformer should be as long as they can enable the current to pass at full load. Maximum current that can pass through "**1mm**" according to the power of transformer is shown in figure 10.12

| POWER OF TRANSFORMER<br>(WATT) | CURRENT PASSING<br>THROUGH 1 mm <sup>2</sup><br>(AMPER) |
|--------------------------------|---|
| 0-50                           | 4,0   |
| 51-100                         | 3,5   |
| 101-200                        | 3,0   |
| 201-500                        | 2,5   |
| 501-1000                       | 2,0   |

**Figure 10.12**

The mathematical relation between the cross-section of wire and current is shown in the table. Yet, diameter information is not provided by the producers of commonly used conductors. Because of that, conversion from cross-section to diameter is required. For this, cross-section of the wire and diameter should be calculated.

Power of transformer is 170,5Watt in the example. It is observable in table 19.9 that maximum 3A current passes through 1mm<sup>2</sup>. Cross-section is calculated by the following formula:

$$S = \frac{I}{D}$$

### In Formula;

**S**= Cross-section of wire (**mm<sup>2</sup>**)

**I**= Current (**Amper**)

**D**= Maximum current can pass through 1mm<sup>2</sup>(**Amper**).

Secondary currents in our example are known. Let's find the diameter of 1. secondary winding.

$$S = \frac{I}{D} = \frac{5}{3} = 1,66mm^2$$

Cross-section of the conductor is in the form of circle and the area of the circle is 1,66mm<sup>2</sup>. From area formula of circle to diameter (**d**);

$$S = \frac{\pi \cdot d^2}{4}$$
$$\pi \cdot d^2 = 45$$

$$d^2 = \frac{45}{\pi}$$
$$d = \sqrt{\frac{45}{\pi}}$$

Diameter of wire for 5A:

$$d = \sqrt{\frac{4 \cdot 1,66}{\pi}} = \sqrt{2,11}$$
$$d = 1,45mm$$

1A current will pass through the second secondary winding. Diameter of wire;

$$S = \frac{I}{D} = \frac{1}{3} = 0,33mm^2$$
$$d = \sqrt{\frac{4 \cdot S}{\pi}} = \sqrt{\frac{4 \cdot 0,33}{3,14}}$$
$$d = 0,64mm^2$$

Primary current (**I<sub>p</sub>**) should be calculated first to find the diameter of primary wire. It is easy to calculate because we know the primary power and primary voltage.

$$P = E \cdot I$$
$$I = \frac{P}{E} = \frac{170,5}{220}$$
$$I = 0,77 \text{ Amper}$$

After that we repeat the processes we carried out for the secondary windings.

$$S = \frac{I}{D} = \frac{0,77}{3} = 0,256mm^2$$

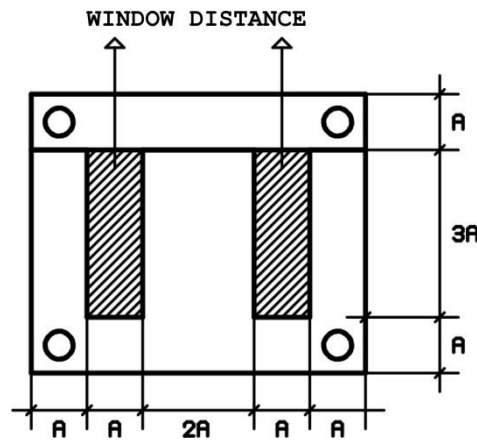
$$d = \sqrt{\frac{4.S}{\pi}} = \sqrt{\frac{4.0,256}{3,14}}$$

$$d=0,57mm.$$

The diameters we found may not be the standard wire diameters and they may not be produced. In such a situation wires with the nearest greater diameter should be used.

## 6- The Winding

The number of turns for the primary and secondary windings and the diameters of wires are known for a transformer. First the primary and then the secondary windings should be wrapped over the carcass. Although it is easy to find carcass and sheet packs according to the power, it will be a check-up if we try to calculate the area of the coils for finding if they fit into the area over carcass. Sizes of an ideal sheet consisting of parts in "E" and "I" shapes are shown in figure 10.13.



**Figure 10.13**

Marked parts in the figure are called windows. There are carcass, conductors and non-conductors in the windows. Conductors should be wrapped in smooth layers. A thin and good non-conductor material should be placed between the layers. To prevent the noise in devices, a magnetic band should be placed between the primary and secondary and it should be wrapped as its origin and its end don't touch each other; this band should be connected to the of chassis device with a conductor.

1/3 of windows consist of isolation materials and carcasses and 2/3 of windows consist of conductors. For example, a sheet with area of  $6cm^2$  window involves  $2cm^2$  of isolation materials and  $4cm^2$  of conductors.

Number of turns to be wrapped on  $1\text{cm}^2$  area for conductors with varying diameters is shown in figure 10.14

| WIRE DIAMETER<br>(mm) | NUMBER OF<br>TURNS CAN BE<br>WINDED ON<br>$1\text{ cm}^2$ | WIRE DIAMETER<br>(mm) | NUMBER OF<br>TURNS CAN BE<br>WINDED ON<br>$1\text{ cm}^2$ |
|-----------------------|---|-----------------------|---|
| 0,10                  | 5500  | 1,00                  | 82  |
| 0,15                  | 2800  | 1,10                  | 68  |
| 0,20                  | 1720  | 1,20                  | 58  |
| 0,25                  | 1140  | 1,30                  | 50  |
| 0,30                  | 810   | 1,40                  | 44  |
| 0,35                  | 590   | 1,50                  | 39  |
| 0,40                  | 470   | 1,60                  | 33  |
| 0,50                  | 305   | 1,70                  | 29  |
| 0,60                  | 215   | 1,80                  | 26  |
| 0,70                  | 160   | 1,90                  | 23  |
| 0,80                  | 125   | 2,00                  | 20  |
| 0,90                  | 100   |                       |   |

**Figure 10.14**

Let's calculate the required window size for the transformer in the previous example.

Number of turns of primary winding is 761 and the wire diameter is 0,57mm. 0,57mm diameter is not a standard value. The winding should be made with wire which has diameter of 0,60mm. A wire with 0,60mm diameter can make 215 turns on  $1\text{cm}^2$ . Required area can be found using the basic proportion.

$$\begin{array}{ll} \text{If, 215 turns} & 1\text{cm}^2 \\ \text{Then, 715 turns} & x\text{ cm}^2 \end{array}$$

---


$$x = \frac{1.761}{215} = 3,5\text{cm}^2$$

Number of turns of 1. secondary winding is 111 and the wire diameter is 1,45mm. 1,45mm diameter is not a standard value. The winding should be made with wire which has diameter of 1,50mm. Required area for 1.secondary winding;

$$\begin{array}{ll} \text{If, 39 turns} & 1\text{cm}^2 \\ \text{Then, 111 turns} & x\text{ cm}^2 \end{array}$$

---


$$x = \frac{1.111}{39} = 2.8\text{cm}^2$$

Number of turns of 2. secondary winding is 45 and the wire diameter is 0,64mm. 0,64mm diameter is not a standard value. The winding should be made with wire which has diameter of 0,70mm. Required area for 2.secondary winding;

|                                   |                   |
|-----------------------------------|-------------------|
| If, 160 turns                     | 1cm <sup>2</sup>  |
| Then, 45 turns                    | x cm <sup>2</sup> |
|                                   |                   |
| $x = \frac{1.45}{160} = 0,28cm^2$ |                   |

Total area of conductors in windows;  
 $3,5+2,8+0,28=6,58cm^2$ .

This area is twice the area of carcass and nonconductors. So, the total window size is;

$$6,58 + \frac{6,58}{2} = 9,87cm^2$$

In sum, window size of the sheet should be at least 9,87cm<sup>2</sup> and 13cm<sup>2</sup> of "S" area should be chosen as square or the closest shape.