

**AUDIO TRANSFORMER**  
**DESIGN MANUAL**

**ROBERT G. WOLPERT**

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## **PREFACE**

This manual is intended to show how to design and manufacture audio transformers.

It will explain the various things that have to be considered and the problems that will be encountered in achieving the desired results. It will show how to design to meet the requirements and give examples and test results.

It will also give methods of manufacturing to achieve the results desired, with some of the things that will prevent the design from being successful.

This manual is written with the assumption that the designer has experience in the design of power transformers. Therefore, it covers only those manufacturing techniques that are different and necessary to achieve the proper results in an audio transformer.

If the designer needs more information on the construction methods, the TRANSFORMER DESIGN AND MANUFACTURING MANUAL published by the author in 1984, or some other publication, should be consulted.

The appendix will have various tables and charts to assist in the design of the transformers.

Robert G. Wolpert

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## **PART I. DESIGN CONSIDERATIONS**

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### **CHAPTER 1. GENERAL REQUIREMENTS**

By definition, an audio transformer is designed to operate within the audio range of frequencies. However, the upper and lower limits are extended beyond the audio range for many uses.

For example, usage in high fidelity circuits might desire a range from 10 Hz to 30000 Hz or higher, while a telephone transformer could have a range from 30 Hz to 3000 Hz.

The frequency range, both high and low limits, will determine to a great extent, the design and method of manufacture.

Transformers designed to work at audio frequencies can be put into three general categories. These are input, output and impedance matching. Actually, the only differences between these are the usage and the impedance ratios. They all can be considered as impedance matching transformers, as they are used to transmit signals from one impedance to another impedance either higher or lower or sometimes, when isolation only is desired, between equal impedances.

There are several things to be considered in the design of audio transformers:

- a. Frequency response
- b. Impedances
- c. Power level
- d. THD or total harmonic distortion
- e. Value of D.C. in windings, if any
- f. Hum reduction level, if required
- g. Longitudinal balance
- h. Insertion loss

In addition, the flux density of the core material must be considered in order to not operate the core into saturation.

## 1.1 Frequency Response

The frequency response of a transformer is that range of frequencies that is desired to be passed.

It is desirable to have the same response or voltage level of all frequencies within this range. The extremes of the range will fall off. These are usually called out as a range of DB, such as  $\pm 3$  DB or  $\pm 1$  DB, etc. This means that all the voltages between the two extremes will not vary more than the limits shown.

The variations called out will usually be referred to a certain frequency in the center of the response. Usually this will be 1000 Hz for audio transformers. Thus, if a certain voltage or DB level is called out for 1000 Hz, then all frequencies within the range should be within the limits of  $\pm 3$  DB or  $\pm 1$  DB or whatever is required.

The -3 DB frequencies will have a voltage level that is 70.7% of the voltage at the middle of the frequency range.

The best way to measure the response is to use a meter that is calibrated in DB rather than trying to calculate the DB from the voltage levels. However, the DB can be calculated from the voltages by using the following formula:

$$DB = 20 \text{ LOG } \frac{E_O}{E_{IN}}$$

The lower limit of the frequency range is controlled by the primary inductance. This will fall off 3 DB at the frequency where the inductive reactance of the primary equals the primary impedance. It will fall off 1 DB at two times the primary impedance and 0.5 DB at approximately 4 times the primary impedance.

The following formulas are used:

$$L = \frac{Z_1}{2\pi F_1} = -3 \text{ DB}$$

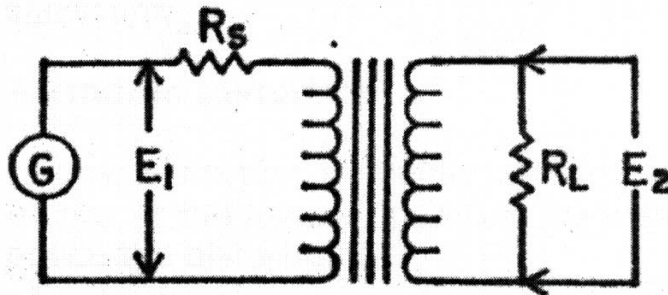
$$L = \frac{2 Z_1}{2\pi F_1} = -1 \text{ DB}$$

$$L = \frac{4 Z_1}{2\pi F_1} = -0.5 \text{ DB}$$

Where:  $L$  = primary inductance  
 $Z$  = primary impedance  
 $F_1$  = lower frequency desired

The upper frequency will be down 3 DB where the normalized impedance equals the reactance of the leakage inductance.

The frequency response can be measured using the circuit in Figure 1.



**Figure 1**

$R_S$  = the impedance of the primary  
 $R_L$  = the impedance of the secondary

The voltage of  $E_1$  must be held constant for all frequencies. The output voltage,  $E_2$ , is then set for a middle frequency, usually 1000 Hz, and the deviation from this voltage is the response over the frequency range.

## 1.2 Impedances

The impedances of both the primary and the secondary must be known or can be calculated. The impedance ratio is equal to the turns ratio squared and also equal to the voltage ratio squared.

$$\frac{Z_1}{Z_2} = \left( \frac{N_1}{N_2} \right)^2 = \left( \frac{E_1}{E_2} \right)^2$$

## 1.3 Power Level

The operating power level is usually called out. This can be sine wave power or music power. Sine wave power will be approximately three times the effective music power.

The transformer must be able to handle the full voltage and current at any frequency within the operating range for sine wave power. For music power it must handle the full voltage but only one third of the current for heating purposes. This will allow the use of smaller magnet wire and will result in a smaller unit.

## 1.4 Total Harmonic Distortion

The total harmonic distortion is mainly a function of the operating flux density in the core at the lowest operating frequency. Reducing the flux density will reduce the distortion.

The distortion at a given frequency and flux density will vary with the type of magnetic material used.

## **1.5 Direct Current in the Windings**

When one or more of the windings is required to carry unbalanced direct current, it is necessary to design that winding for the proper inductance the same way you would design an inductor carrying direct current. The proper air gap spacer must be put in the magnetic path. This will result in a larger unit than one that does not carry unbalanced direct current.

## **1.6 Hum Reduction**

When designing for low level usage, it is often necessary to keep the external flux fields at a very low level. Levels of -60 DB to -80 DB requirements are not unusual.

This is accomplished by enclosing the unit in a case or cases using high permeability materials. 80% nickel is often used for this application. A single case or a nest of cases using alternate cases of high permeability material and copper may be needed.

## **1.7 Longitudinal Balance**

Longitudinal balance is a measure of a transformer's balance and ability to prevent longitudinal signals or signals that have been induced in the power line from being transferred into the secondary of the transformer.

## **1.8 Insertion Loss**

Insertion loss is a measure of the power available out of the transformer versus the power induced into the transformer.

## CHAPTER 2. LOW FREQUENCY RESPONSE

The requirements of an audio transformer are all inter-related and must all be considered in the design. The first step is to design for the low frequency. This will establish the size of the core and the number of turns needed. It is also the easiest part of the design.

### 2.1 Open circuit inductance

Calculate the inductance necessary. Assuming a -3 DB requirement at the low frequency end, the inductance needed will be:

$$L = \frac{Z_1}{2\pi F_1}$$

For -1 DB and -0.5 DB requirements, the formula is changed accordingly, as called out in 1.1.

It can now be seen that the higher the primary impedance, the larger the inductance needed. This translates to a larger core and/or more turns. It also makes it more difficult to obtain the higher frequency limit as will be seen later.

### 2.2 Primary voltage and current

Calculate the primary voltage and current. This depends on the information given. If the power (wattage) is given and the impedance is known, Ohm's law may be used to calculate the voltage and current.

$$E_1 = \sqrt{Z_1 \times W} \quad \text{AND} \quad I_1 = \frac{E_1}{Z_1}$$

If the power is given in DB or DBm, the power in watts must be either calculated or taken from a chart. A chart of DB versus watts is in the Appendix. DBm is DB for a 600 ohm impedance.

### 2.3 Secondary voltage and current

Calculate the secondary voltage and current. The secondary voltage can be calculated from the impedance ratio. By rearranging the formula from 1.2:

$$E_2 = \sqrt{\frac{E_1^2 \times Z_2}{Z_1}}$$

The current ratios are inversely proportional to the voltage ratios so the secondary current can be calculated by rearranging the equation:

$$\frac{E_2}{E_1} = \frac{I_1}{I_2} \quad \text{TO} \quad I_2 = \frac{I_1 \times E_1}{E_2}$$

### 2.4 Core size and material

The core material will depend largely on the application. If the transformer is a small, low-level unit, the material can be either 50% or 80% nickel. These are high permeability materials and will require fewer turns than 4% silicon steel. If a higher level unit is desired, 4% silicon steel will probably be the best choice as the cost of nickel laminations will be prohibitive in larger units. Also, the operating flux density can be higher in silicon steel, which will result in a smaller unit.

The power requirements will help choose the core size. If the core size is called out, there is no choice. If not, then experience from past designs, or an adjustment to the information from the 60 Hz tables will have to be used.

For example, a 150 watt, 60 Hz core will probably be about right for a 50 watt, 20 Hz audio transformer. This will be a good starting point. See the table in the Appendix.

The core size obtained in this manner is an approximation and adjustments will have to be made to get the proper fill. When the turns are calculated in the next step and the wire sizes are chosen, the fit in the core can be calculated.

When the core has been chosen, an easy and quick way to calculate the turns needed to give the required inductance for any given core size and magnetic material is to refer to a lamination catalog put out by the various manufacturers. A formula is given for inductance for each size of core. This can be turned around to find the turns. The only other requirement is that the permeability of the material must be known. This can also be obtained from data published by the manufacturers.

For example, from a catalog, a core size of EI-100, with a square stack, has an inductance formula:

$$L = .5289 \times 10^8 \times K \times U_{AC} \times N^2$$

$$\text{AND } N = \sqrt{\frac{L \times 10^8}{.5289 \times K \times U_{AC}}}$$

Where: K is the stacking factor  
 $U_{AC}$  is the permeability of the material

The wire size is determined by the current. The primary current will be as calculated in 2.2. The secondary current can be calculated from 2.3.

If the requirement is for sine wave power, the size of the wire should be from 650 to 1000 circular-mils per ampere. This will be determined by the insertion loss allowed. In general, 800 CM/A will be about right, and will be used as a starting point in this manual. If music power is called for, the size can be reduced to about 300 CM/A.

The core size and wire sizes have now been determined. By referring to the tables in the Appendix (wire sizes and turns versus lamination sizes), the fill can be checked before going any further. In general, the primary wire should use up half the fill and the secondary the other half.

This chapter should pretty well tie down the core size, turns and wire sizes for both the primary and secondary. It may be necessary to make adjustments if interleaving is necessary to meet the high frequency response.

## CHAPTER 3. HIGH FREQUENCY RESPONSE

The limit of the high frequency response is controlled by the leakage inductance and the impedances.

The leakage inductance is proportional to the square of the turns, thus, it is possible to reduce this value greatly by reducing the turns, but since the lower frequency limit depends on the primary inductance and that is controlled by the turns and the type of magnetic material used in the core, the turns are pretty well set. Also, care must be taken that the maximum flux density of the material is not exceeded in reducing the turns. The leakage can be reduced by interleaving the primary and secondary windings.

### 3.1 Interleaving the winding

As mentioned before, the high frequency response is determined by the leakage inductance and the winding impedances.

In order to reduce the leakage inductance, it is sometimes necessary to interleave the windings. That is, split the windings and wind one part primary, one part secondary, one part primary, etc. This can result in 1:2, 2:3, 3:4, etc, interleaving.

The examples will show designs with this interleaving used. A 3:2 interleave would be 1/3 primary, 1/2 secondary, 1/3 primary, 1/2 secondary and 1/3 primary, and so on. In some cases interleavings of 5:4, 6:5 and more are used.

### 3.2 Leakage inductance

The leakage inductance of a transformer can be calculated in many ways. Some of these are extremely complicated.

A good compromise for a transformer that is wound concentrically, that is one winding over the other, is the following:

$$L_L = \frac{10.6 \times N^2 \times MLT \times (2 \times S \times T + H)}{S^2 \times WL \times 10^9} = HYS$$

Where: N = number of turns  
MLT = mean length turn  
H = winding height  
WL = winding length  
T = insulation space  
S = number of interleaves

The high frequency response can now be calculated by using the values of leakage inductance and the normalized impedance. The upper frequency limit will be:

$$Z_T = \left[ \frac{N_1}{N_2} \right]^2 \times Z_2 + Z_1$$

$$F_2 = \frac{Z_T}{2\pi L_L}$$

## **CHAPTER 4. SPECIAL REQUIREMENTS**

### **4.1 Total harmonic distortion**

If THD is called out, the flux density in the core and the type of core material must be considered. This may require the core size or turns or both be modified.

The distortion is normally only of concern at the lowest frequency as it falls off rapidly as the frequency increases.

If you consider the three most commonly used types of materials, 80% nickel, 50% nickel, and silicon steel, the flux densities will vary from the lowest for the 80% nickel to the highest for the silicon steel. A table in the Appendix will give some representative values for the three materials at various flux levels. These numbers will allow you to estimate the distortion that can be expected at the flux level and frequency of operation.

### **4.2 Shielding for hum reduction**

Many low level transformers are required to function within an external field without picking up that field and transmitting it into the operating circuit.

The transformer can be enclosed within a case or cases to achieve the desired results. For example, a single case of steel will give about 10 DB of shielding. A case made of 50% nickel will give about 20 DB. A case made of 80% nickel will give 30 DB. A nest of cases consisting of an 80% nickel case, a copper case and another 80% nickel case will give 60 DB of shielding. If this is extended to three 80% nickel cases with two copper cases in between, it will give 90 DB of shielding.

These 80% nickel cases must be properly annealed and the copper cases must be soft copper to obtain the desired results.

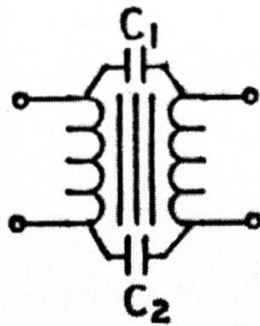
Care must be taken that the external field is not so high as to saturate the 80% nickel or the expected results will not be obtained. If this occurs, a steel case on the outside may be used to reduce the field to a level that can be tolerated.

These methods will also apply when the transformer is placed in a very sensitive circuit and the external flux of the transformer must be reduced.

### 4.3 Longitudinal balance

A longitudinal signal is one that is induced along the power lines and enters the transformer in both the primary leads as if they were one lead. This signal must be prevented from passing through the transformer as a signal in the output.

To prevent the passing through, the transformer must be balanced so that it has the same coupling from the input leads to the output terminations. See Figure 2.

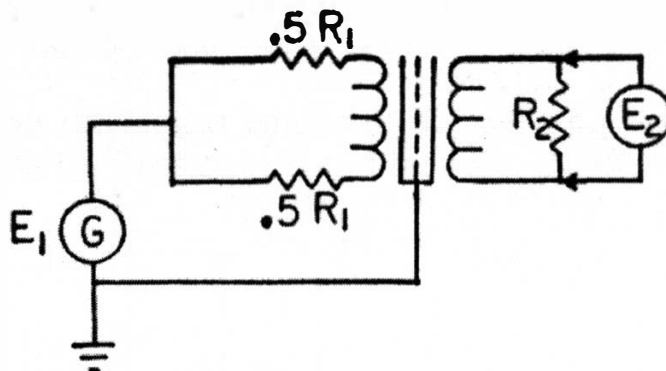


**Figure 2**

This coupling is represented by the two capacitors,  $C_1$  and  $C_2$ . If  $C_1$  equals  $C_2$  then there is no feed through and no imbalance. Of course, this is a simplification as the coupling can occur anywhere within the windings.

There are several ways to reduce imbalance. Some of these will be shown later.

Figure 3 shows a method of measuring the longitudinal balance.



**Figure 3**

$.5 R_1 + .5 R_1 = \text{primary } Z$  and must be matched to within 0.1% for a 40 DB balance and to be within 0.01% if 60 DB of balance is required.  $R_2$  will be equal to the impedance of the secondary. The core should be connected to ground. If a shield is used it should be connected to the core and ground.

$E_2$  should be a voltmeter with a DB scale. Perfect balance will be when  $E_2$  reads zero. When measuring  $E_2$ , there should be no voltmeter connected to read  $E_1$ . Short direct wiring should be used to minimize capacitance unbalance. The level of  $E_1$  should be the operating level of the transformer, or as called out by the customer.

#### **4.4 Insertion loss**

The insertion loss of a transformer is a measure of the efficiency as it shows how much power is consumed by the transformer. Thus, it is important to keep these losses as low as possible.

The most obvious of these losses is the DC resistance of the windings. The larger the size of the wire that can be used, the lower the losses. The losses in the magnetic material can also contribute to the total loss. The magnetic material losses can usually be ignored if the flux density is kept within reasonable limits.

The following method can be used to determine the approximate insertion loss before building the unit. The total or normalized winding resistance, that is the resistance of the secondary referred to the primary, or the primary referred to the secondary, will normally be 10 to 20% of the load resistance. If it is 10%, it will have a loss of approximately 0.5 DB and, if 20%, it will be approximately 1.0 DB.

By using the calculated values of the winding resistances, the calculation of the normalized resistance can be done as follows:

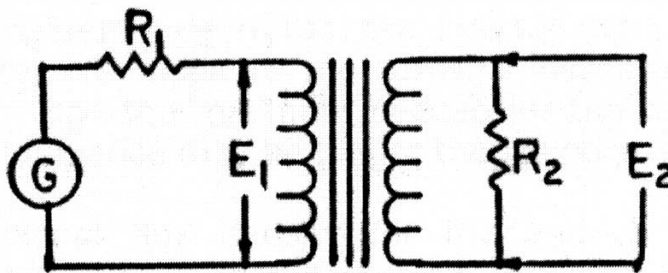
$$R_T = \left[ \frac{N_1}{N_2} \right]^2 \times R_2 + R_1$$

Then the percentage loss will be:

$$\frac{R_T}{Z_1} \times 100$$

Where:  $R_1$  = DC resistance of the primary winding  
 $R_2$  = DC resistance of the secondary winding

Figure 4 shows how to measure the insertion loss.



**Figure 4**

Where:  $E_1$  = Voltage across the primary  
 $E_2$  = Load voltage  
 $R_1$  = Primary impedance  
 $R_2$  = Secondary impedance

It should be noted that the insertion loss test circuit is the same as the frequency response circuit, except that the primary voltage is taken after the primary resistor instead of across the generator.

Then the insertion loss is:

$$20 \text{ LOG } \frac{E_1 \sqrt{Z_2}}{E_2 \sqrt{Z_1}}$$

The voltages obtained from this test can be used to calculate the insertion loss at any given frequency.

## CHAPTER 5. DESIGN METHODS

Before the design of any transformer can begin, it is necessary to understand the general construction and how to calculate the turns, winding fill and DC resistances of the winding.

The following will show the methods used to determine these values.

### 5.1 Flux density

The formula for calculating the open circuit primary inductance needed to meet the low frequency response is given on page 7. In this formula, no provision is made for the flux density. It is always necessary to calculate the flux density to be sure that the core will not be operating in saturation and adjustments made to the turns, if necessary. This may result in more turns than the minimum needed for the required inductance. The resulting inductance may be higher than is necessary.

The operational flux density for the various core materials can be obtained from a core manufacturer's catalog. For the purposes of this manual, the maximum flux densities used will be 17 kilo-gauss for 29M6 material, 8 kilo-gauss for 50% nickel and 5 kilo-gauss for 80% nickel. If other materials or flux densities are desirable, the literature should be consulted.

The formula for determining the turns for a given core is:

$$N_p = \frac{E \times 10^8}{4.44 \times A_C \times F \times B}$$

Where:  $N_p$  = Number of turns  
 $E$  = Voltage applied  
 $A_C$  = Effective core area in square inches  
 $F$  = Lowest frequency of operation  
 $B$  = Flux density in lines per square inch  
(Gauss x 6.45 = lines per square inch)  
4.44 is a constant

## **5.2 Construction suggestions**

The construction of an audio transformer differs from a regular power transformer in that the leakage inductance must be kept as low as possible.

The interleaving has been covered for the leakage inductance, but the advantages of interleaving can be offset by improper or sloppy winding. The windings must be directly above one another. The margins called out must be maintained and the winding lengths must be fully utilized. If the turns are not sufficient to fill out the winding length, then the wire must be spiraled to fill it out. The margins for all windings must be the same. If one size wire calls for a 1/4" margin, for instance, then all windings must have 1/4" margins.

The windings, when layer-wound, must be even and no cross-overs allowed. In bobbin windings, they cannot be in perfect layers, but they should be wound as evenly as possible.

In general, good, high quality workmanship is essential for an audio transformer to meet the design goals. No matter how good the design is, sloppy construction techniques can result in a failed transformer.

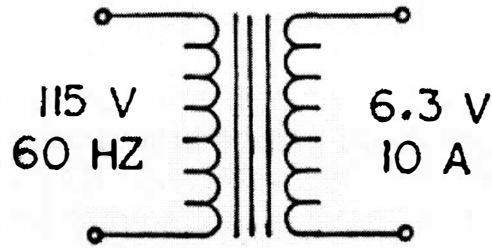
These methods should be called out in the construction specifications.

## **5.3 Calculating the physical parameters**

The following design example is for a simple power transformer. This is used in order to conserve space. It will demonstrate the principles used for calculations of the turns, winding fill and DC resistances of the magnet wire the same as for an audio transformer.

It is desired to design a transformer to operate from a 115 volt line at 60 Hertz and to deliver 6.3 volts at 10 amperes AC. The physical size is not given.

Write down all information known.



**Schematic diagram**

$$\begin{aligned} E_p &= 115 \text{ V} \\ F &= 60 \text{ Hz} \\ E_s &= 6.3 \text{ V} \\ I_s &= 10 \text{ A} \end{aligned}$$

Calculate the total VA:

$$VA = E_s \times I_s = 6.3 \times 10 = 63$$

Calculate the primary current:

$$I_p = (VA \times 1.11) / E_p = (63 \times 1.11) / 115 = 0.0608 \text{ A}$$

Choose a core from the Lamination Table in the Appendix. From the VA column, it is seen that EI-1 1/8" size with a 1 1/8" stack height has a VA rating of 65. This should be a good core for this transformer.

The manufacturers will give the core losses at flux densities in kilo-gauss. This can be converted to lines by multiplying by 6.45.

For example, 15 KG or 15000 gauss x 6.45 = 96750 lines

The conversion can be done directly in the formula for primary turns by using the gauss number and adding the 6.45 factor below the line.

The window of the lamination is 9/16" x 1 11/16". The effective core area is 1.164 square inch.

We will choose to try 29M6 grade laminations with a flux density of 95000 lines as a starting point. This is 14.72 KG.

Calculate the primary turns.

$$N_p = \frac{E \times 10^8}{4.44 \times A_C \times F \times B} = \frac{115 \times 10^8}{4.44 \times 1.164 \times 60 \times 95000} = 390 \text{ T}$$

Calculate the secondary turns.

$$N_s = N_p / E_p \times 1.05 \times E_s = 390 / 115 \times 1.05 \times 6.3 = 22.4 \text{ turns}$$

Change the turns to an even number or 22 turns.

Choose the wire sizes.

The primary wire should be .608 x 800 circular mils = 486.4. For this we will see that #23 wire is the closest with 509.5 cm. See Wire Table in the Appendix.

The secondary wire should be 10 x 800 cm = 8000. #11 wire has 8234 cm and will be used. It should be noted that this is conservative and in practice there is room for adjustment up or down, if needed. The only limiting factors will be temperature rise and regulation.

Calculate the turns per layer and number of layers.

The window length is  $1 \frac{11}{16}$ " long. In order to fit, the coil length should be  $\frac{1}{16}$ " shorter or  $1 \frac{5}{8}$ " long. From the wire table, it is seen that the margin for #23 wire should be  $\frac{1}{8}$ " on each end. The margin for #11 wire should be  $\frac{1}{4}$ " on each end. The turns per layer is determined by the winding length x the turns per inch for that wire size. This is also obtained from the wire table. The values should be put down on the work sheet clearly to show the construction of the coil.

With a coil length of  $1 \frac{5}{8}$ ", the winding length for #23 wire will be  $1 \frac{3}{8}$ " and a margin of  $\frac{1}{8}$ " on each end.

The turns per layer will be:

$$1 \frac{3}{8} \times 37.4 \text{ (turns per inch from table)} = 52 \text{ turns.}$$

$$\text{Layers} = 390 / 52 = 7.5 \text{ layers. Use 8.}$$

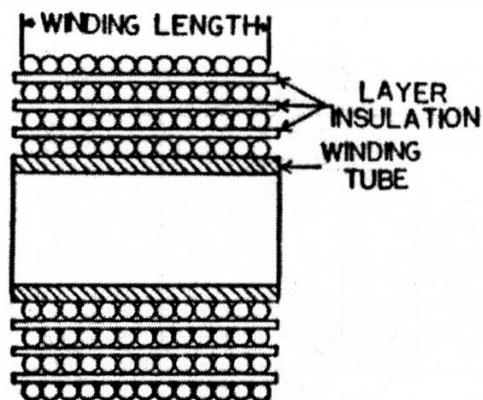
#11 wire winding length =  $\frac{1}{8}$ ", margins  $\frac{1}{4}$ " each end.

$$\text{Turns per layer} = 1 \frac{1}{8} \times 10.2 = 11 \text{ turns}$$

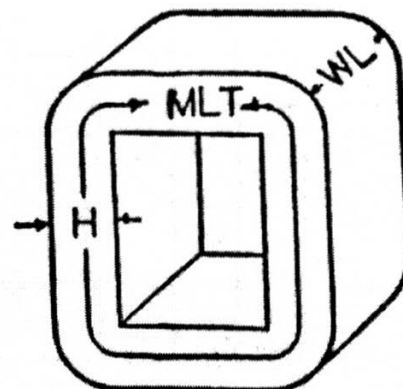
$$\text{Layers} = 22 / 11 = 2$$

It should be noted that for a power transformer, the margins of the windings do not have to be the same for all windings.

Figure 5 shows the cross section of a coil with 4 layers. The space between the layers is, for practical purposes, the layer insulation and the impregnating compound. The mean length turn is the distance around the winding at the center. See Figure 6. In Figure 6, the mean length turn would be between layers 2 and 3.



**Figure 5**



**Figure 6**



The fill can now be calculated:

Winding tube	=	.0400
8 layers #23	=	.1920
Layer ins.	=	.0210
Wrapper	=	.0100
2 layers #11	=	.1858
Layer ins.	=	.0100
Wrapper	=	<u>.0100</u>

Total fill  $.4688 / .5625 \times 100 = 83.3\%$

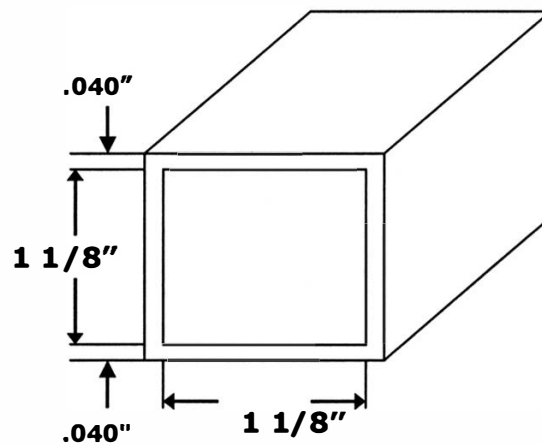
This is an acceptable fill.

The voltage drops and resistances can now be calculated. In order to obtain the voltage drops in each winding, it is first necessary to picture the build-up of the coil as calculated above in the fill. This build-up is accomplished in the following order:

1. Winding tube
2. Primary wire separated by the layer insulation
3. Wrapper between windings
4. Secondary wire separated by the layer insulation
5. Finally, the outside wrapper.

The mean length turn can be determined by taking the build-up and adding up the various sections.

Figure 8 shows a view of the tube upon which the wire is wound.



**Figure 8**

In order to simplify the calculations it is advisable to reduce the winding tube to a square if it is not already one. This is done by taking the total distance around and dividing it by 4. This will give an equivalent dimension of one side only.

For example, a winding tube that is 1 1/2" x 1 3/4" would be:

$1\ 1/2" \times 2 + 1\ 3/4" \times 2 = 3" + 3.5" = 6.5" / 4 = 1.625"$  equivalent square.

In the example used the winding tube is already a square so the 1 1/8" dimension will be the starting point.

Starting with the size of the lamination and adding the winding tube thickness to each side, the actual dimension of the winding form will be obtained. The wire and insulation is added on top of this.

Lamination	=	1.1250	(1 1/8")
Tube x 2	=	.0800	
8 - #23 wire	=	.1920	
Insulation	=	<u>.0210</u>	
Total	=	1.4180	

This gives the build-up in one direction of the primary winding. When this number is multiplied by 4, it will give the length of one turn in the center of the winding, or the mean length turn of the primary wire. Thus,  $1.4180 \times 4 \times 390 \times 1.6966 / 1000 = 3.75$  Ohms. The 1.6966 is the resistance of this size wire per 1000 inches.

It should be noted here that this mean length turn value is used in the calculation of the winding leakage inductance of an audio transformer.

The value, 1.4180, is the build-up to the center of the primary winding, so the primary values must be added in again to get to the start of the secondary winding. The entire build-up is now repeated to clearly show the calculations.

Lam. = 1.1250  
 Tube = .0800  
 8 - #23 = .1920  
 Insul = .0210

$$1.4180 \times 4 \times 390 \times 1.6966 / 1000 = 3.75 \times .608 = 2.28 \text{ V}$$

8 - #23 = .1920  
 Insul = .0210  
 Wrap = .0100  
 2 - #11 = .1858  
 Insul = .0100

$$1.8368 \times 4 \times 22 \times .1050 / 1000 = .0169 \times 10 = .169 \text{ V}$$

These values can be used to determine the output voltage under loaded conditions. This is done by subtracting the primary voltage drop from the input voltage and, from the turns ratio, obtain the secondary voltage. The secondary voltage drop is then subtracted from this value to obtain the loaded voltage.

$$115 - 2.28 = 112.72 \text{ V}$$

This is the effective input voltage.

$$\text{From the turns ratio, } 112.72 / 390 \times 22 = 6.358 \text{ V}$$

$$\text{Subtracting the secondary voltage drop, } 6.358 - .169 = 6.189 \text{ V}$$

This is lower than the 6.3 V desired so adjustments must be made. This can be done by adjusting either the primary turns down or the secondary turns up. This will not be carried any further as the purpose of this example is to show how to calculate the fill and the resistances of the windings.

The weight of the wire can be obtained by using the DC resistances. Referring to the wire table, the weights are given in Ohms per pound.

For example, #23 wire is 12.88 Ohms per pound.

$$\text{Then the weight is } 3.75 / 12.88 = .291 \text{ pounds.}$$

As indicated previously, this example was used only to show the methods of calculating the winding layers, turns per layer, fill and DC resistance. It can also be used as a guide for designing power transformers.

The complete design and construction of power transformer and inductors can be found in the TRANSFORMER DESIGN AND MANUFACTURING MANUAL published by the author in 1984.

The methods described above will be used in the following examples of audio transformers.

## **PART II. DESIGN EXAMPLES**

## **PART II. DESIGN EXAMPLES**

In the actual design of an audio transformer it is necessary to consider all of the requirements one at a time. However, many of these requirements interact and this will affect the results so they must all be kept in mind while doing the design.

The examples that follow will cover a broad range of audio transformers. Some of them will be relatively easy to design and some will be more difficult and time consuming.

An attempt will be made to go through each design, step-by-step, explaining the thinking as the design progresses.

The calculations of the various parameters will be given and then the actual transformer will be built and tested. The results will be compared with the calculated values.

In order to demonstrate the results of interleaving, a design for a 600 watt transformer has been made and built for a 4 Ohm to 200 volt line transformer.

The complete design will not be shown as the following designs will thoroughly demonstrate the design and construction of enough types of audio transformers to suffice.

The lamination size is EI- 2 1/8" with a 2 1/8" stack. The first design was not interleaved. It was built with the primary first and then the secondary.

The high frequency response was calculated to be down 3 DB at 9600 Hz. The measured response was down 3 DB at 11000 Hz.

The unit was then redesigned and built with a 2:1 interleaving. The secondary was split in half and the primary was put in the center.

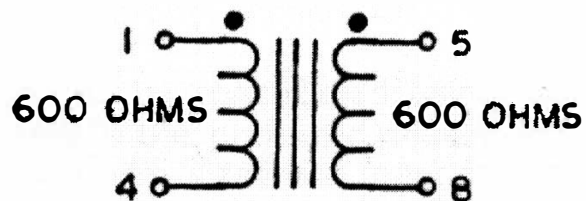
The calculated 3 DB down-point was 26400 Hz and the measured frequency was down 3 DB at 30000 Hz.

The low frequency response was not affected.

The following designs have been chosen to demonstrate the three most representative types of audio transformers.

## EXAMPLE 1: VOICE FREQUENCY TELEPHONE TRANSFORMER

This example will be for an audio transformer used in a telephone circuit that has a voice frequency response requirement.



**Circuit Diagram**

The polarity dots indicate the instantaneous polarity of the windings. This is important in many audio transformers.

The specifications call for the following:

Impedances are 600 Ohms to 600 Ohms

Frequency response is  $\pm 1.0$  DB from 300 Hz to 3500 Hz

Insertion loss is 1.0 DB maximum

Longitudinal balance is 60 DB minimum from 20 Hz to 1000 Hz and 40 DB at 4000 Hz

Operating level is +10 DBM

THD at 300 Hz = 0.5% maximum

Primary DC current is .090 amperes

Physical size is given as EI- 3/8" lamination with a square stack to be wound on a printed circuit bobbin

Primary DC resistance = 50 Ohms maximum

Secondary DC resistance = 65 Ohms maximum

From page 7, the inductance needed is:

$$L = \frac{Z}{\pi F} = \frac{600}{\pi \times 300} = .636 \text{ HY}$$

The design for turns on the primary is done the same as for an inductance that carries direct current. Any method for obtaining the proper result is satisfactory.

In this case Hanna's curves were used to calculate the turns and air gap needed to obtain the proper inductance.

This transformer can be constructed using either 29M6, 50% nickel or 80% nickel. 29M6 is the preferred choice, if it will result in the proper inductance and the wire sizes will meet the specification for resistance, because it is the least expensive.

29M6 will be chosen to start the turns calculations. From Hanna's curves for 29M6 core material, the turns will be 1000 and the gap spacer needed is .005".

Since the gap spacer is put across both legs and the center E, the spacer is divided by 2 for a thickness of .0025". A spacer of .003" will be used to start as this is a standard thickness of insulating paper. This value may have to be adjusted when the unit is tested.

The flux density in the core must be checked. +10 DBM (+10 DB in 600 Ohms) is the power level. By checking the DB Expressed in Watts Table in the Appendix, the power level is seen to be .01 watts. The voltage is:

$$E = \sqrt{0.01 \times 600} = 2.45 \text{ V}$$

The flux density is calculated:

$$B = \frac{2.45 \times 10^8}{4.44 \times .1336 \times 300 \times 1000} = 1376 \text{ lines} = 213 \text{ gauss}$$

This is a low flux density. In general, when using Hanna's curves, it is not necessary to calculate the flux density as they are designed to keep it within the proper range.

The curves in the Total Harmonic Distortion Table in the Appendix show the expected THD for this material and flux density. They show that the THD will be less than .03%. This is lower than the required 0.5%.

The current is .01 watts divided by 2.45 V, which is .004 amperes.

The .090 ADC in the primary and the required resistance will determine the wire sizes to be used:

$$.09 \times 0.7 = .063 \quad (0.7 \text{ is } 700 \text{ CM/A})$$

From the Wire Table in the Appendix, #32 AWG can be used, however, the customer has called out the DC resistance and to meet this requirement, the EI-375 Lamination turns table shows that #33 AWG will fit and should meet the resistance requirement. #34 AWG will be used for the secondary.

It can be seen from these calculations that 29M6 material will meet the inductance and DCR requirements.

The frequency response will not be difficult to meet, but the longitudinal balance must be considered. This will call for splitting the primary in two parts as a 2:1 interleave. This will be wound on a bobbin as required by the customer.

The following calculations are explained in Section 5.3 Calculating the physical parameters.

The fill will not be calculated:

The window of the lamination is 5/16" x 3/4"

The winding length of the bobbin is .673" (from manufacturer's catalog)

$$\#33 \text{ wire turns per layer} = 75 \text{ layers} = 500 / 75 = 6.66 \text{ (use 7)}$$

$$\#34 \text{ wire turns per layer} = 84 \text{ layers} = 1000 / 84 = 11.9 \text{ (use 12)}$$

Bobbin	=	.0300
7- #33	=	.0553
Wrap	=	.0060
12- #34	=	.0840
Wrap	=	.0060
7- #33	=	.0553
Wrap	=	<u>.0060</u>

$$.2426 / .3125 = .776 \times 100 = 78\% \text{ fill}$$

Calculating the DC resistances.

.3750  
.0600  
.0553

.4903 x 4 x 500 / 1000 x 17.2416 = 16.9 Ohms

.0553  
.0060  
.0840

.6356 x 4 x 1000 / 1000 x 21.7416 = 55.27 Ohms

.0840  
.0060  
.0553

.7809 x 4 x 500 / 1000 x 17.2416 = 26.92 Ohms

This is 16.9 + 26.92 = 43.82 Ohms total for the primary, 55.27 Ohms for the secondary. These are in conformity with the requirements.

The customer called for a 1:1 turns ratio so the turns cannot be adjusted.

The insertion loss is calculated using the formula from page 17:

$$R_T = \left[ \frac{N_1}{N_2} \right]^2 \times R_2 + R_1$$

Since the turns are equal, the first value becomes 1.

Then:

$$R_T = R_2 + R_1 = 55.27 + 43.82 = 99.09$$

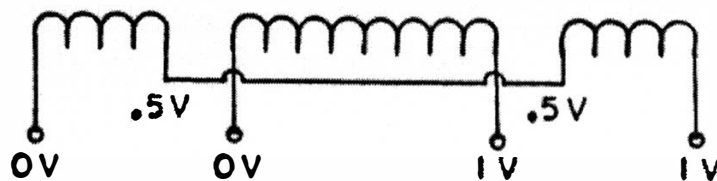
$$IL = \frac{R_T}{Z} = \frac{99.09}{600} \times 100 = 16.5\%$$

If this is interpolated, it will be .75 DB for 15%, so it is approximately .82 DB for 16.5%. The requirement of 1.0 DB will be met. See page 17.

The next requirement to be considered is the longitudinal balance. This is a small transformer with impedances of 600 Ohms for both windings. The size and the low impedance makes it easier to meet the requirements.

There is no easy way to calculate the longitudinal balance, so past experience must be called on. A 2:1 interleave has been chosen. The high frequency response is only 3500 Hz so that should be no problem and can be met without interleaving, but the balance will require that voltage gradients be considered.

The 2:1 interleave will split one winding so that the voltage gradient on each side of the center winding is small.



If the start of the primary winding is 0 volt and the finish is 1 volt and the secondary will be the same since they have the same number of turns, then the center of the primary will be 0.5 volt to 0 volts on the start of the secondary and also 0.5 volt to 1 volt to the finish of the secondary.

This will result in a difference of 0.5 volt from the primary to both the start and finish of the secondary. This will provide a fairly equal voltage gradient. Of course, there are other paths that can upset a perfect balance, for example, from windings to core and the dressing of the leads.

Another way to increase the balance is to put shields in between the windings and connect these to ground. A further increase can be accomplished by putting in additional shields and using box shields that completely enclose both windings. These methods are used in instrument transformers, where maximum isolation is necessary.

This interleaving will result in a frequency response much higher than required for this transformer.

The frequency response can now be calculated.

The leakage inductance is calculated using the formula from page 13.

Where:

N = 1000  
MLT = 2.54"  
S = 2  
T = .006"  
H = .2692"  
WL = .673"

Assigning the proper values:

$$L_L = \frac{10.6 \times 1000^2 \times 2.54 \times (2 \times 2 \times .006 + .2692)}{2^2 \times .673 \times 10^9} = .00293$$

The high frequency limit is calculated:

$$Z_T = \left[ \frac{1000}{1000} \right]^2 \times 600 + 600 = 1200$$

$$F_2 = \frac{1200}{2 \pi \times .00293} = 65215 \text{ HZ}$$

The transformer manufacturing specifications can now be written up and the unit built and tested.

The frequency response test results were plotted on the curve shown on page 43. These were run without DC on the primary and no air gap and with DC and the necessary air gap. They compare favorably with the calculated results.

The insertion loss measurements were tested to be 0.78 DB. The calculated value was approximately 0.82 DB.

The total harmonic distortion from the curves is 0.03%. The measured distortion was approximately 0.03%. This compared to the requirement of 0.5% maximum.

The longitudinal balance test was measured as -75 DB at 300 Hz. The requirement was for a minimum of -60 DB.

This same transformer was constructed with shields between the primary halves and the secondary to show the improvement that can be obtained. This resulted in a measurement of -86 DB, an increase of 11 DB.

**WINDING SHEET**

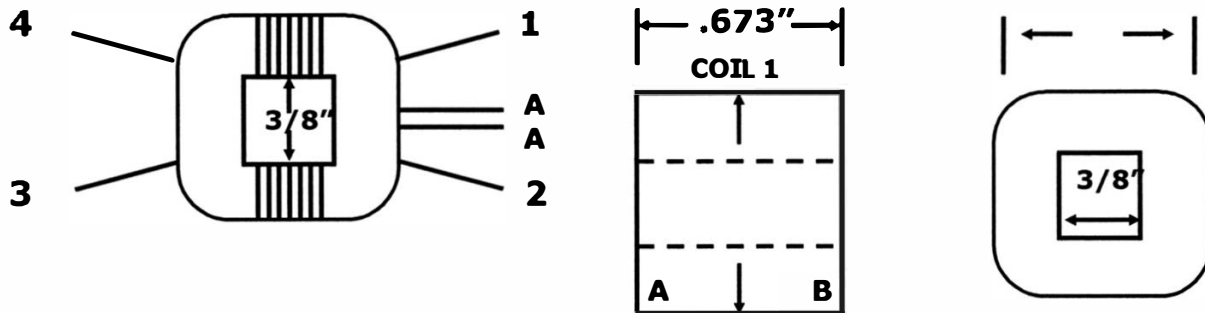
PAGE 1 OF 5 PAGES

SPEC NO. TELEPHONE TRANSFORMER

ENGINEER. RGW DATE 6/24/89

TYPE AUDIO 600 OHMS TO 600 OHMS

<b>WINDOW</b>	<b>5/16" X 3/4"</b>
<b>COIL BUILD</b>	<b>78 % NET GROSS</b>
<b>TUBE (NET GROSS)</b>	<b>3/8" X 3/8" BOBBIN</b>
<b>OVER TUBE</b>	
<b>DENSITY</b>	<b>218 GAUSS</b>
<b>FREQUENCY</b>	<b>300 HZ</b>
<b>AREA</b>	<b>0.129 IN<sup>2</sup></b>
<b>AT</b>	<b>+10 DBM VOLTS</b>
<b>TERMINALS</b>	



CONNECT A'S TOGETHER AND BLIND

WINDING	1	2	3
WIRE SIZE	<b>#33</b>	<b>#34</b>	<b>#33</b>
TOTAL TURNS	<b>500</b>	<b>1000</b>	<b>500</b>
TAPS			
WINDING LENGTH	<b>.673</b>	<b>.673</b>	<b>.673</b>
MARGIN	<b>BOBBIN WIND - NO MARGINS</b>		
URNS PER LAYER	<b>RANDOM WIND IN</b>	<b>LAYER AS CLOSE</b>	<b>AS POSSIBLE</b>
% FILL			
NO. OF LAYERS			
LAYER INSULATION			
WRAPPER	<b>2L MYLAR TAPE</b>		
TERM COIL	<b>1-A</b>	<b>3-4</b>	<b>A-2</b>
START AT			

**MATERIAL SHEET**

PAGE  2  OF  5  PAGES

SPEC NO.  TELEPHONE TRANSFORMER

	PART NO.	AMT.	TO PRICE	TO PRICE	TO PRICE
CORE	<b>EI- 3/8"</b>	<b>.110#</b>			
	<b>29M6</b>				
COPPER					
<b>#33 MAGNET WIRE</b>		<b>.034#</b>			
<b>#34 MAGNET WIRE</b>		<b>.026#</b>			
CAN					
LID-T					
LID-B					
TERMINALS					
BOBBIN	<b>3/8" X 3/8"</b>	<b>1</b>			
TERM BOARD					
LUG PANEL					
BKT	<b>3/8" X 3/8"</b> <b>HORIZ. FRAME</b>	<b>1</b>			
LEADS	<b>#22 SLW x 7"</b> <b>LONG</b>				
<b>#1</b>	<b>BLACK</b>	<b>1</b>			
<b>#2</b>	<b>BROWN</b>	<b>1</b>			
<b>#3</b>	<b>RED</b>	<b>1</b>			
<b>#4</b>	<b>GREEN</b>	<b>1</b>			
<b>NOTES:</b>					

**FINISHING**

PAGE  3  OF  5  PAGES

SPEC NO.  TELEPHONE TRANSFORMER

LEADS SIZE	COLOR	LENGTH OUT OF COIL	LEAD #
<b>#22 SLW</b>	<b>BLACK</b>	<b>6"</b>	<b>1</b>
<b>#22 SLW</b>	<b>BROWN</b>	<b>6"</b>	<b>2</b>
<b>#22 SLW</b>	<b>RED</b>	<b>6"</b>	<b>3</b>
<b>#22 SLW</b>	<b>GREEN</b>	<b>6"</b>	<b>4</b>

**LUGS OR LUG PANEL:**

PART #	LEAD #

**SPECIAL INSTRUCTIONS:**


**STACKING & ASSEMBLY**

PAGE 4 OF 5 PAGES

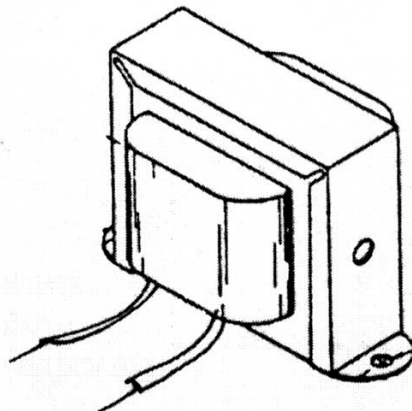
SPEC NO. TELEPHONE TRANSFORMER

LAMINATION:

SIZE:	<b>EI- 3/8"</b>
GRADE:	<b>29M6</b>
STACK HEIGHT:	<b>3/8"</b>
INTERLEAVE:	<b>1 x 1</b>
KEEPERS:	
CUT OFF E'S:	
GAP SPACER:	<b>.003K</b>
BRUISERS:	
SIZE:	
SHIELD:	
U INSULATORS:	
SIZE:	
BRACKETS - QTY: <b>1</b>	<b>3/8" x 3/8" HORIZONTAL FRAME</b>
HARDWARE:	
QTY:	
QTY:	
QTY:	
TO BE REMOVED	<b>NO</b>

SPECIAL INSTRUCTIONS:

**BUTT STACK WITH .003" GAP SPACER  
 VACUUM VARNISH AFTER ADJUSTING FOR PROPER INDUCTANCE - LEADS OUT BOTTOM.**



**TEST INSTRUCTIONS**

PAGE 5 OF 5 PAGES

SPEC NO. TELEPHONE TRANSFORMER

**PROCEDURE**

1ST TEST	<b>2, 6</b>
2ND TEST	<b>7</b>
3RD TEST (AFTER VARNISH)	<b>5, 6</b>
FINAL TEST	<b>2, 6, 7</b>

1. NO LOAD VOLTAGE RATIO

APPLY \_\_\_\_\_ V \_\_\_\_\_ HZ TO TERM. \_\_\_\_\_ I<sub>ex</sub> \_\_\_\_\_ MAX.

READ \_\_\_\_\_ V TERM. \_\_\_\_\_  
 \_\_\_\_\_ V TERM. \_\_\_\_\_  
 \_\_\_\_\_ V TERM. \_\_\_\_\_

2. INDUCTANCE TEST

APPLY 1.0 V 1000 HZ TO TERM. 1-2 & 0.090 A.D.C.

READ "L" .636 HY MIN.

3. INDUCED VOLTAGE TEST

APPLY \_\_\_\_\_ V \_\_\_\_\_ HZ TO TERM. \_\_\_\_\_ FOR \_\_\_\_\_ SEC.

4. MUST MEG. \_\_\_\_\_ MEGOHMS MIN. \_\_\_\_\_ VOLTS D.C.

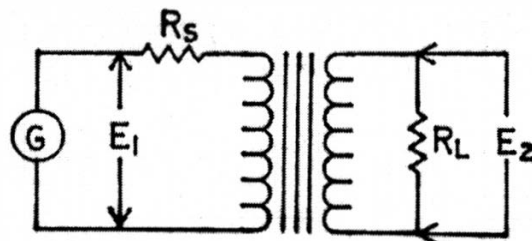
5. HIPOT

LEAD NO.	TO	VOLTS
<b>1</b>	<b>3</b>	<b>100</b>
<b>1, 3</b>	<b>CORE</b>	<b>100</b>
	<b>CASE</b>	

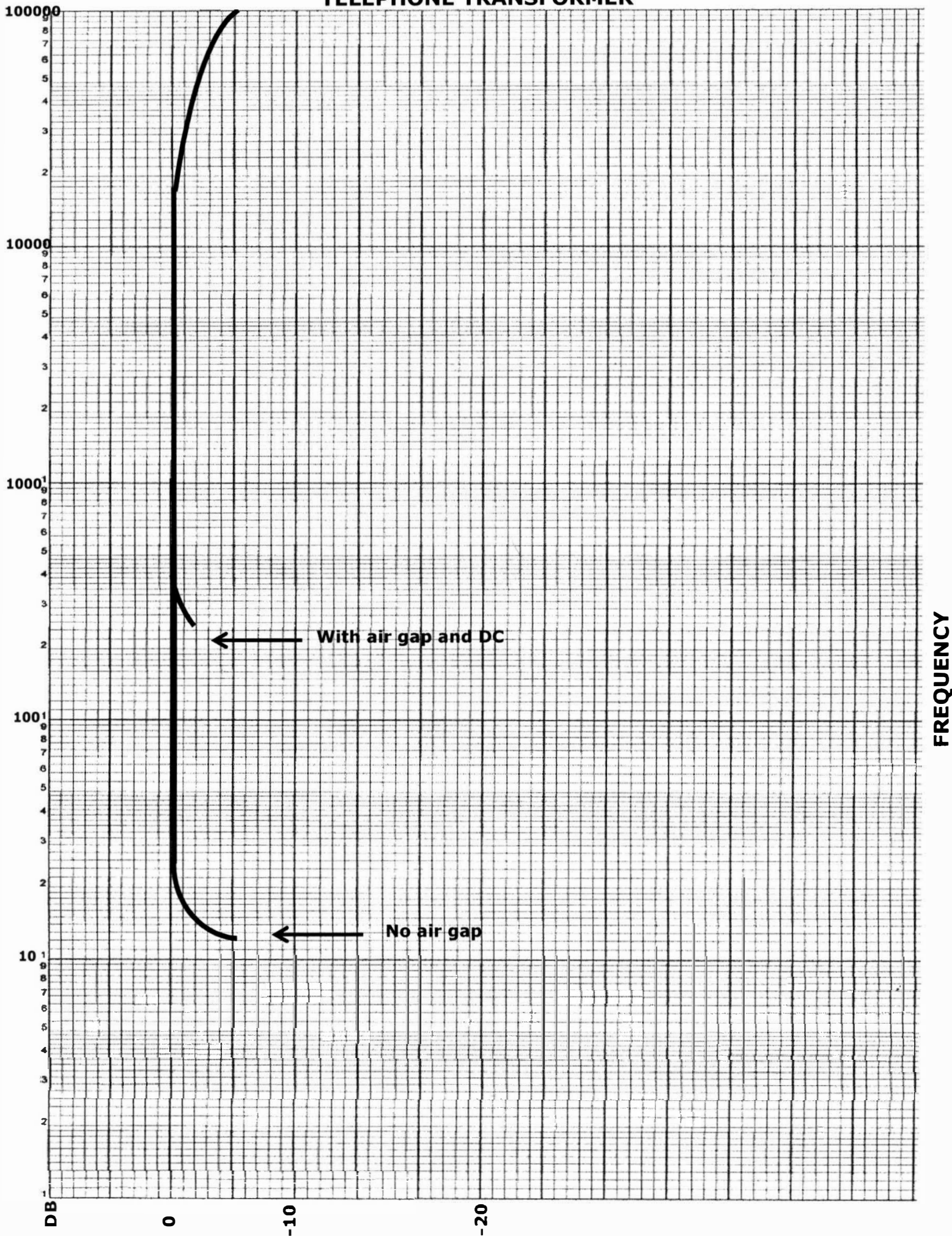
6. CONTINUITY

7. SPECIAL TESTS

R<sub>S</sub> = 600 ohms  
 R<sub>L</sub> = 600 ohms  
 Frequency response



# TELEPHONE TRANSFORMER



With air gap and DC

No air gap

FREQUENCY

DB

0

-10

-20

## EXAMPLE 2: AUDIO OUTPUT TRANSFORMER

Audio amplifiers using vacuum tubes are again in favor after a period where transistors were used exclusively.

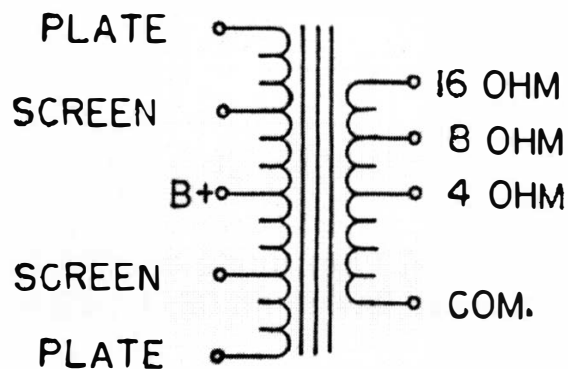
Vacuum tubes have a high plate-to-plate impedance while transistor impedances are usually quite low. This makes the design of transformers for use with vacuum tubes much more difficult. The impedances can be 10000 ohms, plate-to-plate and above and are therefore a more difficult design in order to obtain the high frequency response.

The output transformer chosen for this example is a 100 watt, sine wave power, unit with a primary plate-to-plate impedance of 1250 ohms. The secondary must deliver power to 16, 8, and 4 ohm impedances.

The frequency response is to be  $\pm 1$  DB from 20 Hz to 20000 Hz.

The primary is to have screen taps for ultra-linear operation. These taps are at the 60% point of the primary from the center tap. That is, 60% of the plate voltage is applied to the screens.

See the circuit diagram.



**Circuit Diagram**

First it is necessary to choose a core size, if it is not called out by the customer. As explained in page 11, the core size will be about the same as for a 300 watt, 60 Hz transformer. Since the windings must be interleaved, it will need to have a slightly larger core. An EI 1.75 lamination with a square stack will be tried.

$$\text{Area} = 1.75 \times 1.75 \times .92 = 2.81$$

The inductance needed will be:

$$L = \frac{1250}{\pi \times 20} = 19.89 \text{ HY}$$

We will design for 20 HY.

Referring to a manufacturer's catalog, the formula for inductance for this lamination is:

$$L = .9283 \times 10^{-8} \times K \times U_{AC} \times N^2$$

Then using a permeability of 4000 for 29M6 material:

$$N = \sqrt{\frac{20}{.9283 \times 10^{-8} \times .92 \times 4000}} = 765$$

A permeability of 4000 is about right for 29M6 laminations. The primary voltage for 100 watts, 1250 ohms will be:

$$W = \frac{E^2}{R}$$

$$E = \sqrt{100 \times 1250} = 353 \text{ V}$$

The turns for a maximum flux density of 17 KG at 20 Hz will be:

$$N = \frac{353 \times 10^8}{4.44 \times 2.81 \times 20 \times 17000 \times 6.45} = 1290 \text{ T}$$

1300 turns will be used.

In this case the turns needed for the inductance are less than those necessary for the flux density so the 1300 turns will have to be used.

The B+ voltage will be applied to the center of the winding. 60% of the voltage will be at  $1300 / 2 = 650 \times .60 = 390$  turns from the center tap. This will be  $650 - 390 = 260$  turns from the plate end of the windings.

Secondary voltages will be:

$$16 \text{ OHM } E = \sqrt{100 \times 16} = 40 \text{ V}$$

$$8 \text{ OHM } E = \sqrt{100 \times 8} = 28.28 \text{ V}$$

$$4 \text{ OHM } E = \sqrt{100 \times 4} = 20 \text{ V}$$

The secondary turns will be:

$$\frac{1300}{353} \times 1.05 \times 40 = 155 \text{ T}$$

$$\times 28.28 = 110 \text{ T}$$

$$\times 20 = 78 \text{ T}$$

The 1.05 factor is to compensate for the losses.

Primary current:

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

$$I_p = \frac{100}{353} = .283 \text{ A}$$

Secondary currents:

$$16 \text{ OHM} = \frac{100}{40} = 2.5 \text{ A}$$

$$8 \text{ OHM} = \frac{100}{28.78} = 3.53 \text{ A}$$

$$4 \text{ OHM} = \frac{100}{20} = 5.0 \text{ A}$$

The configuration must be chosen. This is for the most part, a guessing game, using past experience. A 4 to 5 interleave will be tried for this design since the primary can naturally be divided into 4 sections in series and the secondary will be wound in 5 sections that will be put in parallel.

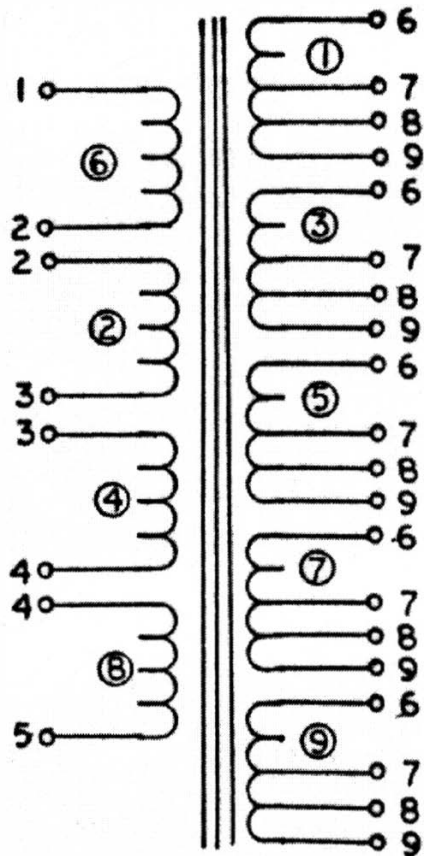
The lamination size, the number of turns and the currents are known and the configuration has been decided upon, the wire sizes can be chosen.

The primary current is .283 amperes.

Using 750 CM/A,  $.283 \times .750 = .212$ , so #27 wire with 201 circular mils will be chosen.

The secondary is divided into 5 parts. The largest current for any one winding will be for the 4 ohm winding, 5 amperes divided by 5 or 1 A. per section. Then,  $1 \times .750 = .750$ . So #21 wire with 810 circular mils will be used.

The following circuit diagram will show how the winding will be done. The circled numbers indicate the winding sequence.



**Winding Diagram**

The lead numbers shown will be connected so that like numbered leads are connected together and brought out as one lead.

For the primary, leads numbered 1 and 5 will be the plates. Leads numbered 2 and 4 will be the screen taps. Leads numbered 3 will be the center tap for the B+ voltage.

For the secondary, leads numbered 6 will be for the 16 ohm winding. Leads numbered 7 will be for the 8 ohm winding. Leads numbered 8 will be for the 4 ohm winding and the number 9 leads will be the common point lead.

The fill can now be calculated. The window for the EI 1.75 lamination is  $\frac{7}{8}$ " wide by  $2 \frac{5}{8}$ " long. The coil length will be  $\frac{1}{16}$ " less than the window length or  $2 \frac{9}{16}$ ".

Using the methods shown in the example in Section 5.3:

The fill will be calculated using the winding order as shown in the circuit diagram on page 48.

The total turns for the secondary are 155. This will be on each secondary winding as they are to be put in parallel. The turns for the primary are split as shown on page 47. The circuit diagram shows how this is done.

The winding length is 2 9/16".

1	#21 wire turns per layer = 52	Layers = 155 / 52 = 3
2	#27 wire turns per layer = 130	Layers = 260 / 130 = 2
3	#21 wire turns per layer = 52	Layers = 155 / 52 = 3
4	#27 wire turns per layer = 130	Layers = 390 / 130 = 3
5	#21 wire turns per layer = 52	Layers = 155 / 52 = 3
6	#27 wire turns per layer = 130	Layers = 390 / 130 = 3
7	#21 wire turns per layer = 52	Layers = 155 / 52 = 3
8	#27 wire turns per layer = 130	Layers = 260 / 130 = 2
9	#21 wire turns per layer = 52	Layers = 155 / 52 = 3

The winding tube will be made up of .040" thick material.

Winding tube	=	.0400	
3 layers #21	=	.0903	
Layer ins.	=	.0100	(2 layers of .005" Kraft paper)
Wrapper	=	.0050	
2 layers #27	=	.0308	
Layer ins.	=	.0020	
Wrapper	=	.0050	
3 layers #21	=	.0903	
Layer ins.	=	.0100	
Wrapper	=	.0050	
3 layers #27	=	.0462	
Layer ins.	=	.0040	
Wrapper	=	.0050	
3 layers #21	=	.0903	
Layer ins.	=	.0100	
Wrapper	=	.0050	
Layer ins.	=	.0100	
3 layers #27	=	.0462	
Layer ins.	=	.0040	
Wrapper	=	.0050	
3 layers #21	=	.0903	
Layer ins.	=	.0100	
Wrapper	=	.0050	
2 layers #27	=	.0308	
Layer ins.	=	.0020	
Wrapper	=	.0050	
3 layers #21 =	=	.0903	
Layer ins.	=	.0100	
Wrapper	=	<u>.0100</u>	
Total	=	.7675 / .8750 x 100 = 86.5% fill	

This fill is higher than the 85% ideal, but it will fit with a good winding job.

An audio transformer that is layer wound must be wound carefully. The margins at the ends of the windings must be maintained even if it is necessary to spiral the windings. This is so that the windings are directly above on another and not staggered. Staggering will greatly increase the leakage inductance and throw off the calculations.

For this transformer the #21 wire at 52 turns per layer on the secondaries will take  $52 \times .0301 = 1.565$ " of winding space.

Then,  $1.565 / 2.3125 = 67\%$  fill. So the secondary windings will have to be spiraled, however, each secondary will have 2 taps brought out and that will take up some space. A little experimentation on the first winding will result in a properly filled winding space.

The primary windings are 130 turns per layer of #27 wire.

$$130 \times .0154 = 2.002" / 2.3125 = 86.5\% \text{ fill}$$

This is about right and there should be no problem in holding the margins.

The DC resistance of the windings can now be calculated. See the example on page 27.

$$\begin{array}{r} 1.7500 \\ .0800 \\ .0903 \\ \underline{.0100} \end{array}$$

$$1.9303 \times 4 \times 155 \times 1.0666 / 1000 = 1.276 \text{ ohms}$$

$$\begin{array}{r} .0100 \\ .0903 \\ .0050 \\ .0308 \\ \underline{.0020} \end{array}$$

$$2.0684$$

DC resistance calculations, continued

$$2.0684 \times 4 \times 260 \times 4.2891 / 1000 = 9.226 \text{ ohms}$$

.0020  
.0308  
.0050  
.0903  
.0100

$$2.2065 \times 4 \times 155 \times 1.0666 / 1000 = 1.459 \text{ ohms}$$

.0100  
.0903  
.0050  
.0462  
.0040

$$2.3620 \times 4 \times 390 \times 4.2891 / 1000 = 15.80 \text{ ohms}$$

.0040  
.0462  
.0050  
.0903  
.0100

$$2.5175 \times 4 \times 155 \times 1.0666 / 1000 = 1.664 \text{ ohms}$$

.0100  
.0903  
.0050  
.0462  
.0040

$$2.6730 \times 4 \times 390 \times 4.2891 / 1000 = 17.88 \text{ ohms}$$

.0040  
.0462  
.0050  
.0903  
.0100

2.8285

DC resistance calculations, continued

$$2.8285 \times 4 \times 155 \times 1.0666 / 1000 = 1.87 \text{ ohms}$$

.0100  
.0903  
.0050  
.0308  
.0020

$$2.9666 \times 4 \times 260 \times 4.2891 / 1000 = 13.23 \text{ ohms}$$

.0020  
.0308  
.0050  
.0903  
.0100

$$3.1047 \times 4 \times 155 \times 1.0666 / 1000 = 2.053 \text{ ohms}$$

The total primary resistance is:

$$9.226 + 15.80 + 17.88 + 13.23 = 56.13 \text{ ohms.}$$

The voltage drop in the primary is  $56.14 \times .283 = 15.88 \text{ V.}$

The secondaries are all in parallel so that the sum of the windings will be:

$$R_S = \frac{1}{\frac{1}{1.276} + \frac{1}{1.459} + \frac{1}{1.664} + \frac{1}{1.87} + \frac{1}{2.053}} = .323 \text{ OHMS}$$

This will be for the 16 ohm winding.

Calculate the output voltage:

$$(353 - 15.88) / 1300 \times 155 = 40.195 - .809 = 39.38 \text{ V}$$

In order to increase the output to the desired 40 volts, the secondary turns should be increased to 157. Then the output will be 39.9 V.

The other taps can be calculated rapidly by taking a percentage of the total winding.

For the 8 ohm winding it will be  $110 / 157 \times .323 = .226$  ohms.  
Then  $.226 \times 3.53 = .798$  V drop.  
 $(353 - 15.88) / 1300 \times 110 = 28.52 - .798 = 27.72$  V.  
Adjusting for 28.28 V = 112 turns.

For the 4 ohm winding it will be  $78 / 157 \times .323 = .160$  ohms  
Then,  $.160 \times 5 = .802$  V drop.  
 $(353 - 15.88) / 1300 \times 78 = 20.22 - .802 = 19.42$  V.  
Adjusting for 20 V = 80 turns.

These adjustments will result in a small change in the DC resistances, but it won't be necessary to go back and make all the new calculations.

Calculate the leakage inductance using the formula from page 13.

N = 1300  
MLT =  $2.5175 \times 4 = 10.07$  (from the center winding)  
WL = 2.3125  
S = 4 (interleaves)  
T = .005  
H = .7675

$$L_L = \frac{10.6 \times 1300^2 \times 10.07 \times (2 \times 4 \times .005 + .7675)}{4^2 \times 2.3125 \times 10^9} = .00393 \text{ HY}$$

For the high frequency response:

$$Z_T = \left[ \frac{1300}{157} \right]^2 \times 16 + 1250 = 2347$$

$$F_2 = \frac{2347}{2 \pi \times .00393} = 95095$$

This calculates to be 0. K.

The design is now ready to write up the manufacturing specifications and build and test the unit.

The graph on page 61 shows the frequency response test results.

**ROBERT G. WOLPERT**  
*TRANSFORMER DESIGN SERVICES*

**WINDING SHEET**

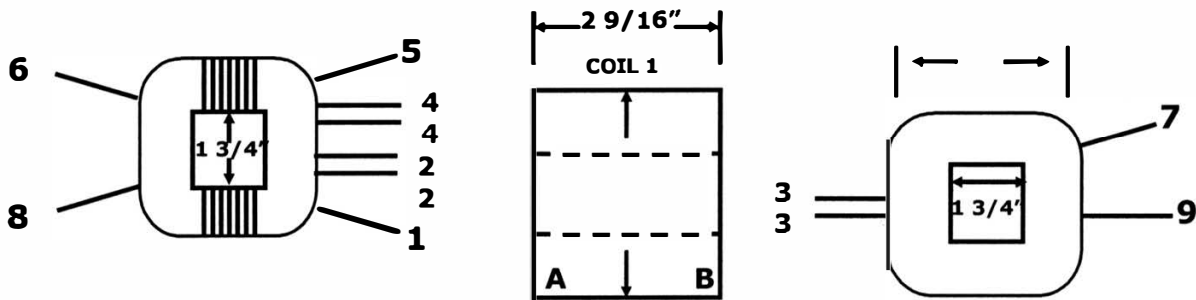
PAGE 1 OF 5 PAGES

SPEC NO. AUDIO OUTPUT

ENGINEER. RGW DATE 6/25/89

TYPE 1250 OHMS TO 16, 8, 4 OHMS, 100 WATTS

<b>WINDOW</b>	<b>7/8" X 2 5/8"</b>	
<b>COIL BUILD</b>	<b>86 % NET GROSS</b>	
<b>TUBE (NET GROSS)</b>	<b>1 3/4" X 1 3/4" X .040</b>	
<b>OVER TUBE</b>		
<b>DENSITY</b>	<b>17 KG</b>	
<b>FREQUENCY</b>	<b>20 HZ</b>	
<b>AREA</b>	<b>2.81</b>	<b>IN<sup>2</sup></b>
<b>AT</b>	<b>353</b>	<b>VOLTS</b>



**CONNECT LIKE NUMBERED LEADS TOGETHER; WHEN WINDING #21 WIRE, HOLD TO 1/8" MARGINS EVEN IF YOU HAVE TO SPIRAL WIND. HOLD ALL MARGINS TO 1/8".**

WINDING	1	2	3	4	5	6	7	8	9
WIRE SIZE	#21	#27	#21	#27	#21	#27	#21	#27	#21
TOTAL TURNS	157	260	157	390	157	390	157	260	157
TAPS	82,110	--	82,110	--	82,110	--	82,110	--	82,110
WINDING LENGTH	2 5/16"	2 5/16"	2 5/16"	2 5/16"	2 5/16"	2 5/16"	2 5/16"	2 5/16"	2 5/16"
MARGIN	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"
TURNS PER LAYER	53	130	53	130	53	130	53	130	53
% FILL	70%	87%	70%	87%	70%	87%	70%	87%	70%
NO. OF LAYERS	3	2	3	3	3	3	3	2	3
LAYER INSULATION	.005K	.002K	.005K	.002K	.005K	.002K	.005K	.002K	.005K
WRAPPER	1L - .005K	1L - .005K	1L - .005K	1L - .005K	1L - .005K	1L - .005K	1L - .005K	1L - .005K	1L - .005K
TERM COIL	6, 7, 8, 9	1-2	6, 7, 8, 9	2-3	6, 7, 8, 9	3-4	6, 7, 8, 9	4-5	6, 7, 8, 9
START AT									

**ROBERT G. WOLPERT**  
 TRANSFORMER DESIGN SERVICES

MATERIAL SHEET

PAGE 2 OF 5 PAGES

SPEC NO. AUDIO OUTPUT

	PART NO.	AMT.	TO PRICE	TO PRICE	TO PRICE
CORE	<b>EI- 1 3/4"</b>				
	<b>29M6</b>	<b>8.7#</b>			
COPPER					
<b>#21 MAGNET WIRE</b>		<b>1.63#</b>			
<b>#27 MAGNET WIRE</b>		<b>0.68#</b>			
CAN					
LID-T					
LID-B					
TERMINALS					
TUBE	<b>1 3/4" x 1 3/4" x .040</b>	<b>1</b>			
	<b>x 2 9/16" LONG</b>				
TERM BOARD					
LUG PANEL					
BKT	<b>1 3/4" HORIZ. "L"</b>	<b>4</b>			
BOLTS	<b>#10 X 2"</b>	<b>4</b>			
NUTS	<b>#10</b>	<b>4</b>			
WASHERS	<b>#10 STEEL</b>	<b>8</b>			
WASHERS	<b>#10 FIBER</b>	<b>4</b>			
LEADS	<b>#20 SLW x 10" LONG</b>				
<b>#1</b>	<b>BLACK</b>	<b>1</b>			
<b>#2</b>	<b>BROWN</b>	<b>1</b>			
<b>#3</b>	<b>RED</b>	<b>1</b>			
<b>#4</b>	<b>YELLOW</b>	<b>1</b>			
<b>#5</b>	<b>GREEN</b>	<b>1</b>			
<b>#6</b>	<b>BLUE</b>	<b>1</b>			
<b>#7</b>	<b>ORANGE</b>	<b>1</b>			
<b>#8</b>	<b>WHITE</b>	<b>1</b>			
<b>#9</b>	<b>VIOLET</b>	<b>1</b>			
NOTES:					

**FINISHING**

PAGE   3   OF   5   PAGES

SPEC NO.                   **AUDIO OUTPUT**                  

LEADS SIZE	COLOR	LENGTH OUT OF COIL	LEAD #
<b>#20 SLW</b>	<b>BLACK</b>	<b>8"</b>	<b>1</b>
<b>#20 SLW</b>	<b>BROWN</b>	<b>8"</b>	<b>2</b>
<b>#20 SLW</b>	<b>RED</b>	<b>8"</b>	<b>3</b>
<b>#20 SLW</b>	<b>YELLOW</b>	<b>8"</b>	<b>4</b>
<b>#20 SLW</b>	<b>GREEN</b>	<b>8"</b>	<b>5</b>
<b>#20 SLW</b>	<b>BLUE</b>	<b>8"</b>	<b>6</b>
<b>#20 SLW</b>	<b>ORANGE</b>	<b>8"</b>	<b>7</b>
<b>#20 SLW</b>	<b>WHITE</b>	<b>8"</b>	<b>8</b>
<b>#20 SLW</b>	<b>VIOLET</b>	<b>8"</b>	<b>9</b>

LUGS OR LUG PANEL:

PART #	LEAD #

SPECIAL INSTRUCTIONS:

<b>FINISH ALL LIKE NUMBERED LEADS TOGETHER.</b>

**STACKING & ASSEMBLY**

PAGE 4 OF 5 PAGES

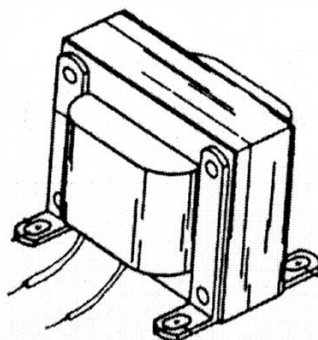
SPEC NO. **AUDIO OUTPUT**

**LAMINATION:**

SIZE:	<b>EI- 1 3/4"</b>
GRADE:	<b>29M6</b>
STACK HEIGHT:	<b>1 3/4"</b>
INTERLEAVE:	<b>1 x 1</b>
KEEPERS:	<b>2</b>
CUT OFF E'S:	
GAP SPACER:	
BRUISERS:	
SIZE:	
SHIELD:	
U INSULATORS:	
SIZE:	
BRACKETS - QTY: <b>4</b>	<b>1 3/4" HORIZONTAL "L"</b>
HARDWARE:	
QTY: <b>4</b>	<b>BOLTS #10-32</b>
QTY: <b>4</b>	<b>NUTS #10-32</b>
QTY: <b>8</b>	<b>WASHERS #10 STEEL</b>
QTY: <b>4</b>	<b>WASHERS #10 FIBER</b>
TO BE REMOVED	<b>NO</b>

**SPECIAL INSTRUCTIONS:**

<b>VACUUM VARNISH</b>
<b>BRING LEADS OUT BOTTOM</b>



**TEST INSTRUCTIONS**

PAGE 5 OF 5 PAGES

SPEC NO. AUDIO OUTPUT

**PROCEDURE**

1ST TEST	<b>6</b>
2ND TEST	<b>7</b>
3RD TEST	--
FINAL TEST (AFTER VARNISH)	<b>5, 6</b>

1. NO LOAD VOLTAGE RATIO

APPLY \_\_\_\_\_ V \_\_\_\_\_ HZ TO TERM. \_\_\_\_\_ I<sub>ex</sub> \_\_\_\_\_ MAX.

READ \_\_\_\_\_ V TERM. \_\_\_\_\_  
 \_\_\_\_\_ V TERM. \_\_\_\_\_  
 \_\_\_\_\_ V TERM. \_\_\_\_\_

2. INDUCTANCE TEST

APPLY \_\_\_\_\_ V \_\_\_\_\_ HZ TO TERM. \_\_\_\_\_ & \_\_\_\_\_ A.D.C.

READ "L" \_\_\_\_\_ MIN.

3. INDUCED VOLTAGE TEST

APPLY \_\_\_\_\_ V \_\_\_\_\_ HZ TO TERM. \_\_\_\_\_ FOR \_\_\_\_\_ SEC.

4. MUST MEG. \_\_\_\_\_ MEGOHMS MIN. \_\_\_\_\_ VOLTS D.C.

5. HIPOT

LEAD NO.	TO	VOLTS
<b>1</b>	<b>6</b>	<b>1000</b>
<b>1, 6</b>	<b>CORE</b>	<b>1000</b>
	<b>CASE</b>	

6. CONTINUITY

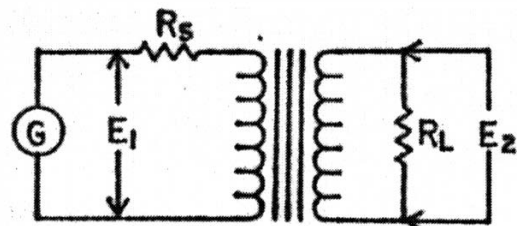
7. SPECIAL TESTS:

R<sub>S</sub> = 1250 ohms

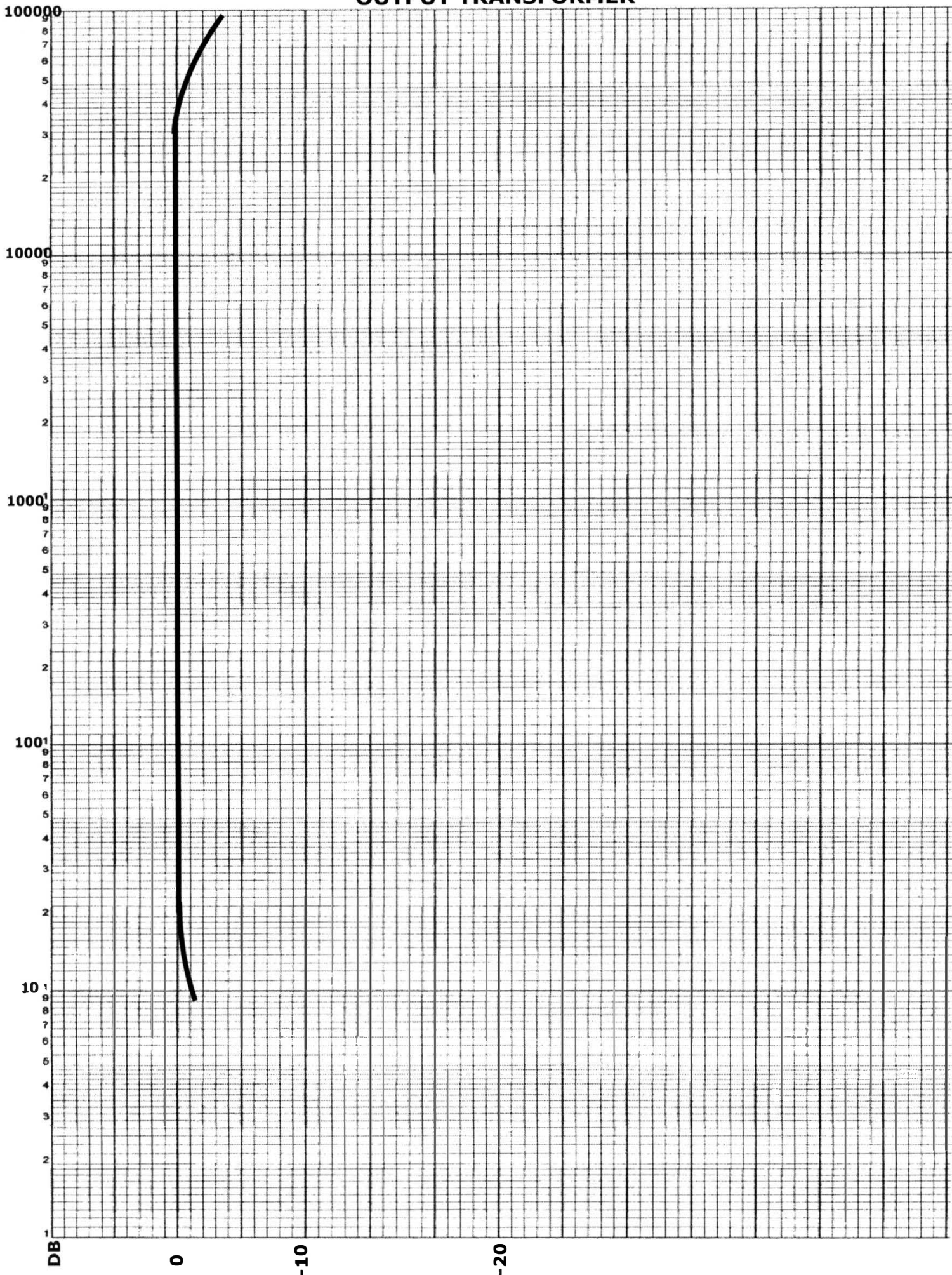
R<sub>L</sub> = 16 ohms

Test is made across the entire secondary.

Test results on the following page.



# OUTPUT TRANSFORMER



FREQUENCY

DB

0

-10

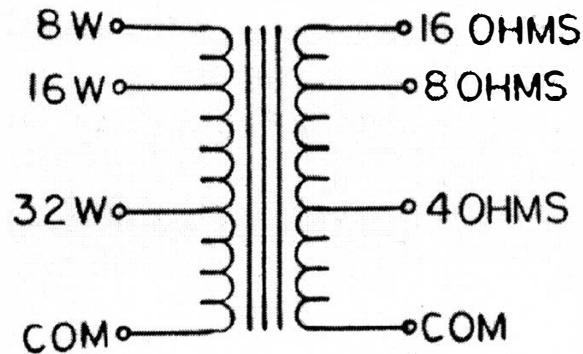
-20

### EXAMPLE 3: LINE-TO-VOICE COIL TRANSFORMER

Line-to-voice coil transformers are widely used in the transmission of music and for public address systems. A design for this type transformer is one of the most difficult to obtain. The following example will show the design of a typical line-to-voice coil transformer.

The requirements for this unit are:

70.7 volt line to 4, 8 and 16 ohms output with power ratings of 8, 16 and 32 watts. The frequency response is  $\pm 1$  DB from 30 Hz to 15000 Hz. Insertion loss of 0.5 DB maximum.



**Circuit Diagram**

Connections to the appropriate leads will give the desired wattage and output impedance.

Since this unit will be about 3 DB down at 15 Hz (-1 DB at 30 Hz), it will require a lamination that can support about 32 watts x 4 = 128 VA at 60 Hz.

By dividing 60 Hz by 15 Hz, a factor of 4 is obtained for power requirements of the lamination for this transformer.

From the Lamination Table in the Appendix, EI- 1 1/4" x 1 1/4" is good for 90 VA.

A 1 1/2" stack of this size lamination should be about right as a starting point for 128 VA.

The primary impedances can be calculated from Ohm's law.

$$\begin{aligned}
 Z &= \frac{E^2}{W} = \frac{70.7^2}{32} = 156 \\
 &= \frac{70.7^2}{16} = 312 \\
 &= \frac{70.7^2}{8} = 625
 \end{aligned}$$

Then calculate the primary inductance necessary, from page 7. For the 32 watt primary. This winding is used as it will have the least number of turns and, as shown later, the maximum flux density must be calculated for this winding.

$$L = \frac{Z}{\pi 30} = \frac{156}{\pi 30} = 1.65 \text{ HY}$$

From the manufacturer's catalog for this lamination:

$$L = .665 \times 10^{-8} \times K \times U_{AC} \times N^2$$

This formula is for a square stack. For a 1 1/2" stack it will be changed by a ratio of 1.5 / 1.25 = 1.2.

The formula will then be:

$$L = .665 \times 10^{-8} \times 1.2 \times K \times U_{AC} \times N^2$$

Using a permeability of 4000 for M6 lamination:

$$N = \sqrt{\frac{1.665}{.665 \times 1.2 \times .92 \times 4000 \times 10^8}} = 237$$

These are the turns needed for the 32 watt winding to obtain the proper inductance.

The area of this core is  $1 \frac{1}{4} \times 1 \frac{1}{2} \times .92 = 1.725$  sq. in.

A reasonable flux density is about 15 KG or 96750 lines. Using this flux density and calculating the turns needed from the formula on page 19:

$$N = \frac{70.7 \times 10^8}{4.44 \times 1.725 \times 30 \times 96750} = 318$$

It can be seen that 237 turns as calculated for the inductance will result in too high a flux density, so the 318 turns must be used for the 32 watt winding. As mentioned before, this winding has the lowest number of turns and 70.7 volts will be applied to all the primary windings as they are used.

By taking 318 turns for the 32 watt winding, since the turns ratio is the square root of the impedances ratio, the turns for the other taps on the primary will be:

$$16 \text{ W} = \sqrt{\frac{312}{156}} \times 318 = 450$$

$$8 \text{ W} = \sqrt{\frac{625}{156}} \times 318 = 636$$

The turns for the secondaries can now be calculated. By taking the 318 turns for 32 watts, the turns for the secondaries will be:

$$4 \text{ OHM} = \sqrt{\frac{4}{156}} \times 318 = 51$$

$$8 \text{ OHM} = \sqrt{\frac{8}{156}} \times 318 = 72$$

$$16 \text{ OHM} = \sqrt{\frac{16}{156}} \times 318 = 102$$

The configuration as shown later will result in a change of turns in both the primary and secondary.

The configuration must now be considered. It is advisable to split the primary so that a 2:1 interleave is achieved. By splitting the primary in the center of the low impedance winding (32 watts) and adjusting the winding configuration of the primary and secondary, the minimum voltage gradient can be obtained.

If the 318 turns can be split into 159 + 159 and then put the 4 watt winding in between. The 4 watt winding is 52 turns.

This is split into 26 + 26.

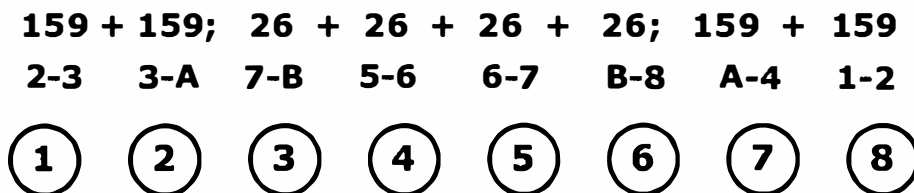
So we now have 159 T primary; 26 T secondary + 26 T secondary; 159 T primary.

We need 318 turns more on the primary and 52 more turns on the secondary. In order to preserve the voltage gradients and split the windings evenly, the additional primary turns should be divided and added at each end. The additional secondary turns should be put in the center of the secondary.

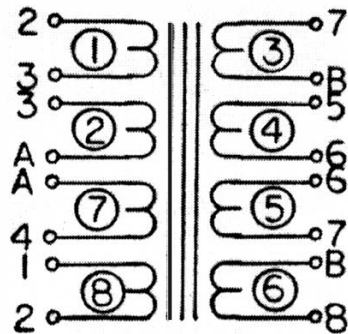
Then the winding configuration will be:

159 T + 159 T; 26 T + 26 T + 26 T + 26 T; 159 T + 159 T.

This will give the total primary turns and secondary turns. It remains to number these windings so they will be connected properly.



This circuit diagram will show how the windings are interleaved. The circled numbers in the diagram show the order in which the windings will be wound.



**Circuit Diagram**

The primary will be:

3-A, A-4 = 318 turns for 32 watts

2-3-A-4 = 477 turns for 16 watts

1-2-3-A-4 = 636 turns for 8 watts

Since 2-3 3-A are together they can be wound as one winding of 318 turns tapped at 159 turns and not be separate windings.

The secondary will be:

5-6 + 6-7 + 7-B + B-8 = 104 turns for 16 ohms

6-7 + 7-B + B-8 = 78 turns for 8 ohms

7-B + B-8 = 52 turns for 4 ohms

This will result in the correct turns for the 8 watt and 32 watt windings, but the 16 watt will be 477 turns. This is a deviation of 6% which is acceptable. Also, the secondary turns have also been adjusted and will result in a deviation for the 8 ohm winding of approximately 6%.

The next step is to determine the wire sizes and calculate the fill.

The highest current in the primary will be in the 32 watt winding.

$$I = \frac{W}{E} = \frac{32}{70.7} = .452A \quad 32 \text{ W}$$

$$\frac{16}{70.7} = .226A \quad 16 \text{ W}$$

$$\frac{8}{70.7} = .113A \quad 8 \text{ W}$$

The highest current in the secondary winding will be the 4 ohm winding and at 32 watts.

$$I = \sqrt{\frac{W}{R}} = \sqrt{\frac{32}{4}} = 2.82 \text{ A} \quad 4 \text{ OHM}$$

$$\sqrt{\frac{32}{8}} = 2.0 \text{ A} \quad 8 \text{ OHM}$$

$$\sqrt{\frac{32}{16}} = 1.41 \text{ A} \quad 16 \text{ OHM}$$

#26 AWG wire will be  $254 / 452 = 562 \text{ CM/A}$  for the primary.

#16 AWG wire will be  $1.624 / 2.82 = 575 \text{ CM/A}$  for the secondary.

These sizes are smaller than suggested previously, but will be sufficient, as they are worst case for 32 watts and 4 ohms.

## CALCULATE THE FILL

The window for this size lamination is  $5/8"$  x  $1\ 7/8"$ . The coil length should be  $1/32"$  shorter than the window.

Coil length =  $1\ 27/32"$

#26 winding length =  $1\ 19/32"$ , the margins will be  $1/8"$  each end.

Turns per layer = 80 (from the Wire Table in the Appendix)

Layers =  $318 / 80 = 4$

#16 winding length =  $1\ 19/32"$ , the margins will be  $1/8"$  each end.

Turns per layer = 26

Layers =  $26 / 26 = 1$

#16, 26 turns = 1 layer

#16, 26 turns = 1 layer

#16, 26 turns = 1 layer

#26, 80 turns per layer =  $159 / 80 = 2$  layers

#26, 80 turns per layer =  $159 / 80 = 2$  layers

The fill can now be calculated using the configuration on page 67.

Winding tube	=	.0400
4 L #26 wire	=	.0684
Layer ins.	=	.0090 (3 layers of .003" Kraft paper)
Wrap	=	.0100 K
1 L #16 wire	=	.0527
Wrap	=	.0100 K
1 L #16 wire	=	.0527
Wrap	=	.0100 K
1 L #16 wire	=	.0527
Wrap	=	.0100 K
2 L #26 wire	=	.0342
Layer ins.	=	.0060 K
Wrap	=	.0100 K
2 L #26 wire	=	.0342
Layer ins.	=	.0060 K
Wrap	=	<u>.0100 K</u>

Total =  $.4265 / .625 \times 100 = 70\%$  fill

This fill is 0. K.

The winding resistances can now be calculated (see page 26).

From the fill figures and the lamination size:

The equivalent of a square tube will be  $1.25 + 1.5 = 2.75 / 2 = 1.375$ .

Core = 1.3750  
.0800  
.0684  
.0900

$$1.5324 \times 4 \times 318 / 1000 \times 3.4005 = 6.628 \text{ ohms}$$

.0090  
.0684  
.0100  
.0527

$$1.6725 \times 4 \times 26 / 1000 \times .3346 = .0582 \text{ ohms}$$

.0527  
.0100  
.0527

$$1.7609 \times 4 \times 26 / 1000 \times .3346 = .0612 \text{ ohms}$$

.0527  
.0100  
.0527

$$1.8763 \times 4 \times 26 / 1000 \times .3346 = .0652 \text{ ohms}$$

.0527  
.0100  
.0527

$$1.9917 \times 4 \times 26 / 1000 \times .3346 = .0693 \text{ ohms}$$

.0527  
.0100  
.0342  
.0030

$$2.0916 \times 4 \times 159 / 1000 \times 3.4008 = 4.523 \text{ ohms}$$

.0030  
.0342  
.0100  
.0342  
.0030

$$2.1760 \times 4 \times 159 / 1000 \times 3.4008 = 4.706 \text{ ohms}$$

The mean length turn will be in the center of the windings which will be  $1.8763 \times 4 = 7.5$ ". This will be used in calculating the leakage inductance.

This winding configuration has all of the secondaries in between the primaries, so a 2 to 1 interleave will be used.

From page 13, the formula for leakage inductance, using the values for this transformer is:

$$L_L = \frac{10.6 \times (636)^2 \times 7.5 \times (2 \times 2 \times .010 + .4265)}{2^2 \times 1.593 \times 10^9} = .00235$$

Where:

$$\begin{aligned} S &= 2 \\ WL &= 1 \frac{19}{32} \\ T &= .010 \\ H &= .4265 \\ MLT &= 7.5 \\ N &= 636 \text{ (the total primary turns)} \end{aligned}$$

The high frequency response can be calculated using this value of leakage inductance.

$$Z_T = \left[ \frac{636}{104} \right]^2 \times 16 + 625 = 1223$$

$$F_2 = \frac{1223}{2 \pi \times .00235} = 82895 \text{ HZ}$$

It should be noted that this has been calculated using the entire primary and secondary. When taps are used for different wattages and outputs, the high frequency response will not be as good.

This is due to the windings that are not used causing the effective leakage inductance to be different. This is difficult to calculate and, when the upper end is beyond the requirements, it will not be attempted. However, it will be tested and the results put on the frequency response graph to show the difference.

The insertion loss requirement is for 0.5 DB maximum. From page 64, the total primary turns are 636. The total secondary turns are 104.

By adding the resistances, as calculated on page 69, the total primary resistance is  $6.28 + 4.523 + 4.706 = 15.5$  ohms.

The total secondary resistance is:

$$.0582 + .0612 + .0652 + .0693 = .2539.$$

$$R_T = \left[ \frac{N_1}{N_2} \right]^2 \times R_2 + R_1 = \left[ \frac{636}{104} \right]^2 \times .254 + 15.5 = 25$$

$$IL \quad \frac{R_T}{Z_1} \times 100 = \frac{25}{625} \times 100 = 4\%$$

Referring to page 17, this being less than 10%, it will meet the 0.5 DB maximum.

The insertion loss will be different for the different taps. This makes it necessary to calculate what probably is the worst case. This is for 32 watts and 4 ohms as they are the windings that will carry the highest current.

Using the resistance of the 32 watt winding, 3-A, A-4:

$$3\text{-A will be } 6.628 / 318 \times 159 = 3.314$$

$$A\text{-4 is } 4.523$$

The total will be  $3.314 + 4.523 = 7.84$  ohms. This is for 318 turns.

The 4 ohm winding is 7-B, B-8.

$$7\text{-B} = .0582$$

$$B\text{-8} = .0693$$

$$.0582 + .0693 = .1275 \text{ ohms.}$$

This is for 52 turns. The impedance for 32 watt is 156 ohms.

Then:

$$R_T = \left[ \frac{318}{52} \right]^2 \times .1275 + 7.84 = 12.60$$

$$IL = \frac{12.60}{156} \times 100 = 8.08\%$$

This is also less than 10% for the 0.5 DB maximum.

The design is now complete and the manufacturing specifications can be written up, the unit built and tested.

**WINDING SHEET**

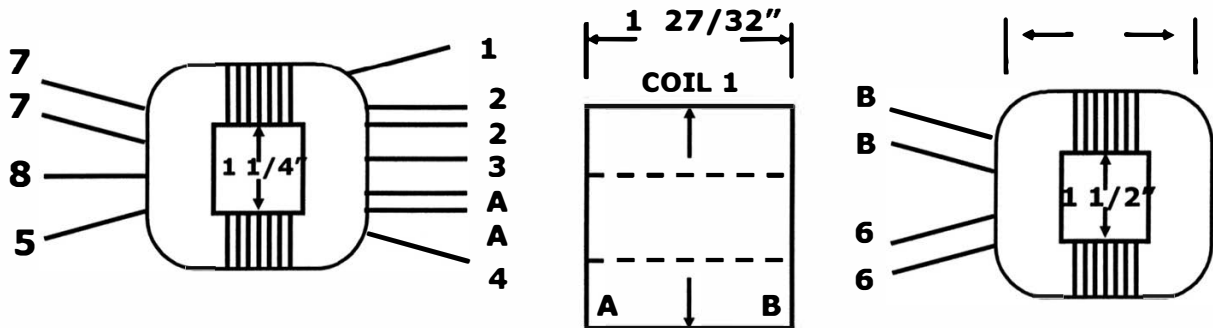
PAGE 1 OF 5 PAGES

SPEC NO. LINE TO VOICE COIL

ENGINEER. RGW DATE 6/20/89

TYPE AUDIO  
32W, 16W, 8W TO 4, 8, 16 OHMS

<b>WINDOW</b>	<b>5/8" X 1 7/8"</b>
<b>COIL BUILD</b>	<b>70 % NET GROSS</b>
<b>TUBE (NET GROSS)</b>	<b>1 1/4" X 1 1/2" X .040 K</b>
<b>OVER TUBE</b>	
<b>DENSITY</b>	<b>15 KG</b>
<b>FREQUENCY</b>	<b>30 HZ</b>
<b>AREA</b>	<b>1.725 IN<sup>2</sup></b>
<b>AT</b>	<b>70.7 VOLTS</b>
<b>TERMINALS</b>	



**HOLD ALL MARGINS TO 1/8"**  
**A's, B's, 2's & 7's CONNECT TOGETHER**

WINDING	1	2	3	4	5	6	7
WIRE SIZE	#26	#16	#16	#16	#16	#26	#26
TOTAL TURNS	318	26	26	26	26	159	159
TAPS	159	--	--	--	--	--	--
WINDING LENGTH	1 19/32"	1 19/32"	1 19/32"	1 19/32"	1 19/32"	1 19/32"	1 19/32"
MARGIN	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"
URNS PER LAYER	80	26	26	26	26	80	80
% FILL	86%	86%	86%	86%	86%	86%	86%
NO. OF LAYERS	4	1	1	1	1	2	2
LAYER INSULATION	.003K	--	--	--	--	.003K	.003K
WRAPPER	1L - .010K	1L - .010K	1L - .010K	1L - .010K	1L - .010K	1L - .010K	1L - .010K
TERM COIL	2-3-A	7-B	5-6	6-7	B-8	A-4	1-2
START AT							

**ROBERT G. WOLPERT**  
*TRANSFORMER DESIGN SERVICES*

**MATERIAL SHEET**

PAGE  2  OF  5  PAGES

SPEC NO.  **LINE TO VOICE COIL**

	PART NO.	AMT.	TO PRICE	TO PRICE	TO PRICE
CORE	<b>EI- 1 1/4"</b>	<b>3.75#</b>			
	<b>29M6</b>				
COPPER					
<b>#26 MAGNET WIRE</b>		<b>0.3#</b>			
<b>#16 MAGNET WIRE</b>		<b>0.5#</b>			
CAN					
LID-T					
LID-B					
TERMINALS					
TUBE	<b>1 1/4" x 1 1/2" x .040</b>	<b>1</b>			
	<b>x 1 27/32" LONG</b>				
TERM BOARD					
LUG PANEL					
BKT	<b>1 1/4" HORIZ. "L"</b>	<b>4</b>			
BOLTS	<b>#8-32 X 2" LONG</b>	<b>4</b>			
NUTS	<b>#8-32</b>	<b>4</b>			
WASHERS	<b>#8 STEEL</b>	<b>8</b>			
WASHERS	<b>#8 FIBER</b>	<b>4</b>			
LEADS	<b>#20 SLW x 10" LONG</b>				
<b>#1</b>	<b>BLACK</b>	<b>1</b>			
<b>#2</b>	<b>BROWN</b>	<b>1</b>			
<b>#3</b>	<b>RED</b>	<b>1</b>			
<b>#4</b>	<b>ORANGE</b>	<b>1</b>			
LEADS	<b>#16 SLW x 10" LONG</b>				
<b>#5</b>	<b>YELLOW</b>	<b>1</b>			
<b>#6</b>	<b>GREEN</b>	<b>1</b>			
<b>#7</b>	<b>BLUE</b>	<b>1</b>			
<b>#8</b>	<b>VIOLET</b>	<b>1</b>			
NOTES:					

**FINISHING**

PAGE   3   OF   5   PAGES

SPEC NO.   **LINE TO VOICE COIL**  

LEADS SIZE	COLOR	LENGTH OUT OF COIL	LEAD #
<b>#20 SLW</b>	<b>BLACK</b>	<b>8"</b>	<b>1</b>
<b>#20 SLW</b>	<b>BROWN</b>	<b>8"</b>	<b>2</b>
<b>#20 SLW</b>	<b>RED</b>	<b>8"</b>	<b>3</b>
<b>#20 SLW</b>	<b>ORANGE</b>	<b>8"</b>	<b>4</b>
<b>#16 SLW</b>	<b>YELLOW</b>		<b>5</b>
<b>#16 SLW</b>	<b>GREEN</b>		<b>6</b>
<b>#16 SLW</b>	<b>BLUE</b>		<b>7</b>
<b>#16 SLW</b>	<b>VIOLET</b>		<b>8</b>

LUGS OR LUG PANEL:

PART #	LEAD #

SPECIAL INSTRUCTIONS:

<b>CONNECT ALL LIKE NUMBERED AND LETTERED LEADS TOGETHER.</b>
<b>BLIND A's &amp; B's</b>

**STACKING & ASSEMBLY**

PAGE 4 OF 5 PAGES

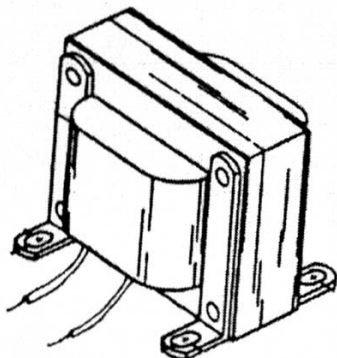
SPEC NO. **LINE TO VOICE COIL**

LAMINATION:

SIZE:	<b>EI- 1 1/4"</b>
GRADE:	<b>29M6</b>
STACK HEIGHT:	<b>1 1/2"</b>
INTERLEAVE:	<b>1 x 1</b>
KEEPERS:	<b>2</b>
CUT OFF E'S:	
GAP SPACER:	
BRUISERS:	
SIZE:	
SHIELD:	
U INSULATORS:	
SIZE:	
BRACKETS - QTY: <b>4</b>	<b>1 1/4" HORIZONTAL "L"</b>
HARDWARE:	
QTY: <b>4</b>	<b>BOLTS 8-32 x 2"</b>
QTY: <b>4</b>	<b>NUTS 8-32</b>
QTY: <b>8</b>	<b>#8 WASHERS, STEEL</b>
QTY: <b>4</b>	<b>#8 WASHERS, FIBER</b>
TO BE REMOVED	<b>NO</b>

SPECIAL INSTRUCTIONS:

<b>VACUUM VARNISH</b>
<b>BRING LEADS OUT BOTTOM</b>



**TEST INSTRUCTIONS**

PAGE 5 OF 5 PAGES

SPEC NO. LINE TO VOICE COIL

**PROCEDURE**

1ST TEST	<b>6</b>
2ND TEST	<b>7</b>
3RD TEST	--
FINAL TEST (AFTER VARNISH)	<b>6, 5</b>

1. NO LOAD VOLTAGE RATIO

APPLY \_\_\_\_\_ V \_\_\_\_\_ HZ TO TERM. \_\_\_\_\_ I<sub>ex</sub> \_\_\_\_\_ MAX.

READ \_\_\_\_\_ V TERM. \_\_\_\_\_  
 \_\_\_\_\_ V TERM. \_\_\_\_\_  
 \_\_\_\_\_ V TERM. \_\_\_\_\_

2. INDUCTANCE TEST

APPLY \_\_\_\_\_ V \_\_\_\_\_ HZ TO TERM. \_\_\_\_\_ & \_\_\_\_\_ A.D.C.

READ "L" \_\_\_\_\_ MIN.

3. INDUCED VOLTAGE TEST

APPLY \_\_\_\_\_ V \_\_\_\_\_ HZ TO TERM. \_\_\_\_\_ FOR \_\_\_\_\_ SEC.

4. MUST MEG. \_\_\_\_\_ MEGOHMS MIN. \_\_\_\_\_ VOLTS D.C.

5. HIPOT

LEAD NO.	TO	VOLTS
<b>1</b>	<b>5</b>	<b>500</b>
<b>1,5</b>	<b>CORE CASE</b>	<b>500</b>

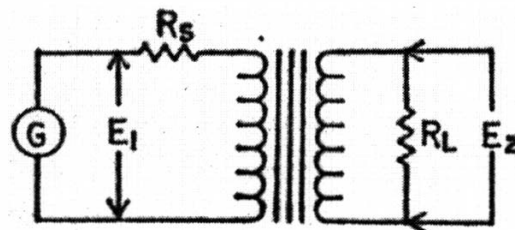
6. CONTINUITY

7. SPECIAL TESTS:

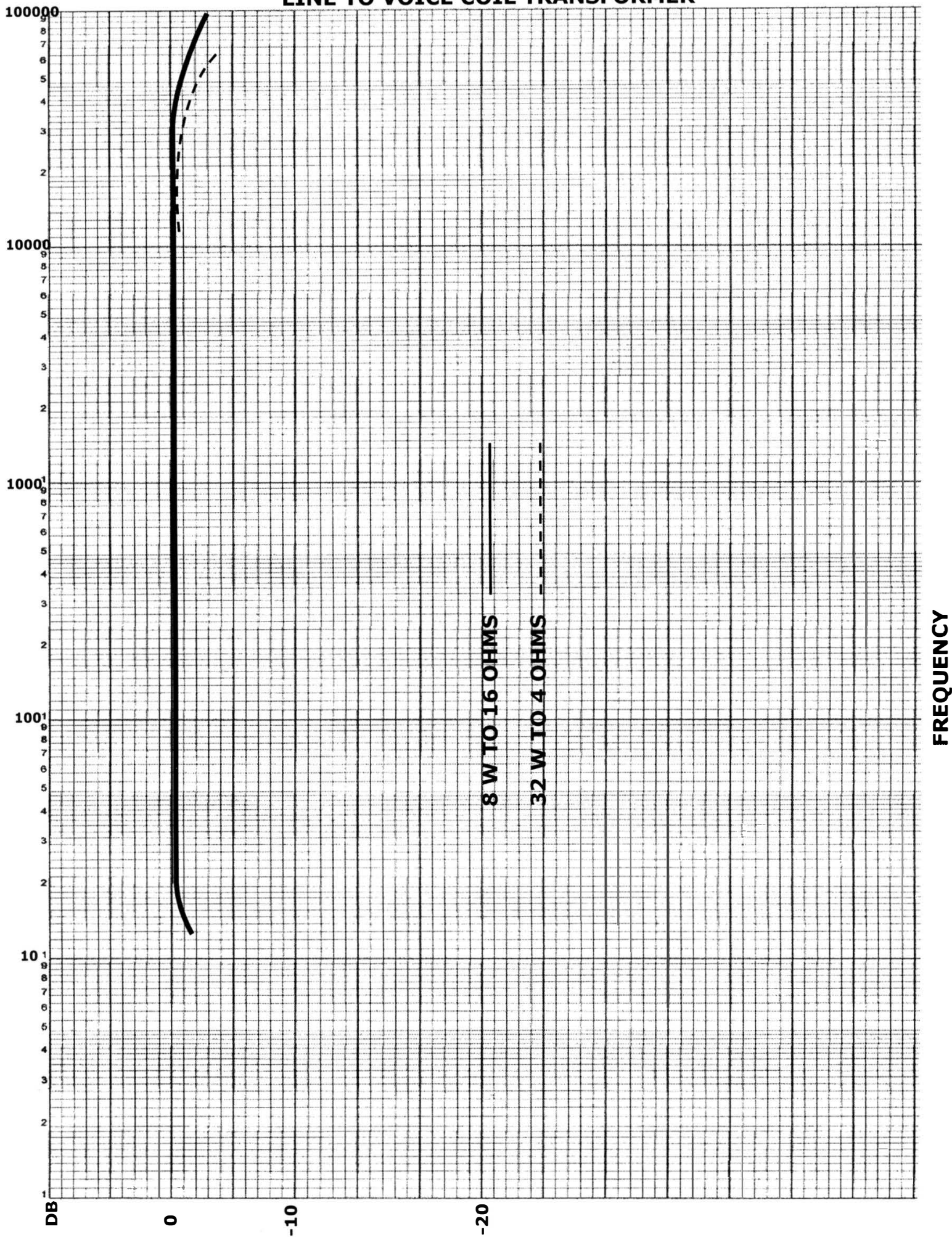
R<sub>S</sub> = 625 ohms

R<sub>L</sub> = 16 ohms

Test across the total primary and secondary.  
 Test results on the following page.



# LINE TO VOICE COIL TRANSFORMER



# **APPENDIX**

## SYMBOLS USED

<b><math>A_c</math></b>	<b>=</b>	<b>Effective area of core in sq. inches.</b>
<b><math>B</math></b>	<b>=</b>	<b>Flux density in Gauss</b>
<b><math>E_1</math></b>	<b>=</b>	<b>Primary voltage</b>
<b><math>E_2</math></b>	<b>=</b>	<b>Secondary voltage</b>
<b><math>F</math></b>	<b>=</b>	<b>Frequency</b>
<b><math>F_1</math></b>	<b>=</b>	<b>Low frequency limit</b>
<b><math>F_2</math></b>	<b>=</b>	<b>High frequency limit</b>
<b><math>H</math></b>	<b>=</b>	<b>Winding build-up</b>
<b><math>I_1</math></b>	<b>=</b>	<b>Primary current in amperes</b>
<b><math>I_2</math></b>	<b>=</b>	<b>Secondary current in amperes</b>
<b><math>K</math></b>	<b>=</b>	<b>Stacking factor</b>
<b><math>L</math></b>	<b>=</b>	<b>Primary open circuit inductance in Henrys</b>
<b><math>L_L</math></b>	<b>=</b>	<b>Leakage inductance in Henrys</b>
<b><math>MLT</math></b>	<b>=</b>	<b>Mean length turn in inches</b>
<b><math>N_1</math></b>	<b>=</b>	<b>Primary turns</b>
<b><math>N_2</math></b>	<b>=</b>	<b>Secondary turns</b>
<b><math>n</math></b>	<b>=</b>	<b>Number of layers</b>
<b><math>R_1</math></b>	<b>=</b>	<b>DC resistance of primary</b>
<b><math>R_2</math></b>	<b>=</b>	<b>DC resistance of secondary</b>
<b><math>R_T</math></b>	<b>=</b>	<b>Total or normalized resistance</b>
<b><math>S</math></b>	<b>=</b>	<b>Number of sections or interleaves</b>
<b><math>T</math></b>	<b>=</b>	<b>Thickness of insulation in inches</b>
<b><math>U_{AC}</math></b>	<b>=</b>	<b>Incremental permeability of core material</b>
<b><math>W</math></b>	<b>=</b>	<b>Power in Watts</b>
<b><math>WL</math></b>	<b>=</b>	<b>Winding length in inches</b>
<b><math>Z_1</math></b>	<b>=</b>	<b>Primary impedance</b>
<b><math>Z_2</math></b>	<b>=</b>	<b>Secondary impedance</b>
<b><math>Z_T</math></b>	<b>=</b>	<b>Total or normalized impedance</b>

## DB EXPRESSED IN WATTS

<b>DB</b>	<b>MICRO-WATTS</b>	<b>DB</b>	<b>WATTS</b>
-80	0.00001	0.0	0.001
-70	0.0001	1.0	0.0013
-60	0.001	2.0	0.0016
-50	0.01	3.0	0.002
-40	0.1	4.0	0.0025
-30	1.0	5.0	0.0032
-20	10.0	6.0	0.004
-19	12.26	7.0	0.005
-18	15.9	8.0	0.0063
-17	20.0	9.0	0.0079
-16	25.1	10.0	0.01
-15	31.6	11.0	0.0126
-14	39.8	12.0	0.0159
-13	50.1	13.0	0.02
-12	63.1	14.0	0.025
-11	79.4	15.0	0.0316
-10	100.0	16.0	0.0398
- 9	126.0	17.0	0.050
- 8	159.0	18.0	0.063
- 7	200.0	19.0	0.079
- 6	251.0	20.0	0.10
- 5	316.0	30.0	1.0
- 4	398.0	40.0	10.0
- 3	501.0	50.0	100.0
- 2	631.0	60.0	1000.0
- 1	794.0	70.0	10000.0
- 0	1000.0	80.0	100000.0

## WIRE TABLE

SIZE	OHMS/ 1000"	INSUL	MARGIN	CM AREA	DIA	URNS/ IN	OHMS/LB
42	139.00	.0007	1/16	6.25	.0028	304.0	84648.0
41	110.25	.0007	1/16	7.8	.0032	267.0	54045.0
40	87.42	.0007	1/16	9.9	.0036	239.0	35610.0
39	69.32	.0007	1/16	12.5	.0040	215.0	22047.0
38	54.97	.001	1/16	15.7	.0045	192.3	12887.0
37	43.59	.001	3/32	19.8	.0051	170.4	8077.0
36	34.56	.001	3/32	25.0	.0056	155.5	5248.0
35	27.42	.001	3/32	31.52	.0062	142.0	3375.0
34	21.74	.001	3/32	39.75	.0070	125.6	2106.0
33	17.24	.0015	3/32	50.13	.0079	110.4	1305.0
32	13.67	.0015	3/32	63.2	.0089	99.0	810.0
31	10.84	.0015	3/32	79.7	.0099	88.9	530.0
30	8.60	.0015	3/32	100.5	.0110	81.0	333.4
29	6.82	.0015	1/8	126.7	.0123	72.5	204.6
28	5.41	.0015	1/8	159.8	.0137	63.0	132.5
27	4.29	.002	1/8	201.3	.0154	57.6	82.5
26	3.40	.002	1/8	254.1	.0171	52.0	52.7
25	2.70	.002	1/8	320.4	.0192	45.9	32.7
24	2.14	.002	1/8	404.0	.0215	41.9	20.7
23	1.70	.003	1/8	509.5	.0240	37.4	12.9
22	1.345	.003	1/8	642.4	.0268	33.6	8.22
21	1.067	.003	1/8	810.1	.0301	30.3	5.12
20	.8458	.005	1/8	1022.0	.0336	26.7	3.23
19	.6709	.005	1/8	1288.0	.0376	24.3	2.04
18	.5320	.007	1/8	1624.0	.0421	21.7	1.29
17	.4220	.007	1/8	2045.0	.0471	19.3	.805
16	.3346	.010	1/4	2533.0	.0527	17.6	.5101
15	.2653	.010	1/4	3257.0	.0590	15.9	.3193
14	.2104	.010	1/4	4107.0	.0661	14.2	.2016
13	.1669	.010	1/4	5778.0	.0741	12.8	.1258
12	.1323	.010	1/4	6530.0	.0829	11.5	.0794
11	.1050	.010	1/4	8234.0	.0929	10.2	.0500
10	.0833	.010	1/4	10380.0	.1042	9.5	.0315
9	.0660	.010	1/4	13090.0	.1168	8.2	.0198
8	.0524	.010	1/4	16510.0	.1310	7.2	.0125

### LAMINATION TABLE

SIZE	STACK HT	VA	AREA	WINDOW	WEIGHT LBS.
EI-187	3/16	0.5	.035	3/16 x 7/16	.015
EE-24-25	1/4	1.0	.0625	1/4 x 1/2	.034
EI-3/8	3/8	3.0	.1406	5/16 x 3/4	.108
EI-5/8	5/8	7.0	.390	5/16 x 15/16	.392
EI-3/4	3/4	14.0	.5625	3/8 x 1 1/8	.678
EI-3/4	1.0	19.0	.75	3/8 x 1 1/8	.904
EI-7/8	7/8	30.0	.765	7/16 x 1 5/16	1.05
EI-7/8	1.0	32.0	.875	7/16 x 1 5/16	1.20
EI-1	1.0	45.0	1.00	1/2 x 1 1/2	1.55
EI-1	1 1/4	50.0	1.25	1/2 x 1 1/2	1.94
EI-1 1/8	1 1/8	65.0	1.265	9/16 x 1 11/16	2.24
EI-1 1/4	1 1/4	90.0	1.5625	5/8 x 1 7/8	3.08
EI-1 3/8	1 3/8	125.0	1.89	11/16 x 2 1/16	4.17
EI-1 1/2	1 1/2	160.0	2.25	3/4 x 2 1/4	5.35
EI-1 3/8	1 3/4	160.0	2.40	11/16 x 2 1/16	5.31
EI-1 1/2	2 1/2	300.0	3.75	3/4 x 2 1/4	8.91
EI-1 3/4	1 3/4	340.0	3.06	7/8 x 2 5/8	8.61
EI-1 3/4	2.0	400.0	3.50	7/8 x 2 5/8	9.84
EI-1 5/8	2.0	450.0	3.25	1 1/4 x 2 5/8	7.78

Note: Values shown for area and weight must be modified by the stacking factor K.

## TOTAL HARMONIC DISTORTION TABLES

The following tables are the results of testing actual transformers. They should only be used as guidelines for estimating the distortion that can be expected using these three materials at different flux levels.

The hysteresis curves of these materials show that the distortion increases as the flux level approaches the knee of the curve.

<b>FLUX (KG)</b>	<b>50% NICKEL (%)</b>	<b>80% NICKEL (%)</b>	<b>29M6 (%)</b>
1	.01	.012	.03
2	.01	.03	.03
3	.066	.06	.03
4	.10	.18	.03
5	.12	.45	.04
6	.14	1.45	.05
7	.16	1.6	.10
8	.46	2.3	.15
9	.75		.25
10			.30
11			.36
12			.41
13			.66
14			.98
15			1.25
16			1.65
17			2.10
18			2.55

The following tables show the turns of each size of wire that can be fitted into different sizes of laminations, both layer wound and bobbin wound.

These tables will be a help in determining the possibility of fit in a design after the turns and wire sizes are chosen and before spending a lot of time calculating the fill.

For example, if the design shown in 5.3, pages 20 and 21, was stopped at the point, page 23, where 390 turns of #23 wire was determined for the primary and the EI-112 Lamination Table in the Appendix is consulted, it can be shown that it will fit,  $390 / 848 \times 100 = 46\%$ . This is less than 1/2 of the available space and is about right for the primary winding in a normal design.

These tables can save a lot of design time that might be necessary in juggling between turns, wire sizes and lamination sizes. However, where extensive interleaving is used, 46% fill for the primary winding might result in a tight fit.

EE-28-29 LAMINATION  
 MAXIMUM TURNS FOR LAYER WOUND COILS

COIL LENGTH = 19/64"  
 WINDOW WIDTH = 1/8"  
 MEAN LENGTH TURN = 0.98"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
22	1l - .003K	6	3	18	.0237
23	1l - .003K	7	3	21	.0345
24	1l - .002K	7	4	28	.0587
25	1l - .002K	8	4	32	.086
26	1l - .002K	9	5	45	.150
27	1l - .002K	11	5	55	.231
28	1l - .002K	12	6	72	.381
29	1l - .0015K	13	7	91	.608
30	1l - .0015K	15	8	120	1.011
31	1l - .001K	17	8	136	1.445
32	1l - .001K	19	9	171	2.292
33	1l - .001K	21	10	210	3.548
34	1l - .001K	24	11	264	5.625
35	1l - .001K	27	13	351	9.431
36	1l - .001K	30	14	420	14.228
37	1l - .001K	34	16	544	23.24
38	1l - .001K	37	18	666	35.87
39	1l - .00075K	43	20	860	58.42
40	1l - .00075K	48	22	1056	90.47
41	1l - .0005K	53	26	1378	148.89
42	1l - .0005K	59	28	1652	225.72
43	1l - .0005K	67	31	2077	356.88
44	1l - .0005K	77	35	2695	588.10
45	1l - .0005K	85	38	3230	883.10
46	1l - .0005K	94	41	3854	1324.10

EI-186 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS

COIL LENGTH = 15/64"  
WINDOW WIDTH = 3/16"  
MEAN LENGTH TURN = 1.39"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
22	1I - .003K	4	5	20	.0374
23	1I - .003K	4.5	5	22	.0512
24	1I - .002K	5	6	30	.0892
25	1I - .002K	6	6	36	.135
26	1I - .002K	6.5	7	45	.212
27	1I - .002K	7	8	56	.334
28	1I - .0015K	8	9	72	.541
29	1I - .0015K	9	10	90	.853
30	1I - .001K	10	12	120	1.435
31	1I - .001K	11	13	143	2.155
32	1I - .001K	12.5	14	175	3.326
33	1I - .001K	14	16	224	5.368
34	1I - .001K	16	18	288	8.71
35	1I - .001K	18	20	360	13.72
36	1I - .001K	20	22	440	21.14
37	1I - .001K	22.5	24	540	32.72
38	1I - .001K	25	27	675	51.57
39	1I - .00075K	29	31	899	86.62
40	1I - .00075K	32	34	1088	132.20
41	1I - .0005K	35	39	1365	209.20
42	1I - .0005K	39	42	1638	317.40
43	1I - .0005K	45	47	2115	515.40
44	1I - .0005K	51	53	2703	836.60
45	1I - .0005K	56	57	3192	1237.90
46	1I - .0005K	63	62	3906	1903.40

**EI-187 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS**

COIL LENGTH = 13/32"  
 WINDOW WIDTH = 3/16"  
 MEAN LENGTH TURN = 1.39"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
22	1l - .0025K	9	5	45	.0841
23	1l - .003K	10	5	50	.1165
24	1l - .002K	11.5	6	69	.2052
25	1l - .002K	13	6	78	.2925
26	1l - .002K	14.5	7	101	.4774
27	1l - .002K	16	8	128	.7631
28	1l - .0015K	18	9	162	1.218
29	1l - .0015K	20	10	200	1.895
30	1l - .001K	23	12	276	3.30
31	1l - .001K	25.5	13	331	5.00
32	1l - .001K	28	14	392	7.45
33	1l - .001K	31.5	16	504	12.08
34	1l - .001K	36	18	648	19.58
35	1l - .001K	40.5	20	810	30.87
36	1l - .001K	45	21	945	45.41
37	1l - .001K	50.5	24	1212	73.44
38	1l - .00075K	56	27	1512	115.50
39	1l - .00075K	65	31	2015	194.20
40	1l - .00075K	73	34	2482	301.60
41	1l - .00075K	80	39	3120	478.00
42	1l - .00075K	88	42	3696	716.30
43	1l - .00075K	101	47	4747	1157.00
44	1l - .0005K	115	53	6095	1886.50
45	1l - .0005K	127	57	7239	2807.40
46	1l - .0005K	141	62	8742	4260.00

EE-24-25 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS

COIL LENGTH = 15/32"  
WINDOW WIDTH = 1/4"  
MEAN LENGTH TURN = 1.87"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
22	1I - .003K	11	6	66	.1660
23	1I - .003K	13	7	91	.2887
24	1I - .002K	14	8	112	.4480
25	1I - .002K	16	8	128	.6422
26	1I - .002K	18	9	162	1.03
27	1I - .002K	20	10	200	1.602
28	1I - .0015K	22	12	264	2.67
29	1I - .0015K	25	13	325	4.143
30	1I - .001K	28	15	420	6.753
31	1I - .001K	31	17	527	10.68
32	1I - .001K	34	18	612	15.64
33	1I - .001K	39	20	780	25.14
34	1I - .001K	44	23	1012	41.14
35	1I - .001K	50	25	1250	64.10
36	1I - .001K	55	28	1540	99.52
37	1I - .001K	62	30	1860	151.60
38	1I - .00075K	69	35	2415	248.20
39	1I - .00075K	80	39	3120	404.30
40	1I - .00075K	89	43	3827	625.50
41	1I - .00075K	98	50	4900	1010.00
42	1I - .0005K	108	54	5832	1520.00
43	1I - .0005K	123	61	7503	2460.00
44	1I - .0005K	140	68	9520	3963.00
45	1I - .0005K	155	73	11315	5902.00
46	1I - .0005K	172	80	13760	9019.00

EE-26-27 LAMINATION  
 MAXIMUM TURNS FOR LAYER WOUND COILS

COIL LENGTH = 2 1/32"  
 WINDOW WIDTH = 1/4"  
 MEAN LENGTH TURN = 2.42"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
22	1l - .003K	16	6	96	.3125
23	1l - .003K	18	6	108	.4435
24	1l - .002K	20	7	140	.7250
25	1l - .002K	23	8	184	1.201
26	1l - .002K	26	9	234	1.926
27	1l - .002K	29	10	290	3.01
28	1l - .0015K	33	12	396	5.184
29	1l - .0015K	36	13	468	7.724
30	1l - .001K	40	16	640	12.47
31	1l - .001K	45	16	720	18.89
32	1l - .001K	50	18	900	29.80
33	1l - .001K	56	20	1120	46.74
34	1l - .001K	64	22	1408	58.76
35	1l - .001K	72	25	1800	119.45
36	1l - .001K	80	27	2160	180.70
37	1l - .001K	90	30	2700	284.90
38	1l - .001K	100	34	3400	452.30
39	1l - .00075K	116	38	4408	739.60
40	1l - .00075K	129	42	5418	1093.00
41	1l - .0005K	142	49	6958	1857.00
42	1l - .0005K	157	53	8321	2808.00
43	1l - .0005K	180	59	10620	4507.00
44	1l - .0005K	205	66	13530	7300.00
45	1l - .0005K	226	71	16046	10836.00
46	1l - .0005K	251	78	19578	16613.00

**EI-375 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS**

COIL LENGTH = 1/2"  
WINDOW WIDTH = 3/4"  
MEAN LENGTH TURN = 2.75"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
20	1l - .005K	13	6	78	.1810
21	1l - .005K	15	7	105	.3079
22	1l - .003K	16	8	128	.4734
23	1l - .003K	18	9	162	.7558
24	1l - .002K	21	10	210	1.235
25	1l - .002K	23	11	253	1.8767
26	1l - .002K	26	12	312	2.917
27	1l - .002K	29	15	435	5.130
28	1l - .0015K	31	16	496	7.376
29	1l - .0015K	36	17	612	11.476
30	1l - .001K	40	20	800	18.92
31	1l - .001K	44	22	968	28.86
32	1l - .001K	49	24	1176	44.224
33	1l - .001K	55	27	1485	70.41
34	1l - .001K	63	30	1890	113.0
35	1l - .001K	71	34	2414	182.0
36	1l - .001K	78	37	2886	274.33
37	1l - .001K	85	40	3400	407.58
38	1l - .001K	96	44	4224	638.48
39	1l - .00075K	107	51	5457	1040.21
40	1l - .00075K	119	56	6664	1602.0
41	1l - .0005K	133	66	8778	2661.37
42	1l - .0005K	152	74	11248	4300.0

EI-21 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS

COIL LENGTH = 25/32"  
WINDOW WIDTH = 5/16"  
MEAN LENGTH TURN = 3.12"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
20	1l - .003K	15	6	90	.2375
21	1l - .003K	17	7	119	.396
22	1l - .003K	20	8	160	.6714
23	1l - .003K	22	9	198	1.048
24	1l - .002K	24	10	240	1.602
25	1l - .002K	27	11	297	2.50
26	1l - .002K	31	12	372	3.947
27	1l - .002K	34	13	442	5.915
28	1l - .0015K	39	15	585	9.87
29	1l - .0015K	43	17	731	15.55
30	1l - .001K	48	19	912	24.47
31	1l - .001K	54	21	1134	38.36
32	1l - .001K	59	23	1357	58.10
33	1l - .001K	67	26	1742	93.71
34	1l - .001K	76	29	2204	118.60
35	1l - .001K	86	32	2752	235.40
36	1l - .001K	95	35	3325	358.60
37	1l - .001K	107	39	4173	567.60
38	1l - .00075K	119	45	5805	995.50
39	1l - .00075K	127	50	6350	1373.30
40	1l - .00075K	154	55	8470	2310.00
41	1l - .00075K	168	64	10752	3698.50
42	1l - .0005K	187	70	13090	5694.00
43	1l - .0005K	214	78	16692	9131.00
44	1l - .0005K	243	87	21141	14687.00

**EI-625 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS**

COIL LENGTH = 29/32"  
 WINDOW WIDTH = 5/16"  
 MEAN LENGTH TURN = 3.62"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
18	1I - .003K	15	5	75	.145
19	1I - .003K	16	5	80	.194
20	1I - .003K	18	6	108	.330
21	1I - .003K	20	7	140	.541
22	1I - .003K	23	8	184	.896
23	1I - .003K	25	9	225	1.382
24	1I - .002K	31	10	310	2.40
25	1I - .002K	35	11	385	3.76
26	1I - .002K	39	12	468	5.76
27	1I - .002K	43	13	559	8.68
28	1I - .0015K	49	15	735	14.39
29	1I - .0015K	54	17	918	22.66
30	1I - .001K	61	19	1159	36.10
31	1I - .001K	68	21	1428	56.10
32	1I - .001K	75	23	1725	85.40
33	1I - .001K	85	26	2210	137.95
34	1I - .001K	96	29	2784	219.10
35	1I - .001K	108	32	3456	343.00
36	1I - .001K	120	35	4200	525.60
37	1I - .001K	135	39	5265	831.00
38	1I - .00075K	150	45	6750	1343.00
39	1I - .00075K	174	50	8700	2183.00
40	1I - .00075K	194	55	10670	3377.00
41	1I - .0005K	213	64	13632	5441.00
42	1I - .0005K	236	70	16520	8338.00

**EI-75 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS**

COIL LENGTH = 1 1/16"  
WINDOW WIDTH = 3/8"  
MEAN LENGTH TURN = 4.33"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
18	1I - .003K	18	6	108	.249
19	1I - .003K	20	7	140	.513
20	1I - .003K	23	7	161	.590
21	1I - .003K	26	8	208	.960
22	1I - .003K	28	9	252	1.467
23	1I - .003K	32	10	320	2.31
24	1I - .002K	36	12	432	4.00
25	1I - .002K	40	13	520	6.07
26	1I - .002K	46	15	690	10.16
27	1I - .002K	51	16	816	15.15
28	1I - .0015K	57	18	1026	24.00
29	1I - .0015K	63	20	1260	37.20
30	1I - .001K	71	24	1704	63.45
31	1I - .001K	79	26	2054	96.41
32	1I - .001K	87	29	2523	149.38
33	1I - .001K	99	32	3168	236.50
34	1I - .001K	112	35	3920	369.00
35	1I - .001K	126	39	4914	583.30
36	1I - .001K	140	43	6020	901.00
37	1I - .001K	157	47	7379	1396.00
38	1I - .00075K	175	54	9450	2249.00
39	1I - .00075K	203	61	12383	3716.00
40	1I - .00075K	227	67	15209	5756.00
41	1I - .0005K	248	77	19096	9115.00
42	1I - .0005K	275	85	23375	14110.00

**EI-87 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS**

COIL LENGTH = 1 1/4"  
 WINDOW WIDTH = 7/16"  
 MEAN LENGTH TURN = 5.04"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
18	1I - .003K	22	7	154	.386
19	1I - .003K	25	8	200	.6763
20	1I - .003K	28	9	252	1.074
21	1I - .003K	31	10	310	1.666
22	1I - .003K	35	11	385	1.97
23	1I - .003K	39	12	468	3.96
24	1I - .002K	44	14	616	6.64
25	1I - .002K	49	16	784	10.66
26	1I - .002K	55	17	935	16.03
27	1I - .002K	61	19	1159	25.06
28	1I - .0015K	69	22	1518	41.38
29	1I - .0015K	77	24	1848	63.51
30	1I - .001K	86	28	2408	104.40
31	1I - .001K	95	31	2945	160.90
32	1I - .001K	106	34	3604	248.40
33	1I - .001K	120	38	4560	396.30
34	1I - .001K	136	42	5712	615.00
35	1I - .001K	153	47	7191	993.70
36	1I - .001K	170	51	8670	1510.50
37	1I - .001K	191	57	10887	2392.00
38	1I - .00075K	213	65	13845	3835.50
39	1I - .00075K	246	74	18204	6360.00
40	1I - .00075K	275	81	22275	9814.00
41	1I - .0005K	302	93	28086	15606.00
42	1I - .0005K	334	102	34068	23939.00

**EI-100 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS**

COIL LENGTH = 1 7/16"  
 WINDOW WIDTH = 1/2"  
 MEAN LENGTH TURN = 5.71"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
16	1I - .005K	21	6	126	.241
17	1I - .005K	23	7	161	.388
18	1I - .003K	26	8	208	.632
19	1I - .003K	29	9	261	1.00
20	1I - .003K	33	10	330	1.60
21	1I - .003K	37	11	407	2.48
22	1I - .003K	41	13	533	4.10
23	1I - .003K	46	14	644	6.24
24	1I - .002K	52	16	832	10.16
25	1I - .002K	58	18	1044	16.08
26	1I - .002K	65	20	1300	25.24
27	1I - .001K	72	22	1584	38.80
28	1I - .0015K	81	25	2025	62.53
29	1I - .0015K	90	27	2430	94.61
30	1I - .001K	102	32	3264	160.27
31	1I - .001K	113	35	3955	244.80
32	1I - .001K	125	38	4750	370.90
33	1I - .001K	141	43	6063	597.00
34	1I - .001K	159	48	7632	947.40
35	1I - .001K	180	53	9540	1493.40
36	1I - .001K	200	58	11600	2289.40
37	1I - .001K	225	64	14400	3584.00
38	1I - .00075K	250	73	18250	5728.00
39	1I - .00075K	290	83	24070	9526.00
40	1I - .00075K	324	91	29484	14716.00

EI-112 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS

COIL LENGTH = 1 5/8"  
WINDOW WIDTH = 9/16"  
MEAN LENGTH TURN = 6.60"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
16	1I - .005K	24	7	168	.371
17	1I - .005K	27	8	216	.602
18	1I - .003K	30	10	300	.984
19	1I - .003K	34	11	374	1.656
20	1I - .003K	38	12	456	2.55
21	1I - .003K	42.5	13	552	3.89
22	1I - .003K	47.5	15	712	6.32
23	1I - .003K	53	16	848	9.38
24	1I - .002K	59	18	1062	15.00
25	1I - .002K	67	20	1340	23.86
26	1I - .002K	75	23	1725	38.72
27	1I - .002K	83	25	2075	58.74
28	1I - .0015K	94	29	2726	97.30
29	1I - .0015K	104	32	3328	149.78
30	1I - .001K	117	37	4329	245.70
31	1I - .001K	131	41	5371	384.30
32	1I - .001K	144	44	6336	571.90
33	1I - .001K	162	49	7938	903.30
34	1I - .001K	184	55	10120	1452.20
35	1I - .001K	208	61	12688	2296.00
36	1I - .001K	230	67	15410	3515.70
37	1I - .001K	258	74	19092	5493.00
38	1I - .00075K	288	85	24480	8881.00
39	1I - .00075K	333	96	31968	14625.00
40	1I - .00075K	372	105	39060	22535.00

**EI-125 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS**

COIL LENGTH = 1 13/16"  
WINDOW WIDTH = 5/8"  
MEAN LENGTH TURN = 7.21"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
16	1I - .005K	27	8	216	.521
17	1I - .005K	30	9	270	.822
18	1I - .003K	34	10	340	1.304
19	1I - .003K	38	11	418	2.022
20	1I - .003K	43	13	559	3.41
21	1I - .003K	48	14	672	5.17
22	1I - .003K	54	16	864	8.38
23	1I - .003K	60	18	1080	13.21
24	1I - .002K	67	20	1340	20.67
25	1I - .002K	75	22	1650	32.10
26	1I - .002K	85	25	2125	52.02
27	1I - .002K	94	27	2538	78.48
28	1I - .0015K	106	31	3286	128.10
29	1I - .0015K	117	34	3978	193.20
30	1I - .001K	132	40	5280	327.40
31	1I - .001K	147	44	6468	505.60
32	1I - .001K	162	48	7776	766.60
33	1I - .001K	183	54	9882	1228.40
34	1I - .001K	207	60	12420	1946.80
35	1I - .001K	234	67	15678	3099.00
36	1I - .001K	260	73	18980	4730.00
37	1I - .001K	292	80	23360	7341.00
38	1I - .00075K	325	92	29900	11849.00
39	1I - .00075K	376	104	39104	19542.00
40	1I - .00075K	421	114	47994	30248.00

EI-138 LAMINATION  
MAXIMUM TURNS FOR LAYER WOUND COILS

COIL LENGTH = 2"  
WINDOW WIDTH = 11/16"  
MEAN LENGTH TURN = 7.66"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
13	1I - .010K	19	6	114	.146
14	1I - .010K	21	7	147	.24
15	1I - .010K	24	8	192	.39
16	1I - .007K	29	8	232	.60
17	1I - .007K	33	10	330	1.07
18	1I - .007K	37	11	407	1.66
19	1I - .005K	43	12	516	2.65
20	1I - .005K	48	14	672	4.35
21	1I - .005K	54	15	810	6.60
22	1I - .005K	62	18	1116	11.50
23	1I - .005K	69	20	1380	17.90
24	1I - .003	78	23	1794	29.50
25	1I - .003	88	26	2288	47.20
26	1I - .003	98	29	2842	74.00
27	1I - .003	110	32	3520	116.00
28	1I - .0015	123	37	4551	189.00
29	1I - .0015	136	40	5440	287.00
30	1I - .001K	153	44	6732	445.00
31	1I - .001K	172	49	8428	700.00
32	1I - .001K	191	53	10213	1060.00
33	1I - .001K	213	58	12354	1630.00
34	1I - .001K	241	69	16629	2765.00

EI-150 LAMINATION  
 MAXIMUM TURNS FOR LAYER WOUND COILS

COIL LENGTH = 1 7/16"  
 WINDOW WIDTH = 1/2"  
 MEAN LENGTH TURN = 8.4"

Wire Gage	Min. Layer Insulation	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
13	1I - .010K	21	7	147	.21
14	1I - .001K	24	8	192	.34
15	1I - .001K	27	8	216	.48
16	1I - .007K	33	9	297	.84
17	1I - .006K	37	11	407	1.44
18	1I - .007K	41	12	492	2.20
19	1I - .005K	47	13	611	3.45
20	1I - .005K	53	15	795	5.60
21	1I - .005K	59	17	1003	9.00
22	1I - .003K	69	20	1380	15.60
23	1I - .003K	77	22	1694	24.00
24	1I - .002K	86	26	2236	41.00
25	1I - .002K	97	28	2716	63.50
26	1I - .002K	109	32	3488	100.00
27	1I - .002K	121	35	4235	153.00
28	1I - .0015K	136	40	5440	247.00
29	1I - .0015K	151	44	6644	381.00
30	1I - .001K	169	48	8112	583.00
31	1I - .001K	190	54	10260	933.00
32	1I - .001K	215	58	12528	1435.00

**EE-28-29 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = .930"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
20	7	2	14	.0121
21	8	2	16	.0174
22	9	3	27	.0373
23	10	3	30	.0520
24	11	3	33	.0723
25	12	4	48	.1325
26	14	4	56	.196
27	15	5	75	.325
28	17	5	85	.469
29	19	6	114	.955
30	21	7	147	1.286
31	24	8	192	2.117
32	26	8	208	2.841
33	30	10	300	5.20
34	33	11	363	5.69
35	37	12	444	12.35
36	41	14	574	20.80
37	46	15	690	29.73
38	51	17	867	47.00
39	58	20	1160	82.80
40	65	22	1430	111.60
41	73	25	1825	164.80
42	80	28	2240	312.70
43	90	31	2790	450.00
44	102	35	3570	780.00
45	118	41	4838	1369.00
46	123	43	5289	1878.00

**EI-186 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 1.4"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
20	5	4	20	.026
21	6	4	24	.039
22	6	5	30	.062
23	7	5	35	.091
24	8	6	48	.158
25	9	7	63	.262
26	10	7	70	.369
27	11	8	88	.572
28	13	9	117	1.42
29	14	10	140	2.09
30	16	12	192	2.875
31	18	13	234	3.93
32	20	15	300	6.25
33	22	17	374	9.89
34	25	19	475	15.91
35	28	21	588	25.00
36	31	23	713	38.40
37	35	26	910	59.70
38	38	29	1102	91.40
39	44	34	1496	162.10
40	49	38	1862	258.00
41	55	43	2365	402.90
42	61	47	2867	609.00
43	68	53	3604	990.00
44	77	60	4620	1540.00

**EI-187 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 1.35"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
20	10	3	30	.0376
21	11	4	44	.070
22	12	4	48	.0963
23	14	5	70	.176
24	15	5	75	.2382
25	17	6	102	.408
26	19	7	133	.675
27	21	8	168	1.07
28	24	9	216	1.72
29	27	10	270	2.72
30	30	11	330	4.24
31	34	12	408	6.58
32	37	14	518	10.40
33	42	16	672	16.72
34	47	17	799	25.80
35	53	20	1060	43.35
36	58	22	1276	65.40
37	65	25	1625	102.90
38	72	27	2656	155.90
39	83	32	2944	278.00
40	92	35	3220	429.00
41	103	40	4120	673.50
42	114	44	5016	1029.00
43	127	50	6350	1683.00
44	145	57	8265	2413.00
45	167	66	11022	4640.00

**EI-375 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 2.49"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
20	18	6	108	.25
21	20	7	140	.423
22	22	8	176	.646
23	25	9	225	1.043
24	28	10	280	1.642
25	31	12	372	2.18
26	35	13	455	4.48
27	38	15	570	6.68
28	43	17	731	10.86
29	48	18	864	16.00
30	53	21	1113	26.40
31	60	24	1440	43.59
32	66	26	1716	61.30
33	75	29	2175	102.10
34	84	33	2772	165.00
35	94	37	3478	262.00
36	103	41	4223	398.00
37	116	47	5452	636.00
38	128	51	6528	965.00
39	147	59	8673	1672.00
40	163	66	10758	2663.00
41	182	74	13468	4660.00
42	202	83	16766	6330.00
43	226	92	20792	10160.00
44	257	105	26985	15900.00
45	298	122	36356	25230.00

**EE-24-25 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 1.86"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
20	11	5	55	.0946
21	12	6	72	.1618
22	14	6	84	.2308
23	15	7	105	.3624
24	17	8	136	.616
25	19	9	171	.954
26	22	10	220	1.54
27	24	11	264	2.315
28	27	13	351	3.94
29	30	14	420	5.81
30	34	16	544	9.63
31	37	18	666	15.00
32	41	20	820	22.70
33	47	23	1081	37.9
34	52	25	1300	57.85
35	59	28	1652	93.20
36	64	32	2048	144.50
37	72	35	2520	223.00
38	80	39	3120	344.00
39	91	46	4186	604.00
40	102	51	5202	956.00
41	114	57	6498	1573.00
42	126	63	7938	2241.00
43	141	71	10011	3663.00
44	160	81	12960	5870.00
45	186	94	17484	9170.00

**EI-21 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 3.01"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
20	19	6	114	.319
21	21	7	147	.5345
22	24	8	192	.856
23	27	9	243	1.36
24	30	10	300	2.123
25	34	11	374	3.34
26	38	14	532	5.60
27	42	14	588	8.49
28	47	16	752	13.50
29	52	18	936	20.75
30	58	20	1160	33.22
31	66	23	1518	55.53
32	72	25	1800	86.00
33	82	28	2296	130.00
34	91	32	2912	210.00
35	103	36	3708	328.00
36	112	40	4480	512.50
37	126	45	5670	800.00
38	140	50	7000	1250.00
39	160	58	9280	2830.00
40	178	64	11392	3385.00
41	199	72	14328	5240.00
42	220	80	17600	8128.00
43	247	90	22230	13130.00
44	281	102	28662	20430.00
45	325	118	38350	32200.00

**EI-625 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 3.53"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
17	16	5	80	.1189
18	18	5	90	.168
19	20	6	120	.284
20	21	6	126	.4135
21	23	7	161	.656
22	26	8	208	1.085
23	30	9	270	1.773
24	33	10	330	2.743
25	37	11	407	4.265
26	42	13	546	7.25
27	46	14	644	10.52
28	52	16	832	17.50
29	58	18	1044	27.40
30	65	20	1300	43.60
31	73	22	1606	68.7
32	81	25	2025	106.50
33	91	28	2548	169.30
34	101	31	3131	264.50
35	115	35	4025	430.50
36	128	39	4992	670.00
37	143	44	6292	1040.00
38	159	49	7791	1630.00
39	183	56	10248	2830.00
40	204	63	12852	4480.00
41	227	71	16117	6750.00
42	255	79	20145	10800.00

**EI-75 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 4.202"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
16	17	6	102	.1435
17	20	6	120	.213
18	22	7	154	.349
19	25	8	200	.564
20	27	8	216	.8425
21	30	9	270	1.37
22	34	10	340	2.157
23	38	11	418	3.27
24	43	12	516	5.10
25	48	14	672	8.36
26	54	16	864	14.60
27	60	17	1020	20.20
28	67	20	1340	33.60
29	75	22	1650	51.60
30	84	25	2100	84.00
31	95	28	2660	135.80
32	104	31	3224	201.50
33	118	35	4130	327.00
34	132	39	5148	516.50
35	148	44	6512	830.00
36	165	49	8085	1290.00
37	184	54	9936	1959.00
38	205	61	12505	3121.00
39	236	70	16520	5370.00
40	263	78	20514	8510.00

**EI-87 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 5.04"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
16	20	6	120	.202
17	23	7	161	.342
18	25	8	200	.536
19	28	9	252	.852
20	32	10	320	1.36
21	36	11	396	2.13
22	40	12	480	3.25
23	45	14	630	5.39
24	50	16	800	8.63
25	56	17	952	12.94
26	63	20	1260	21.59
27	70	22	1540	33.29
28	79	25	1975	53.83
29	88	27	2376	81.65
30	98	31	3088	131.68
31	109	34	3706	202.50
32	122	38	4626	319.40
33	137	43	5891	512.00
34	155	48	7440	815.20
35	175	55	9625	1329.60
36	193	61	11773	2051.00
37	212	67	14204	3120.00
38	222	76	16872	4673.50
39	271	85	23035	8046.60
40	301	95	28595	12597.00

**EI-100 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 5.57"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
15	22	7	154	.227
16	25	7	175	.326
17	28	8	224	.526
18	31	9	279	.826
19	35	11	385	1.44
20	39	12	468	2.20
21	44	13	572	3.40
22	49	15	735	5.50
23	55	17	935	8.83
24	61	19	1159	13.81
25	69	21	1449	21.77
26	77	24	1848	35.00
27	86	26	2236	53.42
28	96	30	2880	86.75
29	107	33	3531	134.10
30	120	37	4440	212.70
31	133	42	5586	337.30
32	148	46	6808	518.60
33	167	52	8684	834.00
34	189	59	11151	1350.00
35	213	66	14085	2146.80
36	236	74	17464	3362.40
37	260	81	21060	5113.00
38	294	92	27048	8281.00
39	331	103	34093	13163.00
40	368	115	42320	20606.00

**EI-112 LAMINATION  
 MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 6.60"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
13	19	6	114	.126
14	22	7	154	.214
15	24	7	168	.294
16	27	8	216	.477
17	31	10	310	.863
18	34	11	374	1.32
19	38	12	456	2.02
20	43	14	602	3.36
21	48	15	720	5.07
22	54	17	918	8.15
23	61	19	1159	12.97
24	68	21	1428	20.16
25	76	24	1824	32.47
26	85	27	2295	51.51
27	95	30	2850	80.67
28	106	34	3604	128.60
29	119	38	4522	203.50
30	133	42	5586	317.00
31	147	47	6909	494.40
32	164	52	8528	769.70
33	185	59	10915	1242.00
34	209	67	14003	2009.00
35	235	75	17625	3189.00

**EI-125 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 7.21"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
12	19	6	114	.109
13	21	7	147	.177
14	24	8	192	.291
15	27	9	243	.465
16	30	10	300	.723
17	34	11	374	1.138
18	38	12	456	1.75
19	43	14	602	2.91
20	48	15	720	4.39
21	53	17	901	6.93
22	60	19	1140	11.00
23	67	21	1407	17.21
24	75	24	1800	27.76
25	84	27	2268	44.10
26	94	30	2820	69.15
27	105	34	3570	110.40
28	118	38	4484	174.84
29	131	42	5502	270.50
30	147	47	6909	428.40
31	163	53	8639	675.30
32	182	59	10738	1058.60
33	205	66	13530	1682.00
34	231	75	17325	2715.80
35	261	84	21924	4333.80
36	289	94	27166	6770.00

**EI-138 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 7.66"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
11	17	6	102	.082
12	19	7	133	.135
13	21	7	147	.188
14	24	8	192	.310
15	27	9	243	.494
16	30	11	330	.846
17	34	12	408	1.32
18	38	13	494	2.01
19	42	15	630	3.24
20	47	17	799	5.17
21	53	19	1007	8.23
22	59	21	1239	12.76
23	66	24	1584	20.58
24	74	27	2268	37.16
25	83	30	2490	51.45
26	93	34	3162	82.37
27	103	37	3811	125.20
28	116	42	4872	201.80
29	130	47	6110	319.25
30	145	53	7685	506.25
31	161	58	9338	775.50
32	179	65	11635	1218.80
33	202	73	14746	1947.50
34	228	83	18924	3151.60
35	258	94	24252	5093.20
36	285	104	29640	7848.00

**EI-150 LAMINATION  
MAXIMUM TURNS FOR BOBBIN WOUND COILS (85% FILL)**

MEAN LENGTH TURN = 8.40"

Wire Gage	Turns/ Layer	Max. Layers	Max. Turns	Resistance square stack
10	18	6	108	.076
11	20	6	120	.106
12	23	7	161	.179
13	26	8	208	.292
14	29	9	261	.461
15	33	10	330	.735
16	37	12	444	1.25
17	41	13	533	1.89
18	46	15	690	3.08
19	51	17	867	4.89
20	58	19	1102	7.82
21	64	21	1344	12.04
22	72	23	1656	18.70
23	81	26	2106	30.00
24	96	29	2784	50.00
25	101	33	3333	75.52
26	114	37	4218	120.49
27	126	41	5166	186.10
28	142	46	6532	296.70
29	158	52	8216	470.60
30	177	58	10266	741.60
31	197	64	12608	1148.20
32	219	71	15549	1786.00

