Audio Transformer Design Manual

ROBERT G. WOLPERT

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
Transformer Design Services
5200 Irvine Blvd. #107
Irvine, CA. 92720
714-838-6817

CONTENTS

A_C = Effective area of core in sq. inches.

B = Flux density in Gauss.

E_1 = Primary voltage.

E_2 = Secondary voltage.

F = Frequency.

F_1 = Low frequency limit.

F_2 = High frequency limit.

H = Winding build up.

I_1 = Primary current in amperes.

I_2 = Secondary current in amperes.

K = Stacking factor.

L = Primary open circuit inductance in Henrys.

L_L = Leakage inductance in Henrys.

MLT = Mean length turn in inches.

N_1 = Primary turns.

N_2 = Secondary turns.

n = Number of layers.

R_1 = D C resistance of primary.

R_2 = D C resistance of secondary.

R_T = Total or normalized resistance.

S = Number of sections or interleaves.

T = Thickness of insulation in inches.

μ_{AC} = Incremental permeability of core material.

W = Power in Watts.

WL = Winding length in inches.

Z_1 = Primary impedance.

Z_2 = Secondary impedance

Z_T = Total or normalized impedance.

PART I. DESIGN CONSIDERATIONS.

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 catagories. These are input, output, and impedance matching. Actually the only differences between these is 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.
f. Insertion loss.

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 ± 3 DB or ± 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 ± 3 DB or ± 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:

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

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

... approximately 4 times the primary impedance.

The following formulae are used.

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

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

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

Where:

L = primary inductance.

Z = primary impedance.

F = lower frequency desired.

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

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

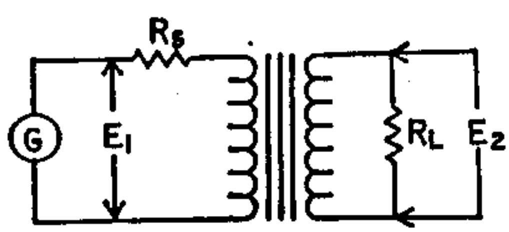


Figure 1.

Rs = the impedance of the primary.

Rl = the impedance of the secondary.

output voltage, E2, 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.

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 which 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 - 60db 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 which 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 vs 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 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 - 3db requirement at the low frequency end, the inductance needed will be:

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

For - 1db 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.

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

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 vs watts is in the appendix, Page 77. 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, page 79.

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:

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

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

Where: K is the stacking factor.
Uac 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.

referring to the tables in the appendix, page 81, (wire sizes and turns vs lamination sizes) the fill can be checked before going any further. In general, the primary wire should use up 1/2 the fill and the secondary the other 1/2.

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 1 part primary, 1 part secondary, 1 part primary etc. This can result in 1:2; 2:3; 3:4 etc interleaving.

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, page 80, 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.

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 which 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.

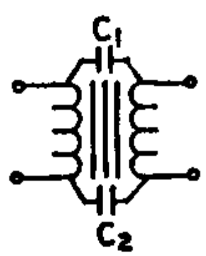


Figure 2.

This coupling is represented by the two capacitors, C1 and C2. If C1 equals C2 then there is no feed through and no imbalance. Of course this is a simplification as the coupling can occur any where within the windings.

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

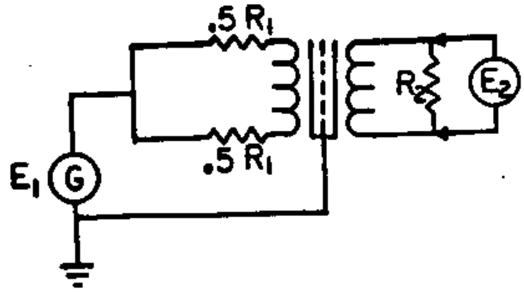


Figure 3.

.5 R1 + .5 R1 = 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. R2 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.

E2 should be a voltmeter with a DB scale. Perfect balance will be when E2 reads zero. When measuring E2, there should be no voltmeter connected to read E1. Short direct wiring should be used to minimize capacitance unbalance. The level of E1 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 effeciency 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 D C 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.

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 % loss will be:

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

Where: R1 = D C resistance of the primary winding.
R2 = D C resistance of the secondary winding.

Figure 4 shows how to measure the insertion loss.

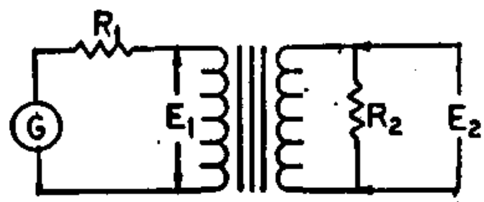


Figure 4.

Where: E1 = Voltage across the primary.
E2 = Load voltage.
R1 = Primary impedance.
R2 = 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.

$$20 \log \frac{E_1 \sqrt{Z_2}}{E_2 \sqrt{Z_1}}$$

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 D C 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.

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

Where: N_p = number of turns.

E = voltage applied.

Ac = effective core area in square inches.

4.44 is a constant.

F = lowest frequency of operation.

B = flux density in lines per sq. in. (Gauss x 6.45 = lines per sq. in.)

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 spiralled 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.

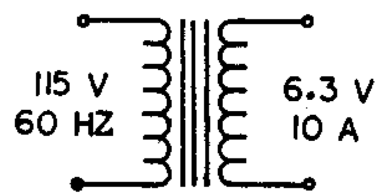
specifications.

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 D C 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 A C. The physical size is not given.

Write down all information known.



Schematic diagram.

Ep = 115 V.
F = 60 HZ.
Es = 6.3 V.
Is = 10 A.

Calculate the total VA.

VA = Es x Is = 6.3 x 10 = 63

Calculate the primary current.

Ip = (VA x 1.11)/Ep = (63 x 1.11)/115 = 0.0608 A.

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 effective core area is 1 1/8 x 1 1/8 = 1.265 sq. in. x K. Assuming a 1 x 1 interleave, it will be 1.265 x .92 = 1.164 sq. in. The .92 is a stacking factor used for a 1 x 1 interleave of the lamination stack. If a butt stack with an air gap is used, for a unit carrying direct current, this will be .95.

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 sq. in.

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.

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

Calculate the secondary turns.

Ns = Np/Ep x 1.05 x Es = 390/115 x 1.05 x 6.3 = 22.4 turns. Change the turns to an even number, or 22 turns.

Choose the wire sizes.

this we will see that #23 wire is the closes with 509.5 cm. (see wire table, page 78).

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 11/16 long. In order to fit, the coil length should be 1/16" shorter or 1 5/8" long. From the wire table, it is seen that the margin for #23 wire should be 1/8" on each end. The margin for #11 wire should be 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 5/8", the winding length for #23 wire will be 1 3/8", and a margin of 1/8" on each end. The turns per layer will be 1 3/8" x 37.4 (turns per inch from table) = 52 turns.

Layers = 390/52 = 7.5 layers. Use 8.
#11 wire winding length = 1/18", margins 1/4" each end. Turns per layer = 1 1/8" x 10.2 = 11 turns.
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.

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.

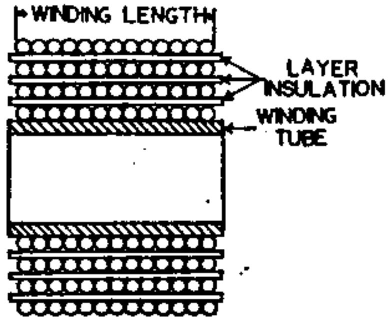


Figure 5.

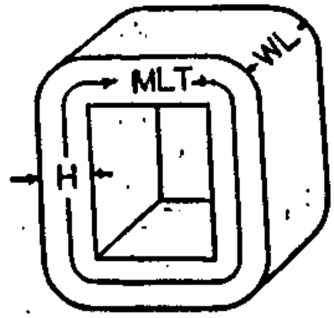


Figure 6.

Calculate the fill of the window. This is done by adding up all the various thicknesses of winding tube, wire diameter, layer insulation, and wrappers. The layer insulation is determined by the thickness needed to support that particular wire size. This is called out in the wire table on page 78.

The winding tube thickness is determined by what is needed to support the coil. Small coils with fine wire need less support than larger coils with heavy wire. This can vary from .020" to .070" or more. A coil for the size used in this example will generally use a winding tube thickness of .030" to .040".

The wrapper is the insulation used between windings. This is determined by the voltage isolation needed and the support needed for the next winding. For this example we will use .010" thick insulation, as this is the value needed to support the #11 wire, and since there are no unusually high voltages involved, it will be used.

add them up, and calculate the percentage of available space in the window that is needed. This lamination has a window width of 9/16" or, in decimals, .5625".

Figure 7 shows the size of the lamination.

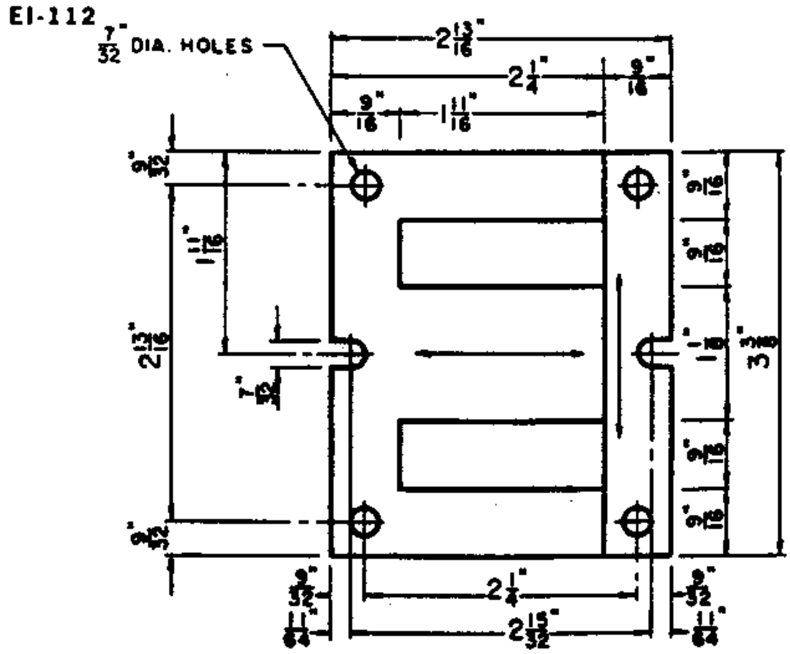


Figure 7.

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

Total fill .4688/.5625 x 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.

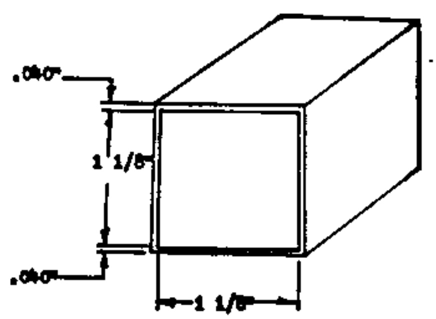


Figure 8.

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" x 2 + 1 3/4" x 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	= .0210	
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 x 4 x 390 x 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.

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

1.4180 x 4 x 390 x 1.6966/1000 = 3.75 x .608 = 2.28 V

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

1.8368 x 4 x 22 x .1050/1000 = .0169 x 10 = .169 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 V. This is the effective input voltage. From the turns ratio, 112.72/390 x 22 = 6.358 V. Subtracting the secondary voltage drop, 6.358 - .169 = 6.189 V. This is lower that 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 D C resistances. Referring to the wire table, the weights are given in Ohms per pound. For example, #23 wire is 12.88 Ohms per pound. Then the weight is 3.75/12.88 = .291 pounds.

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

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.

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 effect 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.

... 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 effected.

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

This example will be for an audio transformer used in a telephone circuit which 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 D C 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 D C resistance = 50 Ohms maximum.
Secondary D C resistance = 65 Ohms maximum.

From P7, the inductance needed is:

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

... of 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, because it is the least expensive, if it will result in the proper inductance and the wire sizes will meet the specification for resistance.

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 table on P77, the power level is seen to be .01 watts. The voltage is:

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

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 appendix, P 80, 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 A D C in the primary and the required resistance will determine the wire sizes to be used. .09 x .7 = .063. (.7 is 700 CM/A). From the wire table, P78, #32 AWG can be used, however the customer has called out the D C resistance and to meet this requirement the turns table, P100, 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 5.3, Calculating The Physical Parameters.

The fill will now be calculated:
The window of the lamination is 5/16" x 3/4".
The winding length of the bobbin is .673". (From manufacturers catalog).
#33 wire turns per layer = 75
layers = 500/75 = 6.66 (use 7).
#34 wire turns per layer =84
layers = 1000/84 = 11.9 (use 12).

7 #33 = .0553

Wrap = .0060

12 #34 = .0840

Wrap = .0060

7 #33 = .0553

Wrap = .0060

.2426/.3125 = .776 x 100 = 78% fill.

The .006 insulation is 2 layers of Mylar tape.

Calculating the D C 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 P18.

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

Then:

$$R_T = R_2 + R_1 = 55.27 + 43\,82 = 99.09$$

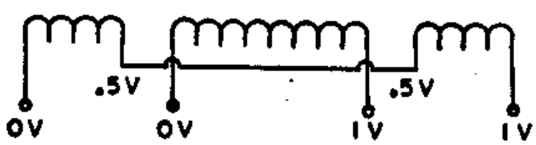
$$IL = \frac{R_T}{Z} = \frac{99.09}{600} \times 100 = 16.5\%$$

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 18)

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 we assume the start of the primary winding to be 0 volts and the finish to be 1 volt, and the secondary will be the same as they have the same number of turns. Then it can be seen that the center of the primary will be .5 volt to 0 volts on the start of the secondary, and also .5 volt to 1 volt to the finish of the primary to both the start and finish of the secondary. This will result in 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 P14. Where:

N = 1000

MLT = 2.54"

S = 2

T = .006"

H = .2692"

WL = .673"

Assigning the proper values:

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

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

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

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.

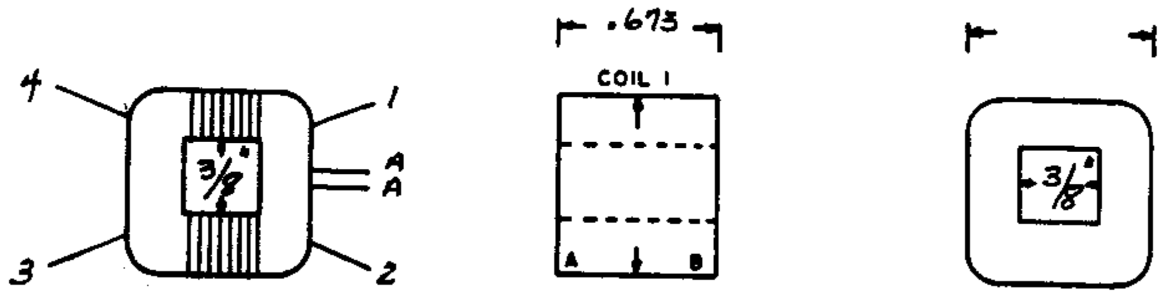
The insertion loss measurements were tested to be .78 DB. The calculated value was approximately .82 DB.

The total harmonic distortion, from the curves is .03%. The measured distortion was approximately .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.

WINDOW 5/16" X 3/4" COIL BUILD 78 % NET GROSS TUBE 3/8 X 3/8 BOBBIN OVER TUBE —	DENSITY 218 GAUSS FREQUENCY 300 HZ AREA 0.129 IN² AT +10 DBM VOLTS TERMINALS	PAGE 1 OF 5 PAGES SPEC. NO. TELEPHONE TRANS. ENGINEER RBW DATE 6/24/89 TYPE AUDIO. 600 OHMS TO 600 OH



CONNECT A's TOGETHER AND BLIND

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

SPEC NO. TELEPHONE TRANSF

MATERIAL

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

NOTES:

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FINISHING

LEADS:

SIZE	COLOR	LENGTH OUT OF COIL	LEAD #
#22 SLW	BLACK	6"	1
✓	BROWN	✓	2
✓	RED	✓	3
✓	GREEN	✓	4

LUGS OR LUG PANEL:

PART #	LEAD#

SPECIAL INSTRUCTIONS:

STACKING & ASSEMBLY

LAMINATION:

SIZE E1-3/8 GRADE 29M6 STACK HEIGHT 3/8" INTERLEAVE 1X1

KEEPERS — CUT OFF E's — GAP SPACER .003 K

BRUISERS — SIZE — SHIELD —

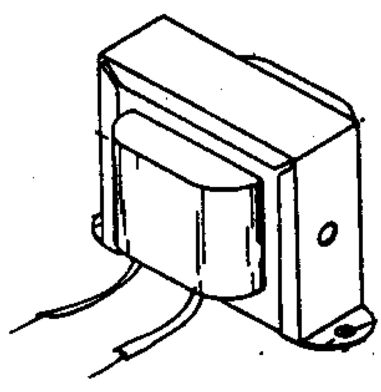
U INSULATORS — SIZE —

BRACKETS 1 3/8X3/8 HORIZONTAL FRAME

HARDWARE ____ ____________ TO BE REMOVED NO

SPECIAL INSTRUCTIONS:

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



1ST TEST

2, 6

2ND TEST

7

3RD TEST (AFTER VARNISH)

5, 6

FINAL TEST

2, 6, 7

1. NO LOAD VOLTAGE RATIO

APPLY________ V ________ HZ TO TERM. ________ Iex ________ MAX.

READ ____________ V TERM. ____________

____________ V TERM. ____________

____________ V TERM. ____________

____________ V TERM. ____________

2. INDUCTANCE TEST

APPLY 1.0 V 1000 HZ TO TERM. 1-2 & .090 A.D.C.

READ "L" .636 H MIN.

3. INDUCED VOLTAGE TEST

APPLY________ V ________ HZ TO TERM. ________ FOR ________ SEC.

4. MUST MEG. ________ MEGOHMS MIN. ________ VOLTS D.C.

5. HIPOT.

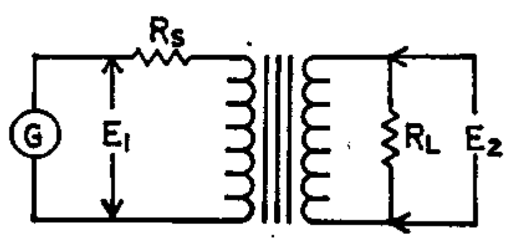
LEAD NO.	TO	VOLTS
1	3	100
1, 3	CORE	100
	CASE	

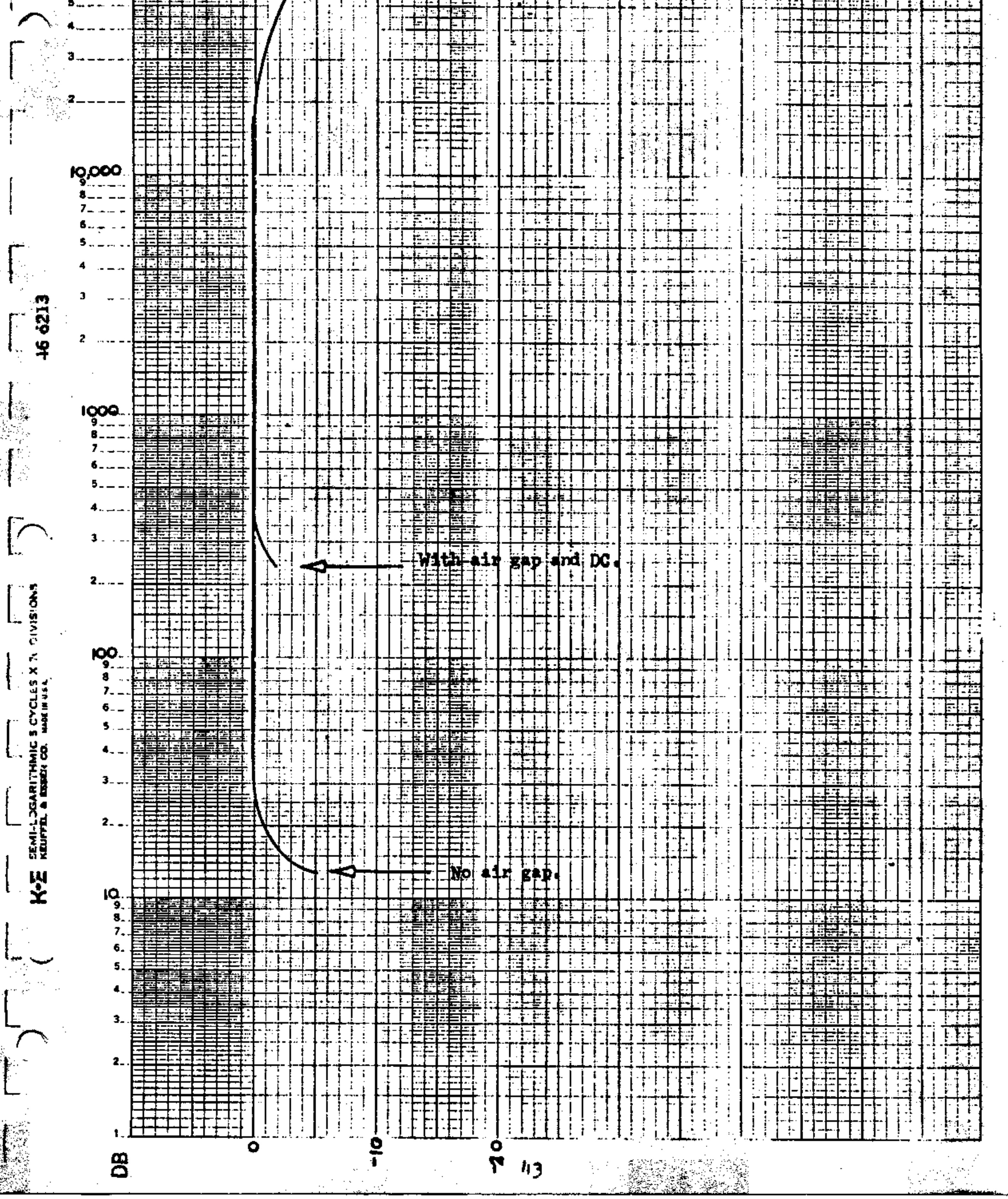
6. CONTINUITY

7. SPECIAL TESTS

R_S = 600 OHMS
R_L = 600 OHMS

FREQUENCY RESPONSE





With air gap and DC.
No air gap.
DB
0
-10
-20
10,000
1000
100
10
K+E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6213

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

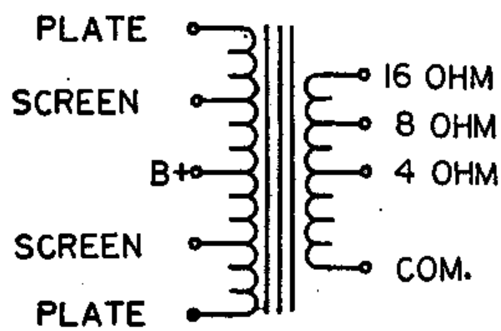
Vacuum tubes have a high plate to plate impedance while transistor impedances are usually quite low. This makes the design of transformers for use with vacuum tubes much more difficult. The impedances can be 10000 Ohms, plate to plate, and above and are therefore a more difficult design in order to obtain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

The circuit diagram is shown.



Circuit diagram.

out by the customer. As explained in P11, the core size will be about the same as for a 300 Watt 60 HZ transformer. Since the windings must be interleaved, it will have to have a slightly larger core. An EI 1.75 lamination with a square stack will be tried.

Area = 1.75 x 1.75 x .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:

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

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:

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

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

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

1300 turns will be used.

In this case the turns needed for the inductance is 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 x .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:

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

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

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

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.

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

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

Secondary currents:

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

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

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

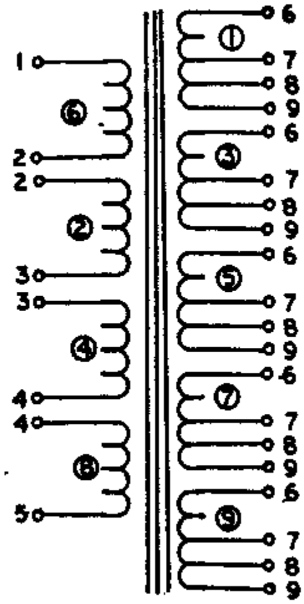
The configuration must be chosen. This is for the most part, a guessing game, using past experience. A 4 to 5 interleave will be tried for this design since the primary can naturally be divided into 4 sections in series and the secondary will be wound in 5 sections that will be put in parallel.

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 x .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 x .750 = .750. So #21 wire with 810 circulary mils will be used.

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 7/8" wide by 2 5/8" long. The coil length will be 1/16" less than the window length or 2 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

Fill continued.

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	=	.0100
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 x .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 x .0154 = 2.002"/2.3125 = 86.5% fill. This is about right and no problem should be had in holding the margins.

example on page 28.

1.7500
.0800
.0903
.0100
1.9303 x 4 x 155 x 1.0666/1000 = 1.276 Ohms.
.0100
.0903
.0050
.0308
.0020
2.0684 x 4 x 260 x 4.2891/1000 = 9.226 Ohms.
.0020
.0308
.0050
.0903
.0100
2.2065 x 4 x 155 x 1.0666/1000 = 1.459 Ohms.
.0100
.0903
.0050
.0462
.0040
2.3620 x 4 x 390 x 4.2891/1000 = 15.80 Ohms.
.0040
.0462
.0050
.0903
.0100
2.5175 x 4 x 155 x 1.0666/1000 = 1.664 Ohms.
.0100
.0903
.0050
.0462
.0040
2.6730

2.6730 x 4 x 390 x 4.2891/1000 = 17.88 Ohms.

.0040

.0462

.0050

.0903

.0100

2.8285 x 4 x 155 x 1.0666/1000 = 1.87 Ohms.

.0100

.0903

.0050

.0308

.0020

2.9666 x 4 x 260 x 4.2891/1000 = 13.23 Ohms.

.0020

.0308

.0050

.0903

.0100

3.1047 x 4 x 155 x 1.0666/1000 = 2.053 Ohms.

The total primary resistance is 9.226 + 15.80 + 17.88 + 13.23 = 56.13 Ohms. The voltage drop in the primary is 56.14 x .283 = 15.88 V.

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

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

This will be for the 16 Ohm winding.

Calculate the output voltage:

(353 - 15.88)/1300 x 155 = 40.195 - .809 = 39.38 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 x .323 = .226 Ohms. Then .226 x 3.53 = .798 V drop. (353 - 15.88)/1300 x 110 = 28.52 - .798 = 27.72 V. Adjusting for 28.28 V = 112 turns.

For the 4 Ohm winding it will be 78/157 x .323 = .160 Ohms. Then .160 x 5 = .802 V drop. (353 - 15.88)/1300 x 78 = 20.22 - .802 = 19.42 V. Adjusting for 20 V = 80 turns.

These adjustments will result in a small change in the D C resistances, but it wont be necessary to go back and make all the new calculations.

Calculate the leakage inductance using the formula from page 14.

N = 1300
MLT = 2.5175 x 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:

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

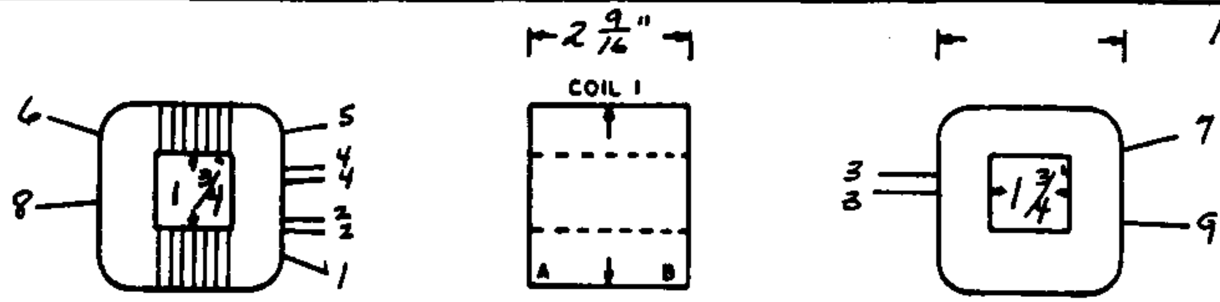
$$F_2 = \frac{2347}{2\pi \times .00393} = 95095$$

This calculates to be O. K.

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

The graph on page 60 shows the frequency response test results.

WINDOW 7/8" x 2 5/8"	DENSITY 17 K.G.	PAGE 1 OF 5 PAGES
COIL BUILD 86 % NET GROSS	FREQUENCY 20 HZ	SPEC. NO.
TUBE 1 3/4" x 1 3/4" x .040	AREA 2.81 IN²	ENGINEER RBW DATE 6/25/8?
OVER TUBE	AT 353 VOLTS	TYPE AUDIO OUTPUT
	TERMINALS	1250 OHMS TO 16,8,4 OHM
		100 WATTS



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 NO	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 1	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 •									

SPEC NO. AUDIO OUTPUT.

MATERIAL

	PART NO.	AMT.	TO PRICE	TO PRICE	TO PRICE
CORE	EI- 1¾				
	29 M6	8.7#			
COPPER					
#21	MAGNET WIRE	1.63#			
#27	MAGNET WIRE	0.68#			
CAN					
LID-T					
LID-B					
TERMINALS					
TUBE	1¾" X 1¾" X .040				
TERM BOARD	X 2 9/16" LONG	1			
LUG PANEL					
BKT 1¾"	HORIZ. "L"	4			
BOLTS	#10 X 2"	4			
NUTS	#10	4			
WASHERS	#10 STEEL	8			
WASHERS	#10 FIBER	4			
LEADS	#20 SLW. X	10" LONG.			
#1	BLACK	1			
#2	BROWN	1			
#3	RED	1			
#4	YELLOW	1			
#5	GREEN	1			
#6	BLUE	1			
#7	ORANGE	1			
#8	WHITE	1			
#9	VIOLET	1			

FINISHING

LEADS:

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

LUGS OR LUG PANEL:

PART #	LEAD#

SPECIAL INSTRUCTIONS:

FINISH ALL LIKE NUMBERED LEADS TOGETHER.

STACKING & ASSEMBLY

LAMINATION:

SIZE *EI-1 3/4* GRADE *29M6* STACK HEIGHT *1 3/4"* INTERLEAVE *1X1*

KEEPERS *2* CUT OFF E's *—* GAP SPACER *—*

BRUISERS *—* SIZE *—* SHIELD *—*

U INSULATORS *—* SIZE *—*

BRACKETS *4* *1 3/4" HORIZONTAL "L"*

HARDWARE *4* *BOLTS #10-32* TO BE REMOVED *NO*

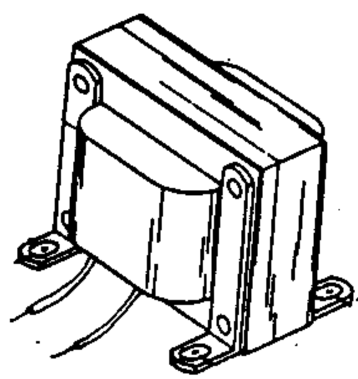
4 *NUTS #10-32*

8 *WASHERS #10 STEEL*

4 *WASHERS #10 FIBER*

SPECIAL INSTRUCTIONS:

VACUUM VARNISH
BRING LEADS OUT BOTTOM



ST TEST
6

2ND TEST
7

3RD TEST
—

FINAL TEST
(AFTER VARNISH)
5, 6

1. NO LOAD VOLTAGE RATIO

APPLY________ V ________ HZ TO TERM. ________ Iex ________ MAX.

READ ________ V TERM. ________

________ 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.

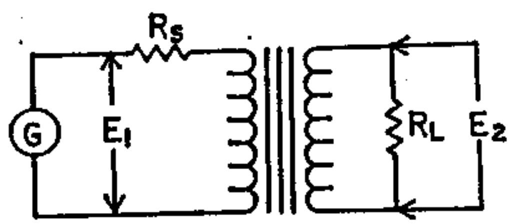
4. MUST MEG. ________ MEGOHMS MIN. ________ VOLTS D.C.

5. HIPOT.

LEAD NO.	TO	VOLTS
1	6	1000
1, 6	CORE	1000
	CASE	

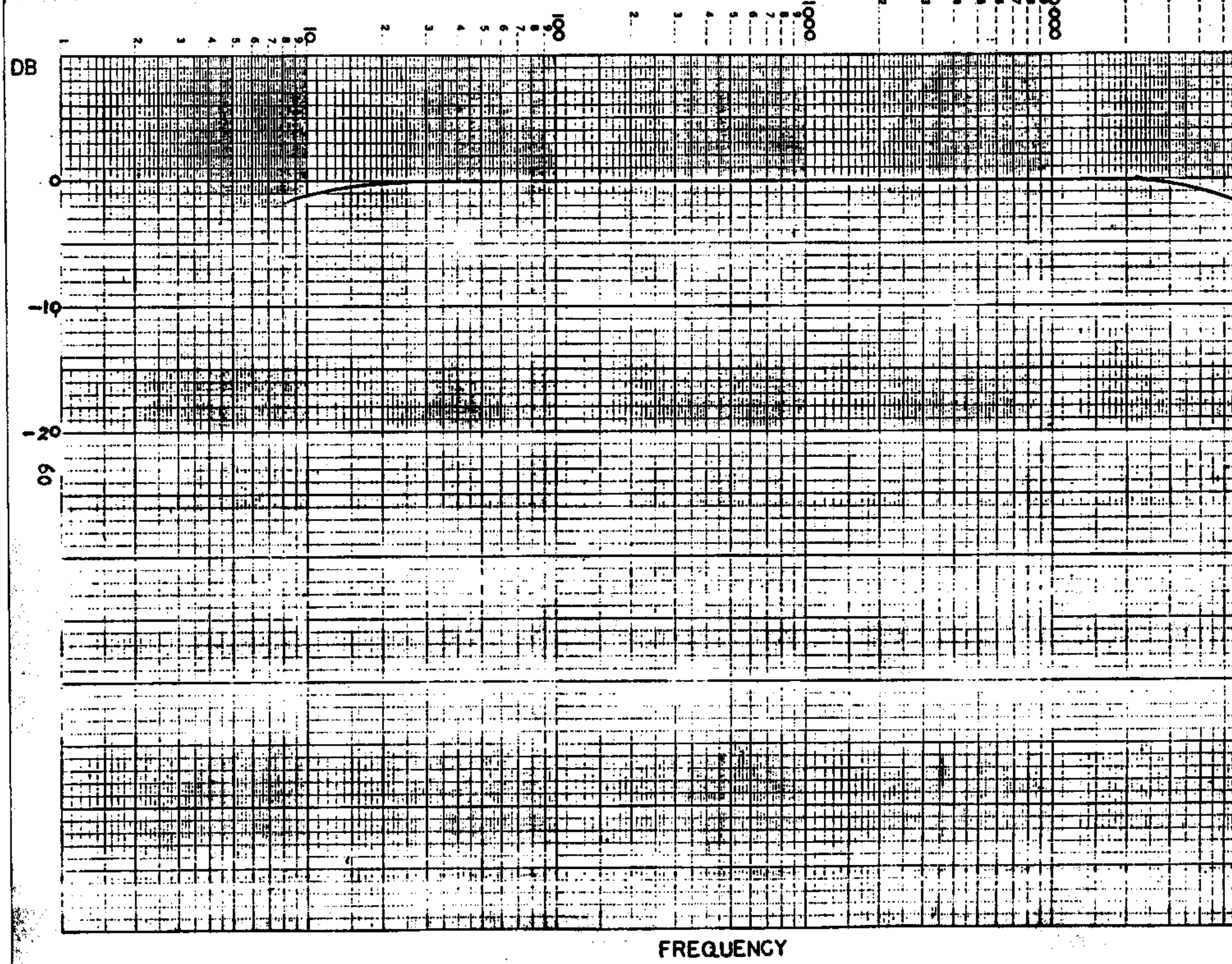
6. CONTINUITY

7. SPECIAL TESTS



R_S = 1250 OHMS
R_L = 16 OHMS

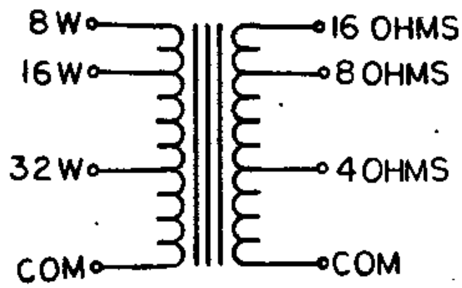
TEST IS MADE ACROSS THE ENTIRE SECONDARY
TEST RESULTS ON THE FOLLOWING PAGE.



DB
0
-10
-20
60
10
100
1000
10,000
FREQUENCY

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 ± 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 table, page 79, EI-1 1/4 X 1 1/4 is good for 90 VA. A 1 1/2 inch stack of this size lamination should be about right as a starting point for 128 VA.

$$Z = \frac{E^2}{W} = \frac{70.7^2}{32} = 156$$

$$\frac{70.7^2}{16} = 312$$

$$\frac{70.7^2}{8} = 625$$

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 manufacturers catalog for this lamination:

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

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

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

Using a premeability of 4000 for M6 lamination.

$$N = \sqrt{\frac{1.655}{.665 \times 1.2 \times .92 \times 4000 \times 10^{-8}}} = 237$$

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

The area of this core is 1 1/4 X 1 1/2 X .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 P 20):

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

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:

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

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

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

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

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

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

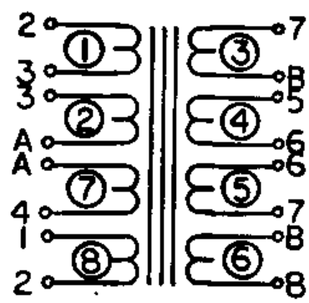
The configuration as shown later will result in a change of turns in both the primary and secondary.

The configuration must now be considered. It is advisable to split the primary so that a 2:1 interleave is acheived. 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.

Watt winding in between. The 4 Watt winding is 52 turns. This is split into 26 + 26. So we now have 159 T pri ; 26 T sec + 26 T sec; 159 T pri. 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.

159 +	159;	26 +	26 +	26 +	26;	159 +	159
2-3	3-A	7-B	5-6	6-7	B-B	A-4	1-2
①	②	③	④	⑤	⑥	⑦	⑧

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 1 3 3 4 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 turms 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 winding will be 477 turns. This is a deviation ot 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.

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

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

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

The highest current in the secondary winding will be the 4 Ohm winding, and at 32 Watts.

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

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

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

#16 AWG wire will be 1.624/2.82 = 575 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 P78).
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 65
Winding tube = .0400
4 L #26 wire = .0684
Layer Insl. = .0090 (3 layers .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 Insl = .0060 K
Wrap = .0100 K

Fill continued.

2 L #26 wire = .0342
Layer Insl. = .0060 K
Wrap .0100 K
.4265/.625 x 100 = 70%.

This fill is O. K. if other parameters are met.

The winding resistances can now be calculated. (See P27).
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 x 4 x 318/1000 x 3.4005 = 6.628 Ohms.
.0090
.0684
.0100
.0527
1.6725 x 4 x 26/1000 x .3346 = .0582 Ohms.
.0527
.0100
.0527
1.7609 x 4 x 26/1000 x .3346 = .0612 Ohms.
.0527
.0100
.0527
1.8763 x 4 x 26/1000 x .3346 = .0652 Ohms.
.0527
.0100
.0527
1.9917 x 4 x 26/1000 x .3346 = .0693 Ohms.
.0527
.0100
.0342

.0030

2.0916 x 4 x 159/1000 x 3.4008 = 4.523 Ohms.

.0030

.0342

.0100

.0342

.0030

2.1760 x 4 x 159/1000 x 3.4008 = 4.706 Ohms.

The mean length turn will be in the center of the windings which will be 1.8763 x 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 P 14 , 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:

S = 2

WL = 1 19/32

T = .010

H = .4265

MLT = 7.5

N = 636 (the total primary turns)

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 P 63, The total primary turns are 636. The total secondary turns are 104.

By adding the resistances, as calculated on pages 67 & 68, the total primary resistance is 6.28 + 4.523 + 4.706 = 15.5 Ohms.
The total secondary resistance is .0582 + .0612 + .0652 + .0693 = .2539

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

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

Referring to P18, 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-A will be 6.628/318 x 159 = 3.314. A-4 is 4.523. The total will be 3.314 + 4.523 = 7.84 Ohms. This is for 318 turns.

.0693 = .1275 Ohms. This is for 52 turns.
The impedance for 32 Watt is 156 Ohms.

Then:

$$R_T = \left(\frac{318}{52}\right)^2 x .1275 + 7.84 = 12.60$$

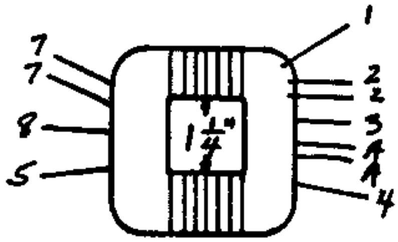
$$IL = \frac{12.60}{156} x 100 = 8.08\%$$

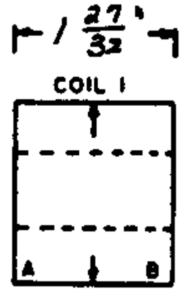
This is also less than 10% for the 0.5 DB maximum.

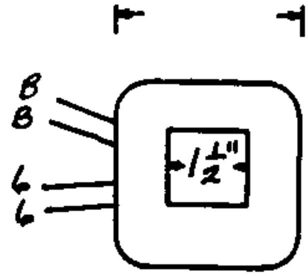
The design is now complete and the manufacturing specifications can be written up, the unit built, and tested.

(714) 838-6817

WINDOW 5/8" X 1 7/8"	DENSITY 15KG	PAGE 1 OF 5 PAGES
COIL BUILD 70 % NET GROSS	FREQUENCY 30 HZ	SPEC NO LINE TO VOICE COIL
TUBE 1 1/4 X 1 1/2 X.040K	AREA 1.725 IN²	ENGINEER RBW DATE 6/20/8?
OVER TUBE	AT 70.7 VOLTS	TYPE AUDIO
	TERMINALS	32W, 16W, 8W, TO 4, 8, 16 OHMS







HOLD ALL MARGINS TO 1/8"

A's, B's, 2's & 7's CONNECT TOGETHER

WINDING NO	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"		
TURNS 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 1	2-3-A	7-B	5-6	6-7	B-8	A-4	1-2		
START AT •									

SPEC NO. LINE TO VOICE COIL

MATERIAL

	PART NO.	AMT.	TO PRICE	TO PRICE	TO PRICE						
	E1-1¼	3.75#									
	29 M6										
	MAGNET WIRE	0.3#									
	MAGNET WIRE	0.5#									
	1¼ X 1½ X .040										
D	X 1 27/32" LONG	1									
"	HORIZONTAL "L"	4									
	#8-32 X 2" LONG	4									
	#8-32	4									
RS	#8 STEEL	8									
S	#8 FIBER	4									
	#20 S.L.W X 10" LONG										
	BLACK	1									
	BROWN	1									
	RED	1									
	ORANGE	1									
	#16 S.L.W X 10" LONG										
5	YELLOW	1									
6	GREEN	1									
7	BLUE	1									
8	VIOLET	1									

FINISHING

LEADS:

SIZE	COLOR	LENGTH OUT OF COIL	LEAD #
#20 SLW	BLACK	8'	1
✓	BROWN	✓	2
✓	RED	✓	3
✓	ORANGE	✓	4
#16 SLW	YELLOW		5
✓	GREEN		6
✓	BLUE		7
✓	VIOLET		8

LUGS OR LUG PANEL:

PART #	LEAD#

SPECIAL INSTRUCTIONS:

CONNECT ALL LIKE NUMBERED AND LETTERED LEADS TOGETHER.

BLIND A's AND B's.

STACKING & ASSEMBLY

LAMINATION:

SIZE E1-1¼ GRADE 29M6 STACK HEIGHT 1½" INTERLEAVE 1X1

KEEPERS 2 CUT OFF E's — GAP SPACER —

BRUISERS — SIZE — SHIELD —

U INSULATORS — SIZE —

BRACKETS 4 1¼" HORIZONTAL "L"

HARDWARE 4 BOLTS 8-32X2" TO BE REMOVED NO

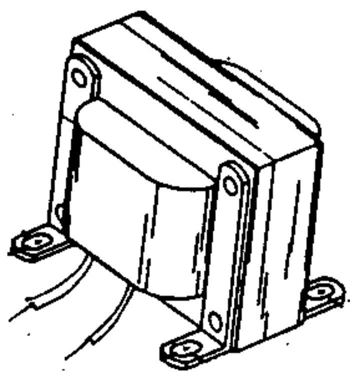
4 NUTS 8-32

8 #8 WASHERS, STEEL

4 #8 WASHERS, FIBER

SPECIAL INSTRUCTIONS:

VACUUM VARNISH
LEADS OUT BOTTOM.



1ST TEST
6

2ND TEST
7

3RD TEST

FINAL TEST
(AFTER VARNISH)
6, 5

1. NO LOAD VOLTAGE RATIO

APPLY ________ V ________ HZ TO TERM. ________ Iex ________ MAX.

READ ________ V TERM. ________

________ 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.

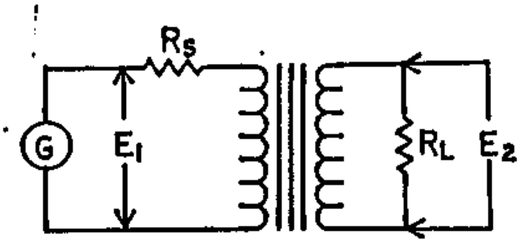
4. MUST MEG. ________ MEGOHMS MIN. ________ VOLTS D.C.

5. HIPOT.

LEAD NO.	TO	VOLTS
1	5	500
1, 5	CORE	500
	CASE	

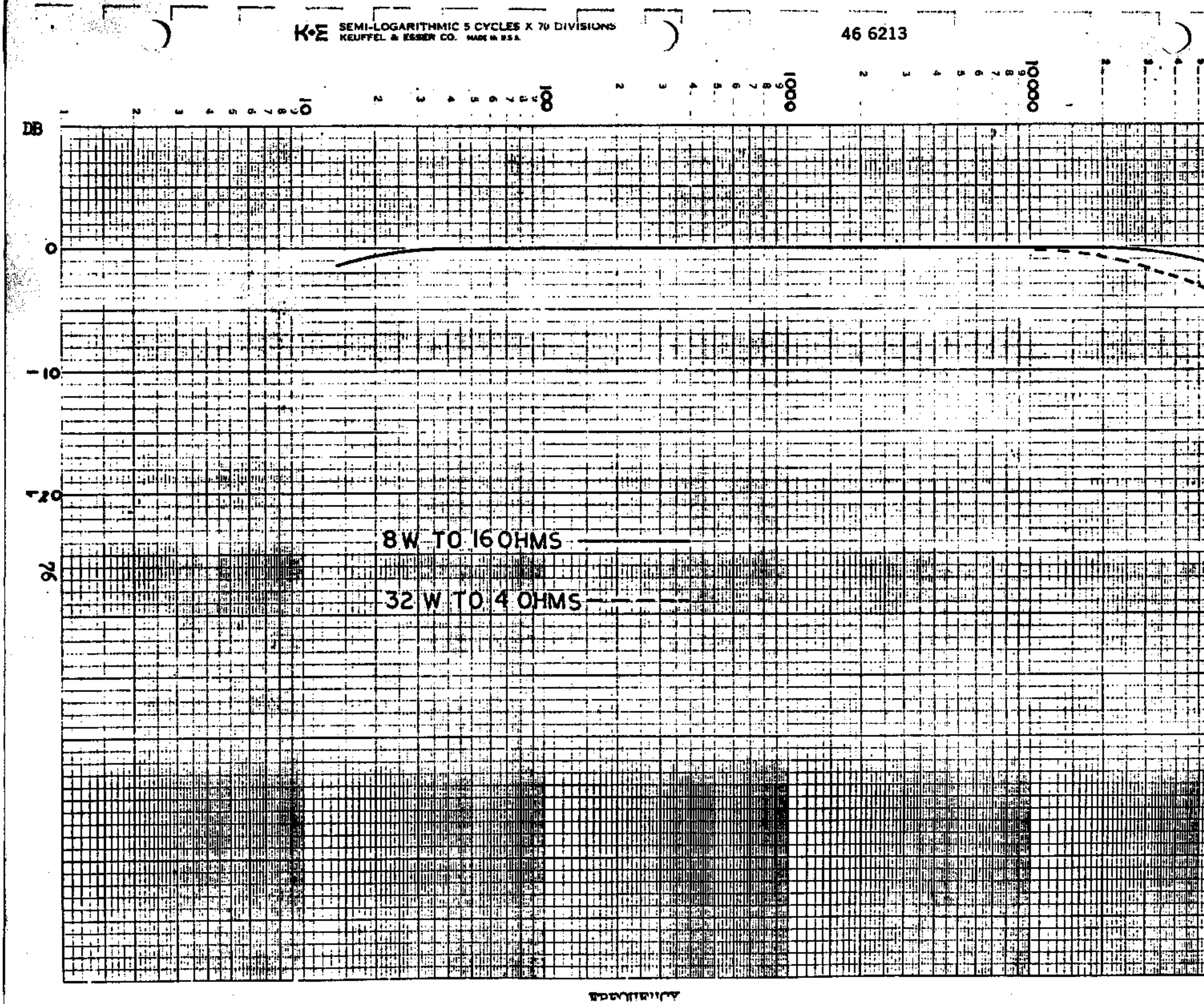
6. CONTINUITY

7. SPECIAL TESTS



R_S = 625 OHMS
R_L = 16 OHMS

TEST ACROSS THE TOTAL PRIMARY AND SECONDARY
TEST RESULTS ON FOLLOWING PAGE


K+E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6213
10
100
1000
10000
DB
0
-10
-20
76
8 W TO 16 OHMS
32 W TO 4 OHMS

DB EXPRESSED IN WATTS.

DB	MICRO-WATTS	DB	WATTS
-80	0.00001	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

SIZE	OHMS/1000"	INSUL	MARGIN	CM AREA	DIA	TURNS/IN	OHMS/LB
42	139.0	.0007	1/16	6.25	.0028	304	84648
41	110.25	.0007	1/16	7.8	.0032	267	54045
40	87.42	.0007	1/16	9.9	.0036	239	35610
39	69.32	.0007	1/16	12.5	.0040	215	22047
38	54.97	.001	1/16	15.7	.0045	192.3	12887
37	43.59	.001	3/32	19.8	.0051	170.4	8077
36	34.56	.001	3/32	25.0	.0056	155.5	5248
35	27.42	.001	3/32	31.52	.0062	142	3375
34	21.74	.001	3/32	39.75	.0070	125.6	2106
33	17.24	.0015	3/32	50.13	.0079	110.4	1305
32	13.67	.0015	3/32	63.2	.0089	99.0	810
31	10.84	.0015	3/32	79.7	.0099	88.9	530
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

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.

The following tables are the results of testing actual transformers. They should only be used as guide lines 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.

FLUX (KG)	50% NICKEL (%)	80% NICKEL (%)	29M6 (%)
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			2.1
18			2.55

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, page 21, was stopped at the point, page 23, where 390 turns of #23 wire was determined for the primary, and the table of page 93 is consulted, it can be shown that it will fit, 390/848 X 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.

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	11-.003K	6	3	18	.0237
23	11-.003K	7	3	21	.0345
24	11-.002K	7	4	28	.0587
25	11-.002K	8	4	32	.086
26	11-.002K	9	5	45	.150
27	11-.002K	11	5	55	.231
28	11-.0015K	12	6	72	.381
29	11-.0015K	13	7	91	.608
30	11-.001K	15	8	120	1.011
31	11-.001K	17	8	136	1.445
32	11-.001k	19	9	171	2.292
33	11-.001K	21	10	210	3.548
34	11-.001K	24	11	264	5.625
35	11-.001K	27	13	351	9.431
36	11-.001K	30	14	420	14.228
37	11-.001K	34	16	544	23.24
38	11-.001K	37	18	666	35.87
39	11-.00075K	43	20	860	58.42
40	11-.00075K	48	22	1056	90.47
41	11-.0005K	53	26	1378	148.89
42	11-.0005K	59	28	1652	225.72
43	11-.0005K	67	31	2077	356.88
44	11-.0005K	77	35	2695	588.10
45	11-.0005K	85	38	3230	883.1
46	11-.0005K	94	41	3854	1324.1

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	11-.003K	4	5	20	.0374
23	11-.003K	4.5	5	22	.0512
24	11-.002K	5	6	30	.0892
25	11-.002K	6	6	36	.135
26	11-.002K	6.5	7	45	.212
27	11-.002K	7	8	56	.334
28	11-.0015K	8	9	72	.541
29	11-.0015K	9	10	90	.853
30	11-.001K	10	12	120	1.435
31	11-.001K	11	13	143	2.155
32	11-.001K	12.5	14	175	3.326
33	11-.001K	14	16	224	5.368
34	11-.001K	16	18	288	8.71
35	11-.001K	18	20	360	13.72
36	11-.001K	20	22	440	21.14
37	11-.001K	22.5	24	540	32.72
38	11-.001K	25	27	675	51.57
39	11-.00075K	29	31	899	86.62
40	11-.00075K	32	34	1088	132.2
41	11-.0005K	35	39	1365	209.2
42	11-.0005K	39	42	1638	317.4
43	11-.0005K	45	47	2115	515.4
44	11-.0005K	51	53	2703	836.6
45	11-.0005K	56	57	3192	1237.9
46	11-.0005K	63	62	3906	1903.4

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	11-.0025K	9	5	45	.0841
23	11-.003k	10	5	50	.1165
24	11-.002K	11.5	6	69	.2052
25	11-.002K	13	6	78	.2925
26	11-.002K	14.5	7	101	.4774
27	11-.002K	16	8	128	.7631
28	11-.0015K	18	9	162	1.218
29	11-.0015K	20	10	200	1.895
30	11-.001K	23	12	276	3.30
31	11-.001K	25.5	13	331	5.00
32	11-.001K	28	14	392	7.45
33	11-.001K	31.5	16	504	12.08
34	11-.001K	36	18	648	19.58
35	11-.001K	40.5	20	810	30.87
36	11-.001K	45	21	945	45.41
37	11-.001K	50.5	24	1212	73.44
38	11-.00075K	56	27	1512	115.5
39	11-.00075K	65	31	2015	194.2
40	11-.00075K	73	34	2482	301.6
41	11-.00075K	80	39	3120	478.0
42	11-.00075K	88	42	3696	716.3
43	11-.00075K	101	47	4747	1157.0
44	11-.0005K	115	53	6095	1886.5
45	11-.0005K	127	57	7239	2807.4
46	11-.0005K	141	62	8742	4260.0

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	11-.003K	11	6	66	.1660
23	11-.003K	13	7	91	.2887
24	11-.002K	14	8	112	.4480
25	11-.002K	16	8	128	.6422
26	11-.002K	18	9	162	1.03
27	11-.002K	20	10	200	1.602
28	11-.0015K	22	12	264	2.67
29	11-.0015K	25	13	325	4.143
30	11-.001K	28	15	420	6.753
31	11-.001K	31	17	527	10.68
32	11-.001K	34	18	612	15.64
33	11-.001K	39	20	780	25.14
34	11-.001k	44	23	1012	41.14
35	11-.001K	50	25	1250	64.10
36	11-.001K	55	28	1540	99.52
37	11-.001K	62	30	1860	151.6
38	11-.00075K	69	35	2415	248.2
39	11-.00075K	80	39	3120	404.3
40	11-.00075K	89	43	3827	625.5
41	11-.00075K	98	50	4900	1010.0
42	11-.0005K	108	54	5832	1520.0
43	11-.0005K	123	61	7503	2460.0
44	11-.0005K	140	68	9520	3963.0
45	11-.0005K	155	73	11315	5902.0
46	11-.0005K	172	80	13760	9019/0

MAXIMUM TURNS FOR LAYER WOUND COILS.

Coil length = 21/32" Window width = 1/4"

Mean length turn = 2.42"

Wire gage	Min. layer insulation	Turns/layer	Max. layers	Max. turns	Resistance square stack
22	11-.003K	16	6	96	.3125
23	11-.003K	18	6	108	.4435
24	11-.002K	20	7	140	.7250
25	11-.002K	23	8	184	1.201
26	11-.002K	26	9	234	1.926
27	11-.002K	29	10	290	3.01
28	11-.0015K	33	12	396	5.184
29	11-.0015K	36	13	468	7.724
30	11-.001K	40	16	640	12.47
31	11-.001K	45	16	720	18.89
32	11-.001K	50	18	900	29.8
33	11-.001K	56	20	1120	46.74
34	11-.001K	64	22	1408	58.76
35	11-.001K	72	25	1800	119.45
36	11-.001K	80	27	2160	180.7
37	11-.001K	90	30	2700	284.9
38	11-.001K	100	34	3400	452.3
39	11-.00075K	116	38	4408	739.6
40	11-.00075K	129	42	5418	1093.0
41	11-.0005K	142	49	6958	1857.0
42	11-.0005K	157	53	8321	2808.0
43	11-.0005K	180	59	10620	4507.0
44	11-.0005K	205	66	13530	7300.0
45	11-.0005K	226	71	16046	10836
46	11-.0005K	251	78	19578	16613

MAXIMUM TURNS FOR LAYER WOUND COILS.

Coil length = 1/2" Window width = 3/4"

Mean length turn = 2.75".

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

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	11-.003K	15	6	90	.2375
21	11-.003K	17	7	119	.396
22	11-.003K	20	8	160	.6714
23	11-.003K	22	9	198	1.048
24	11-.002K	24	10	240	1.602
25	11-.002K	27	11	297	2.50
26	11-.002K	31	12	372	3.947
27	11-.002K	34	13	442	5.915
28	11-.0015K	39	15	585	9.87
29	11-.0015K	43	17	731	15.55
30	11-.001K	48	19	912	24.47
31	11-.001K	54	21	1134	38.36
32	11-.001K	59	23	1357	58.1
33	11-.001K	67	26	1742	93.71
34	11-.001K	76	29	2204	118.6
35	11-.001K	86	32	2752	235.4
36	11-.001K	95	35	3325	358.6
37	11-.001K	107	39	4173	567.6
38	11-.00075K	119	45	5805	995.5
39	11-.00075K	127	50	6350	1373.3
40	11-.00075K	154	55	8470	2310.
41	11-.00075K	168	64	10752	3698.5
42	11-.0005K	187	70	13090	5694.
43	11-.0005K	214	78	16692	9131.
44	11-.0005K	243	87	21141	14687.

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	11-.003K	15	5	75	.145
19	11-.003K	16	5	80	.194
20	11-.003K	18	6	108	.330
21	11-.003K	20	7	140	.541
22	11-.003K	23	8	184	.896
23	11-.003K	25	9	225	1.382
24	11-.002K	31	10	310	2.40
25	11-.002K	35	11	385	3.76
26	11-.002K	39	12	468	5.76
27	11-.002K	43	13	559	8.68
28	11-.0015K	49	15	735	14.39
29	11-.0015K	54	17	918	22.66
30	11-.001K	61	19	1159	36.1
31	11-.001K	68	21	1428	56.1
32	11-.001K	75	23	1725	85.4
33	11-.001K	85	26	2210	137.95
34	11-.001K	96	29	2784	219.1
35	11-.001K	108	32	3456	343.
36	11-.001K	120	35	4200	525.6
37	11-.001K	135	39	5265	831.
38	11-.00075K	150	45	6750	1343.
39	11-.00075K	174	50	8700	2183.
40	11-.00075K	194	55	10670	3377.
41	11-.0005K	213	64	13632	5441.
42	11-.0005K	236	70	16520	8338.

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	11-.003K	18	6	108	.249
19	11-.003K	20	7	140	.513
20	11-.003K	23	7	161	.590
21	11-.003K	26	8	208	.960
22	11-.003K	28	9	252	1.467
23	11-.003K	32	10	320	2.31
24	11-.002K	36	12	432	4.00
25	11-.002K	40	13	520	6.07
26	11-.002K	46	15	690	10.16
27	11-.002K	51	16	816	15.15
28	11-.0015K	57	18	1026	24.0
29	11-.0015K	63	20	1260	37.2
30	11-.001K	71	24	1704	63.45
31	11-.001K	79	26	2054	96.41
32	11-.001K	87	29	2523	149.38
33	11-.001K	99	32	3168	236.5
34	11-.001K	112	35	3920	369.
35	11-.001K	126	39	4914	583.3
36	11-.001K	140	43	6020	901.
37	11-.001K	157	47	7379	1396.
38	11-.00075K	175	54	9450	2249.
39	11-.00075K	203	61	12383	3716.
40	11-.00075K	227	67	15209	5756.
41	11-.0005K	248	77	19096	9115.
42	11-.0005K	275	85	23375	14110

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	11-.003K	22	7	154	.386
19	11-.003K	25	8	200	.6763
20	11-.003K	28	9	252	1.074
21	11-.003K	31	10	310	1.666
22	11-.003K	35	11	385	1.97
23	11-.003K	39	12	468	3.96
24	11-.002K	44	14	616	6.64
25	11-.002K	49	16	784	10.66
26	11-.002K	55	17	935	16.03
27	11-.002K	61	19	1159	25.06
28	11-.0015K	69	22	1518	41.38
29	11-.0015K	77	24	1848	63.51
30	11-.001K	86	28	2408	104.4
31	11-.001K	95	31	2945	160.9
32	11-.001K	106	34	3604	248.4
33	11-.001K	120	38	4560	396.3
34	11-.001K	136	42	5712	615.
35	11-.001K	153	47	7191	993.7
36	11-.001K	170	51	8670	1510.5
37	11-.001K	191	57	10887	2392.
38	11-.00075K	213	65	13845	3835.5
39	11-.00075K	246	74	18204	6360.
40	11-.00075K	275	81	22275	9814.
41	11-.0005K	302	93	28086	15606.
42	11-.0005K	334	102	34068	23939.

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	11-.005K	21	6	126	.241
17	11-.005K	23	7	161	.388
18	11-.003K	26	8	208	.632
19	11-.003K	29	9	261	1.00
20	11-.003K	33	10	330	1.60
21	11-.003K	37	11	407	2.48
22	11-.003K	41	13	533	4.10
23	11-.003K	46	14	644	6.24
24	11-.002K	52	16	832	10.16
25	11-.002K	58	18	1044	16.08
26	11-.002K	65	20	1300	25.24
27	11-.002K	72	22	1584	38.8
28	11-.0015K	81	25	2025	62.53
29	11-.0015K	90	27	2430	94.61
30	11-.001K	102	32	3264	160.27
31	11-.001K	113	35	3955	244.8
32	11-.001K	125	38	4750	370.9
33	11-.001K	141	43	6063	597.
34	11-.001K	159	48	7632	947.4
35	11-.001K	180	53	9540	1493.4
36	11-.001K	200	58	11600	2289.4
37	11-.001K	225	64	14400	3584.
38	11-.00075K	250	73	18250	5728.
39	11-.00075K	290	83	24070	9526.
40	11-.00075K	324	91	29484	14716

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	11-.005K	24	7	168	.371
17	11-.005K	27	8	216	.602
18	11-.003K	30	10	300	.984
19	11-.003K	34	11	374	1.656
20	11-.003K	38	12	456	2.55
21	11-.003K	42.5	13	552	3.89
22	11-.003K	47.5	15	712	6.32
23	11-.003K	53	16	848	9.38
24	11-.002K	59	18	1062	15.0
25	11-.002K	67	20	1340	23.86
26	11-.002K	75	23	1725	38.72
27	11-.002K	83	25	2075	58.74
28	11-.0015K	94	29	2726	97.3
29	11-.0015K	104	32	3328	149.78
30	11-.001K	117	37	4329	245.7
31	11-.001K	131	41	5371	384.3
32	11-.001K	144	44	6336	571.9
33	11-.001K	162	49	7938	903.3
34	11-.001K	184	55	10120	1452.2
35	11-.001K	208	61	12688	2296.
36	11-.001K	230	67	15410	3515.7
37	11-.001K	258	74	19092	5493.
38	11-.00075K	288	85	24480	8881.
39	11-.00075K	333	96	31968	14625,
40	11-.00075K	372	105	39060	22535.

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	11-.005K	27	8	216	.521
17	11-.005K	30	9	270	.822
18	11-.003K	34	10	340	1.304
19	11-.003K	38	11	418	2.022
20	11-.003K	43	13	559	3.41
21	11-.003K	48	14	672	5.17
22	11-.003K	54	16	864	8.38
23	11-.003K	60	18	1080	13.21
24	11-.002K	67	20	1340	20.67
25	11-.002K	75	22	1650	32.1
26	11-.002K	85	25	2125	52.02
27	11-.002K	94	27	2538	78.48
28	11-.0015K	106	31	3286	128.1
29	11-.0015K	117	34	3978	193.2
30	11-.001K	132	40	5280	327.4
31	11-.001K	147	44	6468	505.6
32	11-.001K	162	48	7776	766.6
33	11-.001K	183	54	9882	1228.4
34	11-.001K	207	60	12420	1946.8
35	11-.001K	234	67	15678	3099.
36	11-.001K	260	73	18980	4730
37	11-.001K	292	80	23360	7341
38	11-.00075K	325	92	29900	11849
39	11-.00075K	376	104	39104	19542
40	11-.00075K	421	114	47994	30248

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	11-.010K	19	6	114	.146
14	11-.010K	21	7	147	.24
15	11-.010K	24	8	192	.39
16	11-.007K	29	8	232	.60
17	11-.007K	33	10	330	1.07
18	11-.007K	37	11	407	1.66
19	11-.005K	43	12	516	2.65
20	11-.005K	48	14	672	4.35
21	11-.005K	54	15	810	6.6
22	11-.005K	62	18	1116	11.5
23	11-.005K	69	20	1380	17.9
24	11-.003K	78	23	1794	29.5
25	11-.003K	88	26	2288	47.2
26	11-.003K	98	29	2842	74.
27	11-.003K	110	32	3520	116.
28	11-.0015K	123	37	4551	189.
29	11-.0015K	136	40	5440	287.
30	11-.001K	153	44	6732	445.
31	11-.001K	172	49	8428	700.
32	11-.001K	191	53	10213	1060.
33	11-.001K	213	58	12354	1630.
34	11-.001K	241	69	16629	2765.

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	11-.010K	21	7	147	.21
14	11-.001K	24	8	192	.34
15	11-.001K	27	8	216	.48
16	11-.007K	33	9	297	.84
17	11-.006K	37	11	407	1.44
18	11-.007K	41	12	492	2.2
19	11-.005K	47	13	611	3.45
20	11-.005K	53	15	795	5.6
21	11-.005K	59	17	1003	9.0
22	11-.003K	69	20	1380	15.6
23	11-.003K	77	22	1694	24.0
24	11-.002K	86	26	2236	41,0
25	11-.002K	97	28	2716	63.5
26	11-.002K	109	32	3488	100
27	11-.002K	121	35	4235	153
28	11-.0015K	136	40	5440	247
29	11-.0015K	151	44	6644	381
30	11-.001K	169	48	8112	583
31	11-.001K	190	54	10260	933
32	11-.001K	215	58	12528	1435

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	.052
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	5.2
34	33	11	363	5.69
35	37	12	444	12.35
36	41	14	574	20.8
37	46	15	690	29.73
38	51	17	867	47.0
39	58	20	1160	82.8
40	65	22	1430	111.6
41	73	25	1825	164.8
42	80	28	2240	312.7
43	90	31	2790	450
44	102	35	3570	780
45	118	41	4838	1369
46	123	43	5289	1878

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.
36	31	23	713	38.4
37	35	26	910	59.7
38	38	29	1102	91.4
39	44	34	1496	162.1
40	49	38	1862	258.
41	55	43	2365	402.9
42	61	47	2867	609.
43	68	53	3604	990.
44	77	60	4620	1540.

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	10.4
33	42	16	672	16.72
34	47	17	799	25.8
35	53	20	1060	43.35
36	58	22	1276	65.4
37	65	25	1625	102.9
38	72	27	2944	155.9
39	83	32	2656	278.
40	92	35	3220	429.
41	103	40	4120	673.5
42	114	44	5016	1029
43	127	50	6350	1683
44	145	57	8265	2413
45	167	66	11022	4640

MAXIMUM TURNS FOR BOBBIN WOUND COIL (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	16.0
30	53	21	1113	26.4
31	60	24	1440	43.59
32	66	26	1716	61.3
33	75	29	2175	102.1
34	84	33	2772	165.0
35	94	37	3478	262
36	103	41	4223	398
37	116	47	5452	636
38	128	51	6528	965
39	147	59	8673	1672
40	163	66	10758	2663
41	182	74	13468	4660
42	202	83	16766	6330
43	226	92	20792	10160
44	257	105	26985	15900
45	298	122	36356	25230

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	15.0
32	41	20	820	22.7
33	47	23	1081	37.9
34	52	25	1300	57.85
35	59	28	1652	93.2
36	64	32	2048	144.5
37	72	35	2520	223
38	80	39	3120	344
39	91	46	4186	604
40	102	51	5202	956
41	114	57	6498	1573
42	126	63	7938	2241
43	141	71	10011	3663
44	160	81	12960	5870
45	186	94	17484	9170

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	5.6
27	42	14	588	8.49
28	47	16	752	13.5
29	52	18	936	20.75
30	58	20	1160	33.22
31	66	23	1518	55.53
32	72	25	1800	86.0
33	82	28	2296	130
34	91	32	2912	210
35	103	36	3708	328
36	112	40	4480	512.5
37	126	45	5670	800
38	140	50	7000	1250
39	160	58	9280	2830
40	178	64	11392	3385
41	199	72	14328	5240
42	220	80	17600	8128
43	247	90	22230	13130
44	281	102	28662	20430
45	325	118	38350	32200

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	17.5
29	58	18	1044	27.4
30	65	20	1300	43.6
31	73	22	1606	68.7
32	81	25	2025	106.5
33	91	28	2548	169.3
34	101	31	3131	264.5
35	115	35	4025	430.5
36	128	39	4992	670.
37	143	44	6292	1040
38	159	49	7791	1630
39	183	56	10248	2830
40	204	63	12852	4480
41	227	71	16117	6750
42	255	79	20145	10800

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	14.6
27	60	17	1020	20.2
28	67	20	1340	33.6
29	75	22	1650	51.6
30	84	25	2100	84
31	95	28	2660	135.8
32	104	31	3224	201.5
33	118	35	4130	327
34	132	39	5148	516.5
35	148	44	6512	830
36	165	49	8085	1290
37	184	54	9936	1959
38	205	61	12505	3121
39	236	70	16520	5370
40	263	78	20514	8510

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	202.5
32	122	38	4626	319.4
33	137	43	5891	512
34	155	48	7440	815.2
35	175	55	9625	1329.6
36	193	61	11773	2051
37	212	67	14204	3120
38	222	76	16872	4673.5
39	271	85	23035	8046.6
40	301	95	28595	12597

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	3.4
22	49	15	735	5.5
23	55	17	935	8.83
24	61	19	1159	13.81
25	69	21	1449	21.77
26	77	24	1848	35
27	86	26	2236	53.42
28	96	30	2880	86.75
29	107	33	3531	134.1
30	120	37	4440	212.7
31	133	42	5586	337.3
32	148	46	6808	518.6
33	167	52	8684	834
34	189	59	11151	1350
35	213	66	14085	2146.8
36	236	74	17464	3362,4
37	260	81	21060	5113
38	294	92	27048	8281
39	331	103	34093	13163
40	368	115	42320	20606

EI 112 LAMINATION

MAXIMUM TURNS FOR BOBBIN WOUND COILS. (85% FILL).

Mean length turn = 6.6"

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	128.6
29	119	38	4522	203.5
30	133	42	5586	317
31	147	47	6909	494.4
32	164	52	8528	769.7
33	185	59	10915	1242
34	209	67	14003	2009
35	235	75	17625	3189

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	11.0
23	67	21	1407	17.21
24	75	24	1800	27.76
25	84	27	2268	44.1
26	94	30	2820	69.15
27	105	34	3570	110.4
28	118	38	4484	174.84
29	131	42	5502	270.5
30	147	27	6909	428.4
31	163	53	8639	675.3
32	182	59	10738	1058.6
33	205	66	13530	1682
34	231	75	17325	2715.8
35	261	84	21924	4333.8
36	289	94	27166	6770