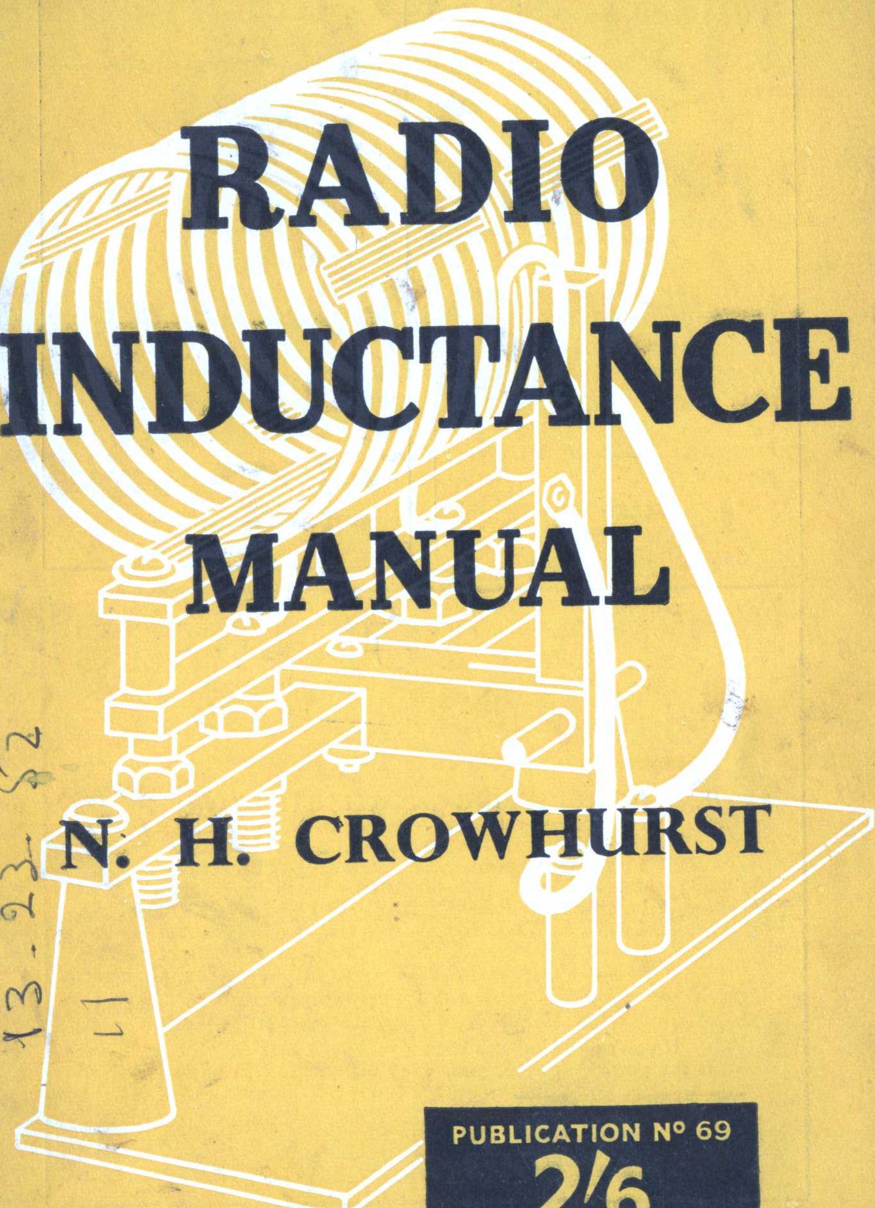
RADIO INDUCTANCE MANUAL



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RADIO INDUCTANCE MANUAL

by

N. H. CROWHURST

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CONTENTS

PREFACE

There is a noticeable lack of literature on the design of iron cored components for use on audio frequencies. Principles are usually outlined somewhat vaguely, making the reader think he has useful information, but on trying to apply it, he is still "lost."

Having obtained the turns ratio, the number of actual turns required is one question usually left unanswered. Even many professional designers use "rule of thumb" methods, basing new designs on old ones by appropriate guess-work, because the usual complete design procedure is tedious. Largely because the "thumbs" are not very good, the modern trend is to avoid the use of iron cored components in audio frequency circuits, on the assumption that such components are inherent sources of distortion.

The author has proved that a well designed component introduces no more distortion than the average valve, and often considerably less by investigating each type of application treated in this book, and determining the best and most economic arrangement in each case.

The presentation adopted first explains the various factors to each problem, and then gives information as to correct designs to meet these factors, arranged in simple tabular form. Finally typical examples are added showing how to derive individual designs by simple "rule of thumb" (a good thumb in this case !). The method adopted in choke design, with DC is more direct than any hitherto published.

It is confidently believed that this book will prove very useful, both to regular designers, and to the "ham" who wants to make his own gear.

London, 1948 *N. H. CROWHURST*

CHAPTER I—CHOKES CARRYING DIRECT CURRENT

Inductance.

Chokes of this type are generally required for one of two purposes: (1) Smoothing, and (2) Coupling. In either case, the inductance necessary is based on the impedance which it will have at a certain frequency. For smoothing, this frequency is that of the ripple to be eliminated in smoothing, and for coupling chokes it is the lowest frequency required to be reproduced.

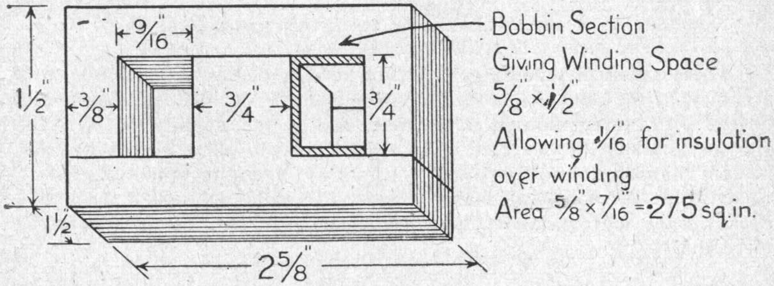


FIG. 1

The reactance of an inductance is given by the formula:—

$$X_L = 2\pi fL,$$

where π is 3.14, f is the frequency and L the inductance in Henries.

For a smoothing circuit, the condenser reactance must also be known, and this is given by the formula:—

$$X_C = \frac{1000000}{2\pi fC}$$

where C is the capacity in Microfarads.

If a smoothing circuit is required to reduce the ripple voltage to 1/40th of that across the reservoir condenser, then the required ratio of reactance of smoothing choke and condenser will be given by

$$\frac{X_C}{X_L} = \frac{1}{40}$$

Assuming an 8 mfd. electrolytic condenser is to be used, then its reactance to a ripple voltage of 100 cycles (the predominant frequency from a 50 cycle full wave rectifier) will be

$$\frac{1000000}{2 \times 3.14 \times 100 \times 8} = 200 \text{ ohms approx.}$$

Therefore, the reactance of the choke must be 40 × 200 or 8000 ohms. From the formula, $8000 = 2\pi 100L$, therefore

$$L = \frac{8000}{2 \times 3.14 \times 100} = \text{nearly 13 Henries.}$$

In the same way, the inductance can be calculated for any given degree of smoothing.

For a coupling circuit, the inductance must have a given reactance at the lowest frequency to be reproduced (usually taken as 50 cycles for good reproduction, although other values may sometimes be desired, see Chapters II and V). This reactance is usually taken as equal to the valve's anode load impedance.

Thus, if a valve has an optimum load impedance of 10000 ohms, and is required to handle down to 50 cycles, the value of inductance required in a coupling choke will be

$$L = \frac{10000}{2 \times 3.14 \times 50} = 32 \text{ Henries approx.}$$

These values of inductance must not be regarded as obtainable to great accuracy, as the actual value for any given applied A.C. voltage is dependent on the D.C. current flowing at the time, and on the amplitude of the A.C. voltage. Because of this fact, it is always good to allow a little in hand, so that performance will not vary too much if operating conditions should change, due to changes in mains voltage. It would be well to design the chokes in the above examples to have inductances of, say, 15 and 40 Henries respectively.

Current and Volt Drop.

The direct current to be carried by the choke will be fixed by other considerations. In the case of the smoothing choke, by the total current to be taken by the set, and in the case of the coupling choke by the anode current of the valve. As well as being required to give the required inductance at this current, there will usually be an additional requirement that the choke shall not drop more than a certain voltage D.C. across it, due to its resistance.

We now have three factors, which roughly determine how large the choke must be physically. These three factors and the size do not have some simple relation, such as that the size of the choke in, say, cubic inches, is equal to the inductance × current × volt drop. For this reason, Tables 1-5 have been prepared to give a quick means of finding a suitable design.

Choice of Stampings.

There are available, from different manufacturers, hundreds of different shapes and sizes of laminations which could be used for chokes. Some are definitely wasteful to use, as they would require a heavier or more bulky design to meet certain requirements. The shapes shown in Figs. 2, 3 and 4 are good shapes to use from the viewpoint of obtaining any required values of inductance, current and volt drop in the smallest or lightest possible design. The shape at Fig. 5 is that known as the " waste-free " (for further details, see Chapter V). This is also a good shape, especially in the larger sizes, and has the additional advantage that it is often cheaper than other shapes. In the smaller sizes, the disadvantage is that much of the winding space is taken up by the bobbin, due to the shape of the " window."

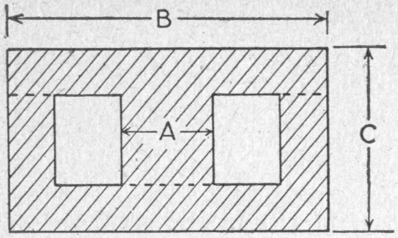


FIG. 2

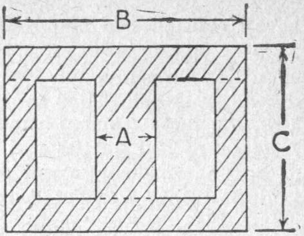


FIG. 3

There is another factor which may influence the choice of laminations. If there is to be a large A.C. voltage across the choke (such as there is in a choke for use between the rectifier and reservoir condenser), then with some designs there will be a loss of inductance due to the fact that the iron core will be saturated with A.C., over and above the effect due to the D.C. A good design for such a case employs a shape such as that at Fig. 2 or 5, and preferably a fairly large stack, or thickness, of laminations (i.e., if there should be a choice between, say, a 1" stack of one size, or a larger stack of a smaller size, then the latter would give best results).

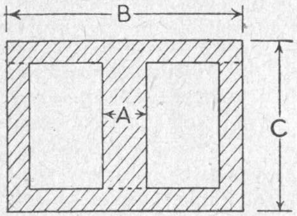


FIG. 4

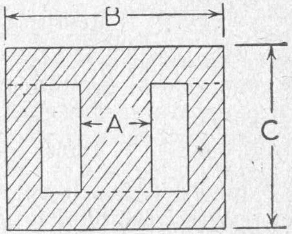


FIG. 5

Use of Tables 1-5.

The first table gives a range of 36 different designs, all of which can be wound using a 1½" stack of laminations as shown at Fig. 1, allowing for a bobbin made of material $\frac{1}{16}$" thick. There are six different values of inductance given for each of six different values of direct current flowing. These necessitate a number of different windings, of which the turns and resistance are shown in the table. The D.C. Volt Drop is also tabulated for convenience.

If the value should be outside the range covered by the 36 given, then it may be obtained with the aid of the factors at the bottom of the table. Two examples will best illustrate the use of these factors :—

Example 1.—An inductance of 200 Henries at 5 milliamps is required. In the table is shown a value of 20 Henries at 50 milliamps. The factors at the bottom show that if the inductance is multiplied by 10 (bottom line), then the resistance and volt drop will each be multiplied by 32, and the turns required by 5.6. Thus, an inductance of 200 Henries at 50 milliamps will have a resistance of 250 × 32 ohms, or 8000 ohms, giving a volt drop of 12.5 × 32, or 400 volts, and requiring 3600 × 5.6, or 20000 turns, approx. Now, from the previous line, it is shown that if the current is divided by 10, then the resistance is divided by 10, and the volt drop by 100, the turns required being divided by 3.2. So the inductance originally required, of 200 Henries at 5 milliamps, will have a resistance of 8000 ÷ 10, or 800 ohms, giving a volt drop of 400 ÷ 100, or 4 volts, and requiring 20000 ÷ 3.2, or about 6300 turns.

Example 2.—To design an inductance of 1 Henry at 1 amp. on this core size: In the table an inductance of 100 Henries at 10 milliamps is given as having a resistance of 550 ohms and requiring 5300 turns. 1 amp. is 1000 milliamps, or 100 × 10 mA. From the factor given, if the current is multiplied by 10, then the resistance will be 10 times, using 3.2 times the turns. So, if the current is multiplied by 100, then the resistance will be 100 times, and the turns will need to be 3.2 × 3.2, or 10 times. As the inductance is to be divided by 100, the resistance due to this change will be divided by 32 × 32, or 1000, and the turns required will be divided by 5.6 × 5.6, or 32. Thus, the values given in the table for 100 Henries at 10 milliamps can be converted into those for 1 Henry at 1 amp. as follows:—

$$\text{Resistance} = 550 \times \frac{100}{1000} = 55 \text{ ohms.}$$

$$\text{Volt Drop} = 5.5 \times \frac{10000}{1000} = 55 \text{ volts.}$$

$$\text{Turns} = 5300 \times \frac{10}{32} = 1650.$$

Thus, it is seen that the table can be used to find the necessary value of resistance and turns to give any inductance and direct current on this core size. If the resistance and volt drop are of a suitable value, then this size could be used, if laminations are available, and when the coil is wound, it is necessary to find the air gap required from the tables in Chapter IV.

If the resistance or volt drop obtained in this way is either (1) unnecessarily low, or (2) too high, then an appropriate core size may now be chosen directly from reference to one of Tables 2-5, which list a variety of shapes, sizes and stacks, together with a factor showing the relation between resistance and turns for a design on this size as compared to that having the same inductance at the same D.C. on the size shown in Fig. 1, and tabulated in Table 1.

It will be realised that it is unimportant whether the laminations take the form of E's and I's, or of T's and U's, so long as they fit together to make approximately the shape shown. If a stamping is available which does not fit all the dimensions shown, the best method is to see which shape it most nearly resembles. This can readily be found by holding a lamination in one hand and this book in the other, and by holding them at different distances from the eye so that the outline of the lamination and the figure in the book appear the same size. It will then be easy to see which of the four shapes given most closely correspond to the actual stamping.

To find the stack required, use the resistance factor column to find what stack of the given shape whose dimensions B and C most closely correspond with the actual stack which is required. Then, to find the turns factor, use the size whose dimension A is the same as the actual stamping, and of the same stack as nearly as possible. Generally it will be seen that when the shape which is nearest to the actual is found, the size as judged by the nearest correspondency of dimensions B and C will also give the right value for dimension A.

Example 3.—Continuing the case of the 200 Henry 5 milliamp inductance of Example 1, suppose that a 4 volt drop is unnecessarily low. Assume that a drop of 20-25 volts can be allowed. This means that the resistance and volt drop can be 5 or 6 times that of the design given on the size of Fig. 1. From Table 2 we find that a lamination of this shape, having overall dimensions 1" × 1¾", will give a design having a volt drop of 5.5 × 4, or 22 volts, using a 1" stack. Or a larger one of the same shape, having dimensions 1¼" × $2\frac{3}{16}$", and ⅝" stack, gives volt drop of 4.8 × 4, or nearly 20 volts. Using the shape of Fig. 3, from Table 3 we find a size having overall dimensions 2" × 1½" and stack ½", which gives the same drop. This would obviously be the most compact size for this particular design. There is another alternative in Table 5, using a ⅝" stack of a lamination having outside dimensions $1\frac{9}{16}$" × 1⅞", and giving a volt drop of nearly 20. In each case the number of turns required is calculated by multiplying the factor in the Turns Factor column by the number obtained from Table 1, i.e. 6300.

Example 4.—Continuing the case of the 1 Henry 1 amp. choke of Example 2, suppose that 55 volts is much too great, and that a limit of 5 volts has been set. Then a size must be chosen which gives a division factor of 55/5 or 11. The largest size on Table 2 gives 14; there are two in Table 3 that give 11, one in Table 4 that gives 12, and one in Table 5 that gives 11—a choice of five sizes. As this is a large-size choke, the best shape is the "waste-free," giving a 2¼" stack of laminations 3¾" × 4½". The turns required will be 1650 ÷ 1.9, or about 900.

For the method of finding wire gauge in these examples, see Chapter X.

As well as the variation of inductance mentioned already as due to variation of current and A.C. voltage, the D.C. resistance cannot be expected to conform to close limits either, because of slight variations in wire gauge from the standard.

TABLE NO. 1

Values of Current and Inductance for Choke to Dimensions of Figure 1

Current milliamps	Inductance Henries	Resistance Ohms	Volts dropped	Turns
10	30	100	1	2200
	50	200	2	3200
	70	350	3.5	4100
	100	550	5.5	5300
	150	1000	10	7300
	200	1600	16	9000
15	10	30	0.45	1200
	15	50	0.75	1600
	20	75	1.1	2000
	30	140	2.1	2700
	50	300	4.5	3900
	70	500	7.5	5000
20	10	35	0.7	1400
	15	65	1.3	1800
	20	100	2	2200
	30	180	3.6	3000
	50	400	8	4500
	70	650	13	6000
30	10	55	1.7	1700
	15	100	3	2200
	20	150	4.5	2800
	30	270	8.1	3700
	50	600	18	5700
	70	1000	30	7300
50	10	90	4.5	2100
	15	160	8	2900
	20	250	12.5	3600
	30	450	23	4800
	50	1000	50	6500
	70	1600	80	9000
70	5	45	3	1500
	7	75	5	2000
	10	120	8.5	2500
	15	230	16	3400
	20	350	24	4100
	30	650	45	6000
× ÷10	—	× ÷10	× ÷100	× ÷3.2
—	× ÷10	× ÷32	× ÷32	× ÷5.6

TABLE NO. 2

Values of Resistance and Turns compared to those in Table No. 1 for cores shapes as at Figure 2

Dimensions to Fig. 2	Winding Area	Core Stack	Turns Factor	Resistance Factor
A=½″	0.095 sq. in.	½″	×2.8	×12
B=1¾″		¾″	×2.1	×7.5
C=1″		1″	×1.7	×5.5
A=⅝″	0.17 sq. in.	⅝″	×2.2	×4.8
B=2 3/16″		⅞″	×1.7	×3.2
C=1¼″		1¼″	×1.3	×2.2
A=¾″	0.275 sq. in.	¾″	×1.7	×2.3
B=2⅝″		1⅛″	×1.3	×1.4
C=1½″		1½″	As in Table No. 1	
A=1″	0.55 sq. in.	1″	×1.2	÷1.4
B=3½″		1½″	÷1.2	÷2.3
C=2″		2″	÷1.5	÷3.2
A=1¼″	0.92 sq. in.	1¼″	÷1.1	÷3.3
B=4⅜″		1⅞″	÷1.5	÷5.5
C=2½″		2½″	÷1.9	÷7.5
A=1½″	1.375 sq. in.	1½″	÷1.5	÷6.5
B=5¼″		2¼″	÷2	÷10
C=3″		3″	÷2.4	÷14

TABLE NO. 3

Values of Resistance and Turns compared to those in Table No. 1 for cores shaped as at Figure 3

Dimensions to Fig. 3	Winding Area	Core Stack	Turns Factor	Resistance Factor
A=½″	0.33 sq. in.	½″	×3.2	×4.8
B=2″		¾″	×2.3	×3
C=1½″		1″	×1.9	×2.1
A=⅝″	0.56 sq. in.	⅝″	×2.4	×2
B=2½″		⅞″	×1.9	×1.4
C=1⅞″		1¼″	×1.4	÷1.1
A=¾″	0.86 sq. in.	¾″	×1.9	×1
B=3″		1⅛″	×1.4	÷1.7
C=2¼″		1½:	×1.1	÷2.3
A=1″	1.65 sq. in.	1″	×1.3	÷3
B=4″		1½″	×1	÷5
C=3″		2″	÷1.3	÷7
A=1¼″	2.6 sq. in.	1¼″	×1	÷7
B=5″		1⅞″	÷1.4	÷11
C=3¾″		2½″	÷1.7	÷15
A=1½″	3.8 sq. in.	1½″	÷1.3	÷11
B=6″		2¼″	÷1.7	÷20
C=4½″		3″	÷2.2	÷30

TABLE NO. 4

Values of Resistance and Turns compared to those in Table No. 1 for cores shaped as at Figure 4

Dimensions to Fig. 4	Winding Area	Core Stack	Turns Factor	Resistance Factor
A=½″ B=2¾″ C=2″	1 sq. in.	½″	×3.4	×2.5
		¾″	×2.5	×1.5
		1″	×2	×1
		1½″	×1.5	÷1.5
A=⅝″ B=3 7/16″ C=2½″	1.65 sq. in.	⅝″	×2.6	×1.1
		⅞″	×2	÷1.4
		1¼″	×1.5	÷2.2
		1⅞″	×1.1	÷3.5
A=¾″ B=4⅛″ C=3″	2.4 sq. in.	¾″	×2	÷1.7
		1⅛″	×1.5	÷3
		1½″	×1.2	÷4
		2¼″	÷1.1	÷6.5
A=1″ B=5½″ C=4	4.4 sq. in.	1″	×1.4	÷5
		1½″	×1	÷8.5
		2″	÷1.3	÷12
		3″	÷1.6	÷18
A=1¼″ B=6⅞″ C=5″	6.8 sq. in.	1¼″	×1.1	÷10
		1⅞″	÷1.3	÷18
		2½″	÷1.6	÷25
		3¾″	÷2.1	÷40

TABLE NO. 5

Values of Resistances and Turns compared to those in Table No. 1 for Cores shaped as at Figure 5

Dimensions to Fig. 5	Winding Area	Core Stack	Turns Factor	Resistance Factor
A=½″ B=1½″ C=1¼″	0.078 sq. in.	½″	×2.8	×13
		¾″	×2.1	×8
		1″	×1.7	×6
A=⅝″ B=1⅞″ C=1 9/16″	0.15 sq. in.	⅝″	×2.1	×4.8
		⅞″	×1.7	×3.3
		1¼″	×1.3	×2.3
A=¾″ B=2¼″ C=1⅞″	0.25 sq. in.	¾″	×1.7	×2.2
		1⅛″	×1.3	×1.4
		1½″	As in Table No. 1	
A=1″ B=3″ C=2½″	0.47 sq. in.	1″	×1.2	÷1.3
		1½″	÷1.1	÷2.1
		2″	÷1.4	÷2.8
A=1¼″ B=3¾″ C=3⅛″	0.875 sq. in.	1¼″	÷1.1	÷2.9
		1⅞″	÷1.5	÷4.8
		2½″	÷1.9	÷7.5
A=1½″ B=4½″ 3=3¾″	1.3 sq. in.	1½″	÷1.4	÷7
		2¼″	÷1.9	÷11
		3″	÷2.3	÷15

CHAPTER II—INTER-VALVE TRANSFORMERS CARRYING DIRECT CURRENT

Primary Inductance and Resistance.

Tables 1-5 may be used to find the inductance of any given number of turns on the sizes given, but the resistance calculated from these tables will be increased, and with it the volt drop.

Suppose that the primary consists of 3000 turns on the fourth size listed in Table 3, i.e., a ⅝″ stack of laminations with dimensions A = ⅝″, B = 2½″, and C = 1⅞″ (see Fig. 3), and that the primary current is 10 milliamps. From Table 3 we see that 3000 turns is 2.4 times as many as would be required on the size given in Table 1 to have the same inductance at the same current. This means that 3000 ÷ 2.4, or 1250 turns would be required on this larger size. Now, referring to Table 1, at 10 milliamps there is no number of turns as low as 1250, but the factor at the bottom for multiplying or dividing the inductance by 10 is 5.6. Multiplying 1250 by 5.6 gives 7000 turns, which does fall within the range given by the table. 5300 turns give an inductance of 100 Henries at 10 mA., and 7300 turns give an inductance of 150 Henries at 10 mA., so 7000 turns will give an inductance of about 140 Henries at 10 mA. Now, dividing by 5.6, this means that 1250 turns on this size, or 3000 turns on the actual size, will give 14 Henries at 10 mA.

As a choke, the 7000-turn winding would have a resistance of about 900 ohms (see Table 1, between 550 and 1000, for 5300 and 7300 turns respectively). By the factor at the bottom of Table 1, the resistance of the 1250 turns will be 900 ÷ 32 = 28 ohms approx. From the resistance factor in Table 3 for the actual size, the resistance of a choke having the 3000 turns as specified would be 28 × 2 = 56 ohms. But, in this case, the primary will only occupy one-half or perhaps one-third of the total winding space. This means that its resistance will be increased by two or three times, to 112 or 168 ohms. This, then, allows the remaining one-half to two-thirds of the space for the secondary. If a very high step-up is used, needing a very large number of turns on the secondary, then even less than one-third of the space may have to do for the primary.

Choice of Size.

Of the sizes shown in the tables, the one already mentioned is the best for an inter-valve transformer for direct coupling. It gives the greatest possible step-up in any given inter-valve circuit, consistent with a balanced frequency response. If a smaller size is used, then either step-up must be sacrificed or the frequency band will be higher up the scale, giving a " thin " quality reproduction. If a larger size is used, then again step-up must be reduced, or else the frequency band will be moved down the scale, giving a " woofy " reproduction.

Choice of Ratio and Turns.

The response curves shown in Figs. 6 and 7 show various shapes of the frequency response obtained with the ratios and turns given in Table 6.

For all these curves, the design is taken as being for a transformer to work with a valve having an anode current of 10 milliamps, and an anode impedance (*not* the optimum anode load) of 7000 ohms. This would be a typical medium slope triode.

In Fig. 6, the same ratio is achieved with three different numbers of turns. Curve AA is the result of using 4000/12000 turns; curve BB with 3000/9000; and curve CC with 2000/6000.

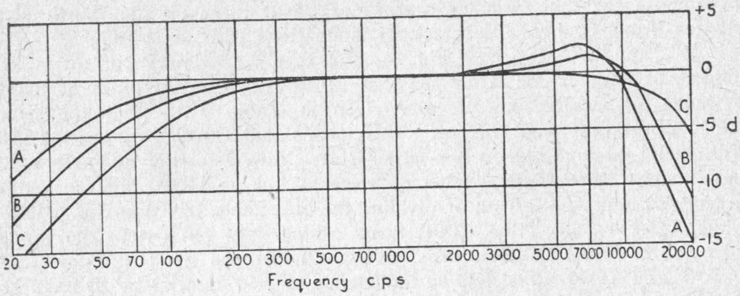


FIG. 6

In Fig. 7, different turns ratios are used, having the same number of secondary turns, 12000. Curve AAA is obtained as in Fig. 6, for a 3/1 using 4000/12000; curve B is for ratio of 4/1, using 3000/12000 turns; curve C for a ratio of 5/1, using 2400/12000 turns; and curve D for a ratio of 6/1, using 2000/12000 turns. In this case, it will be seen that increasing the ratio narrows the frequency band, but that it is kept balanced about a mid-frequency of about 600 or 700 cycles. For reproduction of music this is a good ideal.

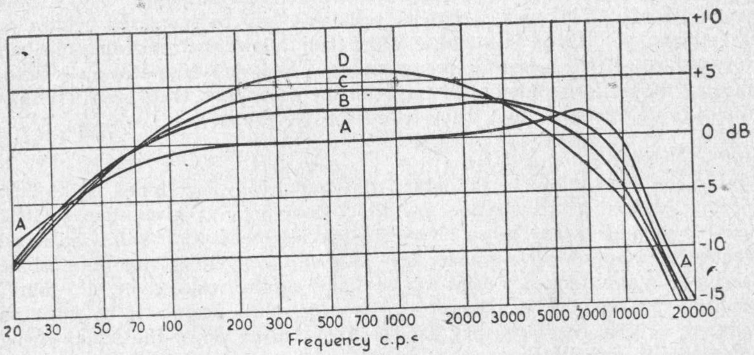


FIG. 7

To enable the information given in these curves to be applied to other cases when other types of valve may be used, the column "referred impedance" is given. This is simply the anode impedance of the valve multiplied by the square of the turns ratio. Any other transformer will have the same shape cut-off at the high frequency end of its response if it has the same number of secondary turns, and the same referred impedance as that given in the table. The shape of the cut-off at the low frequency end of the response depends upon the primary inductance and the anode impedance of the valve, as stated in Chapter I.

Example 5.—To estimate the best ratio and turns for use with a valve having an anode impedance of 2500 ohms and an anode current of 20 milliamps.

The widest frequency range is obtained with the use of 12000 turns on the secondary, and with a referred impedance of 63000 ohms gives a response cut-off at the top end as shown in curves A (Figs. 6 and 7). To make 2500 ohms refer as 63000, the square of the turns ratio must be $\frac{63000}{2500}$, or about 25/1. This gives a turns ratio of 5/1. Then the primary turns will need to be 2400. Using Tables 1 and 3, as before, this winding will have an inductance of about 6 Henries with 20 mA. flowing. This makes the cut-off frequency at the low end that at which 6 Henries has a reactance of 2500 ohms. $X_L = 2\pi fL$, i.e., $2500 = 2 \times 3.14 \times 6 \times f$.

therefore, $f = \frac{2500}{2 \times 3.14 \times 6} = 65$ cycles, approx. This means that the point where the response is 3 dB down from level is at 65 cycles. Curve A shows this as 50 cycles.

Thus this case, using a 5/1 of 2400/12000 will give an L.F. response not quite so good as that in curves A, while the H.F. response will be identical. Using the same turns on the next size (a ¾" stack of the next larger laminations listed) will have the effect of bringing the whole response down by a ratio of about 5/6. This will about balance the frequency response.

Example 6.—To estimate the best arrangement to use with a valve having an anode impedance of 10000 ohms, and an anode current of 5 mA.

Using the same reference impedance, the square of the ratio needs to be 63000/10000 or 6.3/1. This gives a turns ratio of about 2.5/1, and so the primary turns would be 4800.

To work out the primary inductance, as before: 4800 turns on the best size as already stated have the same inductance for the same current as 4800 ÷ 2.4, or 2000 turns on the size of Fig. 1. There is no section of Table 1 for 5 mA., but there is for 50 mA., and the factor at the bottom shows that multiplying or dividing current by 10, multiplies or divides turns by 3.2. So the same inductance with 50 mA. instead of 5 mA would need 2000 x 3.2, or 6400 turns. This closely corresponds with the figure for 50 Henries, and the error introduced by assuming that 4800 turns on our actual size will produce an inductance of 50 Henries at 5 mA. is quite small.

To find the 3 dB frequency: $X_L = 2\pi fL$; $10000 = 2 \times 3.14 \times f \times 50$,

$$\text{or } f = \frac{10000}{2 \times 3.14 \times 50} = 32 \text{ cycles.}$$

This is rather better than necessary, and it will be found that an inductance of 32 H will bring the 3 dB point to 50 cycles. Working back, we find this needs less than 4000 turns on the actual primary. If 4000 turns is used, the ratio is 3/1, and the referred impedance will be $9 \times 10000 = 90000$ ohms. This will give a H.F. cut off mid-way between that for curves A and B in Fig. 7, whilst maintaining the L.F. cut-off a little better than that for curve A. This will be reasonably well balanced, giving a range from about 45 to 10000 cycles.

Method of Winding and Connection.

With any inter-valve transformer it is important to keep the winding capacities to the lowest possible figure, as these introduce further loss of high frequencies. The secondary, being the winding at the highest impedance, is the most important in this respect. For this reason the following method should be adopted:

TABLE NO. 6

Conditions required for response curves in Figures 6 and 7

Ratio	Primary Turns	Secondary Turns	Response Curve	Referred Impedance
3/1	4000	12000	{AA, Fig. 6 AAA, Fig. 7	63000
3/1	3000	9000	BB, Fig. 6	63000
3/1	2000	6000	CC, Fig. 6	63000
4/1	3000	12000	B, Fig. 7	112000
5/1	2400	12000	C, Fig. 7	175000
6/1	2000	12000	D, Fig. 7	250000

The secondary should be wound on first, so as to have the smallest diameter, and the inside, or start, of the winding should be the end which is eventually connected to the grid of the next valve. This means that the outside, or finish, will be connected either to the grid bias or earth.

After insulation has been placed between windings, the primary will be wound on. This may be of the same or of different gauge from the secondary (see Chapter X). The inside, or start, should be connected to H.T. supply or decoupling, while the outside, or finish of this winding should be connected to anode.

This practice will always be found to give the best results.

CHAPTER III—OUTPUT TRANSFORMER FOR SINGLE VALVE

Turns and Impedance Ratio.

The purpose of this type of transformer is to match the impedance of a loudspeaker, or group of loudspeakers, to the optimum load of the valve. That is, the transformer has the effect of transforming the impedance of the speaker so that the impedance which it presents in the primary winding is equal to the optimum load of the output valve.

It is well known that the impedance ratio of a transformer is equal to the square of the turns ratio. To assist in calculating one ratio from the other, a table giving numbers and their squares in reasonable steps is included in Chapter X.

Impedance/Turns Relationship.

This depends on the D.C. current flowing in the primary, on the size and shape, and on the lowest frequency required. To make calculation easier, if the actual D.C. current flowing in the primary is referred to a theoretical 1000 ohms winding, then the turns for such a winding can readily be found, and from that the turns in the actual windings determined. Using this reference, the current in this winding will bear a relationship to the maximum output power which will vary very little, although widely different types of valve may be used.

Table 7 gives a series of reference figures. For each value of current referred to 1000 ohm winding, is given two figures for the turns in a 1000 ohm winding: one for general use, giving a low frequency cut-off of 50 cycles; and the other for special use when a circuit is used for speech only, giving a low frequency cut-off of 200 cycles. For each value of current is given an approximate figure of maximum output. This may be found useful if some of the valve data is not obtainable (e.g., the optimum load). For each value of current and cut-off is given the approximate percentage loss due to winding resistance.

Choice of Size.

The figures in Table 7 are for the same core dimensions as those shown in Fig. 1. In practice, for an output transformer it will be better from the constructional viewpoint if the stack is less than twice the A dimension, preferably equal to it. The chief factor in determining size is the amount of power that can be allowed as loss in the transformer. The appropriate loss factors for other sizes may be found from the figures given by multiplying or dividing by the Resistance Factor given in Tables 2-5 for the appropriate shape and size.

Having chosen a suitable size, the number of turns for a 1000 ohm winding can be found by use of the Turns Factor in the same table, applied to the value given in Table 7.

Example 7.—Calculate the turns required to match a 15 ohm speaker to a valve having an optimum load of 4500 ohms, and an anode current of 48 milliamps for general use on music and speech. It should be at least 90% efficient.

If 48 milliamps are flowing in a winding of impedance 4500 ohms, then the equivalent in a 1000 ohms winding will be $48 \times \sqrt{\frac{4500}{1000}} = 100$ mA. approx. From this value in Table 7 it is seen that on the size shown in Fig. 1, for a 50 cycle cut-off, 1300 turns for 1000 winding give a loss of 13%.

To have at least 90% efficiency, the loss must be at most 100—90=10%. This means that a size must be chosen with a dividing Resistance Factor of at least 1.3. The following sizes satisfy this:—

Table No.	Dimensions A	B	C	Stack	Turns Factor	Resistance Factor
2	1"	3½"	2"	1"	×1.2	÷1.4
3	¾"	3"	2¼"	1⅛"	×1.4	÷1.7
4	⅝"	3$\frac{7}{16}$"	2½"	⅞"	×2	÷1.4
5	1"	3"	2½"	1"	×1.2	÷1.3

It will be noticed that there is little difference in size, and therefore there is not much to choose as to which is the best to use. Assume that a size similar to the one from Table 3 is available, then the loss will be 13 ÷ 1.7 = 7.6% and the efficiency 100 — 7.6 = 92.4%. The turns for a 1000 ohm winding will be 1.4 x 1300 = 1800 approx. Then the turns for a 4500 ohm winding will be $1800 \times \sqrt{\frac{4500}{1000}} = 3800$. The turns for the 15 ohm winding will be $1800 \times \sqrt{\frac{15}{1000}} = 220$.

Thus the transformer will require a primary of 3800 turns and a secondary of 220 turns.

Example 8.—The only details known about an output valve are that with 450 volts H.T. it should give about 12 watts output, taking an anode current of 120 milliamps. It is required to match a horn type speaker for use on speech only, with an efficiency of about 90%. The speech coil impedance is 4.5 ohms.

From Table 7 it is seen that 12 watts corresponds to a current referred to a 1000 ohms winding of 200 mA. The actual current is 120 mA, so the optimum load must be $1000 \times \frac{200^2}{120^2} = 2800$ ohms.

Also the loss for a 200 cycle cut-off type on this size is only 4%. As the efficiency is only required to be 90%, the loss can be up to 10%. This means a smaller size can be used, which may facilitate fitting the transformer into the horn housing. Thus the resistance can be multiplied by 2.5 (but not more). It will be seen that a ¾" stack of the same lamination will give a resistance factor of x 2.3. An alternative is found in Table 5, using a ¾" stack of a similar size. In either case the turns factor is x 1.7, so the calculation of turns in this case will be the same whichever is chosen.

From Table 7 the turns for a 1000 winding are 650. So for this size the turns will be 1.7 x 650 = 1100. The turns for a 2800 ohms winding will be $1100 \times \sqrt{\frac{2800}{1000}} = 1850$. The turns for the 4.5 ohm winding will be $1850 \times \sqrt{\frac{4.5}{2800}} = 74$. The ratio in this case is $\frac{1850}{74} = 25/1$.

TABLE NO. 7

Impedance/Turns Relationship for Core of Size shown in Figure 1

D.C. referred to 1000 ohms	Turns for 1000 ohms	Series loss	Turns for 1000 ohms	Series loss	Max. power
	50 cycle cut-off		200 cycle cut-off		
50	900	7%	310	1%	800 mW
70	1100	9%	380	1.3%	1.5 W
100	1300	13%	450	2%	3 W
150	1600	20%	550	3%	7 W
200	1900	28%	650	4%	12 W

Special Precaution for 200 Cycle Cut-off.

When an amplifier is to be used under conditions required to operate a loudspeaker having a 200 cycle cut-off (i.e., a horn type), there are two precautions necessary: (1) To see that no signal of any considerable amplitude reaches the speaker. This is to prevent damage to the speaker itself, or the introduction of distortion by it, due to receiving frequencies which it is not designed to handle. (2) To see that no signal of a lower frequency which may be present in the amplifier causes distortion to frequencies which do reach the loudspeaker.

This second requirement means either that the output of the amplifier must be correctly matched at these frequencies although arrangement is made so that they do not reach the speaker, or that arrangement must be made to ensure that these frequencies do not reach the output stage of the amplifier.

Chapter V shows a way in which matching can be maintained with a push-pull stage output by means of a series condenser, but this is not applicable to the cases considered in this section. It is therefore necessary, when using a 200 cycle cut-off type, to take steps to ensure that there is a similar cut-off in the amplifier, somewhere before the output stage. This should take the form of a coupling condenser whose impedance at 200 cycles is equal to that of the grid leak following it.

CHAPTER IV—AIR GAP DETERMINATION

With each of the types of component considered in Chapters I-III there is D.C. flowing in one of the windings which has a tendency to saturate the iron core. For this reason an air gap is employed, instead of laminating the transformers in the manner required for types considered in Chapters V-VII.

For any given case, too small an air gap will result in the magnetic flux due to the D.C. component producing saturation, while too large a gap will cause loss of inductance because of the magnetizing current necessary to drive the A.C. component of flux across the air gap.

The chief factor which determines the best air gap for any given example is the total effective D.C. magnetizing force, which may be expressed in ampere-turns—that is to say, the current in amperes multiplied by the turns in the winding. The type of transformer iron used, and the length of iron path (see Fig. 8), both have a slight effect upon the best gap, and on the resulting inductance. As the effect of different iron is so slight, the use of more expensive irons is not considered worth the extra cost in general, so the only iron considered here is ordinary grade transformer iron (usual lamination thickness about 0.016″).

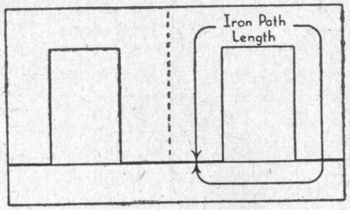


FIG. 8

All the figures in Chapters I-III for Current and Inductance assume that the air gap is adjusted to the best size. Table 8 gives the approximate gap lengths for different values of ampere turns. Only two values of length of iron path are shown, as this has so little effect, and so practical values will fall between those shown, which are respectively smaller and greater than all the sizes of lamination listed in Tables 2-5. The length of air gap given is half the total required air gap, because generally, with either T and U, or E and I type laminations, there will be two gaps in the iron circuit. If a type is used which only utilises one gap in the iron circuit, then twice the figure given in Table 8 should be taken.

The gaps listed include very small values, which can in practice only be obtained by squeezing the two sections of laminations together without any gap spacing material. For larger gaps, pieces of insulating material of the required thickness may be inserted in the gaps to maintain uniform spacing of the whole cross section of the core.

If equipment is available to test the component for inductance under operating value of D.C. current (as outlined in Chapter IX), then the values given in Table 8 will give a good starting point, which will usually be found within a close percentage of the actual optimum. Deviations will generally be due to practical variations on account of difficulties in clamping up. If such equipment is not available, then care should be taken to produce as near to the specified gap as is possible, making slight allowances if the edges of the laminations should have been slightly burred in stamping.

To give examples of the use of this table, and to complete the examples given in previous sections, those numbered 1-8 are listed below, with a repetition of current flowing and turns :—

TABLE NO. 8

Air Gaps for Components Carrying D.C.

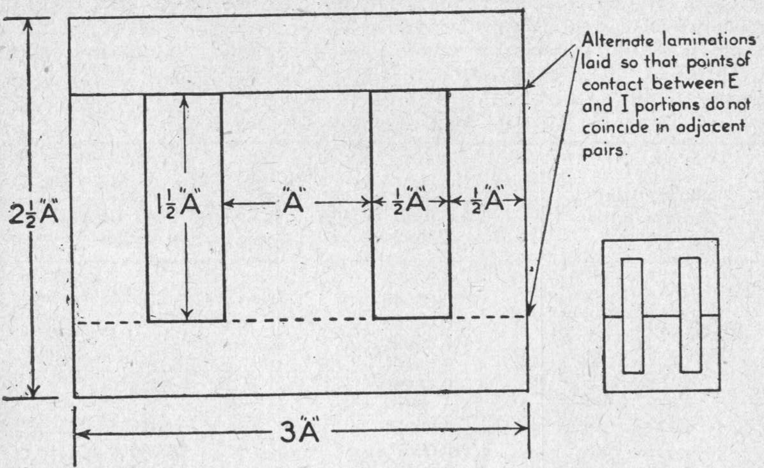
Magnetizing Ampere-turns	Air Gap	
	Iron Path Length 2 inches	Iron Path Length 20 inches
10	0.00033″	—
15	0.00048″	—
20	0.00063″	—
30	0.0009″	—
50	0.0014″	—
70	0.0019″	0.0023″
100	0.0025″	0.0032″
150	0.0037″	0.0046″
200	0.0047″	0.006″
300	0.0068″	0.0085″
500	0.0105″	0.0135″
700	0.0145″	0.018″
1000	0.020″	0.025″
1500	0.028″	0.036″
2000	0.037″	0.047″
3000	0.055″	0.067″
5000	0.083″	0.105″
7000	0.110″	0.140″
10000	0.155″	0.195″
15000	0.220″	0.280″
20000	0.290″	0.360″

Example No.	Current D.C.	Turns	Ampere Turns	Iron Path Length	Air Gap
1	5 mA	6300	31.5	4.1″	0.001″
2	1 Amp	1650	1650	4.1″	0.035″
3	5 mA	20000	100	4″	0.027″
4	1 Amp	900	900	9″	0.021″
5	20 mA	2400	48	6″	0.015″
6	5 mA	4000	20	5″	0.007″
7	48 mA	3800	183	6″	0.005″
8	120 mA	1850	222	4.1″ or 4.5″	0.006″

CHAPTER V—PUSH-PULL OUTPUT AND LOUDSPEAKER TRANSFORMERS.

Choice of Size.

For this purpose the best shape is that known as the "Waste-free." The dimensions are set out in Fig. 9, referred to the width of the centre limb. The small diagram shows the way the laminations are stamped from the sheet so there is no waste portion. It will be seen that this method of cutting can only be employed to make laminations of the E and I type. However, from the point of view of efficiency, frequency band, etc., it is obvious that a core of the same shape constructed from laminations of the T and U type will be equally good.



Alternate laminations laid so that points of contact between E and I portions do not coincide in adjacent pairs.

FIG. 9

Table 9 gives data for a series of easily obtainable sizes, in different stacks. It shows the turns for a 1000 winding which give a transformer of maximum efficiency at a frequency of 400-1000 cycles. The section headed "Maximum power, Watts," shows the maximum power that can be handled by the transformer under this condition at two frequencies, 50 c and 200 c, without introducing serious distortion. The figures in the 50 c column in brackets are so shown because they cannot be applied at that frequency under maximum mid-band efficiency condition, because they are below cut-off, and hence the inductive load on the output valve would introduce distortion by mismatching. However, if appropriate factors from Table 10 are used to reduce cut-off to 50 cycles or below, the corresponding factors from the same table may be used to obtain the maximum output at 50 cycles in conjunction with the figures in brackets.

Table 10 shows how increased power and a lower cut-off frequency may be obtained when the impedance/turns relationship is increased above the figure given for any size in Table 9, together with the increases in losses, from which may be deduced the efficiency obtainable.

The factors at the bottom of Table 10 show how the figures can be improved by the use of Radiometal laminations instead of standard transformer iron.

For designs of both Class A Push-Pull Output and Loudspeaker matching transformers, the total winding space occupied by the primary winding should be approximately equal to that occupied by the secondary.

For any type of Q.P.P. output stage, the most efficient disposition of winding space is when each half of the primary occupies about 30% of the space, and the secondary occupies 40%. Under this condition the figures given by Tables 9 and 10 have to be modified slightly. For maximum efficiency at mid band, the turns for 1000 ohms should be divided by 1.1, the maximum power in watts figure reduced by 1.2, and the mid band losses increased by 1.2. The L.F. cut-off frequency will also be multiplied by 1.2.

200 Cycle Cut-off Matching.

With push-pull type outputs the author does not recommend the incorporation of 200 cycle cut-off in the output transformer. If it should be regarded as essential to do so in order to save space, then the precaution mentioned in Section 3 must be observed. A preferable method is to incorporate the bass cut between the output transformer and the matching transformer by means of a series condenser, which should be chosen so that its reactance at the cut-off frequency is equal to the load impedance referred to that point.

Methods of Winding and Connection.

For the smaller size push-pull output transformers, the best method of winding to preserve a good balance at the higher frequencies is to wind one half of the primary before, and the other half after, the secondary. The two ends of these two windings which are adjacent to the secondary are then connected together to form the centre tap. This method is shown diagramatically at Fig. 10a.

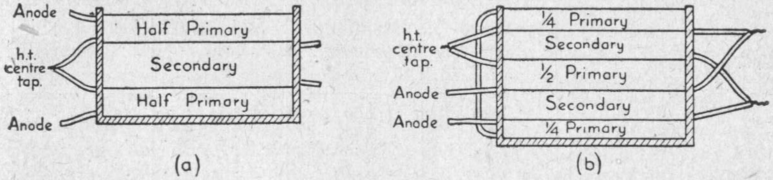


FIG. 10

For larger sizes, and especially those intended for Q.P.P. type output circuits, closer coupling of the windings may be considered necessary. The method of winding and connection shown at Fig. 10b has been proved to give very accurate balance indeed at the high frequencies. Some authorities recommend complicated arrangements using a divided bobbin, so as to maintain geometrical symmetry. The arrangement here shown maintains just as good electrical symmetry, with a far simpler winding arrangement, and gives a wider frequency response band for a given size and complexity of design. The secondaries are shown as two windings connected in parallel. This arrangement preserves the best balance, especially if secondary has a fairly high impedance. If the secondary impedance is quite low compared to the primary, then a series arrangement will serve equally well, when the junction can be used as a centre tap, and earthed.

TABLE NO. 9
Impedance/Turns Relationship, Maximum Power, and L.F. Cut-off for Maximum Efficiency at Mid-Band Condition

Dimension A, Fig 9	Core Stack	Turns for 1000 ohms	Maximum Power Watts		Mid-Band Losses	L.F. Cut-off Cycles
			50 c.	200 c.		
¾″	¾″	750	(1.75)	28	11.5%	90
	1⅛″	660	(3.5)	56	10%	80
	1½″	500	(5.25)	84	9.3%	70
1″	1″	770	(7)	110	8.5%	65
	1½″	670	(12)	190	7.4%	60
	2″	500	(17)	270	6.8%	55
1¼″	1¼″	790	(18)	280	6%	53
	1¾″	700	28	450	5.4%	46
	2½″	620	45	700	4.8%	43
1½″	1½″	800	40	650	4.8%	39
	2¼″	720	70	1100	4.3%	35
	3″	640	100	1600	4%	32

TABLE NO. 10
Factors for other impedance/turns relationships, and for change from standard transformer iron to Radiometal

	Turns ×	Maximum Power ×	Mid-Band Losses ×	L.F. Cut-off ÷
Factors for Turns Referred to Table No. 9	1.25	1.5	1.1	1.5
	1.5	2.25	1.35	2.25
	1.75	3	1.7	3
	2	4	2.2	4
	2.5	6.25	3.2	6.25
	3	9	4.6	9
	3.5	12	6.1	12
	4	16	8	16
Factor for change to Radiometal	÷1.3	×2.3	÷1.7	equal

For loudspeaker matching transformers, a simple arrangement with the primary and secondary (each in only one section) is adequate. It is not important in this case which winding is nearest to the core, so the order of winding may be determined by convenience from the point of view of the particular wire gauges to be used.

Example 9.—A push-pull amplifier giving an output of 10 watts, with an anode to anode load of 4000 ohms, requires an output transformer with an efficiency of about 90% to match it to a 10 ohm speaker for music and speech.

A 1″ stack of 1″ waste-free laminations operating at maximum mid-band efficiency has 8.5% losses and a cut-off of 65 cycles. If the turns are multiplied by 1.25, then the mid-band losses become 1.1 x 8.5 = 9.5% (or an efficiency of 90.5%), and the cut-off becomes 65 ÷ 1.5 = 43 cycles. Thus the maximum output at 50 cycles can now be 1.5 x 7 = 10.5 watts.

winding for 4000 ohms will require a total of $\sqrt{\frac{4000}{1000}}$ x 960 or 1920

The turns for a 1000 winding will need to be 1.25 x 770 = 960. A

turns, and a winding for 10 ohms will require $\sqrt{\frac{10}{1000}}$ x 960 = 96 turns.

Thus the winding will be:

1. Half Primary, 960 turns.
2. Secondary, 96 turns.
3. Half Primary, 960 turns.

Example 10.—A large amplifier, having an output of 40 watts, has an anode to anode load figure of 8000 ohms, and requires to be matched to 250 ohms for speaker distribution. Give appropriate designs in standard transformer iron and in Radiometal, for use on music and speech, efficiency to be 95%.

Using standard transformer iron: Either a 2½″ stack of 1¼″ waste-free, or a 1½″ stack of 1½″ waste-free will satisfy the required conditions without modification. Each gives an efficiency of 95.2%.

Using Radiometal: A 1″ stack of 1″ waste-free gives a mid-band loss of 8.5 ÷ 1.7 = 5%. Under this condition the cut-off frequency is 65 cycles, and maximum output without distortion would only be 7 x 2.3 = 16 watts. A 1½″ stack of 1″ waste-free gives, under maximum mid-band efficiency, a loss of 7.4 ÷ 1.7 =4.35%, a cut-off of 60 cycles, and a maximum output of 12 x 2.3 = 27.6 watts. Increasing the turns by 1.25, the maximum power is increased to 1.5 x 27.6 = 41 watts, the mid-band losses become 4.35 x 1.1 = 4.8%, and the L.F. cut-off will be 60 ÷ 1.5 = 40 cycles.

Thus it is seen that a 1½″ stack of 1″ waste-free Radiometal will give almost identical performance with that of either a 2½″ stack of 1¼″, or a 1½″ stack of 1½″ in standard transformer iron. This results in a reduction of outside dimensions from 3¾″ x 4½″ to 2½″ x 3″.

To complete the design on Radiometal: The turns for a 1000 ohm winding will be 670 ÷ 1.3 x 1.25 = 640 approx. Thus the primary will require a total of $640 \times \sqrt{\frac{8000}{1000}} = 1800$ turns and the secondary turns will be $640 \times \sqrt{\frac{250}{1000}} = 320$. Thus, following the winding arrangement of Fig. 10b, the required sections are: 1, Quarter Primary, 450 turns; 2, Secondary, 320 turns; 3, Half Primary, 900 turns; 4, Secondary, 320 turns; 5, Quarter Primary, 450 turns.

Example 11.—A cabinet type speaker with a speech coil impedance of 15 ohms is required to take one-eighth of the power from Example 10. Efficiency to be not less than 80%.

One-eighth of the power is 40/8 = 5 watts. The primary impedance must be 8 x 250 = 2000 ohms. Using a ¾″ stack of ¾″ waste-free, with 1.75 times the turns from Table 9, the maximum power is 3 x 1.75 = 5.25, the mid-band losses are 1.7 x 11.5 = 19.5%, and a L.F. cut-off of 90 ÷ 3 = 30 cycles. This satisfies the conditions. Then the turns required are:—

1. Primary $750 \times 1.75 \times \sqrt{\frac{2000}{1000}} = 1850$ turns.
2. Secondary $750 \times 1.75 \times \sqrt{\frac{15}{1000}} = 160$ turns.

Example 12.—A horn type speaker, speech coil impedance 5 ohms, is required to take one-quarter of the power from the same amplifier, with a 200 cycle bass-cut. What condenser is required, and what will be the efficiency, using the same size transformer as Example 11?

Using maximum mid-band efficiency, this size can handle 28 watts at 200 cycles, with losses of 11.5%, giving an efficiency of 88.5%. The primary impedance will be 4 x 250 or 1000 ohms. Thus the condenser must have an impedance of 1000 ohms at 200 cycles:

$$C = \frac{1000000}{2 \times 3.14 \times 200 \times 1000} = 0.8 \text{ MF.}$$

Turns required as follows:—

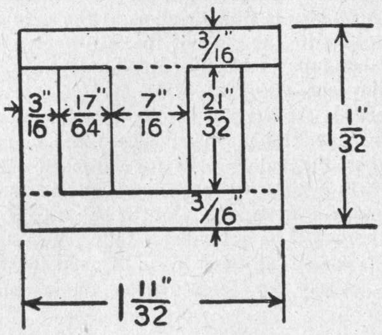
1. Primary, 750 turns.
2. Secondary, $750 \times \sqrt{\frac{5}{1000}} = 53$ turns.

CHAPTER VI—INPUT AND INTER-VALVE TRANSFORMERS (PARALLEL FED).

Core Material.

It is essential for good reproduction of the low frequencies at low levels to have a material for the core which will maintain the inductance at very small values of A.C. magnetization. Ordinary transformer iron has a low initial permeability. Mumetal is the best material at present produced from this viewpoint. It has a higher permeability than other materials, but saturation occurs at a lower value, and hence it is not suitable where power is required.

The best shape for this type of transformer is shown in Fig. 11, together with full dimensions. Another type, having much larger winding window, has had considerable favour, but it will be realised that increasing the cross section of iron will reduce the turns necessary for any given impedance. For this reason the shape shown gives not only a wider frequency band, but also gives a more level response within that range, by reducing tendencies to L.F. and H.F. resonances. The core stack should be $\frac{7}{16}$″, so that the section is square.



No. 21 Lamination

FIG. 11

Turns and Ratio.

If the valve into which the transformer operates is a triode, a secondary composed of 4000 turns of 44 S.W.G. enamelled copper wire will give as good a step-up condition as any smaller gauge. But if the valve following the transformer is a tetrode or pentode, the input capacity will be much smaller, and so further advantage can be gained by reducing the wire gauge, so that the secondary may consist of 6000 turns of 46 S.W.G. enamelled copper wire.

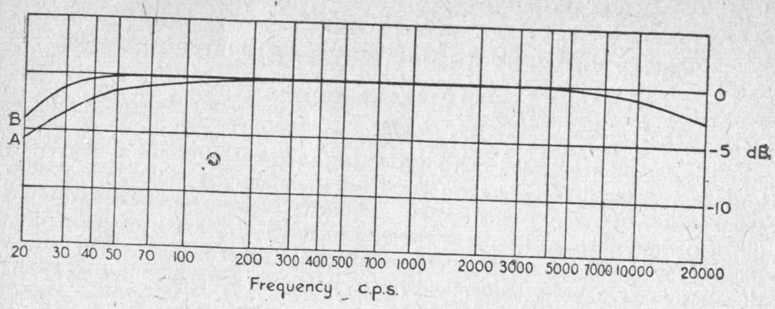


FIG. 12

Fig. 12 shows the form of frequency response when the primary impedance referred to the secondary is 65000 ohms in the case of the 4000 turn winding, or 150000 ohms in the case of the 6000 turn winding. (These curves allow for a valve input capacity, including strays, but not that of the transformer winding, of 100-120 MMF in the first case, and 30-50 MMF in the second case.) At the low frequency end, curve A is for input transformers, or inter-valve transformers, where the coupling capacity is considerably greater than the value given for curve B. Curve B is for an inter-valve transformer in which the coupling capacity is N^2 x 0.16 MF, where N is the transformer step-up ratio. If the value of coupling condenser is smaller than this, there will be a tendency to produce an L.F. resonance in the region of cut-off, which will need to be damped by the method shown later in this section, unless for some reason the resonance should be desirable.

The step-up may be increased by reducing the primary turns, which will increase the impedance referred to the secondary in proportion to the square of the increase in turns ratio. This will result in narrowing the frequency band from both ends. The whole high frequency cut-off curve will be reduced in frequency by the square of the increase in turns ratio. In the cases where curve A applies for the low frequency end, the whole cut-off curve will be raised in frequency by approximately the cube of the increase in turns ratio. In the case where curve B applies, the value of coupling condenser to give the same shaped cut-off will be reduced in proportion to the cube of the increase in turns ratio, when the whole curve will be raised in frequency by the same ratio. These statements are only approximate. Mumetal has the peculiarity that the inductance of any given number of turns using a Mumetal core is reasonably constant below 50 cycles, but above that frequency gradually tends to vary inversely proportional to frequency, so that above about 600 cycles the law is such that the inductance has a constant reactance. Thus if the ratio is increased so that the cut-off begins above 600 cycles, then the effect will change from that of increasing the cut-off, to one of introducing further loss over the entire frequency. Otherwise stated further increase in step-up ratio will not result in further increased true step-up.

Primary Impedance.

In the case of input transformers, the primary impedance is simply that of the device for which the input is matched—microphone, pick-up, etc. In the case of an inter-valve transformer, the primary impedance may be taken as the equivalent parallel resistance of the preceding valve anode impedance and its anode coupling resistance.

Resonances.

It is possible for a peak in the frequency response to appear due to resonance in the region of either the low frequency cut-off, the high frequency cut-off, or both. If the size recommended is used, the possibility of an H.F. resonance is greatly reduced, but use of a small value of coupling condenser may introduce an L.F. resonance. With the older shaped core, necessitating many more turns for the same impedances, both types of resonance were more likely to appear.

With both types of resonance, the peak may be reduced either by increasing the primary impedance or by introducing a secondary shunt resistance in the form of a grid leak. The primary impedance can usually be increased enough merely by raising the value of anode resistance. If this cannot produce sufficient damping without going to too high a value, a resistance may be inserted in series with the coupling condenser, or the value of grid leak adjusted to bring about the desired response. With each of these methods, response at both ends of the scale will be reduced, so that they may be applied if there are two resonances, one at each end. If there is only a resonance at one end, and the other end does not require reduction, then different methods must be applied.

If there is a low frequency resonance but the high frequency cut-off does not need reduction, then a resistance connected across the primary of the transformer (after the coupling condenser, not from anode to earth) will reduce the resonance at the low frequency end, and at the same time have the effect of improving the high frequensy response.

If there is a high frequency peak, but the low frequency response has none, then a resistance connected in series with the grid will reduce the high frequency peak without introducing greater loss at the low frequency end.

Example 13.—An input transformer is required to give the maximum step-up for speech only (200 cycle cut-off) to work into a pentode grid. Find the step-up that can be used from a microphone of 600 ohms impedance.

From the A curve, the 3 dB point is seen to be just above 30 cycles. This means that the cut-off can be multiplied by about 6.4 to bring it to 200 cycles. From the tables the cube root of 6.4 is found to be about 1.85, and the square of 1.85 is about 3.4. Then the referred impedance can be about 3.4 x 150000 ohms, or 500000 ohms. The impedance step-up can be $\frac{500000}{600}$, or nearly 900/1. This gives a turns ratio of $\sqrt{900}$, or 30/1. So the windings on the transformer will be:

1. Secondary, 6000 turns.
2. Primary, 200 turns.

Example 14.—A triode having an anode impedance of 2500 ohms is used with an anode coupling resistance of 10000 ohms. What step-up can be used to give the response of Fig. 12 with a secondary of 4000 turns of 44E, and what coupling condenser should be used?

The primary impedance is the effective impedance of 2500 and 10000 ohms in parallel or $\frac{2500 \times 10000}{2500 + 10000}$ 2000 ohms. This is to be referred to the secondary as 65000 ohms, so the impedance ratio of the transformer is $\frac{65000}{2000}$, or just over 30/1. This gives a turns ratio of just over 5.5/1. The secondary turns are 4000, so an appropriate primary will be about 700 turns. To give the response of curve B in Fig. 12, the coupling condenser should be 30 x 0.16, or 5 MF. Probably a 4 MF, being a standard value, will be adequate. However, this value may be too large to be practical, in which case a smaller one, say 0.5 MF, may be used. A resistance of about 20000 ohms across the primary will damp the resonance, and the cut-off will now be at about 50 cycles.

CHAPTER VII—PUSH-PULL INTER-VALVE TRANSFORMERS

When an inter-valve transformer has to provide signal for the grids of two valves in push-pull, it is essential that each valve should receive its signal identical in amplitude and in opposite phase to the other. For the lower and middle frequencies, accurate division of turns will secure this condition, but for the upper frequencies further precaution must be taken to maintain this balance.

A simple method, enabling an ordinary inter-valve with only one secondary to be used, is that of connecting two equal resistances across the secondary in series, and taking the centre tap of these resistances to earth or grid bias. Then each end of the secondary is connected to one grid. This method suffers from the disadvantage that the capacity between each end of the secondary winding and earth is not equal, and so these two equal high resistances may be regarded as being shunted by unequal capacities, which, of course, upsets the balance at the high frequency end.

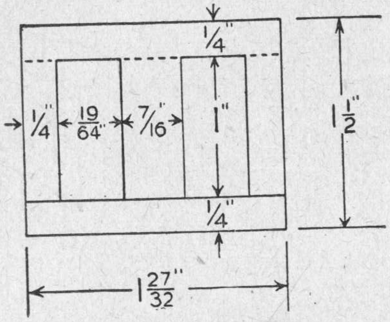
The better method is to wind two separate secondaries so that they are equally well coupled to the primary, and have as near as possible the same capacity from their " live " end to earth. On the size detailed in the previous section, this may be achieved by winding one secondary of 3000 turns before the primary, and then the other secondary of 3000 turns after the primary. The difference in winding capacity will not be great, and will in practice be much smaller than the input capacity of the valves, which will thus help to reduce the effective inequality. The two ends of the secondaries adjacent to the primary should be connected together to form the centre tap, while the extreme ends go to the grids.

As each grid is now only across one half as many turns, and the turns are rather better coupled to the primary, the input capacity per grid may be rather more than twice the figure given in Chapter VI, to obtain the same high frequency characteristic—i.e., about 70-120 MMF. Thus, the ratio may be calculated by making the impedance ratio from primary to the whole secondary such that the primary impedance is stepped up to about 150000 ohms.

If push-pull feed back is being used, or separate grid returns for bias purposes, the two " inside " ends of the secondary may be brought out separately for the purpose.

In designing push-pull transformers on this size, it is necessary to make sure that a certain voltage limit is not exceeded, otherwise distortion will be quickly introduced. A safe figure may be taken as 80 turns per volt at 50 cycles. This means that the total voltage across 6000 turns should not exceed 75. If negative feedback is being used, do not forget to add the feedback voltage to the grid to grid voltage, as this will be the total voltage required across the transformer secondaries.

If this voltage limit is going to be exceeded, then a larger size is necessary. If possible, a lamination size similar in shape to that of Fig. 11, but larger, should be chosen, and all the details multiplied up proportionately. The safe turns per volt will decrease as the cross-sectional area of the core increases. Thus, if a ⅝" stack of a size having a centre limb width of ⅝" is used, the area is ⅝" x ⅝", instead of $\frac{7}{16}$" x $\frac{7}{16}$" or about double. Therefore the safe turns per volt is reduced to about half, or 40. If 6000 turns were still used for the secondary, the safe voltage at 50 cycles would be 6000/40 = 150—twice the previous figure. At present the author knows of only one lamination manufacturer who has tools for such a size, and to date this size has not been produced in Mumetal. A similar overall size is obtained by use of the lamination shown in Fig. 13, which is supplied in Mumetal.



No.36 Lamination

FIG. 13

On this shape, the safe turns per volt are the same as with the smaller size, because the cross-section of the centre limb is the same. So higher voltage can only be accommodated by increasing the turns. Multiplication by 1.4, to 8500, and using the same referred impedance, with a divided secondary, will give approximately the same results as those shown in Fig. 12. This gives a safe grid-to-grid voltage at 50 cycles of 105. If step-up is increased beyond this point by simply increasing the secondary turns (thereby increasing the ratio), the cut-off at the top end of the scale will fall in the same way as shown for a corresponding increase in ratio in Chapter VI, but the L.F. cut-off will remain unchanged. If the safe voltage is increased by increasing primary and secondary turns proportionately (thereby maintaining the same ratio), then the low frequency cut-off will be reduced to a lower frequency, and the high frequency cut-off will be reduced by a less amount, but it will progressively begin to show signs of peaking. This peak can be reduced by the methods outlined in Chapter VI.

CHAPTER VIII—CONSTRUCTION DETAILS

Preparing a Bobbin.

Unless a bobbin of the correct size is available ready-made, it will be necessary to fabricate one. Details are given here of two types that are simple to construct without special tools.

Fig. 14 illustrates the method with the first type, which is suited for the smaller sizes, as it gives adequate strength to support a small winding, whilst taking up little of the available winding space. It should be constructed from stiff cartridge paper, or similar material. Five pieces should be cut, according to the final required dimensions, one as at (a), and two each as at (b) and (c). A centre block, as at (d), will be required to support the bobbin while winding, and may also be used in making up the bobbin. Great care should be taken in the construction of this centre block, to ensure that all its faces are "square," and to the correct dimensions (very slightly larger than the core cross-section, and a little shorter than the window length, about 1/64″). Also, to see that the hole drilled through it is absolutely parallel to its sides. The method of bending each of the parts is clearly shown in sketches (e), (f) and (g) of Fig. 14. At each stage the parts of the bobbin should be carefully glued so that the whole bobbin is united by glue, but is not stuck to the centre block, as this has to be removed after winding. After the glue has set, small holes may be drilled or punched in the cheeks of the bobbin, so that the winding leads may be brought out and properly anchored. Finally, end support plates will be needed during winding. These should be made of metal or wood, and secured in position by the centre spindle as shown at (h). The holes drilled in both the centre block and the end support plates should be only just the required clearance hole for the size of centre spindle to be used—say, 2 B.A. Nuts on the centre spindle are used to secure the whole assembly, and should be tight enough to secure that the spindle will not turn by itself inside.

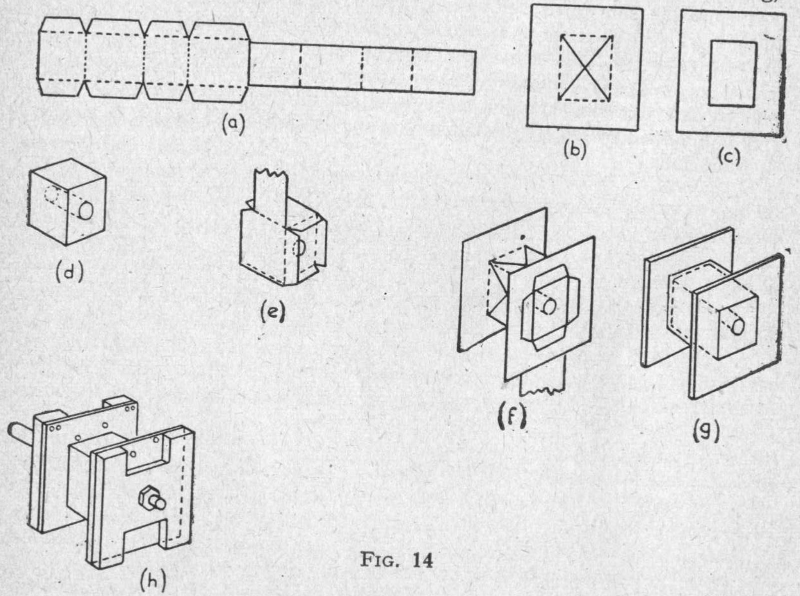


FIG. 14

Fig. 15 shows a method of construction for larger bobbins, where the fabricated bobbin would not be strong enough to support the winding. It is made of bakelized paper or cloth sheet, about $\frac{1}{16}$″ thick. It has the advantage that all the parts can be cut from sheet—no tube is required—and that the "tags" on two of the centre-pieces prevent the cheeks from falling off during or after winding. Two pieces each are required as sketched at (a), (b)

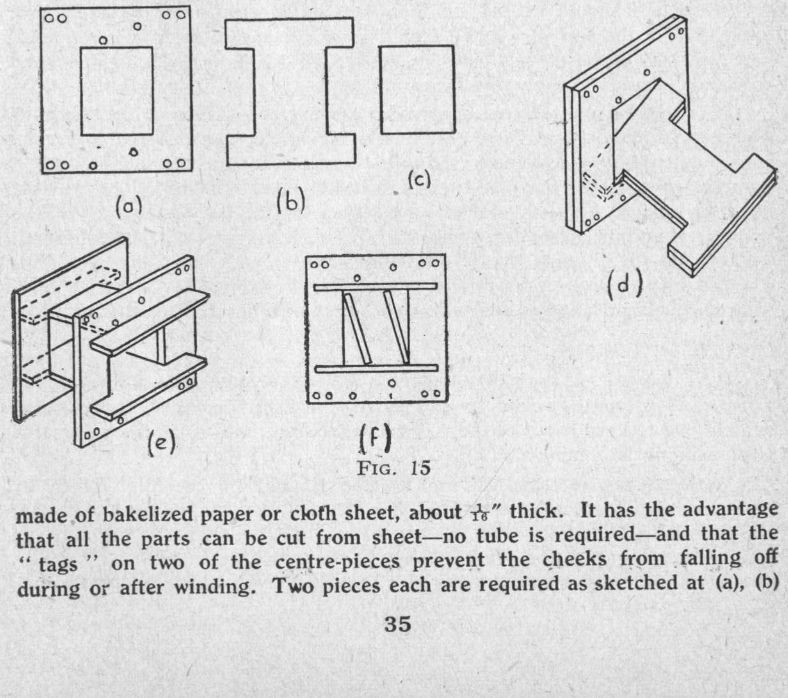


FIG. 15

and (c). Necessary holes in the cheeks for lead-outs and anchoring may be made before the bobbin is assembled. The method of assembly is clearly shown by sketches (d), (e) and (f). A centre block and end support plates will be required, to mount up for winding. The centre block will be exactly the same in form as that shown at Fig. 14 (d), but the end support plates must be different, being only simple rectangular pieces with a hole in the middle, of such dimensions that they fit conveniently between the end "tags" of the centre-pieces. A spindle will again be required, but for the larger sizes should not be relied upon to turn the bobbin during winding. It is suggested that one or two additional small holes be made in the end plates and centre block, through which steel pins should be inserted to provide means of obtaining a positive drive to the bobbin.

Improvising a Winding Machine.

Two fundamental arrangements are necessary for successful winding: a means of rotating the bobbin, and some provision for holding the reel of wire. A lathe makes a very successful winding machine. For the smaller sizes a standard three or four jaw chuck can be used to grip the centre spindle. For larger sizes, the pins already inserted into the centre block may be arranged to take a drive by bearing against the jaws of the chuck.

If a lathe is not available, an ordinary wheel-brace mounted in a vice so that the chuck rotates in a horizontal position, will serve as a good substitute. It will be found rather laborious, operating by hand, if a great many turns are required.

A spindle should be set up in a horizontal position a little distance away to hold the reel of wire so that it is free to rotate as wire is required. The wire should be passed between the thumb and first finger of one hand to steady it and to apply the necessary tension.

It is a great convenience to provide some means of counting turns. If a proper turns counter is not available, a cyclometer can be used as a good substitute. The turns counter should be coupled to the machine so that it numbers upwards in the direction of rotation when winding. The winding direction should be such that the wire goes on to the upper side of the bobbin. If an improvised turns counter is used, it may not register coincident with turns—i.e., it may take 5 turns to register each 1. This should be checked up before it is used, and the required readings at start and finish worked out in advance so that all attention can be devoted to winding.

Methods of Winding.

Wire gauges of, say, 24 and larger may be brought out of the bobbin direct, and a length wound around either the centre spindle or some convenient peg to keep it out of the way while winding, until it can be terminated after winding is complete.

Wire gauges of, say, 26 and smaller should be carefully joined by soldering to a piece of silk-covered flex, taking care that a neat, flat joint is made that will not take up too much room, and will not cut through and cause short-circuited turns. It should be insulated at the joint by means of a small piece of insulating material. The silk flex should come out through the hole in the bobbin, and should make about two turns round the bobbin before the proper wire gauge " takes over." The silk flex should be anchored conveniently to await proper termination after winding.

All windings should be wound so that one turn lays as close as possible to its neighbour, until a layer is full, when another layer should be commenced in the return direction. On larger size coils, a layer of paper insulation will be inserted every layer, or perhaps every few layers, to prevent a turn from a high layer from slipping down into contact with lower layers. On smaller coils, and particularly with the very small gauges (beyond, say, 36), it is not possible to insulate the layers in this way, and a method known as " random " winding is employed. The turns still go on approximately in layers, but it is not possible to guarantee that no space is lost between adjacent turns of the same layer, and so later turns may fill spaces left previously. In winding by this method care should be taken that the winding builds up level along the whole width of the bobbin, otherwise useful winding space will be wasted. For this reason it is especially important, too, that the bobbin shall rotate " true." This means that when the centre is spun before winding is commenced, the four sides of the centre must turn parallel with the spindle, and not show any sign of a skew wobble, and further the cheeks must not show any sign of wobble from side to side.

At the finish of the winding, the end should be brought out in the same way as the beginning was, according to the gauge being used.

Insulation.

Between windings, as well as between the layers on larger sizes, a layer or two of insulation must be provided. Two or three layers of very thin material are better than one layer of thicker material. This should be cut to the exact width between the bobbin cheeks, and wound on carefully and tightly over the winding. The insulation may be of thin high-quality paper, or may be of one of the acetate substitutes. Before proceeding with a further winding, the insulation should be firmly secured in position by the use of a little adhesive. For paper, some Chatterton's compound, or, as an alternative, some high-quality wax, may be used to fix the last turn of the paper to the preceding one by applying quickly after heating momentarily on the butt of a soldering iron. If one of the acetate films is used, a little acetate may be quickly applied to weld the film, but care must be taken to see that no acetate comes into contact with the wire if it is enamel insulated, as the acetate may dissolve or soften the enamel and cause turns to short.

Terminating the Windings.

After winding is complete, a layer of insulation should be wound on to cover the windings and insulate them from possible contact with the outside limb of the laminations. Then all the ends of windings should be properly terminated. The ends should each be threaded through the pairs of holes in one of the corners of the bobbin several times. Before so threading, the whole length that will go through the holes should be stripped of insulation. The threading should allow the portion of lead from the hole where it comes out of the bobbin to the corner where it is threaded to lie slack. If it is tight, it may break later, especially if the bobbin cheek is slightly flexible and may bend. After threading in this way, the end should be quickly tinned with a soldering iron, which will secure it, and also provide a form of tag to which the external leads can be soldered.

Laminating and Finishing.

Care must be taken when inserting the laminations that they do not damage the winding. For a choke, or a transformer in which there is D.C. flowing, all the E-shaped pieces, or T-shaped pieces, should be inserted first from the same side, until the centre of the bobbin is full of laminations. An equal stack of I- or U-shaped pieces should then be taken, and brought into contact with the E's or T's with the appropriate gap spacing. Some form of clamps will be necessary to hold the whole core together and keep the gap tight up to the spacing used. These can easily be improvised, using an appropriate width of strip metal which can be drilled for clamping bolts either side of the laminations, and possibly the end of the clamps can be turned over to form mounting feet for the completed component.

For transformers with no D.C. the laminations of different shapes should be inserted from opposite sides of the bobbin in pairs. A convenient way of doing this quickly is to arrange a small stack of each shape on each side of the bobbin. Then, by working with both hands, alternate pairs may be picked up and inserted quite quickly. When laminating is complete, similar clamping arrangements to those suggested for the choke may be employed.

Ordinary transformer iron is very subject to attack by rust, so it is a good plan, when the component is complete, to paint the exposed edges of the core with a good quality paint as a protection against rust.

The clamps may be bent at one end to provide feet for mounting, and at the other end to take a bakelized sheet panel on which soldering tags or terminals are mounted to make a finished terminal board for the transformer or choke.

CHAPTER IX—METHODS OF TESTING

Turns Ratio.

This is comparatively simple to check, if there is available A.C. mains, two A.C. voltmeters, and a variety of odd resistances. At least one of the voltmeters should be a high-grade multi-range instrument. The other may be any indicating instrument that will give a consistent indication when the same volts are applied. In this case, readings on the poorer instrument may be calibrated by comparing the two instruments in parallel on the same voltage, adjusting the voltage to various values by means of different arrangements of resistances.

It is important when checking turns ratio that an A.C. voltage no higher than that for which any given winding is designed shall be used. Having checked on this by calculation, readings can be taken of the voltage across the two windings, first by feeding a voltage into the primary and measuring the voltage on both primary and secondary simultaneously with the aid of both voltmeters, then by feeding a voltage into the secondary. The ratios of these two sets of readings can then be calculated, and if there is any discrepancy between them, the mean value may be taken as the correct one.

Frequency Response.

This requires more apparatus than the previous test. An audio oscillator is needed, together with some voltmeters whose performance at various frequencies besides 50 cycles is reliable. Also, the conditions under which the component is to operate must be simulated. That is, the primary must have the signal applied to it from an impedance equal to the one which it will have in practice, and the secondary must work into the same impedance as that for which it is intended. If it is designed to operate with D.C. flowing in one winding, then this condition, too, must be reproduced in testing its response.

Transformers with no D.C. Components.

Fig. 16 shows a way in which components of the types detailed in Section V may be tested. The resistance between the primary voltmeter and the actual primary is equal to the equivalent source impedance. In the case of a push-pull output transformer (class A) it will be twice the anode impedance of each valve. The resistance across the secondary is equal to the required load impedance at the secondary. It should be noted that the primary source impedance is not the same as the optimum load at the primary side. It may be more (as in the case of transformer to work with tetrodes or pentodes) or less (as in the case of transformer to work with triodes).

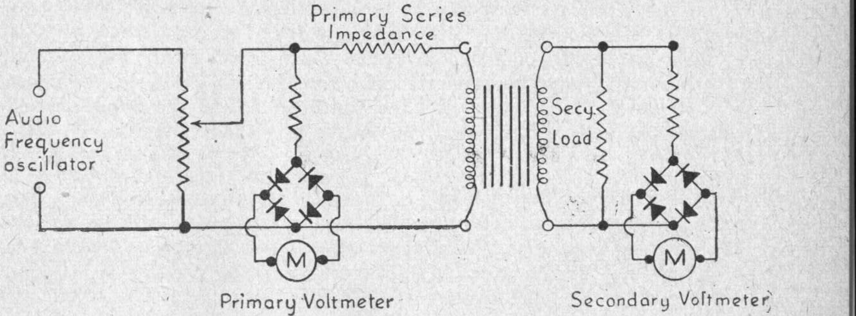


FIG. 16

A frequency response may be taken by setting the voltage at the primary voltmeter to the same reading, and then noting the reading on the secondary voltmeter. If the readings on the secondary voltmeter are plotted against frequency on graph paper, a frequency response will be obtained.

In the case of loudspeaker transformers, the source impedance should be that of the output valve, as it will be referred to the primary of this transformer.

Example 15.—An amplifier has output valves having an anode impedance of 2500 ohms each, and an optimum load of 8000 ohms anode to anode. This is matched to 250 ohms. From this it is distributed to several speakers. One of these is intended to take one-eighth of the output.

The output transformer has a step-down of $\frac{8000}{250}$ or 32/1 impedance ratio.

Thus, the source impedance at the secondary will be $\frac{2500}{32} = 78$ ohms.

The share of this applicable to a speaker taking one-eighth of the power will be 8 × 78, or 625 ohms, while the load impedance referred to this primary, due to its own speaker load on the secondary, will be 8 × 250, or 2000 ohms.

Parallel Fed Inter-Valve Transformers.

The primary source impedance for these may be simulated in the same way, but the secondary must also be arranged to have the same loading as in practice. This may be only at the grid or grids of the next stage. In this case, the meter itself would impose a load which would falsify the reading. So the secondary must be connected to valve grid, or grids, in the same way as it will be in practice, and the signal voltage in the anode circuit can be read by resistance capacity coupling to a voltmeter.

Transformers with D.C. Flowing.

The simplest method of testing the frequency response is to set up the actual operating conditions. A voltmeter measuring the volts applied to the grid of the valve into whose anode the primary of the transformer is connected is set to the same reading at different frequencies. The secondary reading is taken in the same way as before, according to whether it is an output or inter-valve transformer.

Air Gap Adjustment of Chokes and Transformers carrying D.C.

A simple method of doing this is to set up a full-wave rectifier circuit with no smoothing. Across this, connect the component to be tested in series with a resistance to limit the D.C. to its rated value. If, on measuring the A.C. component across the choke, this is more than required in practice, a suitable reservoir condenser should be applied across the supply to reduce it to a practical value. Check that the D.C. flowing is correct, as altering the reservoir condenser alters the output of a rectifier. Having ascertained that D.C. flowing and A.C. across are correct, connect the A.C. voltmeter in series with a D.C. blocking condenser across the resistance in series with the choke, and adjust the gap. The highest inductance will be when the voltmeter across the resistance shows the lowest reading.

Winding Insulation.

The insulation between windings and between each winding and earth should be tested with a suitable " flash test " device. This is simply a fairly high voltage (higher than that which the insulation must stand in practice), either A.C. or D.C. In series with the supply on one side is a high resistance, sufficient to limit a short-circuit current to about 5 mA., and a neon bulb. The other side is connected to an earth plate on which the component can be placed for test. To the high potential side is connected an insulated test prod. The usual procedure for a transformer would be as follows: Earth secondary with a lead and apply test prod to primary; earth primary with lead and apply test prod to secondary. The neon should not light in either case. Finally, to check the tester connection, the prod may touch the earth plate, when the neon should light.

In the case of a choke, of course, the component is simply placed on the earth plate and the prod applied to the winding terminals.

Shorted Turns Tester.

A useful adjunct to the regular winder is some device to detect the existence of shorted turns before the component is cored up, thus saving time if the component should prove faulty.

A simple method of constructing such an instrument is to make up a simple triode feed-back oscillator of any type (to give, say, 400 cycles), using for the coil an inductance wound on an iron core of similar or slightly cross-section to the components to be tested. Instead of making this inductance in the usual way of an iron-cored inductance, it is so arranged that the core is open and can have the coil to be tested placed over the core adjacent to the inductance coil of the oscillator, which is arranged so that it can be adjusted by means of a variable bias control, so that it only just operates. Under this condition, if the coil applied for test has any shorted turns, then the oscillation will either stop, or be greatly reduced in amplitude. On the other hand, self-capacity in the coil applied will only alter the frequency slightly.

CHAPTER X—CALCULATION OF WIRE GAUGE

The table in this section enables the correct wire gauge to be chosen to get a given number of turns into a given winding space. For each wire gauge, with its covering there appears two figures: the figure for turns per inch should be used for cases of layer winding, and the figure for turns per square inch for random winding. To illustrate the use of these tables, the wire gauges for each example given in the previous sections is worked out below.

Example 1.—The winding area in this case (see Fig. 1) is 0.275 sq. in. It is required to get 6300 turns into this space. This is equivalent to $\frac{6300}{0.275} = 23000$ turns per sq. in. 38 S.W.G. enamelled only gives 21000 turns per sq. in., so the next even gauge will be 40 S.W.G.

Example 2.—This is on the same size, but as the turns are fairly low, it should be possible to layer-wind it. Using 32 S.W.G. enamelled gives 83 turns per inch, or just over 50 in a $\frac{5}{8}''$ layer. This requires $\frac{1650}{50} = 33$ layers. At 83 turns per inch 33 layers will occupy a depth of $\frac{33}{83} = 0.39''$. If the paper used is 0.003″ thick, 33 layers will take up 0.1″, total 0.49″. This allows enough for top insulation to make up $\frac{1}{2}''$.

Example 3.—Using the figure from Table 3, the winding space will be about $\frac{7}{8}'' \times \frac{3}{8}''$, or 0.33 sq. in. The turns will be 6300 × 3.2 = 20000. This requires $\frac{20000}{0.33} = 60000$ per sq. in. 44 S.W.G. enamelled gives 65000 per sq. in.

Example 4.—900 turns will again be layer-wound. Using 22 S.W.G. enamelled gives 33 turns per inch, or 70 per $2\frac{1}{8}''$ layer. 900 turns at 70 per layer requires 13 layers, say 14, as there will be very little clearance. 14 layers at 33 turns per inch will take up $\frac{14}{33} = 0.43''$. Allowing for layer insulation will bring this to about 0.48″. This leaves a good clearance, but it will probably be needed with a fairly heavy wire gauge and a long-shaped bobbin.

Example 5.—In this case there are two windings, one of 2400 and one of 12000, to be wound in a space of 0.86 sq. in. 40 S.W.G. enamelled gives 31500 turns per sq. in. Thus, 12000 takes about 0.4 sq. in. For the primary, 34 S.W.G. enamelled gives 9400 turns per sq. in., so 2400 turns takes up $\frac{2400}{9400} = 0.266''$. Total area, 0.666″. This allows good margin for insulation.

Example 6.—In this case the two windings have to occupy 0.56 sq. in. 12000 turns, as before, take 0.4 sq. in. in 40 S.W.G. enamelled. Using 42 S.W.G. enamelled, 43000 turns per sq. in., 12000 turns take $\frac{12000}{43000} =$ 0.28 sq. in. 4000 turns of 40 S.W.G. enamelled take 0.135 sq. in., total 0.415 sq. in.

Example 7.—Here, again, layer-winding will be used. For the 3800 turns, using 36 S.W.G. enamelled, 116 turns per inch gives about 156 per layer ($1\frac{3}{8}''$). This requires $\frac{3800}{156} = 25$ layers. 25 layers will take $\frac{25}{116} =$ 0.216″ for wire, and at 0.003″ per layer insulation, 0.075″, total 0.291″.

For the 220 turns, using 20 S.W.G. enamelled, 26 turns per inch gives 35 per layer. This will require 7 layers, taking up $\frac{7}{26} = 0.27''$ for wire, and 0.021″ for insulation, total 0.291″. Total depth of both windings 0.582″, which leaves room for insulation between windings and on top in a bobbin of depth $\frac{5}{8}''$ or 0.625″.

Example 8.—Using the size from Table 2. Layer length $\frac{5}{8}''$, depth $\frac{1}{2}''$. Using 36 S.W.G. enamelled for 1850 turns: 116 × $\frac{5}{8}''$ or, say, 70 turns per layer, gives $\frac{1850}{70} = 27$ layers. Wire $\frac{27}{116} = 0.233''$, insulation 0.081″, total 0.314″. Using 22 S.W.G. enamelled for 74 turns. 33 × $\frac{5}{8}''$ or 20 turns per layer, gives 4 layers. Wire $\frac{4}{33} = 0.122''$, insulation 0.012″, total 0.134″. Total winding depth 0.448″, which allows room for insulation between and on top of the windings.

Example 9.—A 1″ waste-free will allow a layer length of $1\frac{3}{8}''$, and a total depth of $\frac{7}{16}''$. Using 34 S.W.G. enamelled for primary windings: Turns per layer, $1\frac{3}{8} \times 97$—say, 130. Each half primary takes $\frac{960}{130}$, or 8 layers (always take next whole number). Depth for wire $\frac{8}{97} = 0.083''$, for insulation 0.024″, total per half 0.107″, for whole primary 0.214″. Using 20 S.W.G. enamelled for secondary, giving 35 turns per layer, requires 3 layers, taking 0.116″ for wire, 0.009″ for insulation, total 0.125″. Total depth for windings 0.339″. Using 3 layers of 0.003″ each between windings and on top, gives 0.027″, total 0.366″, which allows about $\frac{1}{16}''$ clearance on top.

Example 10.—Each quarter primary will use 4 layers of 34 S.W.G. enamelled, taking 0.054″ (including insulation). The half primary 8 layers taking 0.107″, total for primary 0.215″. Using 30 S.W.G. for the secondaries. 4 layers taking 0.068″, total secondary space 0.136″, total winding depth 0.351″. Inter-winding insulation, as before, 0.045″, total 0.396″.

Example 11.—A $\frac{3}{4}''$ waste-free will allow a layer length of 1″, and a depth of $\frac{5}{16}''$. Using 38 S.W.G. enamelled, 13 layers, with insulation 0.130″. And for secondary, using 22 S.W.G. enamelled, 5 layers, with insulation 0.167″. Total, 0.297″.

Example 12.—For the primary, using 32 S.W.G. enamelled requires 10 layers, taking, with insulation, 0.150″. For the secondary, 2 layers of 20

S.W.G. enamelled will just fit in. This will take, with insulation, 0.083″; or, if another layer is required for the last few turns, 0.125″. Total, 0.275″.

Example 13.—Here the winding space may be taken as $\frac{9}{16}'' \times \frac{3}{16}''$, or 0.105 sq. in. 6000 turns of 46 S.W.G. enamelled will occupy $\frac{6000}{110000} = 0.055$ sq. in. Allowing that only about 70% of such a small space can be utilised—i.e., $0.7 \times 0.105 = 0.073$ sq. in.—this leaves 0.018 sq. in. for the primary. If 200 turns are to go in 0.018 sq. in., there would be $\frac{200}{0.018} =$ 11100 per sq. in. 36 S.W.G. enamelled gives 13400 per sq. in.

Example 14.—4000 turns of 44 S.W.G. enamelled will occupy $\frac{4000}{71000}$ or 0.057 sq. in. This leaves about 0.016 for the primary. If 700 turns go in 0.016 sq. in., there would be $\frac{700}{0.016} = 4400$ per sq. in. 30 S.W.G. enamelled gives 5300 per sq. in.

TABLE NO. 11

S.W.G.	Enamel Covered		Enamel and Single Silk Covered		Single Silk Covered		Double Silk Covered		Single Cotton Covered		Double Cotton Covered	
	Turns per inch	Turns per sq. in.	Turns per inch	Turns per sq. in.	Turns per inch	Turns per sq. in.	Turns per inch	Turns per sq. in.	Turns per inch	Turns per sq. in.	Turns per inch	Turns per sq. in.
16	14.8	219	14	196	14.8	219	14.4	207	13.8	190	13	169
18	19.6	383	18.9	357	19.8	392	19.4	376	18	324	16.8	282
20	26	675	24.5	600	26	675	25.2	635	23.5	550	21	441
22	33	1090	31	960	33	1090	31.8	1010	29.2	850	25.3	640
24	41.5	1720	38.5	1550	42	1760	37	1370	36.5	1330	31	960
26	50	2500	48	2300	50.5	2550	48	2300	43	1850	35	1225
28	61	3700	57	3250	61	3700	57	3250	50.5	2550	39	1520
30	73	5300	67	4500	72	5200	66.5	4400	57	3250	44.5	1980
32	83	6900	76	5800	82	6700	74	5500	63	4000	48	2300
34	97	9400	88	7750	94	8850	84	7050	69	4760	51.5	2650
36	116	13400	102	10400	112	12500	97	9400	85	7200	59.5	3550
38	145	21000	125	15600	135	18200	113	12700	98	9600	67	4500
40	178	31500	151	22700	160	25600	132	17400	112	12500	76	5800
42	208	43000	175	30500	188	35400	158	25000	—	—	—	—
44	255	71000	208	43000	222	49000	182	33000	—	—	—	—
46	330	110000	255	71000	270	75000	212	45000	—	—	—	—

TABLE NO. 12

Ratio	Square	Cube
1.1	1.21	1.33
1.2	1.44	1.73
1.3	1.69	2.20
1.4	1.96	2.75
1.5	2.25	3.38
1.6	2.56	4.10
1.7	2.89	4.92
1.8	3.25	5.83
1.9	3.61	6.85
2	4	8
2.2	4.84	10.64
2.4	5.76	13.82
2.6	6.76	17.55
2.8	7.84	21.9
3	9	27
3.2	10.25	32.8
3.4	11.56	39.3
3.6	12.96	46.6
3.8	14.44	54.8
4	16	64
4.2	17.64	74
4.4	19.4	85.2
4.6	21.2	97.2
4.8	23	110.8
5	25	125
5.5	30.25	166.2
6	36	216
6.5	42.25	275
7	49	343
7.5	56.25	422
8	64	512
8.5	72.25	614
9	81	729
9.5	90.25	858
10	100	1000

NOTES

NOTES

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