AUDIO HANDBOOK No. 3

The Use of a.f. Transformers

N. H. CROWHURST, A.M.I.E.E.

To work properly an a.f. transformer, like a valve, requires suitable circuit values. This book shows in detail how circuit values affect a.f. transformer performance.
Simple-to-use charts are provided to find a circuit suitable for any a.f. transformer, with the aid of a detachable special ruler.
An appendix lists the parameters of stock lines by leading manufacturers—input, interstage, drive, output and matching types.

With 44 diagrams drawn by the Author

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ILLUSTRATIONS

INTRODUCTION

For many years now there has been a general prejudice against the use of transformers in audio circuits except where absolutely necessary. Quality enthusiasts have aimed at transformerless amplifiers, and circuits have even been devised to eliminate input and output transformers.

Much of this prejudice is due to lack of understanding of the functional details of an audio transformer. Plenty of good components are available, and properly used they need introduce no more distortion than the ingenious circuits which have been devised to eliminate them. When properly understood audio transformers will be found to have a useful place in audio circuitry. Essential features in the presentation of this book are the charts for predicting performance in varying circuits and the appendix giving practical data of manufacturers' products.

The author would like to take this opportunity of thanking the manufacturers listed in the appendix for their co-operation in making this data available. When preparation commenced it was hoped that a larger number of manufacturers could be included, particularly some of the American companies. To make this data available, each manufacturer has had to adopt one of three courses: (*a*) making the necessary measurements himself, which are non-routine from his production view-point and hence require special facilities not normally catered for; (*b*) supplying samples of each component so that measurement could be made; (*c*) supplying complete internal data of the construction of the transformer from which the necessary data could be derived. The English manufacturers listed have all co-operated in one or more of these ways.

The fact that none of the American manufacturers has so far been able to co-operate should not be taken as a reflection on them, because of the particular difficulties involved for them in each of the above courses. Making the necessary measurements themselves required man-hours which were not available; supplying samples for measurement is out of the question due to current trade restrictions; while the supplying of internal data, especially for release outside their own country, is understandably against their policy. The author is confident that this presentation of information about audio transformers will prove its value; he feels sure that our American friends, when they have seen the presentation, will want to avail themselves of the opportunity of being included in later editions. Meanwhile, American readers can apply the methods presented in the book to home-bought components by using the simple measurement procedure outlined in Chapters 1 and 4.

The older reader may have noticed that technical literature has tended to make circuits go by fashions. For instance, when the cathode follower was first introduced, ingenuity led to its being applied on every available occasion, sometimes useful and sometimes merely to incorporate the latest fashion in circuits. In drawing attention to the usefulness of audio transformers the author does not wish to start a vogue returning to wide scale use of them at every stage in a circuit; but it is hoped that a proper understanding of how to apply them will enable technicians and engineers to give a useful component its rightful place.

London, 1952. N. H. CROWHURST.

I

ASSESSING THE PERFORMANCE

AUDIO transformers have come to be viewed with a certain amount of suspicion and for a long time the policy has been only to use an audio transformer where absolutely necessary. Which usually means at the input and output of an amplifier. Probably some of the suspicion is the outcome of some early efforts at producing audio transformers, based on the idea that all an audio transformer needed was some sort of core with some turns wrapped round it—some even tried making the core from flattened out cocoa tins! Modern material and design have resulted in a range of audio transformers that can serve many useful purposes, and, if properly used, will not do any of the funny things of which they are so often suspected.

The first thing a user wants to do with an unknown audio transformer is to check up its performance from the various viewpoints in which it could fail to meet his requirements.

Ratio

The first property to check is its ratio. The classic method uses a ratio bridge built round a complicated multi-ratio transformer which is used as a standard, capable of giving steps in ratio at extremely small intervals. By balancing the transformer to be tested against this standard in the bridge circuit the ratio can be checked to such accuracy that one turn too many or too few on either the primary or secondary windings can be detected; but the average transformer user is not interested in knowing ratio to this degree of accuracy. Usually, simple measurements with a voltmeter will enable the ratio to be calculated with quite enough accuracy.

A word or two is necessary here about the precautions necessary to prevent arriving at a seriously wrong answer. The best frequency to use for the test would really be somewhere near the middle of the audio range; but it is often simpler to use a voltage obtained from the mains, and this will give quite good accuracy if precautions are taken to see that the transformer core is not being saturated. Frequencies above the middle of the audio range are likely to give seriously inaccurate results because of the effect produced by the internal reactances of the transformer, leakage inductance and winding capacitance.

To ensure that the transformer is not saturating, the best plan is to compare the voltage across the primary and secondary at a number of settings of an input potentiometer. Figure 1 shows

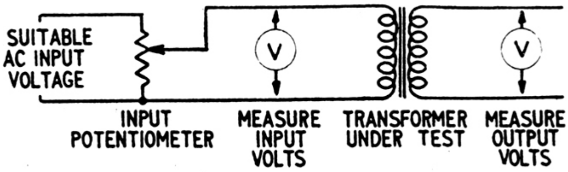


FIG. 1. METHOD OF MAKING RATIO CHECK.

a simple arrangement for such a ratio check. A reasonably high resistance rectifier type voltmeter should be used for making these checks, preferably one of the multi-range types with at least 1,000 ohms per volt.

Having checked the frequency ratio, the user now knows what effect the transformer will have on impedances connected to it: they will be transformed in proportion to the square of the turns ratio; resistances and inductances will be stepped up by a step-up transformer, whilst capacitance will be stepped down by a step-up transformer, and *vice versa.*

Frequency Response

The next thing to check is the frequency response of the transformer. This is not quite such a simple matter as checking ratio.

Many frequency responses are published by manufacturers for their products which are practically meaningless to the user because they do not state the conditions under which the frequency response is taken. As will appear from the later part of this book, it would be quite possible to adjust circuit values to produce an extremely nice looking frequency response which might not be obtained when more practical circuit values are applied. But the reader should not infer that manufacturers who publish these curves are trying deliberately to mislead. Usually the curves have been taken in a circuit similar to the one for which the transformer is intended and which is probably quite a practical circuit. Even so, the manufacturer omits to tell the user what his circuit was, so the response curve only indicates that the frequency response will be somewhere in that region with the nominal impedances values stated in its specification.

What seems to be overlooked in specifying the circuit impedances related to transformer operation is that transformer action is a two-way effect. Take, for example, an output transformer: not only does the transformer multiply the load applied to its secondary by the square of the turns ratio to produce a working load for the anode circuit of the output valves; the a.c. resistance of the output valves is also transformed down, being divided by the square of the turns ratio to appear as a source resistance at the output terminals. From the viewpoint of frequency response the important thing to realise is that the source impedance from which the transformer operates, in this case the a.c. resistance of the output valves, as well as the load impedance into which it feeds, both affect its frequency response.

Some responses have been taken by holding the voltage at the primary terminals of the transformer constant as frequency is varied and plotting the variation of voltage at the secondary terminals as the frequency response. Such a response has no practical significance at all because it is using zero source impedance in effect. All practical circuits work with some actual value of source impedance.

To take a frequency response that has practical significance the input voltage should be applied through a series resistance of the same value as the practical source impedance to be used. Figure 2 shows the arrangement for checking frequency response of an output transformer and Figure 3 for checking the frequency response of an input or interstage transformer. Input or interstage types are best measured working into the grid of the actual valve for which they are designed because there will be the same grid input capacitance applied to their secondary terminals.

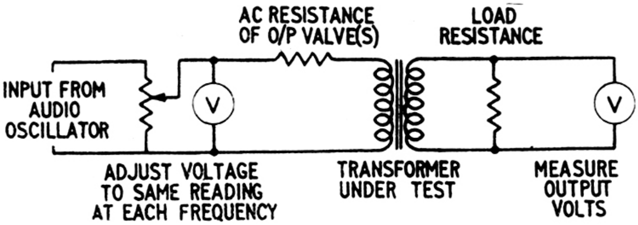
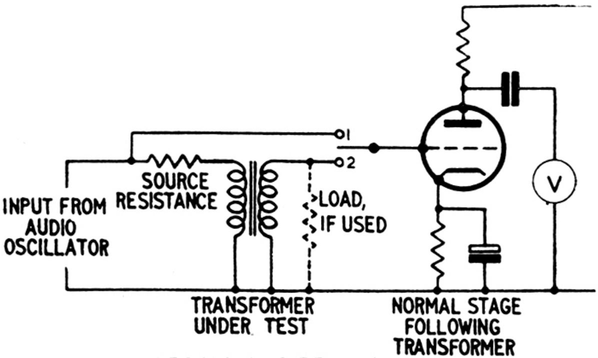


FIG. 2. CHECKING THE FREQUENCY RESPONSE OF AN OUTPUT TRANSFORMER.



WITH SWITCH IN POSITION 1, SET INPUT TO GIVE SAME READING AT EACH FREQUENCY;
READ OUTPUT INDICATION IN POSITION 2.

FIG. 3. CHECKING THE FREQUENCY RESPONSE OF AN INPUT OR INTERSTAGE TRANSFORMER.

Waveform

Having checked the ratio of a transformer and its frequency response, the next thing to do is to check it for distortion. This particularly applies at the low frequency end of the audio spectrum so these tests should be conducted at the lowest frequencies the transformer is to handle. The same circuit as that used for frequency response measurements should be used, but the waveform at the output should be examined on an oscilloscope.

The obvious method of checking waveform is to apply the oscilloscope first to the input terminals, where the input voltmeter is connected in Figures 2 or 3, and then to transfer it to the output terminals. If the waveform at the input terminals is a good sine wave then any distortion to the sine wave apparent at the output must be due to the transformer; but if the input waveform is not a pure sine wave, a change of shape at the output does not necessarily mean the transformer is distorting. The change may be due to the frequency response of the transformer causing different amplification and phase change for the various components of the input wave. Using waveform examination as a means of checking for distortion, the only satisfactory way is to see that the input waveform is a pure sine wave, using filtering to get rid of harmonics if necessary. The classic way of measuring waveform distortion

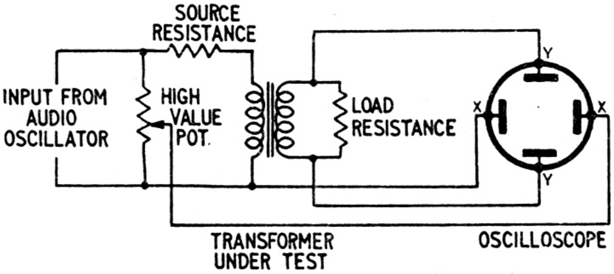


FIG. 4. OSCILLOSCOPE METHOD OF CHECKING FOR DISTORTION IN OUTPUT TRANSFORMER.

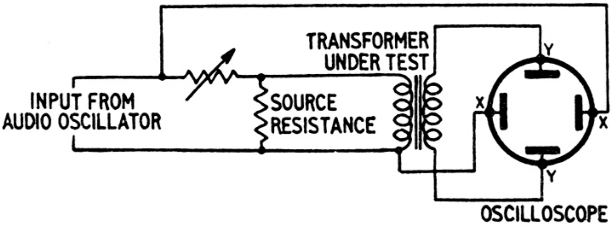


FIG. 5. OSCILLOSCOPE METHOD OF CHECKING FOR DISTORTION IN AN INPUT OR INTERSTAGE TRANSFORMER.

is to put in a good sine wave and measure up the components of various frequencies in the output by means of a wave analyser.

A simple and more direct method of checking for waveform distortion is shown at Figures 4 and 5 for output, and input or interstage types of transformer respectively. Using this method, the absolute purity of the input waveform is not so important. Instead of using a timebase for horizontal deflection of the oscilloscope, the input waveform is used and the output waveform is applied to the " Y " plates in the usual way. The advantage of this method of presentation is that any distortion on the waveform is clearly indicated by deviation from the straight line and the shape of the deviation identifies the cause of distortion more readily than is possible by the classical analysis method, so this way has the advantages of both simplicity of method and clarity of the information conveyed.

Stray Pick-up

Input and interstage transformers for operation at low signal levels may be susceptible to pick-up of stray hum fields or other spurious signals. It is rather difficult to make specific measurements of the efficacy of different kinds of screening in preventing this pick-up.

Manufacturers usually specify the amount of reduction in pick-up that the screening fitted provides; this means that if the transformer is mounted in a uniform hum field out in space, the pick-up in the core is reduced by whatever number of db the specification states when the screen is fitted; but practical hum fields are not usually uniform, due to the fact that the transformer is probably mounted on a chassis and the presence of the chassis distorts the electro-magnetic field causing the trouble. So, although the transformer gives its stated reduction in hum field under idealised test conditions, it may not always give quite such good results under practical conditions. This fact should not be marked up as misrepresentation on the part of the transformer manufacturer: he cannot know exactly what sort of field is going to be found on the amplifier chassis where the user is going to fix the transformer.

The only test of practical use is one using the actual amplifier chassis where the transformer is to be mounted. Having mounted up the transformer and connected it in circuit, the hum level should be measured on a sensitive voltmeter and compared with maximum signal output. To be satisfactory, the hum level should be not greater than .3 per cent. of maximum output voltage and preferably it should be well below .1 per cent.

In making a test of this kind, great care should be taken to see that the hum signal measured is really due to stray pick-up. The simplest way to make certain of this point is to disconnect the primary of the transformer from its associated circuit, twist the leads together and terminate them with a resistance equal to the primary source resistance. The transformer should be removed from its chassis mounting and if it employs a metal case, this should be connected to earth by a clip lead. Now the transformer, while still in circuit on its secondary side, can be moved around to see the effect of stray pick-up. If moving it around in all directions does not affect the hum present in the output, then this hum is not due to pick-up in the transformer and the cause of the hum should be sought elsewhere and remedied before further tests are made. If turning the transformer around does alter the hum level considerably, then it is evident that the transformer is picking up the hum being heard. If possible a mounting position should be found such that the hum is a minimum and of satisfactorily low level. If this is not possible a component with better magnetic screening against hum must be sought.

2

CAUSES OF DISTORTION

AFTER assessing its performance, and checking up on the various points where distortion of signal could occur, the next important thing is to understand clearly the cause of these various forms of distortion.

Frequency Response

This form of distortion has sometimes been called frequency distortion. British Standards Institution recommends calling it attenuation distortion. Although a poor frequency response results in distortion of the input signal so that the output signal differs from it, the author feels that the designation " Frequency Response " is a better heading for consideration of this characteristic.

Any audio transformer—in fact, any piece of audio equipment—fails of perfection, in that the response does not extend uniformly from zero to infinity in frequency, but possesses both a low frequency and high frequency cut-off. By defining this failure as a form of distortion implies that all audio equipment introduces this kind of distortion. In point of fact, provided the response is flat from below the lowest frequency to above the highest frequency, there is no attenuation distortion to the actual signal handled. There may be some phase distortion, at the extreme ends of the range particularly; but this is generally regarded as unimportant in an audio amplifier for its own sake. It is true that phase shift can be important from the viewpoint of feedback amplifier design (this is explained fully in *Audio Handbook No.* 2).

The frequency response of an audio transformer in the middle of its range is almost level, so the critical parts of the spectrum from the viewpoint of distortion are the low frequency and high frequency ends.

Factors affecting the low frequency response of a transformer are its own primary inductance compared with the external circuit impedances and, in the case of parallel fed interstage transformers, the coupling capacitor. Factors affecting the high frequency response of the transformer are the winding capacitances and the leakage inductance between windings.

The idea of winding capacitances is not difficult to grasp, but leakage inductance is a subject that is somewhat misunderstood. It is due to magnetic flux that gets down between the windings instead of going right round both of them through the transformer core, as it should. The flux in the transformer core is governed by the applied voltage and frequency, but the leakage flux is governed by the load current in both windings. If there is no current in the secondary winding then there will be no leakage flux; as current in the secondary windings is increased the leakage flux increases. Due to this leakage flux a difference in voltage between the windings occurs which is not accounted for by the turns ratio of the transformer. The relation between the current, in either winding, and the voltage difference, due to leakage flux because of that current, has the properties of an inductance.

Transformer designers can reduce leakage inductance by sectionalizing the winding so that it is more difficult for flux to creep between sections, (details of this will be given in Handbook No. 5 on Audio Transformer Design). The point to realise here is that the circuit made up by leakage inductance, winding capacitances, and external circuit values, is responsible for determining the high frequency response.

The tendency of leakage inductance combined with winding self-capacitance is to produce a peak at the high frequency end of the response. This suggests that the leakage inductance can be regarded as in parallel with winding self-capacitances. This viewpoint is not quite true. The inductance is best viewed as being in series with winding capacitance, the output being connected across just the capacitance. The reader will remember that if an alternating voltage is applied across an inductance and capacitance in series at their resonant frequency, a voltage appears across both the inductance and capacitance higher than that applied across the two together. This is how the peak appears in the output voltage which is effectively in parallel with the capacitance. This will be better understood after reading the next chapter, on equivalent circuits.

Waveform Distortion

This is generally called harmonic distortion, because it is a distortion that introduces harmonics to a pure waveform, that were not there before. A transformer will not of itself produce appreciable waveform distortion in the middle frequencies of its range. If the load that it provides for the anode circuit of the preceding

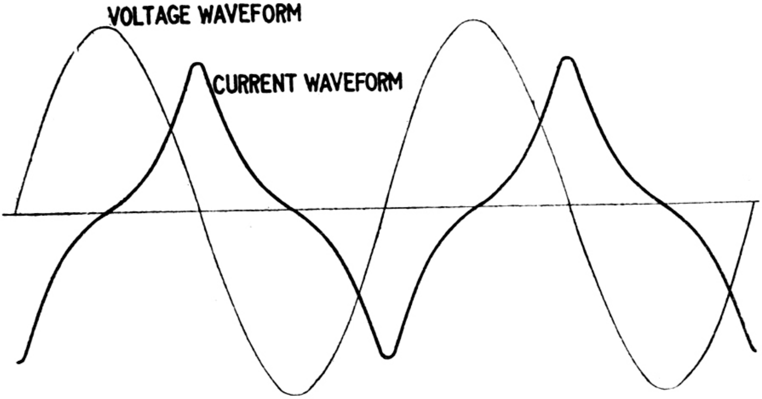


FIG. 6. VOLTAGE AND MAGNETIZING CURRENT WAVEFORMS AS SATURATION IS APPROACHED.

stage is not correct for the valve, then distortion may be present throughout the whole frequency range, but this is not directly due to the transformer.

The only waveform distortion directly due to the transformer appears at the low frequency end of the range and is due to the non-linear waveform of the magnetizing current. Figure 6 shows the corresponding voltage and magnetizing current waveform for a typical transformer approaching its saturation point.

The result of drawing this peaky current waveform from a source possessing resistance, usually the a.c. resistance of the valve, is to produce a distortion in the voltage waveform on both the primary and the secondary. For this reason it will be no use comparing the waveforms on primary and secondary of the transformer, because both will be the same shape, one being larger than the other because of the step-up, or step-down.

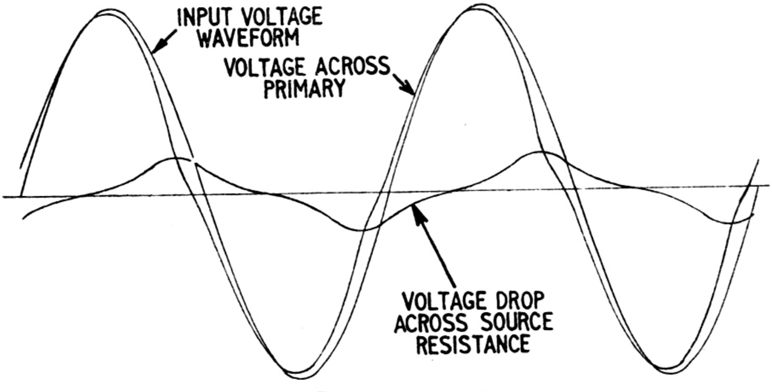


FIG. 7. DISTRIBUTION OF INPUT VOLTAGE ACROSS SOURCE IMPEDANCE AND PRIMARY.

Figure 7 shows how a sinusoidal input voltage is distributed across the source impedance and the transformer primary. The distorted waveform shown as across the primary will merely be enlarged across the secondary.

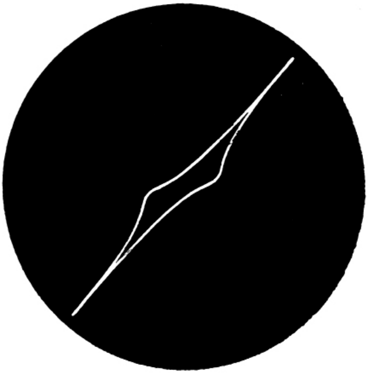


FIG. 8. PRESENTATION OF WAVEFORM OF FIG. 7 ON 'SCOPE SCREEN, USING CIRCUIT OF FIG. 4 OR 5

Figure 8 shows how this waveform will appear on the oscilloscope screen using the method of connection shown at Figure 4 or 5.

Even at low frequencies the waveform distortion produced may not be directly due to the transformer. If the inductance is not sufficient to maintain the frequency response to as low a frequency as may be desired, this will introduce primarily attenuation distortion and phase distortion. However, the low inductance value will shunt the anode load into which the preceding valve is working and this may cause the valve to introduce distortion.

The presence of a shunt inductance causes the load line to become elliptical—Figure 9 shows the effect of adding shunt inductance of progressively lower value in parallel with the ideal

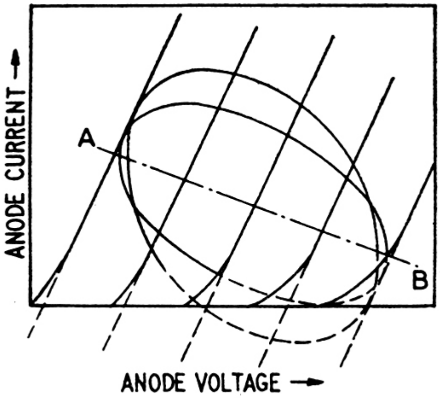


FIG. 9. ELLIPTICAL LOAD LINES DUE TO SHUNTING EFFECT OF PRIMARY INDUCTANCE.

resistance load line, AB. Ideal ellipses are drawn with reference to ideal valve characteristics, each being shown dotted where they depart from the real valve characteristics. This shows where the distortion comes in. In practice, the presence of such a load will modify the operating point somewhat depending on the method of bias used; but Figure 10(*a*) shows the waveform of voltage and current in the anode circuit of the valve. The transformer will pass on a waveform similar to the voltage waveform shown, and the pattern on the oscilloscope screen will take the form shown at Figure 10(*b*).

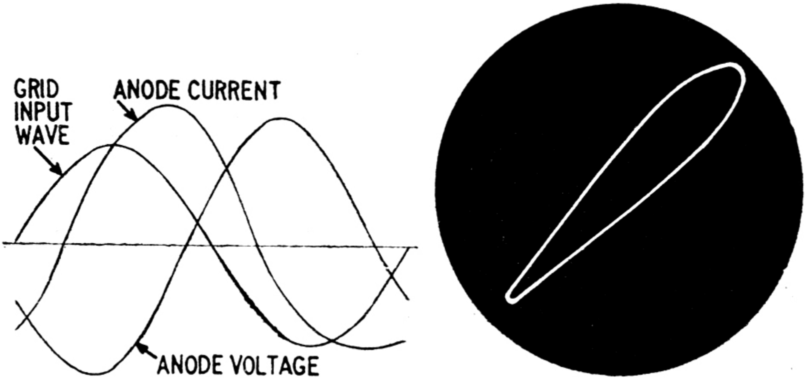


FIG. 10. WAVEFORM DISTORTION DUE TO LOW PRIMARY INDUCTANCE

(a) Voltage and Current Waveforms. (b) Display for method of Fig. 4 or 5.

At the high frequency end of the response the audio transformer can never of itself introduce distortion, but distortion may be caused due to the impedance it presents, either to the anode circuit of the preceding stage, or to the grid circuit of the following stage.

From the viewpoint of the preceding stage, it is again the load impedance provided for the valve that determines when distortion occurs. If a peak occurs due to resonance between leakage inductance and secondary self-capacitance, the impedance reflected into the anode circuit will fall to a value much lower than the mid-band value because the resonant circuit, looked at from the primary, is of the series type.

From the viewpoint of the following stage, the most likely way that a transformer can introduce distortion is by causing parasitic oscillation. To explain this action, the simplest viewpoint is to compare it with the tuned-anode/tuned-grid oscillators used at radio frequencies. These work without any deliberate coupling between anode and grid, simply due to the internal capacitance of the valve and what is known as the Miller effect which this capacitance produces. At a frequency where the anode load possesses inductive reactance and grid circuit has the dynamic impedance of a parallel resonant circuit, the valve will oscillate due to feedback through its anode-to-grid capacitance. This oscillation is dependent upon: the gain of the valve; the value of inductive reactance in the anode circuit; and the dynamic impedance in the grid circuit.

As applied to audio frequency amplifiers, the inductive reactance in the anode circuit will be due to the output transformer in combination with its secondary load. The dynamic impedance of the grid circuit will be due to the resonance between secondary self-capacitance and leakage inductance of the coupling transformer.

Under some circumstances, the output valve would oscillate hard, probably at a supersonic frequency, and attempt to pass audio signal will result in a very broken up reproduction, because the output valve is completely blocked by radio frequency oscillation, except on the louder passages of audio which reduce the amplitude of oscillation momentarily, sufficiently to allow a short burst of audio to break through.

When the effect is not so strong as this, the valve may not oscillate steadily, but may instead produce short bursts of oscillation at certain points in the audio cycle, where the gain of the output valve is higher than average due to the instantaneous position of the operating point on the valve characteristics. This effect is certainly less noticeable than its more violent companion, but it still is evident as a form of distortion.

A particular case, where to avoid the form of distortion just described requires very careful attention in the design of the inter-stage transformer, is that of output stages worked under power drive conditions, *i.e.* where the grids of the output valves are driven positive during part of the audio cycle. The grid circuit must be provided with a low impedance source to prevent waveform

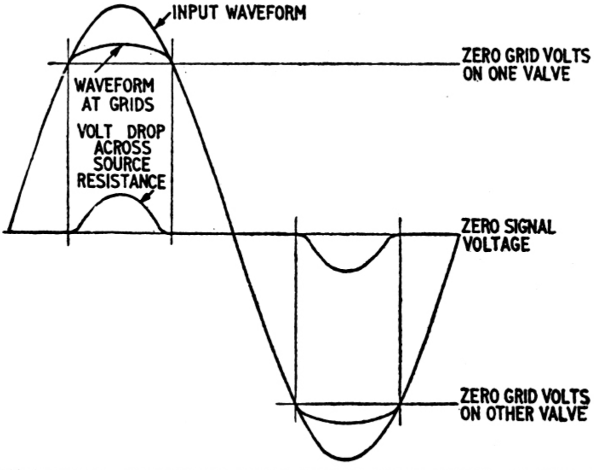
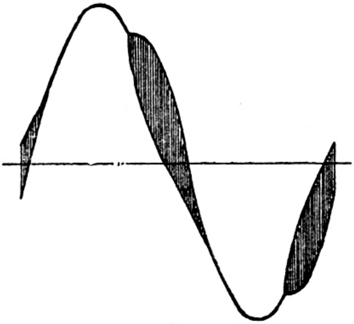


FIG. 11. WAVEFORMS ASSOCIATED WITH POWER DRIVE WHEN SOURCE IMPEDANCE IS TOO HIGH.

distortion at peak amplitude due to grid current bursts. Such distortion would occur with peak amplitude at any frequency if the transformer ratio and primary a.c. resistance were not arranged to present a sufficiently low source impedance to the output valve grids. Unfortunately the circuit values so produced almost inevitably combine so there is a marked resonance between leakage inductance and secondary capacitance at a radio frequency, well above the audio spectrum. Even if the output valves are quite stable during the whole cycle of audio waveform, the resonance on the secondary of the drive transformer will be sufficiently pronounced to produce a damped train of r.f. oscillations, each time grid current ceases, so that the output waveform looks like Figure 12. To cure this: (*a*) the drive transformer must be designed especially to minimise the effect of this resonance; and (*b*) the circuit must be adjusted to kill any residual resonance at this frequency without interfering with its audio frequency response.

FIG. 12.
DAMPED OSCILLATIONS EXCITED BY CESSATION OF GRID CURRENT.



Power Limit Response

Some manufacturers are now introducing into the literature on audio transformers, what has been termed a " power response." The author suggests that the expression " power limit " response is a little more explicit to show better the distinction from the normal frequency response.

The presentation of a frequency response ignores the question of waveform distortion, assuming that there is none. Such a frequency response should apply for low level signals at any rate. It may be modified at high level signals, due to distortion setting in at some frequencies and not at others, but more important than the modification to frequency response it causes, is the effect of distortion on the reproduction of those frequencies. It is to indicate this limitation that the so-called " power response " has been introduced. It is a curve that shows the limit of power which the transformer can handle before distortion sets in, plotted against frequency.

From the viewpoint of the transformer itself this limit applies essentially at the low frequency end of the characteristic and, without considering the shunting effect of the inductance on the anode load, the limit will be a 6 db per octave slope represented by saturation flux density in the core of the transformer. (To maintain a constant flux density in a transformer core, as frequency is varied, voltage must vary in proportion to frequency). Such a power limit response may be strictly true as regards the transformer by itself, but it does not tell the whole story because transformers are invariably operated in conjunction with valves, so the effect of the transformer on the anode load applied to the valve must also be taken into consideration. This means that the shunting effect of the transformer primary inductance will also contribute to the power limit response at the low frequencies, and that the response in the middle of the frequency band will be level at a limit set by the power output of the valve. At high frequencies departure of the load value presented to the valve anodes will again introduce reduction in maximum power, so that a typical transformer characteristic showing frequency response and " power limit " response to the same scales might appear as at Figure 13. As with the presentation of frequency response, it must be realised that power limit response is dependent not only on the transformer itself, but also on the circuit in which it is operated, particularly on the characteristics of the valve or valves used.

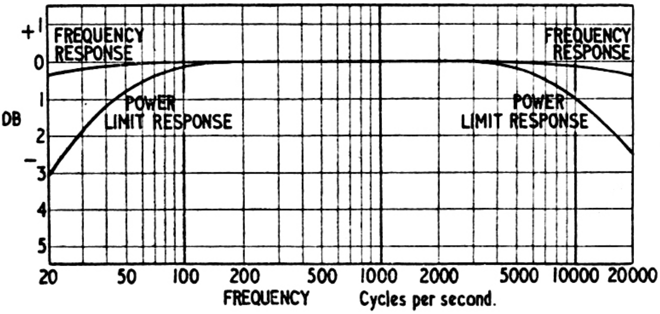


FIG. 13. TYPICAL POWER LIMIT RESPONSE PRESENTATION.

Shorted Turns

A transformer in good working order will not possess any shorted turns, but this is one of the faults that can develop in a transformer, due, perhaps, to overheating, to operation in climatic conditions for which it was not designed, or to poor workmanship in the first place. In some instances shorting turns may be present when the transformer is new, if the manufacturer's test procedure had not been adequate for detecting them. Nowadays however, reputable transformer manufacturers guard themselves against this possibility by careful testing at the various stages during manufacture.

The effect of shorting turns on the performance of a transformer depends (*a*) upon the number of turns shorted; and (*b*) their location in the windings of the transformer.

A small number of shorted turns may not produce noticeable effect in the central part of the frequency response, as the losses introduced will be quite small compared to the main transfer of power from primary to secondary; the more noticeable effect will be on frequency response, due to the way in which the shorted turns influence the leakage flux in the windings. Generally speaking, the result will be evident in the form of a gradual slope one way or the other, usually toward the high frequency end of the response curve. The direction and degree of the slope and the frequency at which it is evident, will depend on whether the shorted turns are in the primary or secondary and how they are located in relation to the leakage flux in the main windings.

A greater number of shorted turns will produce a loading effect on the transformer, making the input impedance lower than it should be. This will probably cause distortion, because the wrong load impedance is presented to the valve anode circuit. A subsidiary effect may be to increase or decrease the effective ratio of the transformer, according to whether the turns shorted are in the primary or secondary winding. Thus, turns shorted in the primary winding of a step-up transformer might appear, on ratio test, to increase its step-up; but in a practical circuit the gain in step-up will invariably be lost due to the increased loading effect.

Change of Frequency Response With Signal Level

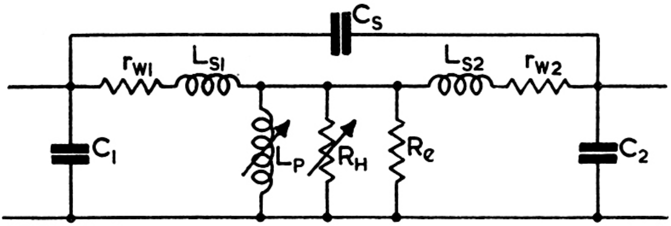
This is another form of distortion that may be noticed when audio transformers are used in amplifying equipment of laboratory standard. For normal audio reproduction the degree of change with level is small compared with the well-known scale distortion produced by the Fletcher-Munson characteristics of the human ear. The principal effect is at the low frequency end due to change of inductance with signal level. Generally speaking, inductance rises with increasing flux density so that the low frequency response is better at high levels than at low levels. This is fortunate for audio reproduction because it is at this end of the spectrum that the scale distortion of the human ear makes low level low frequency sounds disappear anyway.

In theory, there can be no change in frequency response with level at the high frequency end of the spectrum, but in practice some change occurs. This is due, not to the transformer itself, whose leakage inductance and winding capacitance are independent of signal level, but to the valve characteristics again. The effective a.c. resistance of a valve invariably changes to some extent with signal level and this change will produce a variation in frequency response in just the same way as any other alteration to external circuit values, as explained in the following chapter.

3

EQUIVALENT CIRCUITS

TO represent the various aspects of audio transformer performance, equivalent circuits are drawn. A complete equivalent circuit can be drawn showing all the properties of an audio transformer and one such is shown at Figure 14.



C_1	Primary Self Capacitance	L_P	Primary Inductance
C_2	Secondary Self Capacitance	r_{W1}	Primary Winding Resistance
C_S	Interwinding Capacitance	r_{W2}	Secondary Winding Resistance
L_{S1}	Primary Leakage Inductance	R_e	Core Loss due to Eddy Currents
L_{S2}	Secondary Leakage Inductance	R_H	Core Loss due to Hysteresis

FIG. 14. COMPLETE EQUIVALENT CIRCUIT OF TYPICAL AUDIO TRANSFORMER.

When an equivalent circuit is drawn, it is assumed that a perfect transformer with the same ratio as the actual transformer replaces it for the purpose of impedance matching or voltage step-up and that all the " imperfections " of the actual transformer are represented in the equivalent circuit. To make quite clear the idea of the " perfect " transformer: it is defined as one with no losses (*i.e.* the winding resistances are zero and the core requires no current to magnetize it) and with perfect coupling, so that no flux can get between the hypothetical windings, giving rise to leakage inductance. Its property is to provide uniform transformation of voltage and current at all frequencies from zero to infinity.

Having separated the ratio aspect of the transformer in this way, its various shortcomings are represented in the equivalent circuit. It was stated in the first chapter that the transformer acts both ways, transforming impedances actually present in the secondary circuit as referred values in the primary, and *vice versa*. This action is equally true of the internal characteristics of the transformer itself, such as winding inductance, core loss, leakage inductance, winding resistance and capacitance. Because of this, to avoid confusion, the equivalent circuit must refer all circuit values, internal and external to the transformer, to the same winding. If the secondary is the chosen reference winding, then impedances actually present in the primary circuit must be referred, by the square of the transformer ratio, in order to get their effective value in the secondary circuit.

Insertion Loss

Related to amplifier performance, insertion loss is usually given in db; but for estimating transformer performance it is easier to calculate in terms of efficiency and for this reason the chart provided at Figure 42 gives efficiency as a percentage.

Figure 15 shows the essential features extracted from Figure 14 for the purpose of estimating insertion loss in the case of a power type of audio transformer. Interstage types are not basically power transformers, so the important feature is not the loss of power, as an insertion loss, but depreciation of voltage step-up.

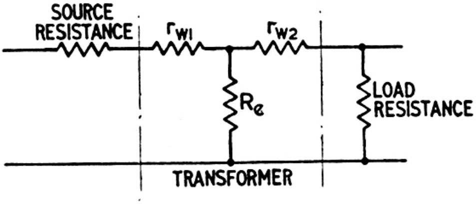


FIG. 15. ESSENTIAL EQUIVALENT CIRCUIT FOR DETERMINING INSERTION LOSS.

In a power type audio transformer the resistance of both windings, as well as the core loss, contribute to the insertion loss; but in a voltage type transformer only the primary resistance and the core loss are of importance, since negligible current flows in the secondary, unless a loading resistor is used for the purpose of maintaining a satisfactory frequency response. Even then, the loading resistor is usually much higher in value than the nominal impedance of the transformer winding to which it is connected, with the result that the secondary current is too small for the secondary winding resistance to contribute appreciably to the total losses. The effect of the loading resistance may be considered as directly in parallel with the core loss for all practical purposes, in an input or interstage transformer.

In input and interstage transformers insertion loss, however assessed, is so small that it is not usually necessary to consider it at all. In power type transformers, used for output or drive, insertion loss is important, because some of the available power output fails to reach the output circuit on account of it.

Low Frequency Response

Low frequency response cannot accurately be represented by a simple equivalent circuit because of the effect pointed out at the end of the previous chapter—effective inductance and core losses change with both amplitude and frequency. However, it is useful to have an approximate reference so that the general order of goodness of the transformer at the low frequency end can be estimated, although it is not possible to give an accurately defined response curve. Figure 16 shows the theoretical equivalent circuit for an audio transformer with its associated external circuit. The resistance r represents the primary source impedance, and, with the transformer direct coupled, will be the a.c. resistance of the valve into whose anode it is coupled. R represents the combined shunt resistance of the secondary load and the fixed component of the core losses (the latter will usually be so high as to be negligible). L represents the average value of primary inductance. Notice that R must be referred to the primary winding, the same as all other values.

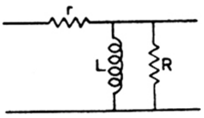


FIG. 16. EQUIVALENT CIRCUIT FOR L.F. RESPONSE OF DIRECT COUPLED TRANSFORMER.

This theoretical circuit gives a response of the form shown at Figure 17. The frequency at mid-scale is where the reactance of L is equal to the combined resistance of r and R in parallel. Having worked this out by the use of the resistances in parallel chart and the reactance chart of figures 34 and 35, the response curve of Figure 17 will give a rough idea of the behaviour of the transformer. It must be emphasised that this response curve cannot be used for detailed plotting, because of the variation in inductance with both frequency and level.

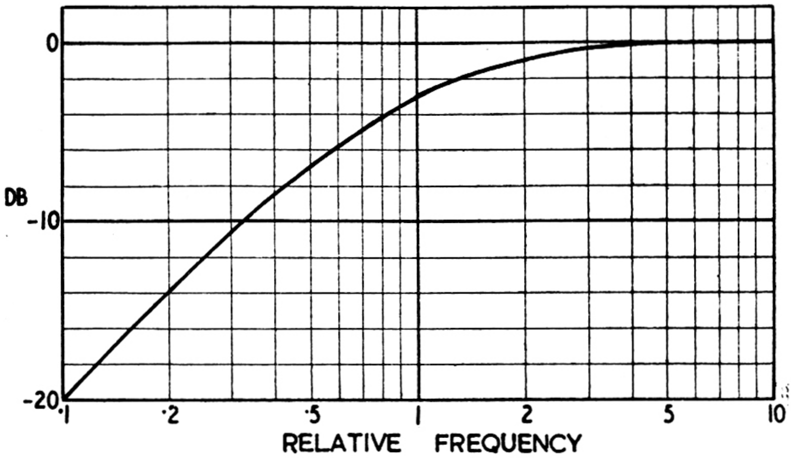


FIG. 17. RESPONSE FORM OF IDEAL LOW FREQUENCY CUT-OFF, ASSUMING CONSTANT INDUCTANCE.

If the transformer core is gapped, as it normally will be when designed for single anode direct coupling, the inductance will be reasonably constant at the current value taken by the valve anode, and the response curve given at Figure 17 will be a reasonably accurate presentation of frequency response at the l.f. end. Some push-pull transformers are also provided with a small gap for the purpose of stabilizing inductance, so that frequency response is more definite at this end. It should not be thought, however, that it would be better to have a gap under all circumstances, because the inductance without a gap, when there is no polarizing current, is always higher than the inductance with a gap; so, although the l.f. response may vary from standard form when a transformer is cored up without a gap, it will be better at all levels than the same transformer would be with a gap.

Parallel Fed

High quality interstage transformers operating from a single anode are usually parallel fed to prevent polarizing current flowing through the primary winding of the transformer. Figure 18 shows a typical circuit for this purpose and Figure 19 shows the equivalent circuit for l.f. response.

In this circuit there are two reactances and the primary inductance tends to resonate with the coupling capacitor; whether this will produce a peak or not depends upon the relative values of the inductance and capacitor and the external circuit values, r and R.

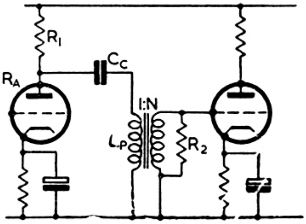


FIG. 18. TYPICAL CIRCUIT FOR PARALLEL FED INTERSTAGE TRANSFORMER.

The charts introduced later for use more particularly in treating h.f. response can be applied to treat l.f. response in parallel fed types of transformer. It should be noted, however, that the charts are based upon an assumed constant value of inductance, and the above remarks about variation of inductance will also mean that accurate prediction of response in parallel fed cases cannot be achieved either.

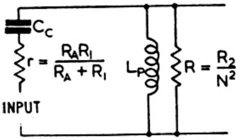


FIG. 19. EQUIVALENT CIRCUIT FOR L.F. RESPONSE OF PARALLEL FED TRANSFORMER SHOWN IN FIG. 18.

High Frequency Response

In practical transformers, steps are usually taken to eliminate the effect of interwinding capacitance by connecting to earth, or the low signal potential point of the circuit, the end of one of a pair of adjacent windings, so that interwinding capacitance is effectively from one side of the other winding to earth, instead of between the hot sides of both windings. This procedure avoids excessive peculiarity in the response curve.

We are now left with two or three reactances that take effect at the high frequency end. Almost invariably only two of them need be seriously considered. If the transformer is working as a step-up, as is usually the case in input or interstage types, the relevant quantities are leakage inductance and secondary winding capacitance. If the transformer is working as a step-down, as is usually the case for output types, the relevant quantities are primary winding capacitance and leakage inductance. Figure 20 shows the equivalent circuits for step-up and step-down.

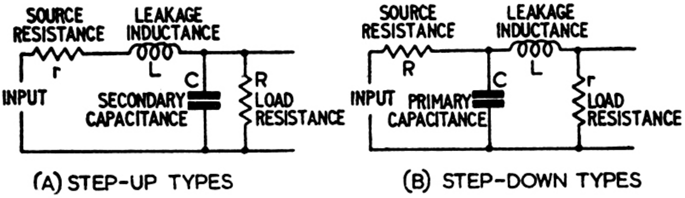


FIG. 20. EQUIVALENT CIRCUITS FOR H.F. RESPONSE OF AUDIO TRANSFORMERS.

An exception to this rule occurs with drive transformers having a step-down. In this case the primary winding capacitance is of little importance because the a.c. resistance in the primary circuit has to be kept low to avoid distortion, which fact ensures that primary capacitance has negligible effect within the useful frequency range. On the other hand, although the secondary winding has the lower number of turns it is connected to the higher impedance, which will usually be almost open circuit, except when grid current flows. So the circuit still conforms to the interstage pattern for high frequency response, although the direction of transformation ratio has been reversed.

It is convenient in presenting the performance charts, to use the same symbols both for input or interstage types and for output types; but it will be noticed from Figure 20 that these symbols have different significance in the two cases. In each case r is the series damping of the resonant circuit, being effectively in series with the leakage inductance, while R is the shunt damping of the circuit, being effectively in parallel with the capacitance.

For input and interstage transformers r is the source resistance, *i.e.* the impedance of the input circuit or a.c. resistance of the preceding stage; and R is the load impedance in the grid circuit.

In output transformers R is the a.c. resistance of the output stage, and r is the load resistance.

Effect of Varying Circuit Values

In each case certain of the values in the equivalent circuit are fixed by the audio transformer in question, but external circuit values may be adjusted so as to alter the response in some way. The actual form of variation will differ for each design of component so it is not possible to give a standard set of curves to show this variation. As well as varying the shape of frequency response, altering circuit values will affect gain or efficiency of power transfer. The series of charts given in Chapter 5 have been prepared so the exact effect of circuit values on any individual design of transformer can be determined quite quickly.

It is realised, however, that most readers will find it rather unsatisfactory to be given only some technical data and a set of charts and be told to work it out for themselves. So, to give some idea of variation in typical cases, Figures 21 to 24 have been prepared, which the reader can study for himself. It must be emphasised, however, that these presentations are only typical and cannot be applied to any particular type. In these diagrams the variation of values is taken over a much wider range than would be practical in any individual transformer, in order to show the complete scope of possibility for the particular examples selected.

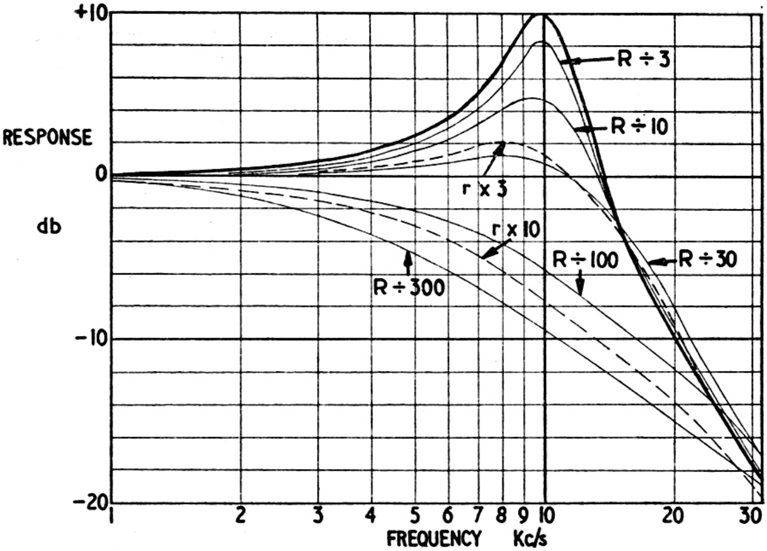


FIG. 21. VARIATION OF H.F. RESPONSE WITH EXTERNAL CIRCUIT RESISTANCE VALUES.
INITIAL COMBINATION (HEAVY CURVE): $\frac{R}{r}=100$; $\frac{L}{CrR}=.13$; $LC=2.5\times 10^{-10}$

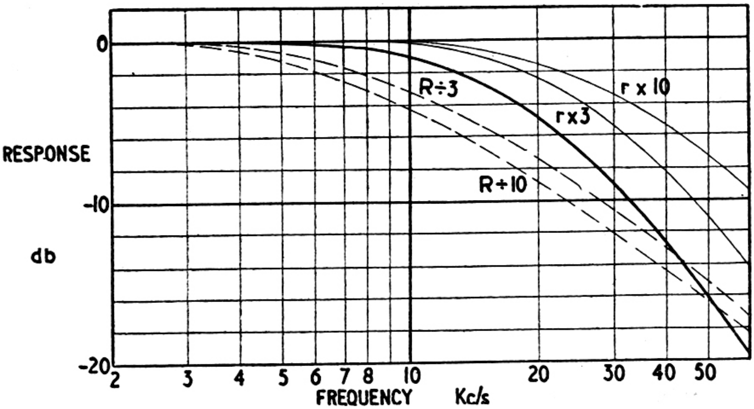


FIG. 22. VARIATION OF H.F. RESPONSE WITH EXTERNAL CIRCUIT RESISTANCE VALUES. INITIAL COMBINATION (HEAVY CURVE): $\frac{R}{r}=1$; $\frac{L}{CrR}=4$; $LC=1.3\times10^{-10}$

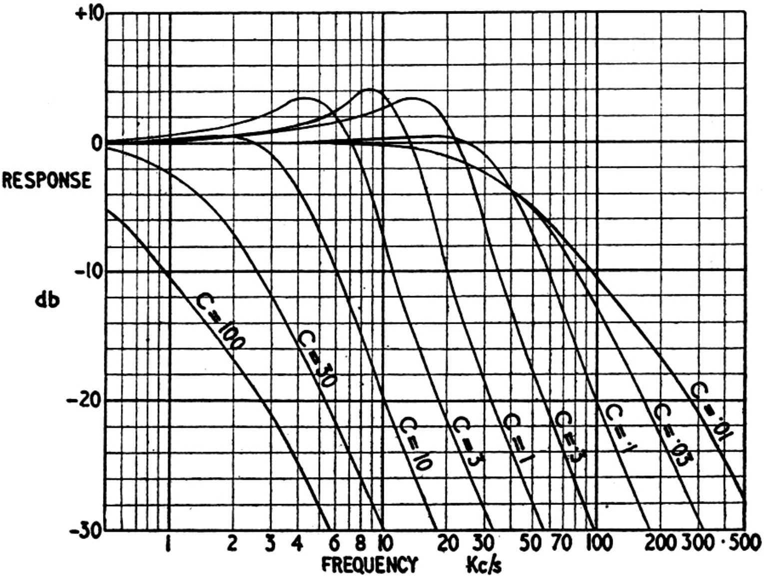


FIG. 23. VARIATION OF H.F. RESPONSE WITH CIRCUIT REACTANCE VALUES. INITIAL COMBINATION (C=1): $\frac{R}{r}=8$; $\frac{L}{CrR}=1$; $LC=2.85\times10^{-10}$

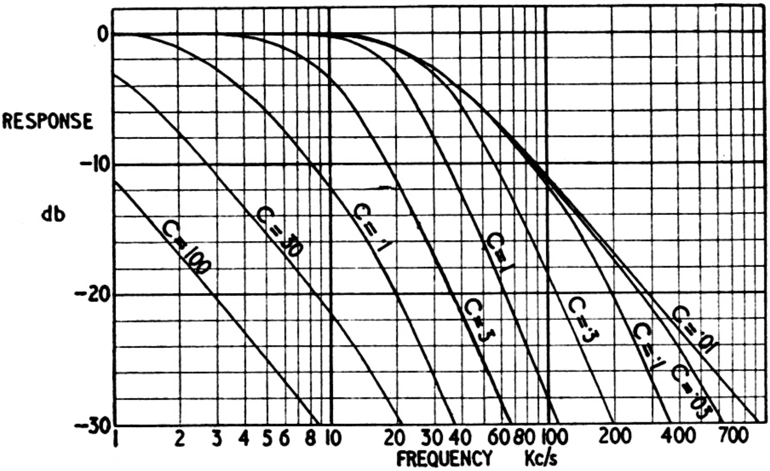


FIG. 24. VARIATION OF H.F. RESPONSE WITH CIRCUIT REACTANCE VALUES. INITIAL COMBINATION (C=1): $\frac{R}{r}=1$; $\frac{L}{CrR}=1$; $LC=5\times10^{-10}$

4

MEASURING UP THE ELECTRICAL PROPERTIES OF TRANSFORMERS

THE data in the appendix, together with the charts introduced in Chapter 5, are very useful for the transformers listed; but literally thousands of audio transformer types have been made and in the appendix only popular current types of several manufacturers have been listed. It is quite likely that the reader may have a transformer from which he would like to obtain the best results by means of the charts; he will want to be able to measure up the transformer so as to get the figures for it in the same form as those listed in the appendix.

Measurement of turns ratio was explained in Chapter 1.

Finding the maximum voltage that the transformer will handle, can be easily achieved by watching the waveform, using the circuit of Figure 4 and 5 and watching the pattern on the screen until it begins to show the defect represented at Figure 8. It will be found that departure from either a straight line or a smooth approximation to an ellipse will be fairly sudden, starting to " crumple up," indicating saturation. The maximum voltage should be just before this crumpling up begins to show. Transformers with Mumetal, Radiometal or C cores saturate more suddenly than the ordinary transformer irons more usually employed for output transformers. For this reason it is wise to allow a slightly larger margin on these high quality transformers, although for good reproduction a fair margin should be allowed on ordinary transformer iron because the distortion, although increasing more gradually, may be sufficient to cause intermodulation at a level lower than what may be regarded as the saturation point.

The figures given in the appendix as maximum voltage for each winding have been derived in a variety of ways. Some manufacturers have supplied information about the distortion characteristic of the transformer; others have supplied samples of their products, still others have allowed the use of their confidential internal design information, from which to extract the data required in the appendix. The endeavour has been to present a reasonably consistent figure for maximum voltage, based upon knowledge of the core materials used in the case where distortion characteristics have been given; upon measurements taken in the case where samples have been submitted; and upon a suitable maximum working flux density in the case where internal data has been supplied.

In any event, maximum voltage figures can be regarded only as giving a safe limit, and not as indicating a specific point where distortion commences. In individual samples of the same type there will be variations in distortion characteristic due to the inconsistency between individual batches of the same core material. So, even had great pains been taken to ensure that the maximum voltage figure represented a certain degree of harmonic distortion in all cases, this figure would be subject to certain variation with individual samples.

Primary Inductance

This property of core materials is subject to even greater variation than distortion characteristic unless the transformer is gapped. For this reason the figures given in the primary inductance column of the appendix can also only be regarded as providing an approximate indication.

To measure the primary inductance of an unknown transformer, the voltage check already described should be made first; after which the impedance of the primary winding may be measured by comparison with stock resistors at a low frequency and with a voltage below saturation point. Figure 25 shows the method of making such a measurement. If a calibrated resistance box is

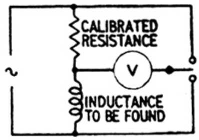


FIG. 25. MEASURING EFFECTIVE PRIMARY INDUCTANCE.

available, a useful method is to adjust the resistance until the voltage across the transformer winding and that across the resistance are equal.

From the impedance value found and the frequency used for the test, an inductance value can be calculated from the reactance chart. It is a good plan to make measurements of this type at several voltages and then take an average or miminum value.

Leakage Inductance and Winding Capacitance

The most successful way of determining leakage inductance and winding capacitance is by finding the resonant point, and then adding externally, known values of additional capacitance, in order to find the actual value of internal capacitance. The difficulty here is that, particularly for small output transformers, or high quality designs, the natural resonance of the transformer will probably be in the radio frequency region, say 100 Kc/s. Larger, or less hi-fi, products will resonate at a lower frequency but may still be beyond the normal audio range.

Figure 26 shows the test circuit best used for finding the resonant frequency. If satisfactory results cannot be obtained using this circuit, or the frequency is beyond the range of the oscillator available, an alternative method may be necessary to find these quantities. If a reasonably sharp resonance can be found, stock values of capacitor should be added in parallel with the high impedance winding until the frequency of resonance is just halved. When this has been found, the extra capacitance connected will be just three times the internal capacitance, making it a simple figure to calculate.

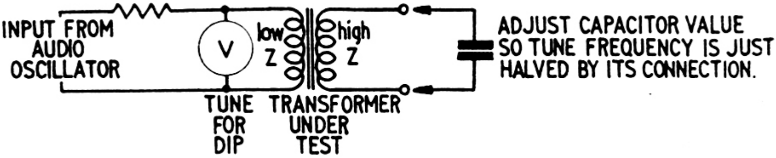


FIG. 26. FINDING LEAKAGE INDUCTANCE AND WINDING CAPACITANCE BY MUTUAL RESONANCE.

Leakage inductance referred to the high impedance winding can then be easily calculated from the reactance chart and the natural resonant frequency. The alternative method of measuring winding capacitance involves tuning it with primary inductance and then adding external capacitance. The exact tune point is much more difficult to find and the best method is to find when the voltage across the transformer is in phase with the voltage across the resistance in series with it, using the circuit arrangement of Figure 26.

Using the low impedance winding for measurement avoids adding external self-capacitance to the winding under test, except

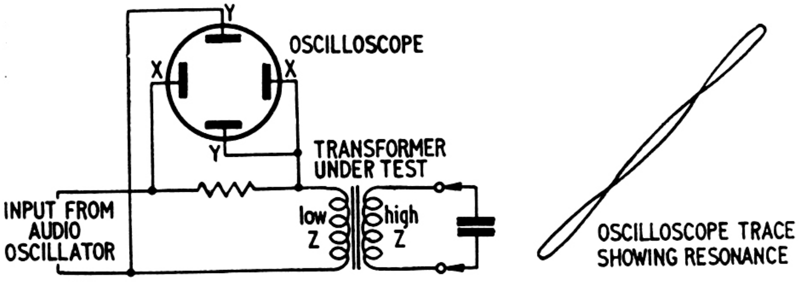


FIG. 27. FINDING APPROXIMATE WINDING CAPACITANCE BY RESONANCE WITH PRIMARY INDUCTANCE.

the known values connected to shift the resonant frequency. A typical display indicating resonant conditions is also shown in Figure 27. The difficulty about this method is that the winding inductance itself changes with frequency, so the answer cannot be found by a simple rule such as was given for resonance with leakage inductance. The best method is to add a number of external capacitors whose values have been checked on a capacitance bridge, and then plot the results in the manner shown at Figure 28 using log-log paper. Two or three curves are plotted assuming different values for winding capacitance and the one representing true winding capacitance is recognised as that giving best approximation to a straight line, or the value is interpolated between two plots, each diverging in opposite directions from straight.

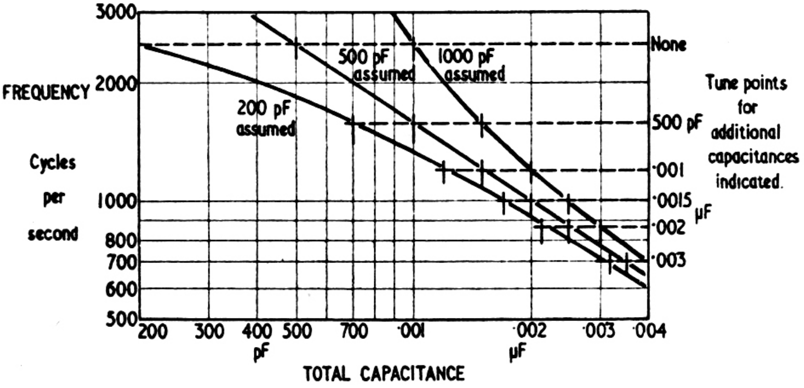


FIG. 28. METHOD OF FINDING CAPACITANCE VALUE GRAPHICALLY FROM RESULTS USING THE SET-UP OF FIG. 27.

Core Loss

This can easily be measured using the same circuit arrangement and method of balancing out reactive components shown in Figure 27. To obtain a value of core loss expressed as shunt resistance, either a resistance box is used for the series resistance, its value being adjusted until the voltage across the transformer is equal to that across the resistance, or else the equivalent core loss resistance is calculated from the voltage ratio across the two parts of the circuit. The advantage of adjusting so that both voltages are equal is that not only voltmeter errors are eliminated from the measurement, but also errors due to the shunting effect of the voltmeter impedance in taking the measurement. When both resistance values are equal, connection of the same voltmeter across each will have exactly the same shunting effect and so need not be taken into the calculation.

Winding Resistance

The resistance of each winding can readily be measured by means of the conventional ohmmeter type of instrument. A more accurate result can be obtained using a Wheatstone type bridge (commonly known as a Post Office Box), but such accuracy is not warranted for this purpose because individual specimens of a given type of transformer will vary as much as 20 per cent. Each winding resistance should be measured and then the resistance of one winding should be referred by the square of the transformer ratio to the other winding and the two values so obtained, added together to give the total winding resistance referred to that winding. This should be the same winding as used for the measurement of core loss.

Generally, more convenient values are obtained by using the lower impedance winding for all these loss references.

5

USING THE CHARTS

THE information obtained from the appendix, or from measurements on transformers, as in the previous chapter, can be applied by means of the charts here given, either to obtain the best results from a specific transformer, or to find out whether a transformer designed for a different circuit will give satisfactory performance for the job in hand, as a makeshift.

No attempt should be made to use the charts or the information contained in them to decide whether one manufacturer's transformer is a better job than another's, or even whether one type is better then another.

From the earlier part of this book it will be apparent that every application requires individual consideration; because of this many transformer manufacturers do not make any stock lines of transformer at all, but prefer to design a component for each application to customers' specification. Handbook No. 5 in this series will give more details about designing a transformer for a specific application.

Often it happens that the job in hand is only one-off and hence it would not be worth while having a transformer designed specially, while on other occasions the job may be too urgent to allow time for special designs to be drawn up and produced. The charts and appendix are intended to serve in such cases, to enable the user to obtain the best results from a ready-made component, or to adapt the nearest possible design where a type exactly suited to his requirements is not available.

Different features will require attention in individual cases, but they are listed below in order of appearance in the tabulation of the appendix.

Impedance Ratio

Nominal impedances are listed in the table but to facilitate determination of the correct turns ratio, Figure 36 enables turns ratio to be determined from a knowledge of the working impedances, or *vice versa.*

In the case of output transformers the impedances related by this ratio are the secondary load impedance and the optimum load impedance required by the output valve(s) on the primary.

In the case of interstage or input transformers the impedances to be considered are the source impedance presented to the primary of the transformer and the referred value of this source impedance in the grid circuit connected to the secondary.

Use of the abac of Figure 36 enables a first check to be made to see whether the ratio of a transformer is right or within a workable tolerance.

Maximum Voltage

All transformers will have a limit to signal handling capacity; this is often listed by manufacturers as a wattage, particularly in the case of output transformers; but such listing is rather unsatisfactory expecially when applying a transformer to a circuit different from that for which it was designed. The critical factor from the transformer's viewpoint is the maximum *voltage* it can handle before distortion commences.

For input and interstage transformers, generally signal voltage at the grid, required for maximum signal will be known from the amplifier design and hence the figures given in the maximum voltage table of the appendix are directly applicable.

For output transformers voltage swing is frequently not regarded as the critical factor, but watts output. The chart of Figure 37 is given to aid in converting maximum volts from the appendix column, with load impedance, to a wattage rating.

As stated in Chapter 2, maximum voltage will vary with frequency; the appendix lists the maximum voltage at 50 cycles;

if maximum signal is never required at 50 cycles, an increased figure of maximum voltage can be used, based upon the lowest frequency at which maximum signal is required. This practice is not to be recommended because it makes the transformer the weakest link in the chain, unless precautions are taken in circuit design to ensure that it is impossible for maximum voltage to reach the transformer at this bottom end of the range. On the other hand if frequencies below 50 cycles are required, the maximum voltage will have to be reduced in proportion to the lowest frequency figure.

Frequency Characteristic

Having ascertained that the ratio is correct or workable and that the transformer will handle the necessary signal level, attention can be turned to its frequency characteristic.

Unless parallel feed is used, the important feature for low frequency response is the primary inductance in conjunction with the parallel combination of the source and load impedance referred to the primary. Figure 34 is a chart that will aid in calculating the equivalent value of resistances in parallel. In the case of interstage and output transformers this parallel combination consists of the a.c. resistance of the valve and the secondary load impedance referred to the primary.

Having determined the equivalent parallel resistance the next step is to find at what frequency the reactance of the primary is equal to it. This is found from the primary inductance by means of the reactance chart of Figure 35. Having found this frequency an approximate low frequency response is given by Figure 17 as explained in Chapter 3.

High frequency response is predicted with the aid of the charts given in Figures 38, 39 and 40. Figure 38 identifies which shape of frequency characteristic shown at Figure 40 gives the correct response curve. Figure 39 fixes the relative frequency used for Figure 40, indicated on the relative frequency scale as 1. If desired, a sliding frequency scale can be constructed to aid in applying the information from Figure 40 to actual frequencies for the transformer in hand.

To use these charts values of source and load impedance referred to one of the windings must be assumed; these assumed values are listed in a column of the appendix tabulation and the corresponding values of $\frac{R}{r}$, $\frac{L}{CrR}$ and LC for use on the charts. Use of these three parameters with the charts for determining high frequency response will identify an appropriate response curve on Figure 40 and locate it in the frequency spectrum. If the response shape does not suit, the effect of varying circuit values from those used initially, can easily be seen with the aid of the detachbale scale attached to Figure 38.

Figures 29 and 30 show how this scale can be used on the charts of Figures 38 and 39 to see the effect of changing values of r or R on the shape and position of a frequency response. Figures 31 and 32 show similarly how the other end of the detachable scale can be used to see the effect of varying L or C.

As affecting high frequency response L is fixed, being the leakage inductance of the transformer, and C can only be increased by the connection of external capacitors.

The charts in Figures 38, 40 and 41 can be used for the prediction of l.f. response in parallel fed cases, in which case C can be increased or decreased at will, since it is the coupling capacitor and L will vary over quite a range with signal level. The charts can be used in this case to see how variation of primary inductance affects the low frequency response and to aid in choosing values so that this variation is kept to a minimum if so required.

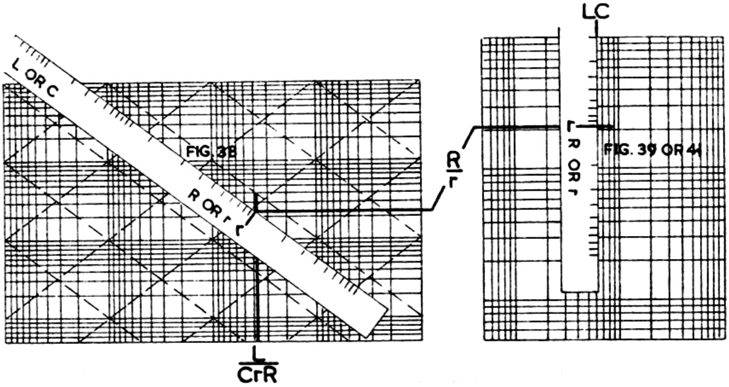


FIG. 29. USE OF THE DETACHABLE SCALE FROM PAGE 46 TO SEE THE EFFECT OF VARYING r.

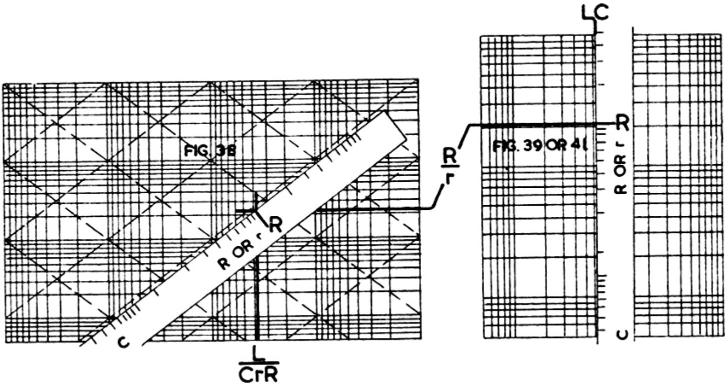


FIG. 30. USE OF THE DETACHABLE SCALE TO SEE THE EFFECT OF VARYING R.

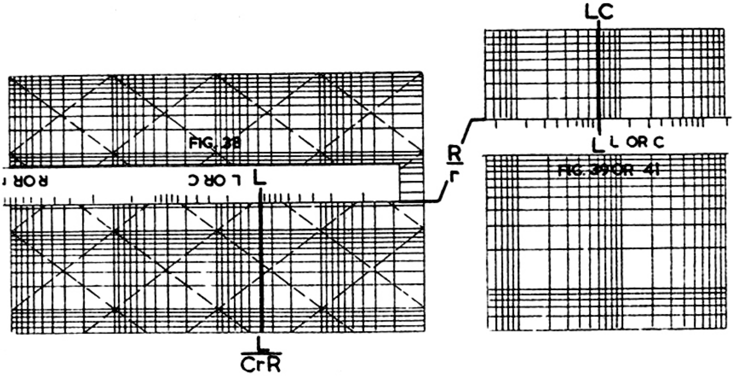


FIG. 31. USE OF THE DETACHABLE SCALE TO SEE THE EFFECT OF VARYING L.

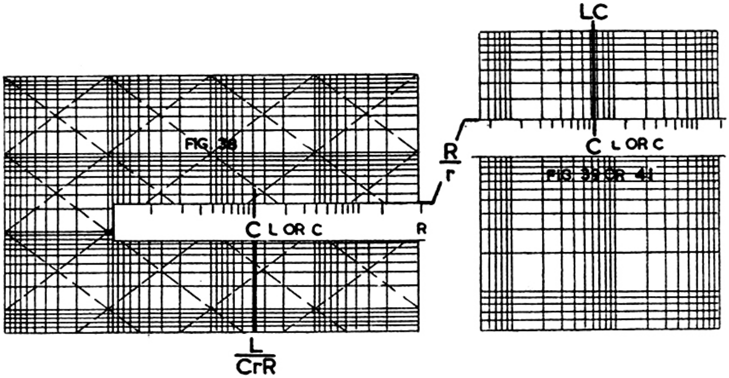


FIG. 32. USE OF THE DETACHABLE SCALE TO SEE THE EFFECT OF VARYING C.

Efficiency

The chart given for efficiency is only applicable for audio transformers required to handle power.

Interstage and input transformers intended to provide voltage transfer usually have an efficiency value sufficiently high to be neglected; but if for any reason the precise value is required, it will be determined from the primary resistance and core loss of the transformer, provided no secondary load is connected. If a secondary load is connected then efficiency can be calculated from the efficiency chart by referring the load, winding resistance and core loss values all to the same winding. .

The method of using the efficiency chart of Figure 42 is illustrated by Figure 33. It will often be found that load impedances,

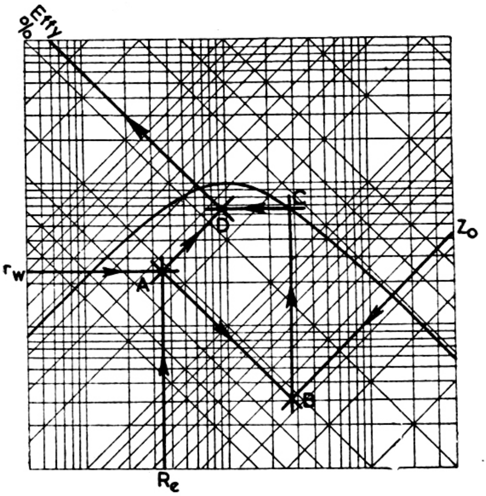


FIG. 33. USE OF THE CHART OF FIG. 42 TO DETERMINE EFFICIENCY.

referred winding resistances, or referred shunt loss values do not come within the range of the chart; this can readily be overcome by multiplying, or dividing, all of these values by a common factor, some power of ten being usually convenient for this purpose. For example, a transformer listed as having a winding resistance of .3 ohms and a core loss of 100 ohms referred to a load impedance of 3 ohms can use the chart simply by multiplying all these values by 10, so that referred winding resistance is 3 ohms, referred shunt loss 1,000 ohms, and referred load impedance 30 ohms.

Having found the points of intersection between referred winding resistance and referred shunt loss, the effect of different load impedances for the same transformer can easily be seen by using different reference lines on the referred load impedance scale. Maximum efficiency will always be achieved when point B, as indicated on Figure 33, falls on the vertical reference line identified by the figure 10 on the REFERRED SHUNT LOSS scale on the chart; as the point B falls to the right or left of this vertical line, efficiency will fall off, as represented by the curve on the chart.

Adjusting Response

The charts of Figures 38 to 41 may be applied for adjusting the overall frequency response by means of external circuit values. Changing circuit resistances will effect a corresponding change in r and R according to the position of the resistor in the circuit. The most usual problem will be that of modifying the response at one end of the spectrum without interfering with the response at the other end.

The first step should be to see that l.f. response is satisfactory. Improvement of l.f. response can be achieved by reducing the associated circuit resistance values, the most effective value to change being that which already has the lowest referred value.

In the case of a triode output stage this would be the a.c. resistance of the output valve. The only way to reduce this is by application of negative feedback from the anode to some earlier point in the amplifier.

In the case of pentode or tetrode output stages, the lower resistance value will usually be the referred load resistance, which is naturally fixed by matching conditions, so the only remaining option is the reduction of a.c. resistance. High quality pentode or tetrode output stages should always have a high degree of negative feedback in order to improve loudspeaker damping. This will also improve l.f. response by reducing the shunting effect of the transformer primary inductance.

Interstage transformers are not often used with pentode or tetrode preceding stages, but where used in direct coupled circuits, the foregoing remarks for output types will apply. Where used with parallel fed coupling, both ends of the response require more careful consideration and the special methods referred to next may be necessary.

To adjust the response at the h.f. end of the spectrum the circuit value which will have most effect depends upon the position of the initial values on the scales of Figure 38. If these result in a value of $\frac{L}{CrR}$ greater than unity R is the most effective circuit component to adjust. On the other hand if the initial value of $\frac{L}{CrR}$ is less than unity r is the most effective circuit value to adjust.

Parallel Fed Transformers

Figure 43 shows methods of adjusting the performance of parallel fed coupling, while Figure 44 shows the equivalent circuits from the viewpoint of l.f. and h.f. response The a.c. resistance of the preceding stage in parallel with the coupling resistor provide the basic effective value of r for both l.f. and h.f. characteristic. The primary shunt resistor R_2 contributes to the shunting effect of R for the l.f. characteristic, but assists in reducing the effective value of r for h.f. characteristic by being effectively in parallel with the two components already mentioned. The secondary shunt resistor R_3 occupies the position of R for both characteristics.

The best resistors to modify in any individual case depends upon the position on the chart of Figure 38 for both response characteristics. It will be realised, from a study of the charts and the illustrations of how to use them, that a wide range of possible adjustment exists in this type of circuit and use of the charts will prove far quicker in finding a satisfactory arrangement than prolonged fiddling of circuit values.

Adapting a Transformer

Frequently it is necessary or desirable to use a stock transformer for an application somewhat different from that for which it was designed or specified. The question then comes as to which of the transformers available will best serve this new purpose, or to what degree the characteristics of the transformer used will fall short of ideal characteristics, that might be available if a transformer could be specially wound for the purpose.

The most frequent application of this nature is for output or speaker matching transformers.

In this case the first requisite is that the transformer must have somewhere near the correct ratio.

Next it must have sufficient turns to be able to handle the maximum signal. This can be checked by means of the maximum voltage figures associated with the winding.

For adaption purposes of this nature the next important factor is the question of efficiency, for which the efficiency chart should be used.

If these three factors give satisfactory answers, the frequency response will in all probability be good enough for the purpose, bearing in mind that the arrangement is an adaption. However, frequency response can easily be checked by means of charts 38 to 41.

Another application where adaption is necessary is for input or interstage transformers. Here, as well as considering maximum signal, often minimum signal will prove a more important question, as transformers designed for use in output circuits usually employ a lower grade of core material quite suitable for output circuits, but not having sufficient permeability for low level input circuits. For this purpose one of the high grade core materials specially produced to have high initial permeability should be employed. Frequency response will be the next requisite to consider for these cases, efficiency usually being relatively unimportant.

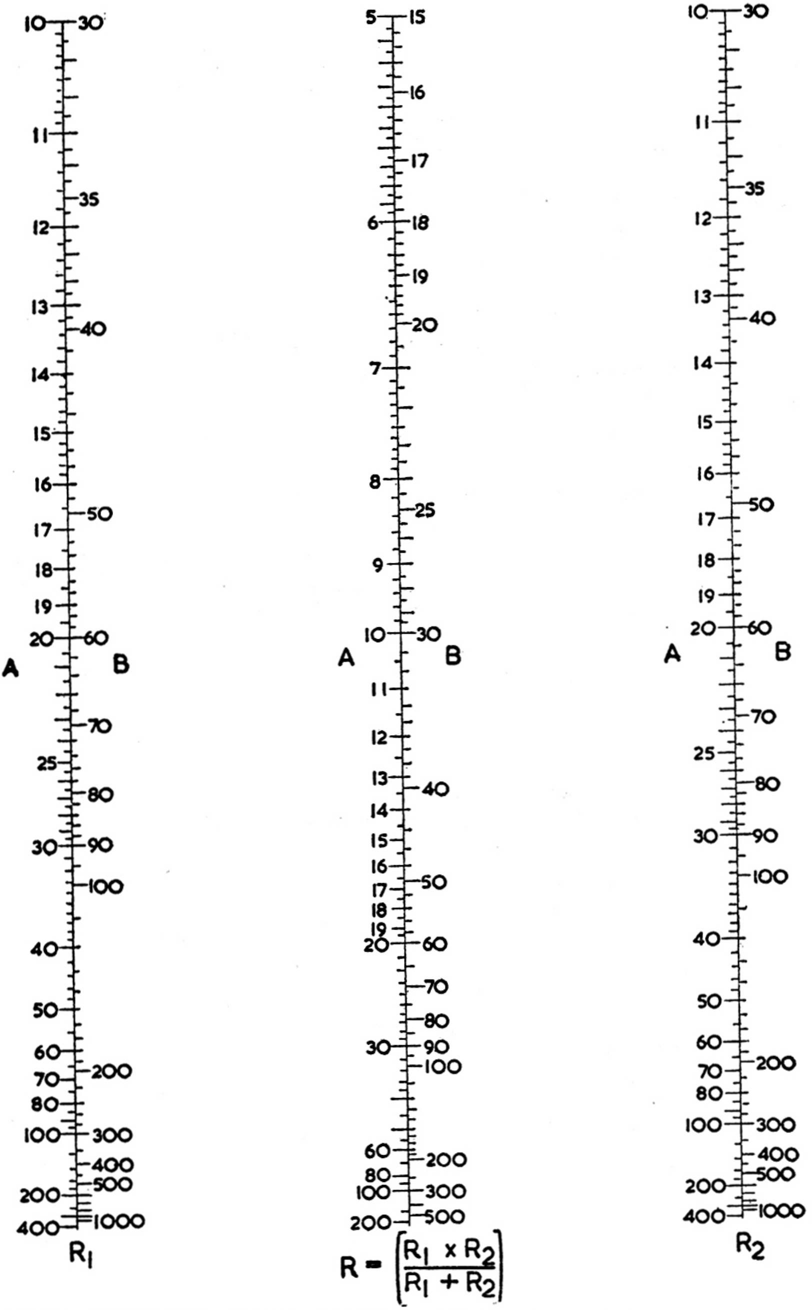


FIG. 34. ABAC FOR CALCULATING COMBINED RESISTANCE OF RESISTANCES IN PARALLEL.

Use of Fig. 34

The important thing with this chart is to remember (a) that for any one calculation, *the figures on the same side of the reference scales must be used—either* A *or* B scales; (b) that the figures must be taken to represent *the same units on each scale.* For example, required the parallel combination of 1 Megohm and 220 K: using A scales for units of 10 K, the result is found to be about 180 K. Required the parallel combination of 50 K and 33 K: using the B scales for units of 1 K, the result is found to be 20 K.

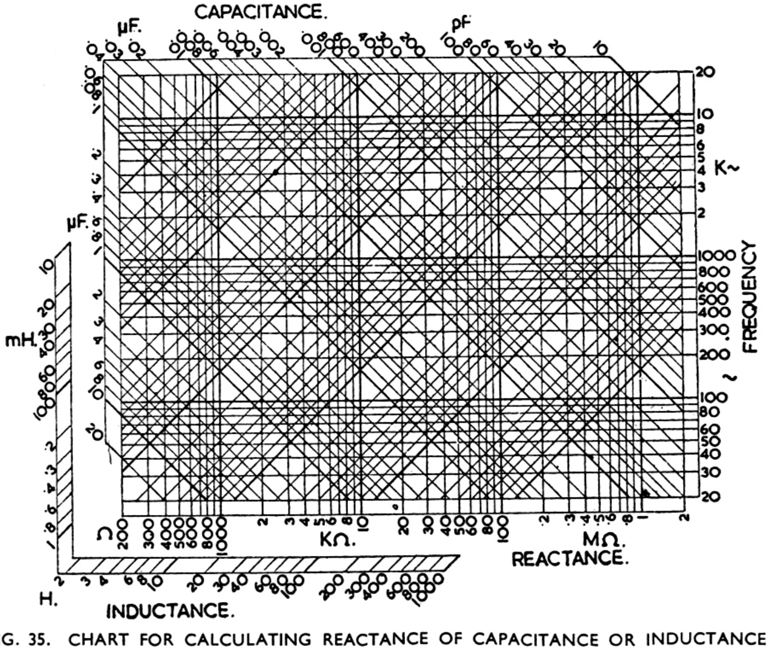


FIG. 35. CHART FOR CALCULATING REACTANCE OF CAPACITANCE OR INDUCTANCE AT ANY AUDIO FREQUENCY.

Examples for Fig. 35

.005 μF has a reactance of 80 K at a frequency of about 410 cycles.

10 H has a reactance of 30 K at about 490 cycles.

10 H and about .0025 μF tune to 1,000 cycles.

These are just sample readings, which the reader can check for himself; use of the chart is quite simple and direct.

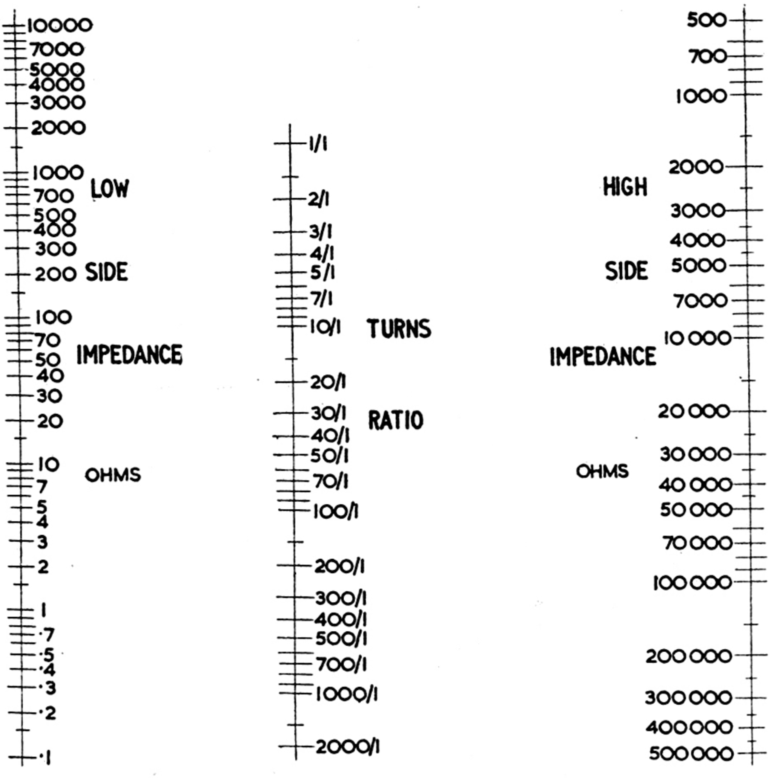


FIG. 36. CHART FOR CALCULATING IMPEDANCE TRANSFORMATION AND TRANSFORMER TURNS RATIO.

Examples for Fig. 36

A 40/1 transformer will match 15 ohms up to 25,000 ohms, or 3 ohms to approximately 5,000 ohms.

To match 50 ohms to 20,000 ohms requires a ratio of 20/1.

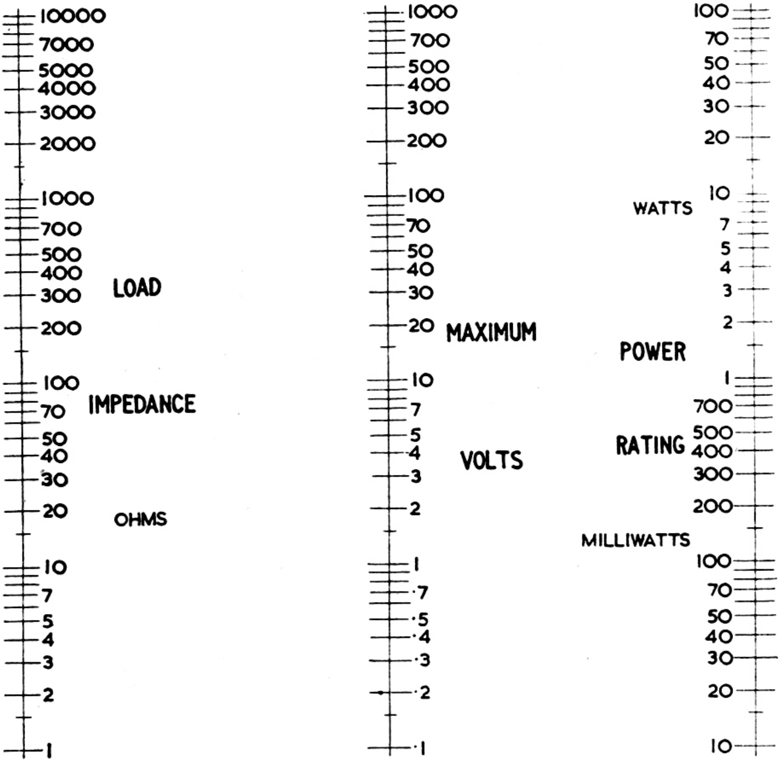


FIG. 37. CHART RELATING LOAD IMPEDANCE, MAXIMUM VOLTS AND POWER RATING.

Examples for Fig. 37

5 watts into a load of 300 ohms gives approximately 40 volts.

1 volt across 15 ohms represents a power of about 65 milliwatts.

Given any two of these quantities, the third can be found by alignment with a ruler or straight-edge.

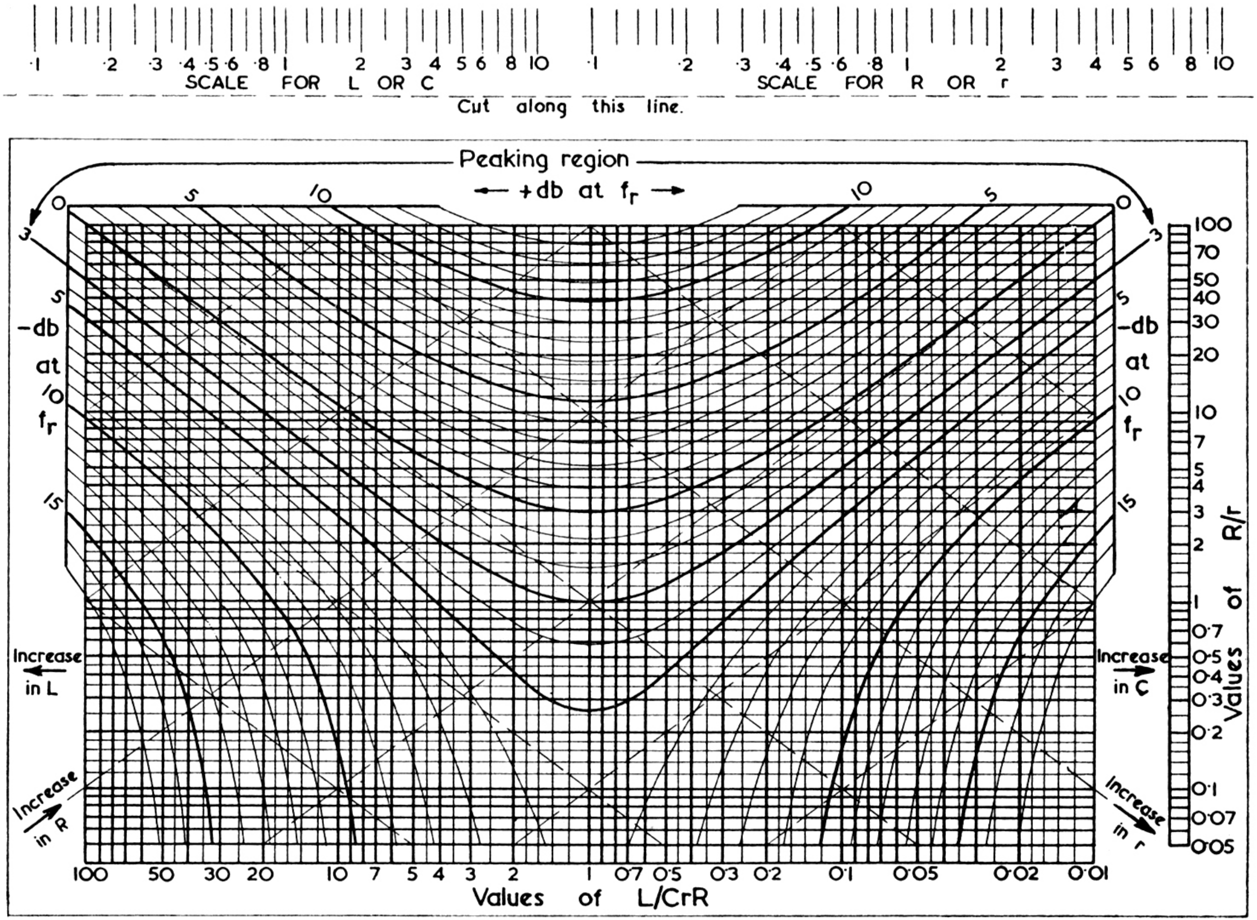


FIG. 38. CHART FOR IDENTIFYING RESPONSE SHAPE ON FIG. 40, AND SHOWING VARIATION WITH CIRCUIT VALUES (SEE FIGS. 20 TO 24)

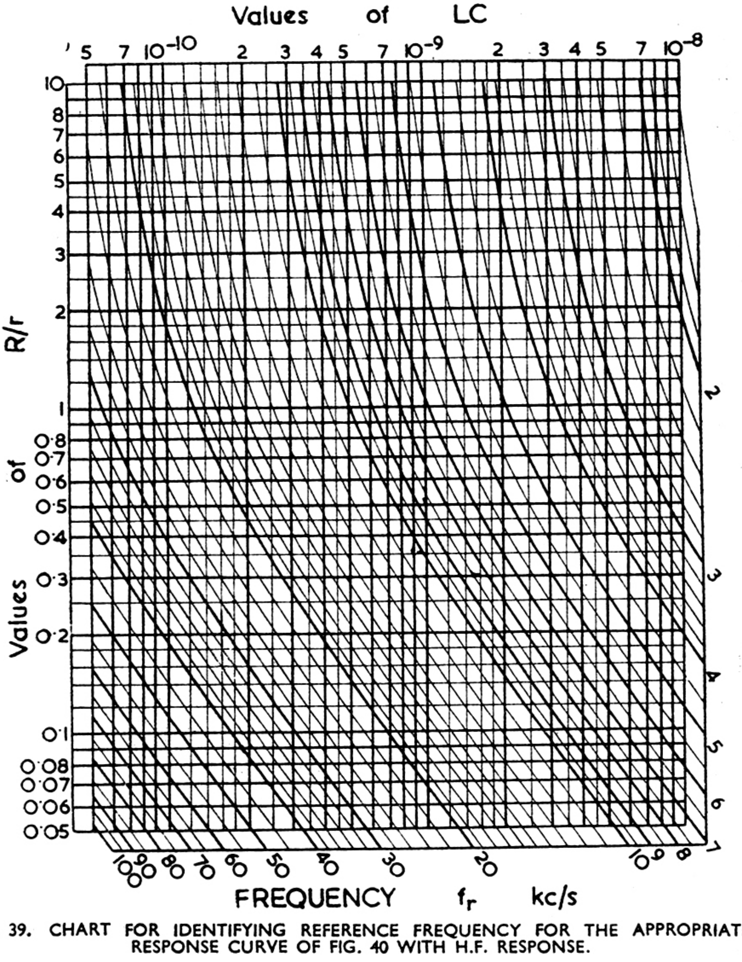


FIG. 39. CHART FOR IDENTIFYING REFERENCE FREQUENCY FOR THE APPROPRIATE RESPONSE CURVE OF FIG. 40 WITH H.F. RESPONSE.

Examples in the Use of Charts, Figs. 38-40

Figures 29-32 illustrate the method, and Figures 21-24 were prepared with the aid of these charts. So the reader can use these as a check on his own use of the charts, the figures are repeated here.

For Figure 21, initial combination $\frac{R}{r}=100$, $\frac{L}{CrR}=.13$, $LC= 2.5\times 10^{-10}$. From Figures 38 and 39 this gives +10 db at f_r, about 10 Kc/s (actually beyond the top of Figure 39). Using the R or r scale, the other curves are located as follows:—

R÷3: +8.2 db at 10.2 Kc/s; R÷10:+4.5 db at 10.5 Kc/s; R÷30: zero db at 11.5 Kc/s; R÷100: —8.5 db at 14 Kc/s; R÷300: —15 db at 20 Kc/s. r×3: +1.2 db at 10.2 Kc/s; r×10: —8.5 db at 10.5 Kc/s.

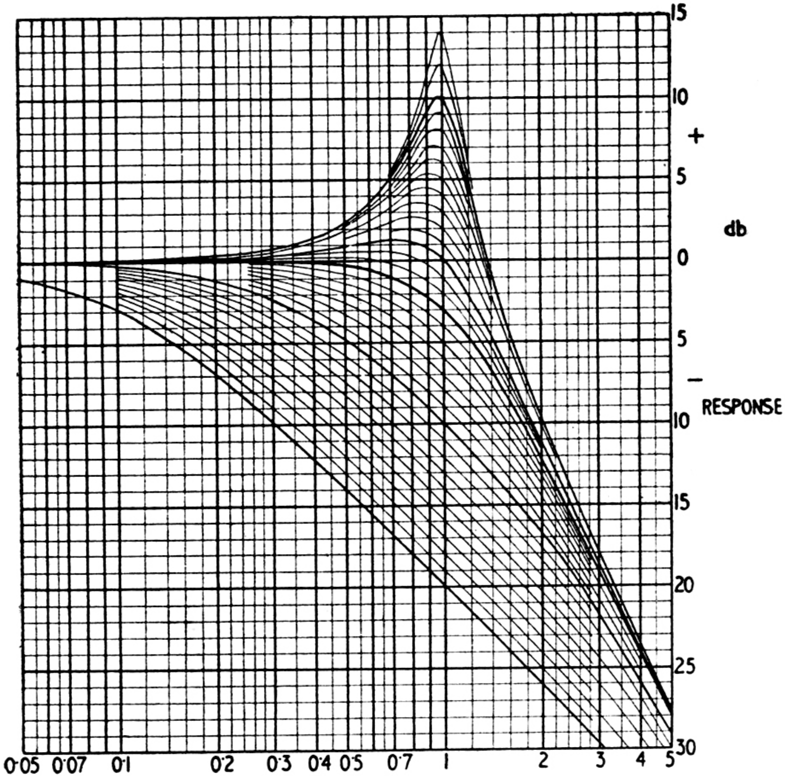


FIG. 40. RESPONSE CURVES, APPLICABLE BY MEANS OF THE CHARTS IN FIGS. 38 AND 39 TO ALL H.F. CUT-OFF SHAPES. ALSO APPLICABLE, WITH THE AID OF FIG. 41, FOR APPROXIMATE PREDICTION OF L.F. SHAPES.

For Figure 22, initial combination $\frac{R}{r}=1$, $\frac{L}{CrR}=4$, $LC=1.3\times10^{-10}$. This gives —5 db at 20 Kc/s. Using the r or R scale, the other curves are located as follows:

R÷3: —10 db at 28 Kc/s; R÷10: —15.5 db at 46 Kc/s; r×3: —4.8 db at 28 Kc/s; r × 10: —6.5 db at 46Kc/s.

For Figure 23, initial combination $\frac{R}{r}=8$, $\frac{L}{CrR}=1$, $LC=2.85\times10^{-10}$. This gives + 3.5 db at 10 Kc/s. Other curves are located with the aid of the L or C scale as follows:

.01: —10.5 db at 100 Kc/s; .03: —6.5 db at 58 Kc/s; .1: —1.2 db at 32 Kc/s; .3: + 2 db at 18 Kc/s; 3: +2.2 db at 5.8 Kc/s; 10: —1.2 db at 3.2 Kc/s; 30: —5.3 db at 1.8 Kc/s; 100: —10.5 db at 1 Kc/s.

For Figure 24, initial combination $\frac{R}{r}=1$, $\frac{L}{CrR}=1$, $LC=1.25\times10^{-10}$. This gives —3 db at 20 Kc/s. Other curves located by movable scale as follows:

.01: —17 db at 200 Kc/s; .03: —12.5 db at 115 Kc/s; .1: —7.8 db at 63 Kc/s; .3: —4.5 db at 37 Kc/s; 3: —4.2 db at 11.5 Kc/s; 10: —7.8 db at 6.3 Kc/s; 30: —12 db at 3.7 Kc/s; 100: — 17 db at 2 Kc/s.

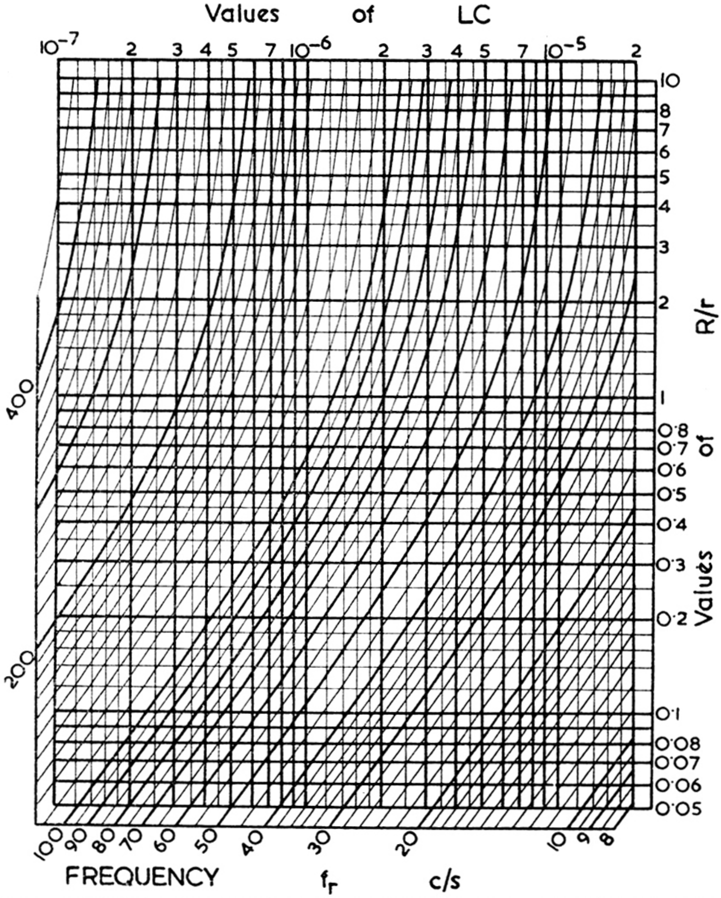


FIG. 41. CHART FOR IDENTIFYING REFERENCE FREQUENCY IN L.F. CASES USING PARALLEL FEED.

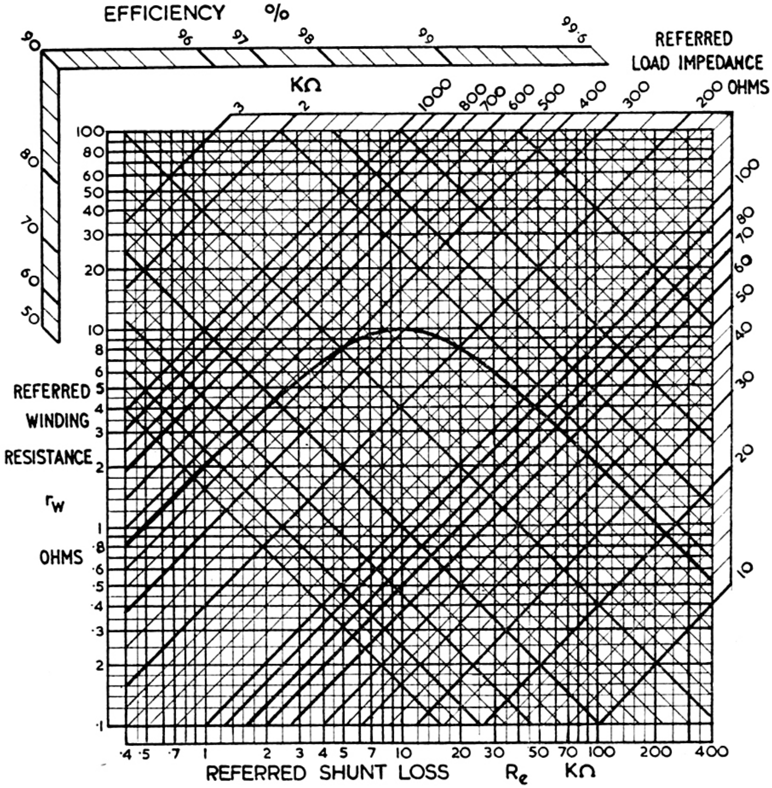


FIG. 42. EFFICIENCY CHART.

Examples in Use of Fig. 42

$r_w=2$ ohms, $R_e=20$ K, referred to a winding impedance of 50 ohms: 95.5 per cent. The optimum impedance for this winding would be 200 ohms, giving an efficiency of 98 per cent.

$r_w=.3$ ohm, $R_e=150$ ohms, referred to a winding impedance of 3 ohms: here two of the values are not on the chart, so use references: $r_w=3$, $R_e=1.5$ K, referred load$=30$: 87.3 per cent. The optimum impedance for this winding would be 6.5 ohms (reference 65), giving an efficiency of nearly 91 per cent.

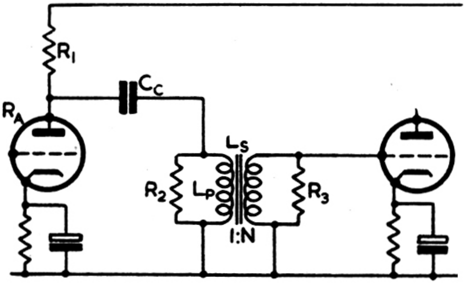


FIG. 43. THE LETTERED COMPONENTS CAN BE VARIED IN ALMO LIMITLESS COMBINATION TO ADJUST THE COMBINED H.F. AND L.F. RESPONSE C A PARALLEL FED TRANSFORMER. THE CHARTS HELP IN QUICKLY LOCATING THE M T SUCCESSFUL COMBINATION.

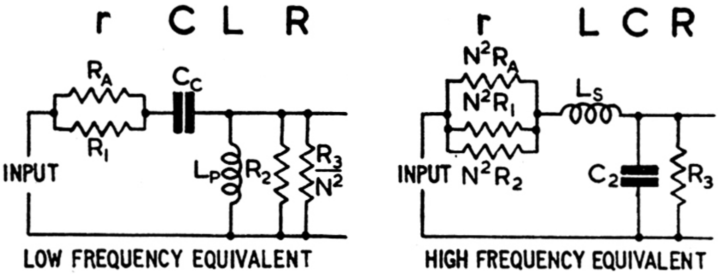


FIG. 44. EQUIVALENT CIRCUITS FOR FREQUENCY RESPONSE OF CIRCUIT OF FIG. 43.

APPENDIX

GENERAL NOTES

Purpose

Transformers are listed under the purpose for which they were designed, or for which they are best fitted. Some types, *e.g.* the Belclere midget series, could almost equally well be used as either input or output transformers. In such cases they are listed under the heading for which they are best suited. They are not repeated under the other heading, because the information is essentially the same. The order of maximum voltage figures and impedance values would be reversed, and a different primary inductance figure would be necessary, but the remainder of the information would be identical. It is a simple matter to obtain the corrected information from the table as it stands, when the transformer is required the reverse way round.

Size

In this column the largest dimension of the transformer is given, together with the letter L or H to indicate whether this dimension refers to length or height.

Ratio

This is listed always as a numeral greater than 1, regardless of whether it is step-up or step-down. The only exception to this is in Table 2, where the direction of step is reversed due to the combination of tappings on primary and secondary chosen, to avoid confusion.

In Table 2, the figures in italics indicate that the section of winding under which they are listed is centre tapped. For complete windings, this fact is indicated by whether or not the maximum voltage figures for the winding are in italics.

The symbol † against a ratio figure in Table 1 indicates that the transformer is of the auto type, instead of double wound.

Maximum Volts

Italic figures in this column indicate that the winding to which they refer has a centre tap. The figures are given in the order of impedance presentation in the next column, according to whether the transformer is being listed as step-up or step-down. Explanation of how to apply maximum voltage figures to work out power rating with the aid of the Chart of Figure 37 is given in Chapter 5.

Nominal Impedances

In Table 1 three figures appear in this column. Two of them, separated by a colon, give the impedance transference across the transformer, while the third figure gives the other impedance referred only to the winding to which it is presented. Examples: The entry 25 : 40K .4M indicates that the transformer used as a step-up will transform 25 ohms source up to 40 K on the secondary. The secondary then works into an impedance of .4 megohm.

The entry of 1M .1M : 25 indicates that a secondary load of 25 ohms is referred back to the primary as a load of .1M. The primary works out of a source impedance (a.c. resistance) of 1 megohm.

These figures form the basis for the parameters given in later columns. To find the response with other values, the simplest way is to find the position on the charts of Figures 38, 39 and 41 for these values, and then use the detachable scale to find the new position.

Italic figures (either or both of those separated by the colon) indicate that the winding to which they refer is centre tapped.

All ratios and impedances in Table 1 are given for whole windings where tapped; and where series/parallel arrangements are available, series connected. The listing in Table 2 shows how tappings on the winding under which they appear affect ratio and nominal impedance, when the whole of the other winding is used.

Primary Inductance

Provision is made in this column for inductance at a specified polarizing current. Where the inductance figure is followed by a dash, no polarizing current is indicated.

Inductance of the other winding can be obtained by multiplying or dividing by the square of the turns ratio, according to whether the transformer is shown as step-up or step-down.

High Frequency Parameters

These values are used with the charts of Figures 38, 39 and 40 to find high frequency response, and show its variation with circuit values.

An asterisk against the $\frac{R}{r}$ figure indicates that, although the transformer is actually connected as a step-down type, the h.f. response is worked out on the same basis as an ordinary step-up interstage. (*e.g.* Woden DT2).

The $\frac{L}{CrR}$ figure can be used as simple indication as to whether higher or lower operating impedances will give satisfactory frequency response: if the figure is greater than 1, higher impedances will be satisfactory; if it is less than 1, lower impedances will be satisfactory. The charts can still be used to determine the actual response, but this is a convenient rule. For other tips about values see Chapter 5.

The listing of winding capacitance enables the effect of additional capacitance connected external to the transformer to be estimated as shown at Figure 32.

Parallel Fed Interstage Types

Transformers of this group are indicated by the symbol ‡ in the winding capacitance column. There are two lines of figures in all the " high frequency parameters " columns. The top line carries the figures for high frequency response, while the lower line carries the figures for low frequency response. The capacitance figure under winding capacitance in this line is the assumed coupling capacitor value in microfarads.

It will be noticed that the $\frac{R}{r}$ value is different in both lines. This is because of the additional shunting effect of core losses at the l.f. end.

Loss References

See Chapter 5, under the heading " Efficiency."

MANUFACTURERERS' NAMES AND ADDRESSES

Belclere. *John Bell and Croyden, Acoustic Works, Chapel Street, Cowley Road, Oxford, England.*

The types listed from this manufacturer are just samples from a very wide possible range, usually manufactured to customer's specification. In the numbering code, the first letter indicates size, the second core material—M for Mumetal, R for Radiometal, and number the transformer ratio.

Elac. *Electro Acoustic Industries Ltd., Stamford Works, Broad Lane, London, N.15, England.*

This manufacturer supplies transformers with tappings according to customer's requirements.

Gardners. *Gardners Radio Ltd., Somerford, Christchurch, Hants, England.*

Parmeko. *Parmeko Ltd., Percy Road, Aylestone Park, Leicester, England.*

Input transformers listed by this manufacturer are provided with an electrostatic screen between windings.

Partridge. *Partridge Transformers Ltd., Roebuck Road, Tolworth, Surrey, England.*

This manufacturer's transformer type CFB is an improved version of the Williamson transformer, using C cores. Only the 1.7 one is listed, but the manufacturer also produces equivalents for the other Williamson ratio.

Muirhead. *Muirhead & Co. Ltd., Elmers End, Beckenham, Kent, England.*

This manufacturer's transformers listed are in Mumetal containers.

WB. *Whiteley Electrical Radio Co. Ltd., Radio Works, Victoria Street, Mansfield, Notts, England.*

Wharfedale. *Wharfedale Wireless Works, Bradford Road, Idle, Bradford, Yorks, England.*

Woden. *Woden Transformer Co. Ltd., Moxley Road, Bilston, Staffs., England.*

This manufacturer's UM series has both primary and secondary windings in two sections, each with a tapping. The variety of possible winding connections (as detailed in Table 2) means that any listing of high frequency parameters could be misleading.

Williamson

This listing has reference to transformers made to the specification given by the designer D. T. N. Williamson, in the *Wireless World* for April/May 1947.

TABLE I

Purpose	Manufacturer.	Type No.	Size	Ratio	Maximum volts 50~	Nominal impedances	Primary L	Primary mA	High frequency parameters $\frac{R}{r}$	$\frac{L}{CrR}$	LC	Winding Capce	Loss references r_w	R_e	Z_o
INPUT	Parmeko	P2549	1⅛" H	40	·45/18	25:40K ·4M	125mH	–	10	·012	4.10^{-12}	150	2·2	380	25
		P2570	1⅛" H	10	2/20	600:60K ·36M	2·5H	–	6	·01	5.10^{-12}	150	34	7·5K	600
		D7076	1·8" H	16	4/64	600:·15M ·6M	1·6H	–	4	·011	$9{\cdot}2.10^{-12}$	300	17	4·3K	600
	Belclere	CM60	13/16" L	60	·29/17	28:·1M 1M	·13H	–	10	·06	$2{\cdot}1.10^{-11}$	60	7·5	500	28
LINE	Muirhead	A907H1	3½" H	1	12/12	600:600	12H	–	–	–	–	–	22	28K	600
		A907H2	3½" H	2·89	35/12	5K 5K:600	100H	–	1	20	$1{\cdot}3.10^{-11}$	50	22·5	28K	600
		A907H3	3½" H	12·9	155/12	·1M:600 600	2000H	–	1	1·5	$1{\cdot}6.10^{-11}$	32	27	28K	600
INTER-STAGE	Belclere	CR4	13/16" L	4	8·5/34	20K:·32M 1M	6H	·2	·31	·014	$2{\cdot}8.10^{-11}$	80	1·5K	56K	20K
		AM3·5†	¾" L	3·5†	1·3/4·5	8K:·1M 1M	4H	–	10 1·5	·05 ·4	$2{\cdot}4.10^{-13}$ 4.10^{-7}	‡ 7 ·1	220	15K	8K
		BM4	¾" L	4	2·4/9·6	6·3K:·1M 1M	12H	–	10 4	·06 ·8	$5{\cdot}5.10^{-12}$ $1{\cdot}2.10^{-6}$	‡ 30 ·1	950	42K	6·3K
	Woden	DT2	3·6" H	1·56	*360/230*	2K *12K:5K*	300H	–	6*	10	$1{\cdot}4.10^{-11}$	600	230	200K	5K
		DT3	3" H	3	*440/1320*	*5·5K:50K* ·1M	350H	–	2	·06	$2{\cdot}7.10^{-11}$	300	3·2K	2M	5·5K
MODU-LATION	Woden	UM1	3·6" H	1·33	*180/240*	*7K:12·5K*	50H	–	*See note in text about these transformers.*				100	85K	7K
		UM2	5" H	1·33	*520/700*	*7K:12·5K*	130H	–					60	100K	7K
		UM3	5" H	1·33	*520/700*	*7K:12·5K*	100H	–					45	75K	7K
		UM4	6¾" H	1·33	*900/1200*	*7K:12·5K*	140H	–					60	220K	7K
OUTPUT	Belclere	AR65	¾" L	65	15/·23	1M ·1M:25	25H	2	10	·075	$4{\cdot}8.10^{-12}$	25	8	64	25
		BR16	¾" L	16	14/·9	1M 60K:230	25H	·2	17	·06	$3{\cdot}3.10^{-12}$	30	40	800	230

TABLE I continued.

Purpose	Manufacturer.	Type No.	Size	Ratio	Maximum volts 50~	Nominal impedances.	Primary L	Primary mA	High frequency parameters. $\frac{R}{r}$	$\frac{L}{CrR}$	LC	Winding Cap^ce	Loss references r_W	R_e	Z_0
OUTPUT	Elac.	T18	$2\frac{3}{8}$″L	68	100/1·5	3K 14K:3	10H	–	·21	10	$7{\cdot}2.10^{-12}$	120	·4	250	3
		T74	3″L	66	200/3	3K 13K:3	14H	–	·23	13	$1{\cdot}6\ 10^{-11}$	170	·4	260	3
		T35	$3\frac{1}{4}$″L	44	270/6	4K 20K:10	20H	–	2	5·1	$2\ 10^{-11}$	220	·55	500	10
	Gardners	OP702	$3\frac{7}{8}$″H	23·2	420/18	1·6K 8K:15	15·5H	50	·2	8	$3{\cdot}3.10^{-11}$	180	2·8	1·3K	15
		OP703	$4\frac{3}{8}$″H	18·7	500/26	1K 5·2K:15	10·6H	85	19	41	$2{\cdot}8.10^{-11}$	230	2·8	2·5K	15
		OP705	$4\frac{3}{8}$″H	18·3	500/28	2K 10K:30	70H	–	2	·026	$2{\cdot}8.10^{-11}$	230	2·9	2·8K	30
		OP707	$4\frac{3}{8}$″H	16·5	580/35	1·6K 8K:30	60H	–	·2	20	$2{\cdot}3.10^{-11}$	300	2·3	2·8K	30
		OP724	5″H	14·1	550/40	1·2K 6K:30	38H	–	·2	23	2.10^{-11}	350	1·4	2·8K	30
		OP750	$3\frac{7}{8}$″H	16	290/18	3K 3·8K:15	15H	50	·8	95	3.10^{-11}	180	2·4	1·6K	15
		OP754	$3\frac{7}{8}$″H	20	290/15	1·2K 6K:15	36H	–	2	58	$1{\cdot}7.10^{-11}$	200	1·8	900	15
		OP756	$4\frac{3}{8}$″H	20	450/23	1·2K 6K:15	51H	–	·2	55	$2{\cdot}1.10^{-11}$	230	1·4	1·8K	15
		OP735/6	*See separate entry 'Williamson'.*												
	Parmeko	D7861	$2\frac{1}{2}$″H	8	460/58	10K 50K:800	85H	–	·2	·07	8.10^{-11}	375	42	11K	800
	Partridge	PPO/1	$4\frac{3}{8}$″H	23	320/14	1·6K 8K:15	75H	–	·2	·045	$1{\cdot}4.10^{-11}$	500	*No data on this supplied.*		
		PPO/2	$4\frac{3}{8}$″H	25·8	360/14	2K 10K:15	95H	–	·2	·036	$1{\cdot}7.10^{-11}$	500			
		WWFB/0	*See separate entry 'Williamson'*												
		CFB/1·7	$5\frac{5}{8}$″H	9·5	1300/135	2K 10K:110	160H	–	2	·83	6.10^{-12}	600	4	20K	110
	WB	T142	$2\frac{5}{8}$″L	80	80/1	4K 20K:3	5H	–	·2	16	$1{\cdot}3.10^{-11}$	100	·35	60	3
		T144	$3\frac{1}{4}$″L	80	250/3·1	4K 20K:3	10H	–	·2	11	$2{\cdot}2.10^{-11}$	160	·3	115	3
		T143	$3\frac{7}{8}$″L	60	330/5·5	2·2K 11K:3	10H	–	·2	25	$3{\cdot}3.10^{-11}$	240	·35	130	3
		T152	4″L	18·7	330/18	1K 5·3K:15	15H	–	·19	38	4.10^{-11}	450	1·5	1·7K	15

TABLE I continued.

Purpose	Manufacturer	Type No.	Size	Ratio	Maximum volts 50~	Nominal impedances	Primary L	Primary mA	High frequency parameters $\frac{R}{r}$	$\frac{L}{CrR}$	LC	Winding Cap^{ce}	Loss references r_w	R_e	Z_0
OUTPUT	WB	T276	5¼″ H	2·45	*1000/40*	800 *4K*:670	60H	–	·2	8	$1{\cdot}23.10^{-10}$	2200	92	·4M	670
		T296	6⅜″ L	4·4	*400/90*	800 *4K*:200	15H	–	·2	·8	$2{\cdot}6.10^{-11}$	3300	5	22K	200
	Wharfedale	OP3	2⅜″ L	90	90/1	1·6K 8K:1	15H	–	·2	28	7.10^{-12}	140	·22	55	1
		P	3″ L	90	180/2	1·6K 8K:1	17H	–	·2	34	$2{\cdot}3.10^{-11}$	230	·34	135	1
		GP8	3″ L	36	*180/5*	1·8K *9K:7*	18H	–	·2	26	$4{\cdot}5.10^{-10}$	230	1·2	850	7
		Universal	3″ L	40	*150/3·75*	1·6K *8K*:5	18H	–	·2	17	$1{\cdot}4.10^{-11}$	250	·85	480	5
		DeLuxe	4″ L	40	*440/11*	1·6K *8K*:5	45H	–	·2	11	$1{\cdot}8.10^{-11}$	350	1·2	1·3K	5
		W12	4″ L	15	*440/30*	700 *3·5K*:15	50H	–	·2	57	$1{\cdot}8.10^{-11}$	350	4·8	9K	15
		W15	4½″ L	20	*840/42*	1·2K *6K*:15	120H	–	·2	4	$2{\cdot}3.10^{-11}$	900	3·5	2·2K	15
	Williamson	*/1·7*	6″ H	9·5	*/000/106*	2K *10K*:110	100H	–	·2	3·3	6.10^{-12}	290	6·8	20K	110
	″	*/3·6*		6·5	*/155*	:230							14	42K	230

Manufacturers' type Nos. listed with their names.

TABLE 2

Manufacturer	Type No.	DETAILS OF PRIMARY TAPPINGS		DETAILS OF SECONDARY TAPPINGS	
		Ratios at tappings	Nominal impedances	Ratios at tappings	Nominal impedances
Parmeko	D7076	32 by series/parallel arrgt.	150	—	—
Woden	UMI–4	8 4 2·7 *4* *2*	110 440 1K *440* *1750*	·26 ·4 ·67 *·53* *·8*	500 1100 3K *2K* *5·5K*
Gardners	OP702	12·9 14·6 19·2	2·5K 3·75K 5·5K	56·5 40 32·7	2·5 5 7·5
	OP703	12·1 14·6 16·7	2·2K 3·2K 4·2K	45·6 32·2 26·3	2·5 5 7·5
	OP705	*11·5* *14·1* *16·3*	*4K* *6K* *8K*	63·2 44·7 36·5 25·8	2·5 5 7·5 15
	OP707	*11·5* *14·1*	*4K* *6K*	56·5 40 32·6 23·1	2·5 5 7·5 15
	OP724	*9·1* *10·8* *12·3*	*2·5K* *3·5K* *4·5K*	49 34·7 28·3 20	2·5 5 7·5 15
	OP750	—	—	39 27·6 22·5	2·5 5 7·5
	OP754	—	—	49 34·7 28·3	2·5 5 7·5
	OP756	—	—	49 34·7 28·3	2·5 5 7·5
Parmeko	D7861	separate feedback winding	—	*16*	*200*
Partridge	PPO/1	—	—	46	3·75
	PPO/2	—	by series/parallel arrangements	51·6	3·75
	CFB/1·7	—	—	76 38 19	1·7 6·8 27
WB	T142	10 20 30 *40* 60 70	300 1200 2·7K *5K* 10K 15K	—	—
	T144	10 30 40 *60* 70	300 2·7K 5K *10K* 15K	—	—
	T143	10 20 30 *40* 50	300 1200 2·7K *5K* 7·5K	75	2
	T152	9·4	1·3K	25 22·4	8 10
	T276	separate feedback winding	—	—	—
	T296		—	—	—

TABLE 2 continued.

Manufacturer	Type No.	DETAILS OF PRIMARY TAPPINGS		DETAILS OF SECONDARY TAPPINGS	
		Ratios at tappings	Nominal impedances	Ratios at tappings	Nominal impedances
Wharfedale	OP3	30 60	900 3·6K	—	—
	P	30 45 60	900 2K 3·6K	—	—
	GP8	6 12 18 12 24	250 1K 2·3K 1K 4K	72 by series/parallel arrgt	1 75
	Universal	20	2K	80 60	1·25 2·2
	DeLuxe	20	2K	80 60	1·25 2·2
	W12	7·5	900	45 22	1·7 7
	W15	10	1·5K	40 by series/parallel arrgt	3·75
Williamson	1·7	—	by series parallel arrangements	76 38 19	1·7 6·8 27
"	3·6	—		52 26 13	3·6 14·5 57·5

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