Input Transformer Design

The choice of an input transformer depends greatly on the use to which it is to be put. The author tells how to determine if a transformer can be made to work satisfactorily under given conditions and how to complete the design to obtain the desired results.

NORMAN H. CROWHURST*

TRANSFORMERS are things we like to do without in audio, but there are some positions in the circuit and some applications in which they seem to be unavoidable. For example, it is not practical to connect the low impedance of a 50-ohm microphone or pickup directly to the input grid of an amplifier, because the output of the device is not sufficiently above the inherent noise levels of the circuit to give a satisfactory signal-to-noise ratio. For this reason it is highly desirable to use a good transformer to step-up the signal without giving a corresponding step-up in background noise.

So we need to design an input transformer that will give the best possible compromise between maximum step-up to achieve good discrimination of signal against noise and the maintenance of a frequency response that is as good as possible. In general, the bigger the step-up the more difficult it is to maintain a good wide-band frequency response.

Where do we start in designing such a component? The first and most important thing to realize is that one cannot design such a transformer without adequate reference with the circuits with which it is going to be used.

With this fact in mind it is well, for both the designer and the prospective user of such a transformer, to first of all explore the situation on the basis of using a hypothetically perfect transformer. Find out what is the maximum performance a transformer could be expected to achieve, assuming that a perfect one might be available somewhere. Having explored the situation from this aspect, it is evident that a practical transformer will achieve a performance somewhat short of this.

A procedure like this may seem to appear like a waste of time, but in practice it is found to save time because it dictates quite simply a reasonable performance specification to lay down. Without this preliminary exploration one might be striving to achieve a performance that is quite impossible even if the transformer were perfect.

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Dynamic Transducers

The commonest application of this type consists of an electro-dynamic transducer, either a microphone or pickup, which requires to be fed through a transformer into the input stage grid of a tube. The dynamic transducer has a source impedance consisting basically of a resistance in series with an inductance as shown at *Fig.* 1, while the grid has an input impedance which is basically capacitive, although there may be a slight resistive element.

If we apply an ideal transformer between these two, the simplest way of visualizing the situation is by consider-

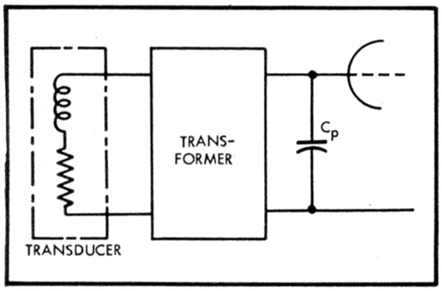


Fig. 1. The commonest function of an input transformer is to couple a low impedance transducer, whose impedance consists of resistance and inductance, to the high impedance grid input circuit of an amplifier. Here C_p stands for the effective grid input capacitance, including that due to wiring strays.

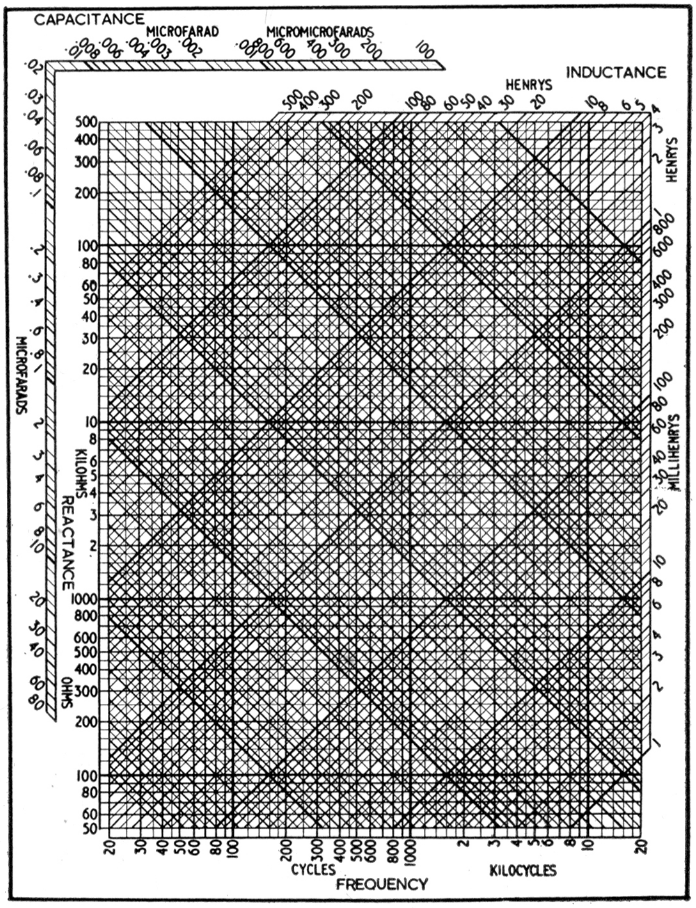
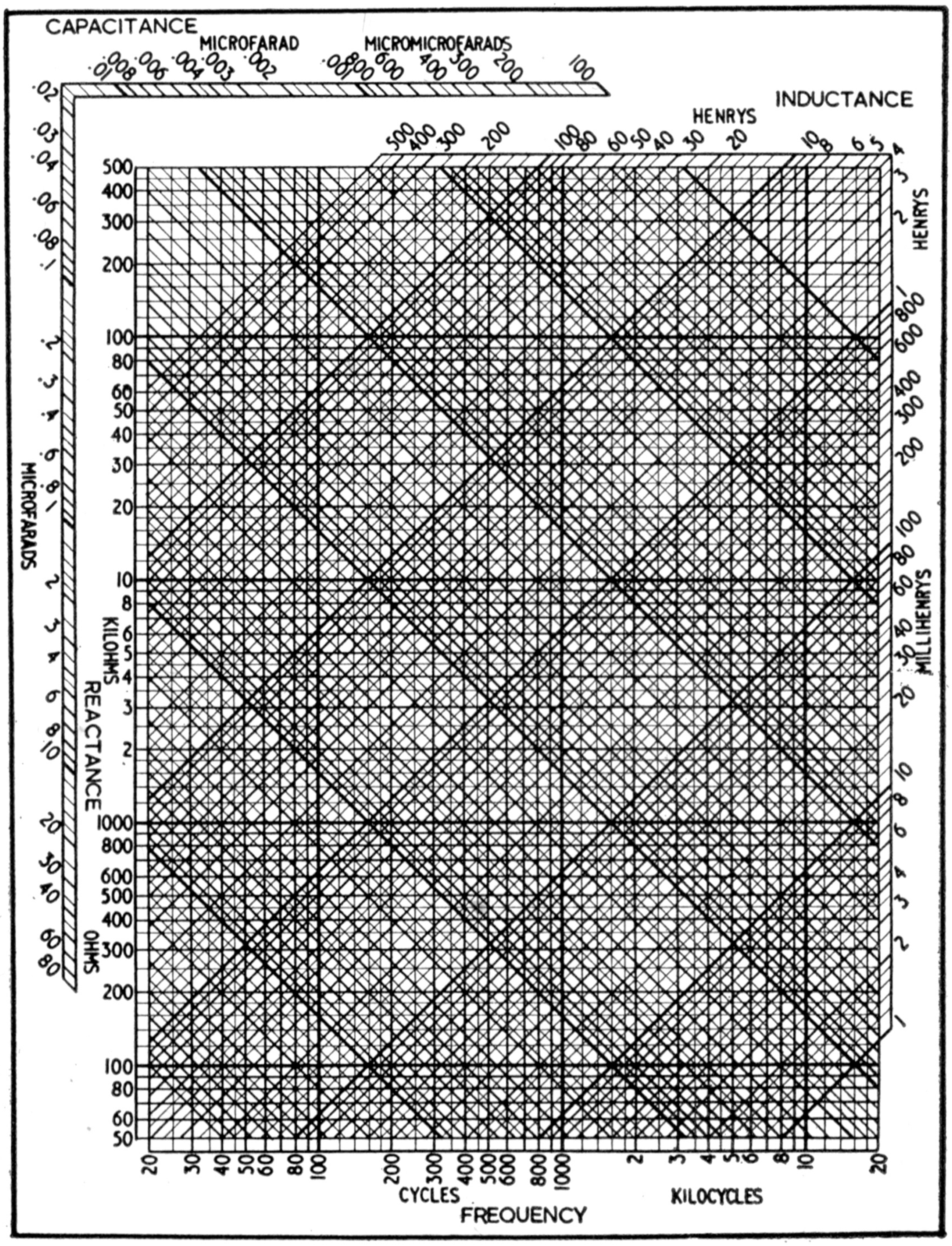


Fig. 2. A reactance chart covering the range most useful in the design of input transformers.



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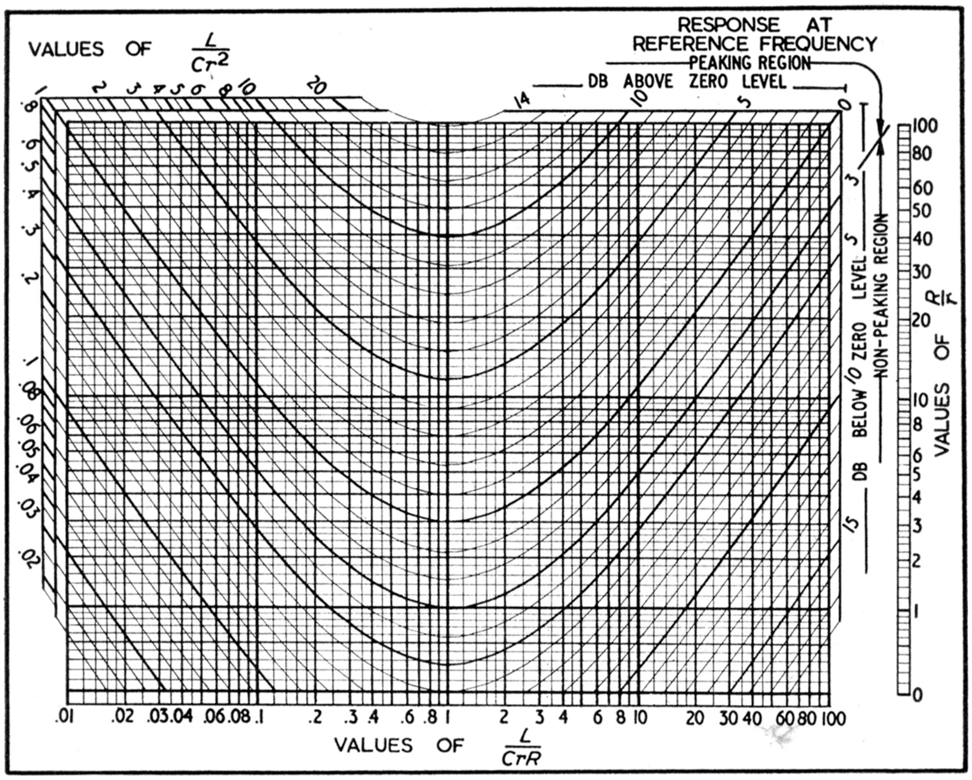


Fig. 4. Chart for determining the response shaping produced by various circuit element combinations. The values of L/Cr^2 at the top and left are for cases where the secondary is unloaded, the db at reference frequency being obtained by following the curves to the top or right side of the chart. Where the secondary is loaded, the equivalent circuit, given at Fig. 7 uses reference values along the bottom and right hand side to locate a position in the body of the chart, the result being read off at the same place.

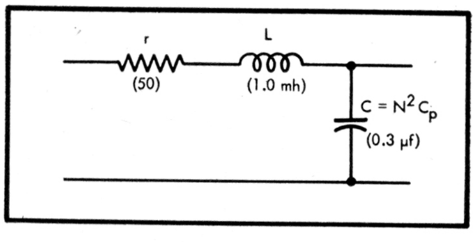


Fig. 3. Equivalent circuit of arrangement discussed in the text. The values in brackets are for the particular case considered.

ing the transformer to multiply the effective grid input capacitance by the square of the step-up ratio of the transformer. Supposing the effective grid input capacitance is calculated to be 30 μμf and the step-up ratio is 100:1; then the capacitance will be multiplied by 10,000, giving an effective shunt capacitance, referred to the primary, of 0.3 μf. This has a reactance of 50 ohms, as shown on the reactance chart of *Fig.* 2, at just over 10 kc.

So a 100:1 step-up from a pure resistance of 50 ohms to a grid with an input capacitance of 30 μμf would produce a response with a rolloff of 3 db at about 10 or 11 kc. This is assuming that the transformer was perfect and did not add any components to the circuit except a straightforward step-up.

But we should also take into account the effect of the inductance component of the transducer. Assume this is 1 millihenry. The basic circuit then consists of 50 ohms, 1 mh and 0.3 μf in the arrangement of *Fig.* 3. From these values we evaluate $\frac{L}{Cr^2}$ as $\frac{10^{-3}}{3\times 10^{-7}\times 2.5\times 10^{3}}=1.33$, and $LC=3\times 10^{-10}$. From *Fig.* 4 the first value gives +1 db at reference frequency, while the second value with *Fig.* 5 gives the reference frequency as 9 kc. Next, from *Fig.* 6, we see that a curve with +1 at reference frequency gives a peak of +2 db at a relative frequency of 0.78. In this case this represents a response with a peak of 2 db at about 7 kc, 1 db up at 9 kc and about 12.5 db down at 20 kc.

This is what a perfect transformer will do. If a response not as good as this can be considered acceptable, then design may be proceeded with for a 100:1 step-up transformer for the operating condition. Otherwise, the best plan is to find suitable step-up ratio that is basically capable of producing a response that will be acceptable. Let's assume that we have set ourselves the target of producing a response to better than ±1 db up to 20 kc.

Halving the step-up will reduce the referred capacitance from 0.3 microfarad to 0.75 microfarad. This changes the values to $\frac{L}{Cr^2}=5.33$ and $LC=7.5\times 10^{-11}$ which indicates a response of +7 db at a reference frequency of 18 kc. This arrangement will thus give a response with a peak of a little more than 7 db at a frequency somewhat below 18 kc, but the use of secondary loading will readily pull this peak down.

A value of resistance referred to the input circuit at 125 ohms gives values of

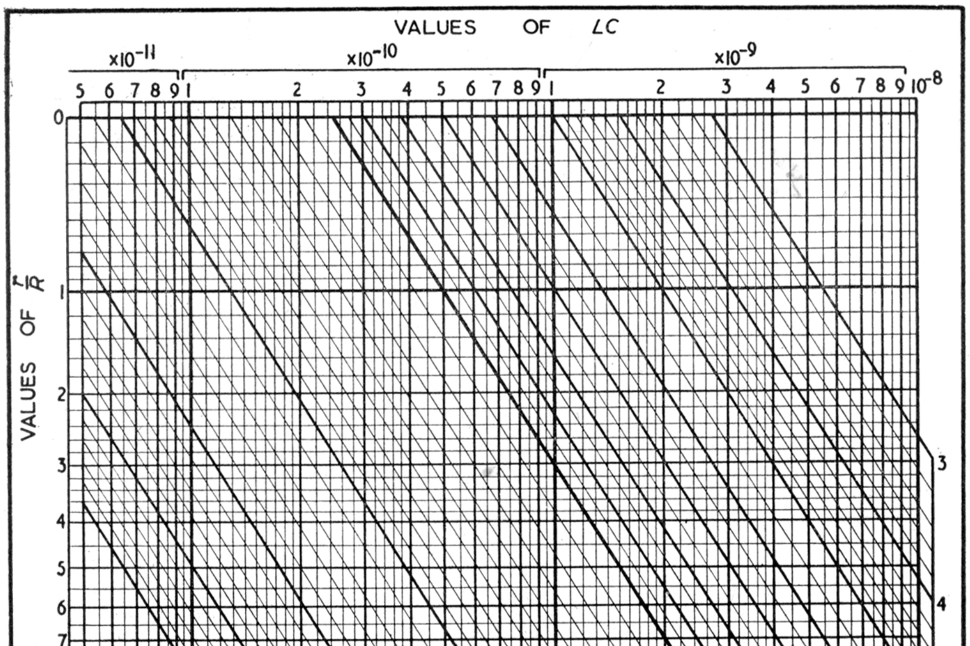
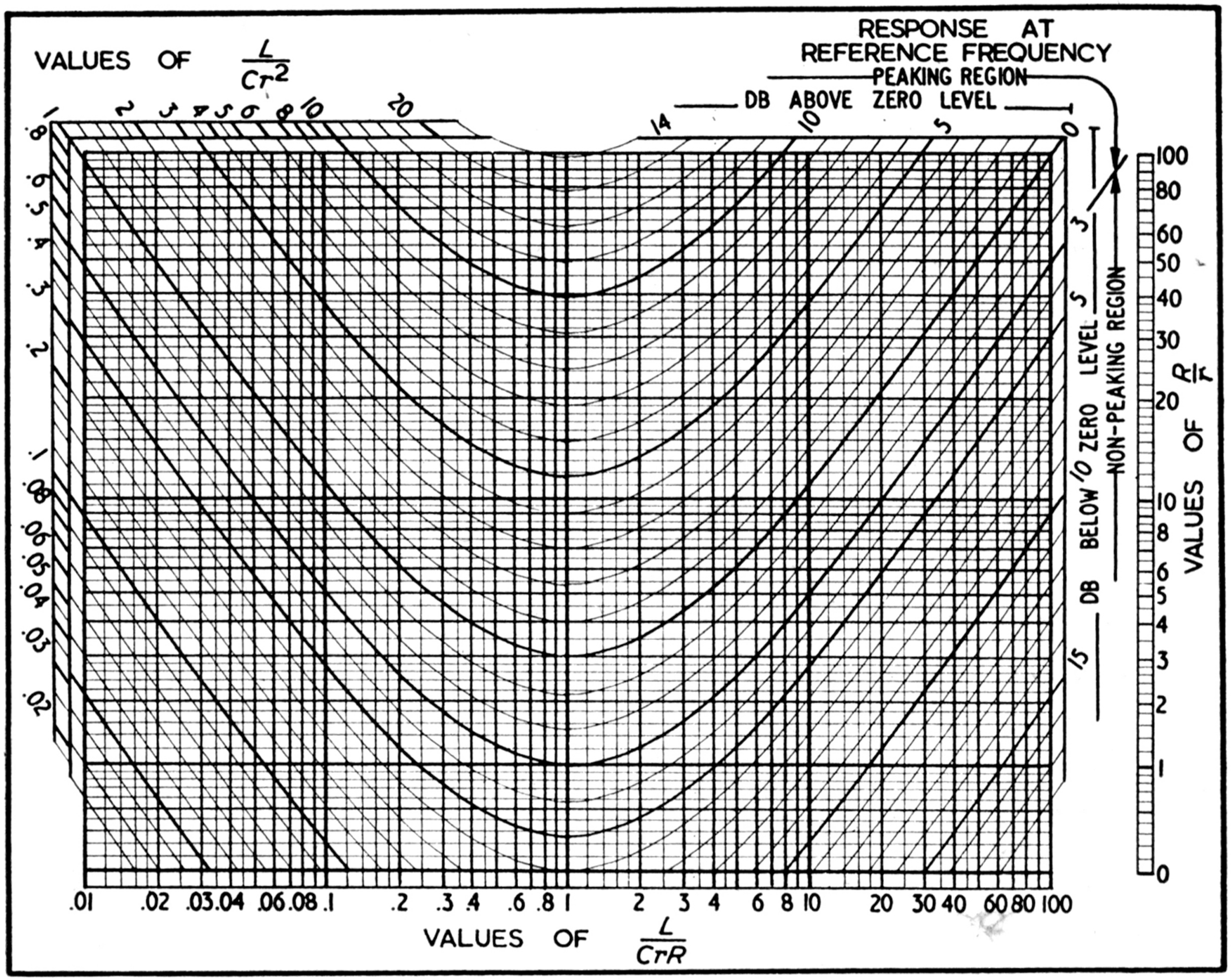


Fig. 5. Chart for determining the reference frequency for the response shaping shown by Fig. 4. If values of L/Cr^2 are used, the line for $r/R=0$ is used, at the top. Where values of L/CrR are used, the appropriate value for r/R is used, noting that this is the reciprocal of the value of R/r used on Fig. 4.



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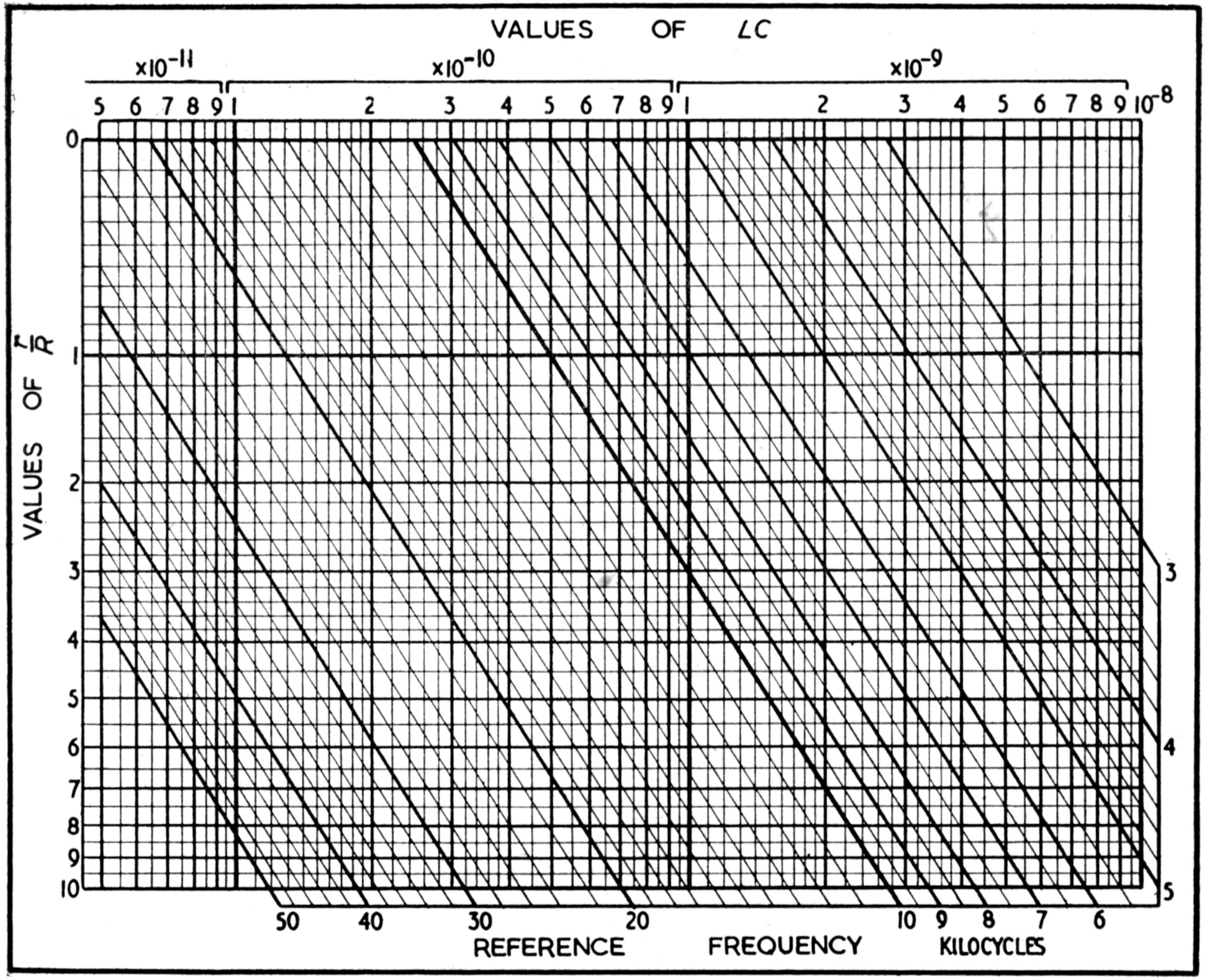

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$\frac{L}{CrR}$ (see *Fig.* 7) as $\frac{10^{-3}}{7.5 \times 10^{-8} \times 6.25 \times 10^{3}}$ $= 2.13$; $\frac{R}{r} = 2.5$ and $LC = 7.5 \times 10^{-11}$. This indicates a response of -1 db at a reference frequency of 22 kc. So this value of referred resistance on the secondary will load this peak down so that the response is -1 db at 22 kc and has a peak of about 0.6 db at 13 kc. On the secondary side this would require an actual resistance of about 0.312 meg. This arrangement is based on the assumption that we use a 50:1 step-up ideal transformer.

In practice, as we have to apply losses to pull the peak down, it may be possible to use the transformer core losses to serve at least part of this function. But there is another factor that has to be considered in designing a practical transformer. This will introduce additional shunt capacitance in the grid circuit, and also increase the effective source inductance by the addition of leakage inductance. So the values of L and C used to compute the response with an ideal transformer will both have to be increased somewhat, and in all probability this will bring the response below the one just computed for an ideal case. This means that some margin should be allowed, if the over-all response is still required to be within the original limits set.

For some applications, for example the ribbon mike, the source impedance is practically a pure resistance throughout the audio band, in which case the design of the transformer can be considered without needing to take into account the inductance component of the input source. This means that the design of the transformer will only need to consider the inductance component contributed by the transformer itself in the form of leakage inductance for the high-frequency response.

Crystal or Electrostatic Transducer

Another application that could be considered for input transformer is to couple a capacitive source such as a crystal microphone or pickup or maybe even some kind of electrostatic transducer. Here, assuming an ideal or perfect transformer, it might be possible to achieve some gain by using a step-up.

For example, if the grid input capacitance is 30 μμf and the capacitance of the crystal is 500 μμf, it should be possible to employ an impedance step-up of 16:1, or a voltage ratio step-up of 4:1 to achieve optimum matching.

But for this kind of application practical transformers completely fall down on the job. It is quite impossible to design a physical component that will achieve this kind of step-up for working between capacitive source and load impedances. The use of reactive terminating impedances means we have to completely reorient our conception of what different components contribute to the performance of the circuit.

With resistance termination, core losses, appearing as a shunt resistance, merely present insertion loss throughout the entire spectrum—except where they may be useful in damping peaks as just mentioned. Winding resistances also contribute to insertion loss. But between reactive source and load impedances, any resistance has frequency discriminating effect.

A shunt resistance, such as a core loss represents, will produce a low-frequency rolloff which will have its 3-db point where the resistance is equal to the referred reactance of the source and load combined in parallel. Series resistance, such as will be contributed by winding resistances, produces a high-frequency rolloff, the 3-db point of which will be at a frequency where the total referred resistance is equal to the combined reactance of the source and load referred in series.

Assuming for the moment that primary inductance can remain infinite, leakage inductance zero, and winding capacitances zero, it appears that the losses in the transformer will result in a frequency response with a rolloff at each end, without taking into account its essential reactances.

Assume the transformer is 80 per cent efficient, which is a reasonably good power transfer efficiency for an input transformer because of its small size—and it would have to be physically small to achieve even an approximation to zero leakage inductance and winding capacitance. Then the core loss, referred to any given winding, will not be more than 100 times the total winding resistance referred to the same winding which means that the spacing between the 3-db points on the low-frequency and high-frequency rolloffs, as contributed by losses alone, will be not more than about a ratio of 400:1. To get a wider frequency response it will be necessary to have a transformer of higher nominal efficiency.

(To be continued)

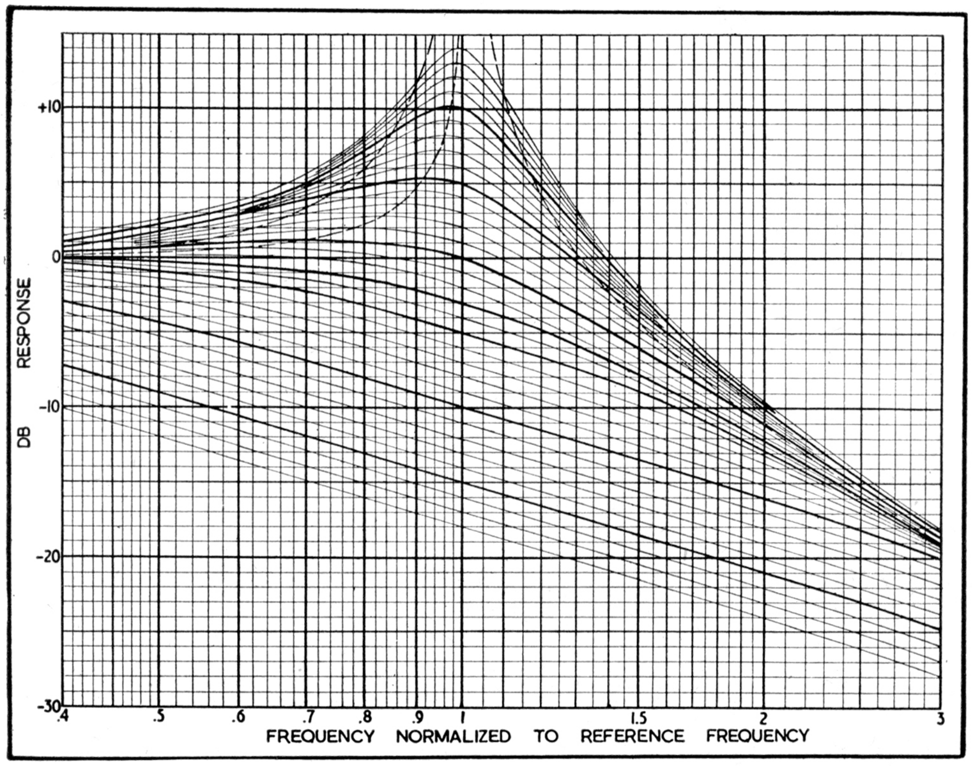

Fig. 6. Response shapings selected by the chart of Fig. 4. Actual frequencies can be calculated from the reference frequency given by Fig. 5. The dotted lines indicate the points of maximum slope on the curves (the outside ones) while the middle one indicates the point of the peak, which is useful in response computation when the peak is not very high.

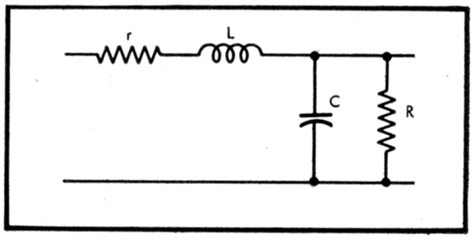

Fig. 7. Basic circuit for the high frequency response of an input transformer: *r* is the source resistance, and *L* the source inductance (if any) plus the transformer leakage inductance referred to the primary; *C* is the total secondary shunt capacitance referred to the primary (i.e. multiplied by the square of the step-up ratio), while *R* is the secondary load resistance (if any) referred to the primary (i.e. divided by the square of the step-up ratio).

Input Transformer Design

NORMAN H. CROWHURST*

Continuation of the discussion of amplifier performance as related to input transformers and their design characteristics.

We will now consider the effect of the reactances which the transformer will contribute. The primary inductance will add a further low-frequency loss element which will make the ultimate slope at the low frequency end in the region of 18 db per octave. This is because it is combined with the source and load capacitances as the other reactance elements for the low-frequency roll-off. Leakage inductance, acting between input and output capacitances, will similarly introduce an 18-db-per octave ultimate rolloff characteristic. The relevant circuits are shown in *Fig.* 8.

Apart from the restricting influence that this will have on the effective frequency bands that could be designed into such a transformer, there is also the practical difficulty of designing a unit that will have a smooth rolloff characteristic at both ends for the required frequencies. Any effort to complete such a design proves that it is impossible to achieve any practical step-up while maintaining a reasonable degree of fidelity.

However the fact that an *ideal* step-up is possible means that such matching can be arranged for a relatively narrow frequency band, and hence might be worth considering for such an instrument as a hearing aid. The factor to consider then is whether the transformer would contribute sufficient extra gain to be worth its additional cost as compared with other methods of picking up gain. In hearing aid work, the reason for which an input transformer is usually employed in high-quality reproduction does not obtain; background noise is not an important factor here.

Practical Design

Having explored the possibilities of a transformer as an ideal component, we next have to consider design of a practical transformer. The first thing to do is to select a suitable core material and core configuration.

As input transformers invariably have to operate at extremely low level and hence low flux density, the important feature about an input transformer core material is that it shall have high initial permeability. The initial permeability of a magnetic material is controlled by the magnetization characteristic of this material in its first stage. According to currently accepted magnetic theory, the first stage is explained as being due to the more close alignment of those crystal lattices in the magnetic structure that are already approximately oriented in a major direction corresponding to the direction of magnetization.

The achieving of a high permeability in this region must rest, according to this theory, upon complete relieving of molecular stress within the material, and in practice this conjecture is substantiated. Materials developed to have high initial permeability require special annealing to relieve every vestige of molecular stress within the material. This is the principal reason why these particular alloys are expensive. Not only do the materials that go to make up the alloys have to be blended with chemical purity and precision but after the material has been worked such as by rolling and stamping it, a costly annealing process has to be applied.

To date the highest initial permeability has been achieved with nickel iron alloys, in a combination that, with proper annealing, gives initial permeabilities better than 10^5. These alloys also have relatively high resistivity, to give low eddy-current losses, but this is not usually very important on input transformer design, for which reason it is unnecessary to go to the extremely thin laminations.

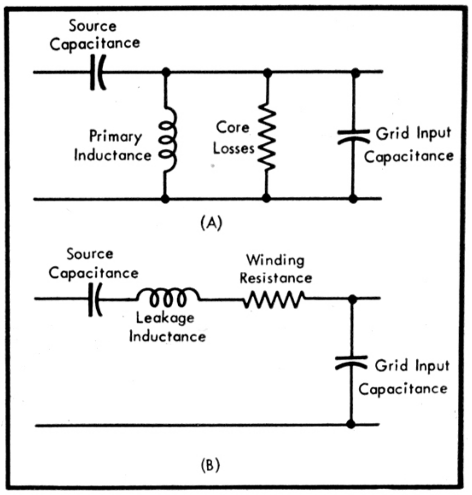

Fig. 8. Equivalent circuits for the low- and high-frequency response of a transformer operating between capacitive source and load. (A), the equivalent for low frequency response, and (B), the equivalent for high-frequency response.

Grain oriented materials do not seem to give appreciably better initial permeability than the simple heat treated nickel iron alloy, so there is no point in going to the C core construction for input transformers.

The next problem is the selection of a suitable core shape. The factors determining shape are: (a) primary inductance; (b) leakage inductance; (c) winding capacitance.

The shape has to be so chosen as to give a maximum value as of (a), consistent with minimum value of (b) and (c). Where (c) can be neglected, as with output transformers and other transformers working at lower impedances on both sides, selection of shape can readily be reduced to a theoretical economic basis, as described in an earlier article on transformer design. ("Audio Transformer Design," Audio Engineering, Feb. 1953). But when capacitance enters the picture the problem is no longer so simple.

In addition to the theoretical factors listed above, there is the practical limitation imposed by the smallest gauge of wire that can be wound with the equipment available. This limits the maximum number of turns that can be gotten into a given winding crossectional area. When applying a purely mathematical theory for optimum shaping, this does not take into account physical limitations of wire gauge, but assumes a wire may be drawn and wound on the bobbin as thin as may be dictated by the mathematical solution.

The writer has found a useful approach in the tabulation of various data about certain available cores, which fall in a general group suitable for this purpose, as shown in *Fig.* 9. For the purpose of the tabulation, it is assumed that the transformer will be wound as full as economically possible with two windings occupying equal winding area. One of these windings is assumed to have 1000 turns of a wire gauge chosen so as to fill its one half of the available

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area and the various losses are referred to this winding.

The d.c. resistance of this winding is calculated and the core losses due to eddy current are referred to it. This information will give a figure of power transfer efficiency (when the secondary is loaded), and also a value for efficiency when unloaded on the secondary. In the first case, the loss in both windings will contribute to the series losses, while in the second case, the loss in the primary winding only is compared with the referred core losses. A working impedance is evaluated for the 1000 turns such as to enable the transformer to operate at maximum power transfer efficiency. This working impedance for a 1000-turn winding can then form the basis of a theoretical frequency response for this type of core. Primary inductance is evaluated from data on the core material, and the 3-db point with this working impedance entered on the table. Leakage inductance is similarly computed with the aid of *Fig.* 10, and referred to this same 1000-turn winding, from which a 3-db point for the upper end of the response is evaluated.

Next calculate the maximum numbers of turns that can be put into the other half of the winding space, using the finest gauges of wire that can be wound successfully on this type of bobbin. These numbers are used in conjunction with the working impedance obtained for 1000 turns to evaluate the maximum referred impedance on the secondary side and the winding capacitance of these turns, from *Fig.* 11. This tabulation is then very useful for applying in practical design.

We shall not necessarily calculate the number of turns on the basis of this theoretical optimum. It may be that the low-frequency rolloff point listed is not low enough, while the maximum available step-up listed gives an impedance which will produce too much loss at the high-frequency end, due to winding and grid input capacitance. If this is the case then a larger number of turns can be used for the working impedance required, which will give a better inductance than that based on the theoretical maximum efficiency condition, and will also reduce the available step-up so that the working impedance in the grid circuit is lower and hence the high-frequency response acceptable.

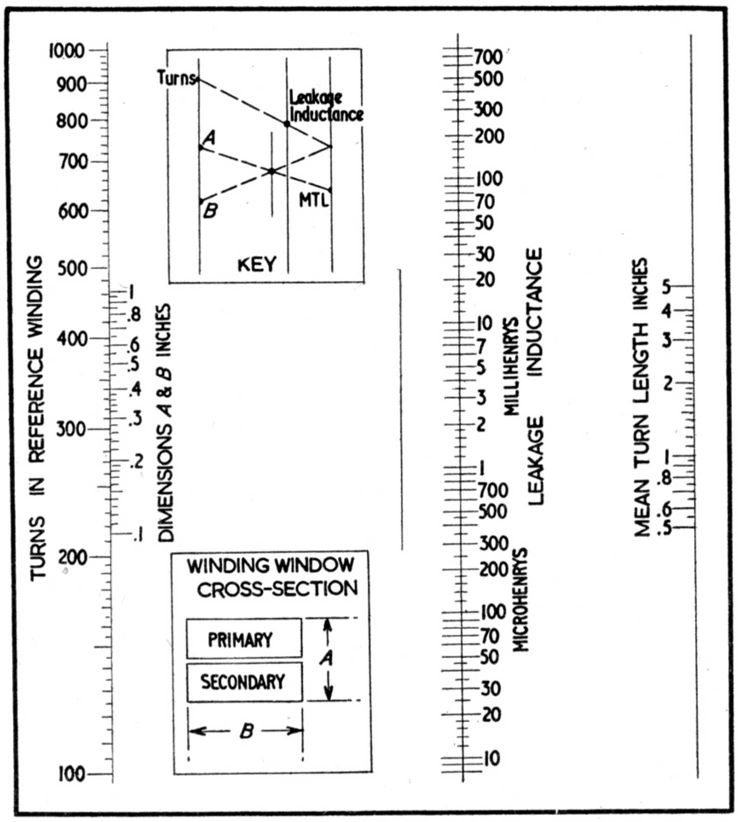
Alternatively, a core having an exaggerated core cross section compared to winding area may give a low-frequency rolloff point which is unnecessarily low and, due to the restricted winding space, may limit the step-up so that the high-frequency response is also unnecessarily good. In this case a lower number of turns can be used to represent the desired working impedance, so as to enable a higher step-up to be obtained, bringing the response range down to something that is still acceptable, although we have increased the effective gain of the transformer.

Having selected a suitable approach the design should be completed out, the primary inductance, leakage inductance and winding capacitances calculated, and the whole frequency response computed with the aid of *Figs.* 4, 5 and 6.

It may be found that the combination of parameters results in a peak at the high-frequency end of the response which will need attention by use of resistance loading. Usually this means that the transformer has been made unnecessarily good, in the sense that too much good material has been put into it. A smaller transformer, using a more slender core cross section, with a greater number of turns, will usually achieve as good a response with less material cost and in addition without the necessity of resistance loading on the secondary.

The important thing to notice in designing an input transformer is that *it is designed for a specific circuit condition.* It is a pity that many manufacturers' catalogs do not indicate precisely the circuit condition for which the transformers are designed.

From the way the catalogs list them, it would appear that a 50:1 step-up transformer from a 50-ohm microphone is designed to be terminated with its matching impedance of 125,000 ohms. In a small transformer, with an efficiency



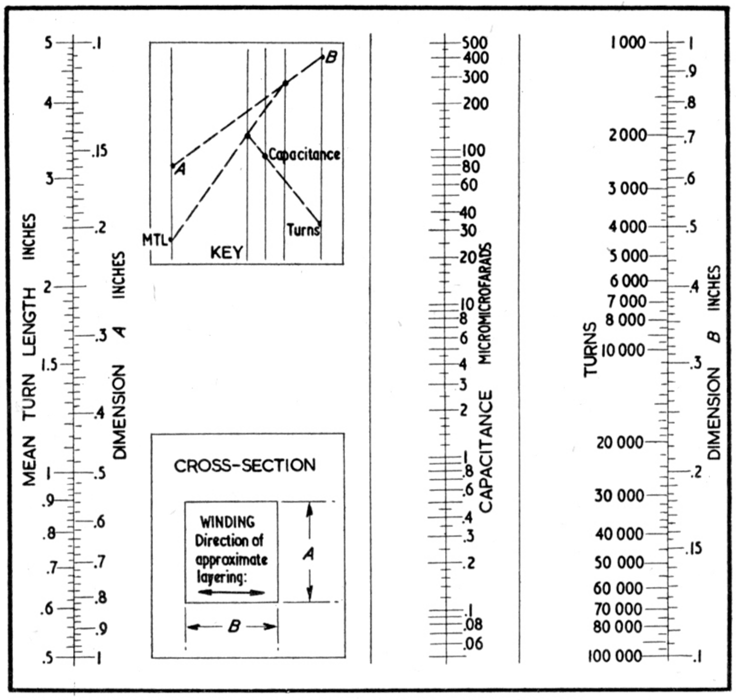
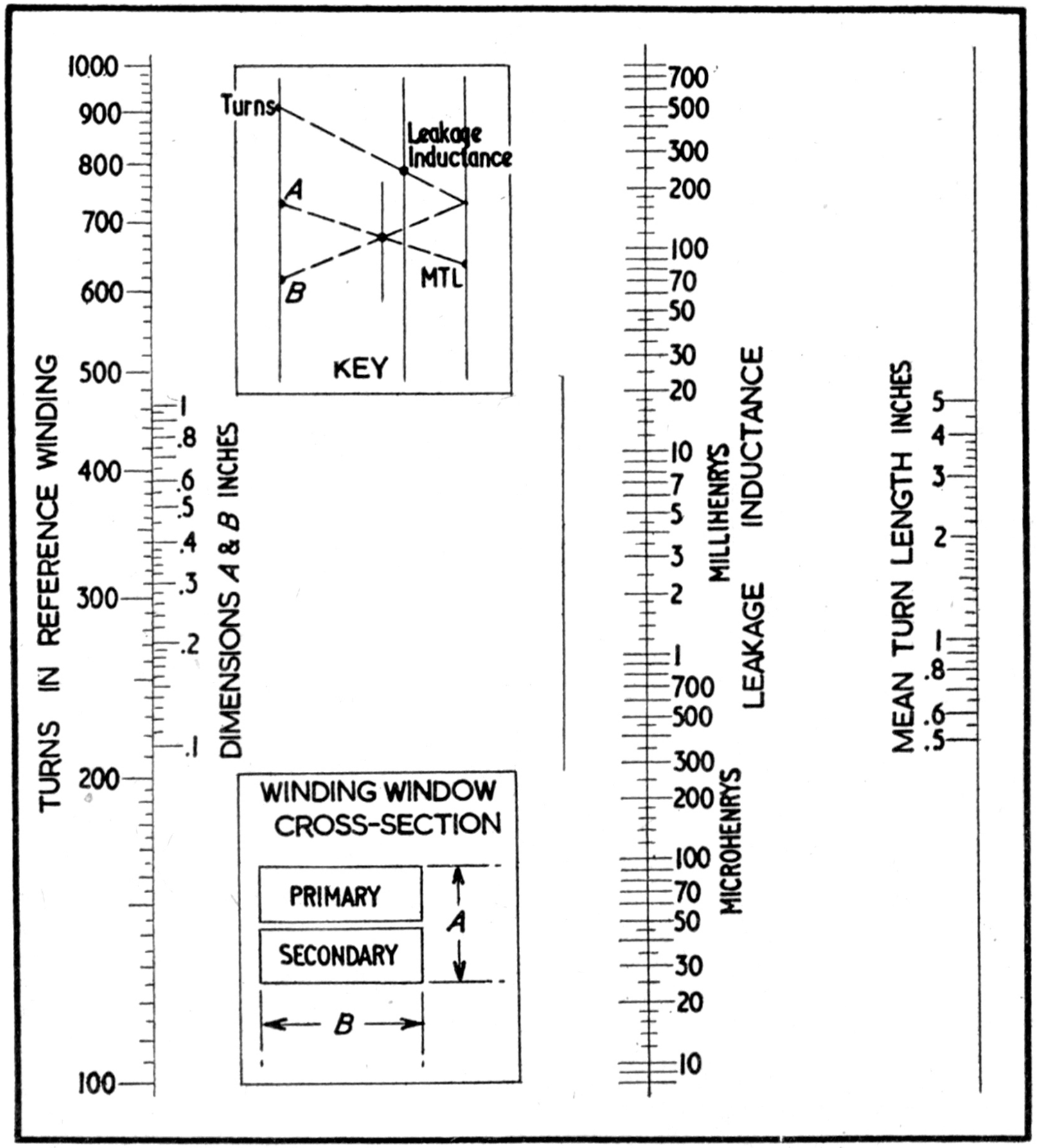
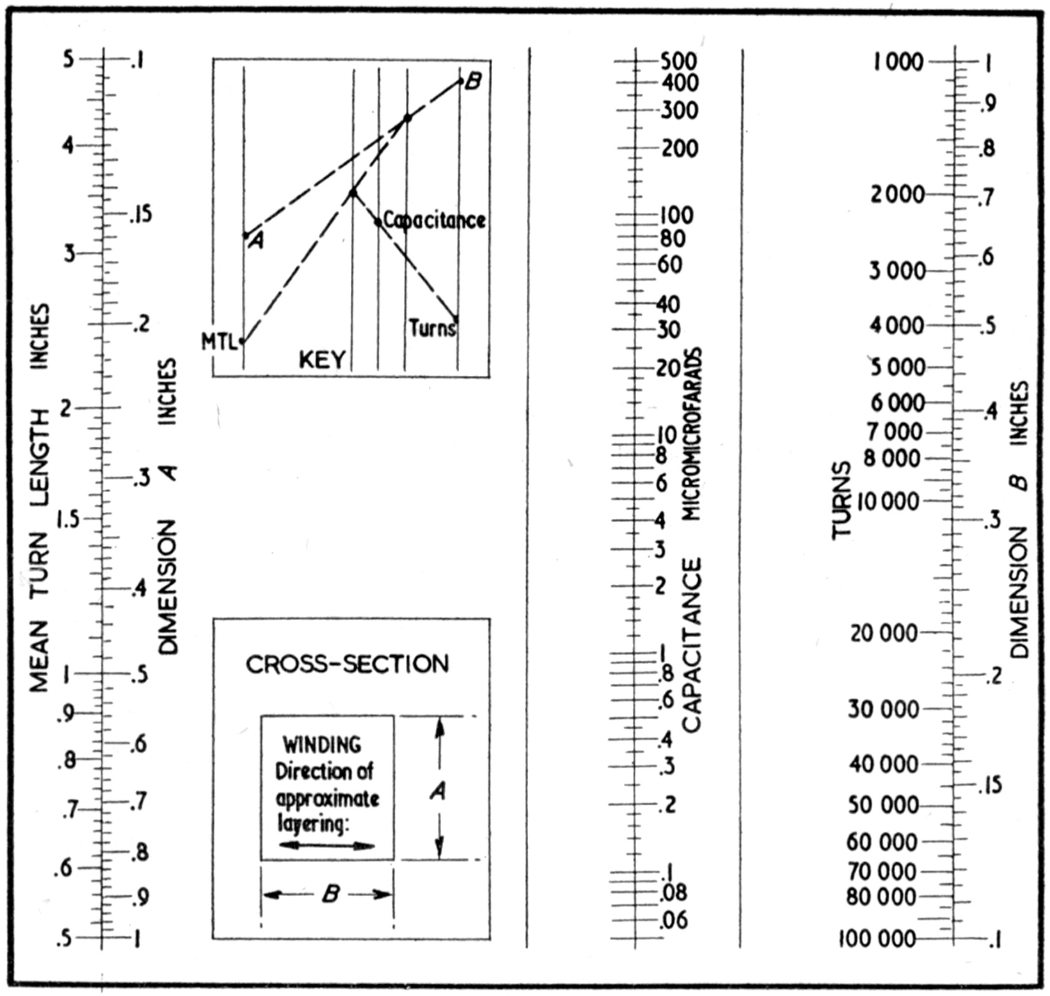


Fig. 10 (left). Chart for calculating the leakage inductance of simple double-wound transformers. This chart assumes that the spacing between the windings is negligible compared to the winding dimensions themselves. Inductances referred to windings outside the range from 100 to 1000 turns can be calculated by using a number that is larger or smaller than the desired number by a multiple of 10, and then multiplying or dividing the result from the chart by the same multiple of 100. Fig. 11 (right). Chart for calculating the self capacitance of a random-wound winding. This chart does not include capacitance from one winding to another, or to core, which can be computed from recognized formulas separately. If the coil is impregnated, the result should be multiplied by the dielectric constant of the compound used.





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CORE DESIG-NATION	MAXIMUM EFFICIENCY		CONDITION OF COLUMN 2						
	Power Transfer %	Step-up %	Impedance for 1000 turns ohms	Low frequency 3 db pt. cps	High frequency 3 db pt. kc	Maximum Impedance #42 AWG	Maximum Impedance #46 AWG	Winding Capacitance #42 AWG	Winding Capacitance #46 AWG
1	2	3	4	5	6	7		8	
A	87.5	99.6	1120	30	20	.4 M	.1 M	28 μμf	17 μμf
B	89	99.7	3400	25	80	.12 M	.3 M	85 μμf	50 μμf
C	87.5	99.6	1800	30	60	.18 M	.4 M	30 μμf	20 μμf

Fig. 9. Method of tabulating data about regular core sizes used for input transformers to give a quick first approach to design. The significance and method of deriving the various columns is described in the text.

probably not better than 80 per cent under maximum energy transfer matching conditions, this results in 2 db loss. This is probably not the method of operation intended, but if it were, a better input transformer could be designed, not to require such heavy resistance loading and so that the secondary could be operated directly into the grid without a shunt resistance. This design would avoid the 2-db loss and probably get a bigger step-up ratio as well.

However, it is suspected that in most instances *the quotation of an impedance figure for the secondary is merely an alternative way of prescribing the step-up ratio.*

In the writer's opinion a successful specification of an input transformer should state:

(a) the source impedance for which it is designed,
(b) its step-up ratio, and
(c) the resistance, if any, which should be placed across its secondary to obtain optimum frequency response.

Multiple Inputs

A special type of input transformer requires to be operated with more than one input source. Here the choice of winding arrangement will again depend on the circuit components with which the transformer is to be used.

If the secondary can be operated unloaded, except for the grid input capacitance, and if, with all the input source impedances used, the leakage induction is unimportant, then the winding arrangement used to provide for alternative inputs is also unimportant. A tapped winding may be used or two separate windings, whichever suits the mechanical details of circuit configuration best.

But if the secondary has to be loaded to achieve the necessary uniformity of frequency response, the best arrangement is to place one winding inside and the other winding outside the secondary so that each of the primaries is closely coupled to the secondary winding.

In many applications an input transformer has only to be designed for one or two specific impedances which are determined beforehand. But occasionally it is desirable to design an input transformer for use with an amplifier to provide a wide variation of input matching to suit any possible impedance that may arise. With an input transformer it is not usually necessary to provide precision matching for a specific impedance. Any matching within a 2:1 range should be sufficiently close. Also the close control of leakage inductance is not vitally important. For this reason an input winding can conveniently be constructed on a tapping arrangement as follows:

Starting with a winding with a single tapping, such that the number of turns between the tap and one end is 1.6 times the number of turns between that tap and the other end, this will accommodate three different impedances spaced in geometric progression, at a ratio of approximately 2.6:1. Suppose the lowest number of turns is 10 and the other part of 16 turns, makes a total of 26 turns. If the 10 turns represents an impedance of 1 ohm, the 16 turns will represent an impedance of 2.6 ohms while the 26 turns will represent an impedance of about 7 ohms.

Another tapping can then be added with an additional 1.6 × 26, or 42 turns which will make available further impedances of 18 ohms and 45 ohms (using round figures). This brings the total number of turns up to 68. If we now add a further 1.6 × 68, or 110 turns, we shall extend the available impedances up to include 120 and 300 ohms.

Thus we have provided an impedance matching covering a range in excess of 300:1 with only five terminals. This is illustrated in *Fig.* 12. The actual numbers used of course can be made to suit the desired impedance range. The nominal impedances can be arranged to go from 2 to 600, in which case the arrangement would satisfactorily cover a range of impedances from 1 ohm to 1000 ohms without any serious mismatching.

Shielding

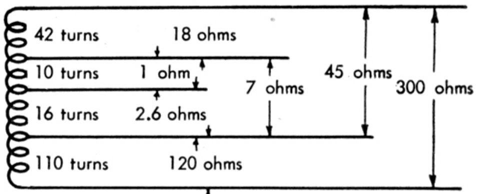
A final very important point in the design of input transformers concerns adequate shielding. Because these components are required to handle low-level signals, they will also be required to discriminate against the pickup of spurious signals. The most notorious form of stray pickup which input transformers can introduce is due to stray magnetic field. Protection against this can be provided by utilizing magnetic and electromagnetic shields to prevent the stray field from reaching the core of the transformer.

Just a word here on a factor that doesn't seem to be generally appreciated. The usual way of testing the effectiveness of shielding against magnetic field consists of placing the transformer, complete in its shielding system, in a calibrated field, which is provided by a loop of wire of specified number of turns, and usually 1 ft. square. The transformer under test is placed at the center of this square. The artificial field thus generated is practically uniform, due to the fact that the square is large compared to the dimensions of the shield and transformer under test.

Thus the value of discrimination against field determined by this test *holds only for a uniform magnetic field.* Unfortunately, many shielding arrangements do not give the same discrimination against stray pickup when the field is not uniform. And in practice, such as when the interfering field radiates from the core of a power transformer or smoothing choke, the field is *not* uniform. Measurements in a non-uniform kind of field are difficult to specify, but tests should be conducted, purely on a comparison basis, to see how much significance can be attached to the measurements according to the standard specification method.

It has been found, in some instances, that two transformers of different construction, which gave identical discrimi-

(Continued on page 39)



(A)

NOMINAL IMPEDANCE	RANGE COVERED
2 ohms	1 ohm to 3.2 ohms
5.2 ohms	3.2 ohms to 8.5 ohms
14 ohms	8.5 ohms to 22 ohms
36 ohms	22 ohms to 57 ohms
90 ohms	57 ohms to 150 ohms
240 ohms	150 ohms to 390 ohms
600 ohms	390 ohms to 1000 ohms

(B)

Fig. 12. Showing the multitapping method described in the text. At (A) the sequence of turns in the winding, and the combinations used for different impedances, on the assumption that 10 turns represents a nominal impedance of 1 ohm. At (B), showing how this arrangement provides continuous coverage for the range from 1 ohm to 1000 ohms, by using a sequence of nominal impedances starting at 2 ohms.

INPUT TRANSFORMER

(from page 19)

nation against the specified test field, give very different performance under practical conditions. Although practical conditions of required hum rejection are difficult to specify, this is what the user wants, so some effort should be expended to see that the transformer shielding gives a really good performance under practical conditions, as well as complying with a given specification under standard test conditions.

Another kind of stray pickup can be transferred through the transformer from primary to secondary by capacitance transfer instead of direct induction. If the primary winding is designed to match a very low impedance, the normal signal voltages on this winding may be of very low order, less than a millivolt possibly. At the same time stray pickup on the low-impedance circuit, if it is not grounded, may well amount to several volts. This means that the discrimination of the transformer between signal in the accepted mode, from one side of the primary winding to the other, as compared with capacitance pickup on both sides together, must be in the region of 120 db or more.

This is an extremely stringent requirement and necessitates more than a simple electrostatic shield between the windings. The electrostatic shield may serve quite well in shunting away the static pickup in the primary without allowing the voltages to be transferred directly to the secondary. But unfortunately the static shield itself is also wound around the same core as the other winding, although it only consists of a single turn. And this is where care is necessary with such static shielding in an input transformer.

Stray capacitance transfer will take place between all points of the input winding and the static shield. These minute transfer currents will be taken to ground from the ground point on the static shield. If these minute currents produce a resultant rotational current around the core in this effective one turn, then there will be a resultant magnetization of the core due to this static pickup. This will get transferred to the secondary in the normal manner of electromagnetic induction.

The only way to eliminate this kind of transfer is to ensure that the resultant current in the shield, considered as a turn around the core, is completely neutral so as not to induce any magnetization of the core. This means that the static shield must be completely balanced with respect to the primary, as considered from the point where its ground connection is made. This is illustrated in *Fig.* 13. If even greater rejection of static pickup is required it may be necessary to employ two static shields as shown at *Fig.* 14. In each case the winding should be completely wrapped in its own shield and the balance preserved between winding and shield and between the two shields. Also the core should be separately connected to ground so as to preserve complete balance of stray current due to static pickup at all points.

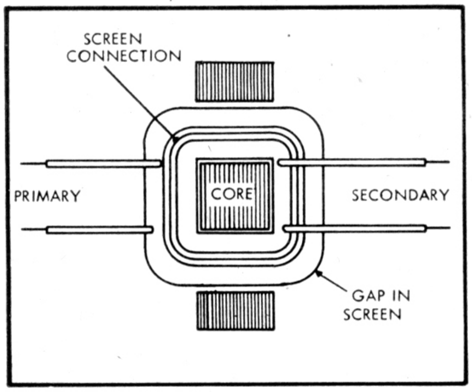


Fig. 13. A section through an input transformer with a single "static" screen, showing how the connection to the screen should be diametrically opposite to the point where the gap is.

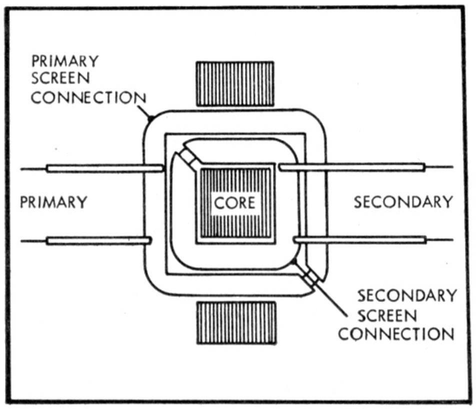


Fig. 14. The construction of a transformer employing a double "static" screen. Each winding should be completely enclosed in its own screen, except for the gap, and the gaps and connection points should be opposite as shown.

A-M TUNER CONVERSION

(from page 16)

boards. With the special board, wiring time was only ten minutes.

The only real work involved in the conversion involves the addition of pickup coil *L* to the last i. f. transformer. As pictured, simply slip the i.f. can up and off without disturbing the existing wiring. Next, make a coil form from gummed brown paper *slightly* larger than the plate coil of the transformer.

After estimating the number of turns on the plate winding (count the number of layers and multiply by the turns per layer) jumble wind an equal number—a ball-park guess will do—of turns on the paper coil form. Preferably, the winding should be Litz wire wound in two pies. Belden 8817 wire, available at