Audio Transformers CAN Be Good

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A study of the influence the parameters of transformers can have in audio circuits—as well as the ones on which the transformer has little influence in spite of the common misunderstanding about them.

An old proverb says: "a person with a bad name is already half hanged." It seems that this principle applies to inanimate objects as well as to persons. In the realm of audio, transformers certainly have a bad name. To be sure, there is no other component in audio circuitry about which more misstatements have been made, and it does seem that the proverb has a parallel here, because some of the earlier forebears of the audio transformer certainly did *earn* themselves a bad name. But this is no reason why this bad name should stick to the present generation of audio transformers. The purpose of the present article is to clarify some of the misstatements that have been made about audio transformers so that some, who are prejudiced against them, will be prepared to accept an audio transformer—provided it behaves itself.

In the early days of radio, when audio was merely the a.f. section of a radio receiver, a great many people went into business—and out again—making various radio components, including audio transformers for duty as interstage coupling units. A number of these short-lived component manufacturers, working on the get-rich-quick principle, manufactured audio transformers from the cheapest possible materials, using sheet scrap iron for core material, and winding on any number of turns that came handy, so long as they gave the ratio advertised. Some were better than others, of course, even at that time, but many of them certainly did introduce quite serious distortion in the a.f. section of the receiver.

The bad name earned in those days has stuck, partly because many manufacturers in our present generation are prejudiced against the audio transformer, and hence do not bother to acquire the necessary know-how to make *good* audio transformers. This fact was pointed up recently when the writer wrote to a large number of transformer manufacturers for information about their audio components, with a view to cataloging the data and providing some performance criteria. The intention was to show that any well-made audio transformer could be utilized in an appropriate circuit to give good performance, in just the same way as a tube needs the correct circuit to give its optimum performance.

But the replies to the writer's inquiry showed unmistakably that a large proportion of transformer manufacturers had an appalling lack of knowledge on the functioning of an audio transformer. They evidently just wind them to some rule-of-thumb specification and sell them according to catalog information. Each manufacturer's catalog uses a slightly different form of listing, which adds to the confusion on the subject. If the transformer manufacturer doesn't know anything about audio transformers, what hope is there of the audio man obtaining the necessary information to *use* one properly?

On the other side of the picture, many may not realize that good audio transformers are in regular service in professional equipment, the quality of which we are listening to every day. These high-quality audio transformers, it is true, are somewhat of a specialist's job, and this fact has given the impression that a good audio transformer is a very expensive one. However, it *is* possible for transformers in the lower price range to be good also.

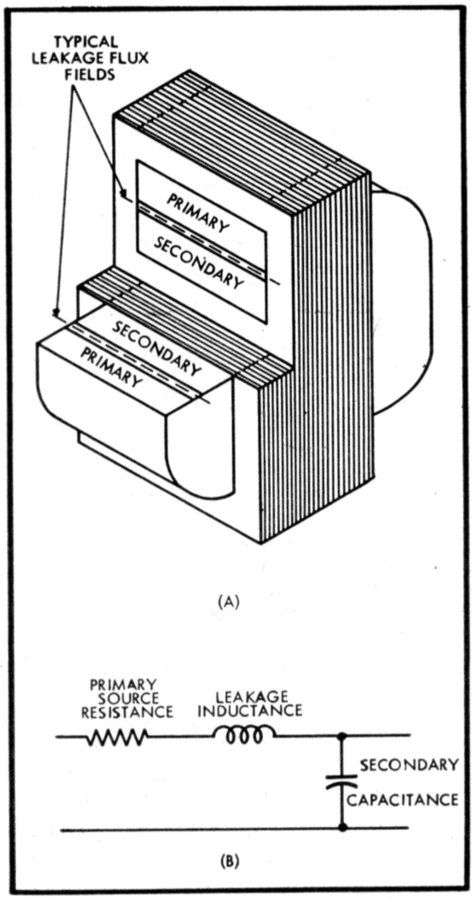

Fig. 1. Typical simple double-wound transformer, showing (A) arrangement of windings, and the path taken by leakage flux, responsible for leakage inductance; and (B) the equivalent circuit of the transformer, taking leakage inductance and secondary capacitance into account.

Distortion

Let's take the question of the distortion an audio transformer introduces, compared with the distortion tubes cause in a circuit. If you have ever made measurements on tubes operating at maximum signal level, you will know that it is difficult, with any type of tube, to achieve a consistent figure lower than 2 per cent harmonic distortion, and this figure of distortion occurs at all frequencies.

If a transformer is designed to maintain a frequency response down to the lowest frequency of interest within say 0.5 db, the distortion at this lowest frequency will almost certainly be as good as 2 per cent, and at higher frequencies—in the main part of the audio range—the distortion will not be even measurable. This may come as a surprise to many readers, but it happens to be true. Only if very cheap core material has been used, not intended for transformer core at all, or if the transformer has been very poorly designed so as to have a serious low-frequency loss, will there be appreciable distortion in comparison with the distortion a tube produces.

To check the statement just made, let's take some practical figures: even the lowest grade of transformer core material doesn't give more than 10 per cent harmonic component of its magnetizing current before saturation level is reached. This is 10 per cent of the component of magnetizing current due to hysteresis loss in the core. At the low-

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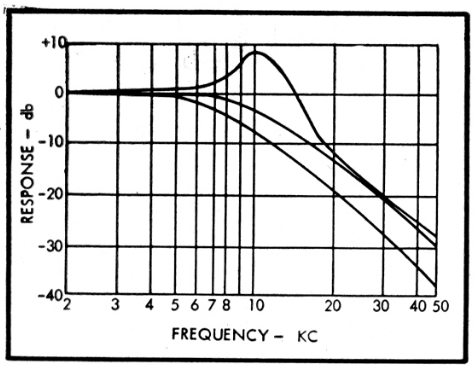

Fig. 2. Varieties of frequency response caused by the arrangement of Fig. 1. The frequency scale is typical—the frequency of peak or roll-off may also vary with different components.

frequency end of the spectrum other losses can be neglected, so we will be correct in saying that the harmonic generation is 10 per cent of the magnetizing current. To maintain a response to within 0.5 db the magnetizing current must not exceed one fourth of the load current, or one fifth of the total current. This means that the 10 per cent distortion component in the magnetizing current is 10 per cent of one fifth of the total load current from the tube, or 2 per cent of the total current. This assumes a high-impedance source, such as a pentode, in which we are neglecting the shunt effect of the pentode plate resistance. Under this circumstance, a 2 per cent harmonic current will produce a 2 per cent harmonic voltage. In the case of triode output tubes, where the source resistance is much lower than the load resistance, the harmonic generated will also be much lower, but we have taken the worst possible condition, at the low-frequency end of the response.

Assume this was 20 cps; now take a figure at 200 cps. The corresponding hysteresis component of magnetizing current will drop to approximately one tenth of its value at 20 cps, and now will be about one fortieth of the total load current. Due to the fact that the iron is not now operating at such a high flux density, the distortion component of this magnetizing current will be less than 10 per cent, but even assuming that operation at lower density does not appreciably reduce magnetizing current harmonic, this means that, at 200 cps, the distortion component of the total current will be approximately .25 per cent. At 1000 cps it will have dropped to less than .05 per cent.

This is surely much better than any tube can claim without the use of feedback to linearize it—and remember we can also use feedback to linearize the transformer's response too.

This discussion has taken an output transformer as an example, but with the same response limitations imposed, the figures would apply to an audio transformer in an input or interstage circuit equally well. In fact, the writer had an application in design recently, in which the lowest possible distortion proved to be with the use of an interstage transformer feeding a cathode follower. This was an application where a high voltage was required at low impedance in the output circuit. With the selection of tubes available, the previous plate would not deliver the swing required without running into greater distortion than the interstage step-up transformer caused. Incidentally the use of the audio transformer solved some other problems as well, and proved to be the best solution all around.

High Frequency Distortion

Another thing audio transformers get blamed for is distortion of the high-frequency end of the spectrum. When we examine the properties of an audio transformer, we find that they contain nothing that can directly cause waveform distortion at the high-frequency end. They *can* produce quite peculiar frequency responses, but not actual waveform distortion.

There seems to be quite a lot of unnecessary mystery surrounding the property known as leakage inductance r leakage reactance. Leakage inductance is due to leakage flux that manages to get either between the two windings, or through one winding without going through the other. None of the paths taken by this leakage field, either through the winding or the space between the windings, is occupied by any magnetic material—unless the winding happens to be wound with iron wire! This being the case, leakage inductance behaves in exactly the same manner as would an air cored inductance connected into the circuit somehow.

The exact behavior of leakage inductance may be a little more complicated to understand than an ordinary air-cored inductance, but its behavior from the viewpoint of distortion is precisely similar. To get an understanding of what leakage inductance can do, let's consider a few typical examples.

First take the simple winding arrangement of *Fig.* 1, which represents an input or interstage transformer. It has a single leakage inductance which may be regarded as an inductance in series with the transfer from primary to secondary. As the secondary has a much higher impedance than the primary winding, the principal capacitance effect in the transformer will be that across the secondary, due to the input grid capacitance and also the winding self-capacitance. This will combine with the leakage inductance, as shown in *Fig.* 1, to produce a series resonant circuit, the output being picked off across the capacitor element. The resistance in the circuit is provided by the source resistance connected to the primary winding, and multiplied by the step-up impedance ratio, which is the turns ratio squared. This configuration can give a response of the shapes shown in *Fig.* 2.

Next take the push-pull interstage arrangement shown in *Fig.* 3. Here two leakage inductances are operative, between the primary and each half of the secondary. Each half secondary will be loaded with its own winding self-capacitance and grid input capacitance, so there are two resonant circuits using the same source resistance. Only if the two resonant circuits contain identical values of both leakage inductance and winding shunt capacitance, will the response be equal in both halves. If, as shown here, the diameter of the windings is different, the leakage inductance at least is bound to be different, and probably the winding self-capacitance will also be different.

This means that the two tuned circuits will resonate at slightly different frequencies, resulting in a response on the separate half secondaries as shown at *Fig.* 4. The dip in each case, one below the peak and the other above it, is due

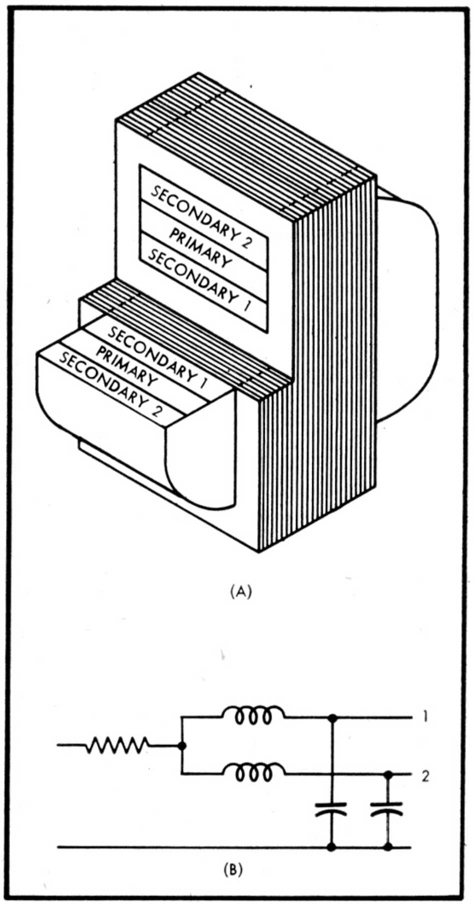

Fig. 3. A transformer intended for single-ended to pushpull operation: at (A) a section showing the winding arrangement; at (B) the equivalent circuit taking leakage inductances and winding capacitances into account. 1 and 2 represent the outputs from the separate secondaries.

to the other winding acting as an absorption circuit across the source resistance.

Such a transformer will not be a very good interstage transformer, because the signal fed to the two grids of the pushpull stage will vary in amplitude and phase in a quite erratic manner, so the over-all response at the output will look very poor. It may even show considerable distortion at some frequencies, but this will be not due to either the interstage transformer or the output transformer, directly, though in all probability the output transformer would get blamed for it.

In fact, if any transformer is to be blamed it would be the interstage transformer, in this case. At some frequency, due to the peculiar phase shift arrangement set up, associated with the responses of *Fig.* 4, the output drive at the plates of the push-pull stage will not be in true pushpull but approximately in phase, and one half will be driven much harder than the other half at this frequency. The output transformer will be transmitting a differential output instead of an additive output from the drive of the two halves. This fact alone would merely result in a very erratic looking frequency response. But the two output tubes themselves will not be operating with their correct optimum load at such a frequency, because they will be working effectively in parallel instead of push-pull.

This means that the tube giving the larger drive will be loaded down by the tube giving the smaller drive. As a result, according to whether the tubes are of the pentode or triode type, the one delivering the larger output will be looking into an open circuit or short circuit condition, instead of its correct optimum load. This means the tube will produce considerable distortion, long before maximum rated output for the single tube is reached, which will be much below the full rated output of the push-pull stage.

This fact alone can result in a considerably distorted waveform. If, on top of this, the output transformer has a notable resonance between the primary capacitance and its leakage inductance, which will overemphasize some of the harmonic frequencies generated in the distortion, the distorted waveform will get even more exaggerated, so as to produce a resultant wave somewhat as shown at *Fig.* 5.

This kind of waveform at the high-frequency end of the audio response usually gets blamed onto the output transformer, because measurements show the waveform at each grid of the pushpull stage to be quite sinusoidal. There may be difference in magnitude at this point, but the waveform is normal on both grids. Transferring the measurement to the plate circuit, the waveform appears as shown at *Fig.* 5 and so the

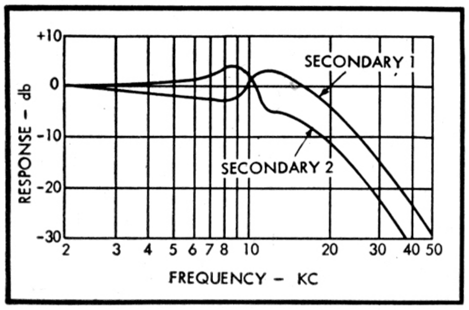

Fig. 4. Typical frequency responses produced by a transformer arranged as at Fig. 3. Notice the different response from each secondary.

output transformer gets blamed. In point of fact, what is happening is that the peculiar impedances presented by the transformers in the drive and plate circuit of this push-pull stage, are causing the non-linear characteristics of the tubes to act as a frequency-doubler circuit instead of a straight amplifier.

While it is quite true that use of a circuit not employing transformers would avoid this kind of distortion, yet the transformers themselves are not *producing* it. In fact, if the equivalent circuit of the transformers were synthesized entirely of air cored inductors, the same distortion would appear, because it is the tubes that are causing it and not the "inherent distortion" of the transformers.

Notice however, that the primary fault with these transformers is in their frequency-response characteristic. If they had a flat frequency response and were balanced on each half, this kind of trouble could not appear. This means that the interstage and output transformer should be arranged to give careful balance of both winding capacitance and leakage inductance, at least over the frequency range to be used.

What Makes Good Balance

Many of the more expensive transformers employ elaborate means to ensure this degree of balance. The windings are sectionalized in both directions, so the sections used in one half are absolutely symmetrical with the sections used in the other half. This involves winding the transformer in a considerable number of sections, and also a considerable amount of cross-coupling.

Often a cheaper and more effective method of construction could be employed, based on a little more knowledge of the characteristics of leakage inductance. First we'll state the characteristics of leakage inductance and then show a practical comparison of the methods of sectionalizing.

Increasing the mean turn length of the windings *increases* leakage inductance in direct proportion to the turn length.

Increasing the length of winding section, in the direction where they lie adjacent one to another, *reduces* leakage inductance in proportion to the length of winding.

Increasing the thickness through the windings, across the direction of interleaving of the windings, *increases* leakage inductance.

These dimensions are illustrated in *Fig.* 6. Now let's take a typical geometrically balanced well mixed transformer, of the arrangement shown at (A) in *Fig.* 7, as compared with the arrangement in (B). The arrangement of (A) employs a split bobbin or two separate bobbins to accommodate the windings; that of (B) accommodates the winding on a single bobbin, and necessitates a lower number of sections.

But from the viewpoint of leakage inductance, the winding of (A) consists of only three sections, one section of primary and two sections of secondary, or vice versa, although physically there is a total of six sections. From the viewpoint of magnetizing effect, the laterally adjacent sections of primary and secondary each count as a single section.

From the viewpoint of generating leakage field the arrangement of (B) consists of three whole sections and two half sections, which will be two sections of primary and the equivalent of secondary, except that the latter will be one whole section and two half sections.

Although the latter arrangement only requires five sections of winding in place of six, it will reduce the effective leakage inductance between primary and secondary using the same total number of turns by a factor of approximately four times. It will also achieve very close matching between the leakage inductance from the primary to each half of the secondary, or vice versa, because the length of mean turn of the center single section of the secondary is the same as the length of mean turn of the two outside half sections. Looking at the coupling from pri-

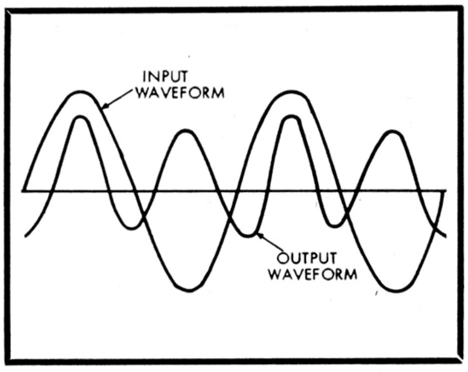

Fig. 5. Due to the phase shift effects in the grid transformer, and the impedance characteristic of the plate transformer, a pushpull output stage may operate as a frequency doubler at one particular frequency, giving waveforms like this. However the non-linearity that causes frequency doubling is in the output tube characteristics.

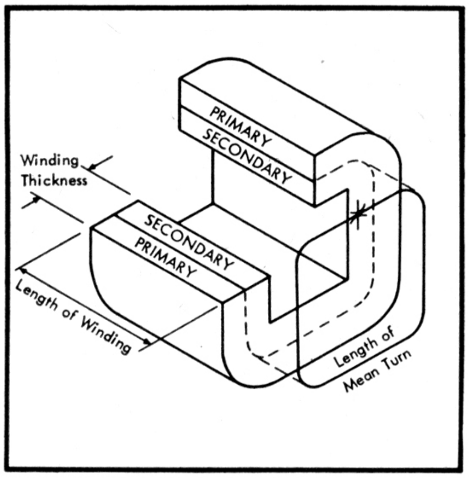

Fig. 6. Section of simple double winding, without core, to show dimensions relevant to leakage inductance value.

mary to one half secondary, the secondary whole section is sandwiched between two sections of the primary. Looking at the other half, the two primary sections are sandwiched between the two half sections of the secondary. This is illustrated by the partial diagrams of (C) and (D) in Fig. 7.

Winding capacitance can be equalized very approximately by the method of connection. In this case, it's true that the winding capacitance is assured of equality by the geometrical symmetry of the arrangement of (A) in *Fig.* 7 which it is not in the arrangement of (B). But the fact that the response is considerably extended by reduction of leakage inductance, together with the close matching in capacitance that can be achieved by careful arrangement and connection of the windings in the manner shown, does result in a transformer of considerably improved performance and at the same time of lower cost than the arrangement of (A).

This is just a simple example of how a correct understanding of the factors contributing to audio transformer design can simplify the arrangement while at the same time improving performance. It is not the purpose of this article to go into detail on transformer design—merely to point out that by correct design and use in circuits, audio transformers *can* be good, and can give results as good as a resistance-capacitance arrangement.

Effect of Feedback

There is one point connected with the use of feedback associated with audio transformers that is often misunderstood: the reason has been given for applying feedback from the secondary of an output transformer, in comparison with taking it from the primary, that connection from the secondary enables the feedback to "work on" any distortion caused by the transformer, whereas connection from the primary does not include the transformer in the feedback loop. This statement is not quite true.

The principal distortion in a transformer, as shown in the foregoing, is caused by the nonlinearity of the magnetizing current and manifests itself at low frequencies. Any other distortion is not directly due to the transformer, but to the effects of its impedances on the tube performance.

The magnetizing current taken by the transformer is drawn by the primary circuit through the a.c. resistance of the tubes, and hence will produce as much distortion voltage on the primary as on the secondary, except for any slight resistance drop in the primary winding. The distortion *voltage* generated is due to the flowing of the distortion current through the source resistance, and the total source resistance, from the viewpoint of the magnetizing effect in the iron, is the a.c. resistance of the tubes plus the resistance of the primary winding.

Usually the resistance of the primary winding will not be more than one tenth of the a.c. resistance of the tubes. This means that, from the viewpoint of working on distortion caused by the transformer, a connection from the primary circuit will be nine tenths as effective as a connection from the secondary circuit. This is hardly what the generalized statement just referred to implies.

In the case of the response caused by leakage inductance and winding capacitances, the situation becomes rather more complicated, because we are introducing additional reactance elements into the over-all feedback loop as soon as we apply the arrangement from the secondary. However, in the average output transformer the most effective winding capacitance is in the primary—the secondary winding capacitance has no effect until a long way above the audio band, because of the low impedance circuit it shunts. So the principal difference from the viewpoint of the feedback network is that a leakage inductance is included in the loop by connection from the secondary that is not included when connected from the primary.

Also, of course, connection from the secondary avoids the use of a blocking capacitor, because one end of the winding can conveniently be connected to ground instead of having to be at a B+ potential. This is in favor of secondary connection, but for a different reason.

Remember here that the primary purpose of an amplifier is usually to feed a loudspeaker, which is a load containing inductance as well as resistance. The inductance of the voice coil is usually many times the leakage inductance of the output transformer. This means that transferring the feedback take-off point from

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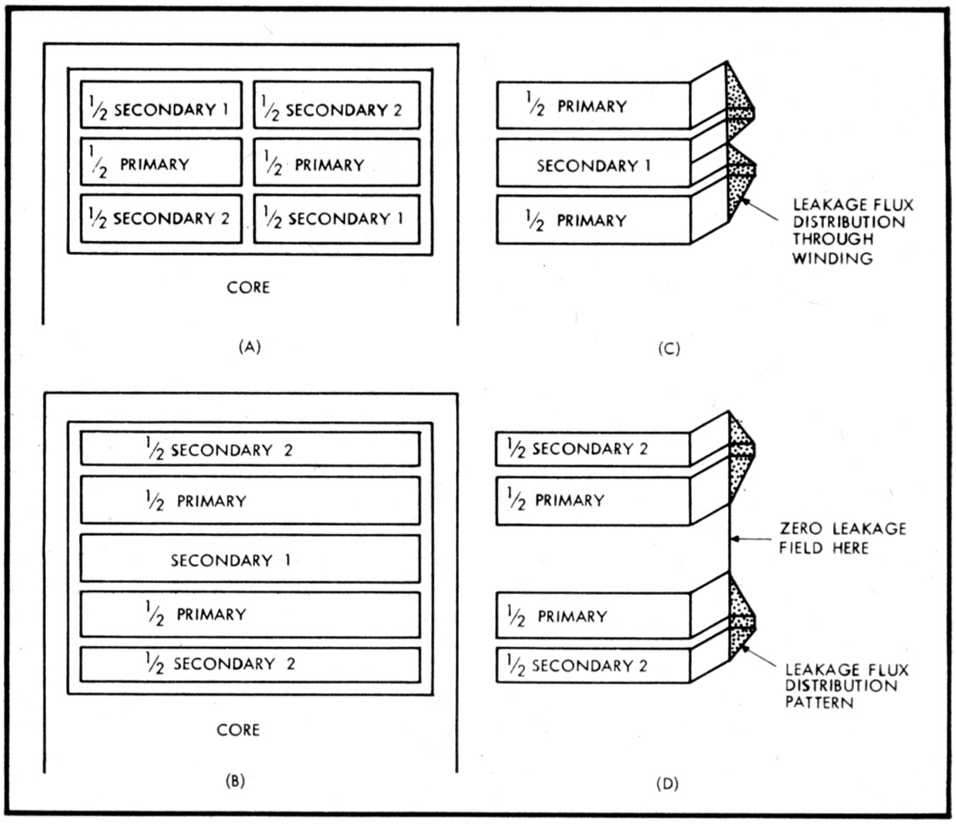

Fig. 7. The relative advantages of these winding cross sections for a pushpull transformer are discussed in the text. (A) a cross section ensuring absolute balance by geometrical symmetry; (B) a method using one less section, but improving coupling factor about four times; (C) coupling between primary and secondary 1; (D) coupling between primary and secondary 2; in (C) and (D), the black areas at the right show the distribution of leakage flux through the winding: note that both have equal area, and are also symmetrical about the mid-point of the winding.

cps point. The speakers (he avers) are thus always loaded by the amplifiers and their distortion is therefore much less than with the conventional crossover. Also, the speaker damping factor in the filter system is more constant. All of this, in a manner of speaking, adds up to the equivalent of a polarized filter introduced to keep unwanted reflections and highlights from bothering and distorting the composition and balance of a "picture"—is sound, here, of course.

It would be doing our subject full and undeserved injustice to end this saga of the separate amplifiers right here. But in all fairness, we feel constrained to observe that the conventional crossover network is not exactly double-crossed out of consideration and use because of the turnabout to a filter network reported here. Nor are the many excellent all-in-one (concentric, co-, Diff- and Tri-axial) units relegated to unexcursioned neglect. The professional who built himself this filter system is not opposing the offerings of the market place. His job of conversion is, let's face it, just one man's way of taking his hi-fi bearings anew as he learns, essentially empirically, to live at home with audio. In sum: the better than his, his best became.

Readers who are of a mind to bone up on the subject before obeying that impulse to take their workbench aprons off the hook might like to dig into an article expatiating on the theory, design, function, and advantages of the filter network in home hi-fi systems, as set forth in "The White Powrtron Amplifier," by Stan White, and reproduced in **the 3rd audio anthology.** The subject is handled from another angle in "A Discussion of Dividing Networks," by J. P. Wentworth, page 84, same **anthology.**

See, in *Fig.* 13, the configurations of the filter network and the formulas by which they are calculated. *Figure* 14 shows a schematic of the complete filter network used here, as constructed from these configurations.

A Precedential Year?

Exposed to this (perhaps) precedent installation, other hi-fi brethren may be expected to get into a "me-too" frame of go-getting, culminating (who knows?) in a spate of rig-conversions. It could be. This time it's the dual-channel amplifier with filter network workout; but, we dare ask, good for how many tomorrows before the next wave of what other kind of hi-fi retread jobs?

With some finality, we can say it is no skin off our nose to acknowledge that the complement of speakers in do-it-yourselfer Crofford's hi-fi rig owes its present format to some years' experience of making a living working with audio. As of now, there's a Jim Lansing DL175 tweeter atop of his enclosure; and enclosed in the folded-horn below are a Jim Lansing 375 mid-range unit, with an 18-inch Electro-Voice woofer. To these, the double amplifier-filter-network crossover combo (with filter between preamplifier and power amplifier to be sure) has brought improved transient response; greater flexibility of balance between the speakers; not to mention a clearing out of the cobwebs of intermodulation distortion—the filter network standing guard against invasion of the low-frequency amplifier by high-frequency signals, and vice-versa.

All of which adds up to a form of segregation that, in this instance at least, has turned out to be unquestionably beneficial to this (hi-fi) community.

Parts list, 60-watt power amplifier

R_1	0.5-meg level control
R_2	10,000 ohms, 1-watt
R_3	10,000 ohms, low noise
R_4	47,000 ohms, wirewound, 1-watt
R_5	316 ohms, wirewound, 1-watt
R_6	10,000 ohms, wirewound, 1-watt
R_7	0.1 meg 2-watt
R_8	10,000 ohms, 2-watt
R_9, R_{10}	22,000 ohms, wirewound, 1-watt, matched
R_{11}, R_{12}	0.5 meg low noise, matched
R_{13}	2,000 ohms, low noise
R_{14}, R_{15}	0.1 meg, wirewound, 2-watt, matched
R_{16}	20,000 ohms, 2-watt
R_{17}, R_{18}	25,000 ohms, 2-watt, bias balance control
R_{19}, R_{20}	0.47 meg 1-watt, matched
R_{21}	30,000 ohms, 2-watt
R_{22}, R_{23}	22,000 ohms, 2-watt, matched
R_{24}	10,000 ohms, 10-watt
R_{25}, R_{26}	1,000 ohms, 1-watt
R_{27}	50,000 ohms, wirewound, 25-watt
R_{28}, R_{29}, R_{30}, R_{31}	50,000 ohms, 1-watt
R_{32}, R_{33}, R_{34}, R_{35}	1,000 ohms, 1-watt
R_{36}	0.47 meg 2 watt
R_{37}	0.2 meg 2-watt
R_{38}	0.1 meg voltage control, 2-watt
R_{39}	50,000 ohms, 2-watt
R_{40}	0.15 meg, 2 watt
R_{41}	56,000 ohms, 2-watt
R_{42}	18,000 ohms, 2-watt
R_{43}	1,000 ohms, 5 watt
R_{44}	22,000 ohms, 1-watt
C_1	0.1 μf, 400 v.
C_2, C_5, C_{10}	40 μf, 450 v.
C_3, C_4	100 μμf, ceramic
C_6, C_7	0.25 μf, 600 v., matched
C_8, C_9	0.1 μf, 600 v., matched
C_{11}, C_{12}	0.1 μf, 600 v.
C_{13}	16 μf, 700 v.
C_{14}	32 μf, 700 v.
C_{15}, C_{16}	0.01 μf, ceramic, 500 v.
C_{17}	0.1 μf, 600 v.
C_{18}	50 μf, 50 v.
C_{19}	100 μf, 250 v.
C_{20}	0.1 μf, 600 v.
T_1	425-O-425 v., 275 ma; 5 v., 6 a.; 6.3 v., 5 a.
T_2	ACRO TO330
T_3	– 150 v. 50 ma.
T_4	– 6.3 CT, 10 a.
L_1	12 H, 300 ma.
V_1	12AY7
V_2	5692, 6SN7GTA
V_3	6SN7GTA
V_4, V_5	6550
V_6, V_7	5V4GA (or 5U4GB)
V_8, V_9	6080 (or 6AS7)
V_{10}	6SJ7
V_{11}, V_{12}	0B2
V_{13}	0A2
$Rect._1$	180 v., 100 ma., Selenium

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the primary winding to the secondary winding includes a small fraction of the effective load inductance in the feedback loop, and hence the change will not have any great *inherent* effect on performance.

Actually, the arguments connected with choice of feedback—whether to use the primary or secondary winding—are not so much concerned with whether cancellation of transformer distortion is effected, as whether the impedance and voltage level available is suited to the requirements of the feedback arrangement.

Feedback from the primary circuit provides a large voltage which can be attenuated by the feedback resistance, but this voltage is provided *at a high impedance,* which means the current through the feedback resistance will constitute a greater loss of the total power output than if the feedback resistance is connected to a lower impedance point. Using the secondary winding—particularly if its impedance is 16 ohms or higher—results in much reduced loss of power output in the feedback resistance network.

Although the resistances used for feedback are helping to reduce distortion, they still constitute a load on the output circuit which has to be supplied from the total available power output from the output tubes. If too much power is required by the feedback resistances, the reduction in available output power may offset the improvement in distortion achieved by the feedback.

Finally, the point in writing this article is not to urge a wholesale changeover from resistance/capacitance coupling to transformer coupling, but rather to take the ban off the use of transformers, so an audio transformer *can* get used where it does happen to be the best solution.

If your supplier of audio transformers does not help in this direction, by giving suitable circuitry to enable you to get the best performance from the transformers, it is suggested that you should look for a supplier who does. The chances are that a manufacturer who can not give circuits for his transformers doesn't know much about the design of audio transformers anyway, and has followed the popular practice of making a chinese copy of someone else's component. If his copy should in fact be a generation or two removed from the original, then the audio transformer may not be as good as advertised, so you will be better off going to a manufacturer who really knows about transformer design. In that way you should obtain an audio transformer that *will* be good and, by using it in the circuit recommended, the results will come up to expectations.