Audio Impedance Matching

Part II—Data on how to match several speakers to an amplifier, each powered as desired and all impedances correctly matched to the output of the amplifier

By WALTHER RICHTER*

IN the first installment (February issue) of this article we showed why amplifier load and internal impedances are important in transferring power to the speaker and in speaker damping. The practical application of the principles presented is best illustrated with the aid of a few examples.

Suppose we are given an amplifier rated at 30 watts, and that the output transformer is provided with 20- and 125-ohm taps. The statement that the amplifier will deliver 30 watts permits us to calculate the maximum voltage and current values of the two taps. Applying one or both of the formulas $P = E^2/R$ and $P = I^2R$, we find that for a single load of 125 ohms, if operated from the corresponding tap, a voltage of 61.2 and a current of 0.49 ampere will result in 30 watts; on the 20-ohm tap, 24.5 volts and 1.22 amperes will result in 30 watts. These, then, are the voltage and current values which must not be exceeded.

Suppose, now, that we want to operate a 500-ohm speaker from the amplifier, and that the speaker is rated at 10 watts. Should we use a matching transformer?

To obtain 10 watts in a resistance of 500 ohms, 70.7 volts are needed; the current will be 0.14 ampere. If we connect the loudspeaker directly to the 125-ohm tap, we cannot quite reach the full 10 watts without exceeding the voltage limit of the amplifier although we will be below the maximum rating as far as current goes.

How will this arrangement be with regard to damping? Whatever the internal resistance of the amplifier, it will certainly appear smaller to a 500-ohm load than to a 125-ohm load. If it happens to be an amplifier with a triode in the output stage, the internal resistance (as seen at the transformer secondary) can be expected to be around 60 ohms. With a load of 500 ohms looking back at 60 ohms, the damping will be considerably better than with a 125-ohm load; and this connection will therefore actually give better results than the 125-ohm load—provided the amplifier is truly capable of 30 watts output.

Now suppose that, instead of a speaker of 500 ohms, we have one with a resistance of 6 ohms and capable of handling 6 watts of power. (To use a 30-watt amplifier to drive a 6-watt speaker seems ridiculous, but let us assume that the two pieces of equipment were inherited from two different uncles.) To obtain 6 watts in a 6-ohm load requires 6 volts at 1 ampere. The 24.5 volts and 1.22 amperes which can be obtained from the 20-ohm tap are in excess of the current and voltage ratings of the 6-ohm speaker, and we could connect the speaker to this tap.

But how does this circuit arrangement look with regard to damping? Again we do not know the internal resistance of the amplifier; but if it is a triode amplifier, the internal resistance at the 20-ohm tap will look like approximately 10 ohms. To connect a 6-ohm speaker to a generator with an internal resistance of 10 ohms is not a very satisfactory arrangement, since the voice coil, instead of looking back into a resistance equal to approximately one-half of its own resistance, is looking back into a resistance almost twice its size!

No build-out resistors

By trying to be too smart, we could do even worse! We might reason, for instance, that for an amplifier to operate most efficiently on the 20-ohm tap, the load connected to this tap should be 20 ohms; and since we have only a 6-ohm speaker, we might have the bright idea of placing 14 ohms in series with it to bring the total up to 20. To be sure, this gets our 6 watts to the speaker, but 14 watts of audio power in the 14-ohm resistor are thrown away and do us no good whatsoever. More important, the total resistance in the voice-coil circuit is now equal to the internal resistance of the generator (which was already too high on the 20-ohm tap) plus the 14 ohms of series resistance.

In this case, we should use a matching transformer, which will make the 6-ohm speaker appear as either 20 ohms (if we wish to connect it to the 20-ohm tap) or as 125 ohms (if that is where we wish to connect it). The design and construction of a matching transformer to take care of a relatively small mismatch, such as perhaps 4 to 1, is not very difficult and can usually be accomplished by utilizing the core of an old audio transformer. Such a design will be discussed in a future article. Matching transformers can be purchased for all common impedances.

A multiple speaker problem

Suppose we have an amplifier rated at 30 watts, with an output transformer having 500-, 16-, and 6-ohm taps. We wish to operate a 500-ohm, 10-watt loudspeaker, a 20-ohm, 20-watt speaker, and four 6-ohm, 4-watt speakers. The full power which all the speakers can take is 46 watts, which exceeds the rating of the amplifier. First, therefore, we must decide how the available 30 watts are to be distributed.

One could argue that the wattage allotted to each speaker should simply be $^{30}/_{46}$ of its maximum. This solution is not necessarily the best one. One of the speakers may be considerably more efficient than the others. Or the speakers may be serving different rooms which

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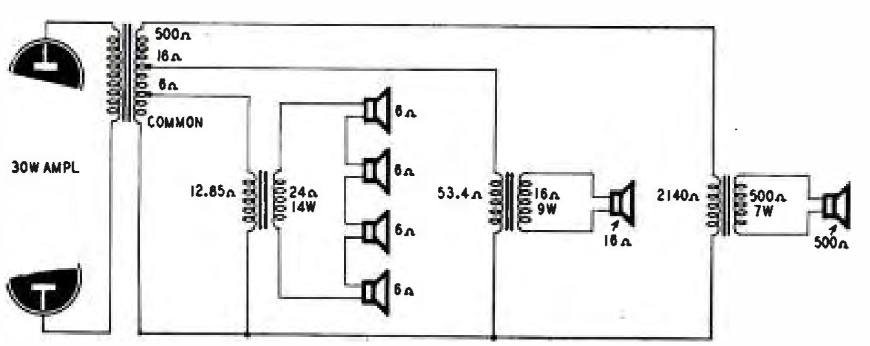

Fig. 1—Simple calculations were used in matching these six loudspeakers to the amplifier.

require different amounts of output.

After the best judgment has been used in distributing available power, it probably will still be necessary to insert attenuators in some of the speaker lines. However, any audio disappearing in an attenuator is a total loss, so it is well worth while to try to make the distribution as close as possible to the required conditions.

Suppose now that with the amplifier wide open delivering 30 watts (See Fig. 1) the 6-ohm speakers are each to receive 3.5 watts; the 20-ohm speaker, 9 watts; and the 500-ohm speaker, 7 watts.

None of the speakers can be connected directly to any of the available transformer taps; the 500-ohm speaker cannot even be connected to the 500-ohm tap, since with this connection alone the amplifier would be fully loaded. If additional loads are to be placed on the other taps, the current taken from the 500-ohm tap must be reduced; which means that the load resistance connected to this tap must be increased.

If a single 500-ohm load were connected to the 500-ohm tap and the amplifier were delivering 30 watts, 122.5 volts would have to be delivered by this tap: $E = \sqrt{PR}$. Since we have decided that only 7 watts is to go to the 500-ohm speaker, a matching transformer must be used between tap and speaker. The transformer primary must form a load which will consume 7 watts when 122.5 volts is placed across it. Substituting 122.5 volts and 7 watts in the formula $P = E^2/R$, and solving for R ($R = E^2/P$), gives us a value of 2,140 ohms. This apparent mismatch is in the right direction, since the internal impedance of the amplifier looks smaller to a 2,140-ohm than to a 500-ohm load.

By the same reasoning, we find that to consume 9 watts the 16-ohm speaker must look to the 16-ohm tap like a load of 53.4 ohms. The four 6-ohm speakers together, to consume a total of 14 watts, must look to the 6-ohm tap like a load of 12.85 ohms. The 6-ohm speakers may be connected either in series or in parallel; whatever the resultant combined impedance is, the matching transformer must make it look to the amplifier like 12.85 ohms. Assuming that we choose the series connection, the impedance ratio must be 24 to 12.85.

It is not necessary to have a multitap output transformer. Suppose the transformer has only one output impedance, 500 ohms. The primaries of all three matching transformers, when paralleled across this 500-ohm output, must result in 500 ohms, and each must draw the required power. Since the voltage available at the 500-ohm output is known (122.5) and we have decided on the power to be drawn by each speaker, we can find the impedance necessary at each matching transformer primary.

Transposing the formula $P = E^2/R$ to solve for R ($R = E^2/P$), substituting 122.5 for E and, successively, 7, 9, and 14 for P, we find that the primary of

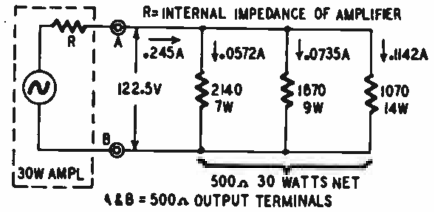

Fig. 2—Matching with 3 output transformers.

the 500-ohm matching transformer must have an impedance of 2,140 ohms; that of the 16-ohm transformer, 1,670 ohms; and the transformer for the four 6-ohm speakers, 1,070 ohms. Fig. 2 shows the resistance, current, and power values. Resistors have been drawn in place of the transformer primaries to accentuate the circuit's similarity to an ordinary resistor network.

It is not usually easy to find matching transformers with the correct values. The next article of this series will demonstrate the simplicity of making transformers to fit the job.

Useful 10-Watt Amplifier

by W. D. HAYES, W6MNU

ONE of the most useful pieces of equipment for the radio builder and experimenter is a simple, medium-powered audio amplifier—free of bugs and flexible with regard to input requirements. Such an amplifier can be used in conjunction with an r.f. tuner to make a complete receiver. It makes an excellent phono amplifier for use with either ordinary records or special sound-effect records for home movie productions. It can act as the principal unit of a small public address system with either phonograph or microphone input.

The amplifier described provides 10 watts output from a pair of push-pull 6V6-GT's, and has sufficient gain to give full output from any high-impedance microphone. Provision is made for two phonograph pickups so that sound effects can be faded in and out in case the amplifier is used with home movies. If two phonos are used. each must have a volume control. Two gain controls are incorporated in the amplifier itself, one in the microphone channel, and one in the phono channel.

The microphone signal is amplified by a 6SJ7-GT pentode, which is resistance-coupled to one half of a 6SN7-GT. The other half of the 6SN7-GT cathode-couples the phono channel into the first half. This provides a very simple and effective mixing arrangement. Transformer coupling is employed both in the input and output of the push-pull 6V6-GT's, and output impedances of 4, 8 and 16 ohms are available.

The amplifier and its power supply are built on an aluminum chassis 5½ inches wide, 10½ inches long, and 2 inches deep. There is ample room below the chassis for the few parts required. To reduce the possibility of hum, the power transformer is mounted at right angles to the two audio transformers. Across the rear of the chassis from left to right are the microphone jack, the two sets of phono input terminals, the speaker socket, the fuse holder, and the 117-volt line cord. Across the front are the microphone gain control on the extreme left, followed by the phono gain control, the pilot light, and the on-off switch.

MATERIALS FOR AMPLIFIER

Resistors: 1—470-ohm, 2-watt; 1—1,000-ohm, 1—2,200-ohm, 1-watt; 1—3,300-ohm, 2—33,000-ohm, 3—330,000-ohm, 1—470,000-ohm, 1—1-megohm, ½-watt; 2—500,000-ohm potentiometers.

Capacitors: 1—.03-µf, 3—0.1-µf, 400-volt, paper; 2—20-µf, 450-volt, 1—8-µf, 450-volt, 1—50-µf, 25-volt, electrolytic.

Transformers: 1—power, 600-volt, center-tapped, 55-ma, 5-volt, 2-amperes, 6.3-volt, 2.7-amperes; 1—interstage, 1:3 turns ratio; 1—output, 8,000-ohm, push-pull, to voice coil.

Tubes: 1—6SJ7-GT, 1—6SN7-GT, 2—6V6-GT, 1—80.

Miscellaneous: 1—2-ampere fuse and holder assembly; 1—s.p.s.t. toggle switch; 4—octal, 1—4-prong tube sockets; 1—5½ x 10½ x 2-inch chassis; necessary hardware.