# P.A. TRANSMISSION SYSTEMS

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PIONEER HOME STUDY RADIO SCHOOL

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the source impedance to give good low-frequency response. Hence a transformer designed for "3600 ohms to 4 ohms" is different from one designed for 14,400 ohms to 16 ohms, although both have the same 30-to-1 ratio.

For this reason, transformers aren't listed by turns ratios; they are described by the impedances between which they are to work. Thus, one rated at "500 ohms to 8 ohms" is designed to match a source (or a line matched to such a source) of 500 ohms to a load of 8 ohms. However, it can be used to match 250 ohms to 4 ohms, because the source is lower in impedance than the value for which the primary was designed. It can also be used to match 1000 ohms to 16 ohms with some loss in low-frequency response. In other words, the secondary impedance can be varied over a range from one-half to twice the value for which the transformer was designed without causing too great a loss in power (under .5 db) and without affecting the frequency response too seriously in any but high-fidelity systems.

## IMPEDANCE-MATCHING PADS

A resistor network can be used instead of transformers to make an impedance match. A disadvantage of using the resistor network is that it always introduces a loss; however, there are occasions when such a loss is permissible or even desirable.

We can, of course, connect the load and source directly together as shown in Fig. 10A. As long as the difference in their impedances is not too great, there won't be a large power loss. For example, in the case shown in Fig. 10A, the load impedance is one-half the source impedance. From the curve in Fig. 10B, we find that when the generator impedance ($R_G$) equals twice the load value ($R_L$) as in this case, we have a loss of only about .5 db. This isn't much power loss. As the difference between the source and load impedances becomes greater, however, the power loss also increases. For example, if we have a 1000-ohm source and a 250-ohm load, $R_G$ equals $4R_L$, and, as the chart shows, we have a 2-db power loss, which represents a loss of about a third of the power.

With the impedance relationship shown in Fig. 10A, we are not losing much power, but the requirements may be such that the frequency response is very poor under this condition. If the poor response is caused by the fact that the source is not properly loaded, we can improve matters by adding a series resistor, as shown in Fig. 11A, having a value such that its resistance plus that of the load equals the source impedance. In this particular example, half the available power is lost in the series resistor, so

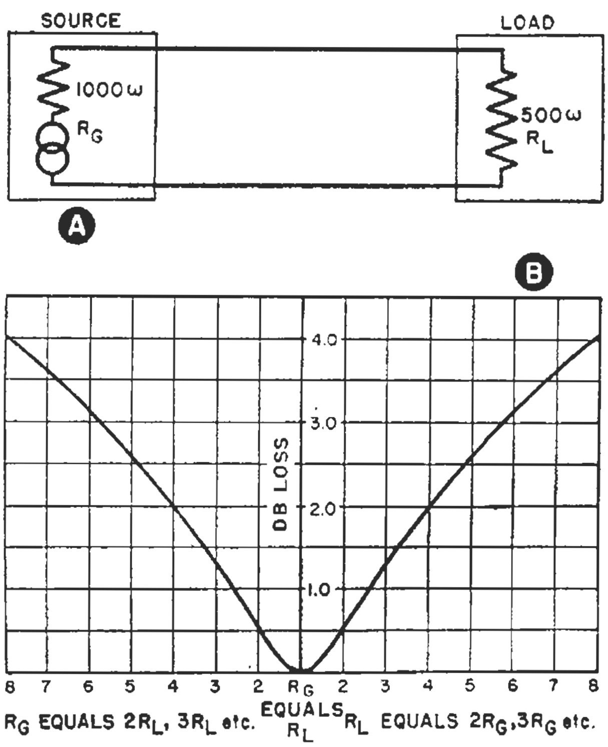


**FIG. 10. The chart in part B of this figure shows how much power is lost for various relationships between the load impedance $R_L$ and the source impedance $R_G$ in a circuit like that in part A.**

# STUDY SCHEDULE NO. 51

**For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.**

- [ ] **1. Introduction - - - - - - - - - - - - - - - - - - - Pages 1-3**

  The kinds of lines used in microphone and loudspeaker cables are described in this section.

- [ ] **2. High- and Low-Impedance Lines - - - - - - - - - - Pages 3-11**

  You learn the electrical characteristics of the lines used to connect microphones and loudspeakers to amplifiers.

- [ ] **3. Impedance Matching - - - - - - - - - - - - - - Pages 12-16**

  Methods of matching impedances with transformers and resistors are described in this section.

- [ ] **4. Microphone Connections - - - - - - - - - - - - Pages 16-18**

  Here you learn the solution to several problems you may meet in connecting microphones to an amplifier.

- [ ] **5. Practical Loudspeaker Connections - - - - - - - - Pages 18-25**

  Methods of distributing power to various groupings of loudspeakers are discussed in this section.

- [ ] **6. Loudspeaker Switching; Equalizers - - - - - - - - Pages 25-28**

  This section contains descriptions of constant-impedance switching networks, volume controls, cross-over networks, and equalizers.

- [ ] **7. Answer the Lesson Questions and Mail Your Answers for this Lesson to NRI for Grading.**

- [ ] **8. Start studying the Next Lesson.**

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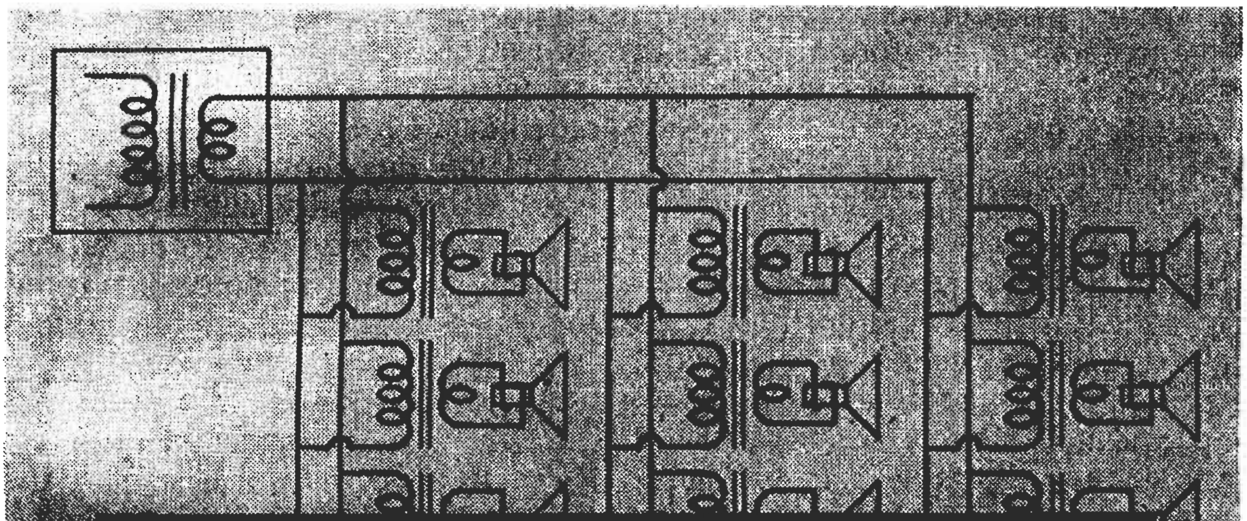


# P.A. TRANSMISSION SYSTEMS

AMPLIFIERS, loudspeakers, microphones, and other components of public address systems may be purchased from their respective manufacturers, from local radio wholesalers, or from the mail-order supply houses that handle radio parts. It is possible to obtain a complete system as a "package" consisting of an amplifier together with suitable loudspeakers and a microphone. The portable units that are intended for temporary installations are almost always sold this way. These even come with pre-cut cables to connect the various components together.

There is no connection problem with such package units—all you need do is plug the cables into the proper outlets and place the components where you want them. If such a package unit is used in a permanent installation, you can conceal the cables and place the amplifier in an out-of-the-way location if you wish. In temporary installation work, you will probably mount the various components of the system in convenient places without making any great effort to conceal anything.

With such package units, there will be no problems of impedance matching nor of excessive line losses (provided you use the lines supplied). You can assume that the components of a particular assembly were chosen to operate properly together.

Of course, all sound installations aren't this simple. For most permanent and some temporary installations, you will have to assemble a sound system rather than use one that is offered as a unit.

One of the major problems you will meet in doing so is making the proper connections between the various components. You will have to match impedances to get maximum power transfer and normal frequency response, and you will also have to make sure that excessive power and frequency losses will not occur in the transmission lines used to connect the various components. This last is often a problem when a line must be run several hundred feet from an amplifier to a loudspeaker.

This Lesson is devoted to showing you how to connect the components of p.a. systems properly. We shall study all parts of this problem. As the first step in our studies, let's learn what kinds of lines are used in p.a. work.

## AUDIO CABLES

Any set of conductors used to carry energy between pieces of equipment is called a transmission line. At power-line frequencies, parallel wires strung on insulators several inches apart can be used. However, such a line is not desirable for audio-frequency use, both because of difficulty in installation and because such an "open" line will pick up excessive amounts of hum, noise, and interference.

Such stray pickup is reduced by twisting the wires together so that they are separated only by their insulation. Close spacing and the twisting causes the stray pickup of one wire to be mostly cancelled by that of the other. Hence, such twisted wire—ordinary electric lamp cord, for example—is commonly used as an audio line where the power levels are high enough to make the losses unimportant and where the wire would not be subject to deterioration caused by weather or to wearing caused by excessive motion. Such lamp cord is readily obtainable: it is found everywhere that electrical supplies are handled, even in five-and-ten cent stores.

Radio supply houses carry a better wire for this purpose. A typical example is shown in Fig. 1A. This is a twisted pair of wires that is enclosed in a cotton loom that affords additional protection to the wire. It is possible to get wire like this with the loom specially treated to make it weather-proof. Such wire can be used outdoors.

Either of these two types is satisfactory for connecting loudspeakers to an amplifier, and one or the other is used for this purpose in most installations. These wires may be strung around the room in a temporary installation; in a permanent installation, they are frequently put in the walls, preferably in conduit. Outdoors, such cables are often enclosed in conduit or pipes and buried in the ground; this helps to protect the wire.

Incidentally, in installing any cable of this kind permanently, you will have to meet local electrical codes. Despite the fact that relatively low voltages and moderate power are being handled, there is always a possibility that someone will make a mistake later on and get the wires crossed up with other electric wires. To prevent this from happening, some electrical codes may require special conduits or special marking of the wires. It may be best to have a registered electrician string the cable for you so that the electrical code requirements will be met; in fact, this is required in many communities.

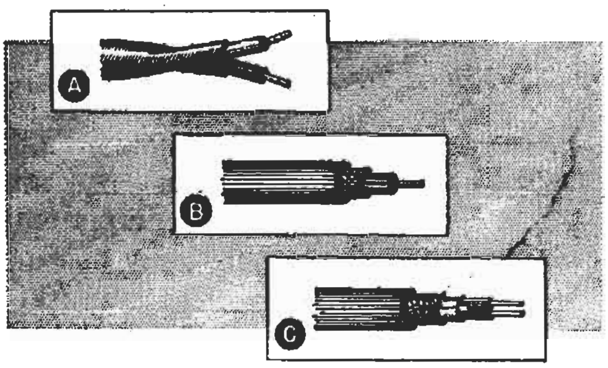


FIG. 1. The three most common kinds of audio lines: A, twisted-pair line; B, unbalanced coaxial line; C, balanced coaxial line.

Ordinary twisted-pair lines cannot be used as high-impedance microphone lines because they are too likely to pick up hum and noise. For this reason, some form of coaxial line is always used for a high-impedance cable. Such a line consists of a conductor surrounded by insulation that in turn is surrounded (coaxially) by a shield that acts as a second conductor. A typical example is shown in Fig. 1B. Because it is necessary that the cable be flexible so that the microphone can be moved about, the outer conductor consists of a number of fine wires braided together rather than a piece of copper tubing. Although the braid shield is not quite as effective a shield as solid tubing would be, it is satisfactory for all normal p.a. uses as long as it is not used near very strong fields.

For balanced microphone lines, two wires are enclosed in a coaxial shield as shown in Fig. 1C. The shield here acts as a third conductor, carrying the ground lead from the microphone transformer to the amplifier.

Shielded wire that has the shield on the outside can be obtained, but for better appearance and for ease in handling, microphone cable commonly has a rubber covering or cotton braid insulation over the shield as shown in the examples in Fig. 1.

Now that you know what kinds of lines are used for microphone and loudspeaker cables, let's learn what important characteristics of these lines must be considered in making an installation.

# High- and Low-Impedance Lines

Regardless of the type of transmission line, it will have the following characteristics:

1. Resistance. No conductor is perfect; all have some resistance.
2. Capacity. Whenever two conductors are separated by an insulator, there is a capacity between them.
3. Leakage. Leakage is a measure of the quality of the insulation. Very good insulation has very little leakage; therefore, the current *between* the wires is very small. If the insulation is poor, however, it is possible for there to be an appreciable current between the wires.
4. Inductance. A wire also has a certain amount of inductance. This inductance is relatively small, however, so it is not appreciable at audio frequencies.

Inductance and leakage, then, can be ignored in considering an audio line if we assume that wire of good quality will be used. However, the resistance and the capacity of the line are very important.

The resistance of a transmission line depends on the length of the wire and on the wire size, increasing if the wire is made longer or if its diameter is reduced. (A wire table later in this Lesson will show you exactly how the resistance varies with each of these factors.)

The capacity between wires varies with the wire size, the length, and the spacing between them. The capacity increases if the wires are brought closer together or if the diameter or length is increased.

The resistance of transmission lines is what determines how much power loss there will be, and the capacity determines the frequency discrimination. The amount of this frequency discrimination and the amount of power loss depend upon the conditions under which the line is to be used. However, since both the resistance and the capacity of a line increase when it is made longer, it is obvious that a line should be kept as short as is practical.

## LINE IMPEDANCES

When we speak of "low" impedance or "high" impedance audio lines for p.a. work, we are not referring to the resistance or capacity that is possessed by the line. If the line length is appreciable (a quarter-wavelength or more) with respect to the wavelength of the signal being handled, then the line does have a characteristic impedance of its own that is called its "surge" impedance. Telephone lines have such an impedance, and the impedance must be matched at each end of these lines for proper signal transfer. However, p.a. lines are at most only a few thousand feet in length, which is short compared to the wavelengths of audio signals. Hence, when we call a line a "low" or "high" impedance, or call it a "500-ohm" line, we are referring solely to the impedances of the terminating devices—the source and load that the line connects, and not to the actual line impedance.

As we shall show, what may be a low-impedance termination for one service may be high for another, so we qualify the impedance term by referring either to "microphone" lines or to "transmission" lines. The latter term is applied to lines carrying power, such as those that connect amplifiers to loudspeakers.

## HIGH-IMPEDANCE LINES FOR MICROPHONES

Microphone lines are considered to be high impedance if they are connected between devices having impedance values above 10,000 ohms. Crystal microphones, for example, may well have impedances of 20,000 ohms or more. A crystal microphone having such an impedance can be connected directly to a tube grid circuit through a connecting line.

The crystal microphone is the only kind that has a high impedance of itself, but a dynamic or other low-impedance microphone is often made to have a high-impedance output by connecting it to a suitable matching transformer, which is frequently built into the case of the microphone. A short line can be used to connect such a microphone to the grid circuit of the preamplifier tube.

When a transmission line is used between two points of high impedance, the power loss in line resistance is negligible. If the terminal impedances are, say, around 10,000 ohms, a line having a resistance of 10 ohms or so will not be able to affect the current distribution appreciably. However, although power loss is no problem with these lines, frequency response and pickup of interference are.

**Interference.** Stray noise and hum fields are troublesome whenever the impedance to ground is high, because even a small field can develop an appreciable voltage across a high impedance. The impedance between the control grid of a tube and ground is usually 50,000 ohms or more, so the grid is particularly likely to pick up interference. Furthermore, the signal level at the grid of the first preamplifier tube is always low, so even a relatively low hum or noise voltage can be appreciable with respect to the desired signal. This difficulty can be minimized by keeping the impedance to ground low, by keeping physically small the amount of the circuit that is at a high impedance, or by shielding all portions of the circuits that are at a high impedance to ground. This latter method is used to minimize pickup in high-impedance microphone cables, which are always shielded coaxial lines. This shielding is always carried right inside the amplifier all the way to the grid of the tube, and sometimes even encloses the input resistor.

Even though it is shielded, however, a high-impedance line always has a certain amount of pickup per unit of its length. It is therefore desirable to keep the line just as short as possible to minimize this kind of interference.

**Frequency Response.** The shunting capacity of a microphone line always has an effect on the frequency response. The exact nature of the effect depends on the characteristics of the microphone impedance.

The average single-wire coaxial microphone cable has a capacity of 25 to as much as 75 mmfd. per foot. (It is possible to get lower capacities by increasing the spacing between the center wire and the braided shielding through the use of fillers made of threads or ropes. This increases both the bulk and the cost of the cable greatly, however; as a result, such low-capacity cable is found only in certain high-fidelity installations.) If we were to use a 20-foot cable that had a medium capacity value of 50 mmfd. per foot, the total capacity would be 20 × 50, or 1000 mmfd. (.001 mfd.), which is very appreciable.

Fig. 2 shows how a high-impedance microphone should be connected to the grid of a tube. The grid circuit is completed by resistor $R_1$, which is chosen to match the impedance $Z_S$ of the microphone. Since the grid of a tube is a voltage-operated device, we might expect $R_1$ to be several times the microphone impedance so that most of the voltage generated by the microphone would be dropped across $R_1$. However, it is desirable to load the microphone to minimize peaks in its response. For this reason, it is common practice to make the load into which the microphone works equal to the microphone impedance, even though this arrangement means that only half the microphone voltage is applied to the amplifier grid.

The capacity of the microphone cable, represented as $C_C$ in Fig. 2, is in parallel with $R_1$. Its reactance, of course, varies with frequency. At low frequencies, the reactance is so high that the capacity is a negligible shunt. It becomes an appreciable factor at higher frequencies, however, and has an effect on the frequency response.

As an example, let's assume that $Z_S$ and $R_1$ are 100,000 ohms each, and that we are using a 20-ft. cable having a total capacity of 1000 mmfd. The reactance of the capacity equals the resistance of $R_1$ at about 1600 cycles. At this frequency, the net impedance of $C_C$ and $R_1$ in parallel is half that of $R_1$ alone, so the voltage across $R_1$ drops to two-thirds its original value. At a frequency twice this, 3200 cycles, the condenser reactance has dropped to 50,000 ohms, so the net impedance is one-third its former value; the voltage across $R_1$ is now one-half what it was at the low frequencies, where the condenser reactance was too high to

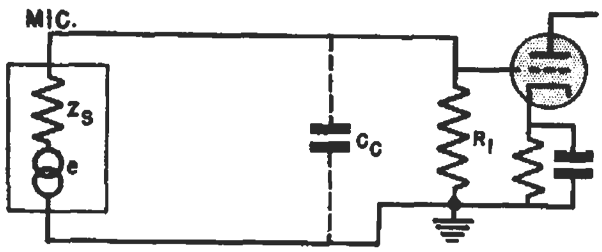



FIG. 2. How to connect a high-impedance microphone to the grid of the input tube of an amplifier.

matter. Obviously, therefore, the shunting capacity has considerable effect on the frequency response when the microphone impedance is essentially resistive.

If we reduce the values of $R_1$ and $Z_S$ to, say, 50,000 ohms each, the effects we have just described will occur at a higher frequency: the voltage is reduced to two-thirds at 3200 cycles and to one-half at 6400 cycles. Obviously, therefore, for a fixed cable capacity, the lower we can make the source and load impedances, the less shunting of high frequencies there will be.

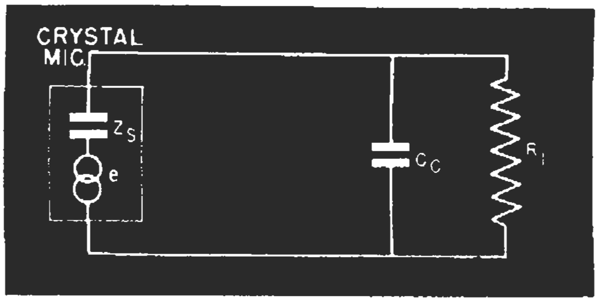



**FIG. 3. If the line is properly chosen, the capacity of a crystal microphone and that of the line can be made to balance, producing a relatively flat frequency response.**

Of course, we can't change the microphone impedance at will, so our choice of microphone fixes $R_1$. We must choose a microphone having a reasonably low impedance if high fidelity is wanted.

The effect of the capacity of the cable is made worse if the microphone has an inductive component in its impedance, as dynamic types that use matching transformers to give a high impedance often have. The inductance tends to make the microphone impedance rise with frequency, which produces an even greater voltage division with the line capacity.

**Crystal Microphone Cable.** Fortunately, the most common high-impedance microphone—the crystal type—has an impedance that is essentially capacitive, as shown in Fig. 3. This comes about because the crystal acts as a dielectric between the two terminal plates of the crystal element. Since it is capacitive, the impedance of the microphone goes down as the frequency increases. If the microphone cable is properly chosen, the internal impedance of the microphone can be made to act with the line capacity as a voltage divider of such a nature that the output is practically constant over the range that the microphone is intended to cover. That is, the impedance $Z_S$ goes down with frequency at the same rate as the reactance of $C_C$ does, so the output remains approximately the same even though the impedances decrease with frequency. Notice that this effect occurs only if the microphone cable has the proper characteristics. Therefore, you should neither shorten nor lengthen the cable that is supplied with a crystal microphone; if you do, the output will not vary uniformly with frequency.

In this case, the value of $R_1$ really sets the low-frequency response rather than the high-frequency response. As the frequency decreases, the impedance $Z_S$ increases. When it gets well above the value of $R_1$, an increasing amount of the signal is dropped in the internal impedance of the microphone. In this particular case, increasing the value of $R_1$ extends the low-frequency response—exactly the opposite of what happens in the circuit shown in Fig. 2. However, the necessity of keeping down hum and noise pickup places a definite limit on the value of $R_1$.

You can see that a line operated with its terminals at a high impedance must be specially chosen. Its length is critical when it is used with a crystal microphone, and it must be as short as possible when it is used with any other form of high-impedance microphone if reasonable frequency response is wanted. In general, therefore, high-impedance microphone cables are around 10 to 15 feet long; even the longest are no more than 25 feet in length. High-impedance microphones must therefore be placed close to the amplifier.

## LOW-IMPEDANCE LINES FOR MICROPHONES

Whenever it is desired to locate a microphone at a distance greater than the allowable length of high-impedance microphone lines, it is necessary to use a line of lower impedance. As a matter of fact, low-impedance lines are generally used even for short distances when low-impedance microphones are used.

Terminating a line with lower impedance cuts down on the noise and hum pickup because the lower impedance to ground decreases the amount of voltage that can be induced by a fixed field. Another advantage of the low impedance is that, as we indicated in the discussion of high-impedance lines, a reduction in the terminating impedance decreases the effect of the capacity of the line on the frequency response. For example, you learned that the 20-foot cable began to be noticeably effective at 1600 cycles when the terminating impedance value was 100,000 ohms. This changes to 3200 cycles when the impedance value is made 50,000 ohms. If we can get the terminating impedances down to 10,000 ohms, we can go out to 16,000 cycles before the capacity of a 20-foot cable will have much effect on the frequency response.

Reducing the terminating impedances also permits the use of longer lines. If we increase the line length to 200 feet instead of 20 feet, the total capacity now becomes .01 mfd. To get out to 16,000 cycles, the terminating line impedance must now be 1000 ohms or less. Because it is sometimes desirable to run microphone lines for 200 feet or more, the industry has standardized the so-called low-impedance microphone terminations at 500 ohms, although a few manufacturers use 200 ohms.

The connections for such a line are shown in Fig. 4. If the microphone is a high-impedance type, transformer $T_1$ steps down its impedance to 500 ohms. If the microphone is low impedance, transformer $T_1$ steps up its impedance to 500 ohms. At the amplifier, transformer $T_2$ matches 500 ohms to the value of $R_1$, which is usually between 50,000 and 250,000 ohms. (This resistor is used because the transformer would be working into an "open" circuit of no definite impedance value if the resistor were not present. The use of the resistor gives a definite load for the transformer and therefore permits the turns ratio of the transformer to be fixed.) Transformer $T_2$ is usually located as close as possible to the tube $VT_1$ so that the lead from the transformer to the tube grid can be as short as possible.

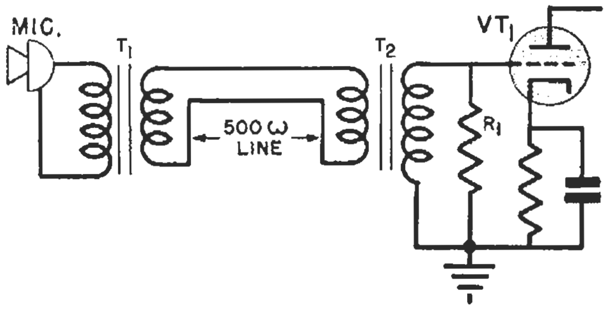



**FIG. 4. How a low-impedance line is connected to a microphone and an amplifier.**

As we have mentioned, the line is called a 500-ohm line purely because it is used between transformer terminations that have this impedance value. The actual line resistance remains that determined by the length and size of the wire, and the capacity is still determined by the size of wire, the spacing between wires, and the length of the line. Exactly the same kind of cable can be used as a high-impedance line in one case, and as a low-impedance line in another; it just depends on the terminating impedances.

A low-impedance line does not have to be a coaxial cable. The impedance is so low that hum and noise pickup is not usually a problem. However, if conditions are such that a.c. power lines must be near the microphone cable, it may be best to use a coaxial cable for a 500-ohm line.

As we said earlier, 200 ohms can be used as a terminating value if desired. It makes little difference whether a 500-ohm or 200-ohm line is used in most cases; the choice depends mostly on the transformers available for matching.

## PREAMPLIFIER LINES

If a microphone must be located a long distance from the amplifier, the very weak microphone signal may be seriously attenuated by losses in the line and the transformers, and may be interfered with by even small amounts of hum and noise interference. In such cases, a preamplifier is used at the microphone location, then the amplified signal is sent down a line to the regular amplifier.

The preamplifier is essentially just a one- or two-stage amplifier, much like the first stage of the regular p.a. amplifier. The signal from the microphone is fed to this amplifier through either a high-impedance or a low-impedance line, depending upon the type of microphone; generally a very short microphone line is used. The output of the preamplifier is fed through a matching transformer or through a cathode-coupling connection to a 500-ohm line that runs from the preamplifier to the main amplifier. At the main amplifier, a transformer matches the line to the grid resistor of the input tube.

## LOW-IMPEDANCE LINES FOR LOUDSPEAKERS

At the other end of our p.a. system, we are faced with the problem of connecting the loudspeaker to the amplifier. Here, we are working *from* plate circuits, rather than *into* grid circuits. Also, we are dealing with low-impedance loudspeaker voice coils. In fact, the impedances with which we deal are so low that a loudspeaker line is not considered to be low-impedance unless it is below 50 ohms. In most instances, such lines terminate in values approximating voice coil impedances, ranging from 2 ohms to 16 ohms.

Obviously, since the signal power levels are high, we needn't worry about hum and noise pickup on a low-impedance loudspeaker line. A twisted-pair line appropriately protected from weather and from mechanical damage is therefore entirely satisfactory. Also, since the terminating impedances on such a low-impedance line (under 50 ohms) are quite low, the capacity across the line will not prove troublesome. The resistance

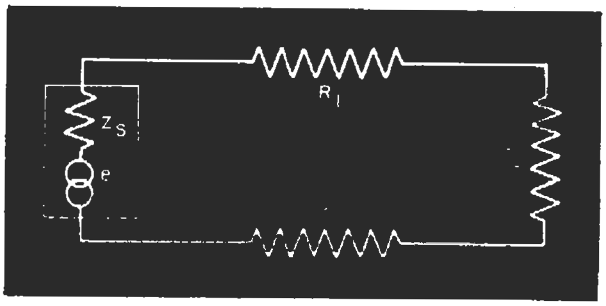



**FIG. 5. The resistance of the wire in a low-impedance loudspeaker line acts as a voltage divider with the load impedance.**

of the line itself is important, however.

The line resistance is distributed in both sides of the line, one half in each, as indicated by $R_1$ and $R_2$ in Fig. 5. (Although we ordinarily think of copper wire as having practically no resistance, actually long lengths of wire have appreciable resistance.) These resistances act as voltage dividers with the voice-coil impedance $Z_L$; if they are relatively high in comparison with $Z_L$, there will be a considerable amount of power lost in the line.

| B & S GAUGE | D. C. RESISTANCE IN OHM |
|---|---|
| 10 | 0.0020 |
| 12 | 0.0032 |
| 14 | 0.0051 |
| 16 | 0.0080 |
| 18 | 0.0128 |
| 19 | 0.0161 |
| 20 | 0.0204 |
| 21 | 0.0256 |
| 22 | 0.0330 |
| 23 | 0.0407 |
| 24 | 0.0513 |
| 26 | 0.0806 |

**FIG. 6. This table shows the resistance per loop foot of various gauges of wire.**

For convenience in use for p.a. installations, tables like Fig. 6 give the resistance "per loop foot for various sizes of wire." A loop foot actually represents two feet of wire, since it is the amount of wire needed to connect an amplifier to a loudspeaker when the two are a foot apart. You can find the total resistance of a loudspeaker cable with the aid of such a table just by multiplying the resistance per loop foot by the number of feet of cable used between the amplifier and loudspeaker locations.

As an example, let's suppose you are using No. 18 wire, which is a common lamp cord size. Its resistance (Fig. 6) is .0128 ohm per loop foot. A 100-foot run of this wire would therefore have a resistance of 1.28 ohms. If we tried to run a wire of this size and length from an output transformer to a 4-ohm loudspeaker voice coil, we would find that we would have appreciable line loss because the line resistance would be high with respect to the load impedance.

In general, engineers consider a line loss of 15% in the 400-to-1000-cycle range to be reasonable. Tables like that in Fig. 7 give the maximum length of line of any one size that can be used for various low-impedance values, assuming a maximum loss of 15%. In our example, the 100-foot run of No. 18 wire is too long for a 4-ohm load; if we were using this load value, we would have to restrict ourselves to 50 feet of No. 18 wire to keep the line loss at 15% or less.

Of course, using a larger size wire reduces the resistance and permits a longer run for the same load impedance, as you will observe from Fig. 7. However, large wire sizes cost considerably more money. Furthermore, if the load consists of a group of loudspeakers, its net impedance will be so low that the permissible length of the line will be severely limited. Hence, you ordinarily will not find low-impedance loudspeaker lines that are longer than about 200 feet and seldom one that is over 50 feet.

| WIRE SIZE (B&S) | LOAD IMPEDANCE 4 OHMS | 8 OHMS | 16 OHMS |
|---|---|---|---|
| 14 | 125′ | 250′ | 450′ |
| 16 | 75′ | 150′ | 300′ |
| 18 | 50′ | 100′ | 200′ |
| 20 | 25′ | 50′ | 100′ |

**FIG. 7. Maximum loop lengths that can be used with various load impedances to keep line loss no more than 15% for audio frequencies below 1000 cycles.**

| WIRE SIZE (B&S) | LOAD IMPEDANCE 100 OHMS | 250 OHMS | 500 OHMS |
|---|---|---|---|
| 14 | 1000′ | 2500′ | 5000′ |
| 16 | 750′ | 1500′ | 3000′ |
| 18 | 400′ | 1000′ | 2000′ |
| 20 | 250′ | 750′ | 1500′ |

**FIG. 8. Maximum loop lengths for high-impedance loudspeaker lines if 5% power loss at the middle frequencies is allowed.**

## HIGH-IMPEDANCE LINES FOR LOUDSPEAKERS

The problem of power loss on the transmission line can easily be solved by operating the line at a high impedance. This we can do by using transformers at each end of the line, one to match the source to the line and the other to match the line to the load. For power transfer to loudspeakers, terminating line impedance values ranging between 100 and 600 ohms are called high impedances. Notice that these correspond to what we call low impedances for microphone lines.

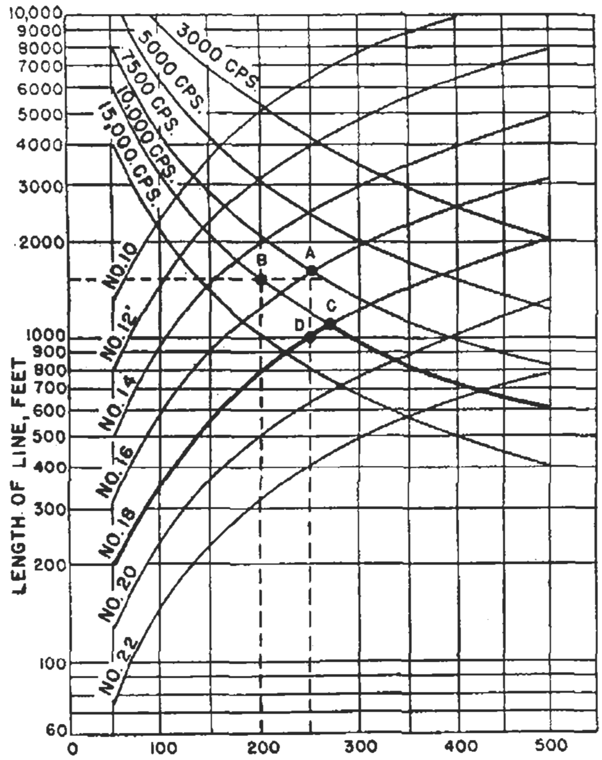
The line loss is negligible when the termination is 500 ohms. Effectively, of course, going to a higher-impedance termination means that, for the same power, we have a higher voltage and lower current. The reduced current causes less drop to occur in the resistance of the line.

Fig. 8 gives line lengths that provide 5% power loss at the middle frequencies. Compare these with Fig. 7. Incidentally, 5% losses are used for these lines rather than the 15% value used for low-impedance lines because the impedance-matching transformers have some loss. The total loss including line and transformer loss will be kept to about 15% if the line loss is kept down to 5%.

Obviously, we can run much longer lines if we terminate them in high impedances. Also, we can use much smaller wire, thus saving something on the cost of the line; this saving is often worth while if a long line is used. Although, of course, we must use transformers at each end of such a line, such transformers may be desirable anyway to give the proper impedance matching and power transfer, as we shall show later.

Although going to a high-impedance line does solve the loss problem, it reintroduces the problem of the shunting capacity. The average capacity of a twisted-pair electric cord is about 50 mmfd. per foot, so the line length must be kept down if the high-frequency response is not to be seriously reduced.

**Line Lengths.** Fig. 9 shows a chart prepared by one loudspeaker manufacturer that permits you to determine the length of line that can be used for a particular frequency response and a fixed impedance, or permits you to determine the impedance that is neces-




*Courtesy Jensen Mfg. Co.*

**FIG. 9. Transmission line design chart prepared by Jensen Radio Mfg. Co. It is based on a 5% power loss in line and a 3-db loss at upper limiting frequency due to a line capacity of 50 mmfd. per foot across a typical moving-coil loudspeaker load.**

sary at the end of the line when a certain length must be used.

As an example, let's suppose that the line is to be 1500 feet long. Also, let's suppose that the response is to go out to 7500 cycles before the power drops to half its normal value (3-db loss). Following the dotted line (at 1500 feet) from the left scale over to the 7500-cycle line, we find that we strike it near point A. Reading downward along the dotted line to the bottom, we find that the line impedance must be 250 ohms for this length and frequency response. The wire size necessary for minimum line loss and for the expected capacity value is the next larger above the point of intersection with the frequency line; in this case, it is No. 16 wire.

If we have a fixed impedance, we can determine the line length for a particular frequency response. For example, let's say that 200 ohms is our impedance value. Reading upward until we strike, let us say, the 10,000-cycle curve at point B, we find that we can again use a 1500-foot line. Notice that changing the impedance from 250 ohms to 200 ohms allows us to go from a 7500-cycle to a 10,000-cycle response for the same line length. If we go the other way—toward a higher line impedance — the fidelity will fall off if we must have a 1500-foot line length. For example, at 500 ohms, the response is something under 5000 cycles for a 1500-foot line.

This same chart can be used to determine the maximum line length for a particular size of wire and a particular frequency response. For example, let's suppose we want to use No. 18 wire. If the frequency response is to be within 3 db to 10,000 cycles, follow the No. 18 wire-size line to where it crosses the 10,000-cycle line. This is at point C. Reading now to the line length scale, you will find that we can use a line length of about 1050 feet, and reading downwards you will find that the impedance should be about 270 ohms. If we used the more practical impedance value of 250 ohms, which crosses the No. 18 wire size at D, we could use a line of 1000 feet of No. 18 wire and have a frequency response that would be somewhat less than 3 db down at 10,000 cycles.

Of course, the response will always be improved if any length less than these maximums is used. For example, returning again to our 250-ohm impedance value, point A shows a length of about 1500 feet and a frequency response out to 7500 cycles. Point D at 1000 feet and the same impedance gives a frequency response flat out beyond 10,000 cycles. If the length is only 800 feet, the frequency response goes out to 15,000 cycles.

To sum up: we see that if we terminate power transmission lines with high impedances, the line losses will in general be negligible, but the frequency response may suffer. On the other hand, the frequency response is good if we use lower impedances as line terminations, but we run into line loss difficulties. Therefore, it is the usual practice to choose some compromise impedance value that gives the desired frequency response without excessive line loss at the line length that is necessary.

Now that you have learned something of the basic characteristics of the transmission lines used, let's turn to the problem of impedance matching.

# Impedance Matching

From your earlier Lessons, you will recall that it is necessary to match impedances whenever maximum power transfer is desired.

In public address work, the microphone does not, strictly speaking, require such impedance matching. Since the microphone eventually feeds into the grid of a tube, which is a voltage-operated device, we would ordinarily want the load impedance to be many times higher than the microphone impedance for maximum voltage transfer. If the microphone is operated this way, however, there will be peaks and humps in its frequency response. It is best to load the microphone to smooth out these irregularities. As a compromise between the two opposing possibilities, it is common practice to terminate the microphone line with a resistor having a resistance equal to the impedance of the microphone. Hence, if the microphone is a high-impedance type, the load into which it operates will have the same impedance as itself. If it is a low-impedance type, impedance-matching transformers will be used to match the microphone to the line and the line to the grid resistor, or a single transformer will be used to match the microphone to the grid resistor. (In the latter two cases, the grid resistor is fixed by practical transformer design and by the need to avoid hum pickup at some value between 50,000 ohms and 250,000 ohms.)

At the other end of the system, we are interested in making an efficient transfer of power from the plate circuit of the power output stage to the loudspeakers. As you have learned elsewhere, we will get the maximum power transfer whenever the load impedance equals the source impedance. However, it so happens that because of the characteristic of vacuum tubes, the maximum *undistorted* power output is not obtained at exactly the same point as the maximum total power output. As a matter of fact, for triode tubes, the load should be twice the plate impedance for maximum undistorted power output. Fortunately, the power output secured with a load of this sort is only slightly less than that obtained when the impedances are properly matched.

In the case of pentode and beam power tubes, the impedance that gives maximum undistorted power is about 1/7 to 1/9 the plate impedance of the tube. Although these tubes give considerably less power output when they are operated with such loads than they would give if their loads were equal to their impedances, the distortion is so severe if they are operated in the latter manner that the power sacrifice is considered worth while. The load values chosen still give a reasonably high output.

It is safe to assume that the manufacturer of an amplifier gives load impedance values in terms of the maximum undistorted power output. In other words, when you must match a particular grouping of loudspeakers to an amplifier, the value specified by the amplifier manufacturer is the value you should match for maximum undistorted power output.

Let's learn something about how to match impedances.

## OUTPUT TRANSFORMERS

Two kinds of output transformers are in common use in amplifiers. Each, of course, has a primary that is properly designed for the output tubes of the amplifier in which it is used. One kind is designed to match the amplifier output stage to a particular loudspeaker or group of loudspeakers, and therefore has a fixed secondary impedance. If for some reason the loudspeakers chosen by the manufacturer are not to be used, others having the same voice-coil impedances may be substituted.

The second kind of output transformer is essentially a universal type in that its secondary has a number of taps that can be used to match to any common loudspeaker or group of loudspeakers. It is not unusual to find secondaries that are designed to match impedance values of 4, 8, 15 (or 16), and perhaps 30 ohms, and in addition have a 500-ohm and perhaps a 250-ohm tap for matching transmission lines.

Another type of output transformer that is occasionally used is primarily designed to match the amplifier to a line. A transformer of this type usually has taps at about 67, 125, 250, and 500 ohms.

Although the output transformer on the average p.a. amplifier does contain a number of taps, it is quite possible that the exact tap needed will not be available. For highest possible fidelity, the source and load impedances should be matched within 10%, but mismatches of up to 25% may be permissible in practice, depending upon the fidelity demanded. If a wide mismatch must occur, it is always better to connect the loudspeaker to the impedance tap next lower than the load impedance to minimize loss of power and distortion. Thus, if the combined loudspeaker load figures out to be, say, 6 ohms, you should use a 4-ohm tap rather than an 8-ohm tap.

**Line Transformers.** In addition to output transformers, there are line-to-loudspeaker matching transformers. These are designed to match the loudspeaker voice coil to whatever value is needed to terminate the line properly.

Incidentally, when we speak of the impedances of a transformer, we refer to the values the transformer is designed to match—not to the actual reactances of the transformer windings. The reactance of the primary winding (when there is no secondary load) should be about ten times the source impedance if good low-frequency response is to be obtained. Then, its turns ratio should be chosen so that the secondary load will appear as the desired "reflected" value in the primary. For example, if a transformer is supposed to cause a 4-ohm secondary load to appear as a 3600-ohm reflected impedance across the primary, its turns ratio should be 30.* The actual impedance of the primary winding depends on the plate resistance of the tube to which it is to be connected. If it is to be used with a triode tube having a plate resistance of about 2000 ohms, the primary winding should have a reactance of 20,000 ohms (or more) at, say, 400 cycles.

A 30-to-1 transformer will also cause an 8-ohm secondary load to reflect as 7200 ohms; a 2-ohm load as 1800 ohms; a 16-ohm load as 14,400 ohms; and so forth. In other words, a transformer having a 30-to-1 turns ratio will always produce a reflected primary impedance that is 900 times as great as the impedance that is connected to the secondary. This does not mean that the same transformer can be used for any application in which an impedance ratio of 900 to 1 is wanted, because there is also the requirement that the primary reactance must be at least 10 times as large as

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* The turns ratio equals the square root of the impedance ratio. Hence:

$$N = \sqrt{\frac{Z_1}{Z_2}} = \sqrt{\frac{3600}{4}} = \sqrt{900} = 30$$

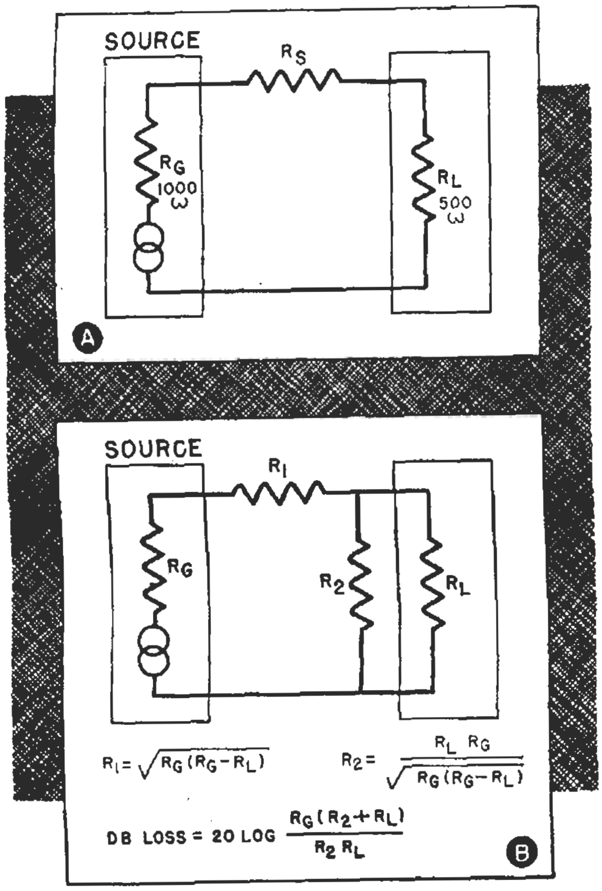


**FIG. 11. Use of a series resistor (part A) and of an L pad (part B) to match a source and a load.**

we have a 3-db power loss—much more than in the direct connection shown in Fig. 10A. If the ratio of source to load impedance were greater, the series resistor would have to be larger, and more power would be lost.

A bad feature of the arrangement shown in Fig. 11A is that the load $R_L$ does not see its own impedance when looking back toward the source; in fact, the series resistor has made matters worse in this respect. (When we say that a source or a load "sees" an impedance when it "looks" in one direction or another, we are using an engineering expression that is often very convenient. The impedance "seen" is the effective impedance in the specified direction. For example, the source in Fig. 11A sees an impedance consisting of $R_S$ and $R_L$ in series when it looks toward the load; the load, on the other hand, sees an impedance consisting of $R_S$ and $R_G$ in series when it looks toward the source.)

If the load is entirely resistive, this won't matter at all. However, if the load is a reactive one such as a loudspeaker voice coil or a long transmission line, it is quite possible for the load characteristics to be such that this mismatch affects the circuit response. For example, if a loudspeaker voice coil does not see its own impedance, it will have much higher peaks and valleys in its over-all frequency response.

If it is necessary that both the source and the load see their respective impedance values (that is, if they must both be matched), an L-type pad like that shown in Fig. 11B may be used. The formulas given in Fig. 11B are correct if the source has a higher impedance than the load. If the load impedance is higher than that of the source, $R_1$ should be placed between $R_2$ and the load rather than as shown, and the terms $R_G$ and $R_L$ in both formulas should be interchanged throughout. (That is, where $R_G$ appears, use $R_L$, and vice versa.) If we calculate $R_1$ and $R_2$, using the formulas given in Fig. 11B and the source and load impedances given in Fig. 11A, we find that they both come out to be about 706 ohms. In this case, $R_G$ sees $R_2$ and $R_L$ in parallel, with $R_1$ in series with the parallel group. The resistance of $R_2$ (706 ohms) in parallel with the 500-ohm load is about 294 ohms; this resistance in series with $R_1$ (706 ohms) makes a total resistance of 1000 ohms.

The load sees $R_2$ in parallel with a series combination of $R_G$ and $R_1$ in series. The combined resistance of these three is 500 ohms, so the load is matched. However, there is now about an 11-db power loss.

Such a power loss always occurs when pads are used to match impedances. The amount of the loss depends upon the ratio of the source to the load impedance, but there is always at least some loss, and sometimes a very large one. Obviously, therefore, this form of impedance matching can be used only if the loss is permissable. If we cannot permit such a loss, we have to use transformers for impedance matching.

# Microphone Connections

The input terminals on a p.a. amplifier provide for a certain number of microphones. The connections are usually all low-impedance or all high-impedance types, but occasionally a combination of these is provided. Obviously, if you use the kinds of microphones for which the amplifier input is designed, there is no problem. However, it may well be that an amplifier with exactly the input terminals wanted is not available, or you may be forced to use microphones with amplifiers that have the wrong kind of inputs. Let's see how to do so.

**High to Low.** First, let's suppose you have a high-impedance microphone that must be used with an amplifier having only low-impedance input terminals. There are two solutions to this problem.

One solution is to modify the amplifier. The fact that an amplifier has a low-impedance input means that it contains a built-in transformer that is designed to match a 500-ohm line to the grid of the first tube. It is possible to remove the transformer and bring the grid lead directly to the microphone jack. If high-impedance microphones are always to be used, such a modification may be worth while. However, if you believe there may be any need in the future for using a low-impedance microphone or for using a line to connect the microphone to the amplifier, such a change should not be made. It should not be made, either, if the additional length of wire connected to the grid of the first tube produces a marked increase in the hum level; unfortunately, you cannot find out whether this will happen without first making the modification.

If changing the amplifier seems inadvisable, the only solution is to use a transformer outside the amplifier that will match the high-impedance microphone to the 500-ohm input. In such cases, it is usually best to obtain a transformer that is designed for this particular microphone from the manufacturer of the microphone. The case of such a microphone often contains space for mounting a transformer right next to the microphone. If it is possible to install the transformer at this position without taking the microphone apart, this is the best place to put the transformer. However, if it is necessary to disassemble the microphone, it is better to send it back to the factory to have this work done, or to place the transformer at the end of the cable, right at the input of the amplifier. The latter method may or may not be desirable, depending on whether the transformer picks up too much hum and noise; again, only a trial will show.

**Low to High.** The opposite problem occurs when the microphone is a low-impedance (500-ohm) type and the only jacks provided on the amplifier are at high impedance. In this case, the only solution is to use a transformer at the amplifier input that is designed to match 500 ohms to the grid of the first tube. Although such a transformer might possibly be mounted outside the amplifier, the chances are that the high-impedance lead from the amplifier connecting jack to the transformer would be so long that it would pick up excessive amounts of hum and noise. The most satisfactory solution is to mount the transformer as close as possible to the grid of the preamplifier tube. This is rarely a difficult problem, because the manufacturer usually provides space for the mounting of such transformers inside the amplifier on the assumption that he may be requested to supply the amplifier with low-impedance inputs. You can probably obtain the necessary transformer for making the conversion as well as mounting instructions from the amplifier manufacturer.

**Multiple Connections.** You will sometimes find it desirable or necessary to operate more microphones than the input jacks on the amplifier provide for. Although only one or two microphones are needed for most installations, high-fidelity music pickup or pickup from a stage often requires the use of a number of microphones. Since the average p.a. amplifier has only two microphone inputs and even the most elaborate types have only three or four, it is quite possible for you to need more microphone input terminals than the amplifier offers.

There are two common answers to this problem. If the microphones are to be located at some distance from the amplifier, the use of a preamplifier may well be justified. This will permit a considerable increase in the number of microphones that can be used, since a preamplier commonly has four inputs, all of which feed through the preamplifier into only one input on the main amplifier.

Of course, if the microphones are to be used in a location near the main amplifier, the expense of a preamplifier may be unwarranted. In such cases, you can use commercially available resistor mixer boxes. Fig. 12 shows the schematic of one such box,

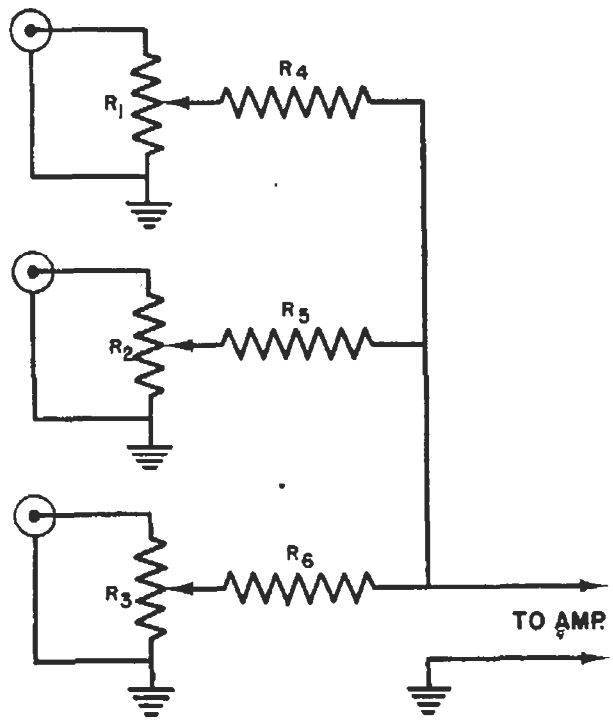


FIG. 12. The schematic of a resistor mixer box used to mix the outputs of 3 microphones.

designed for three microphones, each of which feeds into its own mixer-control potentiometer ($R_1$, $R_2$, or $R_3$). These potentiometers are decoupled from each other by the resistors $R_4$, $R_5$, and $R_6$. The output of the box goes to one microphone input on the amplifier. Thus, like a preamplifier, a box of this sort permits the outputs of several different microphones to be fed into a single input jack on the amplifier.

The mixer boxes available are commonly designed for high-impedance microphone connections. If low-impedance lines are involved, transformers will be necessary for each line, so a preamplifier will probably not be much more costly.

# Practical Loudspeaker Connections

At the other end of the amplifier, we are faced with the problem of connecting one or more loudspeakers to the amplifier. In the average job, usually at most only three or four loudspeakers must be connected together. More elaborate installations may require the use of a great many more, however, particularly when several rooms are to be covered. An extreme example of this is a hotel or hospital installation in which separate loudspeakers are wanted in a number of small rooms; as many as 100 or more may have to be connected in such an installation.

You have already learned how to determine the power ratings and the number of the loudspeakers to be used in an installation. Now we are going to discuss the problems involved in connecting these loudspeakers to the amplifier. Before we do, however, we must learn something more about the voice-coil impedances of loudspeakers.

Although voice-coil impedances are always given as some definite number of ohms, this fact does not mean that the impedance is the same at all frequencies. As a matter of fact, the impedance of a voice coil varies widely over the audio-frequency spectrum, reaching high peaks at some frequencies and falling to low values at others. The voice-coil impedance rating of a loudspeaker is therefore either a nominal value that is representative of the over-all characteristics, or is the impedance at some particular reference frequency, such as 400 cycles or 1000 cycles. There is no general agreement among manufacturers on how voice-coil impedance should be rated.

The variations in the impedance of a voice coil are minimized when the coil is properly matched to an amplifier. For this reason, you can compute the load on an amplifier with reasonable accuracy by using the impedance value given by the manufacturer of the loudspeaker.

Very often you will find that you can choose any of several different voice-coil impedances for a given loudspeaker that is usually equipped with an 8-ohm voice coil may instead be obtained on request equipped with a 4-ohm or a 16-ohm coil. It is particularly helpful to be able to make such a choice when you have to connect together a group of loudspeakers and must arrive at some reasonable combined impedance that can be matched by available transformers.

The same 4, 8, and 16-ohm values are almost standard today for driver units, although some that have a higher impedance (about 45 ohms) are also offered. High-impedance voice coils are useful when several loudspeakers are to be connected in parallel, because the total net impedance of the parallel combination will be very low unless the voice-coil impedances are fairly high to begin with.

Now let's study several practical examples of the problems you will meet in connecting loudspeakers to amplifiers and learn how they can be solved.

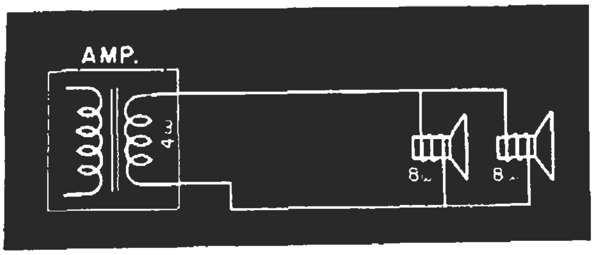


**FIG. 13. Matching impedances of parallel voice coils.**

## LOW-IMPEDANCE CONNECTIONS

If the distance from the amplifier to the loudspeakers is small, it is possible, as you have learned, to run lines at the voice-coil impedance. In such a case, if we have more than one loudspeaker, we can connect the voice coils either in series or in parallel. If we connect them in parallel, and all have the same impedance, the net impedance will be equal to the impedance of any one divided by the number of loudspeakers. For example, the net impedance of the two 8-ohm voice coils in parallel in Fig. 13 is 4 ohms. We can use a low-impedance line to connect these two voice coils to the 4-ohm tap on the amplifier output transformer. In figuring the line loss, we must use the net impedance; in Fig. 13 it is 4 ohms, so the maximum line length is figured on this basis. If we used two 16-ohm loudspeakers, the net impedance would be 8 ohms; this would make it possible to use a longer line for the same wire size.

If two or more loudspeakers are connected in series, and all have the same impedance, the load will be the sum of the voice coil impedances. Fig. 14 shows an example.

It is also possible to connect the loudspeakers in series-parallel, as shown in Fig. 15. The impedance of this combination is the same as that of an individual voice coil as long as all the voice coils are the same and are connected as shown.

As long as the loudspeakers in each of these cases have the same voice-coil impedances, the power will divide equally between them. Thus, if two loudspeakers are connected either in series or in parallel and their voice-coil impedances are equal, each will receive half the power. If there are three loudspeakers, each gets one-third of the power; if there are four, each gets one-quarter of the power; and so on. Therefore, to make sure none of the loudspeakers in such a combination will be overloaded, all we need do is make sure that each has a power rating that is greater than its fractional portion of the amplifier output rating. If the amplifier is rated at 50 watts, for example, and we have two loudspeakers, each will get 25 watts of power and must be rated to handle it.

**Unequal Impedances.** If the loudspeaker voice-coil impedances are unequal, the power distribution will also be unequal. For example, when two unequal loudspeakers are connected in parallel, the resulting impedance is

$$Z_T = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

As an example, if we have an 8-ohm speaker voice coil in parallel with a 16-ohm speaker, the result will be

$$\frac{8 \times 16}{8 + 16} = \frac{128}{24} = 5.33 \text{ ohms}$$

A tap rated at 5.33 ohms will probably not be found on the output trans-


**FIG. 14. Matching impedances of series-connected voice coils.**

former of an amplifier; 4 ohms is about the closest we can expect. Connecting this group to the 4-ohm tap will result in a certain loss of power. There will also be an unequal power distribution; the loudspeaker having the lower impedance will receive the greater amount of power when they are in parallel. In this case, with an 8-ohm and a 16-ohm loudspeaker, the 8-ohm loudspeaker will get twice the power of the 16-ohm loudspeaker. (The same voltage is across both, and the power in each is $P = E^2 \div Z$; hence, the lower the impedance, the higher the power.) You should keep this fact in mind if you are connecting loudspeakers of unequal impedance in parallel, because otherwise you may accidentally overload one of the loudspeakers. If a 50-watt amplifier were connected to the 8-ohm and 16-ohm combination we just described, 33⅓ watts would be applied to the 8-ohm loudspeaker and 16⅔ watts to the 16-ohm one. The 33⅓ watts would be a considerable overload if both loudspeakers were rated at only 25 watts, which is the maximum rating for all but the most powerful loudspeakers.

If these two loudspeakers were connected in series, the net impedance would be the sum of the two impedance values, or $8 + 16 = 24$ ohms. In a series connection, the loudspeaker with the higher impedance will get the more power: in our example, the 16-ohm loudspeaker would get twice the power applied to the 8-ohm loudspeaker.

You can see that it is desirable to have voice coils of equal impedances when low-impedance lines are used, unless you want to apply more power to some loudspeakers than to others. When a high-impedance line is used, the loudspeakers are matched to the line with transformers; in this case, it is not necessary to use loudspeakers having equal voice-coil impedances to secure equal power distribution, nor does the use of equal impedances mean that the power will necessarily be equally divided. Let's take up high-impedance lines now.

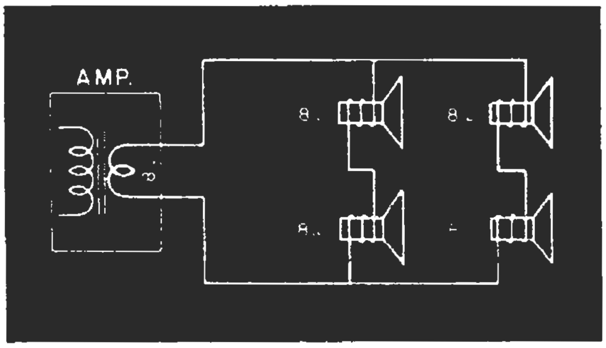

FIG. 15. Matching impedances of voice coils connected in series-parallel.

## HIGH-IMPEDANCE LINES FOR LOUDSPEAKERS

One example of the use of high-impedance lines to match loudspeakers to an amplifier is shown in Fig. 16. Here there are two loudspeakers at a location remote from the amplifier. Since they are grouped together, however, it is practical to connect the loudspeakers together as a low-frequency grouping, then use a transformer to match this group to the 500-ohm line. The line is then terminated at the proper 500-ohm value at the amplifier. Operating this way, as

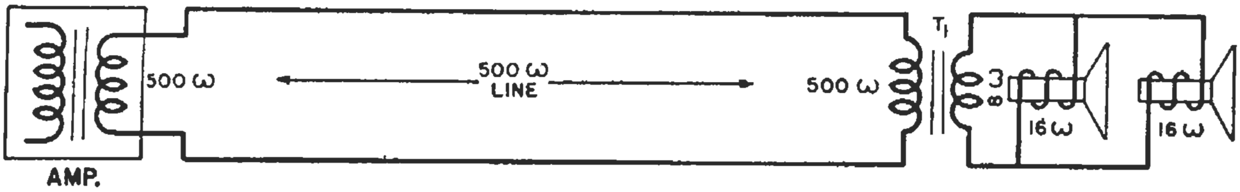


**FIG. 16. Use of high-impedance line with grouped loudspeakers.**

you have learned, provides far less line loss and permits the loudspeakers to be placed much farther from the amplifier. Because of shunting capacities, however, the permissible length of the 500-ohm line depends on the frequency range wanted. If the line has to be so long that a 500-ohm terminating impedance will not permit the desired frequency response to be secured, lower impedances must be used. Hence, in the example shown in Fig. 16, it might be necessary to use 250 ohms instead of 500 ohms at each end of the line. Transformer $T_1$ would then have to be designed to match the impedance of the loudspeaker group to a 250-ohm line. If the amplifier transformer did not have a 250-ohm tap, it would be best to replace it with one that did. Such a replacement would, of course, have to be designed to handle the power output of the amplifier.

Obviously, the arrangement shown in Fig. 16 can be used for practically any number of loudspeakers, provided that the loudspeakers can be connected in the proper series or parallel arrangement to give a terminating impedance that can be matched by transformer $T_1$. If four or more loudspeakers are to be connected in parallel, it is desirable to use 16-ohm rather than 8- or 4-ohm loudspeakers, because the net impedance will be higher and therefore more likely to be a value that can be matched by transformer $T_1$.

The statements made before about power distribution hold here; in fact, you can consider transformer $T_1$ to be the same as the amplifier output transformer. Therefore, if we use loudspeakers of equal voice-coil impedance, they will divide the power equally. If their impedances are unequal, they will divide the power according to their respective impedances and to whether they are connected in series or in parallel.

It doesn't always happen that the loudspeakers are grouped closely enough together to make it practical to run a low-impedance connection between the voice coils. In such cases, the loudspeakers must be located wherever they are wanted, and then a high-impedance line must be run to each location. Each location must, of course, have its own matching transformer.

Fig. 17 shows an example. Here, each loudspeaker has a transformer that is chosen to match the voice-coil impedance to the line in such a way


**FIG. 17. Use of high-impedance line with separated loudspeakers.**

that the net impedance of all the voice coils will equal the proper terminating impedance—500 ohms in this case. Since we have two loudspeakers, the transformers are chosen so that their reflected primary impedances are 1000 ohms; the net impedance of the two in parallel then equals 500 ohms. If we had four loudspeakers, each primary would have to have a 2000-ohm reflected impedance so that the net impedance of all of them would be 500 ohms.

In cases like this, where each loudspeaker is to get the same power, you can find the primary impedance each must have by multiplying the terminating line impedance by the number of loudspeakers wanted. Thus, if there are to be 6 loudspeakers and the terminating impedance is to be 500 ohms, 6 × 500 or 3000 ohms is the primary impedance that each matching transformer must have. Each transformer must then be able to match this impedance to that of the voice coil that is to be connected to its secondary. If each transformer meets this requirement, the power will be evenly distributed among the loudspeakers no matter what their voice-coil impedances may be, since the transformers effectively make them all equal as far as the amplifier is concerned.

## UNEQUAL POWER

In many installations, we don't want equal power at each loudspeaker. One example is an installation in which high-powered loudspeakers are used in an auditorium and one or more smaller loudspeakers are used in side rooms to handle an overflow crowd. Obviously, an equal distribution of power would overload the smaller loudspeakers or under-drive the large ones, or perhaps do both.

To see how to create an uneven power distribution, let's suppose we have a circuit like that shown in Fig. 18, in which $LS_1$ and $LS_2$ are each rated at 25 watts, $LS_3$ is rated at 10 watts, and the amplifier has an output impedance of 500 ohms. Our problem is to find the primary impedance values for each transformer that will provide the proper power distribution.

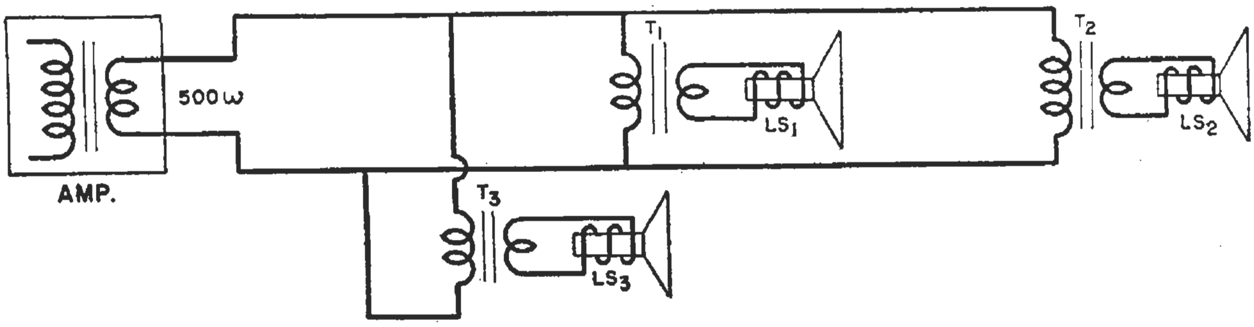


**FIG. 18. Unequal powers can be supplied to the various loudspeakers by choosing the proper impedances for the transformer primaries.**

To find these primary impedances, we must take these steps:

1. Find the total power.
2. Find the ratio between the total power and that needed for each individual loudspeaker.
3. Multiply the line or amplifier impedance by the power ratio to get the primary impedance each transformer must have.

The total power needed (Step 1) for our example is the sum of the powers of the individual loudspeakers. This is 25 + 25 + 10 or 60 watts.

The ratio of the power (Step 2) of each of the 25-watt units to the total power is 60 ÷ 25 or 2.4. The power ratio for the 10-watt speaker is $60 \div 10$ or 6.

The line impedance is 500 ohms. Therefore (Step 3), we must multiply 500 by 2.4 to find the impedance that the primaries of $T_1$ and $T_2$ must have: this turns out to be 1200 ohms. Multiplying 500 by 6 gives us 3000 ohms as the impedance of the primary for $T_3$.

We can prove that we have found the correct ratios by computing the net impedance of these three primary impedances in parallel. The net impedance of the two 1200-ohm primaries in parallel is 600 ohms; this 600-ohm value in parallel with the 3000 ohms of $T_3$ makes a net impedance of 500 ohms for the whole combination. Since this is equal to the amplifier output impedance, the loudspeakers are correctly matched to the line.

Effectively, therefore, if we use transformers that will have reflected primary impedances equal to those we have calculated, the power will automatically be divided so that each speaker will receive the proper amount. Again, it doesn't matter whether the voice coils all have the same impedance or different impedances as long as the transformers match them properly to the calculated primary impedances.

Another way that we can get the same result, and incidentally prove that this power distribution will occur properly, is to calculate the source voltage needed and then to find the impedance of the transformer primary from the source voltage and the required power. In our example, we have a 500-ohm source and require a total of 60 watts. The source voltage can be found from the formula:

$$E^2 = P_S Z_S$$

where $P_S$ is the total power of the source and $Z_S$ is the impedance of the source. Multiplying 500 by 60 we get 30,000 as the square of the voltage. By taking the square root of this value, we find that our source voltage is approximately 172 volts.

The impedance of each primary is given by

$$Z = \frac{P_L}{E^2}$$

where $P_L$ is the power needed for that particular load. As an example, loudspeaker $LS_1$ requires 25 watts, and the square of the voltage is 30,000. Dividing 30,000 by 25 gives us 1200 ohms as the primary impedance, just as we calculated before.

As another and somewhat more difficult example, let's compute the primary impedance needed for the transformers in the circuit shown in Fig. 19. This is a small hotel installation in which two 25-watt loudspeakers are used in a ballroom, four 5-watt loudspeakers are used in a dining room, and fifteen 2-watt loudspeakers are used in individual rooms. The loudspeaker groups therefore take respectively:

$$2 \times 25 = 50 \text{ watts}$$
$$4 \times 5 = 20 \text{ watts}$$
$$15 \times 2 = 30 \text{ watts}$$

making a total power of 100 watts. The power ratio for the 25-watt loudspeakers is 4 ($100 \div 25$). For the 5-watt loudspeakers it is 20 ($100 \div 5$) and for the 2-watt loudspeakers it is 50 ($100 \div 2$).

With an amplifier termination of 500 ohms, the primary impedance for the 25-watt loudspeakers should be 2000 ohms ($500 \times 4$); for the 5-watt loudspeakers it should be 10,000 ohms ($500 \times 20$); and for the 2-watt loudspeakers it should be 25,000 ohms ($500 \times 50$).

If we were to attempt to locate the

parts for this installation, we would find it difficult or impossible to obtain transformers for the 2-watt loudspeakers. Power-handling transformers rarely have turns ratios that would cause a loudspeaker voice coil to appear as a primary impedance of more than 10,000 to 15,000 ohms at the most. Therefore, it would be wiser for us to use some lower value of source impedance so that we can get this turns ratio for the 2-watt loudspeakers down to something reasonable.

If we use a source impedance of 125 ohms, the 25-watt loudspeakers will require primary impedance values of 500 ohms (125 × 4), the 5-watt loudspeakers will require 2500 ohms (125 × 20), and the 2-watt loudspeakers will require 6250 ohms (125 × 50). Transformers having the necessary turns ratios to produce these impedances can be obtained easily.

Incidentally, while we are on the subject of transformers and the values that are available, there is one fact you should keep in mind when you are looking for transformers: a transformer rated to match two specific impedances can often be used for other impedances that are in the same proportion. For instance, a transformer listed to match 4000 ohms to let's say

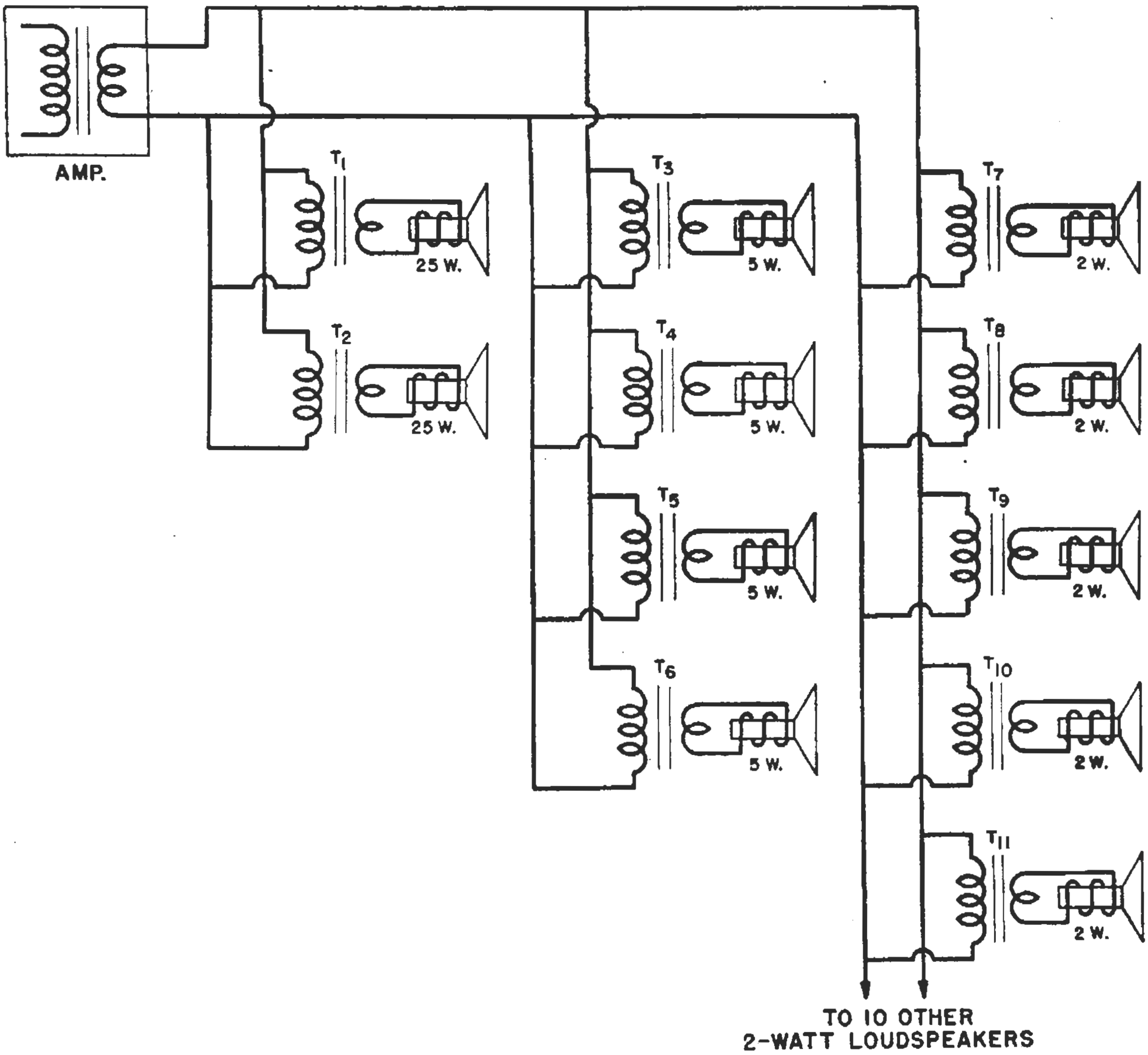


FIG. 19. A small hotel installation in which unequal powers must be applied to the loudspeakers.

an 8-ohm loudspeaker can also be used to match 2000 ohms to a 4-ohm loudspeaker or 8000 ohms to a 16-ohm loudspeaker. Line - to - loudspeaker transformers can be used this way because the source impedance is always less than the actual primary reactance of the transformer, so there is little frequency distortion. Notice that this is different from what you learned earlier in this Lesson about microphone-to-line transformers.

# Loudspeaker Switching; Equalizers

In any installation involving a large number of loudspeakers, such as a hotel installation where loudspeakers are in separate rooms, it will always be necessary to make it possible for loudspeakers to be cut in and out at will to suit the desires of the listeners. As we have just shown, however, the loudspeakers are all matched to the line. If we attempt to cut any of them in or out simply by throwing a switch, we will upset the impedance matching and the power distribution. If even one loudspeaker is cut off, the power applied to the others will increase to some extent; if many small or one or two large ones are cut off, the power increase may be so great that small loudspeakers left in the circuit will be ruined. Even if the remaining loudspeakers are not damaged, the frequent changes in volume level as loudspeakers are cut in and out will be highly undesirable. To prevent such effects, it is common practice to arrange the circuit so that a resistor is substituted for the loudspeaker when the latter is out of the circuit. This keeps the total impedance of the circuit constant at all times and therefore prevents any variation in the power applied to the individual loudspeakers.

One such arrangement is shown in Fig. 20A. Resistor $R_1$ equals the voice-coil impedance. When switch S is in the position shown, resistor $R_1$ is connected to the line in place of the loudspeaker; when S is thrown to the other position, the loudspeaker is energized and the resistor is cut out. Effectively, therefore, there is a constant-impedance load on the line regardless of the position of switch S.

When transformers are used to match the individual loudspeakers, the arrangement shown in Fig. 20B may be used. Here the value of $R_1$ corresponds to the reflected primary impedance of transformer $T_1$. Again the line is not upset whether the loudspeaker is switched in or out.

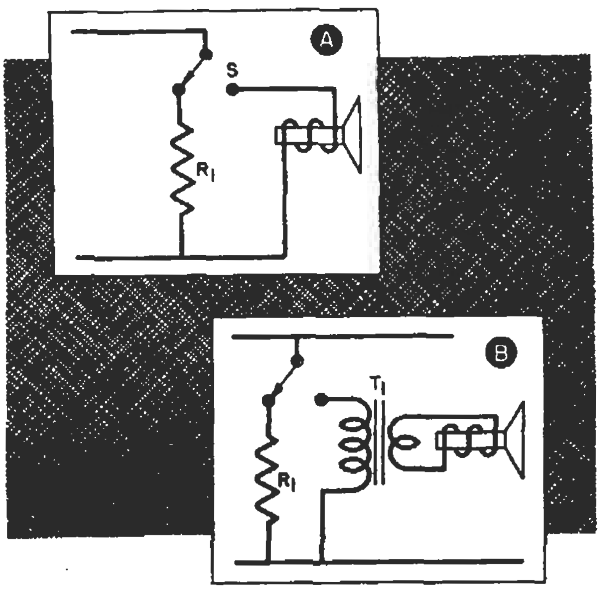

FIG. 20. Two ways of keeping the impedance of a line constant whether loudspeakers are switched in or out.

It is often necessary to make some

provision for adjusting the volume level of individual loudspeakers as well as for cutting them in or out. A hotel room or hospital installation is a practical example of one in which a volume control for each loudspeaker is needed.

Again, it is necessary to be able to

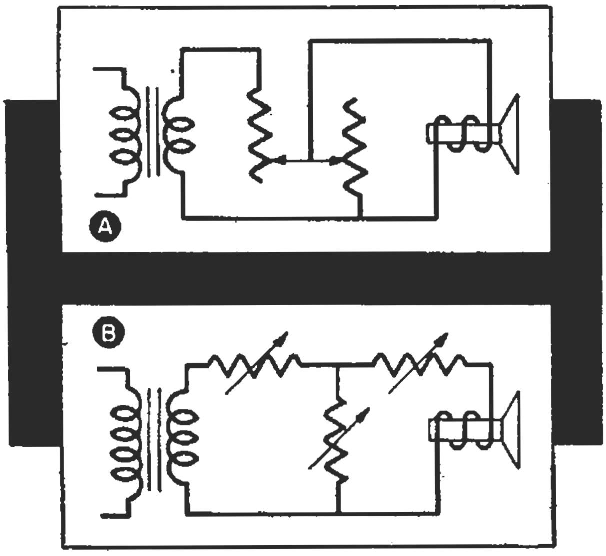


FIG. 21. Typical L pad (part A) and T pad (part B).

control the volume without upsetting the impedance match. Therefore, instead of using an ordinary volume control (which could not handle the power anyway), some kind of special attenuator is used for controlling volume at the loudspeaker. This attenuator is commonly either an L or T pad, so designed that it offers constant impedance at least to the source, and preferably to both the source and loudspeaker loads. Fig. 21 shows typical examples of the L and T connections. The resistor values are so tapered that the proper impedances are maintained. Sometimes these pads are continuously variable, sometimes they are switching units that use fixed resistors to produce a certain amount of attenuation at each position.

In either case, these attenuators are designed to operate between definite impedance values. In the case of the kind shown in Fig. 21, they must be designed to operate at the voice coil impedance.

## CROSS-OVER NETWORKS

In high-fidelity systems, dual loudspeakers are used to give a good over-all frequency response. One is a low-frequency or woofer type and the other a high-frequency or tweeter unit. A much better over-all frequency response can be obtained by the proper use of such combination speakers. The woofer speaker can be designed to handle the low frequencies exceptionally well, and the tweeter will give an extended high-frequency range.

However, it is necessary to prevent high frequencies from being fed to the woofer and to prevent low frequencies from going to the tweeter. Fig. 22 shows a typical cross-over network that is used to direct the various frequencies to the proper loudspeakers. It consists of a high-pass filter, $C_1$-$L_1$, and a low-pass filter, $C_2$-$L_2$. In the high-pass filter, condenser $C_1$ is small in capacity and therefore offers a high

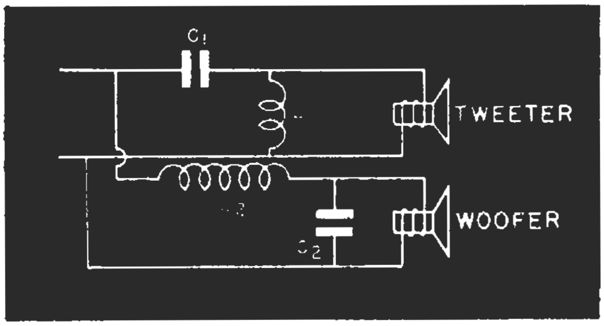


FIG. 22. Typical cross-over network used to separate the frequencies fed to the loudspeakers in a tweeter-woofer combination.

impedance to low frequencies. $L_1$ at the same time offers low impedance at low frequencies, with the result that practically all low frequencies are dropped across $C_1$ and are not applied to the tweeter. As the frequency goes up, however, $C_1$ drops in reactance and $L_1$ increases, so an increasing amount of power is applied to the tweeter.

The opposite action occurs with the

low-pass filter $L_2$-$C_2$ that is connected to the woofer. Here, only the low frequencies get through.

The exact design of the high- and low-pass filters that make up this network depends upon the "cross-over" frequency. The cross-over is the frequency at which the woofer response should begin to die out as the tweeter response begins to increase. The frequency at which cross-over occurs depends on the loudspeaker design. Some loudspeakers are designed for cross-overs around 200 to 400 cycles, others may have cross-overs in the range between 1000 and 3000 cycles. Therefore, the cross-over network used must be designed for the particular loudspeaker combination that is being used. This means that you must select loudspeakers that are designed to work together—you can't just combine a small loudspeaker and a large one and hope to make them work well together. The design of the loudspeaker must be carefully worked out if a smooth over-all response is to be obtained.

If the low-pass and high-pass filters are properly designed, the net impedance at the input terminals of the two loudspeakers will remain practically constant—effectively, as the impedance of one drops, that of the other will rise to compensate for it.

## EQUALIZATION

Ordinarily, the over-all response of a complete p.a. system will be reasonably close to the expected design values. However, it is possible that peaks or valleys will appear in the response of a system when it is assembled. This may well occur if all of the components—the microphone, the amplifier, and the loudspeakers—happen to have peaks or dips in their response that occur at about the same frequencies.

The amplifier will usually have a tone control that will compensate for most of this kind of difficulty. However, there may be installations—particularly those in which transmission lines are used—in which it is not desirable to depend entirely on the tone control. For example, let's suppose that a line somewhat longer than usual is required and that the high-frequency response has suffered accordingly. It may well be that the tone control of the amplifier is unable to make up this deficiency or is able to do so only by being turned to maximum treble gain, in which latter case there will be no reserve left for boosting the high frequencies in programs that need it. In either case, some other method of correcting the high-frequency attenuation should be used. If there is enough gain in the amplifier to permit us to throw away half the voltage, the equalizer shown in Fig. 23 can be used. Here, condenser $C_1$ has a capacity that is approximately equal to the total capacity introduced by the

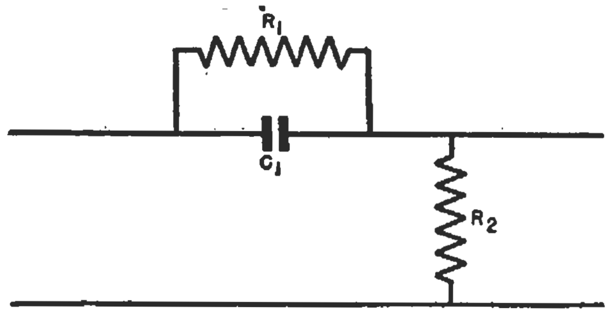


**FIG. 23. Simple equalizer circuit used to correct high-frequency attenuation.**

line. Resistors $R_1$ and $R_2$ have equal resistances. Under these conditions, the over-all gain is reduced one-half, but the frequency response is extended considerably. The over-all response is also flatter. Incidentally, when impedance matching is important, the sum of $R_1$ and $R_2$ should equal the desired terminating impedance for this line.

Obviously, equalizers like this one can be used only where there is sufficient reserve gain to make up for the loss introduced by the equalizer.

Equalizers are also used for somewhat different purposes with phonograph pickups. A pickup may have a fairly high response in the region between 5000 and 7000 cycles, with the result that the normal record noises may prove annoying to some listeners. They may be willing to sacrifice fidelity to get rid of such noise. In such

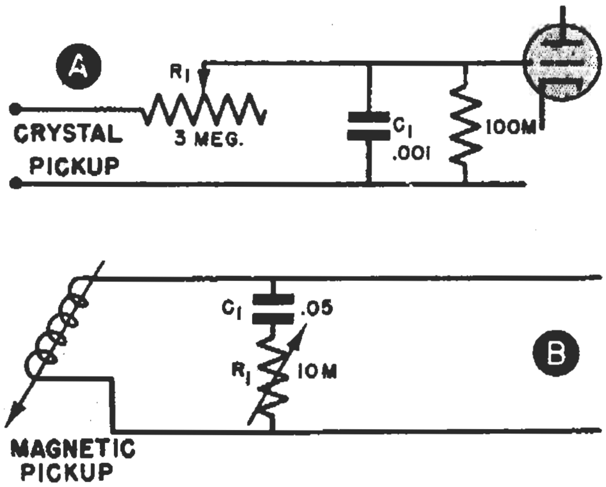


FIG. 24. Scratch filters for a crystal pickup (at A) and for a magnetic pickup (at B).

cases, scratch filters like those shown in Fig. 24 may be used. That in Fig. 24A is for use with a crystal pickup and that in Fig. 24B is for use with the magnetic pickup. Typical values of the circuit components are shown in each instance.

# Lesson Questions

**Be sure to number your Answer Sheet 51RH-2.**

**Place your Student Number on every Answer Sheet.**

***Send in your set of answers for this Lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. Why are twisted pairs preferable to parallel lines as low-impedance audio lines?

2. When we refer to a "low-impedance" line in p.a. work, are we referring to any characteristic of the line itself or to the impedances connected to the ends of the line?

3. Give two reasons why the cable used to connect a high-impedance microphone to an amplifier should be shielded and short.

4. Why are low-impedance loudspeaker lines not used for long runs?

5. What would be the loop resistance of a 200-ft. loudspeaker transmission line made of No. 14 B & S gauge copper wire?

6. If loudspeakers of unequal voice-coil impedances are connected in parallel to a low-impedance line, which loudspeaker will get the most power—the one having the *lowest* impedance or the one having the *highest* impedance?

7. Suppose you are to connect 5 loudspeakers through line-matching transformers to a 250-ohm line, and each loudspeaker is to get the same power. What must the primary impedances of the transformers be?

8. Suppose you have to match 500 ohms to 8 ohms and have available a transformer designed to match 250 ohms to 4 ohms and another designed to match 1000 ohms to 16 ohms. Which of these transformers would give the better frequency response?

9. How are low frequencies kept out of the tweeter in a dual loudspeaker?

10. What is the purpose of the condenser-resistor unit connected across the output of a magnetic phono pickup?