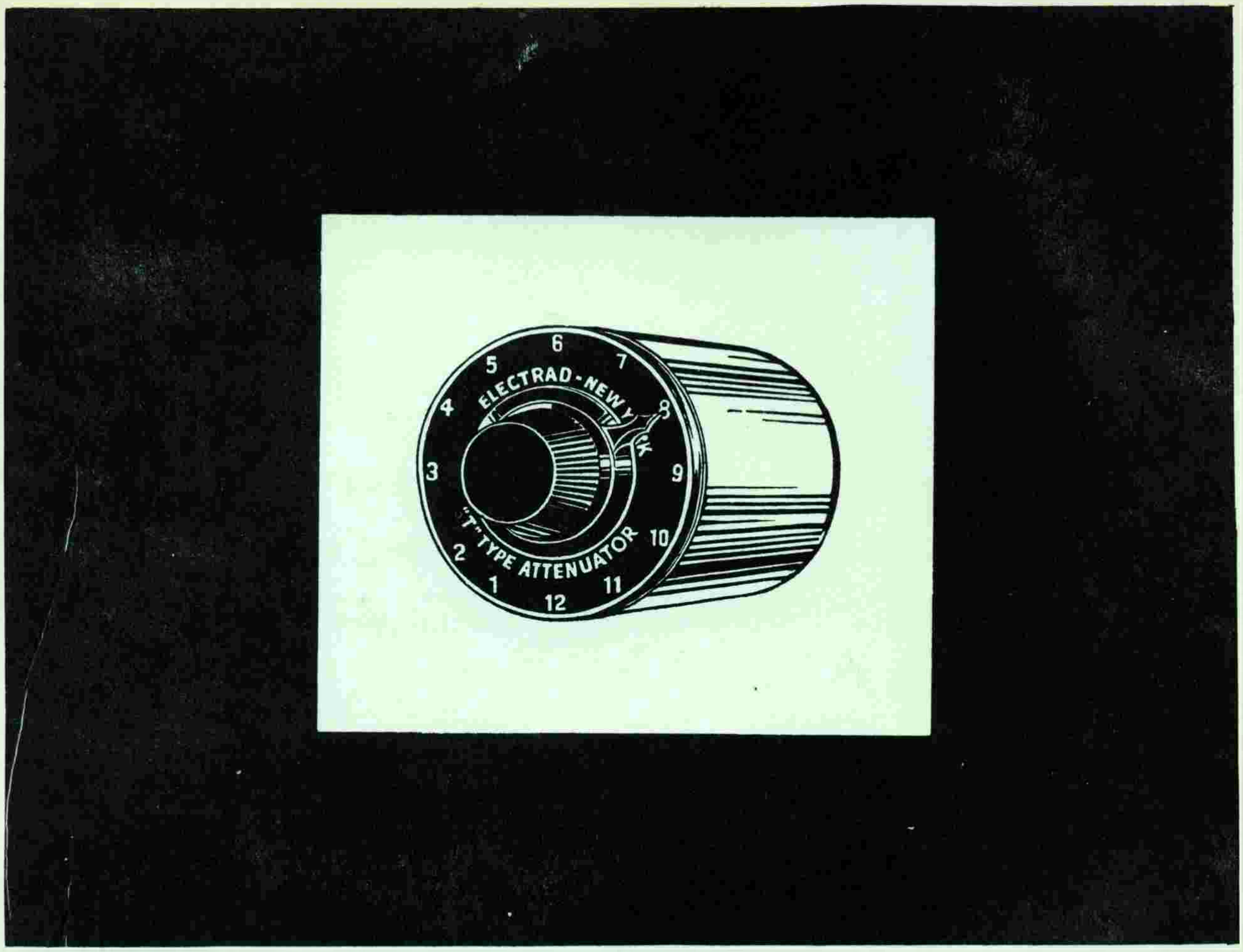

LESSON 59 R

IMPEDANCE MATCHING VOLUME CONTROLS AND ATTENUATORS

RADIO-TELEVISION TRAINING SCHOOL, INC.
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IMPEDANCE MATCHING, VOLUME CONTROLS AND ATTENUATORS

In the operation of public address systems the signal energy is transferred through a series of coupled circuits, and for highest operating efficiency all energy losses at the transfer or coupling points must be kept at a minimum, for any wasted energy has to be made up by additional amplification. This requires that the electrical characteristics of the generating circuit or signal source must be similar to those of the accepting circuit or load. In other words, the impedance of the two coupled circuits must match.

For example, if the signals from a phonograph pick-up are to be amplified and sent out through a loud speaker, the electrical impedance (combined resistance and reactance) of the pick-up coils must match the impedance of the input circuit of the amplifier in order that maximum signal transfer will take place. Similarly, the impedance of the output circuit of the amplifier must match the impedance of the speaker windings.

IMPEDANCE MATCHING TRANSFORMERS

Since it is not always possible to design the various units and circuits in a P.A. system to have similar impedance values, special coupling transformers have been developed that will transfer the signal from one circuit to the other and at the same time match the impedances so that optimum performance results. These are known as impedance matching transformers. They cause the load impedance to appear to be of the same value as that of the source, and the source impedance to appear to be of the same value as that of the load. In other words, they match the impedance of the two coupled circuits so that maximum signal transfer takes place.

This impedance matching is accomplished by designing the transformer so that the ratio between the number of turns in the primary and secondary windings corresponds to the ratio between the source and load impedance values. If the load impedance is less than that of the source, the transformer will have a step-down ratio; while if the load impedance is greater than that of the source, it will have a step-up ratio. It can be proven that this turns ratio is numerically equal to the square root of the ratio of the source impedance to the load impedance. Expressed in formula form this is:

$$\text{Turns Ratio} = \frac{Np}{Ns} = \sqrt{\frac{Zp}{Zs}}$$

In simple words this formula states that the turns ratio between the primary and secondary of an impedance matching transformer is equal to the square root of the number (quotient) obtained by dividing the source or primary impedance by the load or secondary impedance.

The method of figuring the actual design specifications of a transformer is beyond the scope of this text. Impedance matching transformers for coupling all commonly used types of units in P.A. systems are made by the various transformer manufacturers; and since the quality of the output of a P.A. system depends upon the design and construction of the component parts, it is not advisable to attempt designing or building such transformers at home, for the performance will fall far short of a transformer designed by a transformer expert in a factory or laboratory specially equipped for such construction work.

In the case of a pure resistance source or load the impedance equals this resistance and the ohmic value is the same at all frequencies. With transformer windings, however, the impedance consists of the resistance and reactance of the windings; and since the reactance will vary with the frequency, the impedance also will change, being greater at the high frequencies and less at the low frequencies. When impedance matching transformers are selected for such cases, the primary impedance must always be chosen to match the source impedance at the lowest frequency passed. At higher frequencies the impedance will increase, of course, but this will result only in improved performance.

APPLICATIONS OF IMPEDANCE MATCHING TRANSFORMERS

Impedance matching transformers are employed in public address systems wherever units or circuits of different impedance values must be coupled so that signal energy can be efficiently transferred from one to the other. Their purpose, it was explained, is to cause the impedance values of the coupled circuits to appear to be alike. They are not always referred to as impedance matching transformers, but are generally rather named after the part of the circuit in which they are used or the kind of service they are performing.

For example, with a phonograph pick-up an input transformer is used to couple the pick-up to the input circuit or connecting line. The kind of input transformer needed will depend upon whether the pick-up is of low or high impedance, whether it feeds directly into the amplifier, or if it feeds into a connecting line what the operating impedance of the line is. Special input transformers are available for each purpose. Similarly with a microphone ——a "mike to line" or "mike to grid" transformer is needed depending upon the kind of microphone used, whether it feeds directly into the amplifier, or if it feeds into a line what the operating resistance of the line is.

With a small pre-amplifier a "tube to line" transformer is needed to couple the plate of the tube to the connecting line, the transformer depending upon the kind of tube used of course. "Line to line" transformers serve to connect a standard resistance source to a connecting line of standard characteristics, while the "line to grid" transformers are used to couple a feeding line to the grid or grids of the input tubes of the amplifier. Then there are various types of intermediate coupling transformers used in cascade amplifiers to couple the plate circuit of one tube or of two tubes in push-pull to the grid circuit of the following tube or tubes. The transformers needed will also depend on the kind of amplifier system used, etc. In the amplifier output system suitable impedance matching transformers are used to couple the plate circuits of the tubes to the speaker or to the distributing lines and from these lines to the speaker voice coils.

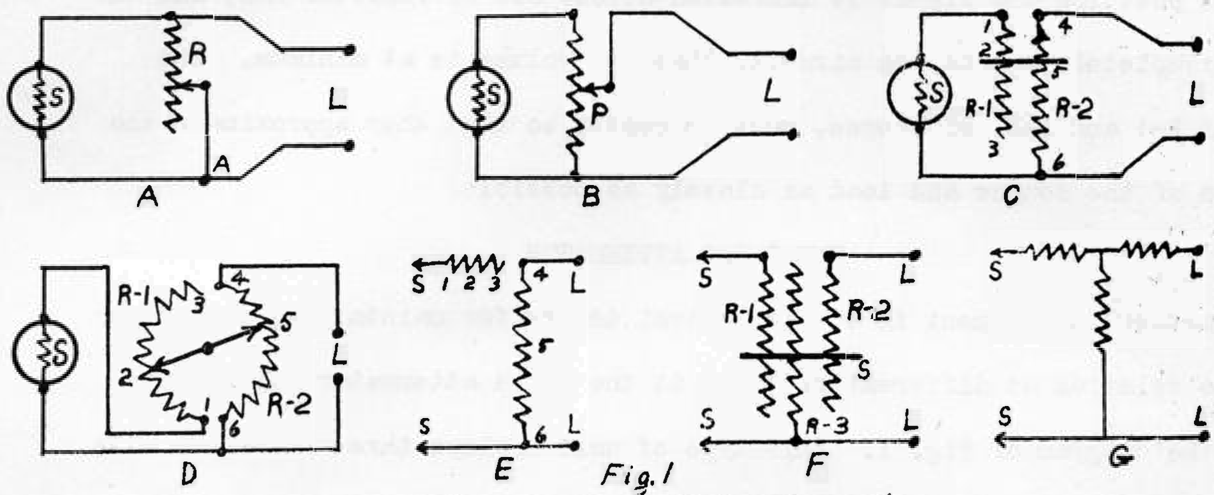
INPUT VOLUME CONTROLS

Input volume controls, sometimes also called attenuators, serve to regulate the signal voltage at the input to the amplifier so that the proper volume is obtained from the loud speaker system. Signals from different sound sources, such as pickups, microphones, or detector tubes vary greatly in strength, and must be brought down to the proper level in order to produce the desired output volume. In some installations these input controls are most conveniently located at the sound source and in others directly at the input to the amplifier, depending upon the nature of the installation.

An important point to observe in the selection of such a volume control unit is that the terminal impedances be properly matched, for if the impedance relations are upset, optimum signal transfer will not take place and the operating efficiency will be greatly impaired. In other words, one side of the volume control must match the source in impedance and the other side the load.

The simplest form of input volume control, though also the least satisfactory, is a rheostat or variable resistance across the lines connecting the sound source to the load, as is illustrated at A in Fig. 1. Such a rheostat serves merely to shunt out some of the signal energy, and for every setting of the rheostat the impedance values are changed and frequency distortion sets in. The general effect is to reduce the higher frequencies more than the lower, in other words, the lower tones appear accentuated.

A somewhat better method is a potentiometer connected across the source as shown at B with the sliding contact going to the load. This gives a constant impedance across the source, but the input impedance to the load changes and therefore also introduces some distortion. This system is used extensively with phonograph pickups.



Circuit connections of various types of input volume controls.

THE L-PAD ATTENUATOR

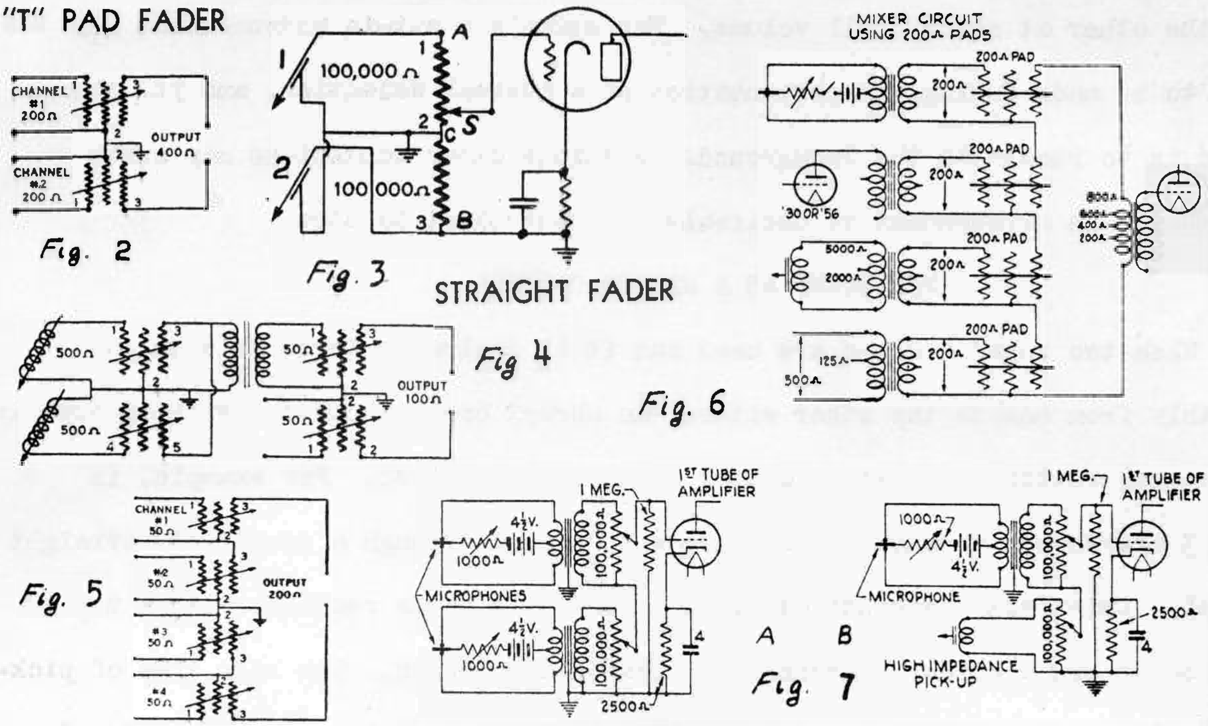
The best arrangement of the simpler input volume control systems is the use of a dual resistor unit as shown at C. Here two similar resistors are used, R-1 and R-2, with a slider that makes contact with both. The same plan is illustrated at D, except that the resistors are shown differently. Volume is increased by moving the slider up or in a counter clockwise direction, and decreased by moving it downward or in a clockwise direction. For any position of the slider the combined value of section 1 to 2 of R-1 and sections 5 to 6 of R-2 always remain the same, which means that a constant impedance is always connected across the source. Similarly, the total resistor R-2 is always connected across the load, and therefore, the load impedance is always constant. This type of control is commonly referred to as an L-pad attenuator, for if drawn as illustrated at E the resistors are at right angles and form an inverted L.

When the slider is at the top (in the extreme counter clockwise position), the signal voltage is impressed across all of resistor R-2, and the volume is at maximum. As the slider is moved downward or clockwise, the signal voltage is impressed across section 1 to 2 of R-1 and section 5 to 6 of R-2, and only part of the signal voltage is impressed into the load. At the bottom or extreme clockwise position the signal is impressed across all of resistor R-1, and the load is completely out of the circuit, that is, volume is at minimum. The values of R-1 and R-2, of course, must be chosen so that they approximate the impedance of the source and load as closely as possible.

THE T-PAD ATTENUATOR

A further improvement in volume control design for maintaining the proper impedance relation at different settings is the T-pad attenuator illustrated at F in the diagram of Fig. 1. This type of unit employs three resistors with sliders operating on all three from a common shaft. An equivalent arrangement showing how the respective resistors fit in each circuit is shown at G. The values of R-1 and R-3 are chosen so that they will match the impedance of the source, and these values in turn will determine the impedance of the load, as will be observed a little later.

Volume is controlled by shifting the slider S up or down. With the slider in the uppermost position, Resistor R-1 is cut out and the entire signal voltage is built up across R-3. But since all of R-3 is also in the load circuit, R-2 being completely out, full signal voltage is transferred from the source to the load and volume is at maximum. As the slider is moved downward, part of R-1 is cut into the circuit and part of R-3 is cut out, the result being that less signal voltage is built up across R-3 and imparted to the load circuit and the volume is reduced. In the lowermost position all of R-3 is cut out, no signal voltage is transferred to the load, and the volume is at minimum.



Circuit connections of various types of input faders and mixing controls

When two or more sound sources are used as separate channels feeding into a common input line, a number of T-pad attenuators are generally used connected in series. For example, in Fig. 2 two 200-ohm channels are employed. Two 200-ohm attenuators are, therefore used, separately operated and with the input of one attenuator connected across channel No. 1 and the input of the other attenuator connected across channel No. 2. As far as the input sides are concerned, each attenuator is independent of the other, and for any setting the net impedance across each channel is always constant. The output sides of the two attenuators are connected in series, and therefore, the output impedance, as well as the impedance of the line to be fed, is 400 ohms. For any setting of the two attenuators the combined output impedance always remains constant at 400 ohms.

A further study of the diagram will show that either channel can be

operated at maximum or partial volume and independent of the other. Also, the two channels can be operated simultaneously, one at low volume in the background and the other at nearly full volume. For example a cut-in announcement may want to be made during the presentation of a musical selection, and yet the music is to remain in the background. Numerous other conditions may arise where such an arrangement is desirable and convenient to have.

THE FADER AS A MIXING CONTROL

When two sound sources are used and it is desirable to be able to pass smoothly from one to the other without an abrupt break as occurs with an ordinary throw-over switch, a fader or mixing control is employed. For example, in Fig. 3 are shown two phonograph pickups connected through a so-called "straight fader". This fader consists merely of a definite value resistor with a tap at the center and a slider S moving over its entire length. The high side of pickup No. 1 is connected to one end terminal A of the resistor and pickup No. 2 to the other terminal B. The low sides of the two pickups are connected together and also to the center tap C. By rotating the slider either pickup can be cut in at any desired volume, and the fader can also be made to serve as a volume control.

With the slider turned clear around to terminal A-full signal voltage from pickup No. 1 is impressed across the primary P of the coupling transformer, and volume is at maximum. Signal flow is from the pickup to terminal A, through the slider and transformer primary to point D where it re-enters the pickup. No signal from pickup No. 2 can reach the transformer. As the slider is moved toward C, less and less of the signal is impressed across the transformer, and the volume is reduced. When the slider reaches point C, no signal voltage at all reaches the transformer and both pickups are silent.

When the slider is moved beyond C, pickup No. 1 is entirely cut out and part of the signal from Pickup No. 2 is impressed across the transformer. As the slider is moved further, the volume from pickup No. 2 increases, and when it reaches point B the full signal is impressed across the transformer primary and the volume is again at maximum. Operation can thus be shifted smoothly and without any abrupt break from one pickup to the other, and either pickup can be operated at any desired volume. When more than two sound sources are used, it is customary practice to use T-pad faders, for with these better matched impedance relations can be maintained.

THE T-PAD FADER

The T-pad fader has the advantage that with it constant impedance relations can be maintained in both the source and load circuits. For example, in Fig. 4 are shown two pickups of a dual turntable installation, each feeding through a T-pad fader into the primary of a line to line coupling transformer having a 500-ohm primary impedance and 50-ohm secondary impedance. By turning the control knob in a clockwise or counter-clockwise direction, either pickup can be operated at any desired volume.

If the sliders (all operated from a single shaft, of course) are moved clear up, clockwise, the upper pickup is in operation at maximum volume, and the lower pickup is completely cut out. All of resistor 2 is cut into both circuits, and a 500 ohm impedance exists across the source and load. As the slider is moved downward, counter-clockwise, part of resistor 2 is cut out, but an equal portion of 1and 3 is cut into the circuit, so that the total impedance across the source and load always remains constant. In the middle or zero position, half way down each pickup is cut out of the load circuit and both turn tables are silent. As the sliders are moved further downward, counter-clockwise, the lower pickup is gradually cut in, and in the extreme position it operates at full volume. And for each setting the total source and load impedance are always the same.

The secondary of the coupling transformer in Fig. 4 in turn is one of two 50-ohm channels coupled through a series mixer to a 100-ohm impedance line. Such an arrangement would be used for making cut-in announcements between records, etc. Each 50-ohm fader, of course, is operated from a separate dial and shaft. Either fader can be set in any position. For maximum volume from a turntable pickup both faders are moved clear up. This renders the lower 50-ohm channel silent. If no announcements are to be made while operation is being shifted from one pickup to the other, this setting is not changed. However, if any announcement is to be made between records, both sections of the series mixer are moved down. This permits maximum volume for the announcement. If an announcement is to be made during the playing of a record, the upper section is moved down only part ways but the lower section clear down. This leaves some music in the background, and permits the announcement to be made at normal volume.

The entire installation thus includes three controls: the first is the T-pad fader for quietly shifting from one turntable to the other (two groups of three sliders operated from a common shaft), the second is the T-shaped attenuator for regulating the input from the turntable line, and the third is the T-pad attenuator for regulating the input from the other line (microphone channel, for example). The second and third controls are electrically connected in series but are independently operated mechanically.

In Fig. 5 is shown another arrangement of a series mixer. Here there are four 50-ohm channels each coupled through a T-pad attenuator to a single output line. Since the output sides of the four attenuators are connected in series, the impedance of the output circuit would be 4 x 50 or 200 ohms. If this output line is later on connected to some form of coupling transformer, the primary of this transformer must have a 200-ohm impedance rating so that proper circuit matching will always exist.

Another series mixer circuit system is illustrated in Fig. 6. Here are shown four familiar types of input channels. The first is from a 2-button microphone connected to a suitable microphone input transformer having a 200-ohm impedance secondary. The second channel is from the detector of a radio tuner also coupled through a suitable input transformer having a secondary impedance of 200 ohms. The third channel is from a high-impedance phonograph pickup similarly coupled through a special transformer, and the fourth channel is a 500-ohm line feeding probably from some distant point. The coupling transformer, in each case has a 200-ohm impedance secondary and all four input circuits are controlled by a T-pad attenuator of 200-ohms. The load sides of these attenuators are connected in series, and the primary impedance of the main input transformer must have a value of 4 x 200 or 800 ohms.

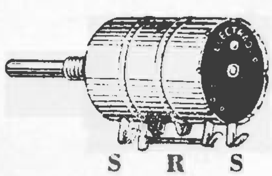
The particular circuit arrangements used in any case will, of course, depend upon the requirements of the installation. The various types of coupling transformers made by the different manufacturers generally have tapped windings so that they can be adapted to circuits having different impedance values as determined by the number of input channels employed, etc. In fig. 7 are shown two other input systems as recommended in the Thordarson Sound Manual. A is for mixing two microphones that are to be operated through a single amplifier. Each microphone can be faded in or out independently of the other. B shows a commonly used input combination consisting of a microphone and a magnetic pickup. Either input channel can be controlled independently of the other. A crystal pickup can be substituted for the high impedance type illustrated without requiring any circuit alterations.

FIXED T-TYPE ATTENUATORS

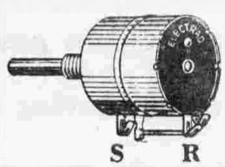
Fixed attenuation pads consist merely of a network of three fixed resistors arranged in T-type fashion, and are used in input circuits that are of too high level for convenient or satisfactory volume control. Such fixed attenuators are connected between the sound source and the adjustable input fader, and reduce the signal source sufficiently so that maximum desirable volume from the speaker is obtained without having to set the fader in too low a position where faulty operation is likely to result.

Fixed attenuators are also used when two sound sources of widely different levels are employed. For example, if a microphone and a phonograph pick-up are connected to the input of an amplifier, a fixed attenuator would be used in the pickup channel, for its signal voltage output is far above that of the microphone. The fixed attenuator will then bring the two sound input levels to nearly the same value and a more desirable relation is maintained between the settings of the volume controls in the two channels. These fixed attenuators are available in standard form in 200 and 500-ohm impedance values, and with attenuation constants of 5, 10 and 15.

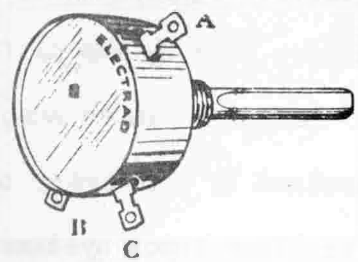
ELECTRAD T-PADS AND LINE-ATTENUATORS



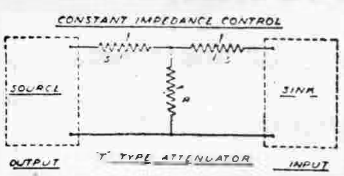
Electrad Royalty T Pad Attenuator

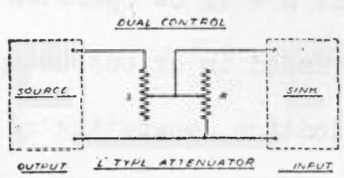


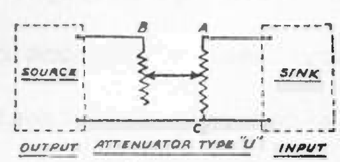
Electrad Royalty L Pad Attenuator



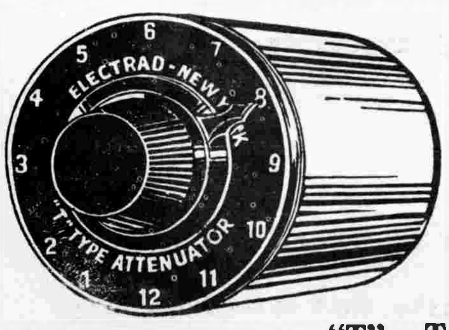
Attenuator Type U

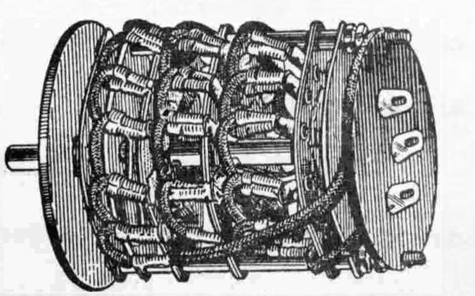


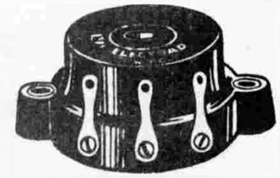




Three types of attenuator controls made by Electrad, Inc., New York City.







FIXED "T"

"T" TYPE ATTENUATOR CONTROLS

T-type attenuator of the tap-switch variety with wire wound resistors, made by Electrad, Inc., New York City. At the right is shown a fixed T-type attenuator.