Loudness Control for Reproducing Systems

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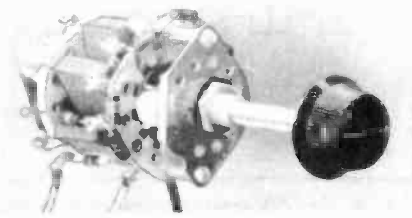
By using the device described, it is possible to maintain a close tonal balance over a wide variation in output level.



Complete loudness control unit.

A NUMBER of different methods have been utilized to control the output of reproducing systems in such a manner that the tonal balance is maintained reasonably constant at all intensity levels. These controls are essentially variable equalizers which modify the gain-frequency characteristic of the system as the intensity is changed; the desired equalization being specified by the intensity vs. loudness characteristics of the human ear. An ordinary resistive potentiometer is actually a simple intensity control, while a properly equalized intensity control might be termed a loudness control. To maintain constant tonal balance as the intensity is changed, the intensity at low frequencies must be changed less than that at high frequencies. The consequence of changing the intensity equally at all frequencies has been experienced by anyone who has noted the apparent lack of bass in the average radio at low volume settings.

A common type of loudness control employs a tapped potentiometer, with a capacitor and resistor in series between the tapped point and ground. This rather elementary structure is a large step in the right direction, and is attractive because of its simplicity. This very simplicity, however, renders it capable of yielding only a moderate approximation to the ideal. The loudness control to be described is an elaboration of the tapped potentiometer, and was designed for those applications in which a considerably closer approximation to the ideal is desired, even though some extra cost is involved.

Fletcher-Munson Curves

The basis for design of a loudness control is the set of curves shown in *Fig. 1*. These are the well-known data of Fletcher and Munson, and are the averaged results of measurements taken with a large number of individuals. Each curve represents a particular loudness, measured in decibels from a reference level; the ordinates of the curve

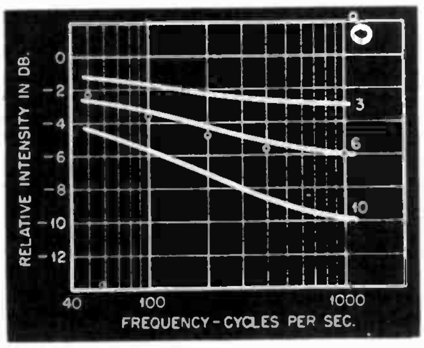


Fig. 2. Curves showing the frequency characteristic of each network section at various intensity levels.

show the intensity in decibels corresponding to that loudness. The departure of these curves from horizontal lines spaced 10 db apart on the intensity scale represents the need for a loudness control. It was concluded that the departure at frequencies above 1000 cps was relatively unimportant, and that only the low-frequency end would be considered. This leads to an appreciable simplification of the problem. Nevertheless, a single network to produce a large loudness change would require a rather complex array of elements because of the rapid change of intensity with frequency. A large loudness change can more readily be built up by the addition of a number of smaller changes, each having an appropriate intensity vs. frequency characteristic. This procedure is facilitated by the fact that the intensity differences between adjacent loudness curves are quite similar. An excellent approximation to the ideal may be realized by a control which inserts successive units of loss, each similar to the other, and having a loss-frequency characteristic proportional to the average intensity differences between loudness curves. These averages are presented in *Fig. 2* as gain-frequency characteristics for 10 db, 6 db, and 3 db loudness intervals. The 3 db interval was chosen for design; it has been found that this increment is sufficiently small for almost all applications where only the listener's reaction need be considered.

It is evident, now, that the loudness control may take the form of a switching device which inserts, successively, a suitable number of identical network sections somewhere in the reproducing system. These sections are designed, on an image impedance basis, to match the characteristic of the 3 db loudness change

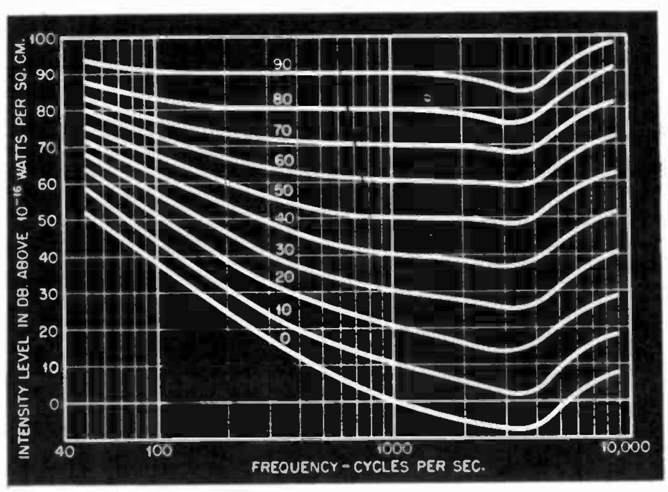


Fig. 1. Fletcher-Munson curves.

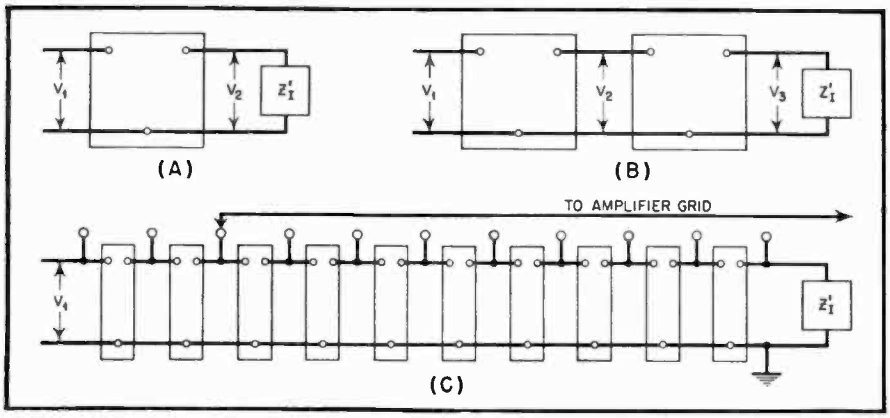


Fig. 3. In (A), representation of network. In (B), two networks in parallel, and (C), ten section in tandem.

of *Fig. 2*, and are inserted between proper terminating impedances. As many of these sections may be placed in tandem as are required to produce the desired loudness change. While this control would be satisfactory in its performance, the switching mechanism would be rather unwieldy. A somewhat simpler method of attaining the same end is available.

Transfer Constant

The transfer constant of a network designed on an image impedance basis defines the complex ratio between the voltages across the input and output terminals of the network, when the output is terminated in the proper image impedance. Thus, in *Fig. 3-A*, the voltage V_1 on the input terminals is related to the voltage V_2 on the output terminals by the equation

$$\frac{V_1}{V_2} = \epsilon^{\Theta}$$

In this equation Θ is the complex transfer constant whose real part is the loss of the network in nepers. If two identical networks are connected in tandem, as in *Fig. 3-B*, then three voltages exist, related as follows:

$$\frac{V_1}{V_2} = \epsilon^{\Theta}, \quad \frac{V_2}{V_3} = \epsilon^{\Theta}, \quad \frac{V_1}{V_3} = \epsilon^{2\Theta}$$

Thus the ratio of voltages between input and output of this two-section network is defined by 2Θ, and the loss in nepers (or in decibels) at any frequency is just twice that of one section. Consider, now, ten sections in tandem with an appropriate terminating image impedance Z'_I, as in *Fig. 3-C*. Let the input to the network be the voltage output, V_I, of a vacuum tube amplifier. Let an eleven-position switch connect the grid of a second vacuum tube amplifier to any of the eleven connection points of the chain. If each network section has a transfer constant such that its transmission is represented by the 3 db curve of *Fig. 2*, and the terminating impedance is the proper image impedance for that network section, this structure will be a loudness control with 30 db total loudness change, in 3 db steps.

Network Section

A satisfactory network section is shown in *Fig. 4-A*. The transmission of this section can be made to match the desired characteristic quite closely. It would, however, require ten series resistors, R_1, eleven shunt arm resistors, R_2, and eleven shunt arm capacitors, C_2, to construct the loudness control of *Fig. 4-B*. The number of shunt arms with their expensive capacitors may be halved by using, instead of ten 3 db sections, five 6 db sections each divided into two parts. Unfortunately, the voltage in the middle of a section is not related to that at the ends by half the transfer constant; still, the section can be divided in such a manner that exactly half the high frequency loss exists across each portion with only a minor distortion of the low-frequency loss. The exact manner in which the section is divided depends on the image impedance of the section, which in turn requires that the element values be specified. *Figure 5-A* presents the design of a section which has the calculated full-section transmission shown by the circles on *Fig. 2*. *Figure 5-B* shows the complete loudness control including the terminating network. The exact image impedance can only be obtained by an infinite number of additional sections, but the elements shown are entirely adequate. The impedance level of the control is determined when R_1 is chosen. This choice will be influenced by the effects of parasitic capacitance in the switching, the desirability of using RMA values for the elements, and the amplifier to be used as a drive for the control.

Amplifier Problems

The problem of the amplifier can be analyzed as follows: consider first that the amplifier has zero internal resistance. The removal of the first shunt arm (shown connected by dotted lines in *Fig. 5-B*) will not affect the voltage at the input to the network, nor the transmission through it. The load presented to the amplifier is now made up of the first two series resistors, which total R_1, plus the balance of the network. This remainder has an impedance which varies from a very high value at low frequencies to R_1 at frequencies above 1000 cps.

When the amplifier has a non-zero internal resistance, two alternatives are available. If R_1 may reasonably be made ten times the magnitude of the amplifier resistance, the amplifier can be considered to have effectively zero resistance, and the network may be reduced by leaving off the first shunt arm. An attempt at this procedure may lead to a value of R_1 which is too large for the parasitic capacitances that will be present in the switching. In this event, R_1 may be adjusted so that the amplifier resistance is any convenient fraction of R_1. The network is now augmented: the first shunt arm is made the same as the others, and the difference between R_1 and the amplifier resistance is inserted between the amplifier and network input. In the special case of an

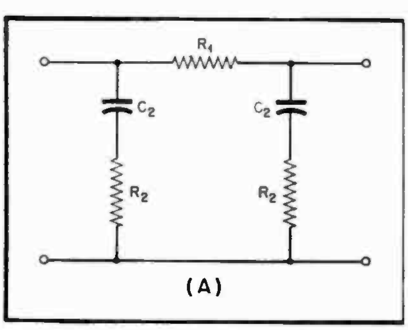


Fig. 4A. Schematic of network section.

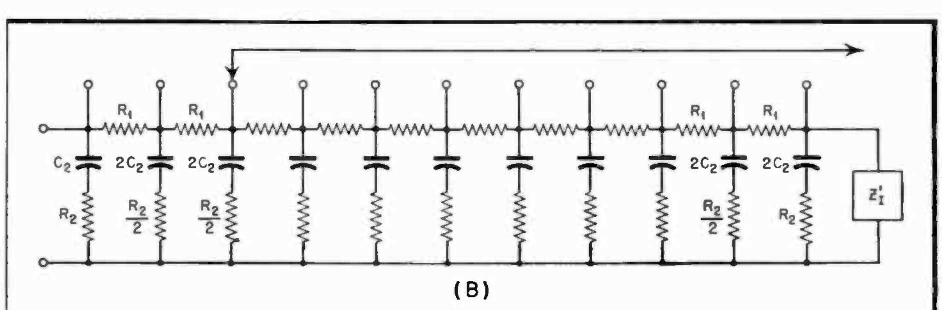
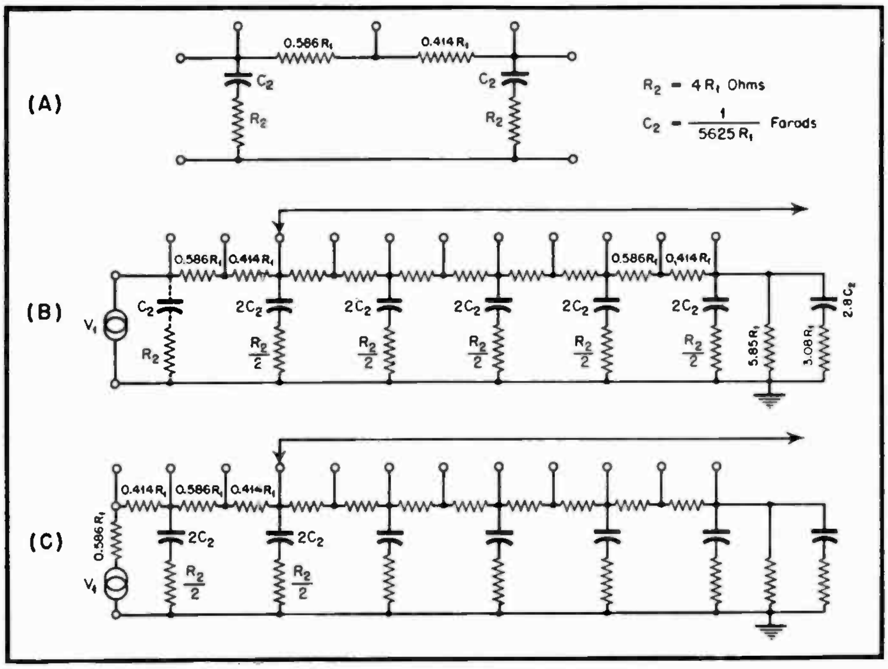


Fig. 4B. Schematic of complete loudness control using the network design of Fig. 4A.

Fig. 5A. Design of section calculated to provide the characteristic shown by circles in Fig. 2.
Fig. 5B. Complete loudness control, including terminating network.
Fig. 5C. Arrangement when the amplifier resistance is 0.586R1.



amplifier resistance equal to 0.586 R_1, the added resistance is 0.414 R_1, and an extra loudness interval is available at the amplifier terminals. This arrangement is illustrated in *Fig. 5-C*; it will be seen that one 3 db loudness interval is inside the amplifier, and so cannot be switched out. If R_1 were adjusted to equal the amplifier resistance, the added resistance is zero; in this case, there is a 6 db loudness interval inside the amplifier.

The network elements may be mounted on a two-deck wafer type switch with shorting contacts. One deck is used for switching, and has the resistors of the series arms mounted between terminals. The capacitors of the shunt arm are mounted between corresponding terminals of the two decks. Shunt arm resistors and terminating elements are then arranged on the circular area of the second deck with a ground termination in the center. The moving arm of this deck should be removed. Constructed in this fashion, the loudness control does not require an excessive mounting space.

A representative network is one which has the basic element values:

R_1	50,000 ohms
R_2	200,000 ohms
C_2	0.00355 µf

Values which approximate the individual network components are:

.586 R_1	30,000 ohms
.414 R_1	20,000 ohms
.500 R_2	100,000 ohms
2 C_2	.0068 µf
5.85 R_1	300,000 ohms
3.08 R_1	150,000 ohms
2.8 C_2	.010 µf

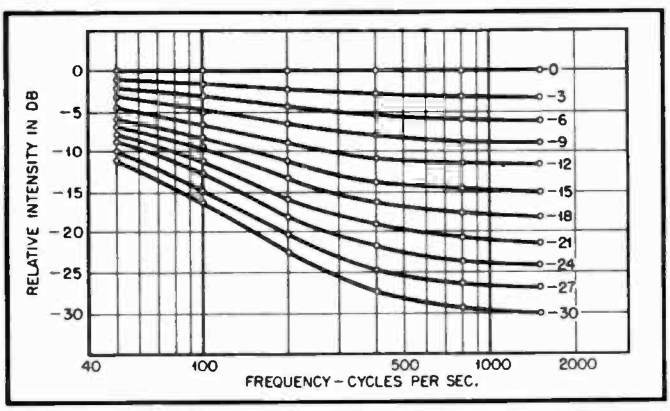


Fig. 6. Measured characteristics of loudness control constructed from data supplied in this article. It closely approximates hearing curves.

A loudness control built with these elements, and driven from a low impedance source, has the measured characteristics shown in *Fig. 6*. The several approximations made in the design, as well as the element deviations, have but small effect on the over-all performance.

It will be recognized that this control is accurate only in producing appropriate changes in intensity. To be correct on an absolute basis, each program to be reproduced should be adjusted by a resistive control elsewhere in the system so that with the loudness control at the top position, the acoustic intensity is equal to that of the original sound. This adjustment is rather impractical. Nevertheless, when the loudness control is simply used as a replacement for the ordinary resistive volume control, quite gratifying results are obtained. The most conclusive evidence of the superiority of this loudness control over flat intensity control is that a low level of intensity in the reproduction of music is as enjoyable as the higher level usually required for good tonal balance.

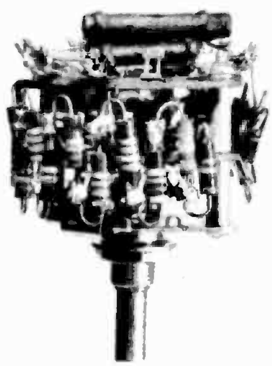
Full-Range Loudness Control

This simplified loudness control uses commercially available components and may be assembled in an hour or so.

SINCE the publication of David Bomberger's "Loudness Control for Reproducing Systems"[1] many readers have expressed considerable interest in this device, mainly with a desire for a control having a larger number of steps so as to be more suitable for use as the only volume control in a radio and phonograph installation. Such a unit was described in the series on "Residence Radio Systems"[2] but no data were given other than the schematic of the particular network employed The photograph showed an enclosed control, using the frame of an IRC attenuator.

This control is not readily available in jobbers' stores, and the construction of a loudness control on this frame is rather a difficult procedure, so the arrangement described herein was assembled in an effort to reduce the work involved, and to use

[1] See pages 37-39.
[2] See pages 106-122.



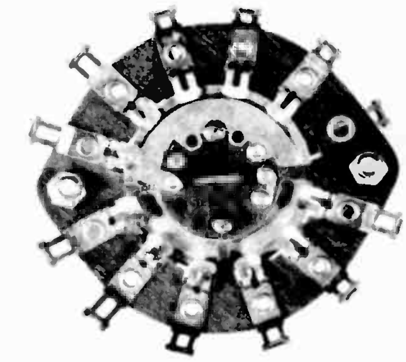


Fig. 1A (left). The fully compensated volume control assembled on a Centralab 1443 switch. Fig. 1B (right). The decompensator made from a modified "G" switch deck and mounted on a standard index assembly.

only those components which are readily available to the experimenter. The result is shown in *Fig. 1(A)*. In addition, a means is provided to reduce the low-frequency boost, thus furnishing one form of tone control for use with the system.

Actually, however, one of the principal advantages of the fully compensated control lies in a reduction of the need for conventional "tone controls." While tapped volume controls are a step in the right direction, their effect is comparatively minor, and when the volume is reduced considerably, additional low-frequency boost is required to retain the correct aural balance. It will be found in most installations that the proper use of the fully compensated loudness control will eliminate most of the need for the tone control and, as has been mentioned before, the apparent quality remains constant over a wide range of audio level.

Two precautions are necessary in using a loudness control. The most important is that all input sources *must* be adjusted to approximately the same level. This means that separate controls must be available between such sources and the selector switch, as shown in the block schematic of *Fig. 2*. The second precaution is that the loudness control be followed by a grid circuit, with no intervening controls. If these two pre-

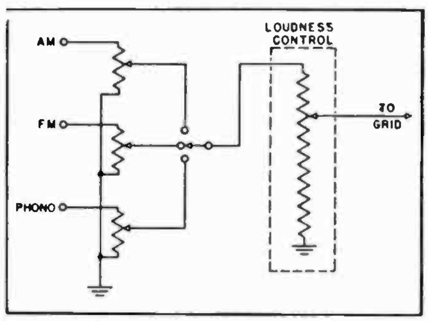


Fig. 2. Block schematic of the preferred method of connecting the loudness control into an amplifier circuit.

cautions are followed, the loudness control will be a revelation to anyone who installs it in a reproducing system.

Control Design

The fundamental features of the loudness control were discussed thoroughly in the Bomberger article, and need not be repeated here. Suffice that it is desirable to vary the frequency response simultaneously with level so as to present a signal which is adjusted to match the sensitivity of the ear to various frequencies at different loudness levels, in accordance with the well-known Fletcher-Munson curves. To make such a control useful as the main gain control of a system, its total range must be of the order of 50 db, and the average change in level between steps about 2 db. This is accomplished by the control whose schematic is shown in *Fig. 3*. The attenuation for 1000 cps at the various steps is indicated on the schematic, while the frequency response at several of the steps is indicated by the curves of *Fig. 4*. These are actual measured values, using 10 per cent resistors (except for two values which are available only in the 5 per cent range). All these resistors are of random selection, but it is seen that they approximate the requirements of the desired control.

Construction

The following material is required for the loudness control:

1 Centralab 1443 switch (23 point)
1 Centralab K-121 index assembly
1 Centralab "B" switch deck
1 0.22-meg ½-watt resistor
9 0.15-meg ½-watt resistor
1 75,000-ohm ½-watt resistor
1 62,000-ohm ½-watt resistor
1 47,000-ohm ½-watt resistor
1 39,000-ohm ½-watt resistor
5 33,000-ohm ½-watt resistor
5 27,000-ohm ½-watt resistor
5 22,000-ohm ½-watt resistor
6 .005-μf Centralab Hi-Kaps
1 .0075 μf Centralab Hi-Kap

The K-121 index assembly is listed because of the need for two long screws to mount the "B" switch deck, as well as for two ½-in. spacers. However, in most instances, the user will wish to make the second switch for reducing the low-frequency compensation—a decompensator—and this assembly is used for the purpose, with only a "G"

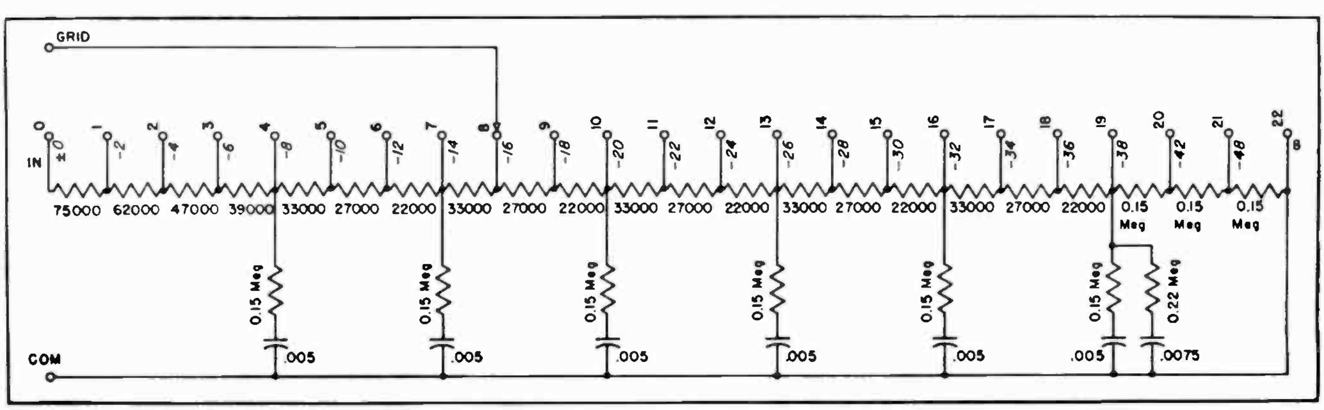


Fig. 3. Schematic of the loudness control described in the accompanying article.

switch deck being necessary in addition to the other parts listed.

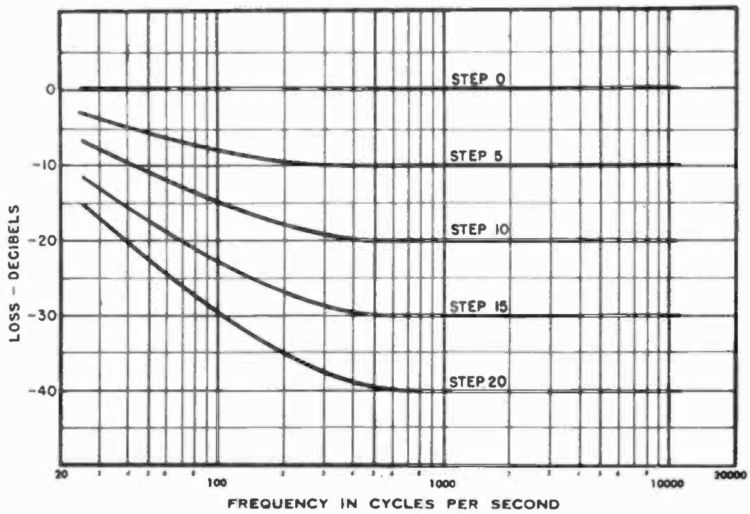
The first step in the construction of the control is to remove the rotor from the "B" switch deck. To do this, break out the thin Bakelite retaining disc on one side, and carefully work the contact arm out of the lugs so as to avoid damaging them. This deck is used only to mount the seven capacitors, with the resistors connecting to the potentiometer at the correct points.

Next, turn the 1443 control to maximum clockwise position and note the position of the contact arm. Calling this point "O" count around in a clockwise direction (viewed from the back) and make a scriber mark on points 4, 7, 10, 13, 16, and 19. Now, solder a 0.15-meg resistor to each of these marked points, with the leads through the eyelets holding the lugs, and allowing only about 1/16-in. between the resistor body and the eyelet. Attach the 0.22-meg. resistor to the lug of point 19 as closely as the others, but do not solder. At this point, the switch deck will be shown in *Fig. 5.*

The two screws holding the switch together are now removed—one at a time—and replaced with the longer ones, with a ½-in. spacer between the 1443 switch deck and the derotored "B" deck. The resistor leads should be fed through convenient lugs on the latter as it is put in place so as to avoid bending the short ends of the resistor leads, as would be necessary if the connections were made later. After the new deck is mounted and the nuts firmly tightened, the remaining 22 resistors may be mounted.

In starting the first of these connections, the wiring may appear to be a bit tricky, but a little experience will make it quite simple. Bend one lead of each resistor back 180 deg. around the tip of long-nosed pliers. The two leads may then be easily inserted through the lugs—one resistor from one side, the next from the other, and so on. When all the resistors are mounted and soldered, including the soldering of the 0.22-meg. resistor on point 19, the six capacitors are mounted on the "B" deck. Three unused lugs are employed for the ground connection, as shown in *Fig. 6*. These grounds should be strapped to the 23rd lug on the main deck, leaving sufficient wire for making the connection to the ground circuit of the amplifier. The finished control should then resemble that shown in *Fig 1(A)*. Input connections to the control are

Fig. 4. Response curves for steps 0 5 10 15 and 20.



made at points 0 and 23, and the output connections to the arm lug and point 23, the latter being the common or grounded side.

Installation

The loudness control may be installed between the existing volume control of any amplifier and the following grid, or it may be installed in place of the present control. It is necessary, however, that the overall gain be adjusted so that normal room volume is at about step 4 of the control. This allows some 8 or 10 db above normal for demonstration purposes, or for those occasions when such an increase is desirable, and some 40 db of range below the normal for late evening listening or for background use.

It will take some time to become accustomed to this control because the average listener fully expects the quality to change as the level is raised or lowered. Since no apparent change in *quality* is encountered, it may seem that the level is not changed, but after a week's use it is almost certain that the listener would not go back to a simple volume control. Even at very low levels, the quality remains constant, giving real listening enjoyment with only one control.

It will be observed that the switch has discrete steps, with the detent action. If this should prove objectionable, the detent may be removed by spreading the flat retaining spring out slightly and allowing the steel ball to drop out, thus giving a continuous smooth action. In addition, this permits the shorting-type arm to shunt two contacts, reducing the level difference between points. Personally, we prefer the step-type control, but it is purely a matter of choice.

The Decompensator

On speech, particularly male, the loudness control may appear to be too bassy, and some means for reducing the compensation may be desired. The logical method for this is to short out the compensating capac-

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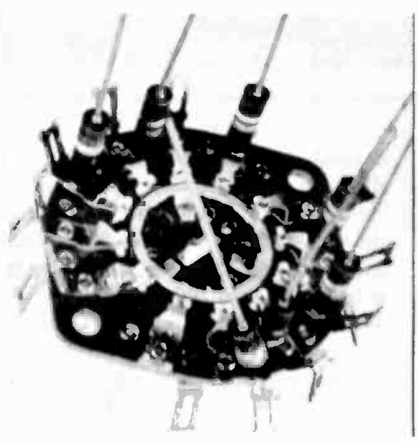

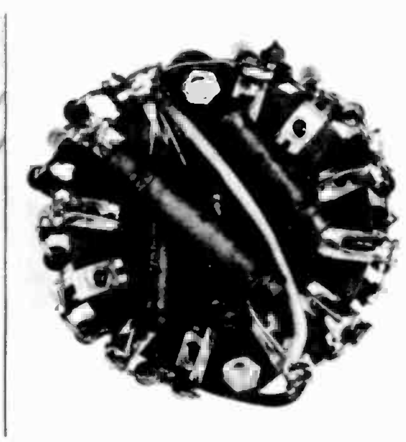

Fig. 5 (left). First step in connecting the resistors to the 1443 switch deck. The 0.15-meg shunt resistors are mounted first, as shown. Fig. 6 (right). Method of mounting the compensating capacitors on the de-rotored "B" switch deck.

LOUDNESS CONTROL

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itors progressively from the high end down. This may be accomplished with the "G" switch deck, with the shorting arm cut in half, and with the normal arm removed. To make the ground connection, it is also necessary to short the grounding ring to the arm contact on the bottom of the rotor. This may be done by adding another rivet between the two rings. The modified switch is shown in *Fig. 1(B)*. In this photo, the rotor is shown in the maximum clockwise position, corresponding to normal compensated operation. The six lugs opposite the rotor ring are connected to the junctions of the six 0.15-meg resistors and the .005-μf capacitors, so that as the decompensator is turned counter-clockwise the capacitors are shorted to ground. In the position shown, all six contacts are open; in the second position the capacitor associated with point 4 is shorted; in the third position, the capacitors for points 4 and 7 are shorted; in the fourth those for points 4, 7, and 10 are shorted, and so on. The stop is set to provide a total of seven positions, the .0075-μf capacitor remaining in the circuit at all times, since the switch will accommodate only six shorting positions.

With the construction of the loudness control reduced to such a simple procedure, it is expected that many experimenters will find it worth the hour or so of work necessary to try it out because of the enjoyment certain to be obtained. The writer firmly believes that no listener will ever give up the loudness control after using it for a few weeks—it's that good.