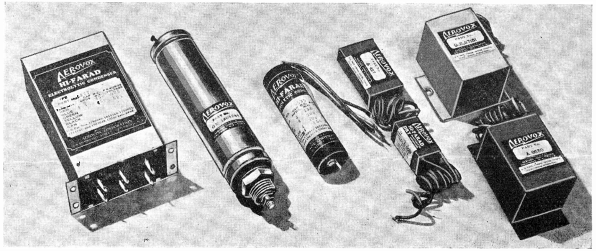
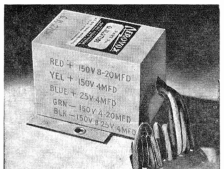


Why Exact-Duplicate Replacements?



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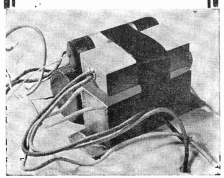

ALMOST daily, AEROVOX receives samples of condensers to be precisely replaced in sets that must last a while longer. These samples come from jobbers, dealers, servicemen, representatives. Exact duplicates are being requested.

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Volume Expansion

By the Engineering Department, Aerovox Corporation

THE purpose of high-fidelity broadcasting and phonograph reproduction is to bring the listener a rendition of speech or music which resembles the original as much as possible. Much of the research in recent years has been concentrated on the design of radio apparatus with the least possible frequency distortion and a minimum of wave-form distortion. In this respect good progress has been made and set designers can now provide receivers with as large a frequency range as is consistent with present-day frequency allocations.

Until recently, no attention was paid to the reproduction of the complete volume range. Yet, from the standpoint of musicians and music lovers, altering the volume range during the transmission means distortion and if we are going to have real high-fidelity, the original dynamic range must be reproduced. For various reasons it is necessary to compress the range at the radio station or the recording studio; therefore, in order to restore the music to its original it is necessary to use a "volume expander." Such a device amplifies loud signals more than weak signals, or, works as an automatic volume control "reversed."

Before going into details regarding automatic volume expansion it may be well to consider where the above viewpoints may lead us. It is very well to say that the reproduced music should resemble the original in everything including volume. This would mean that a brass band is going to sound like a brass brand and a 100 piece symphony orchestra playing the 1812 overture will sound like just that. Who wants a brass band in his living room, and who wants it in the living room of his neighbor?

In spite of this possible complication the inclusion of the volume expander is desirable. Many a listener feels disappointed when he knows that the orchestra is leading up to a climax but due to the doings of the control operator the effect is lost—nor is the control operator to blame. To compensate for the disappointment, such a listener will often run his receiver at a higher volume level causing much more disturbance and annoyance than a similar receiver with volume expansion which would go to full volume only occasionally. In the second place, the user need not necessarily run his receiver at full expansion and full volume. He can retain the original range and drop the average volume still retaining a much more realistic reproduction than he could without expansion.

REQUISITES OF A VOLUME EXPANDER

In a perfect system of musical reproduction, the compression on the transmitting end and the expansion at the receiving end should be perfectly matched. The only possible way of doing this is by means of an automatic compressor which is designed to match the expander. Such a system has been in use in transatlantic telephone communication but it appears far from probable that it will be introduced in broadcasting in the near future. All compression at the transmitting end is being done by hand and must of necessity be full of irregularities which cannot be followed by an automatic expander. Consequently, a perfect restoration of the original volume range is not possible with the present broadcasting set-up. In phonograph reproduction it can be approached somewhat nearer.

How much expansion is

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needed? The maximum volume range of a large orchestra is about 70 db. Authorities differ on the maximum range transmitted by broadcast stations but the concensus of opinion is

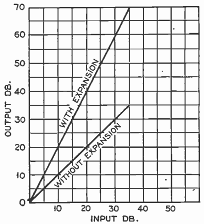

Fig. 1

that for any station connected to a chain the range could not be more than 35 db. The limitation is in the telephone cable—not in the transmitter. Phonograph recording is even more limited in its range; however, both fields are constantly being improved. From the above data one may conclude that the expander must be capable of adding about 35 db. to the volume range. The amount of expansion must of course be adjustable.

What law should the expander follow? This subect has been ably discussed by Ballantine in the May 1934 issue of the Proceedings of the I.R.E. When a compressor and expander are designed together, it does not make any difference which law the devices follow as long as the two are complementary. One of the most logical laws to follow is the exponential law (linear in db.) which can also be obtained in practice. The effect of such

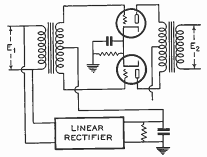

Fig. 2

an expansion is illustrated in Figure 1. In this particular case the expander doubles the original volume range, or the output voltage E_2 is proportional to the square of the input voltage. Where there is no compressor at the transmitting end it is still desirable to follow an exponential expansion law because it agrees with the type of attenuators employed by the control operator.

Should the expansion be dependent on the power level? It would be convenient, says Ballantine, to have the expansion independent of the volume level. In other words, if the signal received is weak and needs more amplification in the audio amplifier it would be expanded at the same rate in such an expander. The rate of expansion in that case depends on the circuit and cannot be adjusted. We shall come back to this subject later; most present-day arrangement have the rate of expansion dependent on the average power level entering the expansion amplifier and can therefore be made adjustable.

Summarizing, a volume expander must satisfy the following requirements:

1. It must complement the compression system as much as possible.
2. It should add the minimum of distortion to the reproduction.
3. Adjustment of average level and expansion should be provided.
4. The circuit should be as economical, foolproof and simple to operate, as possible.

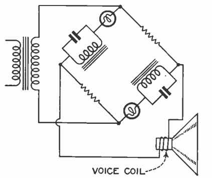

Fig. 3

PRACTICAL SYSTEMS IN USE

Figure 2 shows a circuit which has been in use on the transatlantic telephone circuit (See Electrical Engineering, June 1934, "The Compandor" by Mathes and Wright). As will be seen, the signal is fed into a push-pull circuit, the gain of which is controlled by the grid voltage of the tubes. At the same time, the signal is fed into a second channel containing a linear rectifier. The rectified voltage, after filtering is applied to the grids in such a direction as to increase the gain when the signal level increases. Ballantine in the May issue of the Proc. I.R.E. shows a variation of this circuit where the ideal condition is reached, i.e. the gain of the tubes is directly proportional to the applied grid bias. In this case the output voltage E_2 is equal to kE_1^2, where k is a factor depending on the amplification in the tubes and the setting of the volume controls. It is in this case that the degree of expansion is not dependent on the setting of the control. It is the exponent of E_1 in the above expression which determines expansion. In most cases, however, the gain in the amplifier tubes will not be directly proportional to the grid bias and then control of expansion is possible.

In Figure 2, the input to the expander must be small because the curvature of the controlled-tube characteristic will introduce distortion. The push-pull circuit helps to limit even harmonic distortion but there may be odd harmonic distortion, the percentage depending on the input voltage.

Another system has been in use in England. Special output tubes are available which can be controlled by the grid bias. Still another way is described in the Wireless Engineer for September 1935 by T.S.E. Thomas. This system employs a control tube and several relays which connect the input of the audio amplifier to different taps of a signal-voltage divider according to the average level of the incoming signal.

Coming back to America again, a simple and inexpensive system was used in the Crosley receivers. This is shown in Figure 3. It consists of a bridge in the voice-coil circuit two of the arms consisting of incandescent lamps of a special design. The bridge is nearly balanced, making the amount of current passing through the voice

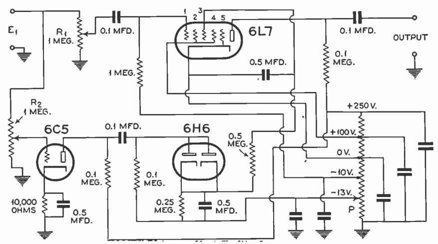

Fig. 4

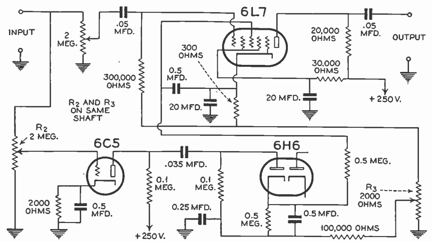

Fig. 5

coil very low. When the volume level increases, the increased current through the lamps increases their resistance, unbalancing the bridge and causing more current to flow through the voice coil. The tuned circuits in the lamp arms of the bridge are tuned to a low frequency accentuating the action on low frequencies and boosting the lows. The lamps have a special filament which is slower in action than ordinary bulbs. The system appears simple and economical but it wastes power necessitating a larger amplifier than normal. Furthermore, there are large changes in the load on the output tubes, increasing distortion.

The system of Figure 2 would be more popular if it could be done with resistance-coupled stages and if the distortion could be kept down. One might think that ordinary variable-mu pentodes could be employed but when drawing the circuit it will be found that applying the control voltage to the same grid as the signal voltage results in the two being in series and causes coupling between the two amplifiers. Filters will not take care of the situation because it would make the time constant too large. It is essential to apply the control voltage to a different tube element. In the type 58 or 6C6 tube this might be done by employing the suppressor grid. However, there seem to be no examples of its use.

The 6L7 tube appeared to be the answer to the problem and the most successful systems now use this tube. The 6L7 is a hexode containing two control grids, the inner one being of the variable-mu type. The signal voltage can be applied to the inner grid and the control voltage to grid number three.

The original circuit, recommended by RCA is shown in Figure 4. The signal is again applied to the 6L7 and the 6C5 tube at the same time, both channels being supplied by a volume control. The output of the 6C5 is applied to the rectifier tube, a 6H6, which is so connected that the rectified voltage being applied to grid number three is positive. The initial bias on the inner grid is 10 volts while the initial bias on the third grid is even more. Under these conditions the tube is working at very low gain. When a strong signal comes in, the voltage on the third grid becomes less negative, increasing the gain of the tube.

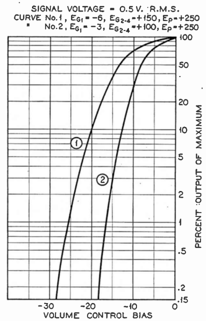

Fig. 6

In order to prevent coupling between the amplifiers, 6C5 and 6L7, the rectifier output is filtered. Here we encounter the difficulty of having to filter the low frequencies and yet keep the time constant low. The best compromise in time constant values has been found to be ¼ second. A shorter time constant results in annoying up-and-down variation for every note played.

The degree of expansion is controlled by the volume control R2. The expansion depends on the voltage applied to the grid of the 6C5 and this is dependent on the volume control setting as well as on the voltage E_1.

In order to minimize harmonic distortion, the peak signal applied to the first grid of the 6L7 should not exceed one volt. This means that there must be at least another stage between the 6L7 and the output tube. Since individual tubes differ it has been found necessary to provide the adjustment of the initial bias on grid three by means of potentiometer P. The plate current should be .15 ma. with no signal input.

The above circuit suffered from certain inconveniences. When switching over from an expansion, the reference level is the softest sound. In other words, the expander only works upwards and the average level increases with the expansion control setting which requires an adjustment of both R1 and R2 when changing the degree of expansion.

A new circuit which adds less distortion and is easier to operate besides being less influenced by tube variations is shown in Figure 5. This circuit was also developed by R.C.A. engineers and was demonstrated at a lecture held by Mr. Sinnett before the Radio Club of America.

The bias of grid number three is adjusted at the same time with the expansion control keeping the average level approximately the same.

PRACTICAL HINTS

Those who wish to make their own expander may find the following suggestions useful.

In order to add 30 db. to the volume range it is necessary to vary the gain of the 6L7 tube in a ratio of 32 to 1. The curve of figure 6, shows the relative gain for the 6L7 tube when used as a radio frequency amplifier. Although not strictly applicable to resistance-coupled amplifiers — because the plate voltage varies when the plate current changes—the curve gives some useful data. The curve also shows how many volts it takes on grid number three to obtain this variation. The signal voltage applied to the first grid of the 6L7 should be kept small.

Condensers employed in the control circuit be of good quality, having high leakage resistance. Being used in high resistance circuits a little leakage may make the circuit inoperative. In this respect the conditions are similar to a.v.c. circuits. Bypass condensers across the voltage divider sections of Figure 4 should be of the high capacity electrolytic type in order to prevent undesirable coupling.

Those who wish to make an expander unit to be added to an existing receiver will find additional complications. The desirability of placing the expander at a point in the receiver where signal voltages are low causes any pickup of hum to be greatly amplified while instability may also be introduced. It is recommended that the expander unit be built as an integral part of an amplifier or receiver.