High-Fidelity Volume Expander

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Presenting for the first time a volume expander in which all forms of distortion are reduced to negligible proportions.

ALMOST ALL devoted listeners to recorded music, after they have gotten their playback systems to the point where the sound is pleasant to hear, feel that the loudness range on records is much too limited. To the listener who is concerned primarily with the aesthetics of the matter, the compromise can be made in either of two ways: the volume level can be set high enough to achieve satisfactory fortissimos—at which setting the pianissimos are too loud and too noisy; or the volume can be adjusted for maximum tolerable surface noise—in which case frustration sets in when the crescendos level off at a feeble mezzo-forte.

A considerable improvement in loudness range can be made by the intelligent use of a well-designed volume expander. The great difficulty is, of course, in the design of the expander itself, which is far from being a simple job. There have been many circuits offered in the past, all of which have at least one of the following defects:

1. The distortion is excessive
2. The expansion is not smooth
3. The rate of action is too slow
4. There is no positive limit to the amount of expansion.

The development of the present circuit was instigated by David Hall, the eminent authority on records and sound reproduction. The equipment had to pass the most stringent tests from the standpoints of both technical and musical listeners. This it seems to have done very satisfactorily, and it is believed that this is the most musically satisfying volume expander yet developed.

In order to keep the distortion to substantially zero level, and at the same time provide a definite limit to the possible increase in gain, it was decided to attack the problem by decreasing the gain of a high-quality low-distortion amplifier stage in a controlled manner, by a method which, in itself, would not introduce distortion.

The use of variable-mu tubes was abandoned at the outset, as soon as inherent intermodulation distortion of the order of 15% was discovered. From the standpoint of low distortion there is still nothing better than a triode of low plate resistance.

The gain of an amplifier tube is given by the following equation*:

$$\text{Voltage across load} = \frac{-\mu e_s Z_l}{R_p + Z_l}$$

where μ = amplification factor
e_s = input signal
Z_l = load impedance
R_p = plate resistance.

Since we have already ruled out the advisability of a variable-mu tube, we must find another way to vary the voltage across the load for a constant input signal, e_s. It is apparent that variations in the load impedance Z_l will change the output, especially if R_p can be varied in the opposite direction at the same time.

Referring to the circuit diagram of *Fig. 1*, it can be seen that the controlled amplifier is essentially a single stage of push-pull amplification. In addition to the plates of the amplifier tubes (6J5) the output transformer supplies current to the plates of the control tubes (6P5). The amount of plate current, and hence the plate resistance, of the control tubes can be determined easily by the instantaneous grid potential. At the same time, the additional plate current flowing through the common cathode resistor causes the plate resistance of the amplifier tubes to increase because of the increase in grid bias.

The actual operation is shown in the curves of *Fig. 2*. The output transformer is loaded with its nominal load of 500 ohms, which reflects a normal load of 15,000 ohms across each amplifier tube (control tubes cut off). This is indicated by the load line *A-A* across the curves. The quiescent operating point is shown by *P* in the diagram. The heavy line, of which *P* is the center, shows the region of actual operation. When a plate current of approximately 10 ma per tube is allowed to flow through the control tubes,

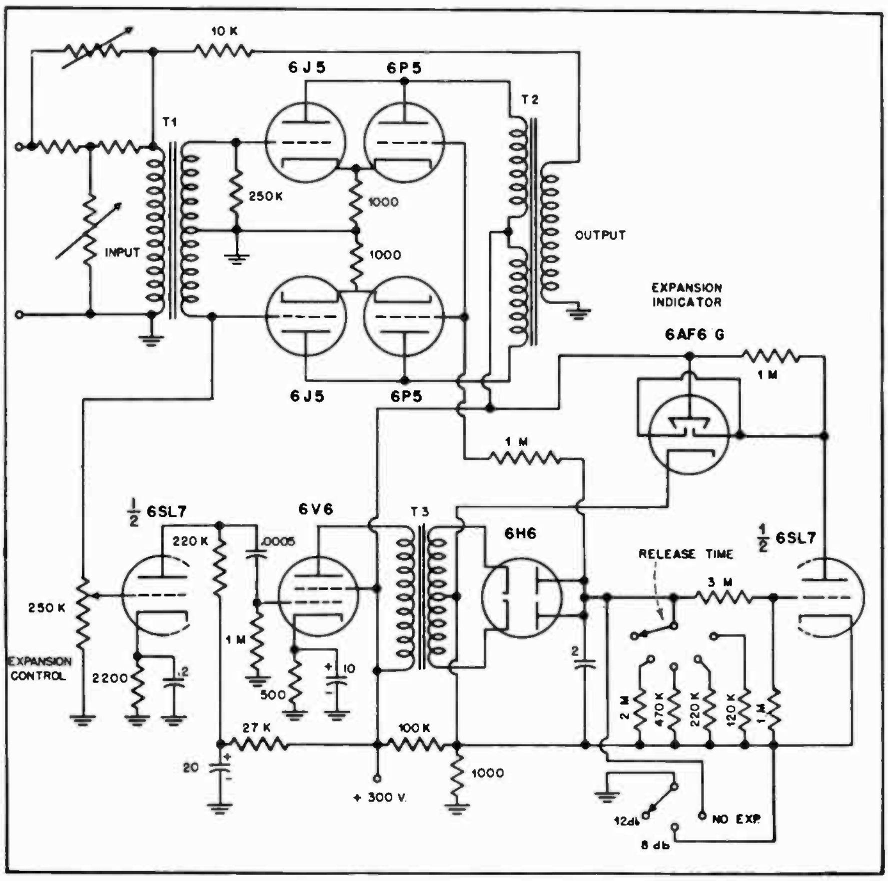


Fig. 1. Schematic diagram of the high-fidelity volume expander.

*Terman—Radio Engineering, p 173.

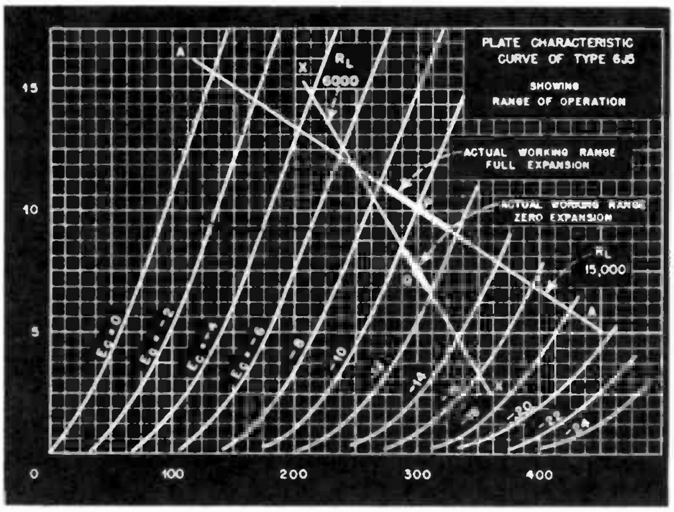


Fig. 2. Curves showing operating range of expander tubes.

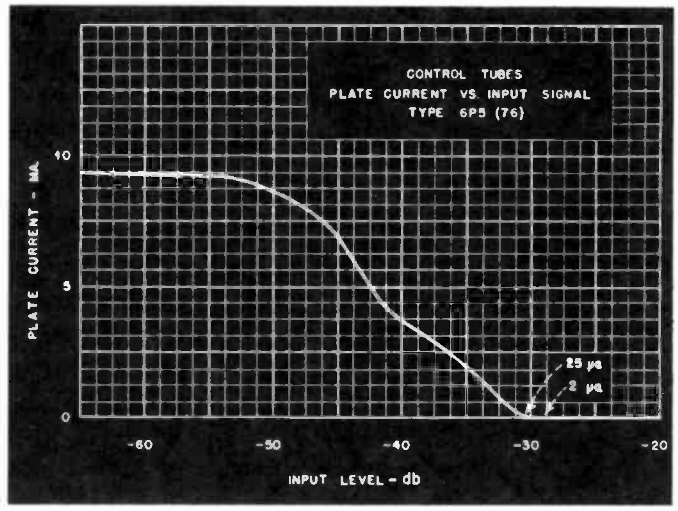


Fig. 3. Plate current vs. input signal curves of control tubes.

their plate resistance drops to 10,000 ohms. This causes the effective load to be:

$$\frac{R_p \; Z_l}{R_p+Z_l} = \frac{10{,}000 \times 15{,}000}{10{,}000+15{,}000} = 6000 \text{ ohms}$$

At the same time the effective increase in cathode current causes the operating point to drop to point Q. This condition of operation is indicated by the load line X-X passing through point Q.

The net result of the two effects is to reduce the amplification as the plate current of the control tubes is increased. The only thing which limits the amount of gain reduction possible is the approach of point Q to the non-linear region of the plate characteristic, with resulting increase of intermodulation distortion. It is interesting to note that the limitation in permissible distortion is on the low-level or unexpanded condition of operation. There is no possibility of running into distortion when the amplifier is wide open.

With the control tubes cut off, the gain of the amplifier stage is approximately 20 db. This will be the maximum possible gain, regardless of the amount of expansion used. A large number of listening tests indicated that, if smoothly applied, a maximum of 12 db expansion is permissible on well-monitored records. On records where there are noticeable "steps" in the volume changes due to too-rapid changes of gain during recording, 8 db is the maximum tolerable amount of expansion. All of these results were based on the premise that the listener must not be able to detect the actual operation of the volume expander.

With the foregoing information as a basis, the type of control tube was chosen, and the operating point was selected to give a loss in gain of approximately 8 db when the control grids were at zero potential relative to ground. It was then found that a grid voltage of –21 volts was sufficient to reduce the plate current to 2 microamperes. A positive potential (relative to ground) of 3 volts, applied to the control grids, decreased the gain by an additional 4 db. It is necessary merely to switch this positive bias on and off in order to change the expansion range from 8 db to 12 db. An additional switch position is provided to ground the control grids, making the unit a fixed-gain amplifier with zero expansion.

Time Constants

The next problem is that of the attack and release time constants of the system. Again it was necessary to resort to listening tests to decide on the optimum conditions. It was quickly decided that an instantaneous attack was necessary to provide unnoticeable operation. In other words, a loud sustained tone reaches its full level at once, and doesn't build up over a noticeable time interval, as so often happens with volume expanders. On the other hand, it is necessary to delay the release time so that the expander will not follow individual cycles at low frequencies. Furthermore, the release time adds to the normal decay of the sound, and, if too rapid, will effectively decrease the amount of reverberation. For this reason it is necessary to have at least 2 seconds delay for normal program material. In the laboratory model of the expander, values of 0.5, 1, 2, 5 and 10 seconds were provided. It was found that 5 seconds gave good results on almost every type of record.

Inasmuch as it is necessary to charge the 2-mfd capacitor in a matter of 1 millisecond or so, it is apparent that a considerable amount of power is required. A 6V6 is used to supply power to the rectifier. The rectifier, type 6H6, is momentarily called upon to supply several times its peak rated current of 10 ma. but because of the extremely short duty cycle, this has no adverse effect on the tube life.

It was necessary to do a considerable amount of testing to determine the opti-

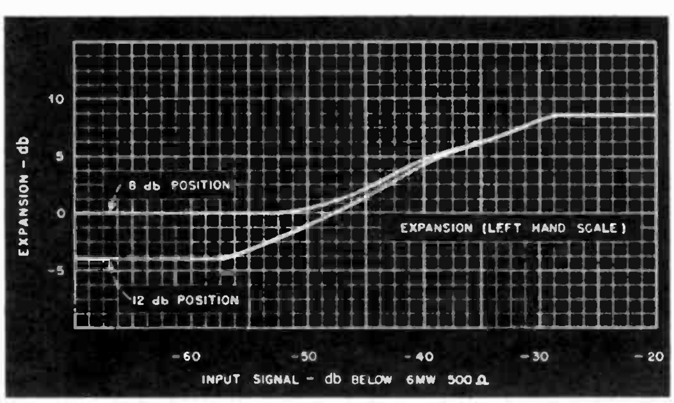


Fig. 4. Input signal level vs. expansion curves.

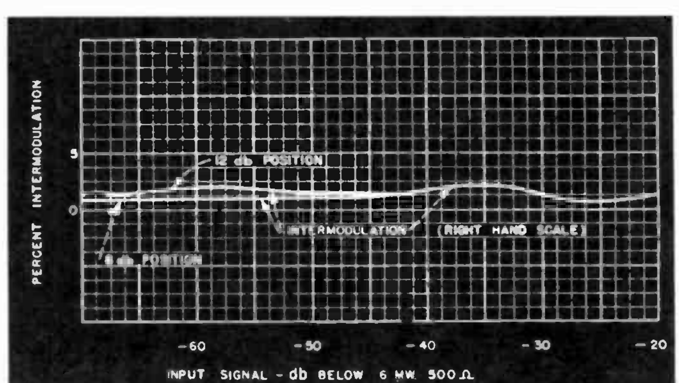
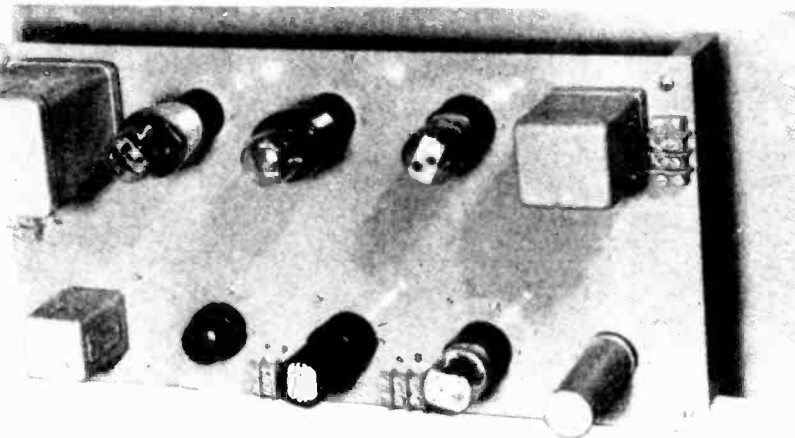


Fig. 5. Intermodulation distortion at various input signal levels.



Rear view of high-fidelity volume expander.

mum frequency response of the amplifier used to supply power to the diode. If a wide-band—30-10,000 cps—frequency range is used, it is apparent that the control voltage will be influenced by the strongest signal currents within that frequency range. Furthermore, low-frequency rumble and thumps, and high-frequency surface noise and clicks, will produce false control and consequent gain increase. It is best, therefore, when using a single band of frequencies from which to derive the control signal, to limit the response to from 500 to 3000 cycles. The effective loudness is determined by this band of frequencies, anyhow, so it is logical to use the same region for the controlling voltage.

An interesting effect was achieved by splitting the control amplifier into two channels, each supplying a separate diode. The outputs of the diodes were connected in series, and the individual amplifiers were arranged so that they would overload when supplying half the necessary control voltage. One amplifier passed the frequency range from 100 to 500 cycles; the other from 600 to 3000 cycles. Either amplifier alone could only produce half the total expansion, regardless of the energy in the pass band. It required energy in both bands to produce full expansion. This condition prevails in full orchestra, organ, or band music, at which time full expansion is required. This system prevented "blasting" when a single instrument or voice momentarily overbalanced the full ensemble. The results were very good, but on most records the improvement over the single-channel system of restricted frequency range did not justify the circuit complexity.

Expansion Indicator

A 6AF6 electron-ray tube is used as an indicator of the amount of expansion. It has a considerable advantage over a pointer-type meter, because of its freedom from dynamic error. It is adjusted so that the eye is just closed when the 6P5 control tubes are cut off.

The last important problem is the linearity of expansion versus input signal. It is very important not to have any "steps" in the expansion control. The plate-current variations with input signal, with the control voltage derived from the previously described rectifier system, are shown in *Fig. 3*. The change in plate resistance is not exactly the type of curve needed to produce a linear expansion. This condition was greatly improved by making the total range of expansion about 6 db more than desired, and reducing the over-all gain by means of inverse feedback. Since the gain reduction is a function of the amplifier gain, it is apparent that the amount of feedback will vary as the amplifier gain is varied. The gain will be reduced more at full amplification than at low levels. This has the effect of straightening out the expansion curve and reducing its slope, thereby accomplishing the desired end. This is shown in *Fig. 4*. The feedback also contributes somewhat to the over-all low distortion obtained with this device. The curves of intermodulation distortion versus input signal level are shown in *Fig. 5*. The harmonic distortion is barely measurable.

Fig. 6 shows the main amplifier circuit arranged to be inserted in a high-impedance amplifier. The action is identical with that of the low-impedance unit.

It will be noticed that this circuit can be used as a remotely operated gain control. It is merely necessary to substitute for the control signal a 22½-volt battery and potentiometer.

A little care must be exercised in using the volume expander. It should never be used on program material where the source of sound is inherently incapable of a volume range of more than 20 to 30 db. This applies to solo instruments (other than piano and organ), solo voices, string quartets, and so on. On orchestral, choral, and organ music it can be used on almost any record with excellent effect. The actual manner in which the original recording was controlled determines whether 8 db or 12 db of expansion can be used. Paradoxically enough, the wider the volume range on the original recording, the more expansion can be tolerated.

In *Fig. 4*, it will be noticed that in the 12 db position the input signal necessary to cover the entire range of expansion is about 29 db. This is about the volume range of a good modern recording. When playing such a recording it is best to set the expansion control so that the eye of the indicator tube fully closes on average peak levels. The expansion will then be completely off on very low-level signals. On records of more restricted range, it is best to set the expansion control so that surface noise just does *not* operate the indicator. This will then give the maximum increase of volume range.

It is good practice to install the expander with a gain control following the unit. The expansion control can then be left in the full-on position, and the input gain control used to adjust for input signal peaks. The output gain control then controls loudspeaker volume, and all of the output peaks will be at the same level, regardless of the actual level on the recording.

Fig. 6. Modifications needed for high-impedance input circuit. Input signal should be about 2 volts rms, maximum.