Improving the Tape Amplifier

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Changes in components often necessitate changes in circuit values in order to ensure optimum operation and to take advantage of the potentially improved performance. The authors' earlier tape amplifier is here brought up to date to permit the use of improved heads

A HIGH-QUALITY tape recorder amplifier was described in the January and February, 1957, issues of this magazine by the writers; the circuit is reprinted here as *Fig.* 1. Since then, the writers from time to time have made changes in the amplifier to improve its performance or operating convenience. The number and nature of changes that have accumulated now seem to warrant another article indicating how satisfactory performance may be won from the electronics of a tape recorder.

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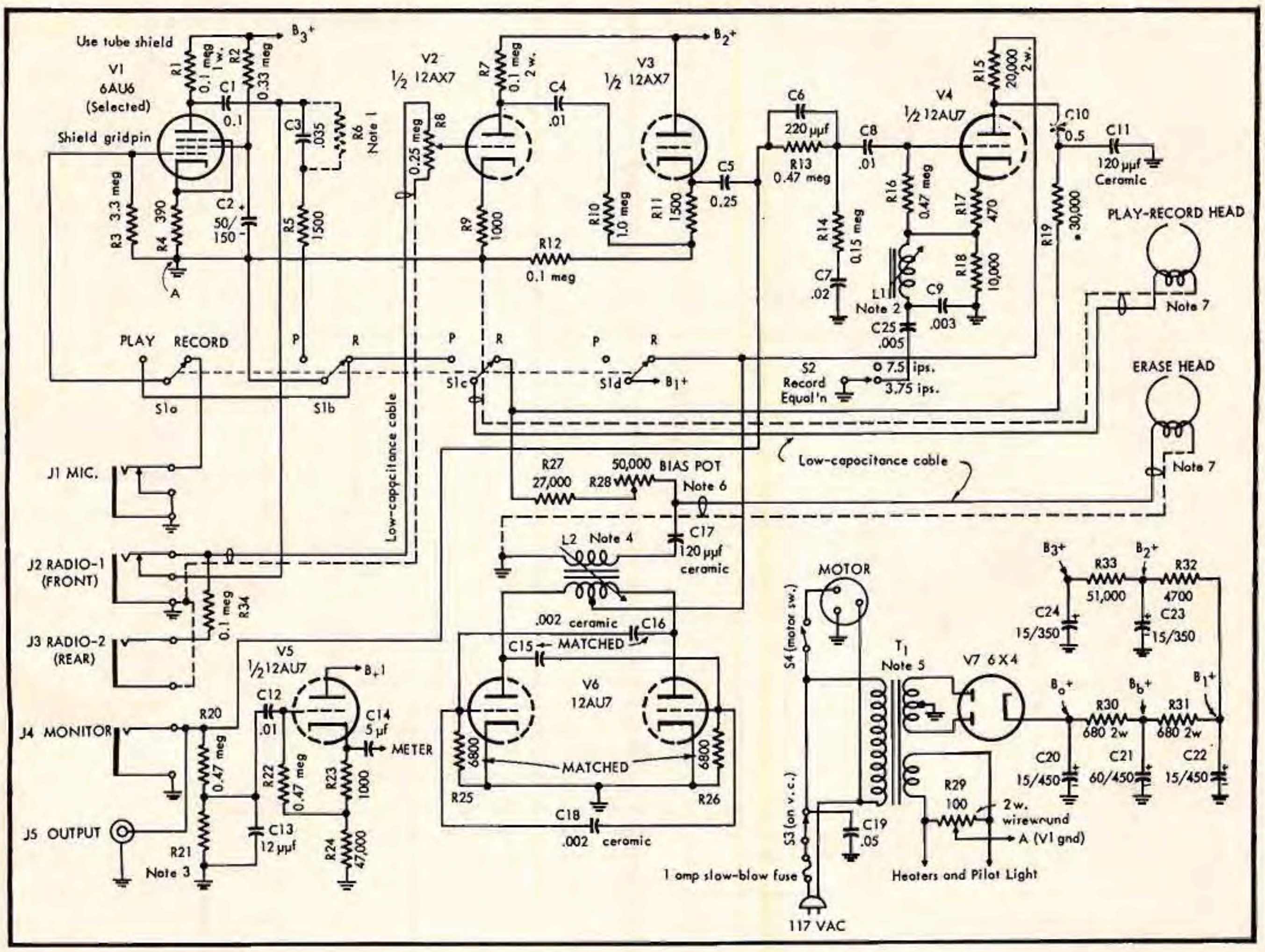
The changes concern installation of professional heads, a more stable oscillator, more accurate equalization, reduced noise and hum, and greater con-

Fig. 1. The original circuit of the tape recorder amplifier as described by the author in the January and February, 1957, issues.



Note 1: If bass response is excessive due to the playback head characteristic, bass may be reduced by using R6 with a value in the range from 0.1 to 0.5 meg. If bass is insufficient, connect the .035-μf capacitor C2 to the plate of V1 instead of to the far side of the 0.1-μf coupling capacitor C_1. See text.

Note 2: TV width coil variable from approximately 5 to 35 mh. Ram 201R3A or eq.

Note 3: Approximate value is 5 meg. Should be varied to produce correct indication on record-level meter or VU meter.

Note 4: Oscillator transformer used is a shielded unit furnished in Pentron HFP-1 amplifier and other Pentron models. Tuned to approximately 65 kc; see text. A suitable coil (part No. D501) may be obtained from Dynamu Magnetronics Corp., 21 N. Third St., Minneapolis, Minn., in which case the recommended Dynamu oscillator circuit should be employed.

Note 5: T_1 is a shielded power transformer. 240-0-240 v at 50 ma, 6.3v at 2.5 a. Merit P3047 or equivalent.

Note 6: Adjusted for 0.68 ma. See text.

Note 7: Dynamu heads. See Note 4 for company address.

Misc.: Resistors R_1 and R_4 are low-noise types. Others are ½-watt, 10% tolerance unless otherwise specified. Capacitors in μf, at least 400 v. rating, paper or ceramic, unless otherwise specified. Switch S_1: 4-circuit, d.t., lever or rotary type. S_2: toggle or slide. S_3: on v.c. S_4: toggle. Jacks: J_1 and J_2, shorting-type phone jacks; J3 and J4, standard phone jacks. J5, pin-plug receptacle ("phono" jack).

Changes as discussed in the text:

- C_6 becomes 50 μμf
- C_{11} is omitted
- C_{13} becomes 100 μμf
- C_{15}, C_{16}, and C_{18} become silver mica instead of ceramic
- R_{18} becomes 20,000 ohms
- R_{21} becomes 0.22 meg
- R_{27} is omitted

venience in switching from record to playback.

Installation of New Heads

The design of the original amplifier was partly based upon use of Dynamu heads. When the Dynamu record-playback head had worn to the point where replacement was necessary—the gap having widened and high-frequency response deteriorated—it was decided to replace this and the erase head with Brush heads, which are in extensive professional and semi-professional use.

The Brush BK-1090 record-playback half-track head was used. It is of laminated-core construction, which minimizes eddy current losses; has a nominal .00025 in. gap, permitting good response to 15,000 cps at 7.5 ips; and has two coil windings, which are hum cancelling when properly connected in series or parallel for the audio signal. It was found that the Brush BK-1090, with its windings in series for maximum playback signal, had greater drive requirements than the Dynamu head, so that more voltage gain was required in recording. Therefore V_3 was converted from a cathode follower into a voltage amplifier stage, as shown in *Fig.* 2; at the same time, equalization was changed from losser to feedback type, as will be discussed later in more detail.

To obtain enough bias current through the new head, the 27,000-ohm resistor R_{27} was omitted and bias was taken directly from R_{28}. Bias was adjusted for 0.7 ma., as measured on an audio VTVM, by reading voltage across a 100-ohm resistor inserted between ground and the ground lead of the head. This represented an optimum compromise affording satisfactorily low distortion and extended high-frequency response. More bias current would have further reduced distortion at high recording levels, but would have caused treble response to deteriorate significantly. At the bias used by the writer, recordings sound clean, and if at 7.5 ips one A-B's tape recording of a high-quality phono disc with the disc itself, the two are virtually indistinguishable.

The Brush BK-1110 half-track erase head was used. For the voltage and current produced by the bias oscillator in *Fig.* 1, the head appeared to work most efficiently with its windings connected in parallel. Current was supplied, as before, through the 120-μμf capacitor C_{17} and measured 12 ma., which is enough for effective erasure with this head. Erase current was measured by reading voltage across a 100-ohm resistor between the head and ground.

The 100-ohm resistors employed to measure bias current through the record head and erase current through the erase head were left permanently in place. This facilitates quick checking of bias current and erase-head operation. It is only a matter of seconds to connect the audio VTVM across these resistors and take current readings. Occasionally, as the oscillator tube ages or when it is replaced, it may be necessary to adjust bias current by means of R_{28}. The recordist desiring top-quality results will want to maintain watch over bias current as religiously as he cleans the heads and guides, demagnetizes the heads, lubricates the tape mechanism, and so on.

Upon installation of the Brush record-playback head, the treble boost requirement for recording purposes appeared to change somewhat. The 10,000-ohm resistor R_{18} was replaced by a 20,000-ohm one, which permitted the series resonant circuit comprising L_1 and C_9 to produce a greater amount of treble emphasis. At the same time, the 200-μμf capacitor C_6 was replaced by a 50-μμf capacitor, shifting upward the frequency at which treble boost begins. The net result was in a steeper treble boost.

Oscillator Circuit Changes

Bias current is fairly critical at speeds of 7.5 ips and less. Relatively small changes, less than 1 db, can appreciably affect high-frequency response and distortion, which both vary inversely with bias. Thus a stable oscillator is much to be desired. Toward this end, ceramic capacitors C_{15}, C_{16}, and C_{18}, all .002 μf, were replaced by silver mica units, which are more stable over time and with temperature changes.

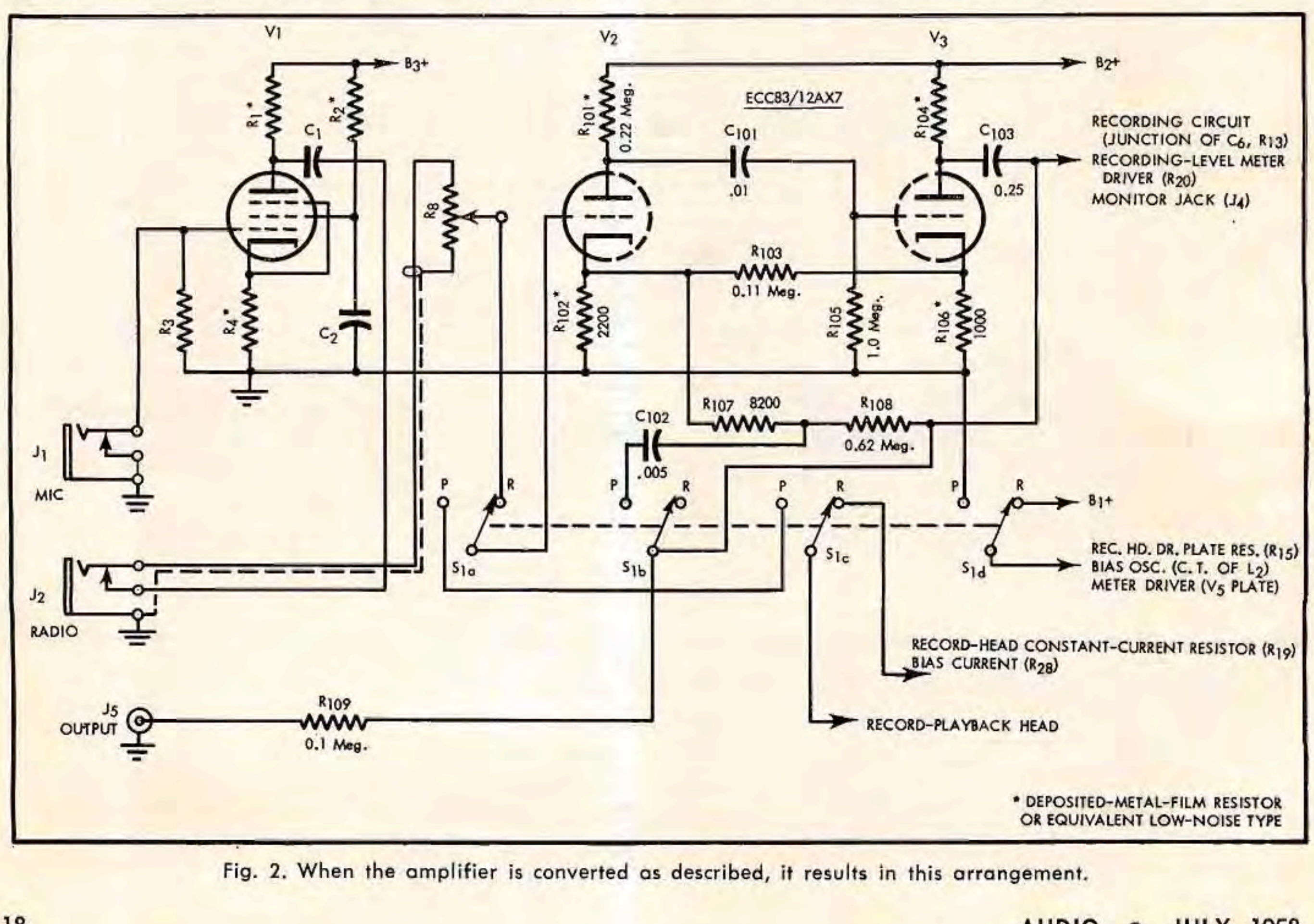


Fig. 2. When the amplifier is converted as described, it results in this arrangement.

Recording-Level Meter Circuit Changes

By providing more gain in the early stages to satisfy the greater drive requirements of the new record head, more signal was also presented to the grid of V_5, which drives the recording-level meter. Therefore it became necessary to reduce the signal reaching the grid of V_5 so that the meter would give the same indication as before for a given amount of signal *recorded on the tape.* Accordingly, the 5-meg resistor R_{21}, part of a voltage divider, was decreased to 0.22 meg, which caused the recording-level meter to be correctly driven. Thus the meter continued to indicate full scale for a signal about 6 db lower than that required to produce 2 per cent harmonic distortion on the tape at 400 cps. As explained in the original article, the meter is set "6 db ahead," so to speak, to make allowance for the fact that the meter indication falls behind the actual level of rapid transients.

Reducing R_{21} to 0.22 meg made it necessary to increase the bypass capacitor C_{13}, which prevents bias current from affecting the record-level indicator. Originally 12 μμf, it was increased to 100 μμf. On the other hand, the 120-μμf capacitor C_{11}, also used to shunt bias current to ground, was found no longer necessary and therefore removed.

Originally the plate of V_5 was permanently connected to B_1+ so that the meter would operate in record as well as playback. This permitted comparison of playback levels among various tapes and enabled one to correlate audible distortion with recorded signal level. Unfortunately, if a signal were fed into the amplifier for recording purposes but switch S_1 was left in the playback mode, the meter gave an indication as though everything were set for recording. For this reason the writer accidentally failed on a number of occasions to obtain a desired off-the-air recording. Therefore it was decided to obtain B+ for V_5 from the same point as the B+ supply for the record-head driver V_4 and the oscillator V_6, which are connected to B+ only in the record mode. This point is the arm of S_{1d}, as shown in *Fig.* 2.

Revised V_2-V_3 Electronics

The circuit revisions in *Fig.* 2 meet the following objectives: (1) V_3 is converted from a cathode follower to a voltage amplifier to provide the greater gain needed in recording. (2) Output impedance is kept low through negative feedback, thus maintaining high-frequency response and permitting a reasonably long run of cable between the tape recorder and the next component in the audio chain for playback (usually a control amplifier). (3) The volume-control setting does not affect playback equalization; in the original circuit, which employed a losser type of bass-

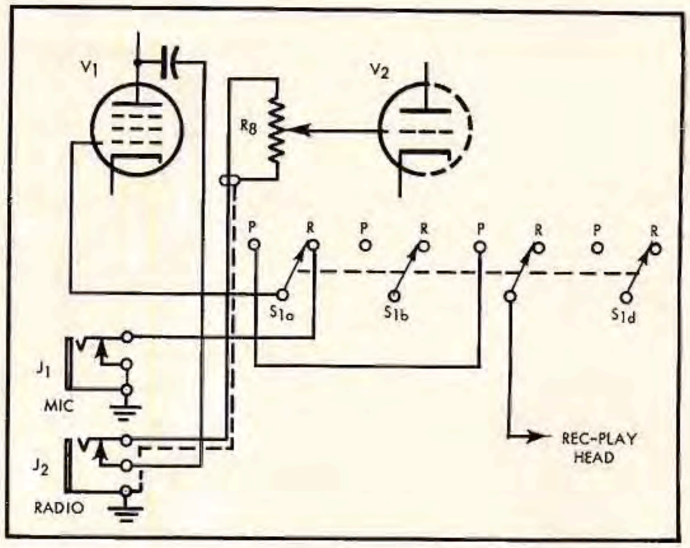


Fig. 3. Revision to increase playback gain by restoring V_1 to the circuit.

boost network, boost at the very low end dropped a few db when the gain control was not at maximum setting. (4) Hum and noise generated in V_2 and V_3 are reduced by negative feedback.

The feedback equalization network, comprising R_{102}, R_{103}, R_{107}, R_{108}, and C_{102}, produces a playback characteristic conforming very accurately to the NARTB curve. C_{102} and R_{102} plus R_{107} in series produce the high-frequency turnover of 3180 cps, while C_{102} and R_{108} produce the low-frequency turnover of 50 cps.

One of the problems in using feedback to obtain an equalization curve with a large amount of bass boost, such as the NARTB curve requires, is that at low frequencies the curve tends to lose its accuracy. That is, gain at the low end no longer varies exactly in inverse proportion to the amount of feedback. The feedback factor (ratio between gain without feedback and gain with feedback) is $1+AB$, where A is gain before feedback and B is percentage of output voltage fed back. At high frequencies, the quantity AB is much greater than 1, so that the feedback factor consists largely of AB; since A is a constant, it can be said that the gain ratio varies essentially with changes in B. At low frequencies, however, B is very small, and the quantity AB begins to approach 1. Therefore the value 1 can no longer be ignored in the expression $1+AB$. And the response curve no longer varies exactly with changes in B. In order to keep the quantity AB significantly higher than 1 (at least four times as great) and thus produce accurate equalization, it would be necessary to increase A, that is, gain before feedback. This can be done by positive feedback. The 0.11-meg resistor R_{103} in *Fig.* 2 produces several db of positive feedback for this purpose.

It should be noted that R_{109}, a 0.1-meg resistor, has been added in series between the output stage and the output jack J_5. A resistor of this sort (about 10,000 ohms) also should have appeared in the original circuit (*Fig.* 1). If the output of the tape recorder is left connected to a control amplifier, usually this output will be shorted to ground by the control amplifier's function switch when this switch is turned to another input source, say the FM tuner. The purpose of R_{109} is to prevent the signal at the plate of V_3 from being shorted out during recording.

Revised Switching

As pointed out in the original article, the hardware employed was that found in a Pentron HFP-1 tape amplifier. This included the function switch, a four-pole double-throw type. Because of the limited number of poles, when switching from record to playback it was necessary to remove the phone plug that had been inserted into the input jack J_2 for recording from a high-level source, such as the tape output jack of a control amplifier. If the phone plug were left in during playback, it would provide a feedback path from the tape output jack of the control amplifier to the tape-recorder input and from the tape-recorder output back into the input of the control unit.

Having to insert and remove the phone plug continually proved to be a nuisance. Therefore the revised switching arrangement of *Fig.* 2 was used, which enabled the phone plug to be left in J_2 during playback. V_1 is now permanently connected to the microphone input jack J_1. Only V_2 and V_3 are used for playback; more will be said about this shortly. In playback, the volume control R_8 and the input jack J_2 are disconnected from the circuit by S_{1a}. Prior to this change, the gain control had always been left in maximum position during playback. Since the change, the lack of command over playback gain *at the recorder* (gain is governed by the control amplifier) has caused no inconvenience.

The function of S_{1b} remains that of introducing playback equalization, but in a different manner from the original circuit. Now S_{1b} places C_{102} across R_{108}, resulting in the NARTB characteristic. When C_{102} is out of the circuit in the record mode of the switch, there is an equal amount of feedback at all frequencies.

There is no change in the purpose or action of S_{1c}. Some alteration was made in S_{1d}. Now the record terminal instead of the arm is connected to B_1+. The arm goes to the plate load resistor of V_4, the plate of V_5, and the plate of V_6 via the center-tap of L_2. The play terminal of S_{1d}, previously not used, is now connected to ground as a means of bypassing stray bias current.

Using only V_2-V_3 as a playback amplifier results in an output signal of only about 0.1 volt or slightly less on peaks. For many or most audio systems this should be enough. A number of control amplifiers have high sensitivity, enabling them to produce an output of 1 volt or more for input signals of 0.1 volt. And the typical power amplifier can be driven to full output or to within a few db of full output by an input signal of 1 volt.

However, if more playback gain is needed, V_1 can be restored to the circuit as in *Fig.* 3. Switch S_{1a} is used to transfer the grid of V_1 between the playback head in playback and the microphone input jack J_1 in recording. The grid of V_2 goes directly to the gain control R_8 instead of being switched to this control in recording and to the playback head in playback. But if V_1 is used for playback, it is again necessary to remove the phone plug from J_2 in this mode.

If V_1 is used in the playback circuit, the tape recorder preferably should be operated in playback with the gain control at maximum. Level should be reduced subsequently by the input level-set and/or gain control of the control amplifier to which the tape machine is connected. Thus when the playback signal is reduced to the desired level, noise and hum in V_2 and V_3 are simultaneously attenuated. The chances of overloading V_2 are small when the gain control of the amplifier is at maximum. The signal from the playback head is a few millivolts at the most. Since V_1 has less than 40 db gain, the signal presented to the grid of V_2 with the gain control full on is less than 1 volt. V_2 can easily handle this with low distortion, especially because of the large amount of negative feedback applied to its cathode. Feedback is greatest at high frequencies, where the output of the tape head, a velocity device, is also greatest.

Reduction of Noise and Hum

To reduce noise, deposited-carbon resistors were used at the plate and cathode of V_1 and an oversize resistor (2 watts) at the plate of V_2 in the original circuit. In the circuit of *Fig.* 2, however, deposited-metal-film resistors are used for noise reduction. These can be virtually as noise-free as wirewound resistors and about one-third as expensive, costing about one dollar each. Moreover, wirewound resistors have some residual inductance, although wound in a manner designed to cancel inductance. This may lead to pickup of hum or possibly to pickup of the audio signal and consequent positive feedback and oscillation in a high-gain circuit.

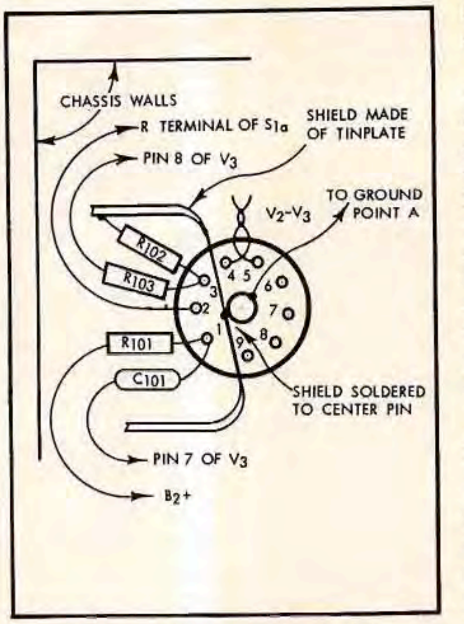


Fig. 4. Physical arrangement of shield and circuit components to minimize hum.

In view of the fact that deposited-metal-film resistors are not too readily available to the individual hobbyist, it is appropriate to mention here that the Davohm Series 850 resistors, covering the range of 2 to 850,000 ohms, are carried by Harvey Radio, 103 W. 43rd St., New York City. The writer has also obtained excellent results with the Nobleloy deposited-metal-film resistors made by Continental Carbon, Inc., and with the S20 resistors recently introduced by Corning Glass Works.

In *Fig.* 2, deposited-metal-film resistors are used as the plate and cathode resistances for V_1, V_2, and V_3. Prior to use of metal-film types, deposited-carbons had been tried for V_2 and V_3 as well as V_1. But each time a metal-film resistor was substituted for a deposited-carbon one, there was a striking improvement, even in late stages. This is not to say that all deposited-carbon resistors are inferior to metal-film ones. In fact, the writer has been given to understand that there are some deposited-carbon resistors of foreign make which have excellent noise characteristics, closely approaching those of wirewounds. However, his personal experience with American-made resistors has been that deposited-metal-film ones have given far better results than the deposited-carbon type.

It may be wondered why the cathode resistors, whose values are quite small compared with the plate resistors, should also be low-noise types. However, when the cathode resistor is unbypassed, as in *Figs.* 1 and 2, its effective value is increased by the amplification factor, μ, of the tube. Thus if the μ of V_2 is 36, then the 2200-ohm cathode resistor is effectively increased by 36×2200, or by 79,200 times. The total effective value is the actual 2200 ohms plus the 79,200 increase, or 81,400 ohm.

This can be explained as follows. Assume that the noise voltage produced by the cathode resistor is 1 per cent of the voltage across the resistor due to tube current flow. The grid-cathode voltage changes accordingly, since the cathode resistor is unbypassed, and the voltage change is amplified μ times by the tube. So far as the output of the tube is concerned, this is equivalent to a 1 per cent noise voltage in a resistor μ times greater than the actual cathode resistance. In effect, the cathode resistance is increased by μ times its physical resistance. Adding the increase to the actual cathode resistance, the total effective value is $\mu + 1$ times the physical resistance.

To reduce hum, V_2-V_3 was enclosed in a tube shield. Underneath the socket, a shield, fashioned from a piece of tin can, was mounted as shown in *Fig.* 4 to isolate the grid of V_2 from heater leads and other possible sources of hum. The shield was soldered to the center pin of the socket and grounded to the main ground point A at V_1 (*Fig.* 1). All components in the circuit of V_2—plate resistor, cathode resistor, positive-feedback resistor, and coupling capacitor—were mounted between the shield and the side wall of the chassis. The cathode resistor R_{102} was grounded to the shield, while insulated leads were used to run the other components to the appropriate points.

Another hum reduction measure was to shield the power transformer with silicon steel I-strips from a junked power transformer. Cellophane tape was used to bind the strips together. The transformer is located in a corner of the tape recorder, as far away as possible from the electronics and heads.

By this time, hum was virtually nonexistent so far as the *amplifier proper* was concerned, being virtually inaudible at correct setting of the hum balance pot R_{29}. However, the playback head picked up a slight but noticeable amount of hum from the power transformer, mostly third harmonic (180 cps). In the original amplifier a "gimmick," consisting of a silicon steel I-strip doubled in hairpin fashion and clamped to the head bracket, was fairly effective in warping the hum field at the head. But this did not con-

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tinue to be true when the Dynamu head was replaced by the Brush unit. However, a different and more workmanlike shielding measure was employed, with considerably greater effectiveness than the gimmick.

A small piece of Co-Netic Shielding[1] was affixed to the reverse side of the bracket that holds the pressure pad on the tape transport. The material is almost paper-thin, cuts easily with a scissors, is easily worked by fingers or simple tools into the desired shape, yet is rigid enough to hold this shape, and does not lose its shielding properties because of shock, repeated bending, temperature changes, etc. Several layers of Co-Netic material were used, each layer

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[1] Made by Perfection Mica Company, 1322 N. Elston Avenue, Chicago 22, Illinois.

increasing the protection against hum. Some experimentation was necessary to find the optimum size of the Co-Netic Shielding and its best location on the pressure pad bracket. It is interesting to note that a small section of this shielding, about ½″ wide, afforded considerably greater hum reduction than a piece double that width. The final result was considerable attenuation of hum. The reduction was not measured, because without the use of filters one would be measuring noise along with hum. To the ear the reduction appeared to be at least 6 db.

Co-Netic Shielding is expensive. In small quantities it is over $3.00 per linear foot for a strip 4 in. wide, and the minimum order is 3 feet. However, for the habitual experimenter or tinkerer it can be a worthwhile investment. A less expensive alternative, closely approaching the Co-Netic material in effectiveness, is a shield made from a piece of silicon steel I-strip. The latter material is more difficult to work and eventually becomes magnetized, while the Co-Netic does not. A magnetized material adjacent to the tape can cause erasure, noise and hum.

For minimum noise and hum, an ECC83, the European version of the 12AX7, was used for V_2-V_3. Of two Mullard ECC83's purchased, both were excellent with respect to noise and microphonics, but one had serious hum. Demagnetizing this tube with a bulk eraser and resetting the hum balance pot did not improve matters. The tube was exchanged for another Mullard ECC83, which proved to be excellent. It is unfair to draw conclusions from a sample of three, but this experience corroborates the writers' experience with other tubes, such as the 5879 and Z729, that one must be selective even when using premium types, which cost appreciably more. The two good Mullards were definitely superior both in noise and hum to each of half a dozen American 12AX7's in the writer's tube chest. A couple of Telefunken 12AX7's were of quality similar to the Mullards.

The ultimate result of the above measures was to reduce noise and hum in the tape amplifier substantially below that inherent in the tape itself, namely tape hiss. Even when a tape has been carefully bulk erased, leaving it as noise-free as a tape can be, it still makes the dominating contribution to noise on the writer's tape recorder, Considering the additional noise produced in recording —at least modulation noise if not also noise due to distortion in the bias waveform—it may safely be said that the tape electronics described here do not constitute a limitation to signal to noise ratio in tape recording and playback. On the other hand, it is to be expected that eventual improvement in the tape, resulting in less tape hiss, will inspire a search for further means of reducing noise and hum.

Stereo Playback Amplifier

There is an increasing demand for a second playback amplifier for stereo purposes. A simple way to satisfy this demand would be to construct a one-tube affair, either on the main amplifier chassis or separately, patterned after the circuit of V_2 and V_3 in *Fig.* 2. Power could be drawn from the main tape amplifier, from an easily built supply such as shown in *Fig.* 5, or from the power amplifier of the audio system.

If power is drawn from the main amplifier of *Figs.* 1 and 2, connection should be made to the point B_2+ via an additional decoupling network consisting of another 4700-ohm resistor and another 15-µf, 350-volt filter capacitor. Since the loading of the main power supply is considerably lighter in playback than in record, this supply can take care of another 12AX7 for stereo playback. At the same time, however, it is highly desirable that a switch be incorporated to remove B+ from the extra 12AX7 during record. Similarly, the heater supply to this tube, if obtained from the main amplifier, should be disconnected during record. On the other hand, if the power transformer used is large enough, these disconnections are not necessary. Æ

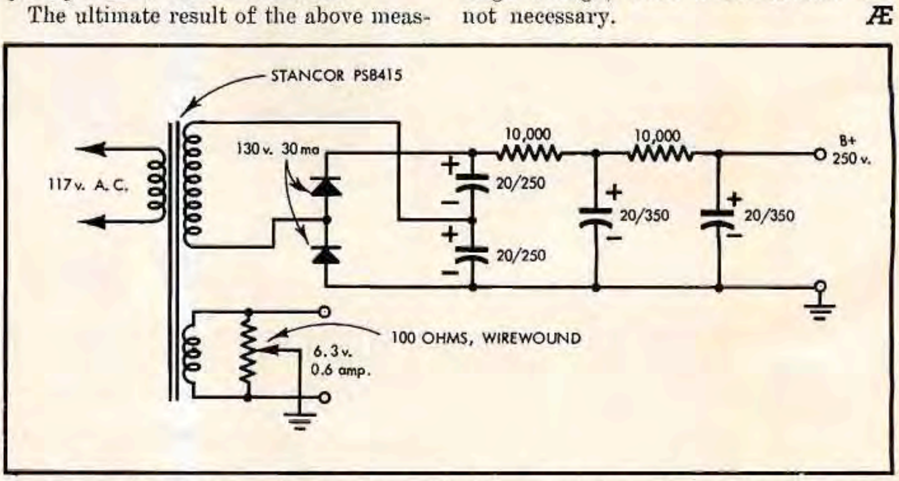

Fig. 5. Simple power supply circuit suitable for second-channel amplifier for stereo.