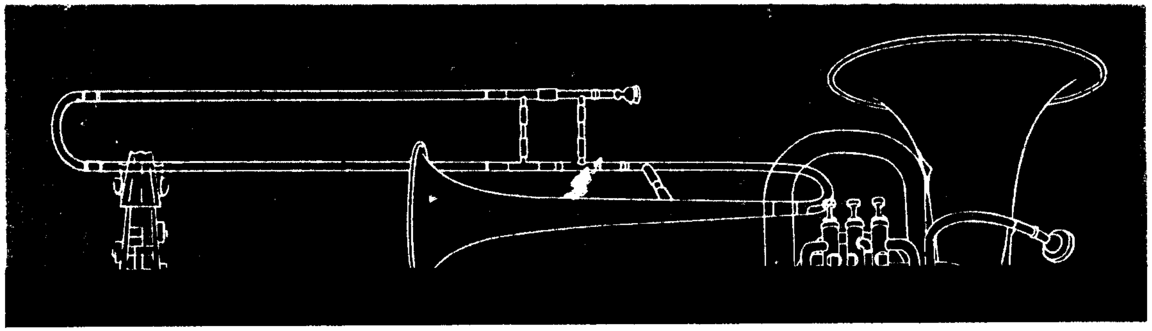
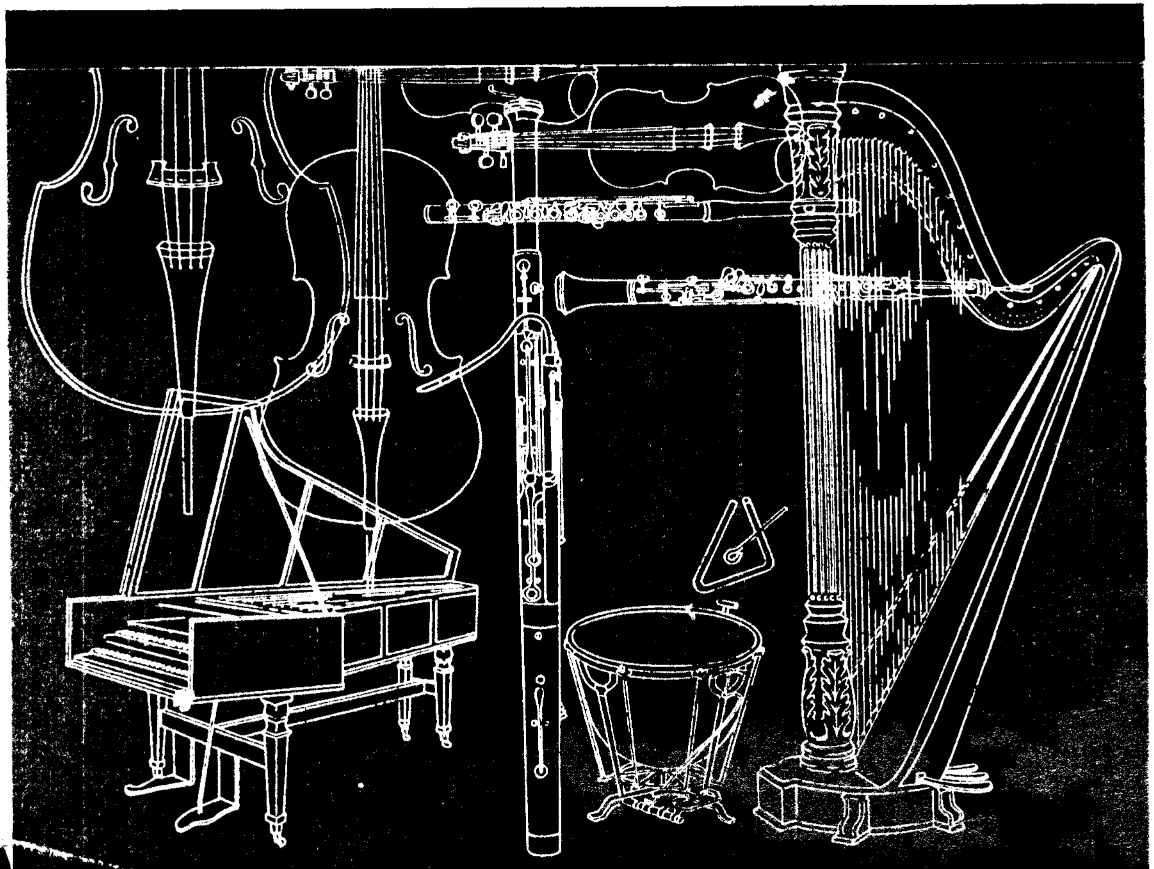


audio designers handbook



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Price $1.50

Amperex is pleased to bring to the audio designer this up-to-date collection of amplifier circuits and design information. The circuits were chosen as being representative of current and possibly future trends in the audio field. Many of these circuits were developed in the Amperex Applications Engineering Laboratory in order to assist customers towards the most effective utilization of Amperex audio tubes. This book is intended to further this end. If additional assistance is required Amperex Applications Engineering Laboratory is constantly available.

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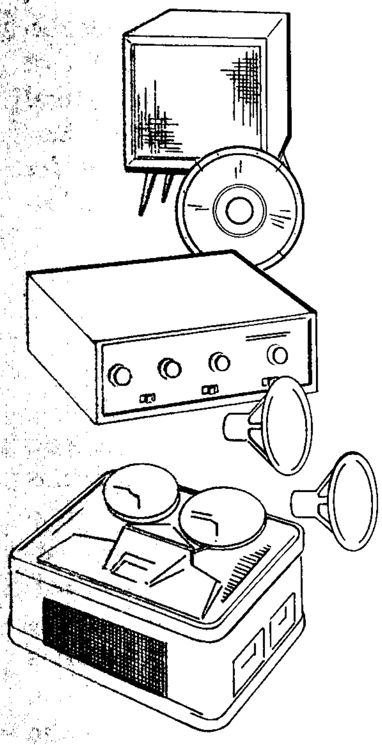
SCHEMATICS



INTRODUCTION

In recent years tremendous strides have been made in the audio field, not only in technology, but in consumer demands as well. The ever increasing quality of recordings has in turn created the need for ever increasing quality in reproducing equipment. In addition to more demanding quality standards, modern audio equipment also has to cope with a variety of different signal sources; several kinds of phonograph pickups, FM tuners, tape (either preamplified or direct from the head), and microphones. The very recent emergence of stereophonic recordings, both disc and tape, has added the need for two channel playback without eliminating any of the previous requirements. It is indeed a tribute to the audio designer that he has not only kept up with the demands but in many cases has exceeded them.

A problem of great importance faced by the audio designer is cost. How can all the technical and consumer demands be satisfied without making the cost prohibitive? It was with the proper quality-cost balance in mind that this handbook was prepared. The design information and schematics in this handbook are meant to provide the audio designer with a collection of useful ideas and circuits. There are designs ranging from the simplest to the most elaborate; from the least expensive to the quality-at-any-price category. In essence, this is a collection of various methods for solving the same design problems. Naturally there are many more methods which are not presented, some of which are being developed in our laboratories at this very moment. Information about these are yours for the asking — just contact the Amperex Applications Engineering Laboratory.

Before plunging into the technical aspects of amplifier design it might be helpful to review some of the overall requirements of monophonic and stereophonic systems.

AUDIO SYSTEMS

A. MONOPHONIC SYSTEMS

In general a monophonic system consists of a phonograph pickup, a preamplifier, a power amplifier, and one or more loudspeakers. In addition, many systems include an AM/FM tuner and a tape recorder. No matter how good these components are, however, they can do no better than reproduce the signal supplied them from the record, tape, or broadcast. The signal will certainly contain some distortion. In the case of records and tapes a part of the distortion is deliberate. As far as the deliberate distortion (recording characteristics) is concerned, compensation is easily effected by means of an equalization network. There is no cure, however, for any other type of distortion in the signal. Fortunately, the recording and broadcast engineers have done an excellent job in producing signal sources with minimum undesired distortion.

Obviously, one of the criteria for selecting components must be the amount of distortion it will add to the signal. It would be incongruous to couple a very low distortion amplifier with a high distortion speaker since the system would sound the same if a lower quality amplifier were used. Therefore, when components are selected, their effect upon the overall distortion of the entire amplifying-system should be kept in mind.

Monophonic systems may be constructed with the preamplifier, power amplifier, and/or tuner all on the same chassis or each on a separate chassis. Usually the separate chassis systems are somewhat more flexible and can be easily adapted to a variety of signal sources. For example, if all the signal sources used in a particular system are high level, say about 500 mV, an additional voltage amplifier is not necessary. On the other hand if a preamplifier is necessary, then there is considerable freedom in the choice of power amplifier. Also the separate chassis construction prevents harmful interaction between the components and simplifies heat dissipation. An additional advantage of this type of system is the possibility of retaining some of the components when converting to a stereophonic system.

On the other hand high fidelity package systems undoubtedly make more efficient use of parts and thus effect cost reduction. The efficiency of this type of unit is the natural result of specific knowledge about the pickup or tuner characteristics which permit design of the optimum circuit for these known quantities. Clearly then, either method may be "the best" depending upon the specific circumstances.

B. STEREOPHONIC SYSTEMS

Perhaps the easiest way to describe stereophonic reproducing systems is that they have *more than double* the problems inherent in the monophonic systems. Not only are there two channels, but there must of necessity be some method for relating these channels to each other to preserve the original balance. In addition, the stereophonic signal in many cases is lower in level than the monophonic signal. This calls for extra gain and less distortion in the system.

The comments in the monophonic section concerning the advantages and disadvantages of single and separate chassis systems apply equally to stereophonic equipment. Each system has its strong points which are directly related to the needs of the particular group of consumers concerned.

AMPLIFIER DESIGN

A. THE IDEAL AMPLIFIER

The principal features of the ideal amplifier are:

1. The distortion produced by the amplifier should be negligible up to maximum output. By distortion we mean the presence in the output of frequency components and phase relationships which were not present in the input. The frequency components consist of harmonics of the signal frequencies and of sum and difference frequencies resulting from intermodulation between different frequencies in the signal. In addition, parasitic oscillations give rise to undesired frequencies commonly called "ringing". The phase distortion is caused by phase shift of different frequencies.
2. The response of the amplifier should be uniform throughout the audible frequency range. The average ear will respond to frequencies in the range of 30 to 15,000 cps. The upper limit of this range may extend to 20,000 cps. To make realistic reproduction possible, therefore, the amplifier should handle frequencies between at least one octave above and one octave below the audible range.
3. The amplifier must have excellent transient response. Many sounds, particularly those from musical instruments, rise very rapidly to a high intensity and decay relatively slowly. Such sounds are spoken of as "transients".
   The steeply rising wave fronts of transients can be shown to consist of a wide range of component frequencies. The ability of an amplifier to reproduce them faithfully will therefore depend on a wide frequency response and little phase shift over the whole frequency range. Variations in the relative phasing of the component frequencies of a transient would result in a change in its aural character.
4. An adequate reserve of power should be available. For faithful reproduction, the sound level should be comparable with that of "live" conditions. The amplifier should thus be capable of handling peak powers considerably above the average level to allow peak sounds to be reproduced without overloading and audible distortion.
5. The output impedance of the amplifier should be low. This will improve the performance of the loudspeaker and insure clean reproduction, particularly of transients. Air loading of the loudspeaker tends to limit the low frequency resonance of the cone and suspension. The electromagnetic damping of a low output impedance in the amplifier is, however, effective in maintaining adequate control of the cone movement over the entire frequency range.
   The output impedance should preferably be much less than the impedance of the loudspeaker voice coil, the ratio of the two being termed the "damping factor". In practice, a damping factor above 10 is desirable.
6. Hum and noise in the amplifier should be below an audible level.

B. AMPLIFIER PERFORMANCE CRITERIA

The performance of an amplifier is normally specified with reference to some or all of the points listed in the previous section. However, these points define the ideal amplifier characteristics. The following definitions provide background for the amplifier performance measurements given in subsequent sections.

1. Power

The audio power available at the output of an amplifier is defined as $(V_{load})^2/R_{load}$, where V_{load} is the voltage developed across a load resistance (R_{load}) connected to the output terminals of the amplifier when driven with sinusoidal input. The rated output power of the amplifier is the maximum audio power which can be obtained without exceeding either the maximum ratings of the tubes or the distortion level permitted for the system.

2. Distortion

The principal form of distortion which occurs in amplifiers is non-linear distortion which is normally divided into harmonic and intermodulation distortion. Each of these contributes some power to the output at frequencies which differ from those occurring in the input signal.

a. Harmonic Distortion

Power which occurs in the output at second, third, fourth, and so on, harmonics of the fundamental signal frequency comprises harmonic distortion. It is expressed as a percentage ratio of the power associated with the particular harmonic to the total output power of the amplifier. Total harmonic distortion is the ratio of the power associated with all the harmonics to the total output power. The total harmonic distortion D_{tot} is the r.m.s. value of the individual distortion D2, D3, D4, etc. — that is:

$$D_{tot} = \sqrt{(D2^2 + D3^2 + D4 + \ldots\ldots)}$$

b. Intermodulation Distortion

If an input signal contains several different frequencies, any nonlinearity in the amplifier will give rise to modulated waveforms having frequencies which are the sums and differences of the interacting waveforms. The extent of this distortion is measured by the degree of interaction between two pairs of test signals. The interaction between signals of very different frequencies is called intermodulation distortion.

Intermodulation distortion is measured with test signals of 100 cps to 1000 cps input. The ratio of the peak-to-peak amplitudes of the low and high frequency test signals is 4 : 1. The output obtained with the two signals is assumed to be equivalent to the output obtained with a single sine-wave signal with a peak-to-peak amplitude of the combined waveform. The distortion is quoted as the r.m.s. value of the amplitudes of the sum and the difference waveforms expressed as a percentage of the amplitude of the high frequency signal.

c. Hum and Noise

Contributions to the output from various stray signals picked up at points in the amplifier are normally lumped together and measured at the output with a load across the input to stimulate the pickup impedance. This voltage is expressed in decibels as a fraction of the rated output voltage measured across the load resistance so that:

$$\text{Hum and Noise (in db)} = 20 \log_{10} \frac{\text{voltage with input loaded}}{\text{rated output voltage}}$$

A level of hum and noise of —60 db means that the rated output voltage is 1000 times the voltage developed when the input is loaded as described.

d. Negative Feedback

Negative feedback is used to improve amplifier performance. Part of the output is re-injected in an earlier stage 180° out of phase with the input signal thus reducing sensitivity and distortion. It is usual to refer to the amount of feedback in terms of the ratio of voltage gain of the amplifier without feedback to the voltage gain with feedback. Thus, a feedback of 26 db would mean that the gain without feedback is 20 times the gain with feedback.

The gain without feedback of an amplifier must therefore be high enough to allow for the loss in gain resulting from feedback. This disadvantage of using feedback is far outweighed by the advantages which are:

1. reduced distortion
2. improved frequency response
3. lower output impedance
4. less phase shift
5. less dependence of gain upon changes in supply voltage

C. CIRCUIT DESIGN

Although the power handling capacity of an audio amplifier is not the property which is most important to the listener (a low level of distortion is usually considered to be so); it is nevertheless the prime concern of the circuit designer. The peak power required for realistic reproduction of music depends mainly upon the size and acoustical nature of the room and upon the taste of the listener. In the home it is generally considered that an output power of 12 to 17 watts will be adequate. If simplicity and economy are the primary considerations, an output of 8 watts can give a generally acceptable standard of performance. In large rooms, however, a maximum output power of at least 50 watts will be necessary. The type of output stage used will depend upon the maximum power required of the amplifier. Consequently, the design of the amplifier usually proceeds from output to input stages, the requirements of the output stage dictating to a large extent the design of preceding stages.

D. OUTPUT STAGE

Not many years ago triodes were considered to be the only useful output tubes. There was good reason for this attitude. The pentode and beam tetrodes available at that time had extremely high distortion. In recent years, however, with the development of low distortion power pentodes such as the 6CA7/EL34, 6CW5/EL86, and the 6BQ5/EL84, this trend has been more than reversed.

For example, when the low distortion characteristic of triode operation is desired, it is not at all uncommon to use a pentode in triode connection; or for a distortion level somewhere between the triode and the pentode a type of distributed loading popularly called "ultra-linear" operation is used.

Recently there has been increased interest in the use of power pentodes such as the 6CW5/EL86 which can operate at low voltage and high current. With this type of tube the low voltage and high current swing (low plate to plate load impedance) reduces the stringent primary inductance requirements of the output transformer. Thus fewer turns are necessary and both the leakage inductance and stray capacitance are also reduced. The result is improved transient response and increased stability.

The ability of the push-pull stage to reduce harmonic distortion has made it the standard for high-quality amplifiers. However, because of the higher distortion tolerated in low cost amplifiers, the single-ended pentode output stage is more economical than the push-pull output stage.

Let us now examine more closely the three types of output stages previously mentioned — pentode, triode connected pentode, and distributed load.

1. Pentode Output Stage

The pentode output stage is usually in push-pull Class AB. The overall efficiency of these stages is fairly high being of the order of 40 - 50% and the harmonic distortion varies up to 4% at full output. Consequently, negative feedback is necessary to reduce distortion.

The recommended operating conditions for Class AB are usually based on measurements with continuous sinusoidal drive. The cathode resistor is chosen so that with zero-signal input, the tubes are operated near Class A and at full drive near Class B. The plate-to-plate load resistance is chosen for optimum performance at full drive. Shifting of the operating point is due to the effect of the increased plate and screen currents on the cathode bias resistor. With a typical output stage using two 6BQ5/EL84 pentodes with a B+ of 310 volts the increase in cathode current and consequently in grid bias is about 40% with a sinusoidal input voltage.

However, when speech and music are used to drive the stage instead of sinusoidal input, the situation is entirely different. The average amplitude of the signal compared with the occasional peaks is now very small and consequently the average variation in cathode current is also very small. Because of the relatively long time constant of the bias network, the operating point even under peak signal conditions shifts so little that the stage can be considered as operating with virtually fixed bias.

Therefore, to approximate speech and music conditions, full sinusoidal drive and fixed bias should be used for measurements.

When a Class AB stage is designed using measurements based upon sinusoidal drive and cathode instead of fixed bias, increased distortion during peak passages of speech and music will result. (See figure 1.) To compensate for this, the quiescent operating point can be adjusted from Class AB_1 operation to a point nearer to Class B operation by increasing the cathode bias resistor. This involves a smaller zero-signal cathode current

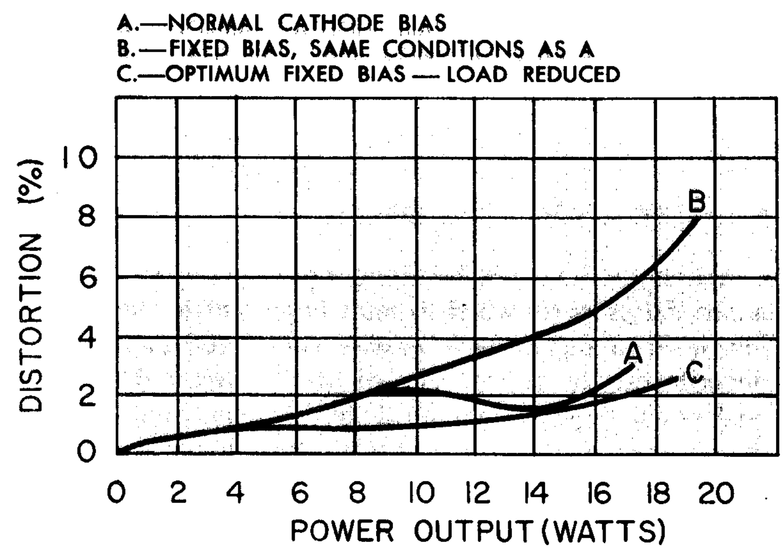


Figure 1

and plate to plate load resistance. As a result there are larger variations in the instantaneous plate and screen currents when the stage is driven. However, this effect is compensated for by the increased time constant in the cathode circuit which keeps shifting of the operating point to a minimum.

It should be noted that this low loading form of operation is suitable only for use in speech or music reproduction and produces excessive distortion when driven by sine-wave. For this reason it is difficult to measure directly the distortion levels which occur under practical conditions unless fixed bias is substituted for the cathode bias during test conditions.

Another method for improving performance is to use distributed loading in the output stage. Depending upon the precise loading used, the variation in plate and screen currents can be reduced to such a level that almost identical performance is obtained under cathode and fixed bias. This type of operation will be described in the section entitled Distributed Load Output Stage.

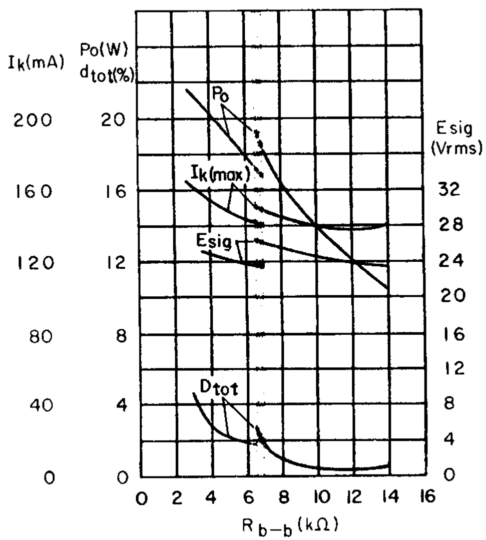


Figure 2

2. Triode Output Stage

A low level of distortion can be obtained in a push-pull triode stage operating Class AB. It has been found that power pentodes such as the 6CA7/EL34, triode connected, easily deliver 12 to 15 watts at harmonic distortion levels below 1% using a supply voltage of about 425 volts.

Maximum power output and the corresponding distortion vary somewhat with the value of the load impedance. This is illustrated in figure 2 where the performance of the 6CA7/EL34 power pentode is shown in triode connection.

For plate-to-plate-load impedance below 7KΩ either a common or separate cathode resistors (bypassed) can be used; above 7KΩ improved operation is obtained with an unbypassed common cathode resistor. Operating conditions approach Class A as the load impedance is raised and optimum performance for high quality operation is obtained with a load impedance of about 10KΩ.

This type of output stage (Williamson) has been used for a number of years in high quality amplifiers. Because of the low inherent distortion, less negative feedback is necessary to give acceptable linearity as compared with the amount of feedback required in pentode or tetrode output stages of similar power outputs. Furthermore in three or four stage amplifiers with most of the feedback applied over the whole amplifier (including the output transformer) it is possible to obtain increased stability for a given distortion level.

3. Distributed Load Output Stage

Although the triode push-pull output stage has great value (if distortion is a primary consideration) its low efficiency and limited power output are usually serious disadvantages. The distributed load output stage seems to have overcome these disadvantages while retaining the lower distortion of the triode stage. This type of operation involves the application of negative feedback in a non-linear manner through the screens. The screens of the output tubes are supplied through taps on the primary of the output transformer (see figure 3). Distributed load characteristics are intermediate between pentode and triode operation and approaches triode operation as the percentage of primary turns to the plate and screen circuits increases.

Under optimum conditions, the distributed load circuit delivers about 65% of the power of the equivalent pentode stage, but with considerably lower distortion. With the output at the level of the equivalent triode output stage, the distortion is reduced to triode magnitude. At the same time the output impedance is reduced to a level comparable with that of the conventional push-pull triode stage.

Laboratory experiments have indicated that with a common winding ratio of 0.2 (that is 20% of the winding common to plate and screen circuits), the distortion level is comparable to triode connection. Also it has been found that at higher outputs appreciable improvement is obtained if the common winding ratio is increased further. The best overall performance has been obtained with a percentage of about 40 - 45%. Approximately 60 watts can be obtained from a pair of 6CA7/EL34 with only about 2.5% distortion at the start of grid current.

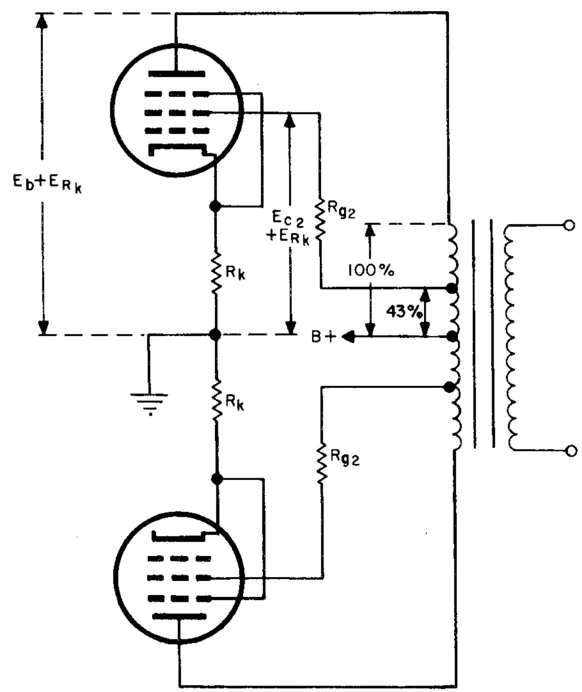


Figure 3

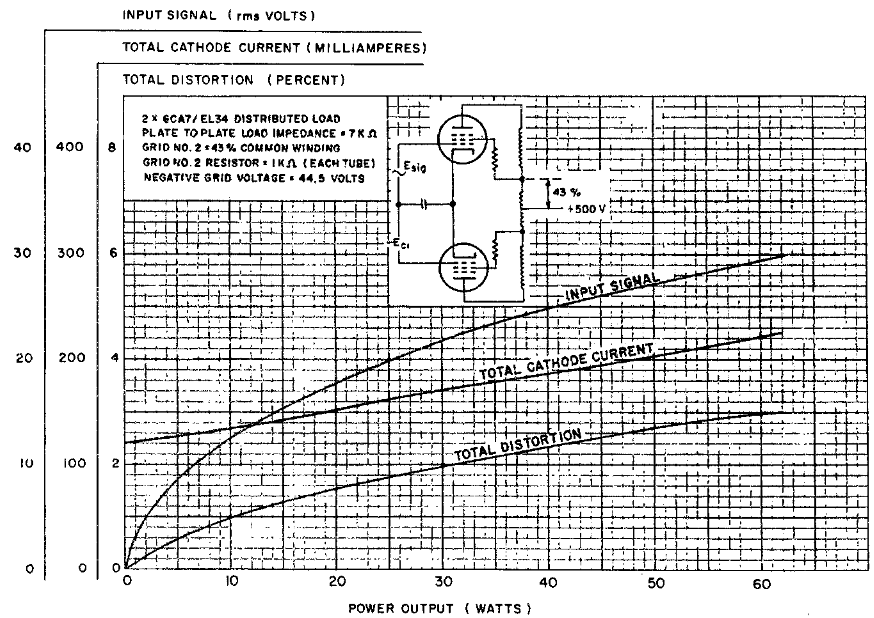


Figure 4

OPERATING CHARACTERISTICS OF 6CA7/EL34 AND 6BQ5/EL84 TUBES IN TRIODE, PENTODE, AND DISTRIBUTED LOAD OPERATION

TUBE TYPE	MODE OF OPERATION	OPERATING CONDITIONS					TOTAL DISTORTION (%)					
		E_b (volts)	E_{g2} (volts)	R_k (ohms)	$R_{p\text{-}p}$ (K ohms)	R_{c2} (ohms)	10W	14W	20W	30W	40W	60W
6CA7/EL34	Triode Connection	400	*	470 (each tube)	10	*	0.5	0.7	—	—	—	—
6CA7/EL34	Distributed Load 20% common winding	400	400	470 (each tube)	7.0	1000 (each tube)	0.7	0.8	1.0	1.5	5.0	—
6CA7/EL34	Distributed Load 43% common winding	400	400	470 (each tube)	6.6	1000 (each tube)	0.6	0.7	0.8	1.0	—	2.5
6CA7/EL34	Pentode Connection	330	330	130 (common)	3.4	470 (common)	1.5	2.0	2.5	4.0	6.0	—
							5W	10W	15W			
6BQ5/EL84	Triode Connection	300	*	150 (common)	10	*	1.0	—	—			
6BQ5/EL84	Distributed Load 20% common winding	300	300	270 (each tube)	6.6	—	0.8	1.0	1.5			
6BQ5/EL84	Distributed Load 43% common winding	300	300	270 (each tube)	8.0	—	0.7	0.9	—			
6BQ5/EL84	Pentode Connection	300	300	270 (each tube)	8.0	—	1.5	2.0	2.0			

* Screen connected to plate

TABLE 1

Figure 4 shows the typical performance of a 6CA7/EL34 when operated with the primary windings tapped at 43% of the turns. The power output shown is into the load.

From the distortion figures in table 1, it appears that little advantage would be gained by further approaching triode operation. There are, however, several advantages in operating at about 40% of the primary turns. In the first place, almost identical performance is obtained under cathode bias and fixed bias because the closer we approach Class A triode operation the less variation we get in plate and screen currents as the stage is driven. Secondly, in common with normal triode operation, power output and distortion are less dependent on the value of the load impedance. With the tap at about 40% of the turns little change in performance is observed by a change in plate-to-plate load impedance of 6KΩ to 9KΩ.

E. PHASE INVERTER AND/OR DRIVER STAGE

The phase inverter delivers signals of opposite phase and appropriate amplitude to the grids of the push-pull output tubes. These signals should be balanced and of low distortion content. In addition, if a considerable amount of gain can be obtained it may possibly eliminate the need for additional

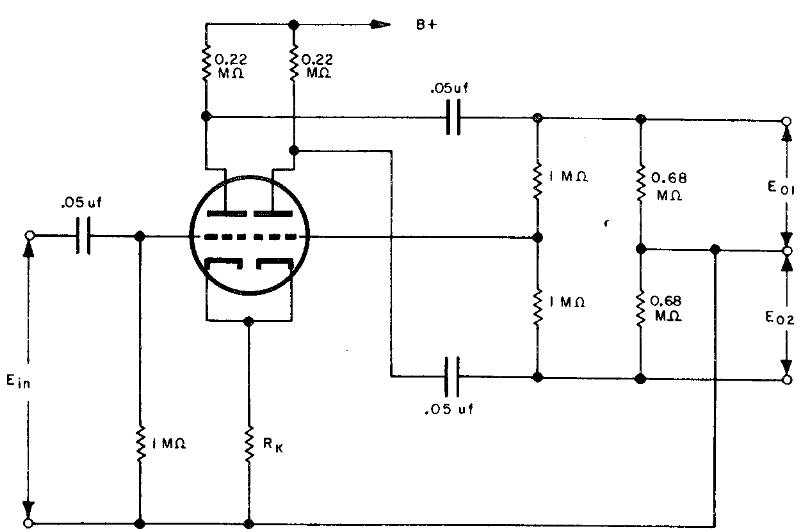


Figure 5

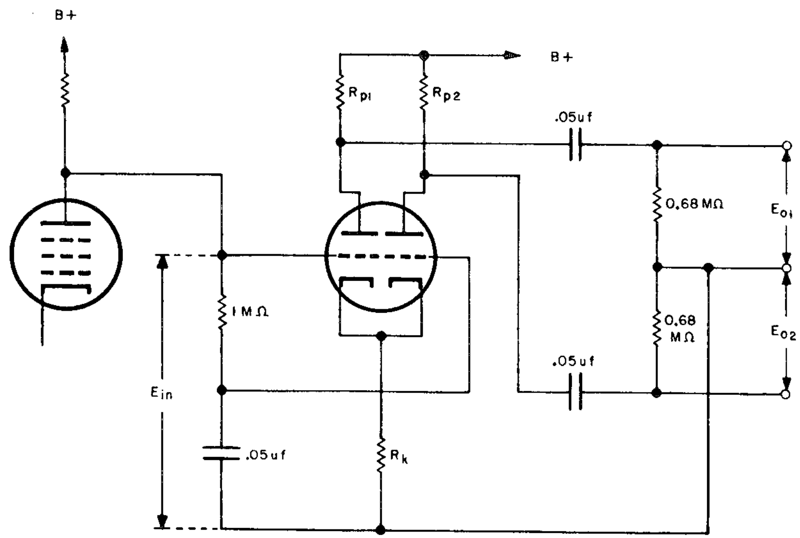


Figure 6

stages. Naturally, the fewer the stages, the less the phase shift will be so that stability can be maintained even with heavy negative feedback.

Some designers prefer a high gain at the cost of high distortion and use a higher negative feedback factor to reduce the extra distortion produced. Other designers prefer a minimum of distortion in the phase inverter stage and obtain their gain by an extra amplifier stage. A typical circuit used by designers of the first group is shown in figure 5 whereas figure 6 shows a low distortion phase inverter. The high mu, low hum twin triode, 12AX7/ECC83 is used in both circuits. Table 2 shows the operating conditions for this tube in each circuit.

Although the first circuit does achieve higher output voltage, the second achieves much lower distortion and very little phase shift because of the phase inverter. Since the gain of the 12AX7/ECC83 is still reasonable in the cathode coupled circuit, it has become very popular with the designers of high quality equipment.

The drive required for a pair of 6CA7/EL34 type pentodes for full output is about 2 x 21 volts rms while the 6BQ5/EL84 type pentodes require 2 x 10 volts rms. In both cases the requirements are similar for triode, pentode, or distributed load connection. This implies that the input voltage of the 12AX7/ECC83 with a 350 volt plate supply should be in the order of 0.4 volts rms to drive a pair of 6CA7/EL34 pentodes in push-pull; with a cathode coupled phase inverted roughly 0.9 volts rms is required. For a pair of 6BQ5/EL84 pentodes these figures are 0.17 and 0.4 volts rms respectively with the plate supply at 250 volts.

With 26 db of feedback, the input voltage requirements are increased by a factor of 20. In this case, the normal phase inverter requires a preamplifier stage. One of the most effective preamplifier tubes in use today is the 6267/EF86, a low noise pentode. If this tube is adjusted for maximum gain, which is the general practice, the total sensitivity of the complete amplifier is too high for use with a high output pickup. In the amplifier shown on page 26 advantage is taken of the excess gain by incorporating tone control circuits. On the other hand when a magnetic pickup is used, the sensitivity is usually insufficient. In that case additional stages of preamplification will be required and this again can be used for control and equalization networks.

With the problem of sensitivity in mind a new type of phase inverter has been developed in which a combination of positive and negative feedback leads to an extremely high gain com-

OPERATING CONDITIONS OF PHASE INVERTERS (Figures 5 and 6)

	FIGURE 5		FIGURE 6		
Plate Supply Voltage	250	350	250	350	volts
Cathode Resistor	1200	820	68,000	82,000	ohms
Plate Resistors	0.22	0.22	0.1	0.15	megs
Output Voltage	35	45	20	35	rms volts
Gain	58	62	25	27	—
Total Distortion	5.5	3.5	1.8	1.8	%

TABLE 2

bined with adequate stability and reasonably low distortion. A gain of about 800 can be obtained with this circuit but the attenuation at high frequencies is considerable. Therefore, the gain of the practical circuit shown in figure 7 has been reduced to about 220.

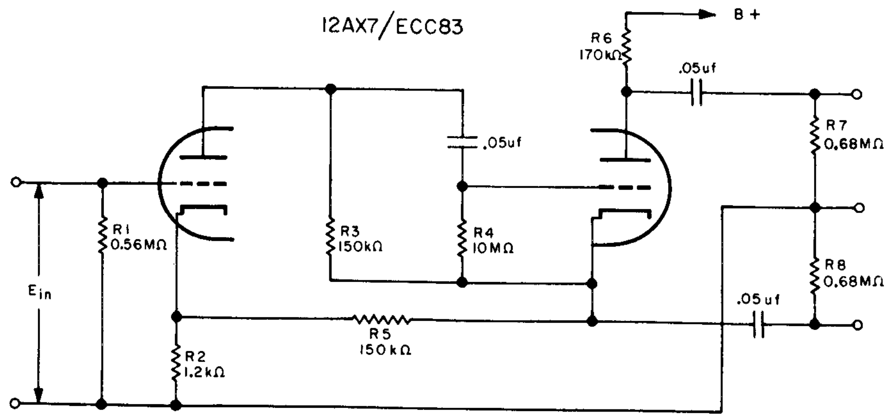


Figure 7

The plate of the left hand section of the 12AX7/ECC83 is fed through R3 from the cathode of the right hand section. The low end of the right hand cathode resistor is connected to the left cathode resistor R2 resulting in positive feedback which increases the gain of the circuits. The positive feedback through R2 might easily lead to instability if the lower end of R3 were not connected to the cathode of the right hand section. The cathode circuit acts as a high resistance in series with the plate resistor of the left hand section for d.c. This results in negative feedback to the plate of the left hand section, preventing runaway.

This phase inverter and conventional push-pull output stage when used with 26 - 30 db of negative feedback makes a voltage amplifier stage unnecessary. If separate tone and equalizing controls are used, then a voltage amplifier stage is required.

F. VOLTAGE AMPLIFIER STAGE

1. For Push-Pull Amplifiers

The input stage of a high quality amplifier requires high gain to provide a good signal to noise ratio and to compensate for the reduction in gain resulting from the use of

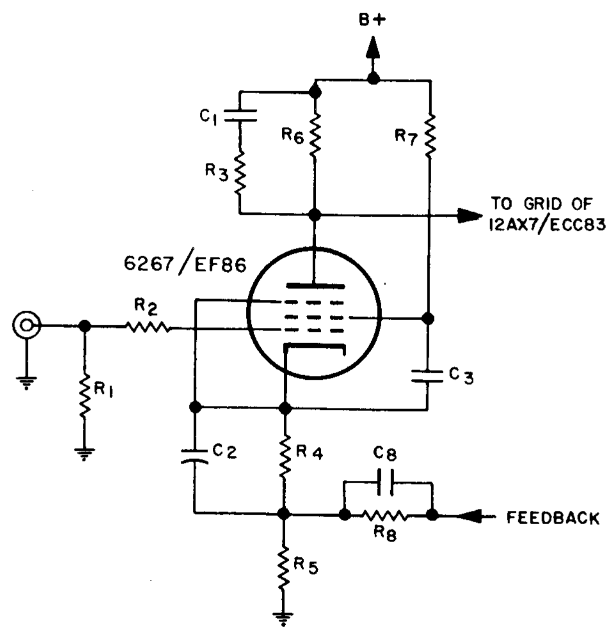


Figure 8

negative feedback. This high gain makes a low hum and noise level a necessity in this stage. The recommended tubes for input stages are the Amperex low-noise pentode 6267/EF86 and the twin triode 12AX7/ECC83.

A conventional 6267/EF86 voltage amplifying stage is shown in figure 8. The plate load is shown shunted by a CR network which shifts the phase ahead and thus increases the stability of the amplifier at high frequencies. Negative feedback from the secondary of the output transformer is introduced across R5 in the cathode circuit. The feedback network C8, R8 shifts the ultrasonic frequencies and thereby increases stability. The stage is intended for direct coupling to the input grid of a cathode-coupled phase inverter so that the phase shift at low frequencies is minimized and the low frequency stability of the amplifier with feedback is improved.

2. For Single-Ended Amplifiers

In a single-ended output stage, pentodes are used because of their high power output. The inherent distortion of single-ended stages is high and a large amount of negative feedback is needed to reduce the distortion to an acceptable level. Consequently, a very high gain input stage is necessary, particularly if only one stage of voltage amplification is used. The gain of a voltage amplifier can never reach the theoretical maximum represented by the amplification factor, μ, of the tube. The gain, in fact, is given by the expression $\frac{\mu R_p}{R_p + r_p}$ where r_p and R_p, are respectively the internal resistance of the tube and external load resistance.

Practical considerations place a limit on the amount that the plate load can be increased. For example, the maximum depends on the frequency response desired. The load will normally be less than 500KΩ which will give a stage gain of about 250 with a 6267/EF86 operating at a supply voltage between 250 and 350V. In this situation the plate and screen voltages will be 60 and 70V respectively.

If a restricted frequency response is acceptable, much higher values of plate load may be used. These higher values produce "starvation" operating conditions: tube currents and voltages are much smaller than those of conventional stages but the stage gain is much higher. The frequency response is poorer under starvation conditions, but it can be improved considerably by the use of feedback.

Because of the high value of plate load for starvation conditions, the input impedance of the following stage has to be high. Preferably, it should not be less than 10MΩ. Direct coupling to the grid of the following stage is possible, and the screen of the voltage amplifier can be fed from the cathode circuit of the following stage. Because of the low values of current and voltage and the favorable effect of these on negative grid current, starvation conditions are useful in high input impedance voltage amplifiers.

G. PREAMPLIFIER STAGE

Preamplification may be required with power amplifiers to provide extra voltage gain when certain kinds of input sources are used. It is usually convenient to include the treble and bass controls and the volume control in the preamplifier. Also, the preamplifier can be designed to compensate for the recording characteristics.

Preamplifiers for stereophonic equipment must of necessity be more complex than monophonic units because they are essentially two monophonic circuits in one. Furthermore, coupling must exist between corresponding controls in each section of the stereophonic circuit so that comparable adjustments can be made to both channels. If both channels must be identical, then controls can be ganged. However, if the channels are not identical, concentrically operated controls which will permit individual adjustment of the channels are needed.

Even if nominally identical channels are used, the acoustical outputs from the two loudspeakers will not be exactly the same unless precautions are taken. Differences can occur because of a slight variation in output from each section of the stereophonic pickup head, the unequal sensitivities of the loudspeakers, and the very small difference in gain of the two channels. If the volume control consists of a dual-concentric potentiometer, individual adjustment to each channel will correct any lack of balance. If a dual-ganged potentiometer is used, a special balance control is required. It should be possible to increase and decrease the gain of one channel with respect to the other, and it is desirable that the degree of control available in either case should be the same. This obviously calls for a symmetrical "center-zero" arrangement.

Another requirement of a stereophonic preamplifier which is not necessary in a monophonic circuit is a switch to transfer the input signals from one channel to the other. Also, this switch usually serves to combine both channels so that the set can be used with monophonic records.

All preamplifiers, because they provide the signal to the power amplifiers, must be designed to inject as little hum and noise as possible into the main amplifier. This is because hum and noise from the early stages have the same effect as signal voltages and are not reduced by feedback in the power amplifier. Feedback in the preamplifier stage cannot be used as it would flatten the frequency response in opposition to the equalization network and tone controls.

H. POWER SUPPLY

The design of power supplies for both high quality and economical amplifiers has become relatively standard in the last few years. Previously it was thought that the only way to keep the hum level low was to use a choke input. However, it has been demonstrated that very low distortion amplifiers are possible with a capacitor input filter, the output stage being fed from the first capacitor. An examination of the various schematics on pages 18 through 31 clearly indicate the relative standardization of power supply design. Special note should be taken of the power supplies on pages 20 and 25 where silicon doublers are used. Silicon rectifiers with low PIV ratings can be used advantageously in circuits such as these because low voltage, high current operation produces reduced peak inverse voltages. This can effect appreciable cost reduction because the power transformer requires much fewer high voltage windings (less than ½ for the doubler) and no center tap or 5 volt winding. In addition the silicon full wave doubler used in these circuits (OA210) achieves extremely good regulation.

It is advantageous for rectifier tubes to be indirectly heated because this prevents the breakdown voltage rating of the input capacitor from being exceeded when the set is first turned on. Also the heating up time of the rectifier tubes should be somewhat longer than that of the power tubes so that the voltage rating of the filter capacitors need not exceed the operating voltage to any large extent.

The transformer resistance (Rt) must not be less than the minimum value quoted in the rectifier tube data. This transformer resistance may be determined as follows. The resistance (Rp) of the primary and the resistance of one of the secondaries (Rs) are measured. The transformer resistance is $Rt = Rs + n^2Rp$ in which n is the winding ratio (voltage ratio) between one secondary and the primary. (See figure 9.) If the value found is below the minimum value given in the tube ratings, a resistor with a value of Rx = Rt min — Rt must be connected in series with each rectifier plate. Each resistor carries half the direct current and half the ripple current so that its power rating should be based on a current of 1.2 times the total direct current delivery by the rectifier. As an alternate scheme, the two resistors may be replaced by a single one of the same value connected in series with the cathode of the rectifier. In this case the required power rating should be 2.4 times the total direct current. The input capacitor should be able to handle a ripple current which is approximately 1.4 times the total direct current delivered by the power supply.

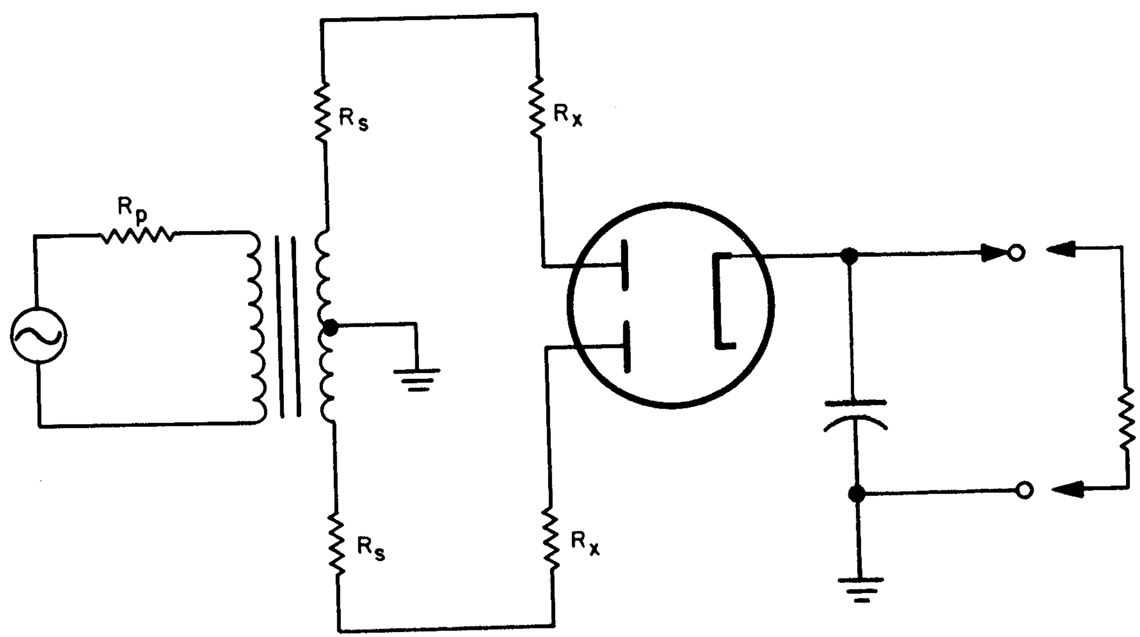


Figure 9

SPECIFICATIONS

Output Voltage

for 10 watt amplifier	40 mV
for 20 watt amplifier	250 mV

Sensitivity

Crystal Pickup	
micro-groove	50 mV
78 rpm	150 mV
Magnetodynamic Pickup	
micro-groove	3 mV
78 rpm	9 mV
Microphone	6 mV
Tape Playback	3 mV at 5000 cps
Tuner Input	250 mV
Auxiliary	250 mV

Harmonic Distortion 0.15%

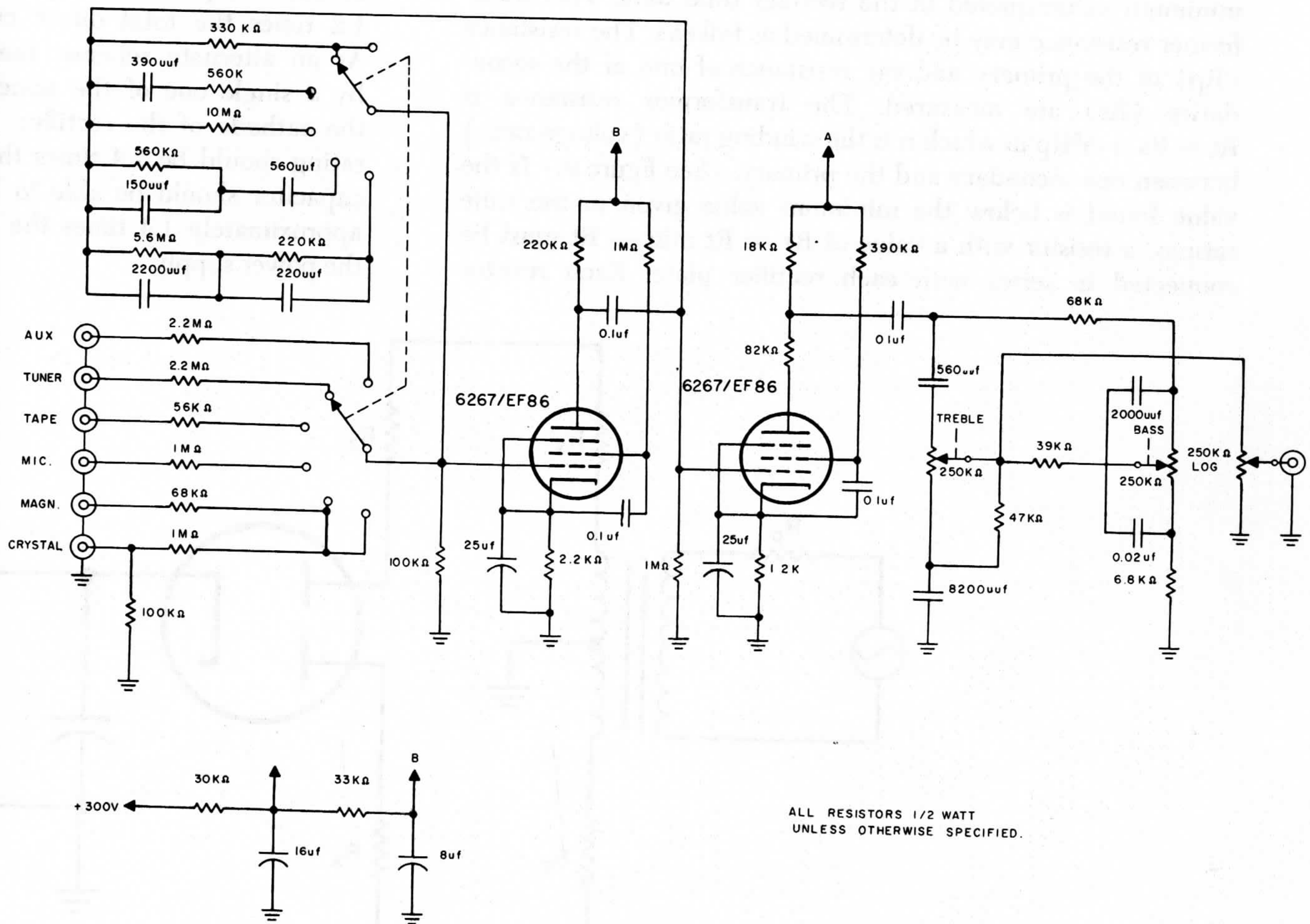
Hum and Noise Levels (Below 10 Watts)

Micro-groove Pickups	55 db (below 10 watts)
78 rpm Pickups	57 db (below 10 watts)
Microphone	44 db
Tape	53 db

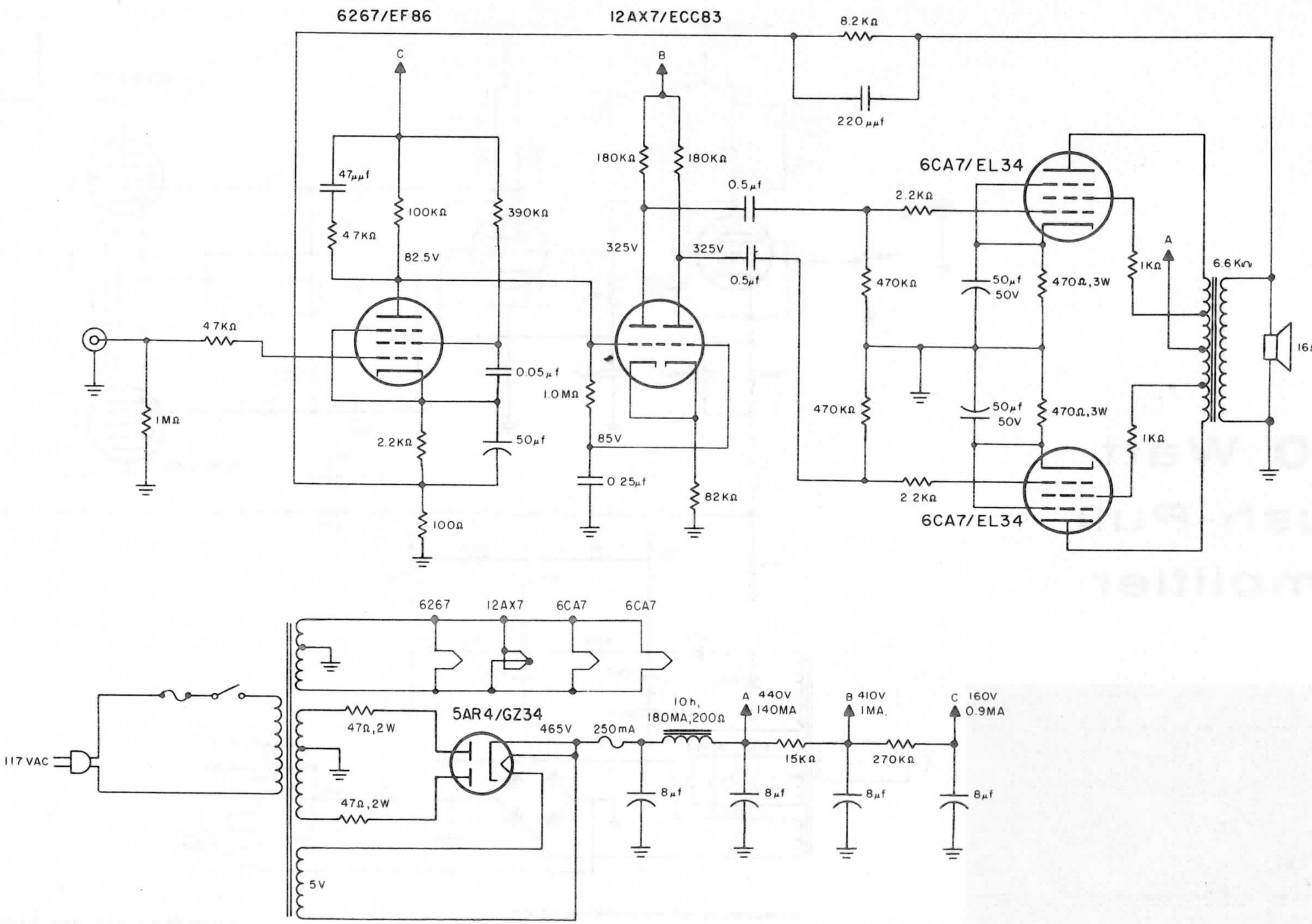
Tone Control

Max. Bass Boost	+17 db at 50 cps
Max. Bass Cut	−14 db at 50 cps
Max. Treble Boost	+14 db at 10,000 cps
Max. Treble Cut	−15 db at 10,000 cps

Two-Tube Preamplifier



ALL RESISTORS 1/2 WATT
UNLESS OTHERWISE SPECIFIED.



ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED.

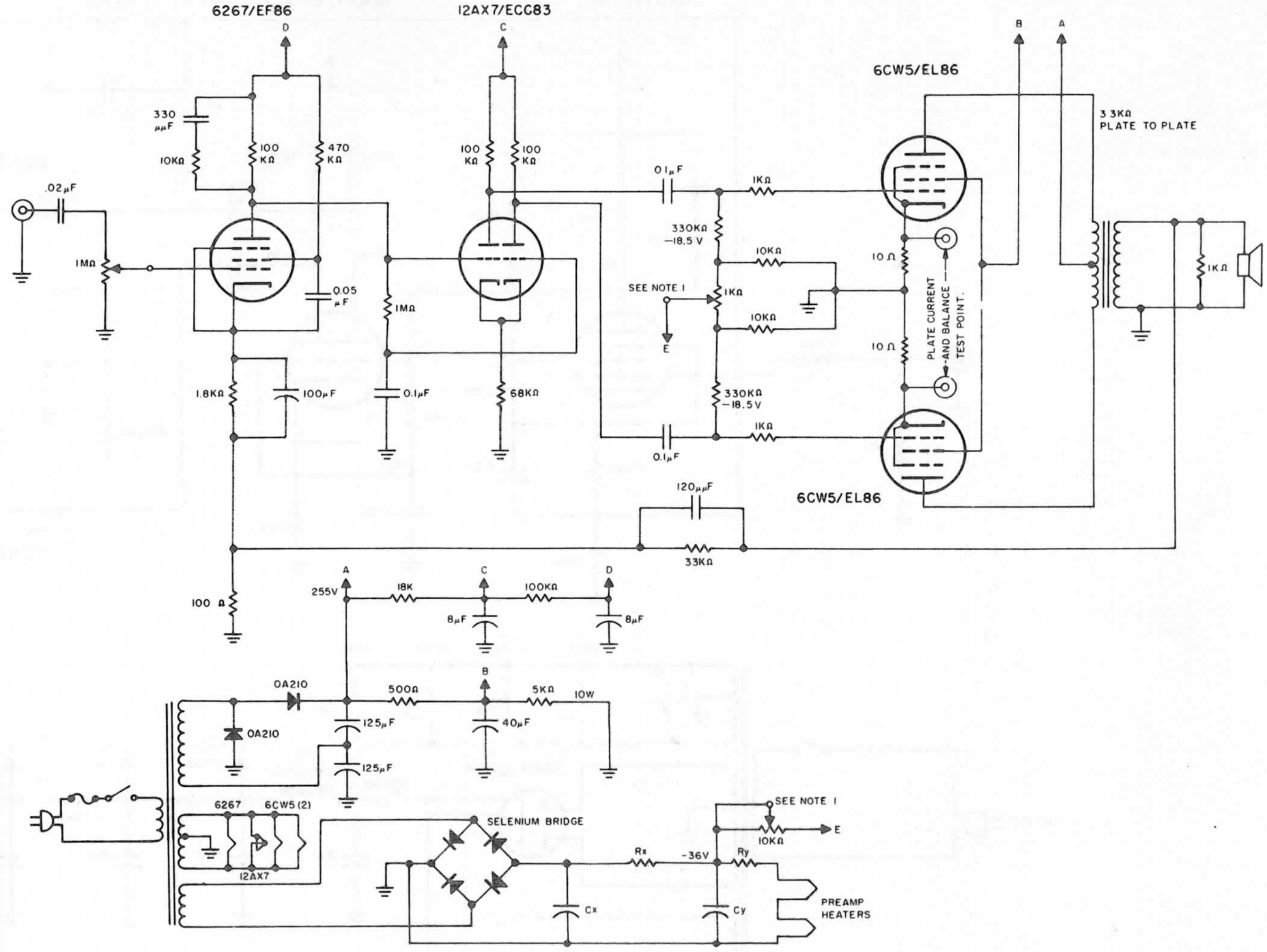
30 Watt, Distributed Load, Push-Pull Amplifier

SPECIFICATIONS

Power Output	30 watts
Input Sensitivity	250 mV
Frequency Response	5 db between 30 cps and 40,000 cps
Harmonic Distortion	1%
Hum and Noise	—80 db
Feedback	30 db

20 Watt Push-Pull Amplifier

SPECIFICATIONS	
Power Output	20 watts
Sensitivity	50 mV
Harmonic Distortion	2%
Frequency Response	±0.5 db between 10-30,000 cps
Controls	
Treble	+10 db to −10 db at 10,000 cps
Bass	+11 db to −5 db at 20 cps
Hum and Noise Level	−73 db
Feedback	20 db



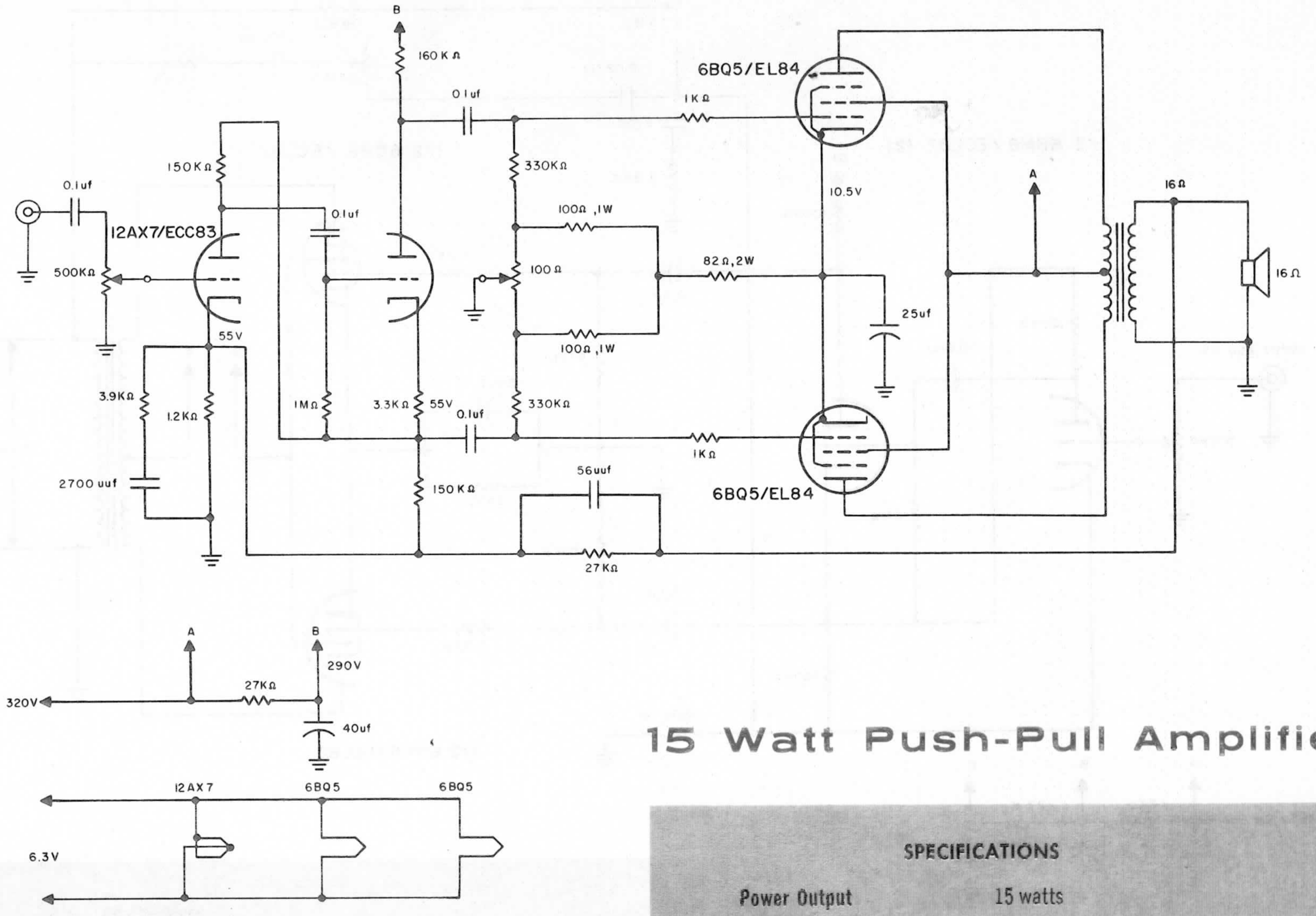
ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED

Rx DEPENDS UPON TRANSFORMER USED (SEE TUBE DATA)

Ry DEPENDS UPON NUMBER OF PREAMP HEATERS IN CIRCUIT

1 - ADJUST FOR 45 mA PLATE CURRENT PER TUBE WITH NO DRIVE APPLIED.

CAUTION — This circuit is intended for speech and music reproduction only. It is not recommended for continuous, full signal, sine-wave drive.

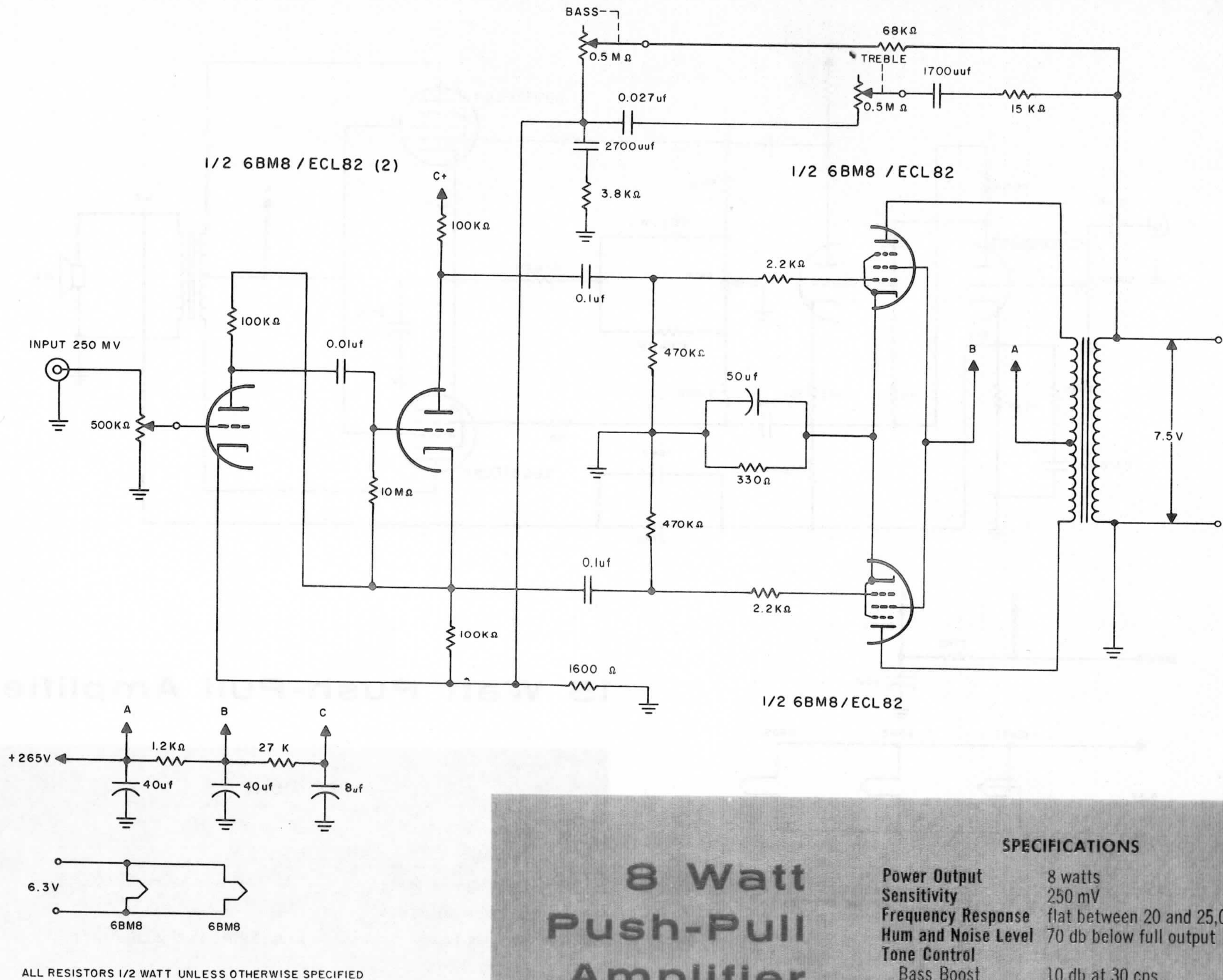


ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED

15 Watt Push-Pull Amplifier

SPECIFICATIONS

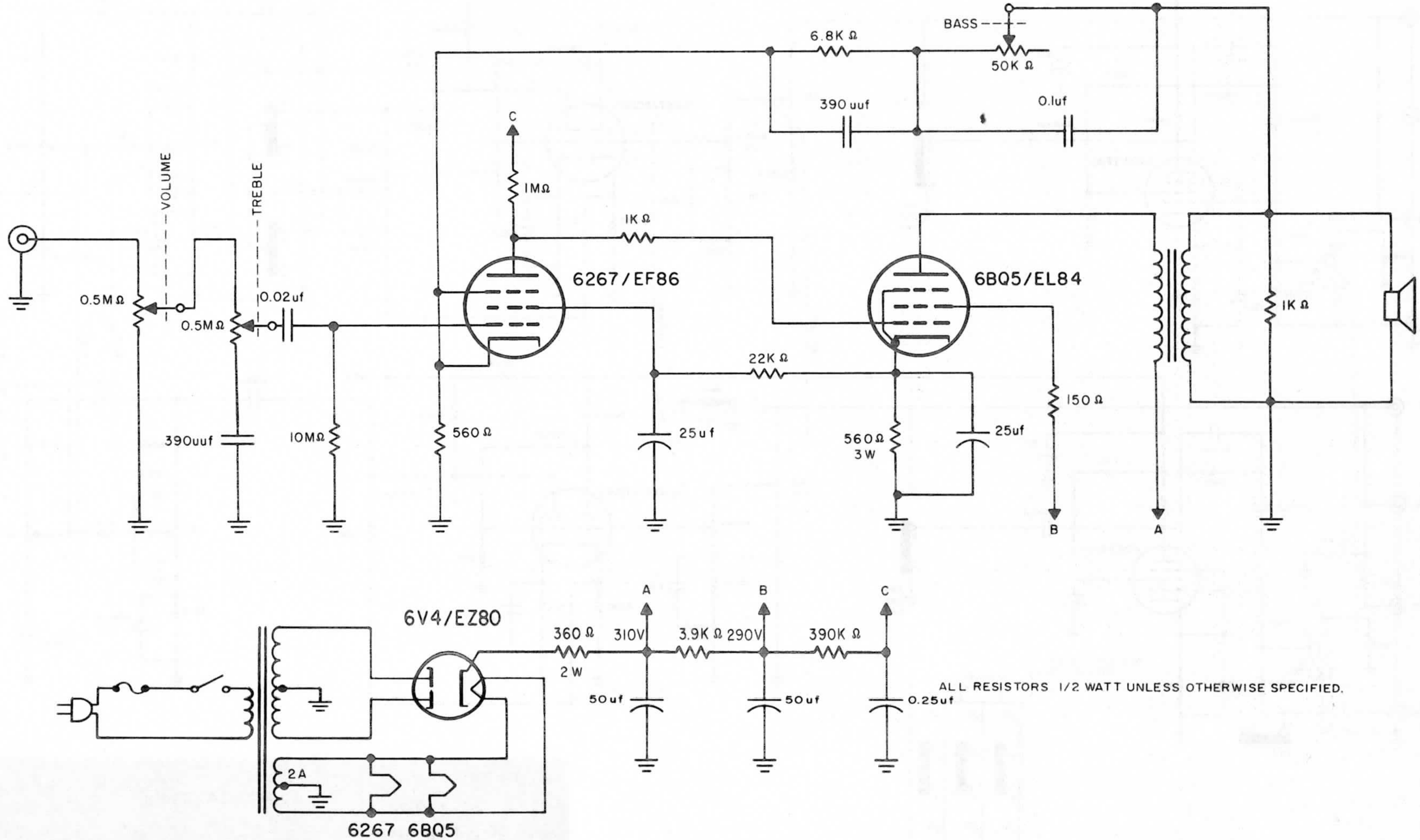
Power Output	15 watts
Sensitivity	600 mV
Frequency Response	1.5 db between 20 and 20,000 cps
Harmonic Distortion	1%
Damping Factor	Greater than 15 at 20 to 20,000 cps
Feedback	27 db



8 Watt Push-Pull Amplifier

SPECIFICATIONS

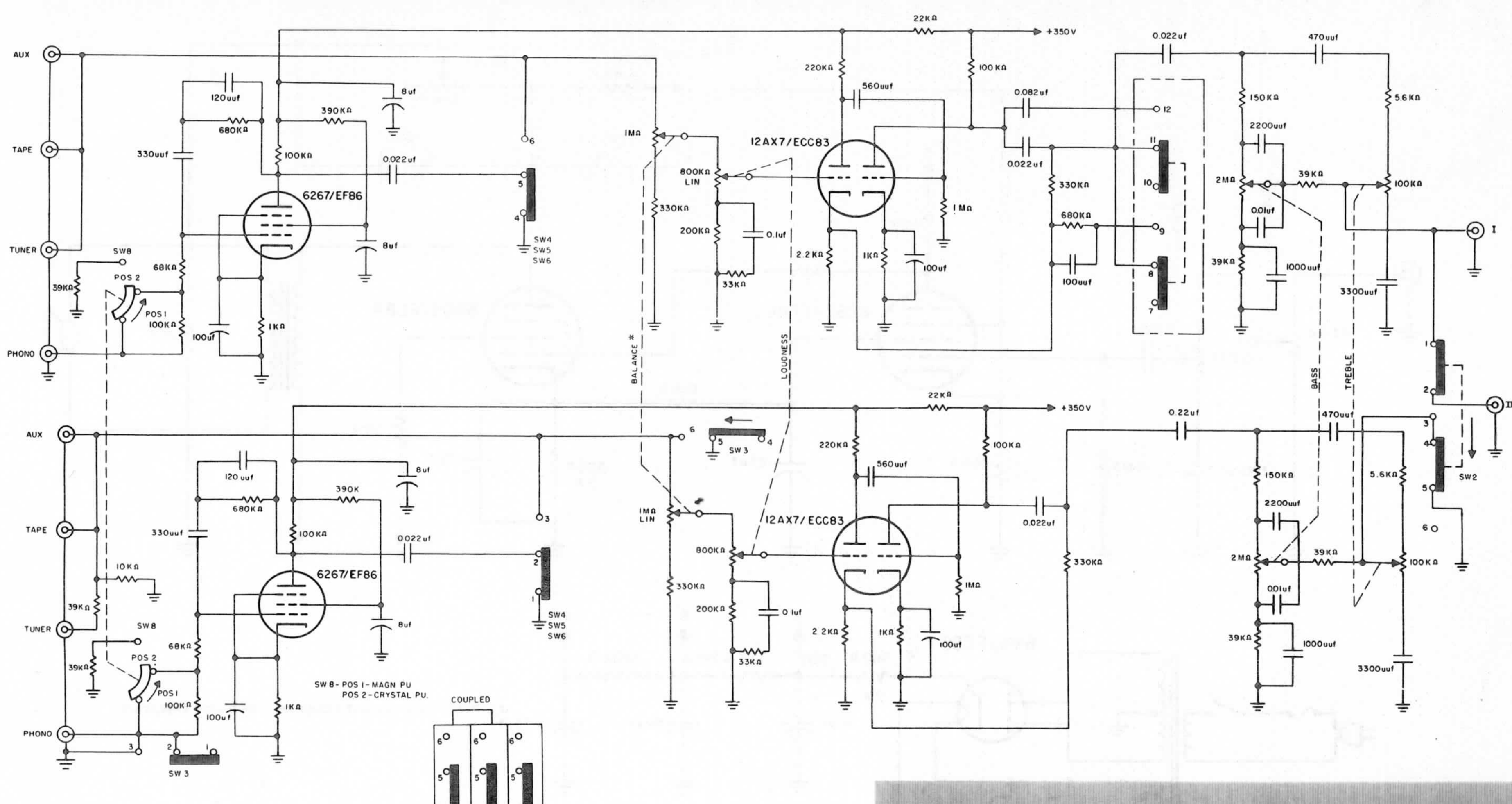
Power Output	8 watts
Sensitivity	250 mV
Frequency Response	flat between 20 and 25,000 cps
Hum and Noise Level	70 db below full output
Tone Control	
Bass Boost	10 db at 30 cps
Treble Cut	—15 db at 15,000 cps
Feedback	10 db

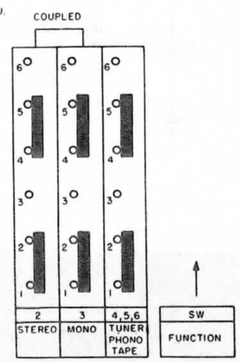


3 Watt, Single-Ended, Amplifier

SPECIFICATIONS

Power Output	3 watts
Harmonic Distortion	1%
Sensitivity	100 mV
Hum and Noise Levels	−70 db at full output
Frequency Response	flat within ±1 db from 20 to 40,000 cps
Tone Control	
Max. Treble Cut	approx. 20 db at 10,000 cps
Max. Bass Boost	approx. 15 db at 70 cps





ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED.

*BALANCE POTENTIOMETERS MOVE IN OPPOSITE DIRECTIONS.

Low Noise Stereo Preamplifier

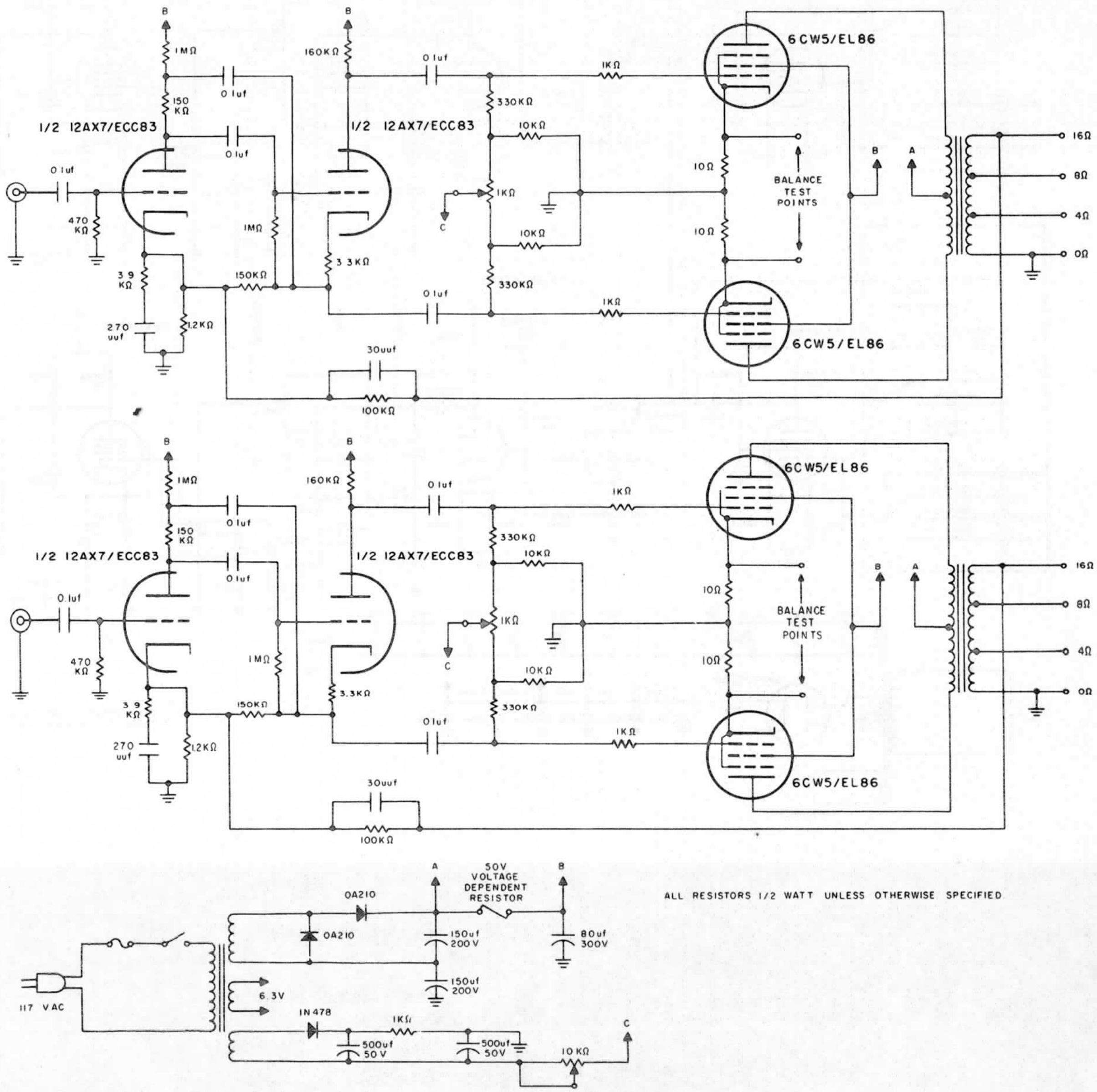
SPECIFICATIONS

Output Voltage	600 mV
Input Sensitivity	
Tape	60 mV
Tuner	300 mV
Magnetodynamic Pickup	5 mV with full equalization
Crystal Pickup	150 mV with full equalization
Controls	
Volume	has loudness control for levels lower than—30db
Treble	±10 db at 10,000 cps
Bass	±10 db at 50 cps
Left-Right Adjustment	±6 db to ∓6 db

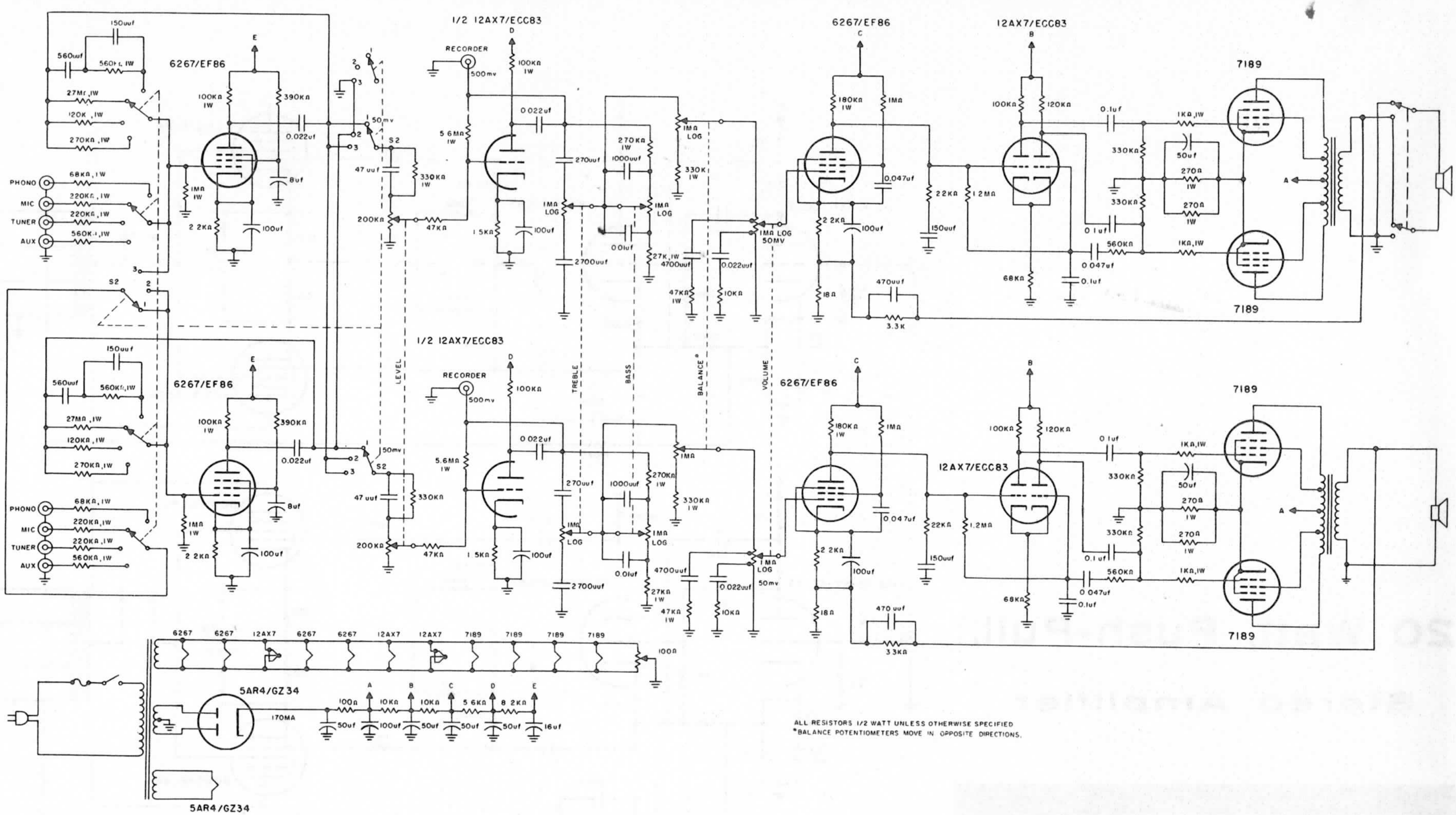
20 Watt, Push-Pull, Stereo Amplifier

SPECIFICATIONS

Power Output	20 watts
Sensitivity	50mV
IM Distortion	2%
Frequency Response	±0.5 db between 20-30,000 cps
Hum and Noise Level	65 db
Feedback	12 db



CAUTION — This circuit is intended for speech and music reproduction only. It is not recommended for continuous, full signal, sine-wave drive.



14 Watt, Distributed Load, Push-Pull Stereo Amplifier

SPECIFICATIONS

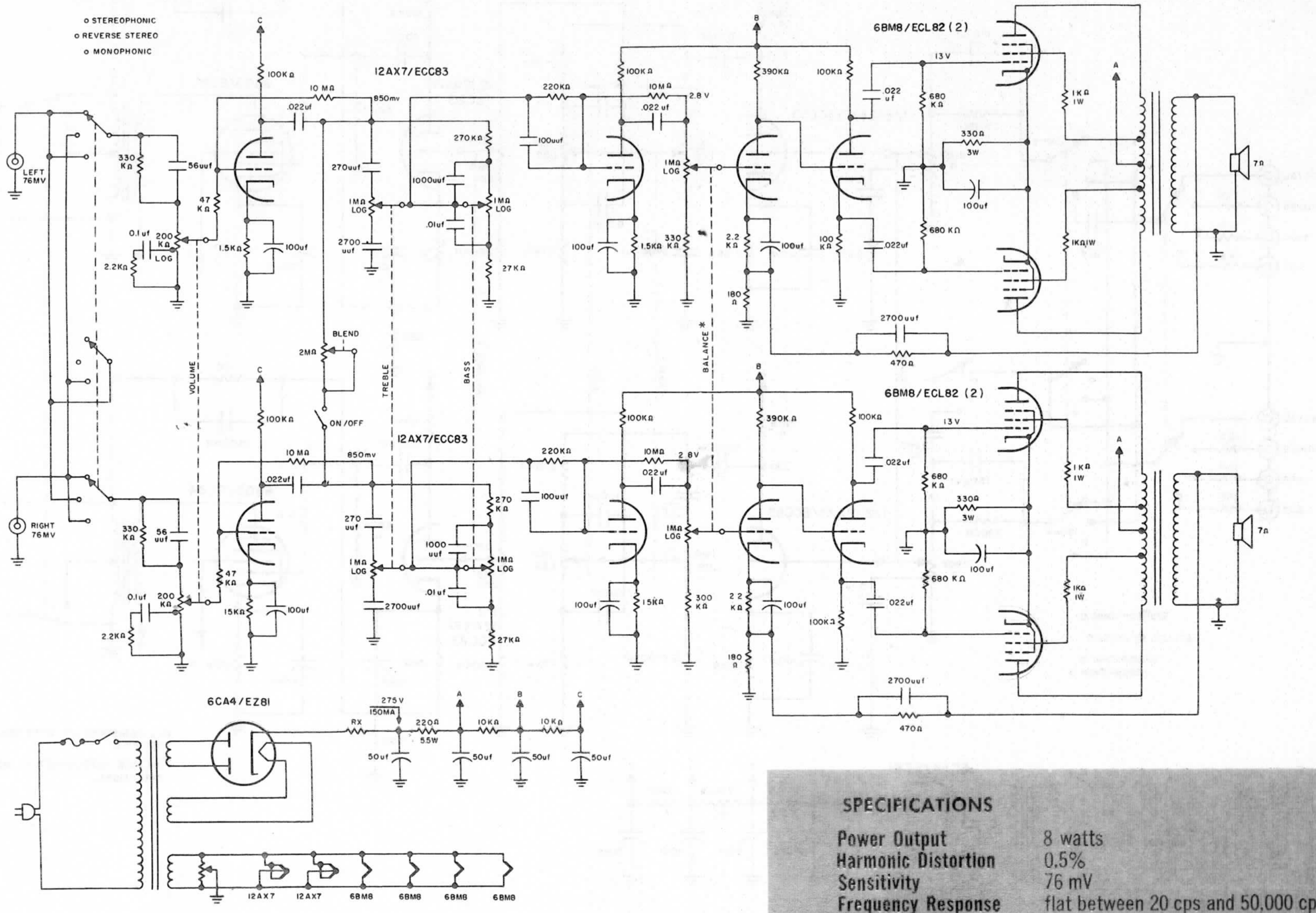
Power Output 14 watts
Harmonic Distortion 1%
Sensitivity
- Phono: 5 mV (Position I of input selector)
- Microphone: 5 mV (Position II of input selector)
- Tuner: 100 mV (Position III of input selector)
- Aux.: 100 mV (Position IV of input selector)

Frequency Response ±3 db between 20 and 70,000 cps

Controls
- Bass: 10 db boost, 16 db attenuation at 40 cps
- Treble: 8 db boost, 10 db attenuation at 10,000 cps

Hum and Noise Levels
- Phono Input: 60 db
- Microphone: 66 db
- Tuner: 70 db
- Aux.: 70 db

Equalization between ±2 db at 30 to 15,000 cps
Feedback 24 db
Power Consumption 120 watts

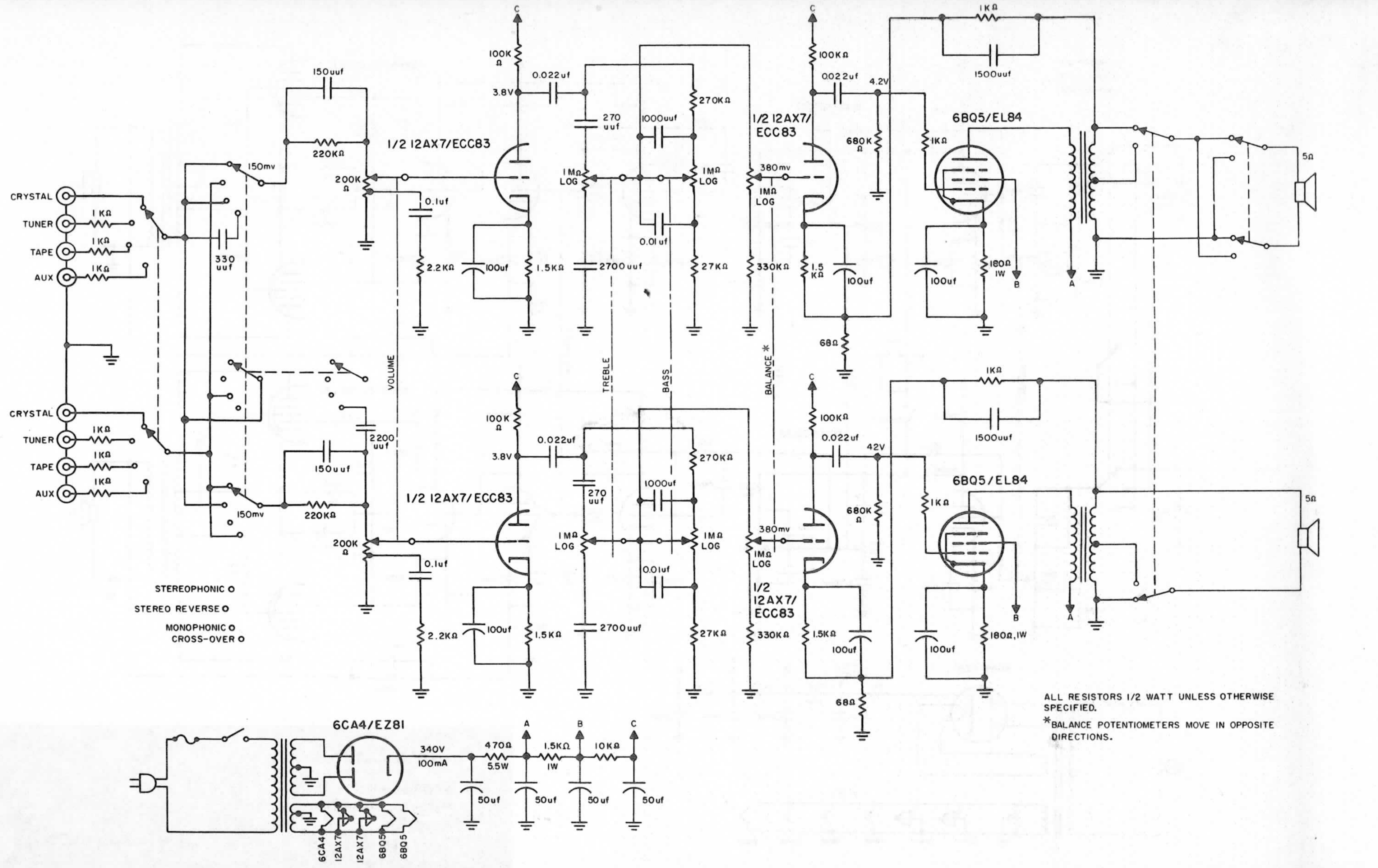


ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED
THE VALUE OF RX DEPENDS UPON THE TRANSFORMER USED.
(SEE TUBE DATA)
*BALANCE POTENTIOMETERS MOVE IN OPPOSITE DIRECTIONS

8 Watt, Push-Pull, Stereo Amplifier

SPECIFICATIONS

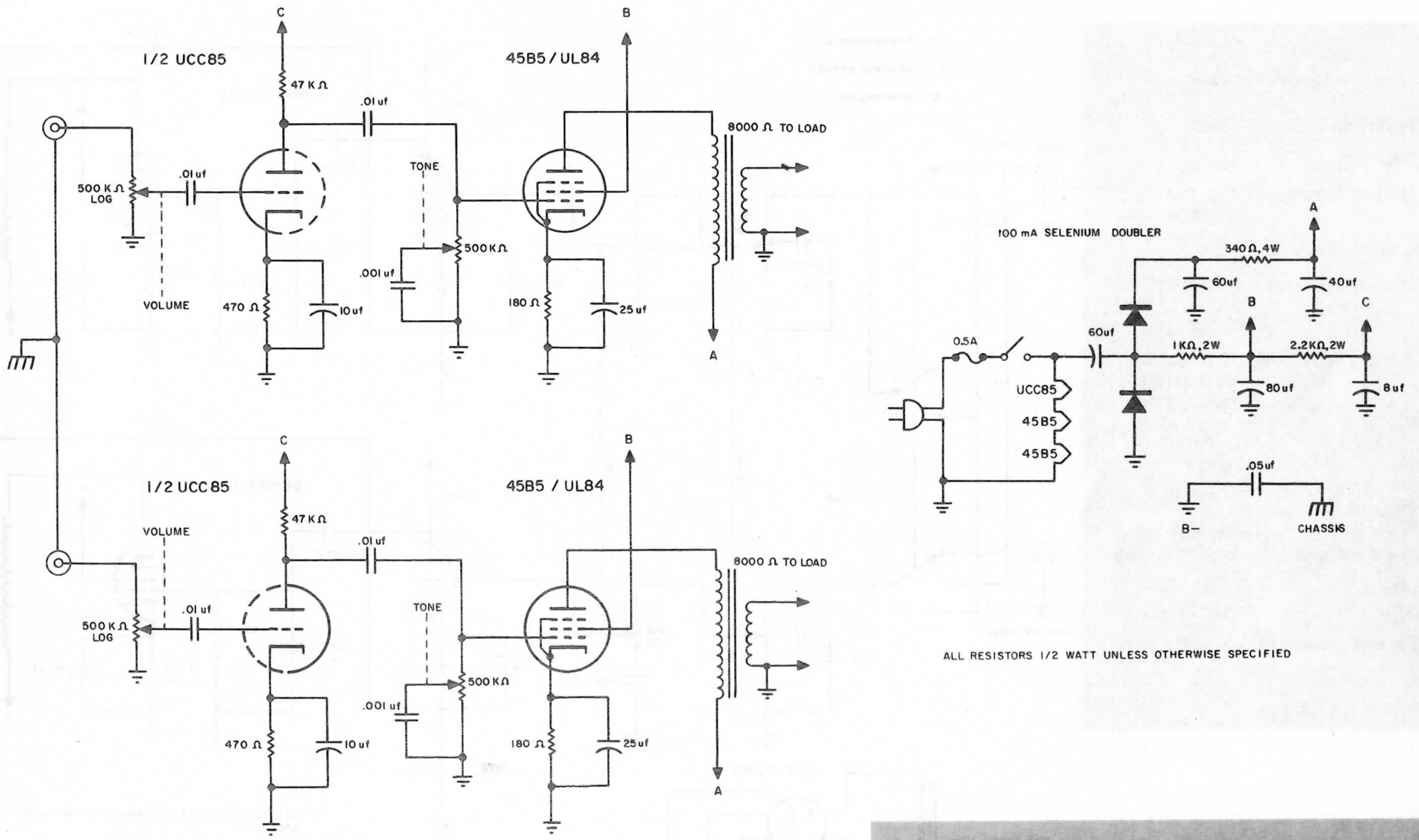
Power Output	8 watts
Harmonic Distortion	0.5%
Sensitivity	76 mV
Frequency Response	flat between 20 cps and 50,000 cps
Tone Control	
Max. Treble Cut	approx. 10 db at 10,000 cps
Max. Treble Boost	approx. 8 db at 10,000 cps
Max. Bass Cut	approx. 17 db at 40 cps
Max. Bass Boost	approx. 10 db at 40 cps
Balance Control	12 db (each channel)
Hum and Noise Level	65 db below rated output
Crosstalk	
at 1000 cps	less than 40 db
at 10,000 cps	less than 30 db
Power Consumption	55 watts



4 Watt, Single-Ended, Stereo Amplifier

SPECIFICATIONS

Power Output	4 watts	Treble	9 db boost, 12 db attenuation at 10,000 cps
Harmonic Distortion	3%	Balance	12 db attenuation (each channel)
Sensitivity	150 mV	**Crosstalk**	less than 35 db at 1000 cps
Hum and Noise Level	—70 db below rated output	**Feedback**	14 db
Frequency Response	—3 db between 20 and 45,000 cps	**Power Consumption**	68 watts (complete amplifier)
Controls			
Bass	10 db boost, 12 db attenuation at 40,000 cps		



3 Watt, Single-Ended, Stereo Amplifier

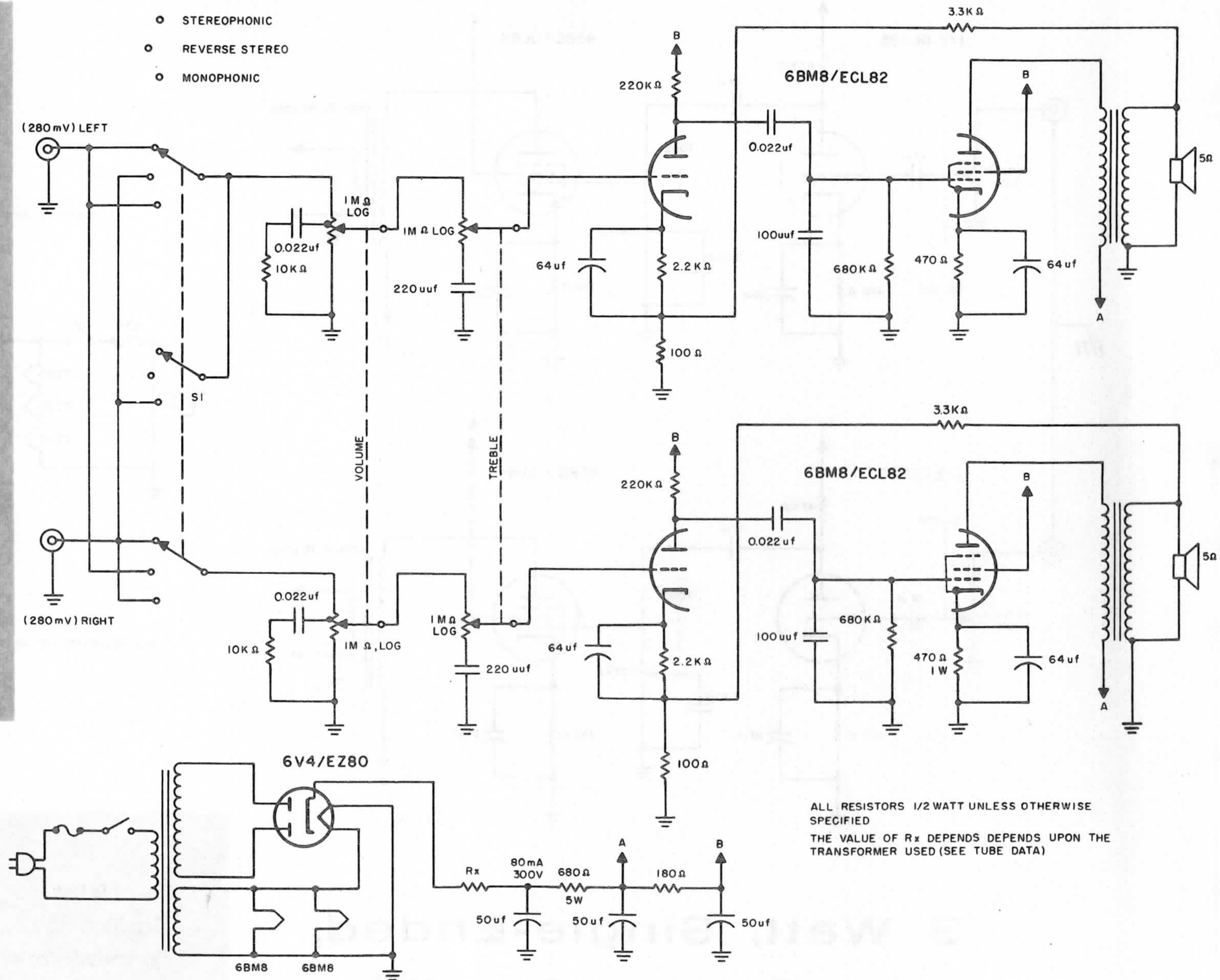
SPECIFICATIONS

Power Output	3 watts
Sensitivity	125 mV
Harmonic Distortion	10%
Frequency Response	—3 db between 150 and 40,000 cps
Tone Control Treble Cut	10 db at 10,000 cps

3 Watt, Single-Ended, Stereo Amplifier

SPECIFICATIONS

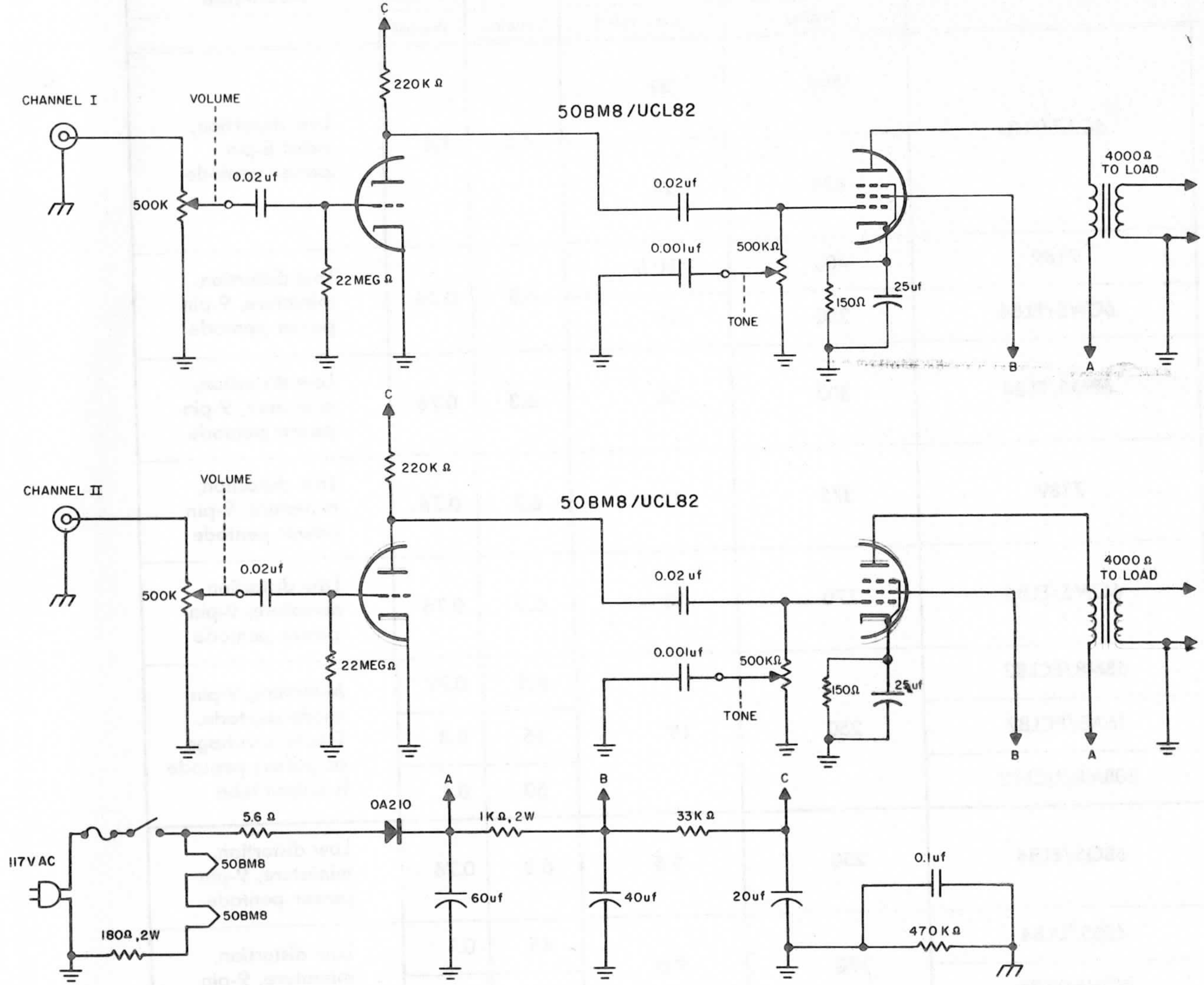
Power Output	3 watts
Sensitivity	280 mV
Frequency Response	3 db. from 30 to 30,000cps
Harmonic Distortion	5%
Tone Control Range	max. treble cut approx. 17 db at 10,000 cps
Hum and Noise Level	64 db below rated output measured with volume control completely counter-clockwise
Crosstalk	
at 1000 cps	less than 42 db
at 10,000 cps	less than 30 db
Feedback	approx. 5 db fixed feedback
Power Consumption	35 watts (complete amplifier)



ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED

THE VALUE OF Rx DEPENDS DEPENDS UPON THE TRANSFORMER USED (SEE TUBE DATA)

1.75 Watt, Single-Ended Stereo Amplifier



ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED.

SPECIFICATIONS

Power Output	1.75 watts
Sensitivity	100 mV
Harmonic Distortion	10%
Frequency Response	—3 db between 150 and 40,000 cps
Tone Control Treble Cut	12 db at 10,000 cps

AMPEREX AUDIO TUBE SELECTOR GUIDE

STAGE		POWER OUTPUT INTO LOAD* (watts)	AMPEREX TUBE TYPE	PLATE VOLTAGE (volts)	DRIVE VOLTAGE (rms volts)	HEATER VOLTAGE (volts)	HEATER CURRENT (amps)	DESCRIPTION
OUTPUT	Push-Pull	50 (distributed load fixed bias)	6CA7/EL34	500	32	6.3	1.5	Low distortion, octal 8-pin power pentode
		30 (distributed load cathode bias)		425	21			
		20 (fixed bias)	7189	400	10.5	6.3	0.76	Low distortion, miniature, 9-pin power pentode
			6CW5/EL86	250	12			
		15 (fixed or cathode bias)	6BQ5/EL84	300	10	6.3	0.76	Low distortion, miniature, 9-pin power pentode
		14 (distributed load cathode bias)	7189	375	12.5	6.3	0.76	Low distortion, miniature, 9-pin power pentode
		11 (cathode bias)	6CW5/EL86	170	13	6.3	0.76	Low distortion, miniature, 9-pin power pentode
		8 (cathode bias)	6BM8/ECL82	250	19	6.3	0.78	Miniature, 9-pin triode-pentode. Triode is voltage amplifier; pentode is output tube
			16A8/PCL82			16	0.3	
			50BM8/UCL82			50	0.1	
	Single-Ended	4.5	6BQ5/EL84	250	3.5	6.3	0.76	Low distortion, miniature, 9-pin power pentode
		4	45B5/UL84	170	7.0	45	0.1	Low distortion, miniature, 9-pin power pentode
			6CW5/EL86			6.3	0.76	
		3	6BM8/ECL82	200	6.6	6.3	0.78	Miniature, 9-pin triode-pentode. Triode is voltage amplifier; pentode is output tube
			16A8/PCL82			16	0.3	
			50BM8/UCL82			50	0.1	

* With 85% efficient transformer for push-pull stages and 75% efficient transformer for single-ended stages

AMPEREX AUDIO TUBE SELECTOR GUIDE

STAGE	Mu	AMPEREX TUBE NUMBER	PLATE CURRENT (mA)	TRANSCONDUCTANCE (micromhos)	HEATER VOLTAGE (volts)	HEATER CURRENT (amps)	DESCRIPTION
PHASE INVERTER VOLTAGE AMPLIFIER	100	12AX7/ECC83	0.5	1250	12.6	0.15	Miniature, 9-pin twin triode
					6.3	0.3	
	70	6BM8/ECL82	2.0	2250	6.3	0.78	Miniature, 9-pin triode-pentode. Triode is voltage amplifier; pentode is output tube
		16A8/PCL82			16	0.3	
		50BM8/UCL82			50	0.1	
	62	12AT7/ECC81	3.0	3750	12.6	0.15	Miniature, 9-pin twin triode
					6.3	0.3	
	16	12AU7/ECC82	5.0	1350	12.6	0.15	Miniature, 9-pin twin triode
					6.3	0.3	

STAGE	VOLTAGE GAIN	AMPEREX TUBE NUMBER	EQUIVALENT NOISE & HUM (grid μV)	HEATER VOLTAGE (volts)	HEATER CURRENT (amps)	DESCRIPTION
PRE-AMPLIFIER	112	6267/EF86	5 max.	6.3	0.2	Internally shielded, 9-pin miniature pentode
	66.5	7025	7 max.	12.6	0.15	Miniature, 9-pin twin triode
				6.3	0.3	

STAGE	OUTPUT CURRENT (mA)	AMPEREX TUBE NUMBER	OUTPUT VOLTAGE (volts)	A-C PLATE TO GROUND SUPPLY VOLTAGE	HEATER VOLTAGE (volts)	HEATER CURRENT (amps)	DESCRIPTION
POWER SUPPLY	250	5AR4/GZ34	480	450	5.0	1.9	Full-wave, high-vacuum, indirectly heated rectifier
	150	6CA4/EZ81	350	350	6.3	1.0	Full-wave, high-vacuum, indirectly heated rectifier
	90	6V4/EZ80	360	350	6.3	0.6	Full-wave, high-vacuum, indirectly heated rectifier
	500	OA210	150	127	—	—	Half-wave, silicon rectifier

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