

Table 7 (continued)

Type	EL84		6V6, 7C5	
	AB ₁		AB ₁	
Working in class	AB ₁		AB ₁	
Heater volts	6.3		6.3	
Heater amps	1.52		0.9	
Plate volts	250	300	250	285
Screen volts	250	300	250	285
Control grid volts	—	—	—15	—19
Bias resistor, ohms	130	130	200	260
Peak volts, grid-to-grid	16	20	30	38
Zero signal plate ma	62	72	70	70
Max. signal plate ma	75	92	79	92
Zero signal screen ma	7	8	5	4
Max. signal screen ma	15	22	13	13.5
Load resistance, ohms	8000	8000	10000	8000
Distortion %	3	4	5	3.5
Power output, watts	11	17	10	14

Type	KT88			
	Fixed Bias		Cathode Bias	
Working in class	AB ₁		AB ₁	
Heater volts	6.3		6.3	
Heater amps	3.6		3.6	
Plate volts	460	625	400	475
Screen volts	345	330	255	320
Control grid volts	—48	—45	—	—
Bias resistor, ohms	—	—	440	each tube
Peak volts, grid-to-grid	98	70	70	98
Zero signal plate ma	100	100	120	160
Max. signal plate ma	240	250	135	180
Zero signal screen ma	7.5	6	7.5	12
Max. signal screen ma	35	32	25	38
Load resistance, ohms	4000	5000	6000	6000
Distortion %	5—7	3.6	3	3
Power output, watts	65	100	34	48

Distortion in the KT88 depends on accuracy of matching.

audio amplifiers: inverters and drivers

THE two tubes in a push-pull power output stage require input signal voltages of equal magnitude but of opposite phase. The signal voltages driving the push-pull stage must be symmetrical with respect to ground: this operation is carried out by a phase inverter. Normally the signal output of the last stage of the voltage amplifier (driving the push-pull tubes) is sufficient to develop maximum power in the output stage, in which case the phase inverter immediately precedes the output stage itself. Where this is not the case (particularly where the output stage consists of two triodes in class AB₂), the penultimate stage is itself push-pull and the phase inverter precedes this stage. Such a penultimate stage is called a driver.

Inductive phase splitters

The simplest method of phase inversion is to use an inductive device, such as a transformer or center-tapped choke. Fig. 301 shows various methods. In Fig. 301-a a transformer with center-tapped secondary is connected in the conventional manner. This method is simple and inexpensive if high-quality reproduction is not essential, but a transformer for high-grade results is rather difficult to design and expensive to make since a wide frequency response with linearity is necessary.

For good bass reproduction the primary inductance must be adequate and since it carries dc the design must be generous. For good treble response the self-capacitance of the windings must be

low and with the generous design postulated for good bass the requirements are in conflict.

These difficulties can be avoided by using a transformer with a high-permeability core, when the windings can be small and a good frequency response secured. Such a transformer must be parallel-fed, as shown in Fig. 301-b. The secondary winding need not be center tapped, for two equal resistors can be connected across

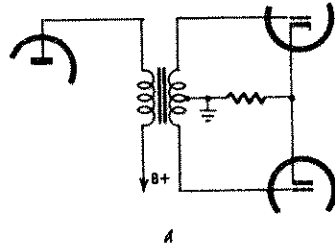


Fig. 301-a. Inductive phase inverter using center-tapped transformer.

the winding to give the center tap. Suitable values would be between 100,000 and 250,000 ohms. A resistive center tap could be applied to the transformer in Fig. 301-a.

Finally, a center-tapped choke can be used as shown in Fig. 301-c. This method is not very satisfactory owing to the loss of gain as compared with a transformer and the difficulty of getting perfect balance between the upper grid which is coupled directly (through the capacitor) and the lower one, which is coupled through the choke.

Stage gain

The stage gain of Fig. 301-a is the same as though phase inversion were not used and a usual ratio for the transformer would be a stepup of 1 to 2. In Fig. 301-b, where T is the transformation ratio and R the sum of the two resistors across the secondary winding, the load reflected into the previous tube is R/T^2 . As the optimum load on the preceding tube is the determining factor for output and distortion, the resistors must be selected to achieve the desired load. In all three methods the output tubes can have common bias or separate bias, as shown in Figs. 301-b and 301-c. A common-bias resistor bypass capacitor is not normally required or desirable. With separate bias, adequate capacitive bypass is necessary to avoid loss of bass.

Vacuum-tube phase splitters

Inductive phase splitters can be avoided by using a vacuum tube for the purpose. In Fig. 302-a the signal is applied to the grid of $V1$, amplified in the normal manner and passed on to output tube $V3$. A tap on the grid resistor of $V3$ is selected so that the signal

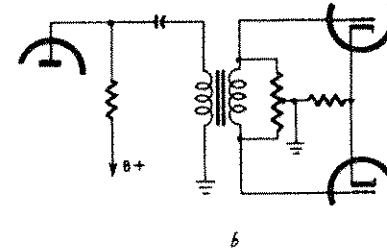


Fig. 301-b. Inductive phase inverter using a resistive center-tapped transformer.

voltage fed to the phase-inverter tube $V2$ is identical with that fed to $V1$. If $V1$ and $V2$ are matched tubes and their associated R-C networks are identical, $V3$ and $V4$ will receive signals equal

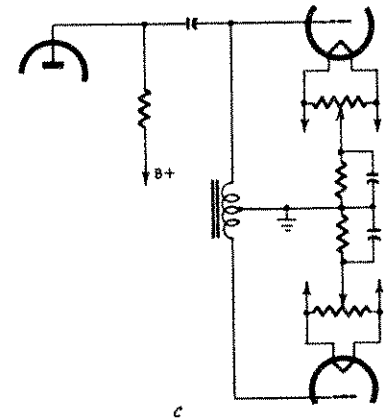


Fig. 301-c. Inductive phase inverter using a center-tapped choke.

in magnitude but opposite in phase. It might be said that $V2$ takes the place of the transformer of Fig. 301-a. Tubes $V1$ and $V2$ can, of course, be twin triodes in one envelope, as can similar pairs in other circuits given.

The phase inverter tube $V2$ can be eliminated by using the arrangement of Fig. 302-b where the upper output tube is also used

as a phase inverter; its half of the output transformer is shunted by a tapped resistor from the tap of which out-of-phase voltages are fed to the grid of the other output tube. This circuit has the

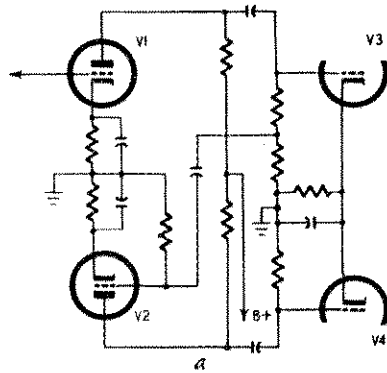


Fig. 302-a. Vacuum-tube phase inverter with excitation from the grid of the output tube.

merit of cheapness but it is not recommended when negative feedback is used as complexities of phase shift can occur to cause instability.

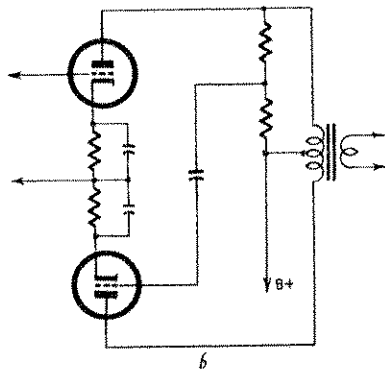


Fig. 302-b. Vacuum-tube phase inverter with excitation from plate of the output tube.

These two circuits are not self-balancing and require adjustment for balance when first set up with every tube replacement. Also, because the circuits associated with V2 have two coupling capacitors as compared with one in the plate circuit of V1, they

will be out of balance with the circuit of V1. They are unsuitable for class-AB₂ output stages as the grid-cathode resistance presented to the push-pull tubes is too high.

A driver stage may be needed for these types and the intertube coupling should be a transformer with center-tapped primary and secondary windings or a direct-coupled pair of cathode followers.

Self-balancing inverter

A self-balancing phase inverter is shown in Fig. 303. Resistors R1 and R2 are the ac load on tube V1; R1 and R3 the load on

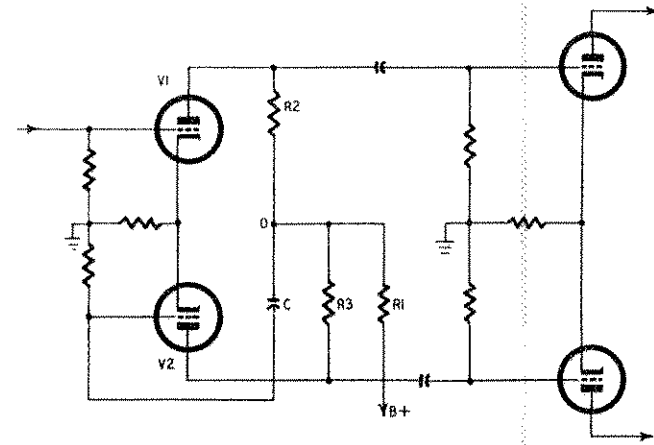


Fig. 303. Self-balancing phase inverter (floating paraphase).

V2. R1 is obviously common to both. Unbalance in the plate currents of the two tubes generates a voltage across R1 which is applied to the control grid of V2 through capacitor C. The potential of point O is floating, changing as the plate currents of the two tubes vary with respect to each other; this gives the circuit its name of "floating paraphase."

Schmitt inverter

Fig. 304 shows a different type of self-balancing phase inverter (credited to Schmitt). It is cathode-coupled and exact balance can be obtained by suitable adjustment of the two load resistors. The component values given in the figure have been found to be most suitable and it should be noted that the coupling capacitors in the two grid circuits should have very good insulation resistance. Tube type 6C8-G should be used.

Split-load phase inverter

One of the simplest and most widely used phase splitters appears in Fig. 305. Usually the load on a tube is in the plate circuit; with a cathode follower the load is in the cathode circuit. The circuit of Fig. 305 shows the load divided between plate and cathode circuits, but also included is an unbypassed cathode-bias resistor R2. Now, degeneration (negative feedback) is set up if the bypass capacitor across the bias resistor is omitted, but this only

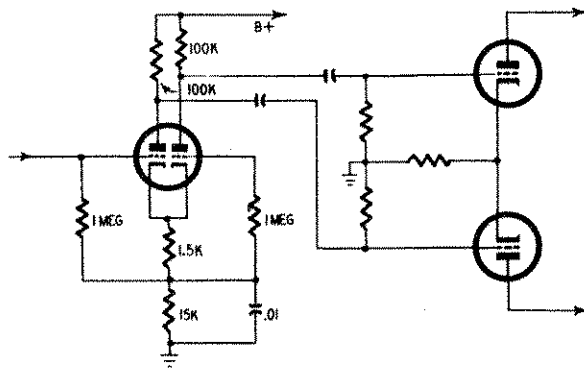


Fig. 304. Self-balancing phase inverter (Schmitt).

operates at low frequencies when the electrode-ground capacitances are small in terms of the signal frequencies. At high frequencies these capacitances act as partial bypasses so degeneration is not constant throughout the range of frequencies, with the result that the stage gain is not constant.

Phase splitting occurs when the output from the plate circuit equals that from the cathode circuit: $R1$ must equal $R2 + R3$. This does not mean that the resistors must be of very close tolerance for what is required is not accuracy of individual resistors but equality of plate and cathode loads. Similar care in balancing the circuit constants must also be exercised in the case of coupling capacitors C1 and C2 and the grid-circuit resistors R4 and R5 of the following stage. This precaution is necessary not only to secure perfect phase splitting; unbalance can cause instability of the type known as motorboating.

Normally the cathode output is taken directly from the cathode as indicated in Fig. 305 but, particularly with tubes of low amplification factor, it may be better to take the output from the junction of R2 and R3 as shown by the broken line. Exact mathemati-

cal analysis of the alternative connections could be given and prove nothing for in practice the choice can be made only by observing the output of the amplifier on an oscilloscope for a given

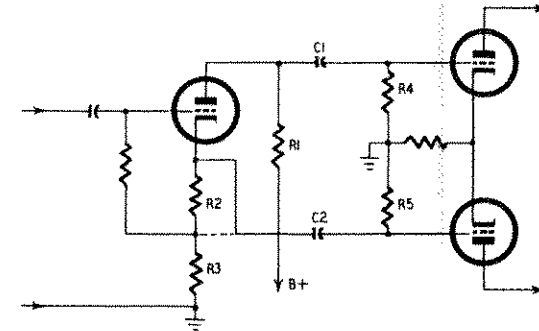


Fig. 305. Split-load phase inverter.

signal input. Changing the connection to C2 from the cathode of the phase splitter to the junction of R2 and R3 will then show, for maximum undistorted output, which is better. The writer has

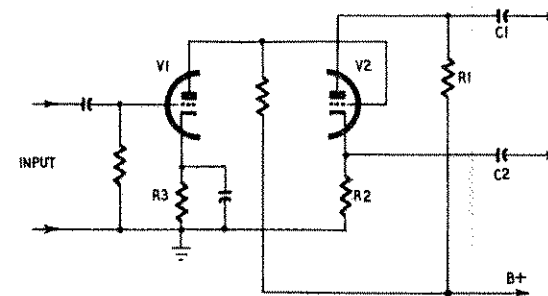


Fig. 306. Split-load phase inverter with preceding direct-coupled amplifier to give full stage gain.

found that for tubes such as the 6J5 the best results are obtained when the output is taken from the junction. In either case the stage gain of the phase inverter is somewhat less than 1, usually about 0.8 to 0.9.

Split load inverter with direct-coupled amplifier

This disadvantage of less than unity stage gain can be overcome by a trick which if it involves the use of another tube does not at least involve fitting an extra tube holder in the amplifier chassis. Consider the circuit of Fig. 306 with respect to that of

Fig. 305. Tubes V1 and V2 are the two sections of a double triode, the section V2 representing the inverter tube of Fig. 305. Section V1 is a straight voltage amplifier with a cathode-bias resistor equal to that of R3 in Fig. 305 and a load resistor correct for the tube as an amplifier. This tube is direct-coupled to V2, the phase-inverter tube, and the load of V2 is, as before, made up of R1 and R2.

This device improves the performance of the inverter quite appreciably for the advantages of direct coupling are secured in a greater gain without the use of extra grid-plate coupling capacitors, a matter of importance in reducing phase shift in a feedback amplifier; capacitors C1 and C2 can also be increased to as much as 0.5 μ f, a somewhat dangerously high value for the circuit of Fig. 305. It will be appreciated that the high value of cathode resistor makes the split-load inverter particularly suitable for direct coupling. The voltage drop across the cathode resistor is substantial compared with an ordinary amplifier and the cathode is at a comparatively high potential with respect to ground. Tube V2 is therefore in a "natural" condition for having its grid directly coupled to the plate of the preceding tube.

A word of warning is, however, necessary. The correct operation of inverter V2 is dependent on the correct dc potential on its grid. This can only be controlled by the potential on the plate of V1, and in practice it will be found that plate-load and cathode-bias resistors should be somewhat larger than would normally be used for that tube. As with all phase-inverter circuits it is almost essential that symmetrical working be checked by oscilloscope tests.

Cathode-coupled phase inverter

In the paraphase circuit of Fig. 303 resistor R1 is common to both tubes of the inverter. Unbalance in the two plate circuit currents generates a voltage across it which is used to balance the whole circuit. This common load can be used in the cathode circuits of the tubes, creating what is known as the cathode-coupled or long-tail inverter. This is illustrated in Fig. 307. It will be clear that there is a similarity to the split-load inverter because the potential of the cathodes is high with respect to ground. At the same time differences in the plate currents of V2 and V3 set up a voltage across R4, which is applied to the grid of V2 through capacitor C1. A suitable grid voltage for V2 is of the order of 85 volts, bearing in mind the comparatively

high positive potential of the cathodes, and thus suggests that, as in the case of the direct-coupled split-load inverter, the input is direct-coupled to the preceding stage V1, and is so shown in Fig. 307. This inverter has good frequency characteristics but only half the gain of the circuit of Fig. 306. It is a popular circuit in Europe—the well-known Mullard 20-watt amplifier using it—and more recently has come into favor in the United States,

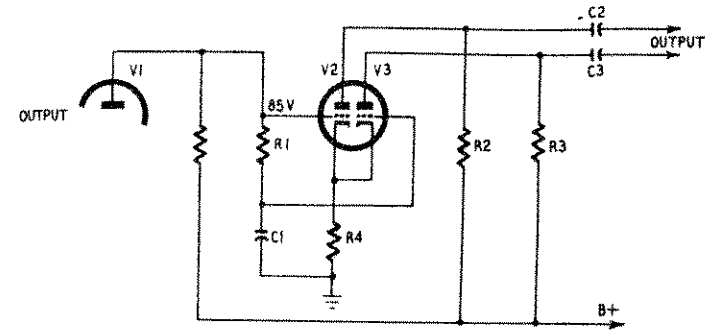


Fig. 307. Cathode-coupled or "long-tailed" phase inverter showing direct coupling to preceding stage.

where examples are to be found in the Eico 50- and 60-watt amplifiers, among others.

There is some difference of opinion as to the optimum values of associated components, which in any event depend on the type of double triode used for V2-V3. The following data compares Mullard with Eico practice.

	Tube	R1	R2	R3	R4	C1	C2	C3
Mullard:	ECC83	1 Meg	180K	180K	82K	0.25	0.5	0.5
Eico:	6SN7-GTB	1 Meg	28,750	33K	18K	0.25	0.25	0.25

Drivers

The stage before the output stage is generally called the driver, although the term is more often restricted to the rather special driving conditions in class-AB₂ and class-B amplifiers. In these, a considerably greater signal voltage is required than with class-A or AB₁ output stages. As the tubes of a class-AB₂ output stage are driven into grid current, a low resistance for the grid circuits is essential and an interstage transformer is generally used.

Transformer coupling

In transformer-coupled amplifiers it is customary to use general-purpose triodes having a plate resistance of about 7,500 ohms, such as the familiar 6J5. The output voltage of such a tube can be obtained from its characteristic curves in a manner similar to that for output tubes. The higher the plate voltage the higher the output ac voltage before distortion commences. If one tube is insufficient to drive the output stage to full output, then two should be used in push-pull (the use of a large single power tube would call for a costly design of the interstage transformer). The transformer would then have both primary and secondary windings center tapped. This is actually an advantage since the opposing plate currents in the two halves of the primary winding call for a smaller core than with one tube, and in terms of frequency response, a better performance is obtained from the transformer.

Overall gain

The overall gain from a transformer-coupled triode is about equal to the product of the amplification factor of the tube and the stepup ratio of the transformer. The 6J5 has an amplification factor of 20, and with a plate voltage of 250 and a grid voltage of -8 , the plate current is 9 ma. One tube would be quite unable to drive two triodes in class AB_2 and even 9 ma plate current is rather high polarizing for an interstage transformer. In class AB_2 , moreover, the driver has to supply power and transformer losses can be appreciable. Two tubes are necessary and, being in push-pull, they make the task of the transformer a simpler one to fulfill. Detailed design of class-B amplifiers is rather complicated and space here does not permit full treatment. The interested reader is referred to the standard textbooks on the subject. In brief:

Class- AB_2 amplifiers operate similarly to class AB_1 and the driving voltage required is less than with class B.

If a transformerless phase splitter is used, remember that inadequate care in design may introduce distortion and instability, mainly through out-of-balance components.

Parasitic oscillation can occur in the grid circuits of the output tubes which can largely be avoided by using a driver transformer having low leakage inductance.

Resistance-coupled driver stages are fairly widely used, particularly when the output stage is two push-pull triodes, or tetrodes or pentodes connected as triodes. This is necessary since

the grid-to-grid swing required for maximum output from two triodes is considerably greater than that for tetrodes or pentodes.

Push-pull drivers

Sometimes a push-pull driver stage is used to swing a pair of tetrodes, apparently on the supposition that there will be less distortion than when using a single tube. This notion is carried to its logical conclusion in designs which show an amplifier en-

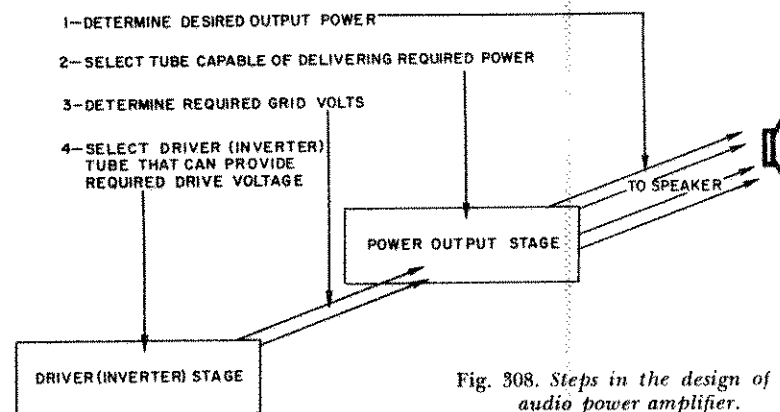


Fig. 308. Steps in the design of an audio power amplifier.

tirely push-pull. In theory, perhaps, it could be shown that a wholly push-pull amplifier has less overall distortion than one in which the voltage amplifier is not push-pull, but in practice, if the voltage-amplifying stages are properly designed, the elaboration is unnecessary. It is also undeniable that the simpler an amplifier the less the possibility of distortion creeping in through tube or component deterioration.

Design sequence

Yet the penultimate or driver stage must have sufficient output ac voltage to swing the push-pull output stage and, if the phase inverter is unable to deliver that voltage without distortion, then the driver stage must be push-pull. A particular type of tube can deliver only so many output volts without distortion, whether it is used as a voltage amplifier or phase inverter. This fact is sometimes not appreciated, since technical writers are often asked for an opinion as to the best type of inverter without any mention being made of the output stage of the proposed amplifier. Hence the sequential treatment in this book. The output stage must first be selected. Given this, the required input grid volts are

known. A tube is then selected which will give that voltage output. If, choosing from among the tubes that are normally used as phase inverters, it is found that the desired voltage cannot be obtained, the driver stage must be push-pull. Then, and only then, can the type of phase inverter be selected. (See Fig. 308.)

This is a problem in voltage-amplifier design, which will be discussed in the next chapter. The matter is mentioned at this stage simply because the driver is a voltage amplifier and properly belongs to the next chapter, but may come under the scope of the present chapter because it may be simply a phase inverter if the output stage does not require a large input grid voltage. Suitable tubes for use as phase inverters are listed in Table 10 at the end of Chapter 4.

audio amplifiers: voltage amplification

POWER is required to drive a speaker or a recording head. The power is obtained from the power-output stage, and to get this power, a voltage of the correct magnitude has to be impressed on the grid circuit of the output stage. As the actuating signal device (phono pickup, signal voltage across the detector diode load, etc.) has a voltage output considerably less than required, amplification of the signal voltage is necessary. The voltage amplifier performs this task. It cannot be a *pure* voltage amplifier since the load into which it works does not have infinite impedance, so there will be some power in the output. The output load may be as high as 1 megohm, but is frequently less, and in the case of transformer coupling may be unknown. The number of stages required in a voltage amplifier depends on the degree of amplification required, postulated by the input and desired output voltages and the type of tubes selected. The fewer the tubes, the less likelihood of instability through a common plate supply impedance, but a selection of tubes giving a high stage gain may result in undesirable performance. The design of the amplifier is wholly dependent on the degree of absence of distortion required.

Transformer-coupled stages have already been mentioned. Almost invariably resistance-capacitance-coupled tubes are used in voltage amplifiers, so further discussion on transformer-coupled stages will not be given. Either triodes or pentodes may be used and an examination of their characteristics can be carried out in a manner similar to those of output tubes.

Resistance—capacitance-coupled triodes

It is customary to use either general-purpose (medium- μ with an amplification factor under 50) or high- μ triodes (amplification factor 50 to 100). The tube manufacturers publish resistance—capacitance design charts for all types of tubes, but a word of warning is needed in connection with these. The figures given seem to indicate that a low source impedance is used whereas in practice the source impedance and grid—cathode impedance are usually fairly high (Fig. 401); therefore, the values of associated

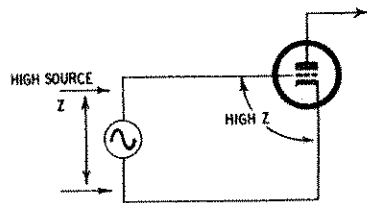


Fig. 401. Source and grid-to-cathode impedances are generally high.

components are not necessarily correct. These charts also refer to average tubes and so can be taken only as a rather rough guide in specific cases.

The figures given also assume a harmonic distortion content of 5% and for high-grade equipment this figure is excessive. In view of the fact that distortion occurs when the tube is called upon to deliver its peak voltage, the obvious way to avoid it is to work the tubes well within their limits. Accordingly, for high-grade amplifiers the designer should not expect to get the voltage output from any particular tube that the chart would indicate as being possible.

This does not mean that the overall gain of the amplifier must be determined so that no tube has to produce more than about three-quarters of the possible output voltage. As this limitation usually arises only in the last stage of the voltage amplifier, earlier stages, including so-called preamplifier stages, may be selected on the basis of the charts. If the last tube is unable to deliver the necessary voltage to drive the output stage or driver stage, then the last stage of the voltage amplifier would have to be a push-pull stage and the phase-splitter would be a part of the voltage amplifier.

Design data

For convenience in design the mass of data presented by the tube makers has been edited and put together in different form.

After eliminating some unnecessary information, what is left produces a recognizable pattern. Table 8, giving the correct values for average triodes of the types listed, is subject to the limitations mentioned. As most designers are interested in equipment deriving power from a line-operated supply, battery operating types of tubes have not been included but the relevant information can be extracted from tube-makers' manuals.

The input resistance should not exceed 1 megohm and subsequent grid resistors should be not more than four times the pre-

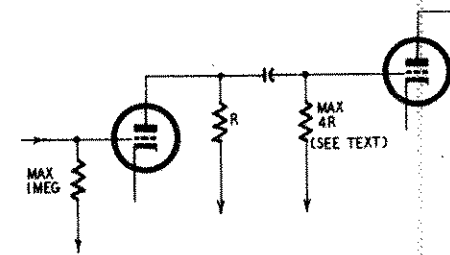


Fig. 402. Relative values of plate and grid resistors.

ceding plate resistor (Fig. 402). With high- μ triodes the grid resistor should be less than this. High values of grid resistor tend to produce hum. It should be remembered that output tubes require a lower grid resistor than an ordinary voltage amplifier (the recommended values being given in the tube handbooks) but a simple rule is to keep this as low as 250,000 ohms for high-grade equipment. With this in mind an examination of Table 8 shows that quite a number of alternative usages are ruled out on the grounds that the value of R_3 will be too high. If R_3 is 0.5 megohm, several opportunities occur of getting a higher output voltage from the preceding tube, but it should be remembered that the 0.22-megohm value is recommended to reduce the effects of reverse grid current in the output stage.

Coupling capacitors

The value of the coupling capacitor C_2 is important. If too small, there will be a loss of amplification at low frequencies. The values shown allow for the amplification at 50 cps to be reduced to 0.8 times the amplification at higher frequencies—a loss of 2 db. If this capacitor is reduced by one-half, the 2 db loss will be at 100 cps; if doubled, the 2 db figure is reached at 25 cps, and so on.

If the capacitor is too large and the whole amplifier has a tendency to motorboat, the motorboating frequency will be passed on without attenuation. So a simple way to stop motorboating is to reduce the value of the coupling capacitors. But this must not be done to such an extent that appreciable loss of amplification occurs at low frequencies; the *cause* of the instability must be sought out.

For inexpensive equipment, C2 can be half the values shown; for high-fidelity amplifiers it should be double. Any further increase will not contribute audibly to quality of reproduction but can permit the transfer of subsonic frequencies.

C1 is most conveniently (and least expensively) an electrolytic capacitor. One rated at 10 μf with a working voltage of 25 or 50 will be suitable for all cases.

The supply voltage should be as high as possible, with a maximum of about 300. Examination of the figures for output voltage show clearly that about double the voltage swing can be had by raising the supply voltage from 180 to 300, the gain not being appreciably affected. The greatest output voltage is obtained when the plate load R1 is highest but, as this requires a high following grid resistor, it may not be possible to use this condition with high-fidelity output stages.

A push-pull output stage requires double the input signal voltage needed to drive a single tube so, in selecting a suitable tube from Table 8, the required grid-to-grid voltage must be remembered. If a single tube will not supply this voltage (and for minimum distortion the designer should expect to get only three-quarters of the output voltage E_o shown in the table) except by using a high plate load, then push-pull working must be used. In general an output stage of two triodes (or two tetrodes connected as triodes) in push-pull will require a push-pull driver stage; two tetrodes can be driven from a single tube.

Resistance—capacitance-coupled pentodes

Table 9 shows suitable operating conditions for resistance—capacitance-coupled pentodes. In a general way considerations are similar to those for triodes, but an additional factor must be taken into consideration—high-frequency attenuation. As will be seen from the data given at the head of the table, the value of the plate load has a bearing on the width of frequency response of the amplifier and R1 must be selected with the performance required in mind.

For a rather low plate load the stage gain is not appreciably greater than that obtainable from a high- μ triode and the ques-

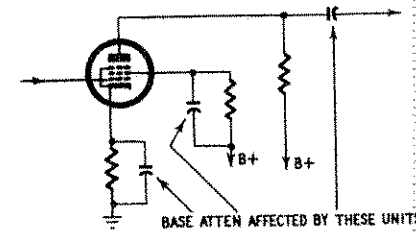


Fig. 403. Amplification of bass is affected by the size of the coupling, cathode and screen bypass capacitors.

tion may be asked, why use pentodes at all? This involves consideration of the dynamic characteristics of both types and, con-

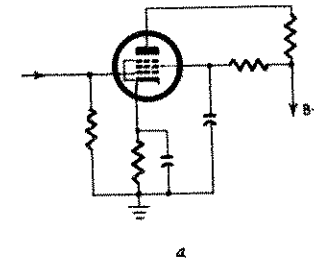


Fig. 404-a. Usual method of applying screen voltage.

trary to generally held opinion, a pentode as a voltage amplifier can give a good deal less distortion than a triode.

Examination of a tube such as the 6SJ7 used as a triode or as a

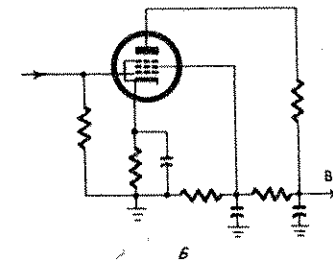


Fig. 404-b. Voltage divider for the screen is a better technique.

pentode will show that, for outputs up to about 10 volts rms, the intermodulation distortion of the pentode is about one-eighth that of the triode, assuming that the operating conditions of both are optimum. At 30-volts output the distortion is about the same; at 60 volts output the pentode has more distortion than the triode. So a pentode is most useful in the earlier stages of an amplifier where the signal voltage to be handled is low. In these positions the pentode has a higher amplification factor and less distortion than the triode and is strongly recommended for high-fidelity amplifiers.

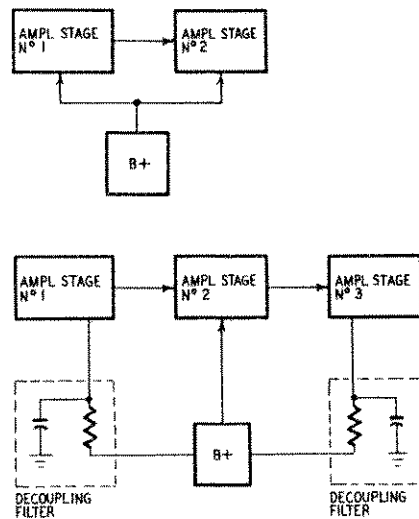


Fig. 405. Block diagram of decoupling circuits. When two or more amplifier stages are used power supply decoupling is necessary.

Bass attenuation is affected by the screen bypass as well as the cathode bypass and coupling capacitors. If, instead of a series screen resistance as shown in Fig. 404-a (the usual method of feeding the screen) a potential divider is used as in Fig. 404-b, the loss of bass through inadequate bypassing is very much less. This has the further advantage of stabilizing the screen potential to some extent, a desirable aim with all pentodes.

The cathode bypass will be seen to be greater than that required for triodes, and it is most convenient to use an electrolytic capacitor of 50 μ f with a working voltage of 12, or over.

Resistance—capacitance-coupled phase inverters

Table 10 summarizes in convenient form the conditions that have to be met when using twin triodes as amplifying phase inverters. No-gain splitters have already been dealt with in Chapter 3, but the table gives the values required for a circuit of the type shown in Fig. 302-a. For the twin triodes included in Table 10, the values shown in that table should be used for R_1 , R_2 , R_3 and C but as the output from the two triode sections of the double triode must be equal, the tap on R_{3a} and R_{3b} must be adjusted to suit.

The twin triode is an amplifier hence the tap on the grid resistor of one output tube must be selected so that the voltage applied to the second triode of the phase inverter is such that the voltage across the grid resistor of the second output tube is identical. If the voltage gain of the stage is, say 20, then the input sig-

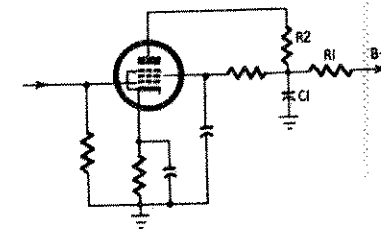


Fig. 406. R_1 and C_1 form a decoupling network.

nal voltage E_i would be one-twentieth of the output voltage, so the voltage tapped off R_3 would be one-twentieth of the total voltage across the two.

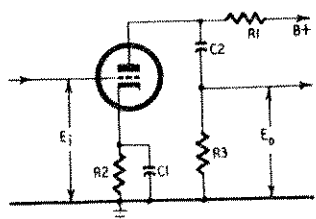
Decoupling

In the discussion on triodes it was stated that the supply voltage should be as high as possible, with a maximum of 300, but this assumes that the supply voltage is applied directly to the load resistor. If an amplifier has only two stages, decoupling is probably unnecessary; but more than two stages are needed in all but the cheapest equipment. Decoupling then becomes essential to overcome common impedance coupling in the power supply. See Fig. 405.

Decoupling involves the use of a series plate resistance R_1 with a low impedance bypass to ground, C_1 , between the supply source and the load resistance R_2 of the tube as shown in Fig. 406. As the tube takes plate current, a very appreciable voltage drop takes

place across the decoupling resistance. The higher the value of the decoupling resistance, the better the decoupling (assuming an adequate bypass to ground). For a supply voltage of 300 applied to the plate resistors, it can be taken as a safe working rule that the actual supply voltage should be 400, or a little more, and the bypass capacitor has a capacitance of 8 μ f with a dc working voltage of 500.

Table 8—Resistance—capacitance-coupled triodes



C1 and C2 adjusted to give 0.8 E_o at 50 cps.

Data for double triodes (types 6SN7-GTB, 12SN7-GT, 6SL7, and 12AX7) apply to each triode section.

R1 and R3 in megohms; R2 in ohms.

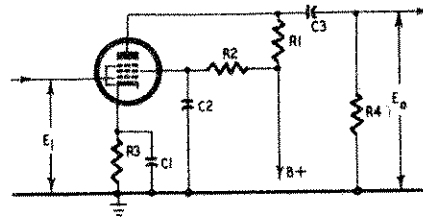
V.G. (voltage gain) = E_o/E_i .

Type	R1	R3	C1	C2	B+ = 180 volts			B+ = 300 volts		
					R2	E_o	V.G.	R2	E_o	V.G.
6BF6	.047	.047	6	.15	2000	32	10	1800	58	10
6SR7		.1	5	.07	2500	42	10	2400	74	11
6ST7		.22	4	.04	3000	47	11	2900	85	11
12SR7	.1	.1	4	.07	3800	36	11	3600	65	12
26C6		.22	3	.03	5100	47	11	5000	85	12
		.47	2	.02	6200	55	12	6200	96	12
	.22	.22	2	.03	8000	41	12	7800	74	12
		.47	1	.02	11000	54	12	11000	95	12
		1.0	1	.01	13000	69	12	13000	106	12
6C4	.047	.047	8	.15	920	20	11	870	38	12
12AU7		.1	6	.1	1200	26	12	1200	52	12
		.22	5	.03	1400	29	12	1500	68	12
	.1	.1	4	.07	2000	24	12	1900	44	12
		.22	3	.03	2800	33	12	3000	68	12
		.47	2	.015	3600	40	12	4000	80	12
	.22	.22	2	.03	5300	31	12	5300	57	12
		.47	1	.015	8300	44	12	8800	82	12
		1.0	1	.007	10000	54	12	11000	92	12
6J5	.047	.047	8	.15	1190	24	13	1020	41	13
6SN7-GTB		.1	6	.07	1490	30	13	1270	51	14
12J5		.22	5	.03	1740	36	13	1500	60	14
12SN7-GT	.1	.1	5	.08	2330	26	14	1900	43	14
		.22	4	.03	2830	34	14	2440	56	14
		.47	3	.02	3230	38	14	2700	64	14
	.22	.22	3	.03	5560	28	14	4590	46	14
		.47	2	.02	7000	36	14	5770	57	14
		1.0	1	.01	8110	40	14	6950	64	14

Table 8 (continued)

Type	R1	R3	C1	C2	B+ = 180 volts			B+ = 300 volts		
					R2	E_o	V.G.	R2	E_o	V.G.
6SQ7-GT	.047	.1	8	.06	2600	16	29	1900	31	31
		.22	7	.03	2900	22	36	2200	41	39
		.47	6	.02	3000	23	37	2300	45	42
12SQ7-GT	.1	.22	6	.03	4300	21	43	3300	42	48
		.47	5	.02	4800	28	50	3900	51	53
		1.0	4	.01	5300	33	53	4200	60	56
	.22	.47	4	.02	7000	25	52	5300	47	58
		1.0	3	.01	8000	33	57	6100	62	60
		2.2	3	.005	8800	38	58	7000	67	63
6AT6	.1	.1	9	.06	1900	19	30	1500	40	34
6SL7-GT		.22	7	.03	2200	25	35	1800	54	38
		.47	6	.02	2500	32	37	2100	63	41
6SZ7	.22	.22	5	.03	3400	24	38	2600	51	42
6T8		.47	4	.02	4100	34	42	3200	65	46
12AT6		1.0	4	.01	4600	38	44	3700	77	48
12SL7-GT	.47	.47	3	.02	6600	29	44	5200	61	48
		1.0	2	.01	8100	38	46	6300	74	50
		2.2	2	.005	9100	43	47	7200	85	51
6AV6	.1	.1	10	.06	1800	18	40	1300	43	45
12AV6		.22	9	.03	2000	25	47	1500	57	52
12AX7		.47	8	.02	2200	32	52	1700	66	57
	.22	.22	6	.03	3000	24	53	2200	54	59
		.47	5	.02	3500	34	59	2800	69	65
		1.0	4	.01	3900	39	63	3100	79	68
	.47	.47	4	.02	5800	30	62	4300	62	69
		1.0	3	.01	6700	39	66	5200	77	73
		2.2	2	.005	7400	45	68	5900	92	75

Table 9—Resistance—capacitance-coupled pentodes



C1, C2, C3 adjusted to give 0.7 E_o at 50 cps.

Upper limits of level frequency response for values of R1:

R1 = 0.1 megohm—25,000 cps.

R1 = 0.25 megohm—10,000 cps.

R1 = .5 megohm—5,000 cps.

R1, R2, R4 in megohms. R3 in ohms.

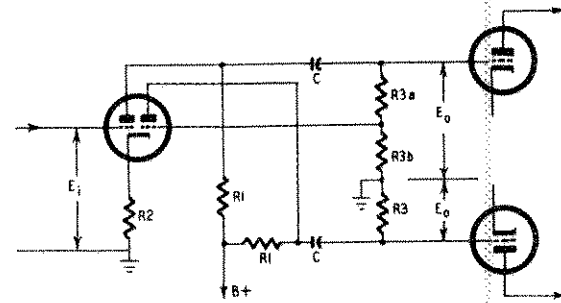
V.G. (voltage or stage gain) = E_o/E_i .

Table 9 (continued)

Type	R1	R2	R4	C1	C2	C3	B+ = 180 volts			B+ = 300 volts		
							R3	E _o	V.G.	R3	E _o	V.G.
6AU6	.1	.12	.1	.36	.3	.05	800	57	74	500	76	109
6SH7		.15	.22	.33	.25	.03	900	72	116	600	103	145
12AU6		.19	.47	.30	.25	.02	1000	81	141	700	129	168
12SH7		.38	.22	.25	.2	.02	1500	59	130	1000	92	164
		.43	.47	.24	.2	.02	1700	67	171	1000	108	230
	.22	.6	1.0	.22	.2	.01	1900	71	200	1100	122	262
		.9	.47	.16	.15	.01	3100	54	172	1800	94	248
		1.0	1.0	.16	.15	.01	3400	65	232	1900	105	318
	.47	1.1	2.2	.15	.15	.005	3600	74	272	2100	122	371
6SF7		.1	.33	.1	.16	.4	.05	1000	32	33	750	62
12SF7	.5		.22	.16	.4	.03	1200	37	45	850	80	46
	.6		.47	.16	.4	.02	1300	43	52	900	93	57
	.76		.22	.12	.3	.02	1700	37	47	1150	63	62
	.9		.47	.12	.25	.015	1700	44	68	1300	78	88
	.22	1.0	1.0	.10	.25	.015	1800	47	82	1500	99	97
		1.8	.47	.7	.2	.01	3300	38	70	2300	71	82
		2.0	1.0	.7	.2	.01	3800	50	85	2500	85	109
	.47	2.2	2.2	.7	.2	.005	4000	57	98	2800	105	125
6SJ7		.1	.29	.1	.24	.2	.04	760	49	55	500	72
12SJ7	.31		.22	.22	.2	.04	800	60	82	530	96	98
	.37		.47	.20	.2	.02	860	62	91	590	101	104
	.83		.22	.17	.15	.02	1050	38	109	850	79	139
	.94		.47	.15	.15	.01	1060	47	131	860	88	167
	.22	.94	1.0	.15	.15	.01	1100	54	161	910	98	185
		1.85	.47	.12	.15	.01	2000	37	151	1300	64	200
		2.2	1.0	.12	.1	.005	2180	44	192	1410	79	238
	.47	2.4	2.2	.12	.1	.005	2410	54	208	1530	89	263

The 6SH7 and 12SH7 are particularly susceptible to hum when used as high-gain audio amplifiers. When the tubes are used as low level drivers this undesirable characteristic need not be considered. However the tubes should be isolated from external hum sources whenever possible. Two separate cathode connections permit the input and output circuits to be isolated from each other.

Table 10—Resistance—capacitance-coupled phase inverters



This table includes double triodes normally used as voltage amplifiers. Other tubes can also be used; e.g. the double triodes listed in Table 8, where the operating conditions listed in that table should be used.

C is selected to give 0.9 E_o at 50 cps.

$R_{3a} + R_{3b} = R_3$. R_{3b} is selected so that the voltage output of each triode of the double triode is equal; e.g. if V.G. = 20 then R_{3b}/R₃ = 1/20.

R₁, R₃ in megohms. R₂ in ohms. V.G. (voltage or stage gain) E_o/E_i.

Type	R1	R3	C	B+ = 180 volts			B+ = 300 volts		
				R2	E _o	V.G.	R2	E _o	V.G.
6SN7- GTB	.047	.047	.15	2000	32	10	1800	58	10
				2500	42	10	2400	74	11
				3000	47	10	2900	85	11
	.1	.047	.07	3800	36	11	3600	65	12
				2830	34	14	2440	56	14
				3230	38	14	2700	64	14
	.22	.047	.03	5560	28	14	4590	46	14
				7000	36	14	5770	57	14
				8110	40	14	6950	64	14
				1.0	.01				
ECC82 12AU7	.047	.047	.15	920	20	11	870	38	12
				1200	26	12	1200	52	12
				1400	29	12	1500	68	12
	.1	.047	.07	2000	24	12	1900	44	12
				2800	33	12	3000	68	12
				3600	40	12	4000	80	12
	.22	.047	.015	5300	31	12	5300	57	12
				8300	44	12	8800	82	12
				10000	54	12	11000	92	12
				1.0	.007				