Amplifiers of the second type have been used for many years, but the low frequency response is limited, and is frequently worse than with resistance-capacitance coupling. The reason for this is that although the coupling from plate to grid is "direct," the coupling from cathode to cathode involves a condenser and/or inductance (e.g. field coil).

The high-frequency cut-off point of "D-C" amplifiers is limited by shunt stray capacitances and "Miller Effect" in a similar manner to resistance-capacitance coupled amplifiers.

PHASE SPLITTING

In any amplifier incorporating push-pull operation, it is necessary to provide some method of phase splitting to derive two input signals 180 degrees out of phase. One of the best known of these methods is that shown in Fig. 8 in which a transformer is used having a centre tapped secondary. Since the secondary of the transformer provides two equal voltages 180 degrees out of phase, the arrangement is entirely satisfactory provided that the transformer is of correct design. This method may be used with almost any type of amplifier and the arrangement illustrated is merely typical. For example, fixed bias operation or operation with triodes in place of pentodes could equally well be adopted.

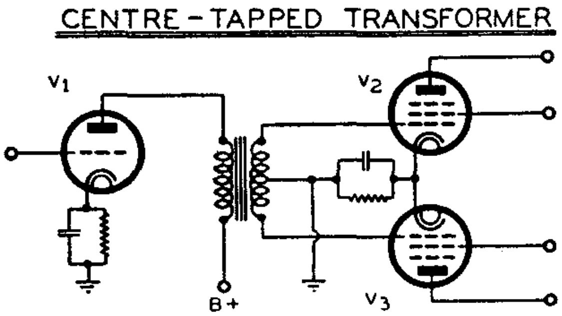
CENTRE - TAPPED TRANSFORMER

Figure 8

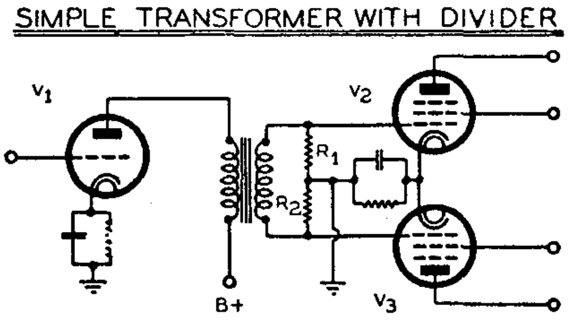
SIMPLE TRANSFORMER WITH DIVIDER

Figure 9

An alternative arrangement which does not require centre-tapping of the transformer secondary is shown in Fig. 9. In this case an ordinary transformer with a single secondary winding is used and a resistance divider is placed across the secondary of the transformer and centre tapped in order that it may be returned to earth. The resistances R_1 and R_2 need careful consideration since they form a load on the valve V_1. The load reflected into the plate circuit of V_1 is equal to

$$\frac{R_1 + R_2}{N^2}$$

where N is the step up ratio of the transformer. For example, if R_1 and R_3 are each 100,000 ohms, their sum is 200,000 ohms and if the ratio of the transformer is 3 : 1 step up, the load reflected into the plate circuit is 200,000 divided by 9 or 22,000 ohms. This load is lower than a number of general purpose triode valves are capable of handling without noticeable distortion, and it might therefore be necessary to increase the values of R_1 and R_2 until a suitable value is reached. The maximum limit to the values of R_1 and R_2 is set by the grid circuit resistance which may be permitted with valves V_2 and V_3. It will be seen that this arrangement necessarily introduces more resistance into the grid circuit than does a centre tapped transformer. The centre tapped transformer is therefore less likely to give severe distortion when the valves are slightly overloaded and run into grid current.

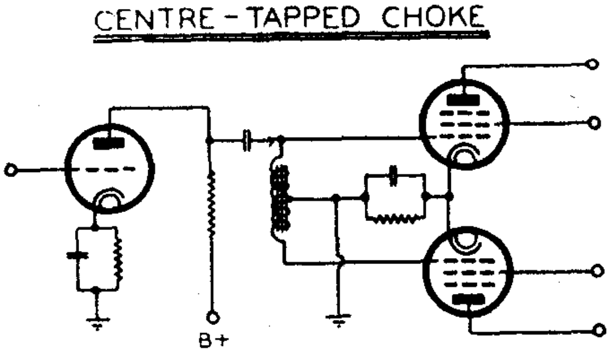

Figure 10

An alternative method which is sometimes used is to reduce the transformer to its simplest form, namely that of an audio frequency choke. If a centre tapped choke is used it is possible by means of the circuit shown in Fig. 10 to obtain reasonably satisfactory push-pull operation. This arrangement has the disadvantage over a correctly designed transformer that perfect symmetry between the two sides cannot readily be obtained. As compared with the transformer there will be less gain since the gain in the coupling circuit will be less by the total step-up ratio of the transformer.

A number of methods are available for phase splitting by the use of valves and resistance coupling. In many cases these are to be preferred to any method employing an iron core transformer since excellent fidelity may be obtained at comparatively low cost. One of the simplest of these arrangements is shown in Fig. 11 and has been very widely used with entire satisfaction. In this circuit valve V_1 is an ordinary amplifying valve which may well be a resistance coupled pentode. V_2 is the phase splitting valve and may be any general purpose triode having an indirectly heated cathode. A sharp cut-off pentode such as the 6J7G functions well when connected as a triode with screen tied to plate. Similar resistances are inserted in both cathode and plate circuits, and it will be seen that these two resistors in series form the load on the valve. Since the input from the preceding stage is applied between the grid of V_2 and earth, there will be a degenerative action resulting in a considerable loss of gain. The actual gain between the input to V_2 and the output to either side of the push-pull stage is slightly less than unity. In a practical case this is generally found to be about 0.9 each side or a gain of 1.8 times grid to grid. This low gain means that the valve does very little amplification and really takes the place of the transformer or centre tapped choke in other arrangements. Although this may appear extravagant with regard to valves, it is frequently the most economical arrangement. It possesses a number of particular advantages among which are low distortion and excellent frequency fidelity. Owing to the capacitance between heater and

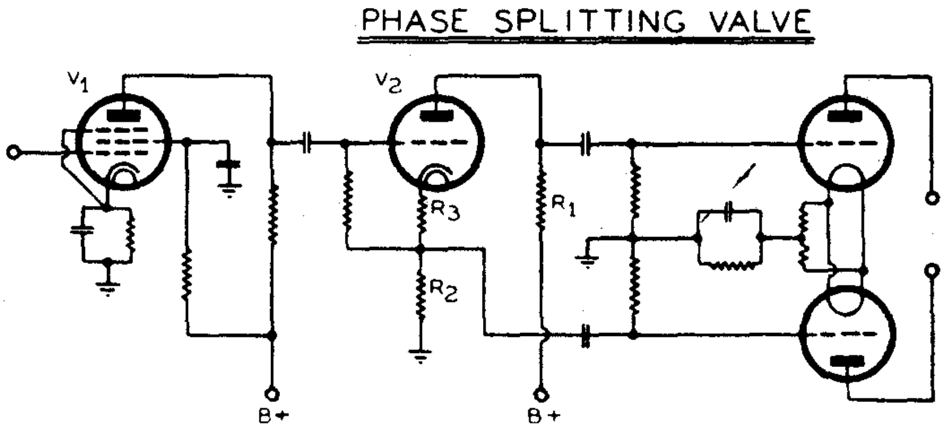

Figure 11

cathode of V_2 there will be a slight out-of-balance between the two push-pull valves at high audio frequencies, but this is slight and occurs only at high frequencies, where no appreciable disadvantage results. It will be noticed that the cathode bias resistor R_3 is not bypassed, this being unnecessary since R_3 is considerably smaller than ($R_1 + R_2$) and the loss of gain through the omission of the bypass condenser is negligible. If a low-μ valve had been used there might have been an advantage in bypassing R_3, since R_3 would then be comparable in resistance with R_1 or R_2. A further advantage in using a valve having a fairly high μ is that the degeneration is thereby increased, with consequent additional reduction of distortion.

The degeneration with this arrangement is known as "Negative Current Feedback" and is treated in detail in Chapter 6. The major effects are the reduction of harmonic distortion, improvement in frequency response, and high input impedance. The input impedance is approximately 10 times the value of the grid resistor; a smaller value of grid condenser may therefore be used.

A by-pass condenser from the cathode to earth should be avoided since it would unbalance the push-pull operation.* An important point in connection with this system of phase splitting is that the phase splitting valve should be operated immediately in front of the push-pull power stage or separated from it by a low gain push-pull stage. If a high gain amplifier is placed between V_2 and the output stage, hum may be troublesome. Part of the hum is due to the considerable difference of potential between the heater and cathode V_2. This may be reduced by operating the heater of V_2 from a separate transformer winding which is connected to a suitable point in the circuit which is at an average potential approximating to that of the cathode. The maximum voltage output which the phase splitter is capable of delivering is similar to that which would apply to an ordinary resistance coupled triode. It is usually safe with general purpose triodes to assume a grid to grid voltage output of 22% of the plate supply voltage to V_2. With 250 volts supply this will reach 55 volts output, while with 400 volts supply the output will be 88 volts. This latter condition is just sufficient to drive two push-pull Class A 2A3 valves operating with 250 volts on the plates. If the phase splitter is used to drive more sensitive output valves there will be no difficulty in supplying the necessary excitation to the grids.

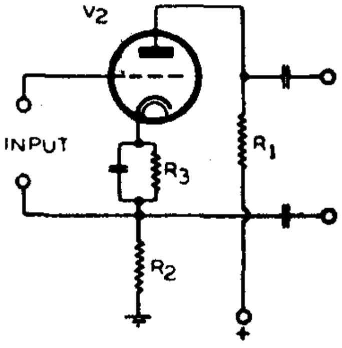

Figure 12

If in the preceding arrangement the input to V_2 is taken between grid and cathode instead of between grid and earth, the degenerative effect will be avoided and the full gain of V_2 will be obtained. A circuit showing this is given in Fig. 12. It will be seen that the input circuit is floating and for this reason cannot generally be used satisfactorily with a pick-up although it may be used under some circumstances in a radio receiver. This circuit is particularly prone to suffer from hum as the gain of V_2 amplifies the hum from its cathode. As in the previous case, this hum may be minimised by adjusting the potential on the heater to approach that of the cathode.

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*This method has been used as a tone control, since a bypass condenser from cathode to earth reduces the degeneration for the higher frequencies and therefore provides greater amplification for the higher than for the lower frequencies. The output with this arrangement will be out-of-balance for the higher frequencies.

An arrangement which is not free from criticism, but has given reasonably satisfactory results over a number of years, is shown in Fig. 13. This is an arrangement in which the grid voltage of V_2 is obtained from a tapping on the output of V_1. There are various methods of obtaining this tapping for the grid, but the one illustrated is fairly typical. The value of R_2 is given by the formula

$$R_2 = \frac{R_1 + R_2}{M}$$

where M is the stage gain of V_1. It is essential for the adjustment of R_2 to be made under working conditions in order that correct balance may be obtained between the two sides. Apart from the necessity for accurate adjustment, this circuit is extremely satisfactory although the effective gain of V_2 is only unity. This valve is therefore used only as a phase splitter and does not add to effective amplification. In this circuit the output of valve V_1 is required to excite only one grid of the push-pull stage. Valves V_1 and V_2 are often combined in a single bulb by using twin triodes such as the 6N7-G(6A6) or 1J6-G(19). In this circuit, since the cathodes are almost at earth potential, the hum introduced in the stage is very low.

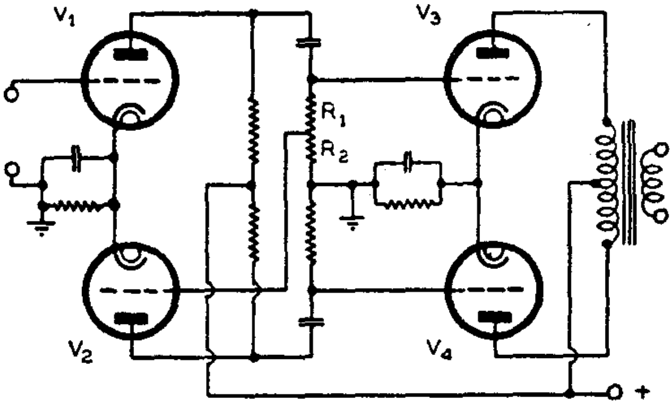

Figure 13

A circuit known as the "Floating Paraphase" is shown in Fig. 14. In order to visualise the operation of this circuit consider firstly the situation with V_2 removed. Resistors R_5 and R_9 in series form the load on valve V_1, and the voltage at the point X will be in proportion to the voltage at the grid of V_3. When V_2 is replaced, the voltage initially at point X will cause an amplified opposing voltage to be applied to resistors R_7 and R_9. If resistor R_7 is slightly greater than R_5, it will be found that the point X is nearly at earth potential. If the amplification of V_2 is high, then R_7 may be made equal to R_5 and point X will still be nearly at earth potential. The point X is therefore floating, and the circuit being a true Paraphase the derivation of the name "Floating Paraphase" is obvious. This circuit has certain advantages over the arrangement of Fig. 11, since V_1 and V_2 each excite only one grid (V_3 and V_4) and since V_1 and V_2 may both be pentodes, thereby again providing a higher voltage output. A further advantage is that provided V_1 and V_2 are pentodes, series negative feedback may be used with pentode or tetrode valves in positions V_3 and V_4; this arrangement is, however, not essentially stable, and motor-boating may be experienced. When feedback is used the preferred arrangement is that of Fig. 11 of Chapter 6.

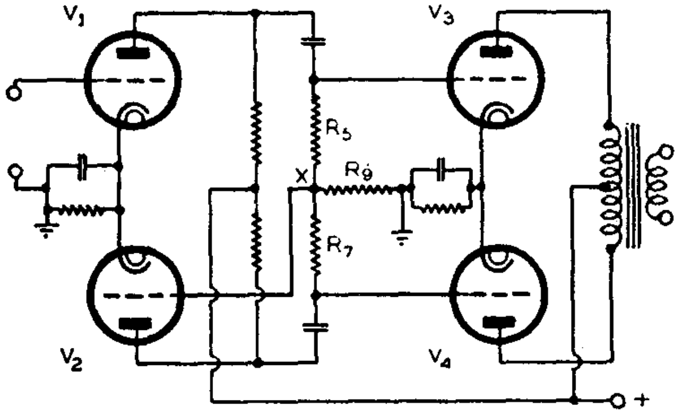

Figure 14