The tube amplifier does not necessarily come off second best as far as its public-address application is concerned. In its favor are these considerations:

1. Lower initial cost.
2. In the event of the failure of a tube, the amplifier service may be restored almost immediately. Replacement of transistors is usually a more laborious job.
3. The tube amplifier is less susceptible to the catastrophic type of failure that sometimes occurs in transistor amplifiers.
4. The tube amplifier is considerably easier to service on the bench than the transistor amplifier.
5. Despite the fact that the tube amplifier runs hotter than a transistor amplifier of the same output power rating, the tube amplifier is less affected by installations where the ambient temperature is high.

Transistor Input Stages

In the case of tube p.a. amplifiers one has two choices with regard to microphone(s) and input impedances-a high-impedance (usually low-cost) system or a low-impedance (usually high-cost) system.

If the microphone is to be located near the amplifier, the most economical system employs a high-impedance microphone into a high impedance input. The least expensive high-impedance microphone is the crystal or ceramic type which requires a very high impedance load for good low-frequency response. This load (around 500,000 ohms) is available in the tube amplifier by connecting directly into the preamplifier stage grid circuit. If the microphone is to be located some distance from the amplifier, the cost runs higher for two reasons. Low-impedance microphones are generally of the moving-coil variety and require a built-in transformer to provide a 200- or 600-ohm output, optimum for the lowest induced noise in the microphone line. In order to properly couple a low-impedance microphone to the preamplifier input grid, a matching step-up transformer is employed.

In the transistor amplifier a number of input conditions can be obtained, as shown in Table 1.

The type of amplifier will determine, to a great extent, the future integration of modules that may be plugged into the basic amplifier to expand its versatility. Many manufacturers provide such "plug-in" accessories to permit more flexible operation from a basic economy amplifier.

One of the basic plug-in modules is the microphone matching transformer. It is usually designed to plug directly into sockets provided on the chassis. This type of design flexibility permits low-to-high impedance matching while maintaining line balance to ground for minimum noise pick-up*

Input volume control from distances as great as 2000 feet is made possible by the use of a plug-in light-sensitive module. The remote station does not control audio volume directly; it simply controls the level of direct current flowing to a lamp in a light-tight enclosure. Within this enclosure is a light-dependent resistor which is tied into the amplifier signal path. The resultant brightness of the lamp in the module changes the resistance of the LDR which acts as a volume control. Despite the fact that the control station is so far away, there is absolutely no extraneous noise pickup as there is complete electrical isolation of the audio signal controlled from the control line. Use of this device permits the operator of the p.a. system to be located with the audience so that he can better judge the proper sound levels that are required.

In some input designs built around expandability, manufacturers have provided both space and receptacles for optional two-channel microphone preamplifiers. It is interesting to note that most of such design features are at the input end of the amplifier, for this is the area of greatest complexity as far as added facilities are concerned.

An example of a group of amplifiers using modular construction to permit up to six additional plug-in input modules is the *Bell P/A* Mod Series. Of particular interest are the microphone input modules using FET's to achieve 1-megohm input impedances. The low-impedance module uses a matching transformer with an electrostatic shield operating into an FET, simulating tube operation. Another interesting use of FET's to achieve results not ordinarily obtainable with other devices is a plug-in volume-limiting module which utilizes, in addition to the FET, an IC operational amplifier.

As with tube amplifiers, it is usual practice to provide high-gain microphone preamplifier stages in order to main-

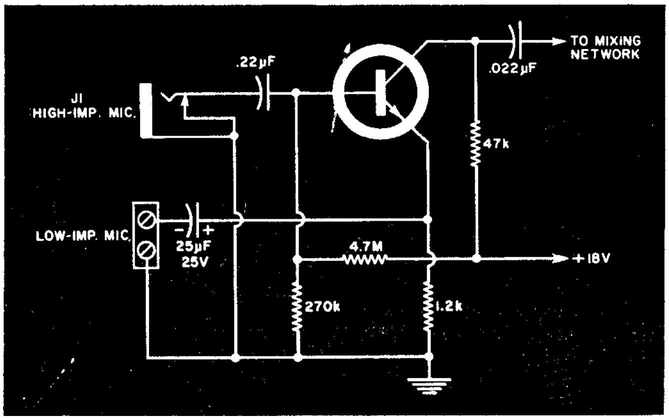


Fig. 1. Multi-impedance microphone preamplifier stage.

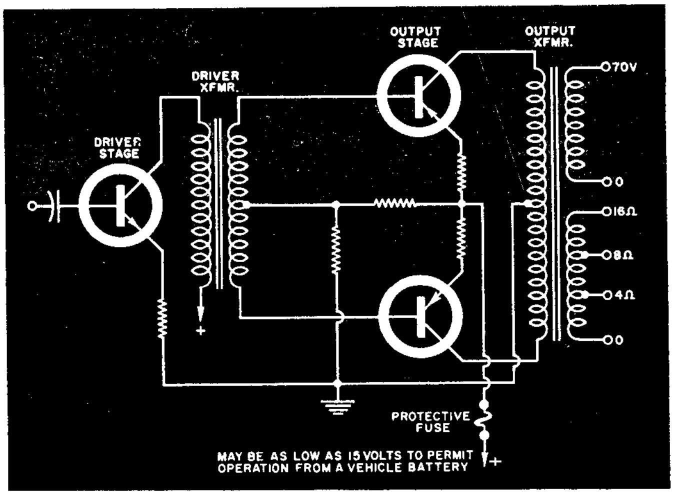
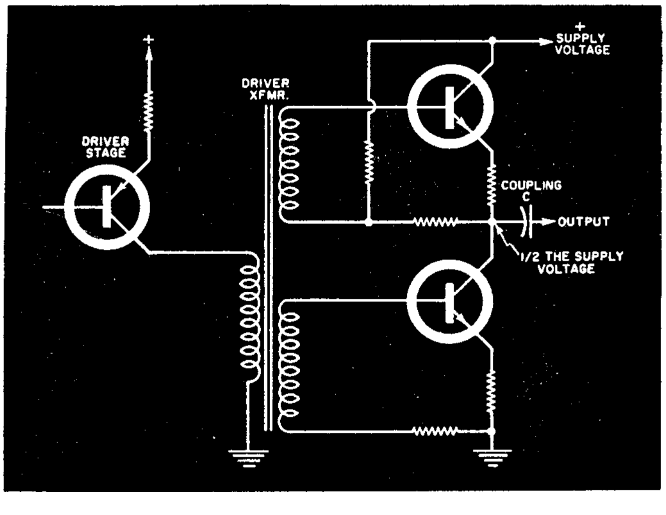


Fig. 2. Basic transistor output stages using two transformers.

Fig. 3. Simple output-transformerless transistor output stage.



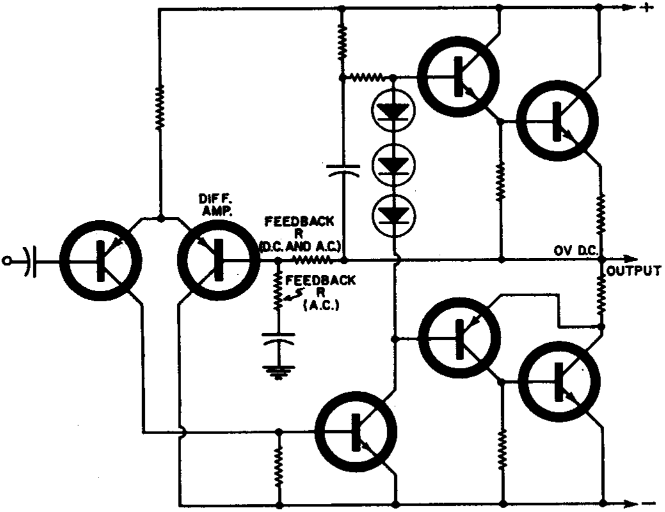


Fig. 4. Output stage that is completely transformerless.

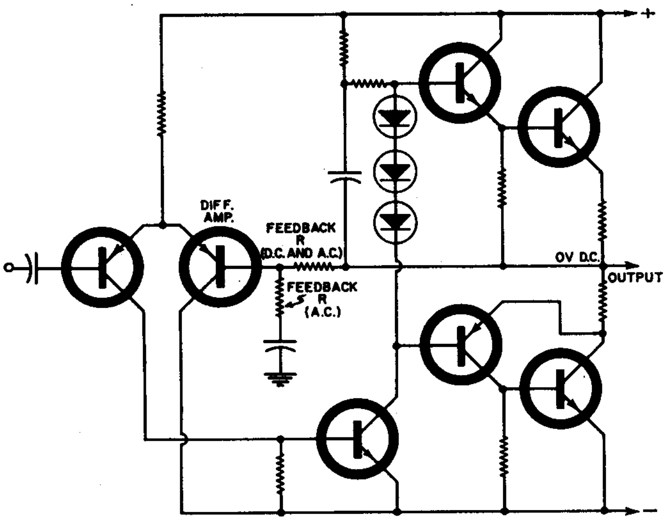


Fig. 4. Output stage that is completely transformerless.

tain a good signal-to-noise ratio by mixing the several inputs at some intermediate level. The proper input impedance is important, not only because of the profound affect it has on microphone performance, but because the relationship of the input impedance (and how it is achieved) to the microphone impedance influences the input signal-to-noise ratio.

The advent of the transistor freed circuits from hum pickup in the input stage. There is still present the "shot" noise effect which requires careful selection of transistor type and proper design of the input stage with regard to collector current in order to eliminate it.

Another factor is the necessity for a wide dynamic range. The input stage must be able to handle a wide range of signal levels without clipping or adding distortion at high levels, or allowing the introduction of spurious noise at low levels. By using a sufficiently high collector supply voltage, large signals can be handled without overload. The effect is that the dynamic range the stage is required to handle will dip down less into the noise level than would be the case if the overload point were lower.

In some amplifiers the 600-ohm and 100,000-ohm unbalanced input impedances are achieved by a simple technique which automatically selects the appropriate impedance, depending on which type of microphone is connected. This is illustrated in Fig. 1 which shows the microphone input stage that is utilized in the *Bogen* CHS-35 p.a. amplifier.

When a high-impedance microphone is employed, it is plugged into *J*1. The stage then operates as a common-emitter amplifier which has a medium input impedance. The emitter resistor is not bypassed. The resulting current feedback helps to raise the input impedance to about 100,000 ohms. If it is desired to operate from a low-impedance (600-ohm) microphone, connection is made instead to the terminal strip. In this mode of operation the base is effectively grounded at signal frequencies by the 0.22-μF capacitor. The signal is fed into the emitter of what has become a common-base amplifier which has low input impedance with high power gain.

The current trend toward lower prices of junction field-effect transistors will be reflected in their increased use in future designs of input and intermediate stages of public-address amplifiers. The use of FET's provides stage input impedances comparable to those of vacuum tubes and will result in designs which are direct analogs of tube designs in terms of input impedance, mixing networks, and tone controls. Since some FET's have better noise characteristics at low frequencies than transistors and are immune to the noise problems of tubes, it is possible to obtain very good input-stage characteristics by using them.

Transistor Output Stages

The vacuum-tube amplifiers used today are essentially the same as those used for over thirty years. Transistor amplifiers, on the other hand, are available from different manufacturers in a variety of output-stage circuits. Why is this so?

The earliest transistor amplifiers were analogous to the tube amplifiers in that the transistors were substituted for tubes while retaining the output (and in some cases the driver) transformer. It is interesting to note that most of the transistor amplifiers sold today are still of this type. Fig. 2 shows the basic output stage. The output transformer is essential to the operation of this circuit but imposes a restriction on the output bandwidth of the amplifier. In practice, however, with the exception of those few installations where large amounts of bass power are required, the performance of the amplifier is completely acceptable and is, in fact, better than the performance of most speakers used in distribution systems.

Impetus was given to the development of improved transistor output circuitry by the demands of the hi-fi field. In order to improve the operation with a single speaker, designers took advantage of the inherent low-impedance characteristics of the transistor to develop a practical output-transformerless output stage.

In Fig. 3, even though the transistors are operated in series directly into the low-impedance load without an intervening transformer, phase inversion and input drive are accomplished through the use of a dual-secondary driver transformer. The upper section acts as an emitter-follower into the load on the half cycle that the upper base is driven positive. Current flows from the supply through the capacitor and through the load. On the alternate half cycles the lower section is driven into conduction and the energy stored in the capacitor drives current through the stage half and the load in series. The use of a driver transformer imposes a restriction on the power bandwidth of the stage, but reasonably good results can be obtained with a carefully designed transformer using inexpensive materials.

Fig. 5. Power-amplifier section of the Bogen Model CHS-35 p.a. amplifier.

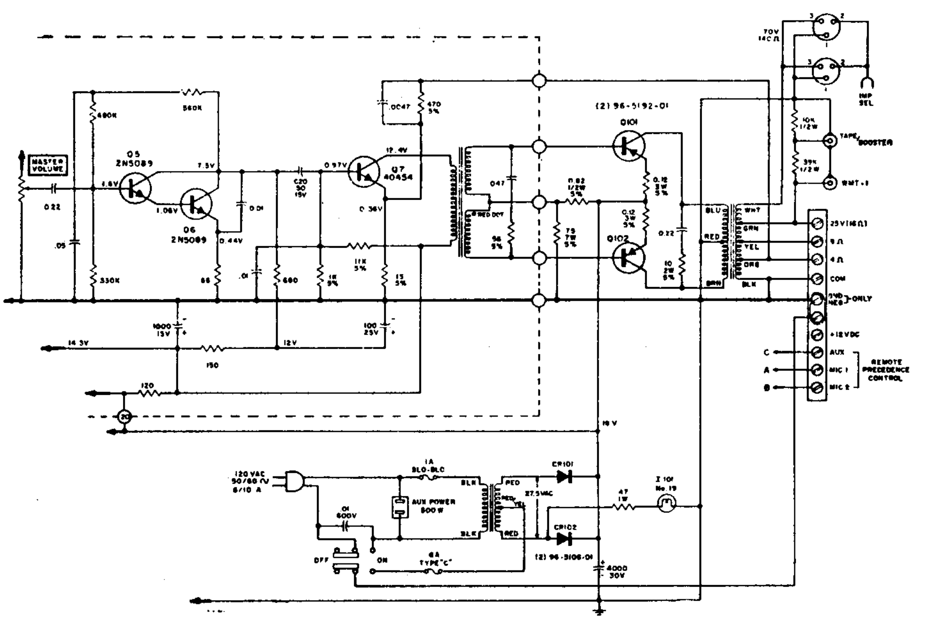
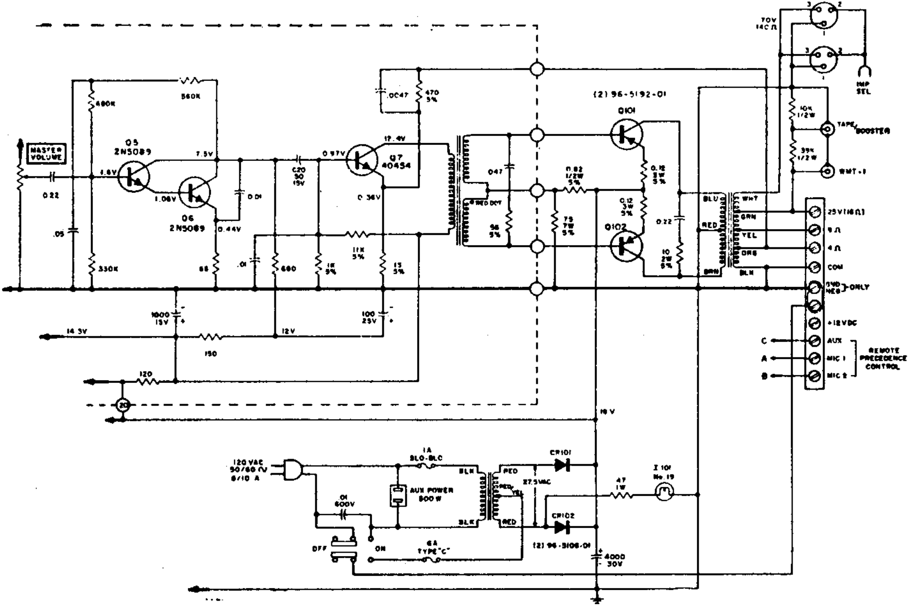


Fig. 5. Power-amplifier section of the Bogen Model CHS-35 p.a. amplifier.



A more recent development in the field of output-transformerless stages is the circuit shown in Fig. 4. The output transistors are in series, as in the previous circuit, but the power supply consists of both a negative and positive supply in series with a common ground. As a result, the d.c. voltage at the junction of the output transistor circuit is at ground potential, eliminating the need for the output coupling capacitor used in the previous amplifier. Because of the large degree of d.c. inverse feedback used, this point is maintained within a few millivolts of zero voltage over a wide range of temperature and line voltage so that under normal circumstances no more than a few insignificant milliamps of current would flow through the speakers.

Phase inversion is obtained by using a complementary *n-p-n/p-n-p* pair of driver transistors. For signal purposes, the bases of these two drivers are essentially tied together (by the bias diodes) and driven by the pre-driver which, in conjunction with the resistor-capacitor network in the base circuit of the upper section, is able to swing these bases through the wide range of voltage necessary for full output. The differential amplifier provides a convenient means of obtaining separate isolated control points for the input signal and the a.c. and d.c. feedback voltages.

Protective Circuits

If a class-AB tube amplifier were operated into a short-circuited load, either the primary fuse would blow or, more likely, the output tubes would operate beyond rated dissipation and the plates would glow red. Even operation over extended periods would only result in some gas evolving from the plates to the hardly perceptible detriment in operation after the fault was cleared.

Transistors, unfortunately, cannot be abused this way. If the junction temperature exceeds a precisely defined point, the device is ruined catastrophically. Protection must be provided to prevent this if a short circuit develops. There are two schools of thought as to how best to accomplish this type of protection.

One group contends that if a fast-acting fuse or circuit breaker is used, it will open up and protect the transistors before the junction temperature rises to a damaging level. The reason this is possible is that the rugged, relatively "slow" (having poor high-frequency gain) transistors usually used in the center-tapped transformer circuit, when effectively coupled to massive heat sinks, have a thermal ballistic characteristic that is long enough to permit the fuse to open before enough energy is pumped into the transistor to raise the junction temperature to an unsafe level when a short occurs in the load.

The other group, in order to achieve better high-frequency power output, utilizes "faster" transistors which use smaller chips and do not have as favorable a thermal configuration and therefore require faster-acting protection. In general, a fuse is not fast enough to provide the needed protection. Instead, a circuit which causes the high output current under short-circuit conditions to activate fast-acting solid-state switches is used to cut the drive signal instantly. These protective devices will be dealt with later in this article.

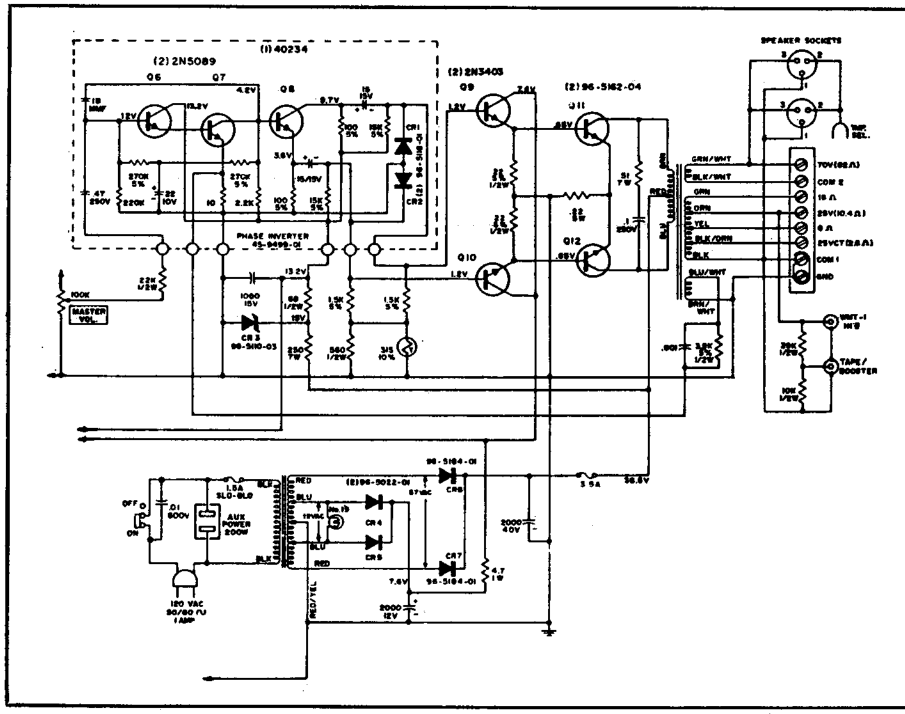
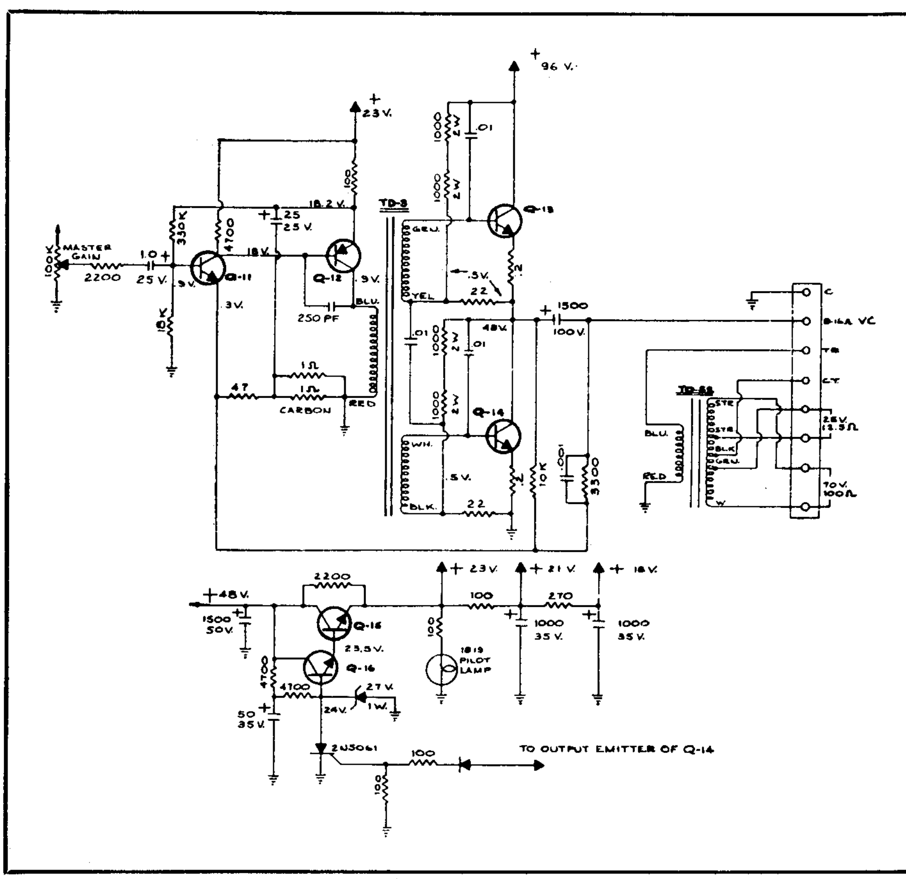


Fig. 6. The power-amplifier section of the Bogen Model MTA-60 p.a. amplifier.

Fig. 7. Power-amplifier portion of the Grommes-Precision Model G-76 amplifier.



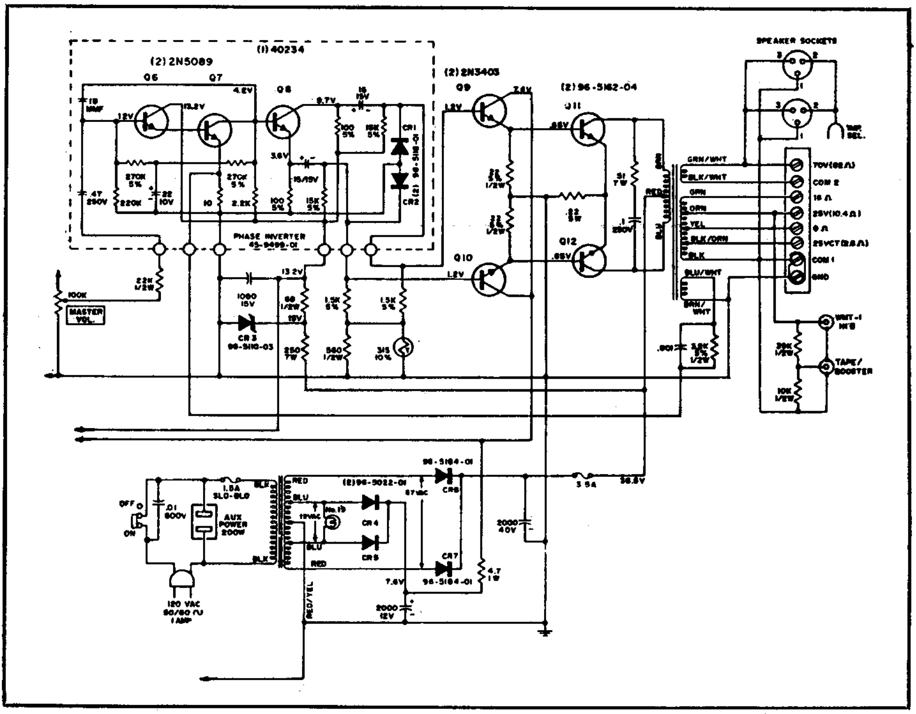
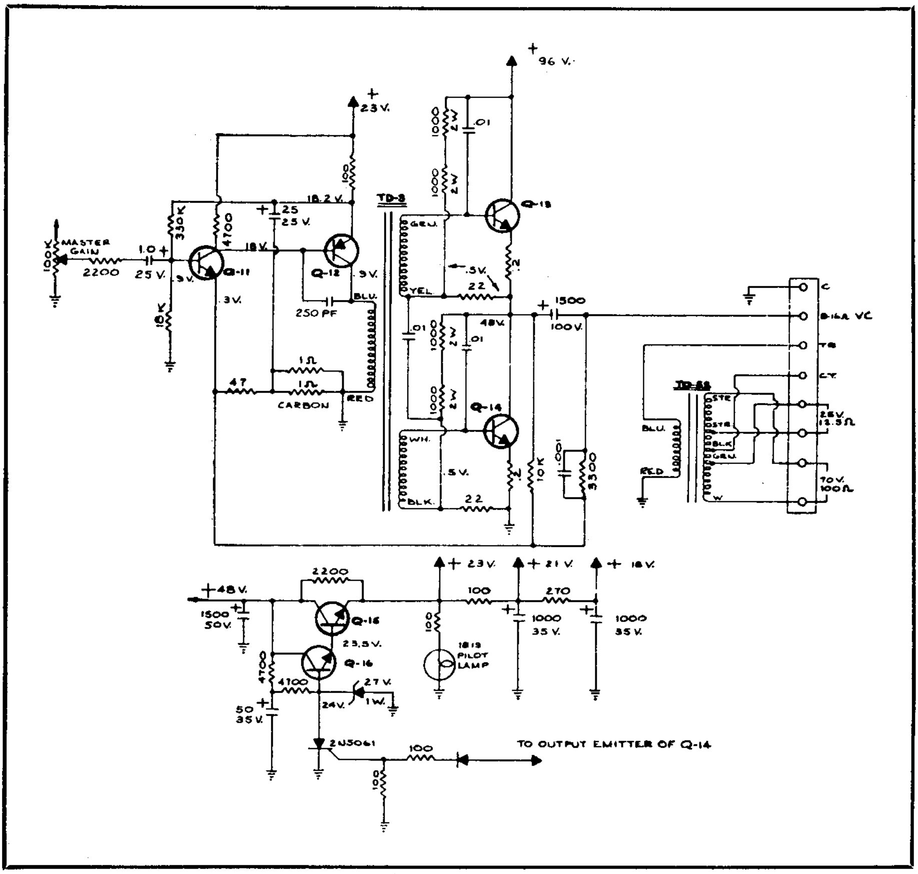


Fig. 6. The power-amplifier section of the Bogen Model MTA-60 p.a. amplifier.

Fig. 7. Power-amplifier portion of the Grommes-Precision Model G-76 amplifier.



The center-tapped transformer-terminated output stage selected for analysis first is that used in the *Bogen* Model CHS-35, a 35-watt p.a. amplifier (Fig. 5).

To achieve high efficiency the output stage is operated in class AB with only a small amount of forward bias to eliminate crossover distortion. This bias is derived from a series resistive network across the d.c. supply. The low voltage at the junction of these two resistors is applied to both bases of *Q*101 *and Q*102 by feeding it into the center tap of the driver transformer secondary. Thermal stability is accomplished by the use of emitter resistors as well as the low d.c. resistance between the base and emitter of the output transistors afforded by the driver transformer's secondary winding.

The output transistors, germanium *p-n-p* devices, are operated into a center-tapped output transformer which reflects the proper low impedance from the load circuit. The output transformer secondary windings provide 4-, 8-, and 16-ohm output impedance taps as well as a 25- and 70-volt output taps. This array of impedance and voltages makes for a flexible, easy-to-use load arrangement.

Since a short circuit in the load network causes a rise in collector current of only the two output transistors, *Q*101 and *Q*102, and since these devices are rugged units, it is possible to protect them from destructively high temperatures under abnormal loads by simply fusing the d.c. supply lead with a 6-ampere fast-acting fuse. Since the built-in power supply delivers only 18 volts d.c., it is possible to operate the amplifier from a 12- to 15-volt vehicle battery system by a simple reconnection at the terminal strip.

The output transformer is essential to the operation of the amplifier and is utilized for all of the output taps. Unless somewhat more costly output and driver transformers are used, the frequency response, and particularly the low-frequency power capability, is limited. Similarly, the combined phase shifts of the two transformers limit the amount of stable inverse feedback that can be applied to reduce distortion and to flatten frequency response. Despite these limitations, this type of amplifier is widely used and has a history of providing satisfactory, reliable service.

A variation of this configuration substitutes a split-load phase inverter and additional directly coupled power gain in the form of a Darlington configuration (*Q*9 and *Q*11 as well as *Q*10 and *Q*12) for the driver transformer (Fig. 6). This circuit is exemplified by the *Bogen* Model MTA-60, a 60-watt amplifier. Elimination of the driver transformer permits more inverse feedback, resulting in better frequency response and lower distortion.

Other Circuit Examples

The *Grommes-Precision* Model G-76, a 50-watt p.a. amplifier (Fig. 7) is an example of a transformer-driven, series-output stage. Two class-AB-operated *n-p-n* transistors, *Q*13 and *Q*14, are connected in series from the d.c. supply to ground. The junction of the two is connected to the load through a 1500-μF capacitor. The individual secondary windings of the driver transformer are connected between the base and emitter of each output transistor in such a phase relationship that *Q*13 conducts current from the supply to the load for one half of the drive cycle and *Q*14 conducts current from the charged coupling capacitor to ground through the load on the other half of the drive cycle. The combined current through the load is a replica of the signal voltage across the primary of the driver transformer.

Forward bias is obtained by returning the driver-transformer secondaries to the junctions of the 1000-ohm and 22-ohm resistors in each half of the stage. Inverse feedback is taken back to the emitter of *Q*11 from two points, before and after the output coupling capacitor. If the full amount of feedback were taken after the capacitor, the phase shift at low frequencies would cause instability.

Operation into a low-impedance load of from 4 to 16 ohms is possible with maximum fidelity characteristics by direct connection to the amplifier output only. The frequency at which output power would be halved by the output capacitor is 30 Hz for a 4-ohm load. For operation into other impedances (25- and 70-volt constant-voltage lines), the autotransformer is connected to the output. This results in some deterioration of response and power bandwidth as compared to the direct connection but is a moderate compromise to make in order to achieve the flexibility of a multi-impedance output.

Output transistor protection is provided by a fast-acting latching circuit using a silicon controlled rectifier. When an abnormal load condition causes the emitter current of *Q*14 to rise to a high value, the drop across the 0.2-ohm emitter resistor drives current through the diode and the two 100-ohm voltage-divider resistors. The junction of these resistors drives the gate of an SCR, which is normally in a non-conducting condition. Whenever the voltage at the gate exceeds a critical "trigger" voltage (on the order of ½ volt) the SCR is turned on. The current which otherwise flowed through the zener diode to maintain its voltage at 27 volts is then diverted through the SCR with the result that the voltage at the input base of the Darlington pair, used as the series regulator for all of the stages before the power stage, is rapidly lowered to about 2 volts. This, in effect, cuts off the d.c. voltage to the driver stage, which has no storage capacitor in the supply circuit, in about 100 microseconds. Switching off the drive to the output stage, this rapidly prevents excessive current from raising the junction temperature to damaging levels. Since an SCR, once in the conducting mode, cannot be turned off except by reducing the current through it to zero, the system is restored to operation after the fault is cleared by turning the power switch "off" for about 5 seconds and then "on" again.

The quasi-complementary, (*Continued on page* 75)

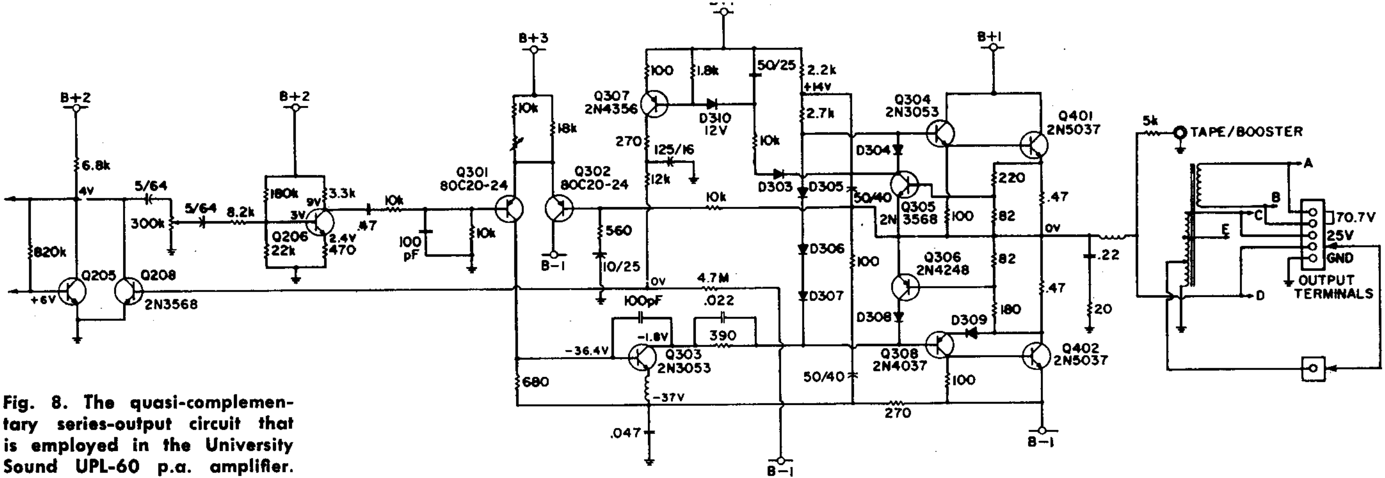


Fig. 8. The quasi-complementary series-output circuit that is employed in the University Sound UPL-60 p.a. amplifier.

series-output circuit as used in the *University Sound* Model UPL-60, a 60-watt amplifier, is shown in Fig. 8.

Two class-AB-operated *n-p-n* transistors, *Q*401 and *Q*402, are operated in series fashion as in the earlier circuit, except that separate positive and negative power supplies are used. This configuration eliminates the need for the output capacitor with its inherent low-frequency power limitation.

Instead of a driver transformer, a complementary pair of transistors, *Q*304 (*n-p-n*) and *Q*308 (*p-n-p*), are used to accomplish the phase inversion. A complementary series pair of transistors may be driven with the same signal phase because the characteristics of the *p-n-p* and *n-p-n* devices automatically select the proper phase and invert one for driving the output transistors.

Forward bias is derived from the drop across diodes *D*305, *D*306, and *D*307. By using junction diodes it is possible to attain excellent compensation for the variation in the base-emitter drop of *Q*304 and *Q*308 with temperature. By thermally coupling the diodes to the transistors, idling current of the output stage is kept fairly constant over a wide range of temperature and supply voltage. This prevents thermal runaway.

The d.c. voltage at the output is essentially zero. This condition is maintained over a wide range of temperature and drive conditions by the use of an extremely large amount of d.c. feedback, back to the base of *Q*302, one half of the differential amplifier.

Protection of the output transistors is accomplished through a sophisticated circuit which operates as follows. When a high emitter current results from a short circuit in the load, it develops a sufficiently high voltage at the bases of *Q*305 and *Q*306 so that they are switched into the "on" mode. As a result, diodes *D*304 and *D*308 provide a shunt path for the drive current from the driver. This limits the drive current, and consequent dissipation of the output transistors, to a level which prevents immediate destruction. If operated in this fashion for more than a second or so the output transistors may be damaged. To keep this from occurring, *Q*305 also switches *Q*307 on, which with its associated circuitry controls the base voltage of *Q*208. This, in turn, acts as a switch controlling the signal to the power stage. The time constants are chosen so that with a severe overload condition the signal is off for about 3 seconds, after which the amplifier is automatically turned on again. If the short circuit persists, the amplifier is turned off again in about 100 milliseconds for another 3-second period. This duty cycle is such that the amplifier may be left operating continuously into a short circuit without damage to the transistors.

A unique feature of this amplifier is that it is available with an output autotransformer or, at lower cost, without a transformer. Since a transformer represents one of the more costly components in the amplifier, eliminating it in those installations where the loudspeaker is capable of true wide-range reproduction and is located close to the amplifier, represents a tidy saving.

The use of the output-transformerless amplifier for large multi-speaker installations does not appear practical. Sound technicians have enough to do laying out the system using transformers marked in watts without making the cumbersome calculations needed to lay out a series-parallel combination of voice coils. Furthermore, the frequent need to re-allocate power to some speakers in the system after it is "fired up" precludes a method which requires a complete rewiring of a group of speakers to adjust the power from one speaker to a different level.