Electric Guitar Amplifier Handbook

by

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Preface

The guitar is a universally popular musical instrument. The use of electronic amplification isn't confined to guitars alone, but is used on many instruments in the band. Unamplified string instruments do not have a great deal of sound output, but with the super-powered amplifiers used today, one guitar can have a sound output greater than a whole old-fashioned brass band.

These musical instrument amplifiers are used everywhere, in cities, towns, and hamlets. The service and maintenance of these amplifiers can provide a good part of an electronics technician's business. These amplifiers contain many "special effects" circuits, such as reverberation, vibrato/tremolo, "fuzz," percussion, and others. However, the heart of every musical instrument amplifier is a plain old audio amplifier, which can be tested and repaired with standard electronic test equipment already on hand in the average service shop.

For the instrument owners who have a good grasp of the fundamentals of electronics, this book will provide the basic information you need to make repairs properly and safely. We'll give you tests to make servicing and troubleshooting much easier, on both tube and transistor amplifiers of all sizes. You can check power output, distortion, and sensitivity, and keep the instrument in perfect working order with a minimum of trouble.

In the past, due to the specialized nature of this field, it has been hard to get service data and information on these instruments. This book has been designed to give you the basic "typical circuits" used in all of these amplifiers. In addition, you'll find schematic diagrams of a great many amplifiers, including the most popular makes, from the small practice amplifiers to the "big boomers" with enough power to fill a football stadium.

Transistor amplifiers, especially the super-power 200 to 300-watt types, require special techniques to service them safely. You'll find an expanded section on these in this edition, as well as a complete listing of all of the "safety precautions" which must be taken when servicing a transistor amplifier. You'll also find data on how to choose a suitable replacement-type transistor for an unknown type. There are a great many types of transistors; however, with this method, you'll be able to use "stock" replacements safely for practically 100% of them.

All of the test and servicing methods mentioned in this book have been "bench-tested;" they were developed by working on actual commercial amplifiers. The power-output tests were taken from official factory service data from the many manufacturers who helped me to prepare this book.

The author wishes to acknowledge the following manufacturers for their cooperation in supplying many of the schematics used in this book: Allied Radio Shack; Ampeg; Chicago Musical Instrument Co.; Ediphone, Inc.; Electro-Voice, Inc.; Estey Company; Fender Electronic Instrument Company; Gibson, Inc.; Kay Musical Instrument Company; Montgomery Ward & Co.; Sears, Roebuck & Co.; Supro; The Harmony Co.; and Valco.

JACK DARR

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SECTION I

How Guitar Amplifiers Work

Chapter 1

Amplifying the Signal

Technically speaking, the title of this book should be "Servicing Electronically Amplified Musical Instruments" since electric guitars are not the only ones involved. Every instrument in the band can have its own pickup—violins, banjos, string basses, etc. However, there is no question that the guitar is the most popular of the group. Keep in mind that everything in this book can be applied to any of the instruments where electronic amplification has been used. So far, drums have been exempt, but anything can happen.

GENERAL DESCRIPTION

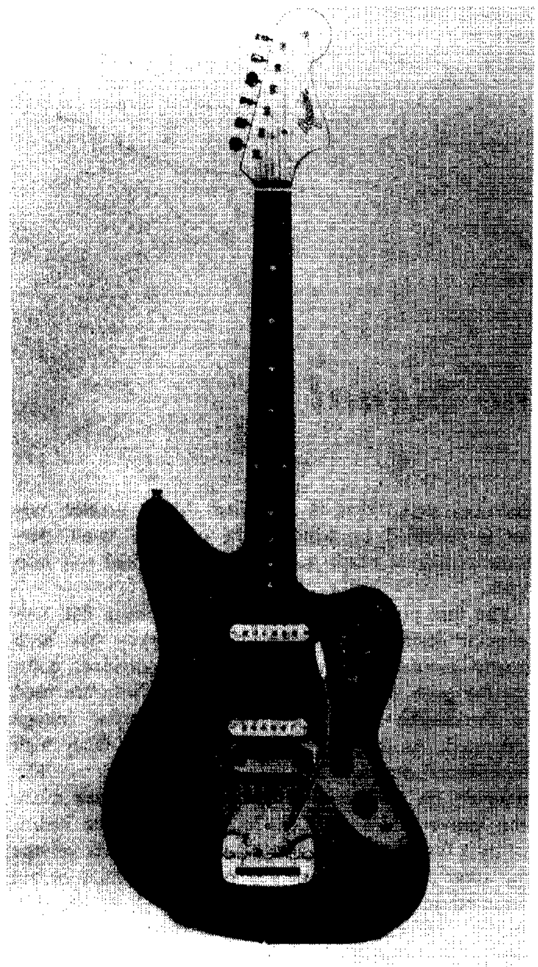
The first electric guitars used contact microphones. These small special microphones, when fastened to the body or shell of an instrument, pick up the actual sound vibrations and convert them into an electrical signal for amplification. They are like a phonograph pickup which changes mechanical vibration into electrical signals. One of the disadvantages is their poor sensitivity. If the amplifier is turned up high enough to get an adequate output, the whole body of the guitar acts as a microphone. When someone speaks toward the instrument or the player shifts it against his clothing, the sound can be heard everywhere. Also, when the sound from the speakers gets into the microphone, acoustic feedback occurs. A different method of picking up the music is obviously needed.

Since all guitars of this type use metal strings, a magnetic pickup has been developed. High impedance coils are wound on iron cores and placed under the strings at a point where the motion of the string is greatest—near the hole of the instrument. Movement of the metal string through the magnetic field of the coil induces a voltage in the coil; this is the electrical signal that is amplified. Much greater output is obtained by winding the coils on small, permanent magnet cores instead of the original soft iron types.

The first pickups used one large coil on a flat, rectangular form. The output of the pickup has been greatly increased by winding small individual coils, one for each string. Many turns of fine wire are used on these—the more wire, the more output voltage generated. As a result, all pickups have a fairly high impedance output. A volume control is usually mounted on the body of the guitar where the musician can reach it quickly. In more elaborate instruments a tone control is also placed here. Other volume and tone controls are located on the amplifier or are mounted in a special foot-pedal housing so the performer can change the volume without taking his fingers off the string.

The first electric guitars were standard instruments with electronic pickups added. Since the acoustic resonance of the guitar body isn't necessary if an electronic pickup is used, special, entirely electric guitars are now built (Fig. 1-1). The body is made of solid wood about 1.5 inches thick. The neck, frets, and proportions are the same as before, of course.

There are two basic types of guitar: the Spanish, which has raised frets on the neck, and the Hawaiian or steel guitar, which has no raised frets. They are played with the fingertips or a pick, by plucking one string at a time or by strumming chords. A steel bar is moved up and down the neck of the Hawaiian guitar to control the pitch, giving the music a characteristic glissando effect. Some special types of guitars have two full sets of strings, each with its own pickup and control (Fig. 1-2). These are built in a rectangu-



Courtesy Fender Electric Instrument Company

Fig. 1-1. An electric guitar.

lar box-shaped case mounted on four legs. The musician sits down to play these, just as he would to play a piano.

The more elaborate instruments have special effects, such as vibrato, tremolo, and echo. These will be discussed in detail in the following chapter. Tone controls of all kinds are used. Most are simple bass-cut or treble-cut types, but some use complex feedback circuits.

THE AMPLIFIER

An electric guitar amplifier is the same as a public address (pa) system. It consists of a source of signal (the microphone or pickup), the amplifier (to build up the weak electrical signal to whatever power is needed), and the speakers. Fig. 1-3 shows a block diagram of such a system.

The amplifiers used are all conventional, meaning that they are practically identical to those used in all kinds of sound equipment. In other words, these amplifiers are basically the same as those used in pa systems, hi-fi record-playing systems, and many others. This similarity makes things easier for the owner and the service technician, too. When they learn the basic circuits, they can apply what they have learned to all guitars. All amplifiers have the same basic divisions; the only difference is in the number of stages used and the total power output of the system.

What does the amplifier do? The signal, which is the electrical equivalent of the musical tone from the guitar, is fed to the input of the amplifier through a shielded cable, to keep it from picking up hum and noise on the way. There it is amplified (raised to a much higher electrical level) to drive the speakers.

There are two kinds of stages in all amplifiers—transistor types and those with vacuum tubes. The first stages are all voltage amplifiers; they build up the signal voltage so that it is big enough to drive the power output stage to full output. The power-output stage—output for short—is always the last stage in an amplifier—just before the speakers.

Fig. 1-4 shows a block diagram of a typical amplifier. Since all amplifiers use a similar pattern, you should remember it. The only difference will be in the total number of stages and in the special effects added along the way. As you can see in the dotted boxes, tone controls of any kind—tremolo, vibrato, and echo effects—can be added to the signal before it goes to the power-output stage and the speakers. These special effects are discussed in detail in the following pages, and instructions are given so you can add them to amplifiers that do not already have them.

THROUGH THE AMPLIFIER, A STEP AT A TIME

In order to see what each stage does, examine the amplifiers, a step at a time. Begin with the power output stage, just as an engineer would if he were designing the amplifier, since this is the stage that determines how much power output the amplifier is going to have.

Fig. 1-5 shows a typical single-ended output stage—the kind you will find in the smaller amplifiers. The tube used here can be a 6V6, 6L6, 6AQ5, 6BQ5, or any beam-power pentode type. In this circuit maximum power output is about 4 to 6 watts, depending

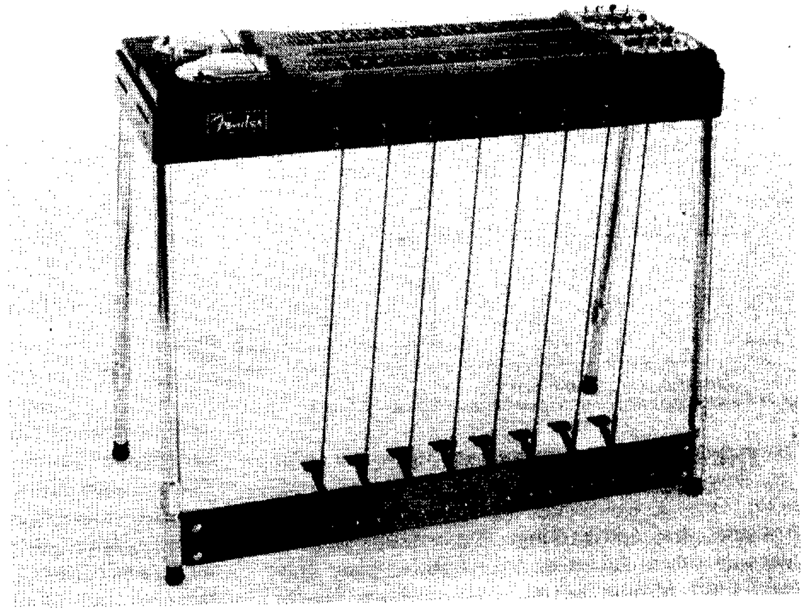


Fig. 1-2. A pedal guitar.

Courtesy Fender Electric Instrument Company

on the tube type used and the voltage fed from the power supply.

These are called power-amplifier stages, because they must do actual work—move the speaker cone to make the sound. Consequently, the power-amplifier stages have to handle high plate currents as well as voltage. Voltage times current equals power, or work done.

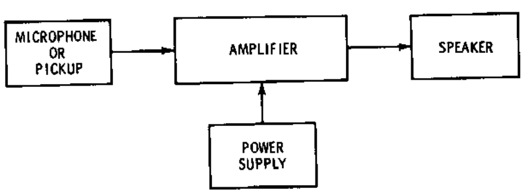


Fig. 1-3. Block diagram of a typical guitar assembly.

To get more power than a single tube can handle and to increase the efficiency of operation, two identical tubes are used in a push-pull circuit. Fig. 1-6 shows this circuit. The object of the game is to get the most current to flow in the output transformer primary, so another tube is hooked up to the other end of it. While the top tube is pushing current downward through the winding, the lower tube is pulling—push-pull. A more technical explanation is that the two tubes are fed signal voltages so that their grids are 180° out of phase, or exactly opposite, one goes up while the other goes down. Because the plates follow the grids, plate current rises in one tube and falls in the other at the same time.

By using a push-pull output circuit, more than double the power output of one tube is obtained. This is due to the increased efficiency of the circuit and the fact that the plate current of both tubes flows through the same primary winding.

TRANSISTOR POWER AMPLIFIERS

If you are used to tube power amplifiers, transistor power-output stages may appear strange. For one thing, most of them do not use output transformers to match the high impedance of the tube plates to the lower impedance of the speaker voice coils. Power transistors are basically low-voltage–high-current devices; therefore, they have very low impedance. This allows them to be connected directly to the speakers, without the use of a large expensive output transformer. This type of circuit is called an "output transformerless" (OTL) circuit, for that reason.

Transformers are used in some of the smaller amplifiers and in certain applications for the higher-powered types. However, most transistor amplifiers use the OTL circuit for its simplicity, lower cost, and efficiency. Although this transistor stage appears different, both physically and schematically, it does exactly the same thing that the tube stage does—it raises the power output (voltage times current) to get the needed amount of power into the speakers.

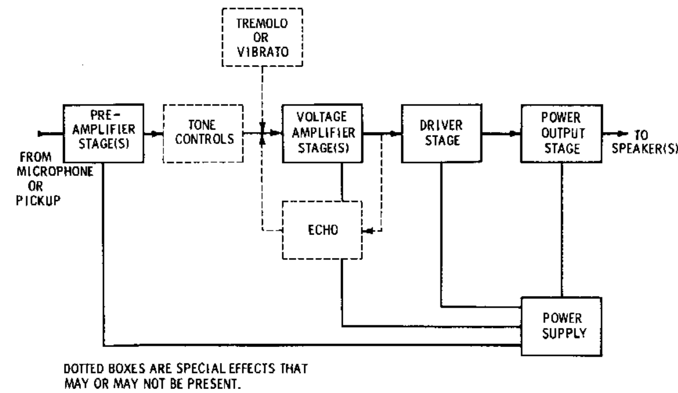


Fig. 1-4. Block diagram of a typical guitar amplifier.

THE OUTPUT TRANSFORMERLESS CIRCUIT—HOW IT WORKS

Transistors accomplish things that are not possible with vacuum tubes. All tubes have positive plate voltages and must have a positive-going voltage on the grid to make the plate current increase. Transistors come in two opposite polarities, npn and pnp. The middle letter in each denotes the polarity of the base element, the control equivalent to the grid of a tube.

In an npn transistor, the base is of a positive material. A positive-going voltage applied to this element makes the collector current increase. However, in a pnp transistor the base is negative, and a negative-going voltage must be applied to increase the collector current. In both types, a bias voltage of the same polarity as the base makes collector current increase; this is called "forward bias." Bias voltage of opposite polarity cuts a transistor off similar to the action of a high negative grid voltage on a tube.

This peculiarity of transistors makes it possible to very readily design push-pull stages of all kinds. Fig. 1-7 shows a basic circuit. Transistors of opposite polarity are used; Q1 is an npn, and Q2 is a pnp. These transistors are exactly alike in characteristics; only the polarity is different.

From the driver stage, a complete ac sine-wave signal is fed simultaneously to the bases of both transistors. During the positive half-cycle (A), Q1 is forward-biased and conducts, while Q2 is reverse-biased and is cut off. Q1 conducts heavily; current flows from the power supply through Q1. Q2 is reverse-biased, and is cut off; it is in effect an open circuit. So, the half-cycle of current flows into the large capacitor C. By normal capacitor-charge action this causes a duplicate pulse to flow through the speaker voice coil to ground.

On the negative half-cycle of the input sine wave (B), Q1 is cut off. Q2 base is forward-biased, and so it conducts, discharging capacitor C and drawing another pulse of current through the speaker to complete the original sine-wave signal. Since this current

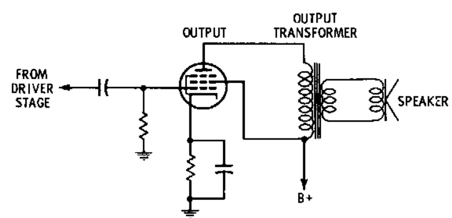


Fig. 1-5. Schematic of a single-ended power-output stage.

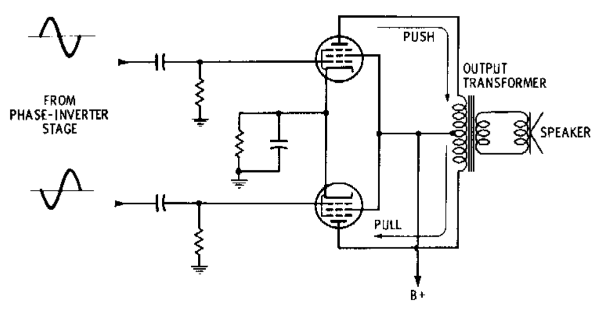


Fig. 1-6. Two-tube push-pull stage.

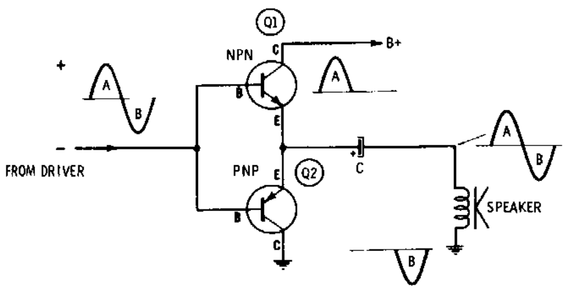


Fig. 1-7. Complementary-symmetry OTL transistor output stage.

flows in the opposite direction to that of the first half-cycle, we have a true ac in the speaker.

If you're wondering where Q2 gets its voltage supply with Q1 between it and the power source and firmly cut off (open circuit), this comes from the big capacitor C. This capacitor was charged during the first half-cycle by current drawn from the power supply through Q1. When Q1 is cut off by the input signal, the capacitor discharges through Q2, and the cycle is complete. Incidentally, this is a highly efficient circuit, due to this action. Note that power is not taken from the power supply during both half-cycles, but only during the *first* half-cycle, when it is used to draw current through the speaker and charge capacitor C. No power is taken from the supply at all during the second half-cycle—we use the same power over again in the opposite direction. So, it is theoretically possible for a Class-B circuit like this to have double the efficiency of a similar tube circuit.

Because the two transistors are just alike but of opposite polarity, this circuit is called a complementary-symmetry output circuit, or "comp-symm" for short.

THE QUASI-COMPLEMENTARY-SYMMETRY OUTPUT CIRCUIT

There is a variation of the complementary-symmetry circuit which uses the same polarity output transistors. This circuit is called a *quasi-complementary-symmetry* (almost complementary-symmetry) output circuit. The necessary phase inversion is done by using opposite-polarity transistors in the driver stages. From input to output, the overall action of this circuit is the same as in the complementary-symmetry circuit. Each output transistor conducts on one half-cycle of the input signal. Fig. 1-8 shows the basic circuit.

The drivers (inverters) are directly connected to the bases of the output pair. Q1 is connected as an emitter-follower, comparable to a cathode-follower in

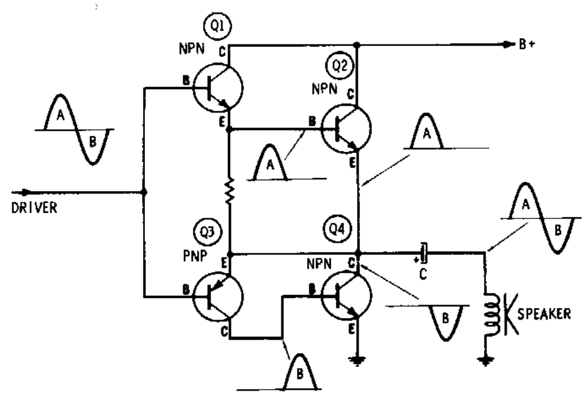


Fig. 1-8. Quasi-complementary-symmetry output stage.

tube circuitry. In transistor circuits, this stage can have current gain, but has little if any voltage gain. Most important of all, the signal is not inverted in polarity. The output signal on the emitter is in phase with the base signal; therefore, with the same polarity, a positive going half-cycle on the base of Q1 appears on the base of Q2. This makes Q2 conduct. The action is exactly the same as before; C is charged, and a half-cycle of current flows through the speaker.

Q3 is a pnp transistor. During the positive half-cycle of the input signal, it is reverse-biased and cut off. This is actually connected as a common emitter; the output is taken off at the collector and is *inverted* in polarity. The negative half-cycle of the signal appears on the base of Q4 as a positive-going signal, making Q4 go into conduction. From here on, the action is exactly the same as before; the top transistor is cut off, so Q4 takes the power from the charge in capacitor C, and the other half-cycle of signal flows through the speaker.

TRANSFORMER-COUPLED CIRCUITS

Fig. 1-9 shows a circuit using an input or driver transformer instead of the phase-inverter transistors. This circuit is not as common as the transformerless type, but it is found in quite a few amplifiers. The only difference is in the use of a driver transformer.

The driver transformer *must* have two separate secondary windings. Since the output transistors are identical, signal pulses of the same polarity are needed to turn them on. The transformer passes the positive going half-cycle through the upper secondary winding without inverting it, to make Q2 conduct. The lower secondary winding inverts the negative half-cycle of the signal resulting in a positive pulse on the base of Q3, causing it to conduct. Aside from this, the action is just the same as before. This type of output stage, using identical transistors, is commonly called a "stacked" circuit—two transistors of the same polarity simply stacked on top of each other.

POWER SUPPLY FOR TRANSISTOR CIRCUITS

There are two types of power supply used in these circuits. The simplest and least expensive one will be by far the most common. This is the one shown in the three preceding output circuits. Voltages will run from about 15 volts up to 45-60 or even 75-100 volts in the bigger amplifiers. One side is ground or common, the other side is hot.

The polarity of the power supply voltage depends on the type of transistor used. In the circuit of Fig. 1-9, for example, pnp transistors are used. The collector of any transistor in an amplifier stage is reverse-biased. With pnp transistors the power supply would be negative to ground. It is quite possible to build this circuit with npn transistors. There will be absolutely no difference in circuit actions, but the polarity of the dc power supply will be positive. Also, the instantaneous polarity of the signal voltage will be reversed. Other than this, there is no difference at all.

Some definitions at this point are in order—common terms that are needed for reference in the test and servicing sections. In the output circuit, the first transistor to go into conduction is called the "top" transistor. This is the one which is connected to the dc power supply in the single-polarity circuits. The one nearest ground or having one element grounded will be the "bottom" transistor. Incidentally, these connections can be reversed, too. You may find a circuit with the emitter of the bottom transistor grounded, as in Fig. 1-9, or with the collector grounded, as in Fig. 1-7. This makes absolutely no difference to the action of the circuit: it is just the same in all types.

THE OUTPUT STAGE AND THE POWER SUPPLY

Since the output stage uses at least 95% of the total power drain of any amplifier, it determines the size and current rating of the dc power supply. Voltages will vary quite a bit, due to the type of tubes or transistors used, but the total "voltage times current" rating of the power supply must be equal to the total of the audio power rating of the amplifier plus the efficiency rating. An amplifier with a 50-watt audio output and a 50% efficiency would need a power supply with a total rating of 75 watts, and so on.

Power supply problems are in the majority, as far as total troubles are concerned; these will be discussed in a separate section.

TUBE-TYPE DRIVER STAGE

A single-ended output stage needs a voltage-amplifier stage capable of delivering enough grid signal to the power stage to drive it to full output. For instance, a single 6V6 tube needs an input signal of about 25 volts peak-to-peak to give a full output of 5.5 watts. (This assumes that the rated voltages, 315 volts plate and 250 volts screen, are applied.) Consequently, a straight voltage-amplifier stage is used just

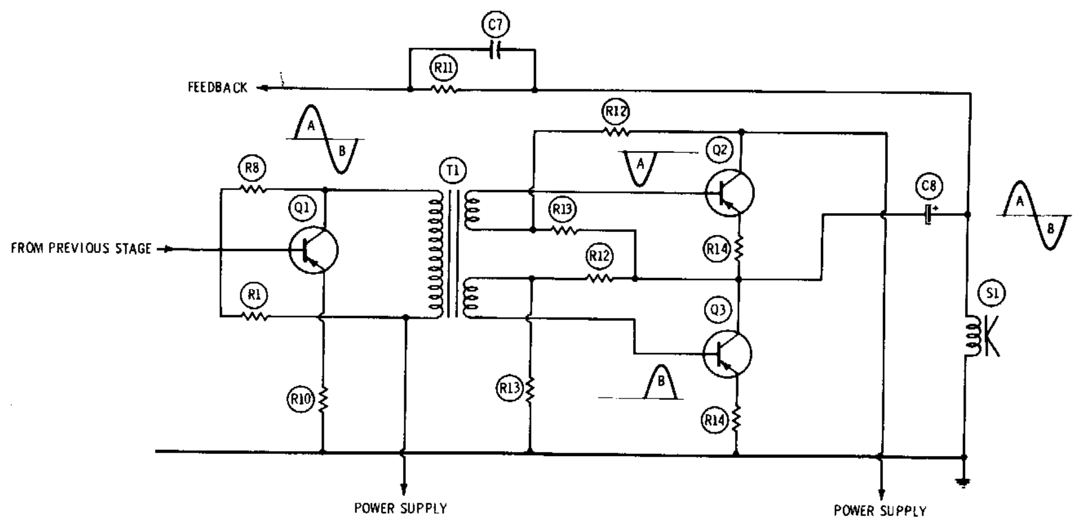


Fig. 1-9. Stacked output stage with an input transformer.

ahead of the output stage to drive it; this is called a driver stage.

Fig. 1-10 shows a typical RC-coupled circuit. This term is used because the signal is transferred from the plate of the 12AX7 tube to the grid of the 6V6 through the .02-μF coupling capacitor (C1), and the dc returns needed are made through resistors (R1). The older amplifiers use audio transformers here. In later designs it has been found that RC coupling can do the job a lot cheaper with better fidelity. The capacitor is also called a blocking capacitor by some, because it blocks the high dc plate voltage of the triode from the negative grid voltage of the 6V6. This component is a source of many amplifier problems.

Fig. 1-10 is a straight voltage-amplifier stage. A high-value (220,000 ohms) plate-load resistor is used, so the stage will not draw a lot of plate current; it doesn't have to. What is required is the developing of a very large signal voltage across the plate load to feed the grid of the 6V6, which is a voltage-operated device.

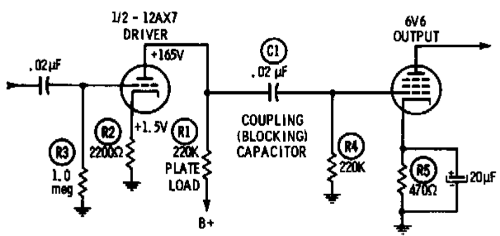


Fig. 1-10. Typical driver stage.

The driver stage is designed to have the needed signal voltage (25 pk-pk in this case) at its output. A high-gain tube, proper circuit components, and correct supply voltages work together to supply the required amount of amplification. The actual amount needed depends on the number of voltage-amplifier stages used in front of the driver. For instance, if there is a 1-volt pk-pk signal on the 12AX7 grid, this stage will have to give a total voltage gain of 25 times—1 volt in and 25 volts out (both pk-pk). The actual figures used will vary a lot between different amplifiers, but the same principle will be used in all of them.

PUSH-PULL DRIVERS AND PHASE INVERTERS

A very special type of input signal is needed for a push-pull stage: two inputs, in fact, each the exact opposite of the other, or 180° out of phase. The circuit that will produce this signal is called a phase-inverter. Fig. 1-11 shows a commonly used example.

Going back for a moment, recall that the output of a voltage-amplifier stage (Fig. 1-12) is developed by drawing plate current through the plate-load resistor. There is a complete circuit here: tube plate to B+, to B− (around the power supply through a large capacitor), to cathode, and back again to plate. As you can see, the signal voltage shows up as a voltage drop across the plate load resistor. What is needed, however, are two signals, each the opposite of the other. These can be obtained by taking advantage of a characteristic of a vacuum tube—the voltages on the plate and the cathode are always 180° out of phase. One goes down when the other goes up, and vice versa.

To get two equal output signal voltages, split the load, putting half of it in the plate circuit and the other half in the cathode, as shown in Fig. 1-11. The similarity to Fig. 1-12 is more apparent in Fig. 1-11A,

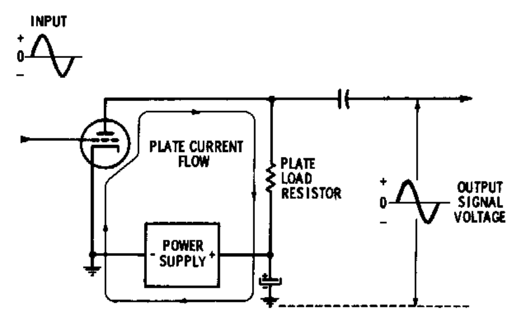
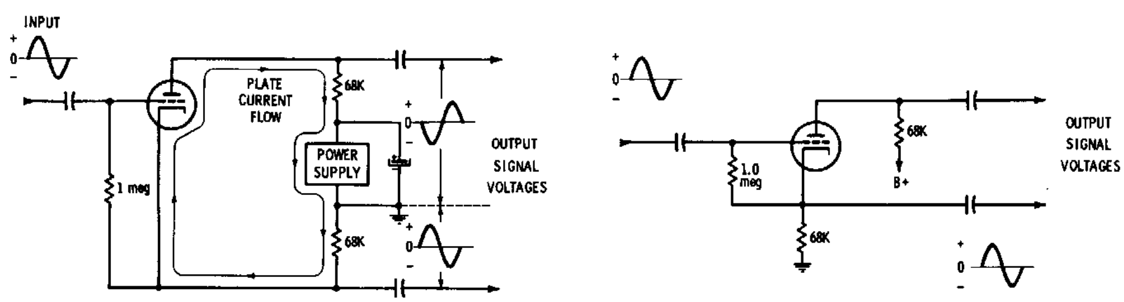


Fig. 1-12. Plate current flow.



(*A*) *Complete current path.* (*B*) *Conventional drawing.*

Fig. 1-11. Split-load phase inverter.

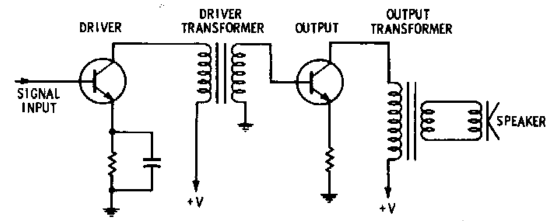
while the conventional method of drawing the circuit (with the power supply indicated but omitted) is shown in Fig. 1-11B. Since the same signal current flows through the whole circuit, a signal voltage will be developed across any resistor that this current flows through. The size or amplitude of this signal voltage depends on the size of the resistor. In the split-load circuit the two resistors are exactly the same size, so equal but out-of-phase signal voltages result across them. Notice that the plate voltage on the first half-cycle is going negative and the cathode voltage is going positive. This is because the grid voltage is going positive on the same half-cycle. Check any textbook on vacuum-tube theory for a fuller explanation.

There are other phase-inverter circuits, but this is probably the most frequently used, because of its simplicity and ease of design. In most applications this circuit will simply invert phases, but if a high-gain tube is used, a little voltage gain can be developed—which is always good.

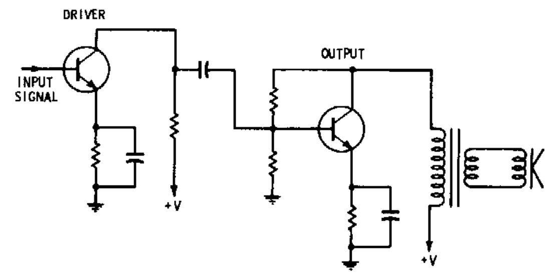
TRANSISTOR DRIVERS AND PHASE INVERTERS

Driver stages in transistor amplifiers do the same thing as in tube types. They must deliver enough signal to drive the power output stage to its full rated output. The driver transistor must be capable of handling a little more power than the small-signal type of transistor. The driver transistor handles an average of 2 or 3 watts of actual power, and is rated at 5 watts.

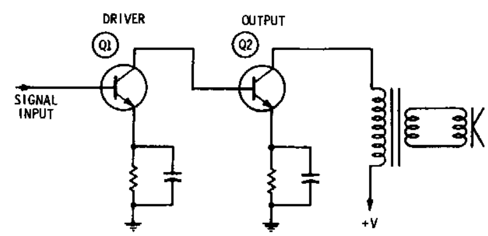
The same basic circuits of tube-type amplifiers are used, with transistors replacing tubes as the active devices. Fig. 1-13 shows three typical circuits for single-ended stages. Single-ended transistor stages are common in the smaller amplifiers.



(*A*) *Transformer coupled.*



(*B*) *Capacity coupled.*



(*C*) *Direct coupled.*

Fig. 1-13. Coupling methods for single-ended output.

THE DIRECT-COUPLED CIRCUIT

Direct-coupled circuits have not been used with tube amplifiers since the 1920s. However, you'll find quite a few of these circuits used in the larger solid-state amplifiers, and some in the smaller ones. The advantage of this type of connection is the reduction in the number of parts, since there are no coupling devices such as transformers, capacitors, etc., needed. Also, this circuit does have a slightly greater frequency response, especially for low frequencies. Frequency range is determined by the high and low cutoff of the transistor itself, which is usually far above the range needed for music amplification.

In the direct-coupled circuit the collector of the driver transistor is connected directly to the base of the output transistor. The collector current variations of the driver become the base-current variations of the output. Also, the collector current of the driver determines the base bias of the output transistor; it flows from the collector through the base-emitter junction of the output transistor. Because of this interrelation, any defects in the driver transistor can upset or even ruin a perfectly good output transistor. This is one of the "mysterious" problems you'll find in some cases. It will be discussed at length in the section on servicing.

THE DARLINGTON PAIR TRANSISTORS

The single bipolar transistor has certain disadvantages when compared to tubes. For one thing, it has a very low input impedance. This makes it slightly inefficient when used as an input stage to a high-impedance pickup, such as that used with a guitar or microphone. Its voltage gain is also low. The loss of gain and the low impedance can be overcome by using a "bootstrap circuit" and more transistors. However, there is an easier way, and one that you will find used in quite a few of the later model amplifiers.

The common-collector transistor amplifier circuit has a very high input impedance, but not too much gain; the common-emitter circuit has good gain, but a low impedance. If we connect these circuits in "cascade," as in Fig. 1-14, we can use the best features of both. The common-collector stage now drives the common-emitter stage by direct coupling. The device has a very high input impedance, suitable for direct connection to a pickup or mike, and a very high gain considerably more than the gain of either transistor alone.

The Darlington amplifier, also called a "Darlington pair," is built into a single package, with only three external leads, as shown in Fig. 1-14. It looks exactly like a plain three-lead transistor. However, if you replace one with a single transistor, you'll wonder why the amplifier has such low gain, and usually high distortion! Unfortunately, these Darlingtons are drawn on some schematics as a single transistor. Be sure to check the parts list. In all cases, this transistor will be identified as a Darlington (sometimes they leave off the "pair"). So, watch out for this. If you find an amplifier with only a single transistor in the input, where there would normally be at least two, look out. This is probably a Darlington. (Details on how to test this unit on a transistor tester are given later.)

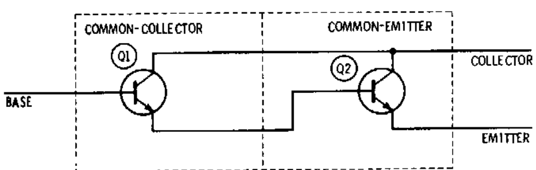


Fig. 1-14. Darlington pair—two transistors in one case.

In cases of emergency, you can make up a Darlington pair from two equivalent silicon transistors. Most of the Darlingtons found in use in amplifiers seem to be silicon types. Germaniums have a little bit too much leakage for use in this kind of application. When you take the old transistor off the PC board, you'll have the standard three holes in the board for the emitter, base, and collector.

By using two identical silicon transistors, you can connect the two collectors together (twist the leads) and put these into the original collector hole. The base of the transistor Q2 is twisted directly to the emitter of transistor Q1. There is *no* circuit connection to this junction. The emitter of Q2 goes to the original emitter hole, and the base of Q1 to the original base hole.

In practically all capacity-coupled circuits, this setup works very well without changes. If the output of the Darlington is directly connected to the base of the following transistor, check its bias to make sure that this is the same as it was before (get this voltage from the schematic.) If the base bias of the driven stage is too high, try using transistors with a lower beta to fabricate the Darlington pair. This will usually correct the bias problems. Check the circuit with the scope for distortion.

THE PREAMPLIFIER STAGES

The signal voltage required at the input of the phase-inverter or driver stage determines the amount of voltage gain needed in the preceding stages of the amplifier. If the type of phase-inverter stage having a gain of one, or unity, is used, the peak-to-peak signal voltage will have to be roughly twice the bias voltage of the output tubes to produce full output.

For example, if the pickup has an output of 50 millivolts (50 mV or .050 volt), and if a signal voltage of 50 volts pk-pk is needed at the grid(s) of the output stage, a total voltage amplification of 1000 times is necessary. This sounds pretty high, but it is not; many amplifiers have voltage gains up to a million! It works very simply: if a stage has a gain of 10 and is followed by another just like it, the total is the product of the individual gains, or 100, from these two stages alone. Adding another stage with a gain of 10 will give 1000 (10×100), and there you are. Modern tubes and transistors are capable of many times this amount of gain. There are other troubles, however, when the gain is high.

The main consideration in designing high-gain voltage-amplifier stages is not gain as much as noise. All high-gain stages have a tendency to make noises internally—random noise from current flow in resistors, shot-effect noise in tubes, and so on. This is the limiting factor in getting a lot of gain out of a single stage. The answer is to use more than one stage to get the amplification needed. By doing this, each stage can work at its maximum noise-free amplification level.

Another troublesome thing is distortion. Every one of these stages must be designed for absolutely linear operation. This means that the signal in the output must be exactly the same shape as the signal in the input. If the stage changes the waveform in any way as the signal passes through, a very poor sound quality results due to distortion. This is the second major consideration.

There are several ways of avoiding distortion. As a matter of fact, you do not have to worry about it, as far as the original design is concerned. This work has all been done for you by the engineer who built the amplifier. In all but the very cheapest amplifiers, distortion and noise will be at a very low level when the instruments are new. What you have to do is put them back in the same condition! Although you don't have to design amplifiers, you do have to know how and why the circuits work so you can tell when they are working correctly.

Many of the better amplifiers use built-in correction circuits to hold the distortion down to a very low level. These are usually inverse-feedback circuits. In them a part of the output of the amplifier is fed back into an earlier stage in such a way that it cancels out some of the distortion. While this does reduce the overall gain of an amplifier, it also improves the tone quality so much that the small loss of gain does not matter. The loss can be corrected by using another voltage-amplifier stage if necessary.

Feedback voltage must get back into the amplifier in the right phase so it will be degenerative—tending to stop oscillation. If the phase is wrong, it will be regenerative—tending to cause oscillation. When certain components are replaced, there is a possibility of wrong connections. If an output transformer is replaced, for example, the amplifier can oscillate if the phase of the feedback is reversed. Other causes of oscillation will be taken up later in the section on servicing.

Distortion is not always easy to detect and cure. The ear alone is seldom accurate enough to pinpoint the actual cause or type. It is necessary in bad cases to use an oscilloscope and very accurately shaped test signals to find and fix this kind of trouble.

THE "BOOTSTRAP" CIRCUIT

Previously we mentioned "bootstrapping" a transistor to get higher input impedance. Fig. 1-15 shows how this is done. Note the high value of the emitter resistor, as compared to the low values used in other common-emitter circuits. This high resistance holds the transistor current down to a very low value, around 300 microamperes. There is no emitter bypass to ground, so practically all of the base signal appears across the 4700-ohm resistor. From here, it is coupled by the 50-μF capacitor to the bottom end of the base resistor.

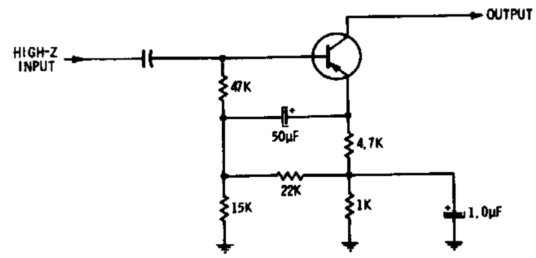


Fig. 1-15. Bootstrapping a transistor input stage to obtain a high input impedance.

Due to this coupling, the base resistor "sees" the same signal voltage at top and bottom ends. So, this resistor looks like an *open circuit* to the input signal! This is a very high impedance. The absence of an emitter bypass also makes the impedance higher. In other words, we have a very high degenerative feedback in such a stage.

This reduces the gain of the stage, but allows high-impedance devices like microphones and pickups to develop a high signal across the high-impedance input. Degeneration also helps to eliminate distortion due to mismatching. We can always get back any gain lost in such stages by adding another amplifier stage following the bootstrapped input—a Darlington amplifier for example.

It's important to remember this, for you could be misled into thinking it was defective, due to its low gain; check the schematic to see if it is bootstrapped. If so, low gain is all right.