THE PROFESSIONAL AUDIO DIVISION OF CROWN INTERNATIONAL, INC.

RESOURCE TEXT

For The

Crown® Professional Products
SERVICE SCHOOL

Notes

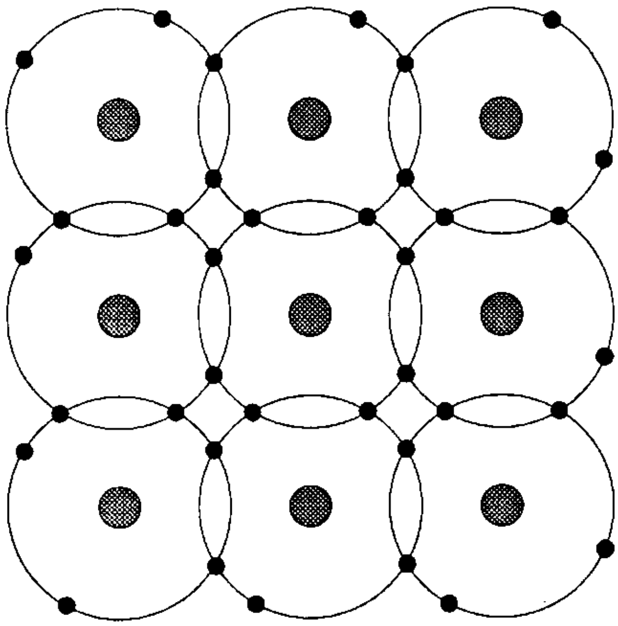
Semiconductors

Active devices are generally those which amplify and/or are polarity sensitive. Diodes are the most simple of all semiconductors having only two parts, and only two leads. Diodes are polarity sensitive devices which, normally, only allow current to flow through them in one direction. Voltage applied to control conduction is referred to as bias. A typical Silicon (Si) diode requires approximately .65VDC of forward bias to conduct. Excessive reverse bias (or excessive conduction) may cause the diode to breakdown and fail catastrophically. The normal mode of diode failure is a short unless it physically cracks due to heat.

PN JUNCTIONS

The basis of understanding operation of any semiconductor, whether it be bipolar (current controlled) or field effect (voltage controlled), is a simple pn junction. Since a diode is nothing more than a simple pn junction, it follows that we must first explore the world of the diode. Diodes are made of two types of material, both of which have a tetravalent substrate of Silicon. The P type material is doped with a trivalent element while the N type material is doped with a pentavalent element. When the two materials are fused together, a series of events take place. The P type has electron shell vacancies and needs additional electrons to fill these vacancies. The N type has excess electrons which do not fall into proper valence shells. At the time of fusion, the N type excess electrons in the vicinity of the P type material cross the boundary to complete the electron shells in it. As this occurs the P type material shells near the boundary become complete, but the ratio of electron to proton increases, causing a net negative charge. Likewise, the N type develops a positive

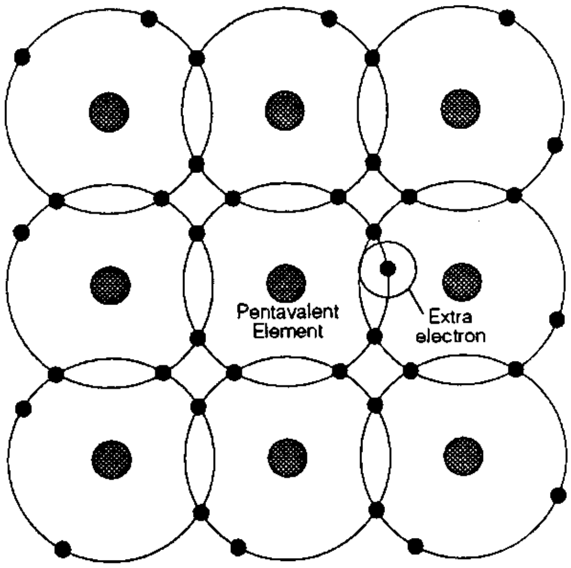
Intrinsic (Pure) Silicon



One atom shown surrounded by eight other atoms. Note that the valence shell of the center atom is complete.

Figure 1. Pure Silicon Substrate

N-Type Material



One atom shown surrounded by eight other atoms. Note that the valence shell of the center atom has an extra electron. When it gives up this electron the material develops a net positive charge.

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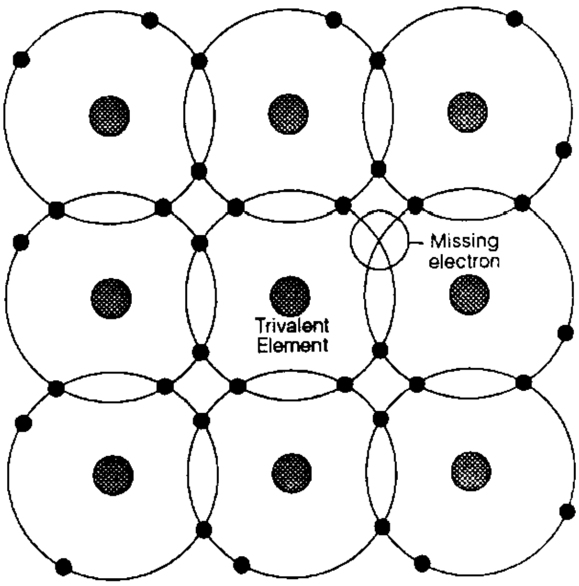
Figure 2. N-Type Material Composed of Silicon Doped With a Pentavalent Element

P-Type Material



One atom shown surrounded by eight other atoms. Note that the valence shell of the center atom is missing electron. When it picks up an electron to fill the vacancy the material develops a net negative charge.

Figure 3. P-Type Material Composed of Silicon Doped With a Trivalent Element

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charge because many of its electrons have left to go to the P type. A point is eventually reached where the negative charge in the P type, along with a region of full valence shells near the joining wall, prevent any further flow of electrons from N to P type material. The total charge differential is typically about 0.65V.

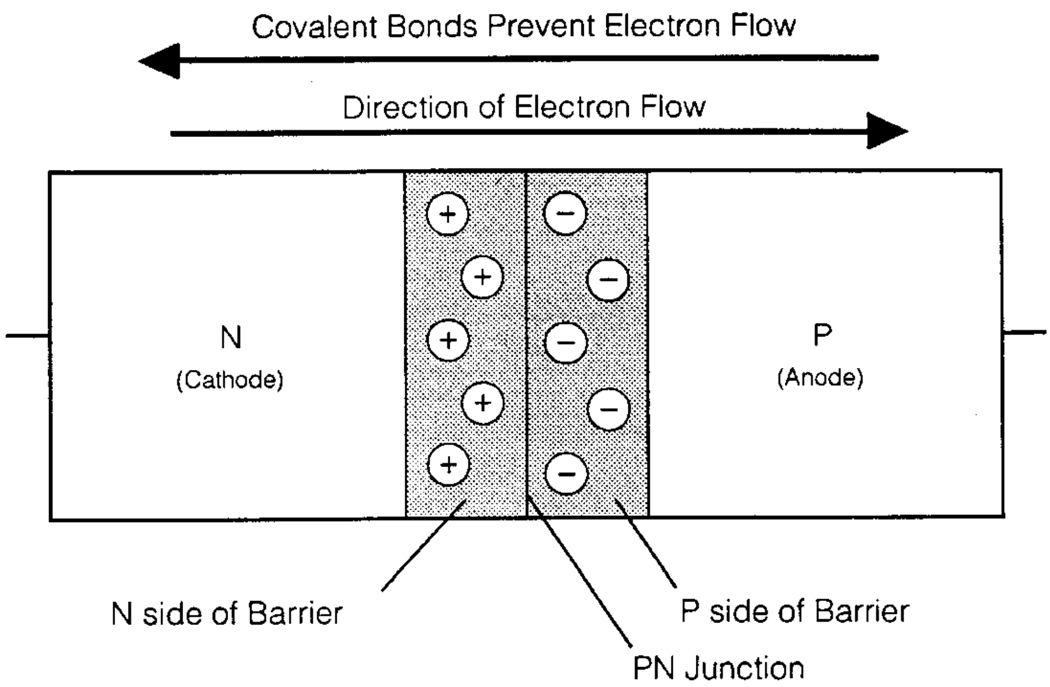

Figure 4. PN Junction (Diode)

Reverse Bias
When an external voltage is applied, the polarity determines what takes place. If a negative voltage is applied to the P type (with respect to the N type), the valence shells in the P type continue to become complete and the excess electrons in the N type are drawn off. The net result is an excellent insulator material. This is called reverse bias, and no conduction will take place. As reverse bias increases, the barrier region will expand; at some point the material will break down, however. The result of such a breakdown is usually catastrophic failure in a standard diode, though some semiconductor devices are designed to handle reverse bias electron flow.

Forward Bias
When the opposite polarity is applied to the junction (positive to the P type with respect to the N type), the situation is quite different. When a positive voltage is applied to the P type, the additional electrons which crossed over the junction are drawn by the charge across the P type, removing electrons. As this goes on, the electrons from the negative source enter the N type and are attracted toward the junction area by the positive charge in that region. When the voltage applied to the PN junction exceeds the static barrier potential (0.65V) with this forward bias, conduction will occur across the device.

BIPOLAR TRANSISTORS

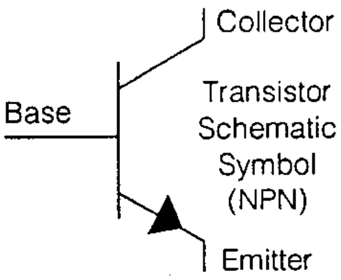

Figure 5. BJT Schematic Symbol

The two main types of transistors are Bipolar Junction Transistors (BJT) and Field Effect Transistors (FET). Bipolar Transistors are current controlled devices used to amplify current, voltage, or both. BJTs are categorized as NPN or PNP. NPN devices require a positive bias of approximately .65VDC (base to emitter) to turn on and conduct current emitter to collector. As base-emitter current increases, emitter-collector current increases by a proportionally larger amount. Maximums are limited by supply voltage and external resistors used to limit current and develop voltages. PNP devices operate in an identical manner, but the base is forward biased with a negative .65VDC base to emitter and the direction of electron flow is reversed through respective paths. Crown uses bipolar technology almost exclusively for a variety of reasons, particularly in high voltage/current audio applications. Bipolar devices are highly predictable, well suited to high current and voltage applications with high linearity and low distortion.

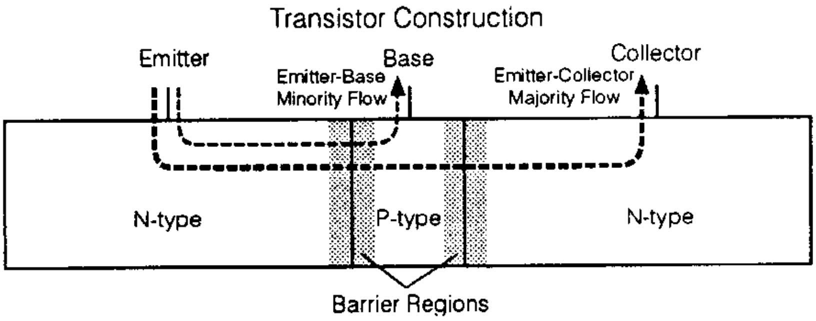

Figure 6. BJT Internal Operation

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FIELD EFFECT TRANSISTORS

FETs are voltage controlled amplifiers capable of voltage or current amplification. FETs can be divided into a variety of categories, but the two main ones are JFET (Junction FET) and MOSFET (Metal Oxide Semiconductor FET, also known as Insulated Gate FET or IGFET). JFETs are the more simple, having one N type section and one P type section. In a JFET, one material (gate) will surround the other (channel), like a hand around a hose. As reverse bias at the gate is increased, a field is created within the channel to restrict electron flow. JFETs normally operate with a reverse bias and would, unlike many other semiconductors, suffer failure if accidentally forward biased. MOSFETs work on a similar principle, but a layer of insulation exists between gate and channel. Although Crown does use field effect technology in selected applications, usually in control circuits which are not in the audio path, Crown does not use FET technology in high power audio stages the reasons mentioned in the above paragraph. Although it is possible to overcome the difficulties of FET technology for audio, the

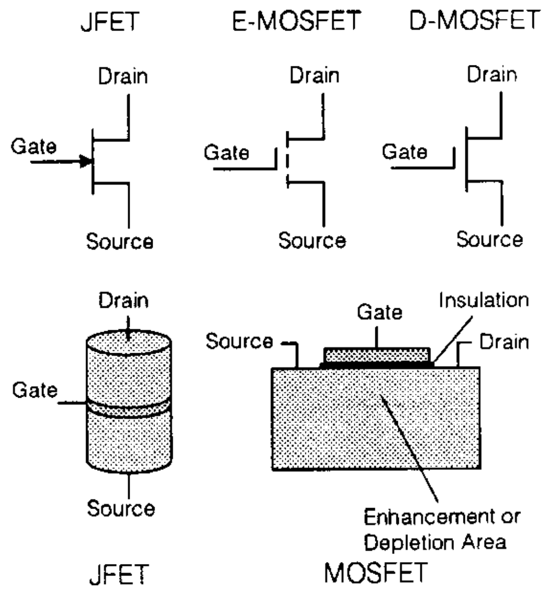

Figure 7. FET Devices & Operation

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available devices are quite expensive and require special designs which are not cost effective.

REAL TRANSISTORS

In real transistors, a number of variables determine how close *real* operation is to *ideal* operation. Depending on the application, some factors are more important than others. Many general ratings for gain, maximum voltage, maximum reverse breakdown voltage, substrate material, and others are used to select the transistor for a given application. Although each of these are used to find a desired device (or which group of devices to select from), some properties must be dealt with in special ways after the device is initially selected for a given application.

Beta

Beta (ß) is a measure of the maximum current gain (ratio of change in emitter-collector current to change in base-emitter current) of a transistor. This is important to any application where the purpose of a transistor is to provide a significant amount of gain. Output transistor device (hereafter called "outputs") choices for Crown amplifiers do not as much on beta, however, as they do on other characteristics.

Inter-element Capacitance

Whenever an N type material is fused to a P type material, a PN junction is formed. As discussed in previous sections, the region near the junction, called the barrier region, is formed when the N and P materials are fused. When forward biased this region is collapsed and electrons are then able to flow. With reverse bias the junction acts like an insulator preventing flow across the barrier. When reverse biased the barrier region grows and the tendency to insulate increases. Capacitors are built of two plates in close physical proximity with a layer of insulation between them called a dielectric. In PN junction devices, the barrier region causes a reverse biased junction to act like a capacitor, resulting in inter-element capacitance between the two materials. In a transistor there are two such junctions, thereby increasing the capacitive effect. For many applications this effect is negligible, but for other applications this effect can present a special set of problems. This is true of the output stage of a Crown amplifier (and most other amplifiers manufactured today). The problem is compounded by placing multiple transistors in parallel, and by driving an inductive load (loudspeaker coils). Proper device compensation and the use of a shunting circuit (the diode strings in the output stages) are methods of correcting for inter-element capacitance. It is worth noting also that this is one significant reason for not using FET technology, as FETs are capacitive by the very nature of their operation.

Turn-on Time

Another problem encountered when multiple transistors are placed in parallel is that of turn-on time. Turn-on time is the basis for grading the devices selected by Crown for use in parallel groups within a Crown amplifier. If three devices are in parallel and one of them consistently turns on several microseconds before the others, it will conduct all of the initial current resulting in excessive stress over time. This device will fail prematurely, potentially causing other devices within that bank to fail unless protective action can shut down the amplifier before failure becomes catastrophic. If all devices share the load equally the net stress will be lower for each device and the bank as a whole. The turn-on time is a direct function of Vbe ratings.

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NPN vs. PNP

Other than the obvious swap of polarity and direction of current, NPN and PNP devices differ in construction at the atomic level. Because N type material is a Si substrate doped with one chemical element and a P type is doped with another, there are differences in chemistry. P type is usually slightly less capable of handling current and heat than an identical size piece of N type with identical doping levels. The main reason for this chemical difference is twofold. First is the uniqueness of the elements used for doping. The other is that the P type uses a trivalent doping material while the N type uses a pentavalent doping material. The trivalent has smaller doping atoms than the pentavalent, causing it to be lighter and more subject to physical deformation at the atomic level. Ultimately a trivalent P material is less capable of handling long term stress and heat than an N type. Because PNP devices contain much more P-type than an "equal" NPN device, the PNP device will be less capable of handling high heat and current. To compensate for this difference, high quality PNP devices frequently require special manufacturing processes which are more expensive. Because manufacturing processes have improved and the quality of transistors in general has improved over time, the cost difference has decreased somewhat, but the comparison is worth noting. These differences also explain why many designs favor the use of NPN devices to the exclusion of equivalent PNP devices.

Coefficient of Thermal Derating

The coefficient of thermal derating is the measure of the loss in power handling capability (thermal headroom) with each degree increase in temperature (mW/C°). Only two things normally cause the premature failure of a good transistor, namely over voltage and over heat. Excessive voltage can usually be avoided by good design. Heat, however, is a function of time, operating power level and current flow, and ambient temperature. In all grounded bridge amplifiers built by Crown, a special analog computer is built in to calculate thermal headroom at the die (PN junction location) of the output transistors and, if necessary, provide protection to limit output power to safe levels for the calculated thermal conditions. This protection circuit design is called ODEP (Output Device Emulation Protection). ODEP will be discussed in detail in a later section.

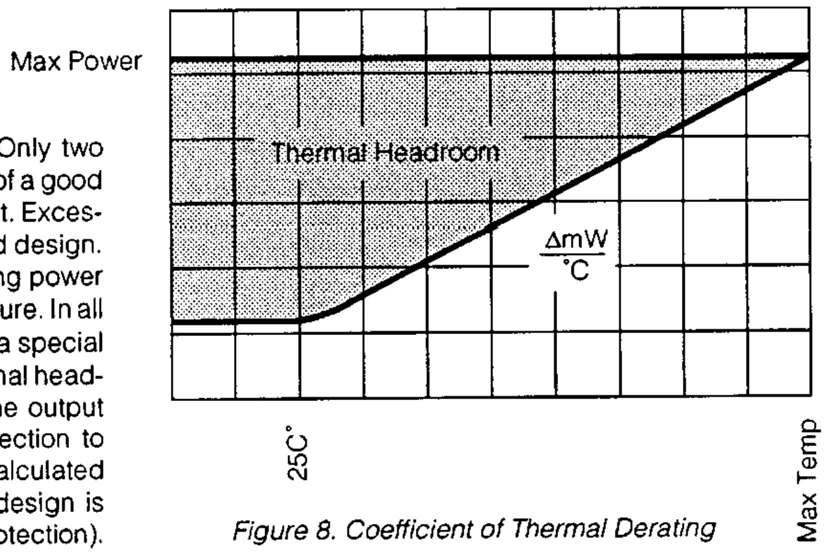

Figure 8. Coefficient of Thermal Derating

OTHER SEMICONDUCTORS

A variety of other types of semiconductors are used in modern electronic circuits. Crown employs certain of these devices in specific applications. Brief descriptions of some of the more popular specialty devices follows.

SCR

A Silicon Controlled Rectifier (SCR) operates like a diode, except that

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it can only conduct when forward biased *and* a control signal is present to gate the SCR on. With a conventional diode, 180 degrees of a sine wave is allowed to pass, producing ripple DC. The SCR allows for control of when, during those 180 degrees, that the device begins to conduct. While this type of control is extremely useful in many industrial applications, such as motor controls, SCRs are rarely used in audio electronics due the high degree of noise, referred to as hash, induced into power supplies and signal path electronics.

TRIAC

A triac is similar to an SCR, except that current can flow either direction through the triac and a reverse signal to the gate can be used to turn off the device. Similar noise problems can occur when using the triac. Low current control circuits in certain Crown amplifiers (such as the Com-Tech series) utilize triacs for fan speed control and other control functions.

Optical Devices

The term optical device is used to describe any type of electronic device which converts electricity to light, or vice versa. The most simple of these are the light emitting diodes (LEDs) used for indication. Optic devices are also used to generate electricity from light, such as photovoltaic cells. Other optic devices are used to couple signals for isolation, control conduction, and to control gain in optic transistors. While these devices provide complete electrical isolation, the more complex devices are frequently expensive and often have poor tolerances. Exposure to ambient light may also affect operation of some types of devices. Crown does use a variety of optic devices for indication (LEDs) as well as control (such as the P.I.P.-PA and -EDC compression circuits).

OPERATIONAL AMPLIFIERS (OP-AMPS)

Op-amps are linear (non-digital) circuits having two inputs and one output. Although composed internally of dozens of transistors and other components, the circuitry of the op-amp is compressed into a single integrated circuit package. Some op-amp ICs only contain one op-amp, some two, and some contain four. Crown uses op-amps extensively for low voltage amplification, summing, and comparison circuitry.

Characteristics

Op-amps have two inputs, one inverting and the other non-inverting. They have virtually infinite input impedance, and very low output impedance. Gain, when used as an amplifier, is controlled by negative feedback. Without feedback (open loop gain) a positive input at the + (non-inverting) input results in nearly full positive power supply voltage on the output. When applied to the - (inverting) input, a positive voltage will result in nearly full negative power supply voltage at the output.

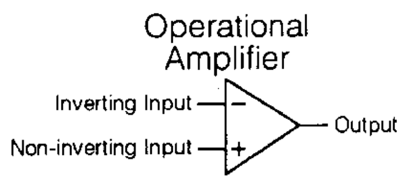

Figure 9. Op-Amp

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Gain (A_v) and Negative Feedback (NFb)

If a system is to perform linearly, it must be able to measure and control the output. Such control is possible through the use of Negative Feedback (NFb). In order to establish control the input signal must be modified in response to the output. Ideally, an amplifier should reproduce at its outputs an amplified version of the signal applied to its input. By closing the feedback loop, a portion of the output voltage is combined with the input voltage to produce a modified input signal. This is accomplished by a summing point which is a circuit arrangement that produces an algebraic sum of the two signals. This summing point subtracts the NFb signal from the input signal and produces what is called an error signal. In our discussion of gain two types of circuit arrangements will be considered: non-inverting and inverting amplifiers.

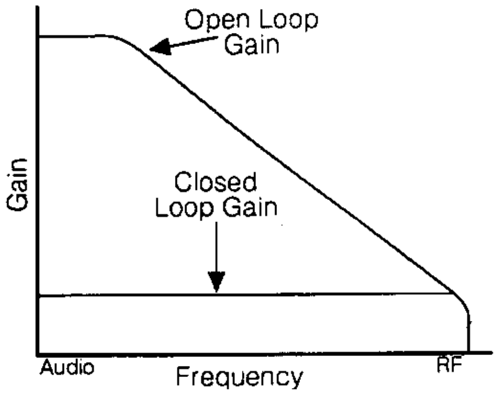

Figure 10. Op-amp Loop Gain

Non-inverting

In the non-inverting amplifier, the signal is applied directly to the non-inverting (+) input. With no NFb (open loop gain) most op-amps have a gain factor of around 100,000 (100dB). Upon inserting R1 and R2 into the circuit the feedback loop is closed and gain is set by the value relationship of R2 to R1. For the non-inverting design, the output signal polarity is the same as the input signal. As R2 becomes larger NFb is decreased and gain increases. As R2 becomes smaller NFb decreases and gain decreases.

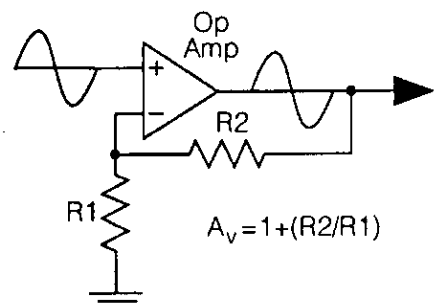

Figure 11. Non-Inverting Op-amp

Inverting

In the inverting amplifier, the signal is applied to the inverting (-) input. For the inverting design, the output signal polarity is opposite that of the input signal. As R2 becomes larger NFb is decreased and gain increases. As R2 becomes smaller NFb decreases and gain decreases.

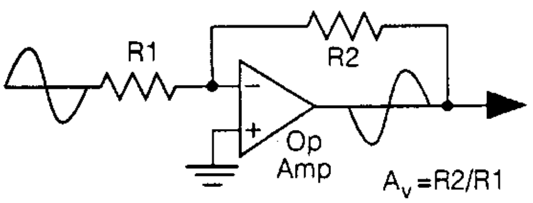

Figure 12. Inverting Op-amp

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Amplifier Basics

TRANSISTOR CONFIGURATIONS

The term "transistor configuration" refers to the arrangement of inputs and outputs. One lead is common to the signal path, one lead is used as the input, and the third lead is used as the output. Each configuration serves a different purpose depending on the need.

Common Emitter

In a common emitter (CE) circuit the input is on the base, the output is on the collector, and the emitter is common to both input and output. CE amplifiers provide both voltage and current gain, and are (in general) the most common of the three configurations. The purpose of such a configuration may be solely amplification, but the CE amp may also be used as an electronic switch. CE amplifiers also have the peculiar (and sometimes desirable) effect of providing a net inversion of the signal. If a signal must have the same polarity at the output as the input, the designer must either use two CE stages or select another configuration. The last voltage amplifier stage in most Crown amplifiers uses a CE configuration for voltage gain and to obtain a signal inversion.

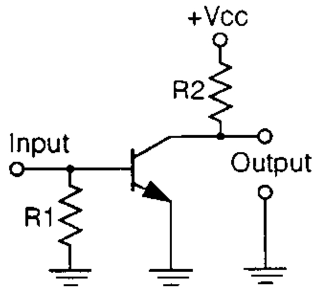

Figure 1. Common Emitter

Common Base

Common base (CB) amps provide high voltage gain with less than unity current gain. There is no polarity inversion. Crown amplifiers utilize the CB configuration in the voltage translator stage to provide the voltage gain necessary to go from operation referenced to the low voltage supply to operation at full rail voltage in the last voltage amplifier stage.

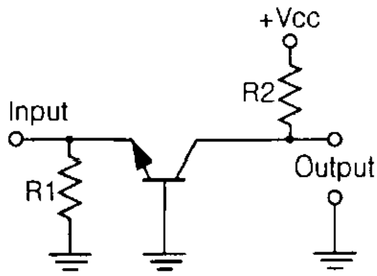

Figure 2. Common Base

Common Collector (Emitter Follower)

The emitter follower circuit provides high current with less than unity voltage gain. Often emitter follower amplifiers use multiple stages ganged together in a "Darlington" configuration for even higher current gain. In a Darlington stage, the input signal comes into the base of the first transistor. The signal is taken from the emitter and is direct coupled to the base of the second device. Crown

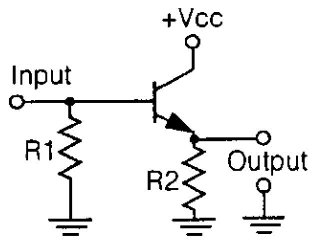

Figure 3. Emitter Follower

amplifiers use a three-deep Darlington composite, after the voltage gain stages, to provide highly efficient current gain in the output stages.

EFFICIENCY AND AMPLIFIER CIRCUIT CLASSIFICATION

Class A

The class "A" amplifier consists of a single transistor which is midpoint biased. The class A amplifier is always biased on and always conducting. Because of this there is a constant current draw from the power supply even when no signal is present. This continuous current, in turn, results in heat (I^2R). The heat produced requires large heatsinks. The maximum theoretical efficiency of this design is only 25%. The major advantage of the class A amplifier is that it has very low distortion nearly to the clip point. Unfortunately transistor operation is not linear at almost off and almost 100% conduction, the result of which is distortion near operational limits.

Class B

The class "B" amplifier is the classic push-pull design where two transistors are used. The bases are connected and biased off. When a positive signal (greater than .65V) is present one transistor turns on to conduct current to the load. When the signal goes negative the other transistor conducts to provide current (in the opposite direction) to the load. The net effect is a full sine wave output. The major advantages are the higher possible efficiency of 78.5% and the reduction in heat produced due to lack of current flow with no input signal. The major disadvantage is the high zero-crossing (notch) region distortion of the signal. This distortion is the result of no conduction between +.65V and -.65V.

Class AB

The class AB amplifier solves the crossover distortion problem by biasing the transistor into slight conduction with no input signal. With a positive input the first device conducts more while the second turns off. When the input goes negative the second transistor turns on before the first turns off. Efficiency is slightly less than the ideal class B, but still high (theoretically 50%).

Class AB+B (Multi-mode)

AB+B is a biasing design originally patented by Crown in the 1960s for the DC-300. The AB+B design is more complex by its construction, as it requires push-pull Darlingtons, biased differently at different points within the Darlington composites. The two transistors (predriver and driver) in a three-deep Darlington is biased class AB biased while the last (output) is class B biased. A low value resistor (5.6 ohms in most models) is placed in parallel with the emitter-base junction of the output device to control its bias and maintain it class B. At the same time this resistor conducts current from the first device to provide smooth operation through the zero-crossing region. With one three-deep Darlington composite in the positive half and another in the negative

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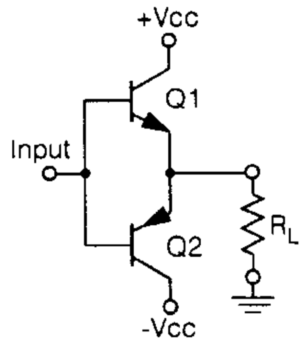

Figure 4. Class B

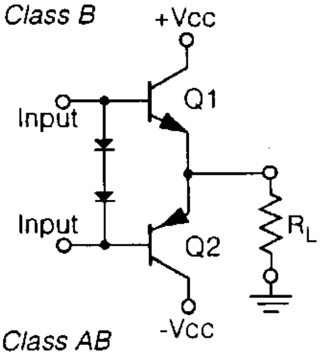

Figure 5. Class AB

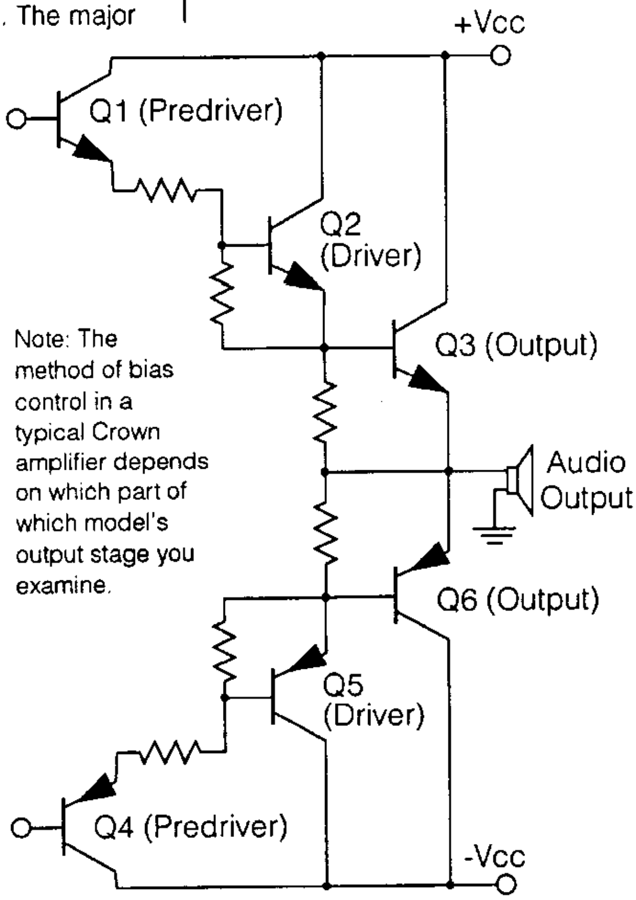

Figure 6. Class AB+B (Multi-mode) Operation

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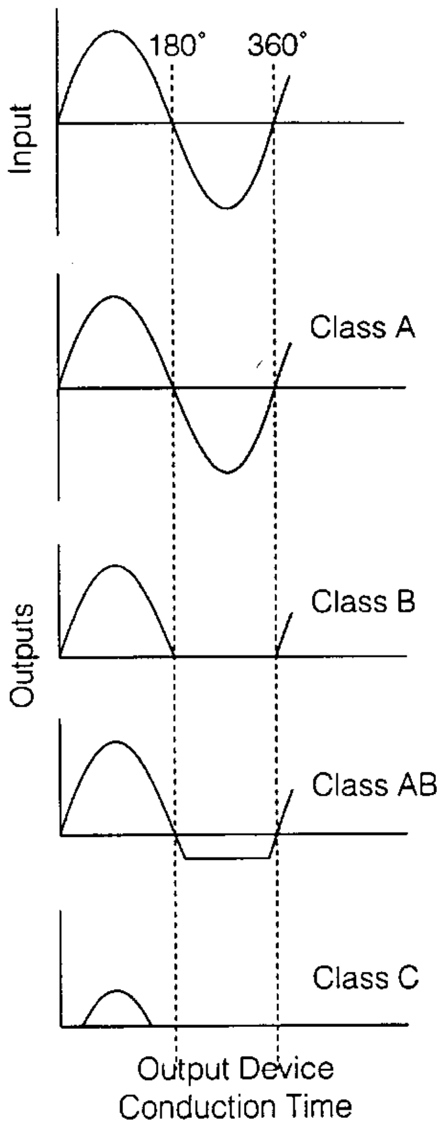

Figure 7. Conduction Times

half, an overall AB+B push-pull current amplifier is achieved. Actual efficiency varies depending on design considerations, but about 65% is typical of most Crown amplifiers.

Class C

The class "C" amplifier consists of a transistor biased into hard cutoff with an LC tank circuit on its output. The dynamic action of the tank circuit produces back EMF to develop the second 180 degrees of the input cycle. Theoretical efficiency of this design can be as high as 99%. Because less than half of the input signal is used, however, there is a higher amount of distortion. This design is rarely used except in high frequency applications where signal quality is less important than gain.

Other Classes

Although some manufacturers make claims to other forms of amplifier biasing, most are variations on one of the above. Today nearly all audio amplifiers use a form of the AB+B design developed originally by Crown. Some of these variations are described in the Amplifier Designs section of this text.

OUTPUT STAGE TOPOLOGIES

During the WWII and post WWII years a number of circuit innovations were developed. In the attempt to devise higher linearity or efficiency many variations, over the last four decades, have come about. Some of these variations have, only recently, been incorporated in the audio industry. Among these innovations are:

1.) PWM (Pulse Width Modulation)
2.) Phase Control Power Supply
3.) Switching Power Supply (Frequency)
4.) Quasi Linear Topology (Class D)

As the need for greater controlled power and efficiency began to appear, industrial power control amplifiers were developed using any combination of the four mentioned technologies. Though efficiency was increased over the older standard Class A or Class B (push-pull) designs, linearity (low distortion) was decreased. With the advent of the semiconductor age. The Linear amplifier was developed. Almost all of todays professional and home Hi-Fi type amplifiers are still designed for linearity. Of the four mentioned technologies, two are being used in current audio design: PMW (Pulse Width Modulation) and Quasi-Linear Topology (often called Class D).

PWM

Present designs modulate a 2 μsecond square wave with the audio signal. After high voltage amplification the signal is passed through a steep filter to eliminate the original 2 μsecond (RF) square wave. Although this design is highly efficient, there are certain disadvantages which have prevented Crown from using it in any design to date. First, the presence of RF in the output stage presents logistical problems in the construction and compensation for the output stage which are costly to overcome. Secondly, a very sharp filter is required at the output to eliminate RF from the audio before delivering the signal to the load. The filter must absorb and dissipate the RF, and in the process it adds undue output impedance to the amplifier lowering damping.

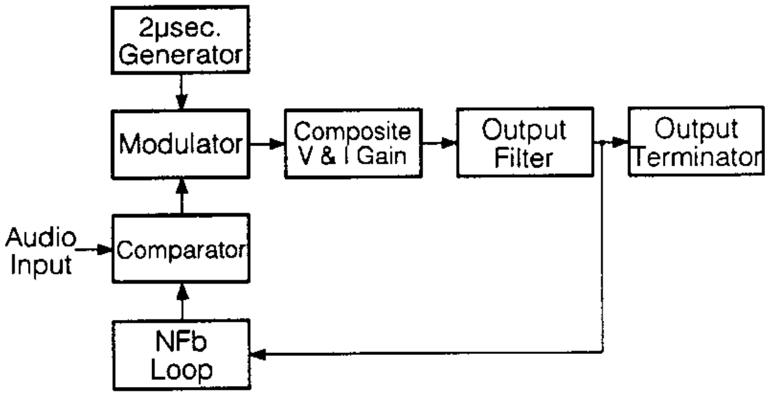

Figure 8. PWM Block Diagram

Quasi-Linear

The Quasi-Linear design uses a totem pole or series connected output stage with diode switching between two or three different transistor/power supply levels in both the positive and negative quadrants respectively. Like PWM, this design offers certain advantages, but with it comes some disadvantages that caused Crown to abandon this technology. The principle advantage is the ability to produce high voltages at the output without exceeding the maximum voltage or current capabilities of any single device. Major reasons for not using the quasi-linear approach include distortion peculiarities, uneven thermal dissipation, and poor utilization of the available power supply. Refer to the sketches provided for the discussion which follows.

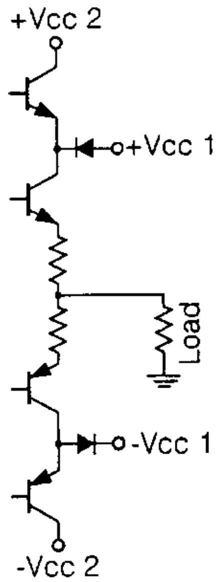

Figure 9. Quasi-Linear Topology

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As mentioned above, the quasi-linear technology requires that two (or more) devices operate in series, with a lower VCC between the two devices, and a higher VCC at the top. If the lower supply were +40VDC and the higher supply were +80V, the maximum peak to peak output voltage to the load would be 160Vpp. Into an 8 ohm load that is about 100W at the lower VCC, and about 400W at maximum. For the second level transistor to conduct, however, the first level transistor must be at full conduction, and operating into its saturation region. Through most of the range of a transistor's conduction the relationship of emitter-base to emitter-collector current is a constant proportion. As a transistor approaches saturation its operation becomes non-linear. For a quasi-linear amplifier to operate above the first VCC level, its first level of devices must go in and out of saturation in each quarter of the waveform. As it does so, the non-linearity presents itself as a distortion peculiarity in the waveform. The worst case condition is when a signal only slightly exceeds the first VCC level.

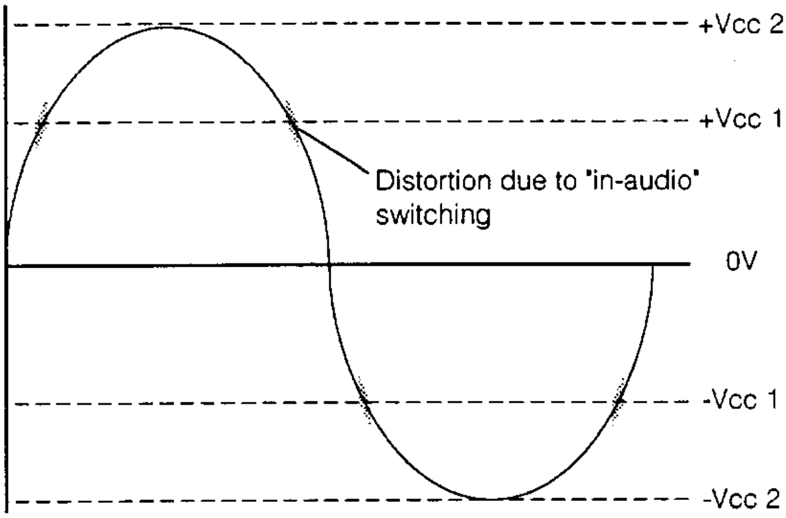

Figure 10. Quasi-Linear Distortion

With regard to thermal conditions, at low power levels the first devices must dissipate all of the heat generated. At higher levels the first transistor generates a relatively low amount of heat at saturation as the second device conducts. With audio signals, however, the first device generates the majority of heat even when dynamic peaks reach the clip point. Good mechanical design can reduce this problem, but it remains an inherent deficiency in these designs. Refer also to the discussion of Grounded Bridge under the Crown Designs section.

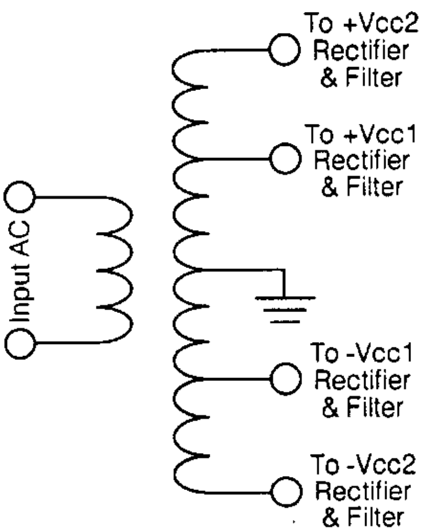

Figure 11. Quasi-Linear Power Supply

The high voltage power supply for such a design must produce four different voltages (more if the application requires more than two levels per positive and negative half). Although a quasi-linear amplifier may use one common supply to power both channels, separate supplies are often used to allow for completely separate channel operation (dual-monaural). This means that the power supply secondary is center-tapped and has at least four voltage output taps. As with any design using a center-tapped secondary, only half of the transformer conducts at any one time. Unlike conventional amplifiers, however, a number of additional windings are also required to supply the high

VCC. Each VCC must have its own rectifier and filter, adding to the total parts count—and taking up more valuable space inside the chassis.

Darlington (Composite) Configuration (Multi-Mode)
Almost without exception modern day professional amplifiers use two three deep Darlington configurations in the output stage. One for the positive half and one for the negative half of each channel. A three deep Darlington (sometimes also called a composite configuration) is a three deep stage. Where as the high voltage gain was obtained from the voltage amplifier; high current gain is obtained from the current amplifier, or output stage. In operation each stage functions differently. In a typical Crown amplifier these three stages are defined as:

1. Predriver
2. Driver
3. Output

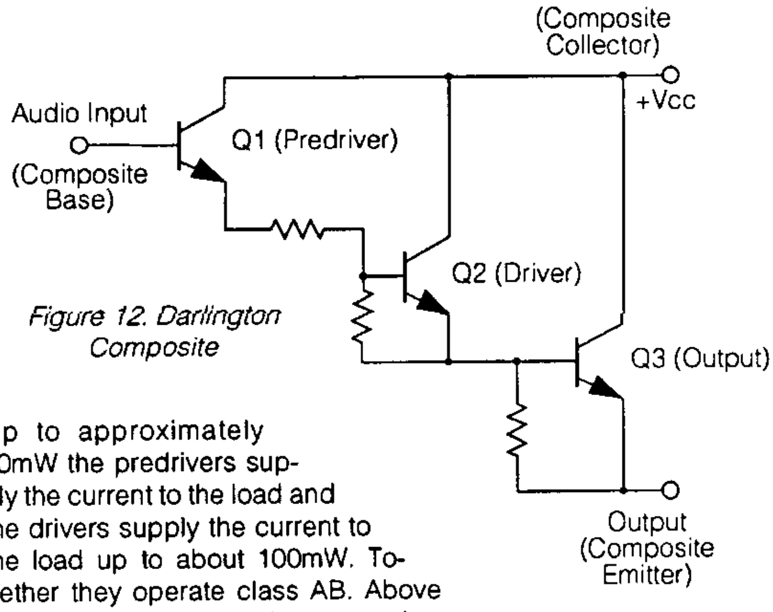

Figure 12. Darlington Composite

Up to approximately 50mW the predrivers supply the current to the load and the drivers supply the current to the load up to about 100mW. Together they operate class AB. Above 100mW the output transistors supply current to the load. There have been audio designs using only a two deep darlington design, but these have been abandoned mainly because of higher inherent THD.

Full Complementary vs. Quasi Complementary Symmetry
A Full Complementary circuit is where both NPN and PNP type transistors are incorporated. In contrast a Quasi Complementary design uses NPN type transistors in both halves of the output stage. Though claims to better symmetry and matching of complementary pairs gives greater linearity, in actual practice matching between PNP and NPN complimentary pairs is not as close as some advertise. For more information refer to the Semiconductors section of this text.

The Grounded Bridge
The grounded bridge is Crown's answer to the problems indicated above, plus a few not mentioned. It operates with four Darlington composite (AB+B) quadrants, two of which control ground reference (the power supply is ungrounded) and two operate like a conventional linear amplifier supplying the load. Operation of the grounded bridge—and other Crown design innovations—is detailed in the Crown Designs section of this text.

Notes