



CROWN®

THE PROFESSIONAL AUDIO DIVISION OF CROWN INTERNATIONAL, INC.



RESOURCE TEXT

For The

Crown® Professional Products SERVICE SCHOOL

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Notes

Semiconductors

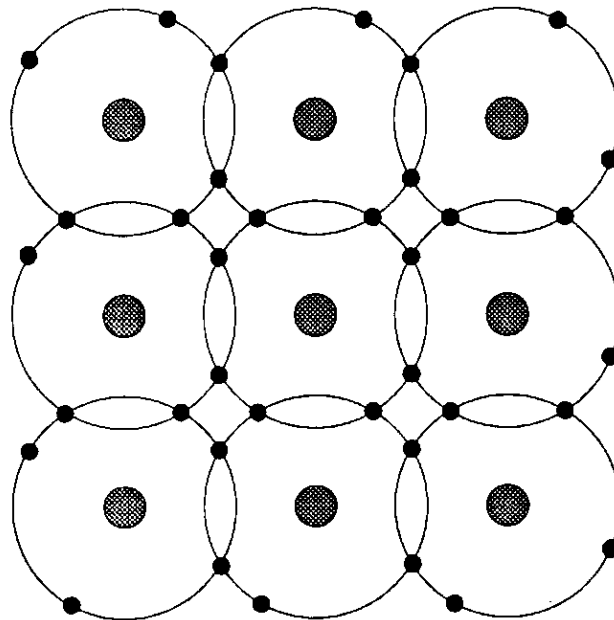
Active devices are generally those which amplify and/or are polarity sensitive. Diodes are the most simple of all semiconductors having only two parts, and only two leads. Diodes are polarity sensitive devices which, normally, only allow current to flow through them in one direction. Voltage applied 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

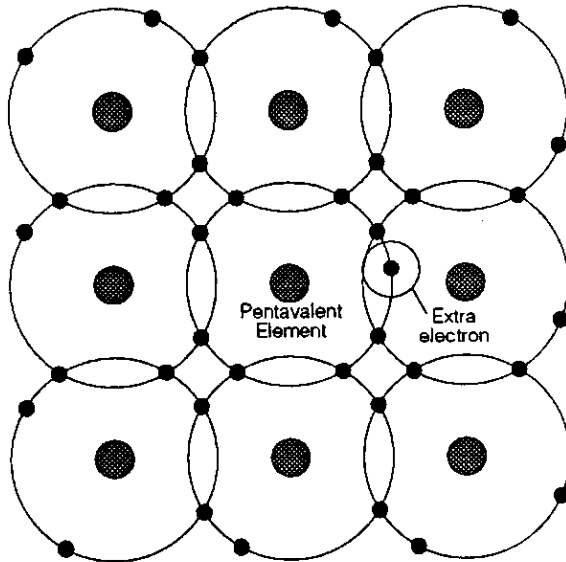


One atom shown surrounded by eight other atoms. Note that the valence shell of the center atom is complete.

Figure 1. Pure Silicon Substrate

N-Type Material

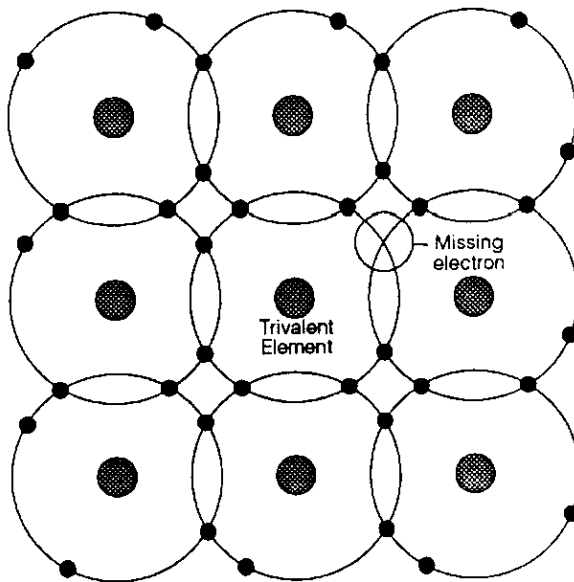
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One atom shown surrounded by eight other atoms. Note that the valence shell of the center atom has an extra electron. When it gives up this electron the material develops a net positive charge.

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.

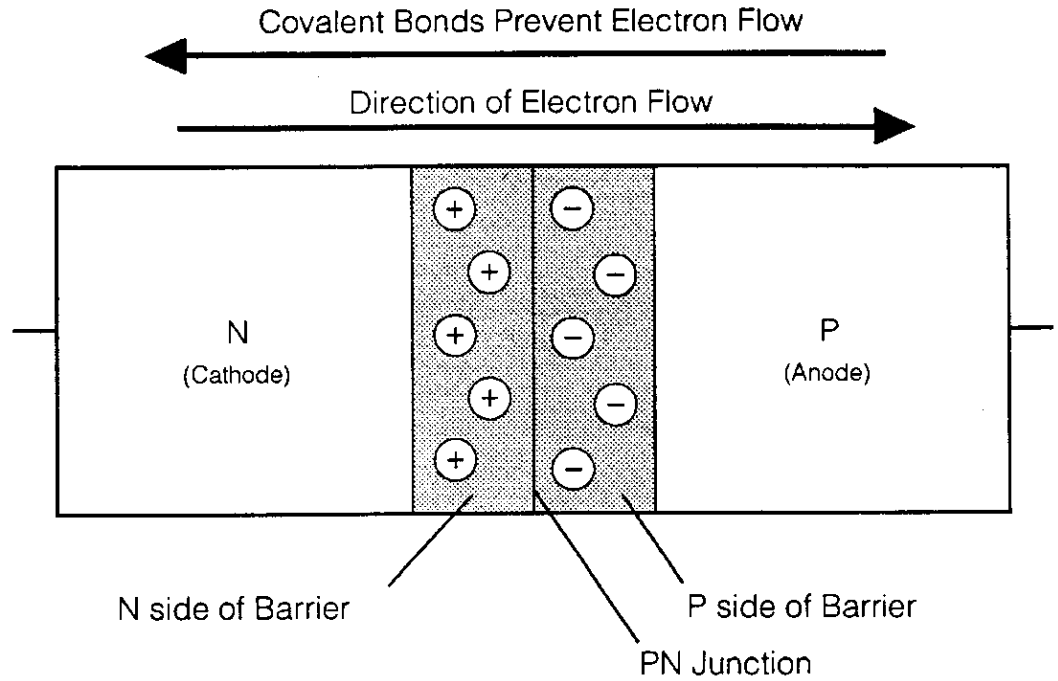


Figure 4. PN Junction (Diode)

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

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.

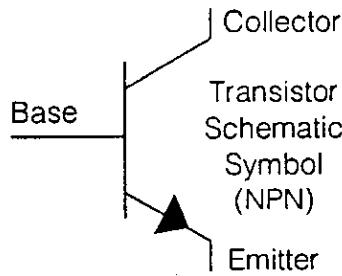


Figure 5. BJT Schematic Symbol

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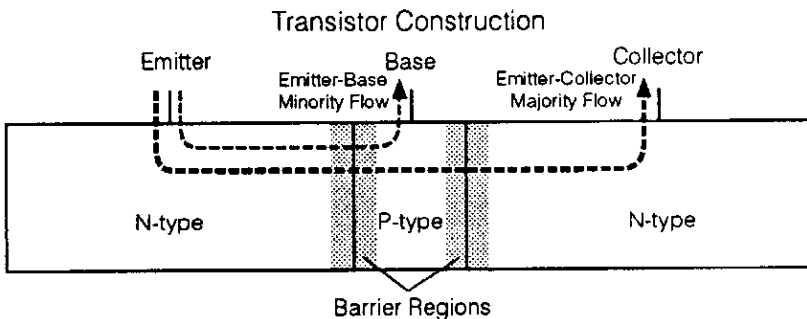


Figure 6. BJT Internal Operation

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

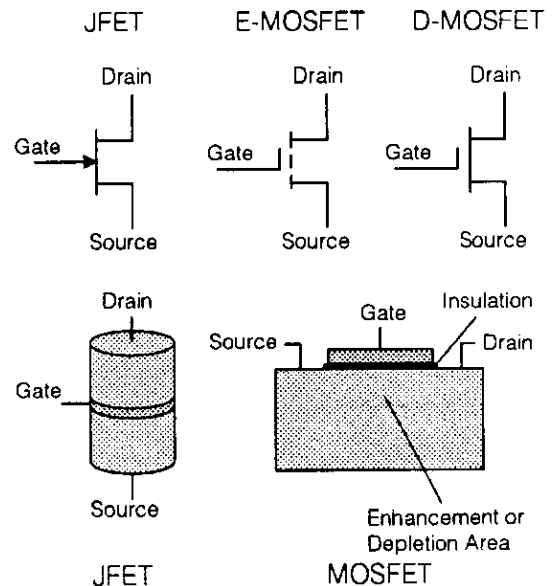


Figure 7. FET Devices & Operation

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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 (β) 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.

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.

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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.

Max Power

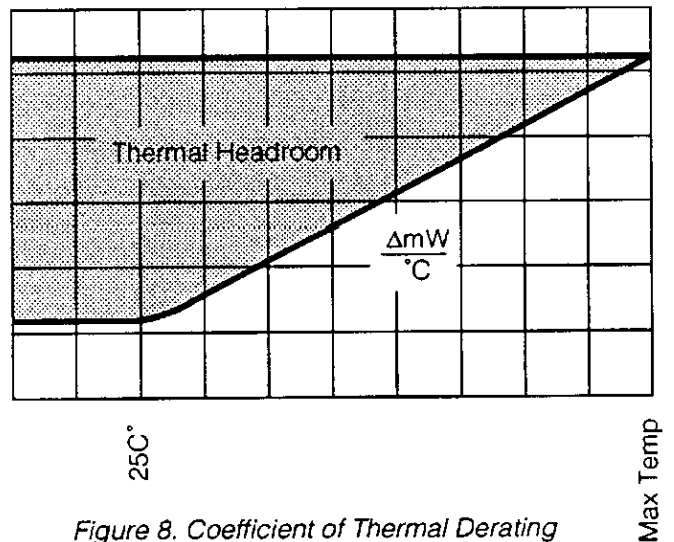


Figure 8. Coefficient of Thermal Derating

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.

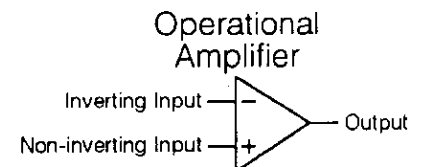


Figure 9. Op-Amp

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

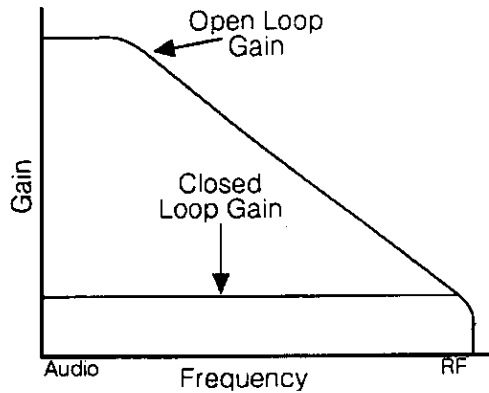


Figure 10. Op-amp Loop Gain

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.

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.

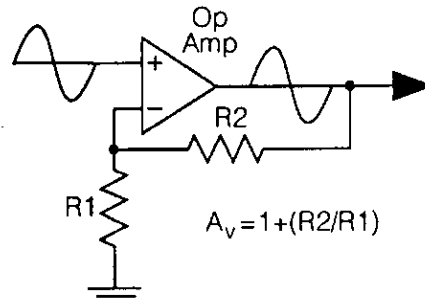


Figure 11. Non-Inverting Op-amp

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.

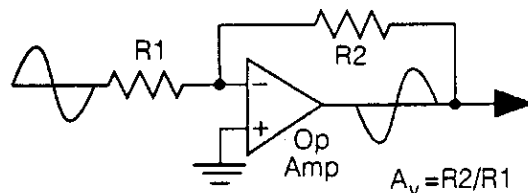


Figure 12. Inverting Op-amp

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