ANALOG AND DIGITAL SYSTEM ELECTRONICS

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Chapter 1

Introduction to Analog Electronics

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Electrical circuits, electronic parts, and networked technologies are central to the field of electronics. These components may all be broadly characterized as digital, analogue, or a hybrid of the two. But in this section, we'll pay close attention to the fundamentals of the analogue category. The field of electronics known as analogue electronics deals with continuously varying signals. It is often used in radio and audio equipment as well as other applications where signals are generated from analogue sensors and then transformed into digital signals for further processing and storage. Even while digital circuits are regarded as a major component of today's technological landscape, some of a digital system's most essential parts are really analogue in nature. Analog denotes real-time and continuous. The analogue nature of the world we live in suggests that there are an unlimited number of potential outcomes. Everything is limitless, including the amount of sounds we can hear, colors it can use to paint with, and the number of odors it can detect. In essence, those employed in the area of analogue electronics work with analogue devices and circuits. For instance, the values in a circuit that counts 1, 2, 3, 4, and 5 are neither unbounded nor continuous. The quantity of information would, however, be unlimited if the circuit counts like 1.00000, 1.00001, 1.00002, 4.99999, and 5.00000.

Analog Signals

Let's first define a signal simply before moving on to analogue signals. Signals in electrical engineering are essentially time-varying amounts (usually voltage or current). Therefore, when we discuss the signal, we are referring to a voltage that is changing over time. To collect or convey information in the form of audio, video, or encoded data, impulses are exchanged between devices. The radio frequency waves used for transmission go via cables or the air. For instance, data impulses between a tablet as well as a Wi-Fi network go over the air, while audio signals are sent from the computer's audio processor to the speakers. The characteristics of the medium are used by analogue signals to transmit their information. As an example, an aneroid barometer uses the angle of the needle to indicate variations in atmospheric pressure. Each signal value represents a unique piece of information, and the signals may take whatever value from a predetermined range. Any change throughout the signal is significant because each level of a signal denotes a different degree of the phenomena. Analog or digital signal graphs may easily be distinguished. Although the latter is edged and manifests as stepping squares, the former is relatively smooth. It is a graph of an analogue signal that shows how voltage changes with time (Figure 1.1).

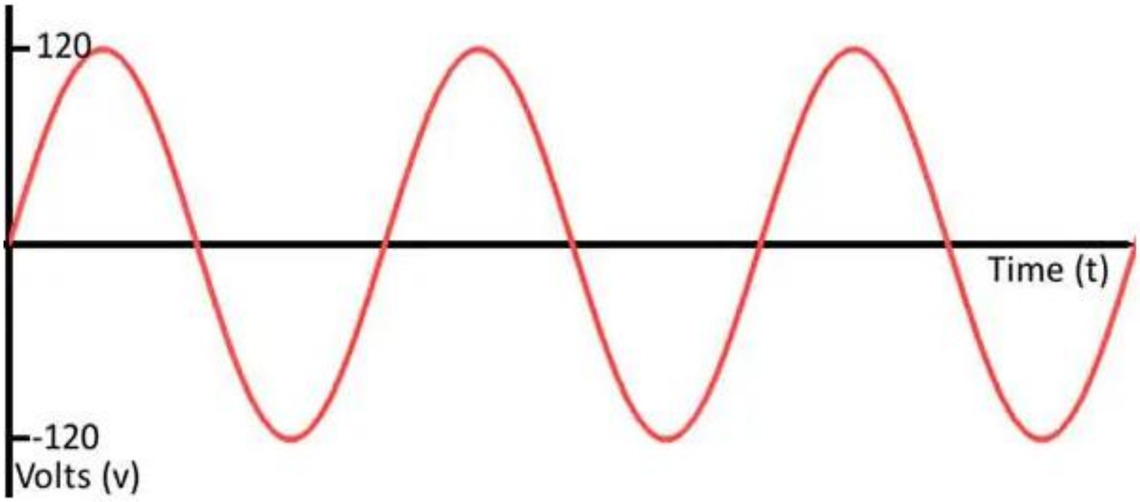


Figure 1.2: Represent the Analog Signal.

Analog Circuits Op amps, resistors, caps, and other common electrical building blocks may all be found in complicated combinations in analogue circuits. These circuits can be elegantly designed with many components or as simple as combining two resistors to create a voltage divider. Such circuits have the ability to alter, distort, isolate, amplify, change, and even turn the original signal into a digital signal. Compared to digital circuits, these circuits need a lot of accuracy and are challenging to design. Due to the fact that current analogue circuitry may include digital or microcomputer approaches to enhance performance, modern circuitry are seldom found to be entirely analogue. Mixed signals are the name for such circuits. Analog circuits come in two varieties: passive and active. The previous don't use any electricity, but the later do.

Analog Components and Circuitry

While digital components are employed extensively in today's electronics, analogue components are the most fundamental kind of components. We are outlining several situations when the analogue parts and wiring would be suitable since both branches are equally important in their own right.

Signal filtering: When working with a continuous signal, a continuous analogue filter is required to eliminate any potential unwanted frequency content. It is far less expensive and easy to use than a digital filter.

High Power: Digital measurement and control could be beneficial for high power systems, although it's possible that a digital signal moving from 0 to 400V won't be as effective. Since analogue components are more reliable and characterized by continuous power supply, they are necessary for AC and DC systems.

Prior to A/D and After D/A: Hybrid systems require both Analog-to-Digital and Digital-to-Analog conversions to transition between continuous and categorical data, but according to the Nyquist Theorem, the frequency response has to be at least twice that of the signal's highest harmonic component [4]. Therefore, any signal that was unintentionally included with the original signal may be filtered to eliminate noise after sampling in order to satisfy the theorem.

The signal can only be filtered using an analogue device since it is not yet digital. All processing must be performed using measuring equipment and circuitry after a signal has been processed digitally and converted back to analogue.

Sensors: Sensors transform information from the outside environment into data that what a computer or embedded system can understand. The sensors first produce an analogue signal, which they then transform into digital signals since the information is often not immediately accessible in the actual world. Contrary to high voltage systems, sensors have weak frequencies amplitude and need signal conditioning to boost the signal's value in order to properly use an ADC's whole dynamic range.

To create a good design for analog electronic control systems, designers have consistently encountered the following challenges: 1. Stability and drift brought on by temperature changes. 2. The dynamic range of signals and nonlinearity when the range's boundaries are being pushed. 3. Computational errors while employing analog quantities. 4. Ample frequency range for the signal. However, the development of integrated circuit technology, notably low-power analog and digital circuits, has provided designers with a substantial alternative. The alternative new design method for analog systems entails sensing the analog signal, converting it to digital signals, carrying out the calculations quickly and accurately using digital circuits, and then converting the resulting digital output back to analog signals. The electrical system designer must interact between two separate design worlds according to the new design methodology. First, there is a difference between analog and digital systems, after which there is a difference between the internal electronics world and the outward human world. Making the interface requires a number of different functions. Beginning with the transition first from human world to the world of electronics and back again, followed by a similar transition from analog to digital systems. Analog and Digital Circuits with Control System Applications discusses the electronic functions that are required, how they are implemented using electronic circuits, and provides examples of how the functions are used in systems.

Refresher

It is important to understand what analog and digital signify since the book is about electrical functions and circuits that interface or link analog-to-digital circuits and systems, or vice versa. Analog Analog systems use electrical signals that fluctuate smoothly and continuously throughout a range to represent underlying analog information. Analog numbers vary continuously. The recording thermometer seen in is an excellent illustration of an analog system. Depicts the equipment as it is in reality. As a drum spins, an ink pen measures the temperature in degrees Fahrenheit (oF) and displays it constantly against time on specialized graph paper. Displays the temperature change history. Keep in mind that the temperature is continually and evenly changing. The data does not include any sudden transitions or gaps.

The vehicle fuel gauge system seen in Figure 1.2 is another example. A potentiometer, which is essentially a resistor linked across a vehicle battery from the positive terminal towards the negative terminal, which is grounded, makes up the electrical circuit. A float resting upon that surface of the liquid within the gas tank rotates a variable tap on the resistor. A voltmeter measures the voltage from either the battery's changeable tap to its negative side (ground). The quantity of gasoline in the gas tank is shown by the voltmeter. It displays the amount of gasoline in the tank. The voltage reading on the voltmeter increases in direct proportion to the amount of petrol in the tank. It is claimed that the voltage and fuel level may be compared. A replica of the fuel level inside another form is referred to as an analog of the fuel level since it is comparable to the original fuel level. The system is analog because the power output is a representation of the real output parameter (fuel level) in a different form, and the voltage (fuel level) varies smoothly and continuously.

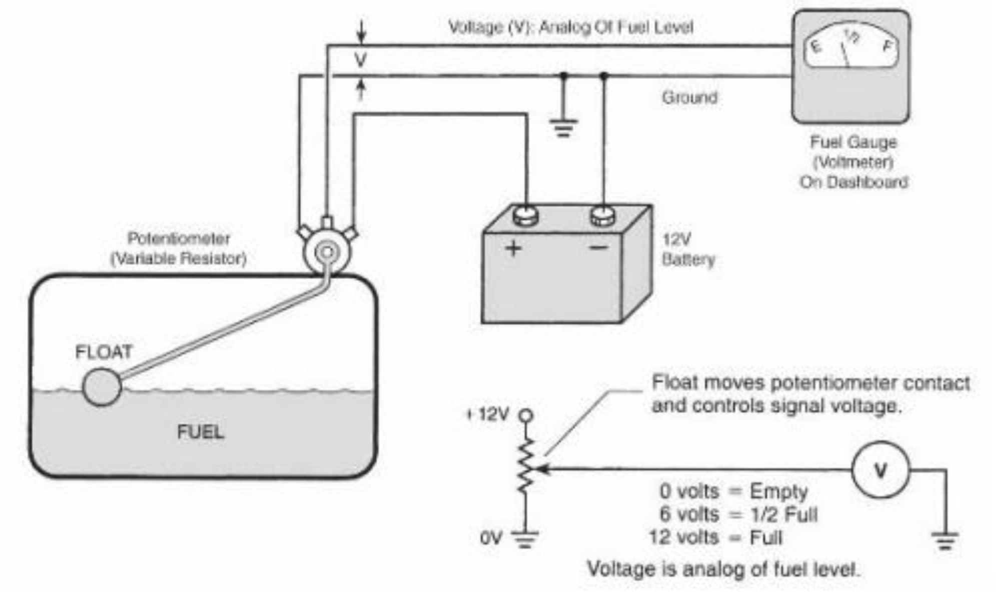


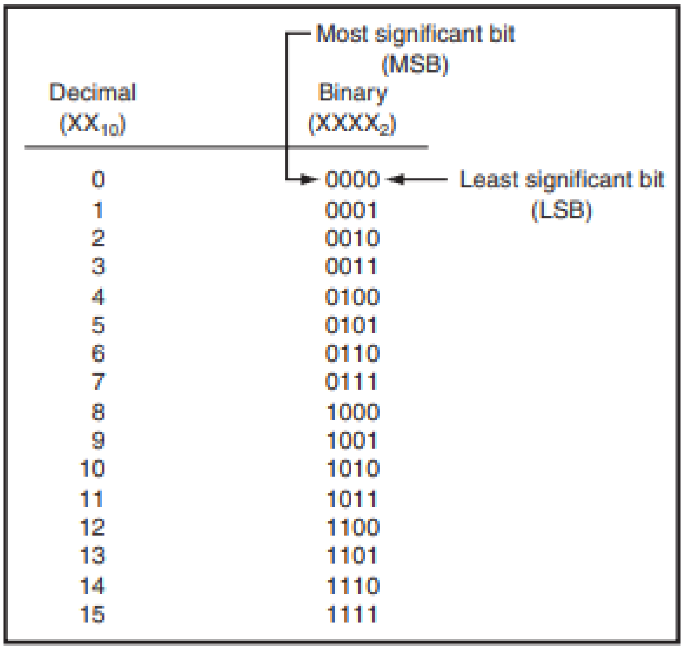
Figure 1.2: vehicle fuel gauge system

Digital quantities have distinct degrees of variation. The discrete levels typically only have the values ON and OFF. Digital systems transmit information utilizing combinations of electrical signals that are ON-OFF and often take the form of codes. An example of a digital system is the telegraph. Is a simplified representation of the original telegraph system, but it still illustrates the idea and provides a definition of a digital system. The electrical circuit consists of a battery, a switch, and a lightbulb at each end. The person at the light bulb is separated from the individual at the switch by a distance.

By encoding the data to be communicated using the International Morse telegraph code, the information is transferred from the person at the switch position toward the person at the light bulb. Figure 1-3b illustrates how Morse code creates characters or numbers using short and long current pulses (dots and dashes). Integrating the codes of dots and dashes for the characters and numbers into words delivers the information, as illustrated in. While maintaining the same shorter time between letters and words, the sender increases the time between words. This enables the recipient to recognize that the code delivered is either the end of a word or a character inside a word. T has one dash (one long current pulse). The H is made up of four little dots (four short current pulses). The R is a dash-dot-dash. The two Es also each have a dot. Current is present or not, and the two states are ON and OFF. By observing the light bulb's illumination, the person in the light bulb position may recognize the code. This individual used a buzzer or "sounder" in the first telegraph to hear the code. The information is encoded in patterns of transitions from one state to the across time. The signal has one of two levels at any given moment. The timing of signals is also a crucial element of digital systems, even if fluctuations in the signal are always between predetermined discrete values. Many times, discrete levels of digital signals or changes between discrete levels must happen exactly at the right moment for the digital system to function. Digital systems need circuits known as system clocks to preserve timing. This is how a digital signal and the data being processed in some kind of a digital system may be distinguished from one another.

Binary

In contemporary binary digital systems, the two levels—ON and OFF—are most often represented by 1(one) and zero (0), which are also known as binary digits or bits for short. The maximal code combinations 2n rely on the amount of bits, n, employed to represent the information since the system is binary (two levels). For instance, the codes would appear as when using a 4-bit code to indicate 16 values if integers represented the only quantities represented. More bits were added to indicate bigger amounts. A 16-bit code, for instance, may represent 65,536 different numbers. The least important bit is the first bit at the right-hand edge of the code (LSB). The most important piece is the one on the left (MSB) (Figure 1.3).



Decimal (XX_{10})	Binary ($XXXX_2$)
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Figure 1.3:binary digital systems

The Basic Functions for Analog-to-Digital Conversion

Sensing the Input Signal

The chain in Figure 1-7's analog-to-digital section expands the chain's fundamental operations. The majority of the inputs from nature, such as temperature, temperature, humidity, wind speed, linear motion, or location, are not in a form that allows them to be immediately entered into electronic systems. In order to connect to electronic circuits, they must be converted to an electrical quantity, such as a voltage or current. Sensing is the fundamental job of the first block. Sensors are the parts that detect physical quantities and produce electrical signals. The sensor seen in this picture measures pressure. The output is an approximation of the detected pressure and is measured in millivolts. It displays a sample output plotted against time.

Conditioning the Signal

Signal conditioning refers to the alteration of a signal characteristic. The block is an amplifier that multiplies the signal's amplitude by 1,000, changing the output signal's unit from millivolts to volts. The output is a precise replication of the input that has only undergone amplitude variation due to the linear amplification. Other signal conditioning circuits might lower the signal intensity, choose a frequency (filter), or change the impedance. A fairly typical signal conditioning function is amplification. While some electrical circuits are only capable of processing small-signal signals, others are categorized as power amplifiers because they must provide a large amount of energy for outputs (watts are joules/second).

Conversion from analog to digital

In order for a digital system to perceive an analog signal and interpret the information, the analog signal must be converted to a digital code in the fundamental analog-to-digital conversion function. Because the analog signal is always changing, a fundamental sub function is necessary. A sample-and-hold function is what it's known as. The sample interval is determined by timing circuits (clocks), and the function then takes a sample of the input signal and stores it. The analog-to-digital converter receives the sample-and-hold value and converts it into digital code with a value that is equal to the sample-and-hold value. The conditioned output signal is transformed to the 4-bit codes displayed as it is sampled at intervals of 0, 1, 2, 3, and 4. There can be a discrepancy between the real input voltage and the voltage recorded at the following sample since the analog signal is constantly changing.

Signal route from digital to analog

The Analog-to-Digital Part separates the digital-to-analog part. The output digital codes from the digital processing system are connected to a digital-to-analog converter, which converts them back into an analog signal once the signal has undergone all necessary signal processing. The analog signal is attached to a signal conditioner, which modifies the signal's properties, at the digital to analog converter's output. Similar to Part 1, depending on what the application requires, the signal's amplitude may be boosted via amplification or lowered through attenuation. Altering the signal's power level or impedance to suit the transducer with which the output signal connects are other possibilities. The system's output is a real-world quantity that is independent of the electronic system. The output, as seen in Figure 1.4, might be a heater, a motor, a lever arm to create motion, a meter, or any comparable output.

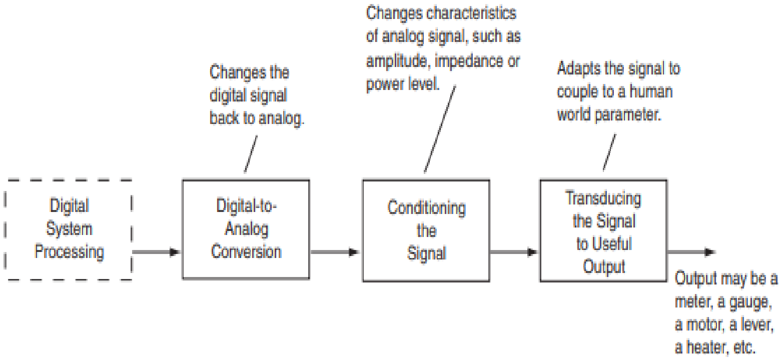


Figure 1.4: Signal route from digital to analog

Serial Data Transfer

Data is sent serially as a second method. The 4-bit codes are outputted one bit at a time, one after the other in succession, with each set of four bits following the other in sequence, as illustrated in Figure 2-2. The speed at which the words are conveyed is controlled by the clock rate. The digital-to-analog converter receives the bits in order and puts them back together into the appropriate bit groups before processing them.

Conversion

The digital-to-analog converter's input digital codes translate to a specific analog value. the output of the input code is transformed to and produced as the equivalent analog value, which is then stored in place until the output of the subsequent code equivalent value. The output of the digital-to-analog converter is therefore, as illustrated, a stair-step output that remains constant at a certain level until the next input digital code is received. Although the output resembles an analog output, more processing is necessary to produce the actual analog signal.

Filtering

Filtering, or more generally smoothing, is a fundamental process needed after the digital-to-analog transformation. This filtering creates an analog signal that is more similar to an analog form which changes constantly and gradually. Physically, the filter might be in the signal conditioner that comes next or in the digital-to-analog converter. Since it really performs a signal conditioning function, it was included in the signal conditioner.

Conditioning the Signal

Similar signal conditioning techniques may be used for the analog to digital and digital to analog portions. Amplification of a signal is a frequently used function, but in a similar vein, attenuation of the signal—that is, lowering the amplitude instead of raising it—is often required. The function used for. The output signal is weakened to half its input value. The signal's other properties remain unchanged. The signal seems the same, with the exception that its amplitude values are decreased, since the waveform's structure of amplitude fluctuations over time is unaltered.

Signal Transduction

The output of the analog systems under discussion is a component of the outside human environment. It might be a temperature, pressure, measure of humidity, linear motion, or rotation, as has been said several times before. Thus, it is often necessary to modify the shape of the electrical output of the signal conditioning function. It has to be converted into another type of energy since it could be either a voltage or a current coming from the electronic system. A transducer is a device that changes or transforms energy from one medium to another. The transducer is a gauge that displays the output voltage's amplitude on a voltage scale. The spinning of a needle in front of a scale marked on the substance behind the needle is converted from the voltage produced from the electrical system. Specific needle deflections correspond to particular voltage levels thanks to the scale's calibration. As a consequence, each deflection of the needle caused by an electrical circuit output may be translated into a specific voltage value at any given moment. The output of the electrical system has been transformed into a meter reading, which may then be calibrated to the kind of parameter the system is monitoring. It could be the fluid level, flow rate, pressure, or something else. In various kinds of transducers, the energy form undergoes comparable transformations. By selecting the right transducer, the voltage or output current from the electrical system may be transformed to any kind of human world parameter (Figure 1.5).

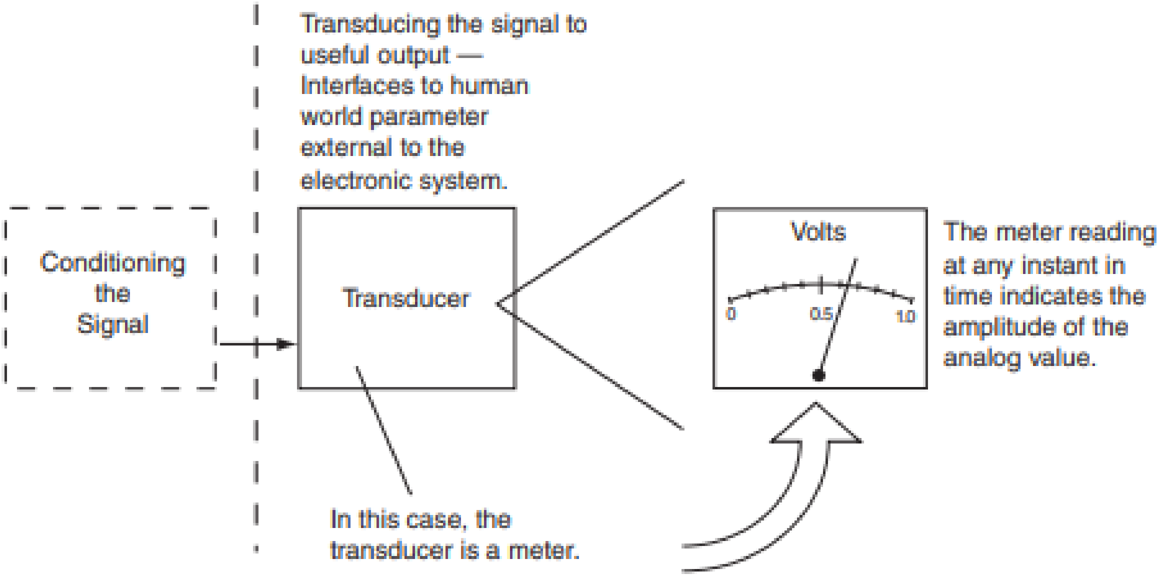


Figure 1.5: Signal Transduction

Sensor

A sensor is a device which detects and transforms a physical quantity present in nature into results that people can understand. Meter readings, light outputs, linear movements, and temperature changes are a few examples of outputs. According to Chapter 1, the bulk of these physical values are analog quantities, meaning that they change constantly and gradually. In its most basic form, sensors are objects that just have one component that undergoes the required transition.

Despite the fact that increasingly intricate sensors are being produced nowadays, the essential functions of detecting, signal processing, and converting are all included in a single unit. The bulk of the sensors in this chapter will be single element sensors that produce electrical signals—voltage, current, or resistance—in order to clearly explain the sensing function. But sensors that operate by using magnetic fields are also present, closely related to sensors with electrical outputs.

Temperature gauge

Temp. of the mouth Everybody has sometimes needed to check their body temperature or the core temperature of a family member. Most likely, an oral thermometer similar to the one in Figure 3-1 was used. As temperature rises, the liquid mercury within a glass tube expand and pushes the scale higher on the tube. The oral thermometer turns the physical amount of temperature into a scale value which humans could read since the scale was calibrated in degrees (oF—Fahrenheit in this instance) of body temperature. A temperature sensor with either a mechanical scale makes up the mouth thermometer readout.

Outside/Indoor Thermometer

A bimetal strip thermometer is what it is. A strip that is fashioned into a spring is joined by two different metals. As the temperature rises, a force between the metals that responds to temperature differently stretches the spring and turns the needle. The scale of the thermometer is calibrated using two well-known temperatures: boiling water and absolute zero. These coordinates create a scale, and the instrument is transformed into a commercial thermometer with scales for Fahrenheit (oF) and/or Celsius (oC). The one for oF is shown in Figure 3-2. Another sort of temperature sensor that transforms the physical amount of temperature into a measurement that is simple for people to see and understand is the outdoor thermometer.

Thermocouples

Another typical temperature sensor is indeed a thermocouple. One may be found in a natural propane furnace in a house like the one. It regulates the furnace's burners' pilot lights. A gas is contained in a closed tube system called a thermocouple. As the gas is heated, it expands, expanding a diaphragm at the tube's end within the gas control module. This is how the system functions: To initially enable gas to flow and ignite the pilot light, a button upon that pilot light gas central controller must be depressed. The button for the pilot light must be kept down until the thermocouple is heated by the pilot light in order for the pressure increases and the diaphragm expands, which in turn controls valve A. Because the pilot light is heating the thermocouple, which maintains the gas expanded, the inflated diaphragm keeps valve an open, allowing the pilot light button to be released. Since the pilot light is lit, every heat demand made by the thermostat will ignite the burners, heating the home until the need is satisfied (Figure 1.6).

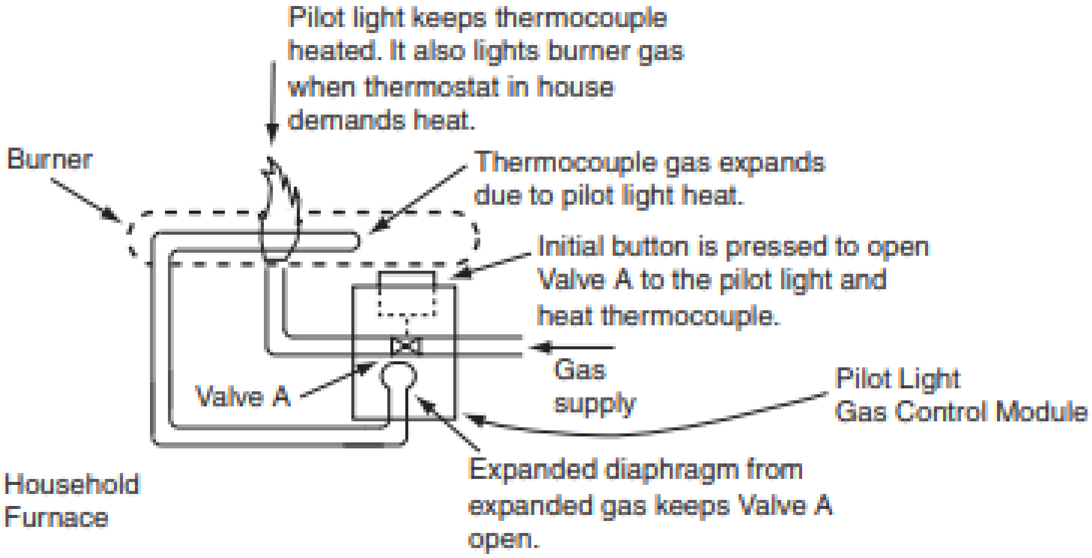


Figure 1.6: Shows the block diagram of Thermocouples

Depicts a thermocouple, which emits an electrical signal when temperature changes. It is made by fusing two metals that aren't compatible. A temperature sensor that produces millivolts of electrical signal instantly is produced when the junction of both the two metals is heated. The application utilizes the package's earth connection as that of the cold reference junction even though the complete circuit really contains a cold-junction reference (Figure 1.7).

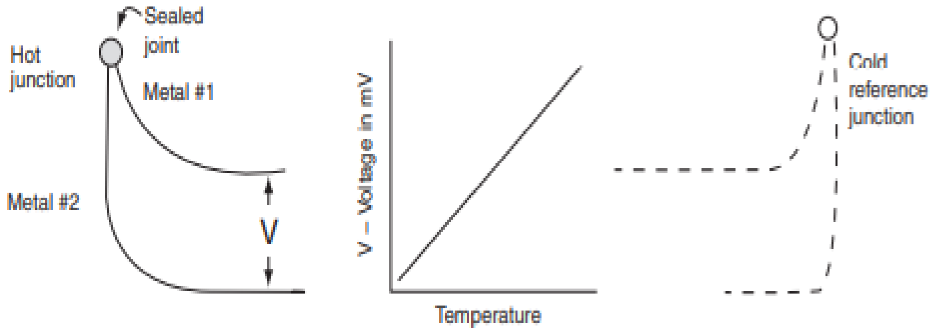


Figure 1.7: Shows the block graph of Thermocouples

Silicon-Junction Diode

A silicon-junction diode is another sensor that directly changes voltage in response to temperature changes. Figure 3-6 displays the characteristic curves of its forward as well as reverse voltage increasing current. When the forward voltage approaches +0.7V, the forward current vs forward voltage for positive voltages grows quickly. The forward resistance in this case ranges from 50 to 80, which is really tiny. For negative reverse voltage, the reverse current is 1,000 times or less than the advance current. Up until the magnitude exceeds the reverse breakdown voltage, it remains comparatively flat with reverse voltage. The reverse resistance is quite high—on the scale of me ohms—when the junction was reversed biased underneath the breakdown voltage. The diode junction does have a negative temperature coefficient because both the forward voltage and the reverse breakdown voltage drop as temperature rises. Compared to the reverse breakdown voltage, the forward voltage's voltage change with temperature is much less. A temperature sensor may be made from the reverse current underneath the breakdown area. According to a general rule, the reverse current doubles for every 10°C increase in temperature. For temperature sensors, the opposite circumstances are employed, although the forward voltage change is used most often.

Chapter 2

Thermistor and Position Sensor—Fuel Level

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A resistor whose value changes with temperature is known as a thermistor. The features of a thermistor that are easily accessible at RadioShack. Figure 3-7 illustrates two thermistors-using circuits. A voltage divider in employs a thermistor to provide a variable voltage output. It makes use of a transistor to magnify the current variation the thermistor provides in response to temperature fluctuations. The resistance of certain micro-machined thermistors is on the order of 10 k at 25 °C. The non-linearity of a thermistor's properties with temperatures is one drawback of utilizing one. As a consequence, the nonlinearity has to be taken into account in order to create linear outputs (Figure 2.1).

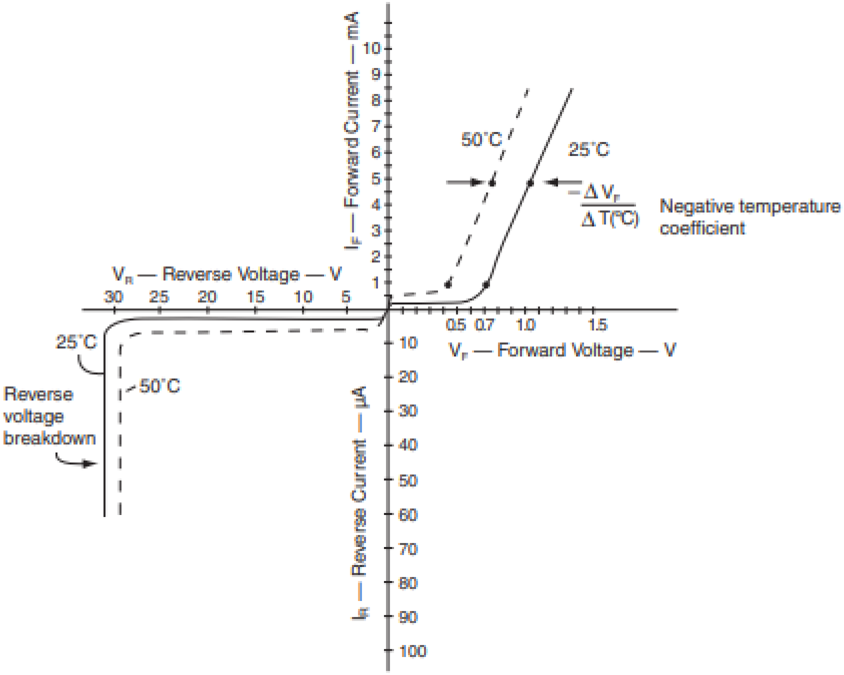

Figure 2.1: non-linearity of a thermistor's properties with temperatures

Angular and Linear Position

Position Sensor—Fuel Level

An analog quantity was shown using an automotive fuel gauge. The sensing function will be shown using the same example. The whole sensor is made up of a float that floats on top of the gasoline in a fuel tank, a lever arm attached to the float place at a single end, and a potentiometer's shaft attached to the other end (variable resistor). The float moves and turns the variable contact on the potentiometer in response to variations in fuel level. The potentiometer is linked across the automotive battery from +12V to ground, as shown by the design. The potentiometer's changeable contact travels in a proportionate way. The output voltage from the variable contact to earth will be 0 volts when the contact is situated at the end of a potentiometer that is connected to ground.

The voltage will be +12V from of the variable contact to ground at the opposite end, the one that is wired to +12V. The voltage from the variable contact towards earth will be proportional to the velocity of the shaft rotation at any configuration of the variable contact between the end points. The liquid-level sensor is finished by calibrating it as seen in Figure 3-8c. The variable contact is located on the +12V end of a potentiometer when the tank is full thanks to the configuration of the float, lever arm, and potentiometer shaft movement.

The same set of components causes varied contact at ground level whenever the tank is empty (0V). Different float settings provide output voltages between both the variable contact and ground that are proportionate. A three-quarters full tank will provide an output of 9V, a half-full tank would produce 6V, and a quarter-full tank would produce 3V. The vehicle fuel gauge is finished by attaching a voltmeter to determine the voltage from either the variable contact towards ground, indicated in liquid surface. It is fairly common to find sensors that transform a physical quantity into such an output of electric voltage. A microvolt to tens of volts might be the output voltage.

Position sensor for the Hall Effect

The Hall Effect It was found by E.H. Hall. If a conductor is carrying current and a magnetic field is produced perpendicular towards the conductor's direction, the conductor will produce a voltage with a direction perpendicular both to the magnetic field's direction as well as the conductor's direction. Particularly whenever a semiconductor chip is employed as the conductor, this characteristic is highly helpful in the creation of sensors. The semiconductor may process this Hall voltage as well as create it, using extra circuitry that can be integrated into the semiconductor.

As a result, in addition to linear sensors that produce an output voltage proportional to the size of the applied magnetics flux, there are additionally sensors that already have switched logic-level outputs, latched output data, or outputs for whom the level depends on the distinction between two implemented magnetic fields, because circuitry can indeed be added to the chip.

The Hall Effect—Switch

The output of a Hall-effect switch whenever employed as a sensor. The output transistor of both the switch is ON whenever the magnetic flux exceeds ON in Maxwell's equation, and OFF whenever the field is less than OFF.

A hysteresis curve is present, as shown. The magnetic field must be larger than zero by ON for the output transistor to turn on, and it remains active until the magnetic field is smaller than zero by BOFF. By using a steady field to create O = STEADY-STATE, the zero magnetic field position may be "biased" up to a certain value (Figure 2.2).

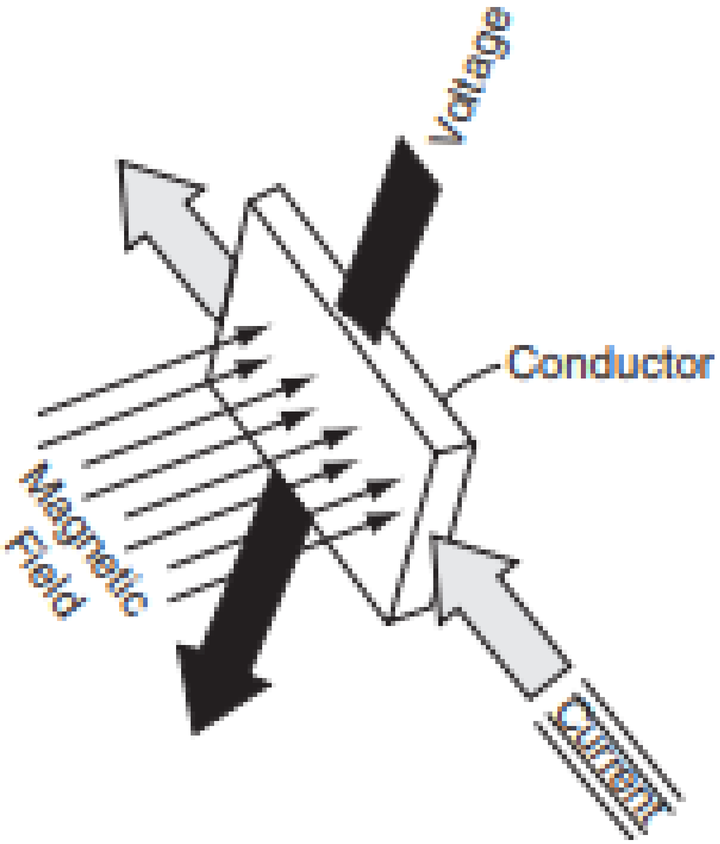

Figure 2.2: The Hall Effect Switch

Rotation

Variable Reluctance Sensor

The physical configuration of an electromagnetic sensor which generates a continuous stream of voltage pulses in response to variations in magnetic flux that fluctuate over time. The iron core of a coiled coil, the cog on the revolving wheel, and the coil itself make up the reluctance path of the magnetic flux. The concentration of flux is highest when the gear on the wheel is in line with the iron core. The flux concentration decreases significantly when the cog travels closer to or further from the coil's core. Any time the magnetic flux shifts and cuts through wires, a voltage is produced in the wires. In the circuit connected to the wires, the voltage results in a current. Depicts a sequence of voltage pulses that are produced as a result of the wheel and cog passing the coil in motion. The cogged wheel's speed affects how long, t, passes between pulses. One may determine the speed (velocity) of a cogged wheel by counting these pulses over a predetermined amount of time, such one second. It is possible to compute the fluctuations in speed for acceleration, and pulses undoubtedly indicate that the wheel is moving. Such a sensor has the drawback that there is no signal with zero speed and that the air space between both the mechanical moving portion and the coil core must be minimal, typically equal to or less than 2 to 3 centimeters (Figure 2.3).

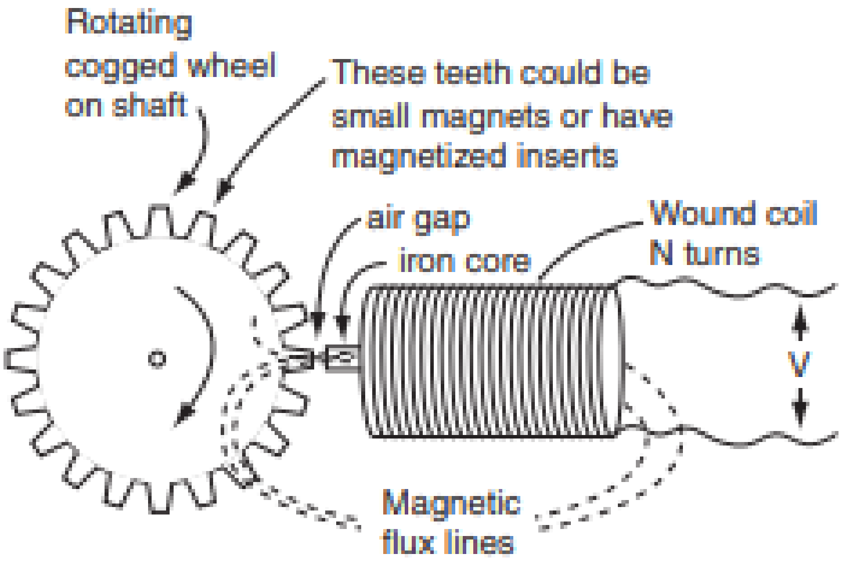

Figure 2.3: Variable Reluctance Sensor

Magneto resistor Sensor

In proportion towards the magnetic flux density it really is exposed to, a magneto resistor sensor alters its resistance. It is constructed from a thin layer of Permalloy, a nickel-iron alloy, that is applied to the a semiconductor surface. Conducting strips over semiconductors with high carrier mobilities, such indium-antimonite or indium arsenide, need to be specially fabricated. The fundamental idea. Strong magnetic fields are used to deposit the thin layer, causing the magnetization M to be aligned parallel to the resistor's length. The thin film is then produced to conduct a current at an angle of to the M orientation. The thin sheet will have the most resistance if the angle is zero. Its resistance will be reduced at an angle. The resistance varies when a magnetic field from outside is introduced perpendicular to M, causing a change in. This is the fundamental idea that causes a resistance change in response to the application of a magnetic field and permits the use of the thin film technology as a sensor.

Pressure

Piezoresistive Diaphragm

A pressure sensor's physical design. A tube with a thin, flexible diaphragm covering the end contains a fluid or gas under pressure. The diaphragm deflects as the pressure rises. To completing the pressure sensor properties, the diaphragm may be matched to the applied pressure. Pressure sensors are now designed and made using contemporary semiconductor technology. In Figure 3-13b, an informative graphic is shown. A silicon substrate with a high-resistivity intrinsic semiconductor has been micro-machined to create the tiny diaphragm. By forming silicon dioxide upon that surface, coating it with photoresist, exposing the photoresist to infrared photons light through a mask to characterize the diaphragm neighborhood, and then etching away the silicon and oxide towards the appropriate depth for the thin diaphragm, the viewpoint of a diaphragm as well as its thickness on and within the substrate are defined using conventional semiconductor techniques. After that, the assembly is packed such that pressure may cause the diaphragm to deflect (Figure 2.4).

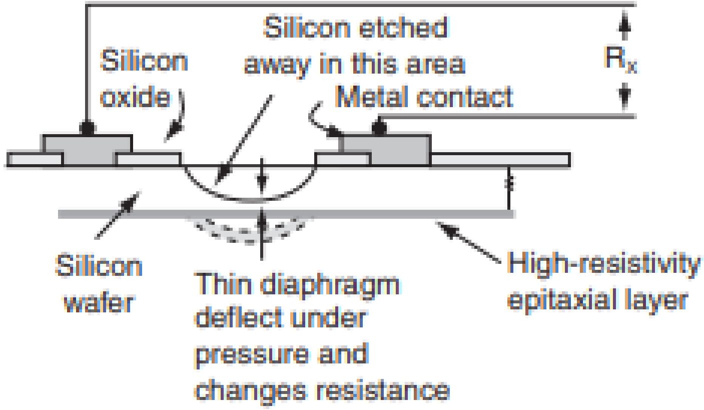

Figure 2.4: Piezoresistive Diaphragm

Capacitive Touch Diaphragm

The micro machined construction is identical to the capacitive touch diaphragm sensor. Its sensor concept, is distinct, nevertheless. The narrow micro-machined diaphragm was deflected as before, but this time it is intended to contact a metal electrode-attached dielectric layer. It creates a capacitor, and the capacitance between both the metal electrode as well as the diaphragm—which are separated by that of the dielectric—increases linearly with pressure as pressure rises. In Figure 3-14b, \the typical curve is shown. The operating range of the two silicon micro machined sensors is -40° to +135°. The product is a capacitive sensors with such a ceramic diaphragm which tries to deflect into a cavity for use in aviation and automotive applications with highly harsh working conditions. Pressure causes its capacitance to rise once again (Figure 2.5).

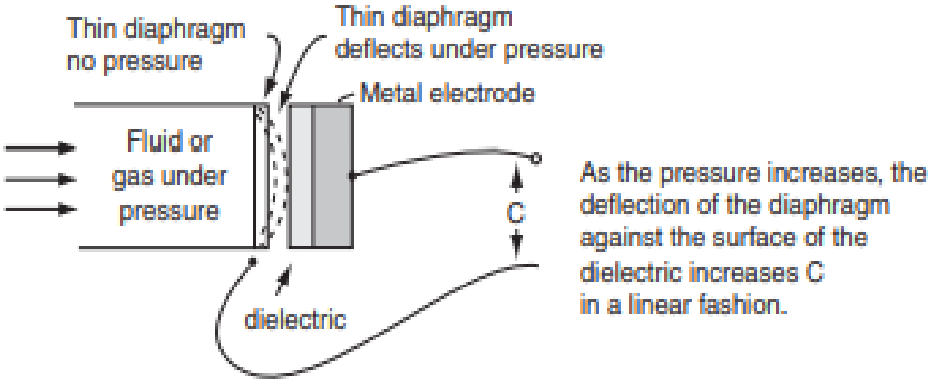

Figure 2.5: Capacitive Touch Diaphragm

The fundamentals of light and how photodiodes and phototransistors sense it are briefly reviewed. Refer to Basic Electronics1 for a more comprehensive explanation of how light shining on something like a reverse-biased photodiode causes its reverse leakage too rise. Inside the reverse-biased diode depletion layer, photons, which have been electromagnetic waves of high frequency, are collected. The reverse current is increased by the free electrons and holes that they create. The intensity of the light increases with the number of photons, as does the amount of energy absorbed and the size of the reverse current. The photodiode is an example of a light sensor with variable current output.

The Electromagnetic Spectrum

According to frequency, the electromagnetic spectrum is separated into radio waves and light waves. The categories of infrared, visible, ultraviolet, and X-rays are further separated into light waves. Both frequency and wavelength are used to describe the spectrum. The length of an electromagnetic wave is the distance it covers in space during one repetition of its frequency. Since distance is calculated by multiplying velocity by time, wavelength may be calculated as electromagnetic wave velocity times the time it takes for one cycles of frequency f. Considering that the recognized speed of light is 186,000 miles per second, or 300,000,000 feet per second, this is: (in meters) = 300/f (in seconds) or, (in meters) = 300,000,000 meters/sec 1/f (in seconds) (in MHz), visible light (white light) divides into its component colors as it passes through with a prism. Visible light has a frequency between 400 million and 750 million megahertz. This wavelength ranges from 400 to 750 nanometers (109). Light sensors cover the infrared spectrum, which is below visible light, as well as the ultraviolet spectrum, which is above visible light. While photovoltaics and phototransistor sensors are also most sensitive in the infrared range, cadmium sulfide sensors are also most sensitive in the visible green light range (Figure 2.6).

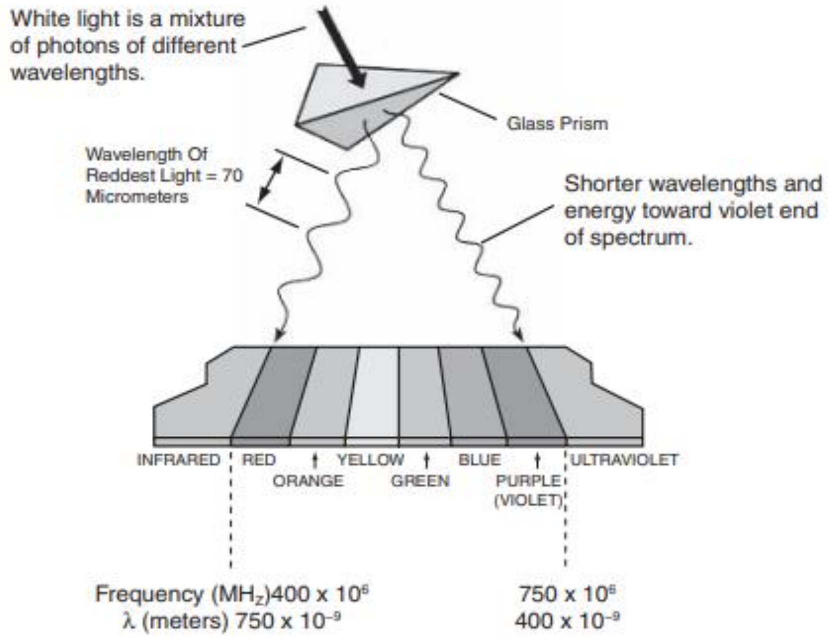

Figure 2.6: The Electromagnetic Spectrum

Photoresist or Sensor

Cadmium sulfide (CdS), a light-sensitive semiconductor, is used to create sensors that alter resistance in response to illumination. Figure 3-17a displays the characteristics of a product that RadioShack sells. Its resistance is higher than 0.5 M when there is no light shining on it when it is dark. Its resistance is 1700 when illuminated by a single foot-candle, and it drops to 100 when illuminated by 100 foot-candles. Circuit applications are shown. It may be used as a sensor delivering current to a load, to modify resistance values, or to output voltages to a sensor.

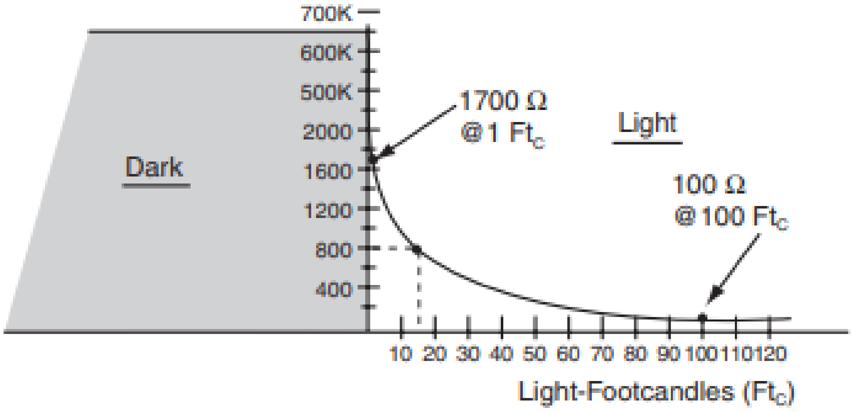

Figure 2.7: Illustrating the Graph of Photoresist

Solar Cell

The solar cell is once again a light-sensitive semiconductor PN junction. It is composed of an N-type substrate that has an extremely thin P area covering the top surface. The cathode of a PN diode is made up of of thin metal strips that cover the small P surface. To boost current output just at PN-junction voltage, a silicon wafer is coupled with a vast network of the thin strips. The cathode of the photodiode is created by coating the back of a silicon wafer with metal. The solar cell's surface produces a maximum voltage of roughly 0.55V when light is shining on it. The typical voltage output while under load is around 0.5V. Displays a typical characteristic curves of voltage plotted against stream. Solar cells may be used in circuits, either connecting several cells are connected in series for a higher voltage output or in parallel for a higher current output. At RadioShack, you can buy individual 2 4 cm solar cells that give 300 mA at 0.55V or enclosed modules which offer up to 6V at 50 mA.

Phototransistors

Enables a rapid study of NPN and PNP bipolar transistor function. Remember that the base voltage is at +0.7V above ground and the forward biases the base-emitter junction inside the NPN grounded emitter stage during active operation. The collector base junction was reverse biased because the collector positive voltage is present above ground (+5V). A greater collector current, IC, flows around across reverse-biased collector-base junction whenever a current into the base, IB, is present across the forward-biased base-emitter junction. The collector current multiplied by that of the base current, or IC/IB, determines the transistor's current gain. Demonstrates that the current gain was hFE. The PNP transistor operates in exactly the same way, with the exception that the voltages all seem to be negative and the emitter is connected to ground. The hFE parameter is identical to that of the NPN. The fundamental function of an NPN or PNP transistor is the same as that of a phototransistor, which is a transistor designed to also be triggered by light, with the exception that it lacks a base connection. Its broad base junction is left in the open to the sun. Infrared light has the highest sensitivity for phototransistors. The symbols but also voltages are displayed. The base current generated by light rays striking the base-emitter connection efficiently turns on the phototransistor. Larger collector current is generated by transistor activity. The representative curves of demonstrate that increased light intensity results in increased collector current. a phototransistor may be connected to the base of a driver transistor to provide a nonlinear driver or a logic-level driver. RBIAS and RE are dropped if a logic-level driver for ON-OFF operations is required, and the RADJUST is utilized to adjust the appropriate sensitivity. To ensure that the driver operates linearly in Q2, RBIAS and RE establish the operating point. A phototransistor is shown in Figure 3-20d detecting the appearance of light to create a logic-level relay driver. The normally-open connection to the center terminal closures in the presence of light, turning on a linked circuit.

Utilizing LED Lighting

Despite not being a sensor, a light-emitting diode (LED) is a crucial light source for sensors that detect light. As shown in Figure 2.8, an LED is a forward-biased semiconductor diode. Although various semiconductor materials whatsoever except silicon are used to make LEDs, they all have the same junctional properties. The forward-biased diode generates light when the required current flows through it. When a particular voltage, V, is utilized, the quantity of current, I, via the diode may be altered by selecting the value of R. Approximate forward bias across the diode is 0.5V, positive (+) on the anode and negativeon the cathode. Displays several LEDs, the components needed to produce them, as well as the color of the light they emit. In this instance, the wavelength is expressed in Angstroms, where one Angstrom equals 10–10 meters. The wavelength of the LED and the phototransistor should match when using LEDs as light sources for phototransistors. The relative output from such a phototransistor employing an LED as a source, for instance. Nearly three times quite so much output from of the phototransistor is produced by an infrared LED with such a wavelength of 898 nanometers (8980) compared to an orange LED with a 650 nanometer (6500) output.

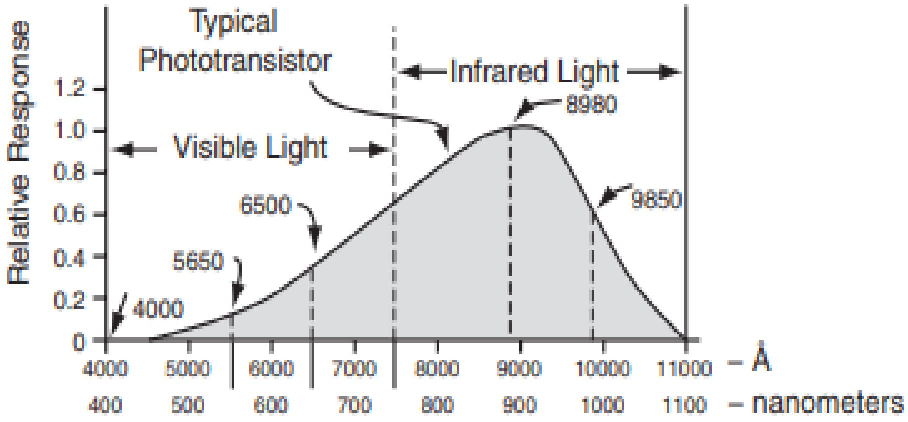

Figure 2.8: LED is a forward-biased semiconductor diode

An electronic system is a collection of interconnected electronic devices and parts that react to one or more specified inputs to create one or more intended outputs. Electronic systems have the ability to receive an input or inputs and modify them to produce an output signal or signals that are desired. A good electronic system consists of one that has been created to address a certain issue in the best and most effective manner possible. In this chapter, we examine several strategies for system design and highlight the advantages of using a rigorous, logical strategy. They also take into account the various phases of system design, touch briefly on the selection of the technology that will be used, and take into account several automated design tools. A fluctuation in these physical values is the output of many systems that accept certain physical quantities as input. Such a system's block diagram. A sensor, transducer, or actuation that produces an electrical signal associated to the physical input is often used in an electronic system to perceive the physical input quantity. Similar to this, a sensor, transducer, actuator, or display that's also controlled either by electronic output from the electronic system normally has no effect on the output quantities in a system. The inputs and outputs will be connected to the relevant external physical quantities when taking into account the sensors, transducers, and actuators. The output and input of such an electronic system would be electronic signals if the sensors, transducers, but also actuators are permitted to be external to the electronic system.

Electronic systems are often utilized because they offer an affordable alternative, and in some circumstances they are the only option available. The kind of input and output signals, as well as the necessary global function, will all influence the processing and operations needed by an electronic system. Amplification, multiplication, subtraction, integration, differentiation, filtering, numbering, timing, signal creation, and other processing and operations may be needed by an electronic system. To forecast an electrical system's behavior, a designer must be able to study a circuit. The designer should have the ability to choose appropriate components on the basis of value, tolerance, voltage, current, power rating, and cost in order to plan and build the circuits that make up an electronic system. Analyzing circuitry is important in order to design or execute analog electronic applications. Analog electronics application design and execution go hand in hand. Electronics principles are necessary in both situations. A designer or practitioner will be able to develop and enhance an electronic system and forecast the behavior of the circuit by understanding the foundations of electronics. They will also be able to change an existing circuit. Students may get acquainted with the idea of design approach as they study about current systems and also how they function. By dissecting them, complex systems may be made simpler to comprehend. To effectively complete the implementation of an electrical design system, a number of stages are required (Figure 2.9).

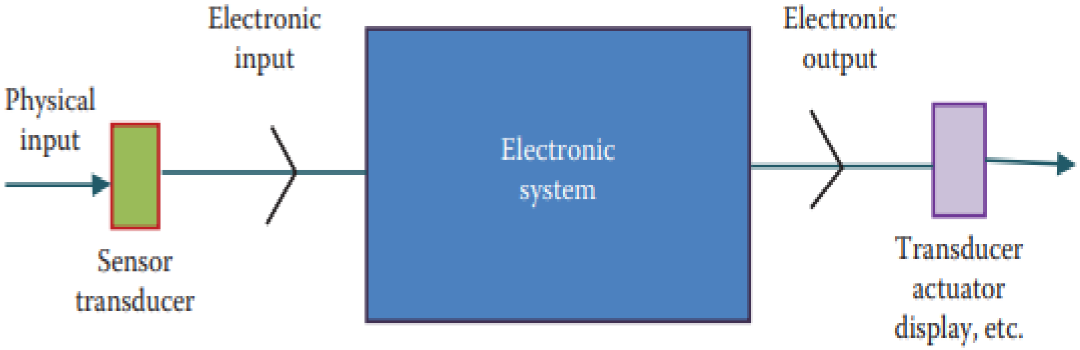

Figure 2.9: implementation of an electrical design system

Applications and Analog System Design

A closed structure with established inputs and outputs may be used to depict an electrical system. In actuality, we pick out a component or collection of components that are of particular interest to us and decide to enclose them.

Requests from customers

Determining the specific requirements of the individual or client is a crucial step in the design process of an application. In many circumstances, the ultimate user of the electronic system would express their expectations in general or vague words. At this point, it is crucial to make clear precisely what the system will accomplish and under what conditions. The requirements for the system must be agreed upon both the designer and the client. This agreement will establish a contract that requires the designer to develop an electronic system in order to fulfill it. These criteria will be transformed by the designer into technical system design specifications.

Top-Level Requirements

In a top-level specification, the system is seen as an international entity. Instead than focusing on particular components, a top-level specification examines qualities that are properties of the overall system. These characteristics are often complicated in nature and may relate to several different system components. Without considering how to do it, the system's top-level specs specify what it must achieve. A system-wide configuration will result from this task. The top-level requirements must identify any limitations on the electronic system's architecture as well as specify exactly what the system should perform in response to all potential inputs. The creation of a system block diagram that lists all the inputs and outputs of the process as well as the inputs and outputs of every block is often one of the top-level requirements.

System Design Approach

In a systematic method, a complicated system is broken down into smaller building blocks that are then further broken down, and so on, until the different sections have degenerated into building units that are sufficiently basic to be readily comprehended. A complicated system may be partitioned into a number of modules or components to help with its design and execution. The output of one subsystem serves as the input for the next subsystem in a system made up of a number of them. Provides an illustration of this approach. The properties of the inputs and results that the system's modules represent may then be used to define them (Figure 2.10). There are two possible ways, depending on the system. Either begin with the overall system at the highest management and work your way down the hierarchy until the design is finished (top-down), or begin with the component at the lowest level and work your way up until the system is finished (bottom-up).

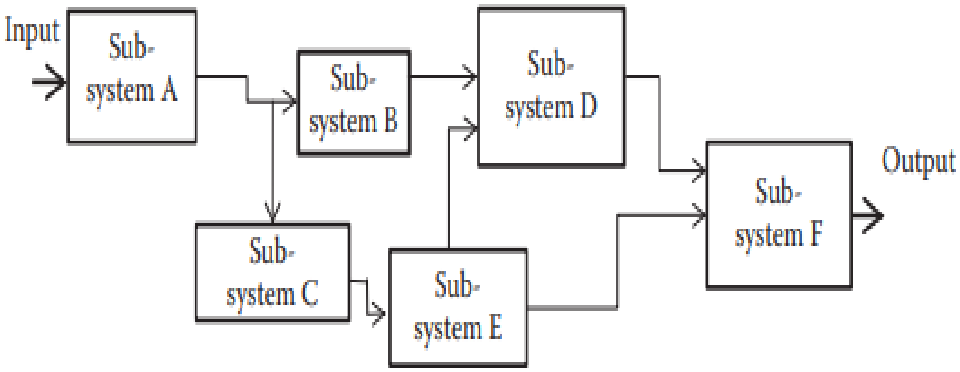

Figure 2.10: System Design Approach

Superior Design

How the top-level specification is implemented is decided by the top-level design. It entails the formulation of one or more solutions to the issue, followed by evaluation and selection of the best one to apply. It entails determining the methods to be used in order to provide the function specified in the requirements. This essentially involves figuring out how they function generally rather than involving the technical construction of circuits or the creation of programs. Determining if system partitioning is part of the suggested solution is also necessary. It involves choosing the system's implementation strategy, the device technology to be employed, whether the system will use discrete components or integrated circuits, etc. This procedure includes all decisions necessary for a worldwide implementation.

Complete Design

Since the technical circuitry or software may be built because the top-level design has revealed the purpose and underlying operating principles of the system or subsystem. The final circuits will be produced down to the level of individual devices, components, and connections thanks to the precise design. The system's operating speed, power consumption, time required for design and implementation, and testability are just a few of the factors the designer must take into account. The designer has to be well-versed in the range of parameters used in manufactured devices and must be aware of all key elements influencing the performance of the design.

Technology Choice

Choosing the appropriate technology and implementation strategy for an electronic system may determine whether a project is successful or not. After the design specification is finalized, the technology that will be employed may be chosen in accordance with the project's needs. There are several options for putting an electronic system into action, including bipolar technology, field effect transistor (FET) technology, discrete components, conventional integrated circuits, programmable logic arrays, microprocessors, and others. All testing must be performed in software if the technology being utilized is based on electronic components, and the system must function exactly as intended. Before it is commited to manufacture, it must function as intended. A prototype is often necessary when using discrete components as the technology of choice. The system will then undergo hardware testing prior to going into production.

The choice of components is crucial when employing discrete components. The physical size variety of components as well as the standards for a particular component type are two significant distinctions to take into account. Low-power devices are compact, and the size of electrical components varies according to their power rating rather than value. Only specific passive component values are produced by manufacturers. The possible values for passive components follow a predetermined hierarchy known called nominal preferred values (npv). The component values generated from a specific design calculation often do not match anpv component. In this situation, the designer might either employ a variable component, which would raise manufacturing costs, or a component with a larger tolerance to get the desired value. However, it is crucial to ensure that the design requirements are met before using the component with the closest npv. If a circuit is to be produced in a large number of units, worst-case analysis should be carried out to make sure that design parameters are met for all values of every component. The component tolerance should be taken into account in the worst-case scenario analysis.

System evaluation

To ensure that the system worked as planned, a thorough and in-depth testing of the complete electronic system was necessary once the system was built.

Environmental and Social Implications

The system's effects on the environment as well as any potential societal repercussions must be taken into account by the designer. There are several laws and rules that must be followed. Some are offered by organizations for professionals, geographic regions of countries, or by specific limitations in the region in which the electronic system would be utilized.

Design documentation

A product is never really finished. It may go into production in order to meet specifications, but it could also be meant to be improved in the future. It can be necessary to adapt existing components to a new application, find new components with superior qualities, or use a new, updated version. The original data gathered during the device's initial design will be needed for any electronic system modifications or new testing methods. Without thorough documentation of the design process, challenge, and outcomes, a design cannot be considered finished. There is always a need for design project documentation documents.

Spectacle and noise

The space environment and electronic devices include a wide variety of electromagnetic impulses. These waves are generated by switches in other electromechanical devices as well as by general communication systems, other electronic systems, and natural electromagnetic phenomena. In many circumstances, an electronic system incorporates.

The performance of the electronic system being used may be impacted by an amplifier and a little noise signal getting amplified. Components and other system modules also provide internal signals that have been implemented at certain voltage and current levels or at various frequencies. To the system that will be used, each of these signals is unwanted noise. An analog electronic system is especially vulnerable to noise because it may modify the voltage and current values employed at a specific point in the system, changing the needed response. The performance of the electronic system may be hampered by distortion and noise in electronic systems in general and analog electronic devices in particular. A system should be designed such that these impacts are either avoided or greatly reduced. Here are a few well-known instances of typical noise and distortion that may be found in analog electrical systems.

Chapter 3

Classification of Electric Circuits

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Students may use these ideas to get through the first stages of circuit analysis and become ready for the subsequent, more in-depth study. This might be a useful review of previously covered content for certain pupils. The fundamental properties and elements of electrical circuits are defined in this chapter. Students are required to comprehend the concepts of units, current, voltage, power, sources, and electrical loads by the time they have finished the chapter. Additionally, they will be able to explain the properties of circuit components and the distinctions between ideal and actual voltage and current sources. They will be able to comprehend how Ohm's law applies to resistive circuits and the relationship between current and voltage in a resistance. Additionally, the properties of active and passive components as well as their connection to voltage and current will be examined. The most common electronic components are resistors, inductors, and capacitors; as such, anybody studying analog electronics must be familiar with how these devices function.

Analogue electronics uses a few fundamental building blocks. To prevent needing to recalculate a design, it is crucial to employ them properly. Institutions, labs, and nations employed several unit systems up to the 20th century. Numerous students and researchers were confused as a consequence of the fact that the same tests' findings were published under various names. To standardize the units' criteria, a meeting was arranged. The International System of Units, or SI system, marked the end of the meeting. Since its official introduction in 1960, the SI system has been adopted as the standard measuring system by several nations and organizations. The SI system of units will be used throughout this work. Six physical quantities are chosen by the SI system as the foundation for its units. From these fundamental units, all other units are generated. The chosen six fundamental physical quantities are listed. Eventually will come across a lot more derived units. The basic quantities of mass, length, duration, electric current, absolute temperature, but also luminous intensity may be used to represent all derived units, which are all connected to the six fundamental units. For instance, the square of length, or square meter, may be used to indicate an area unit. Below are some further typical instances.

Charge Unit

The coulomb is indeed the unit of charge (C). The amount of electricity that travels through a circuit while a current of one ampere (A) is maintained for one second is known as a coulomb (s). The number 6.24 1018 electrons make up one Coulomb. Then, the electric charge (Q) may be represented in terms of time and current using the formula Q I = t C[] (2.1), wherein I is the current in amperes, t is the duration in seconds, while Q seems to be the charge in coulomb.

Measure of Force

The newton is indeed the unit of force (N). A newton is the force that causes a mass of one kilogram (kg) to accelerate at a rate of one meter per second. The force (F) may therefore be described using mass and acceleration by the formula F m= a N[]. (2.2), where F is the force in newtons, m is the mass in kilograms, and an is the acceleration in meters per second squared.

Symbol for Energy

The joule is a measure of labor or energy (J). The term "joule" refers to the amount of energy that is transmitted whenever a force of 1 N was applied across a distance of 1 m inside the force's direction. The energy (E) may then be written in terms of length and force using the formula E F = l J[], where l is the length in meters that the body traveled inside the direction of force, and E is the power in joules.

Symbol for Power

The watt is indeed the unit of power (W). The pace at which energy is transferred is referred to as power. After then, the power (P) may be calculated as P E t = [] W (2.4), wherein E is the amount of energy transferred in joules, t is indeed the amount of time in seconds, and P is the amount of power in watts. Remember that the energy (E) may also be stated in terms of power and time and used the definition of power given above: E P = t J[] (2.5) When dealing with significant volumes of energy consumption, the kilowatt hour (kW h), wherein 1 1000 1000 3600 kW h W = = h W = s, or J J, is employed, offers energy represented in watts every second.

Electric current and Electron Motion

Any motion of charges in a circuit produces an electric current. Traditionally, electron movement has been used to determine current. Although electrons vibrate inside atoms, their individual movements may cancel one another out, resulting in an overall movement of any and all electrons that is equal to zero. As a result, there isn't any current flowing through a material that has no external energy imparted to it. An ammeter attached to measure their combined current will show a reading of 0 A. However, if such an external energy is used to drive the electrons in a material in concert in one direction, a current is created. Electrons have a specific potential energy and may migrate freely between energy levels. Whenever this movement is coordinated, it is referred to as a electric current flow.

A current is often described to flow through positive to negative because it is more convenient to refer to the point having high potential as the positive as well as the point of low potential as that of the negative. Conventional current flow seems to be the polar opposite of the an electron flow since it is considered that electrons have such a negative charge. In the evaluation of circuits, this may lead to some misunderstanding. We'll figure out how to determine the value or direction of current flow in active or passive components without getting lost later throughout the book. Any practical application needs the current to flow continuously for the duration of what is required. There are two requirements that must be met for a current to flow in a circuit: An whole circuit must exist for the electrons to go around. For the continuous flow to occur, there needs to be a driving stimulus. The idea of a circuit and electromotive force would result from these two circumstances (emf). Circuit The route necessary for electrons to travel in order to satisfy condition. This route will produce the so-called electric circuit.

Electrical Force

The electromotive force is the driving stimulus necessary to meet condition. (emf). The source energy given by the emf ensures that a constant current flow is preserved each moment a charge moves through it.

Source

A source is a component that gives electrical energy to that of a circuit. The emf in a circuit, which is measured in volts, is produced by a source of energy like a battery or generator. Potential difference describes the difference in electric potential between two places in an electric circuit.

Load

Some circuit components will absorb or transform whatever electrical energy given by the source when a current is produced inside the circuit. A load is a component that uses the electrical energy provided by the source and either transforms it or absorbs it. Electrical components in a circuit may be categorized based on whether they actively provide energy to both the circuit as active components and passively absorb or transform energy for the circuit.

Passive Elements inductance, capacitance, and resistance

An electric circuit's passive components are those that do not supply energy to the circuit. They typically convert or disperse energy. Depending on how their current and voltages interact, there are many kinds of passive components. The current (I) flowing between two terminals of a circuit component is directly proportional to the voltage difference (V) between those terminals. In proportion to I, V Varying components have different proportions. The relationship between a passive component's voltage and current may be used to determine its kind. Resistors, capacitors, and inductors are a few of the most prevalent kinds of electrical circuit components. We may examine some of these three categories of passive components' characteristics in this section.

Capacitance

A component that really can hold charges called a capacitor. A capacitor's ability to store charges has the effect of complicating the connection between voltage and current and producing an electric field. A dielectric layer serves as an insulating layer between two conducting surfaces to form a capacitor. It displays several capacitor production techniques. If we think of a basic capacitor as being two parallel plate capacitors, we can understand capacitors easier (Figure 3.1).

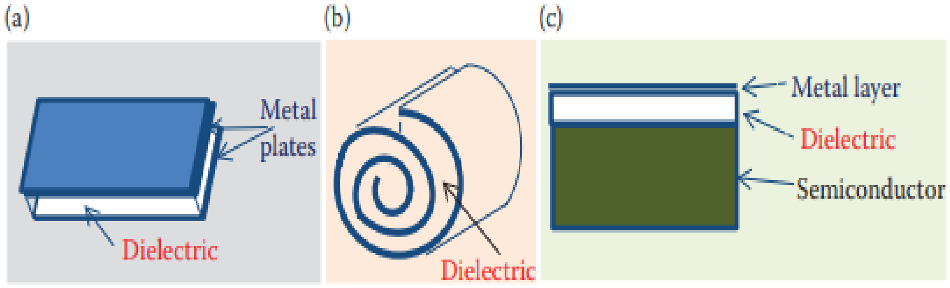


Figure 3.1: Illustrating the Capacitance

A capacitor may develop a positive charge solely on a single side and an equivalent negative charge off the other as result of electrons moving across a circuit. Consequently, an electric field is created between the two plates. The voltage applied across a capacitor directly affects the charge it can hold. Capacitance C is the proportionality constant. The connection between the capacitance C, total charge Q, as well as the voltage V may thus be written as C Q V = (2.14) The quantity of charge that can be held in a capacitor is influenced by its physical dimensions, which also have an impact on the component's capacitance. A parallel plate capacitor's capacitance was inversely related to the distance between the plates' surfaces and proportionate to both (Figure 3.2). The permittivity of a dielectric serves as the proportionality constant. In terms of both the capacitor's physical characteristics, we may express the equation C A d =. 2.15, the capacitance is expressed in farads if the charge is determined using coulombs as well as the voltage in volts. Permittivity is a number that represents a material's electrical properties. The permittivity is often represented as the sum of the relative permittivity r as well as the absolute value o (8.85 1012 F/m).

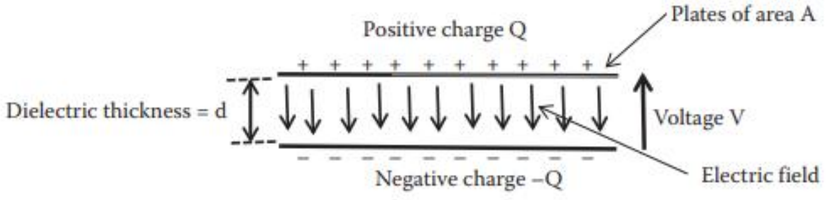
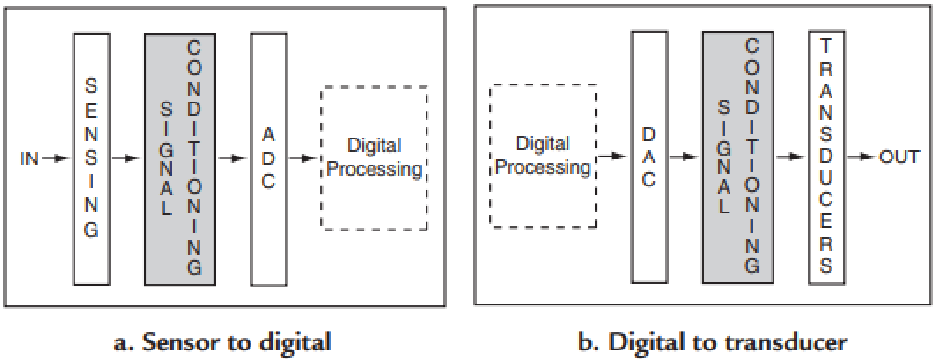


Figure 3.2: capacitance electric field

The capacitance is denoted by the formula C A d. The capacitor's charge creates an electric field E that is inversely proportional towards the gap between the plates' d and proportionate to the voltage applied to it. The force between both positive and negative charges created by the stored charge in a capacitors is then represented in terms of the electrical flux between them, which would be measured using coulombs. One may describe the flux density D, which is determined by the fluxes per unit surface area, as D Q A =, where Q is the capacitor's charge and A is indeed the area of its plates. In contrast to a resistor, the relationship between voltage (vc) and current (ic) in a capacitor is quite different. Either voltage or current may be used to represent the connection between current and voltage. A capacitor's voltage, vc, is determined by the equation v C I dt c c = 1, where ic is the capacitor's integrated current as a function of the time while C is its capacitance. The first derivatives of the capacitor's voltage over time, denoted as dvc/dt, is used to calculate the current entering a capacitor IC. The permittivity of the a dielectric inside a capacitor is equal to the electric flux density to electric field strength, which may be determined by combining Equations for just a capacitor. As ε = D E.

Conditional Signaling

As the name suggests, signal conditioning entails altering the signal's properties and tailoring it to the requirements of the application. This might indicate a change in the magnitude of a voltage signal, overall magnitude of the current signal, the capacity of the signal to produce power, or any combination of these. The signal conditioning mechanism may be found at two points along the chain from the analog input towards the analog output. It is involved in two different chains: the one from the sensor towards the analog-to-digital transformation and the one from the transducer to the digital-to-analog transformation. The amplifier is one of the most crucial electrical circuits to fulfill the signal conditioning role (Figure 3.3).



a. Sensor to digital

b. Digital to transducer

Figure 3.3: Conditional Signaling

Amplification

Whenever a voltage or current signal has to have its amplitude amplified, an electrical circuit known as an amplifier is used. A transistor is the only active component in a single circuit amplifiers may also be made up of many active components. Remember that the functioning of a bipolar NPN transistor was covered, and that of a bipolar PNP transistor was addressed. Field-effect transistors come in a variety of varieties. MOSFETs are what they are (metal-oxide semiconductor field-effect transistors). Devices with N- and P-channels may function in depletion mode or enhancement mode. Depicts the characteristic curve of the field-effect transistor (FET). Current from the source to the drain is controlled by a voltage at the gate. Remember that the collector-to-emitter current of the bipolar transistors is controlled by a current into to the base-emitter junction, while the current from of the drain towards the source is controlled by a voltage applied from the gates to the sources in field-effect transistors. An amplifier will be created and its features investigated and use a single NPN bipolar transistor in some kind of a common-emitter circuit in order to comprehend how an amplifier works and how it may be utilized. Common emitter refers to a circuit where the output signal travels between the collector and the emitter and the input signal travels between the base and the emitter. A common element between both the two is the emitter.

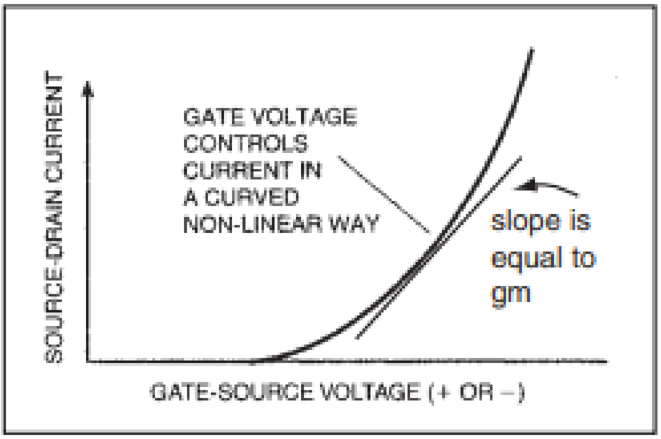


Figure 3.4: Shows the graph of Amplification

Bipolar NPN Amplifier

Selecting a device and studying its features, as illustrated in Figure 4-3a, is the first step in the design process. The amplifier will be a linear amplifier for "small signals." "Small signal" refers to the operational point being adjusted to ensure that amplified output signals are identical to the input signals, with little to no distortion but increased overall amplitude. Small-signal refers to a signal that only deviates little from the steady-state operating time due to the input signal amplitude. The amplification properties retain their linear characteristics as a consequence. Simple rules are used to choose the operating point, which refers to the minimum signal steady-state operating point within which the small-signal ac signals change. The operational point must fall inside the characteristic curves' linear region. 2. VCE need to be about 0.5VCC. 3. The voltage from the emitter to the ground should have been 10% to 15% percent VCC. 4. The voltage from the base to the earth will be around 0.7V higher than the voltage from the emitter to the ground. The supply voltage, VCC, will have to be +12V since the amplifier will be employed in automotive applications. Point A, this same biased operating point depicted in the characteristic curves, will serve as the operating point. The collector current will indeed be 6 mA as well as the VCE (voltage from collector to emitter) will be 6V whenever there is no signal, according to point A.

Amplifier Frequency Response

An amplifier must be able to precisely replicate variations in an input signal's voltage or current as even the signal's frequency varies in addition to amplifying these changes. The term "frequency response" refers to an amplifier's capacity to handle signals at various frequencies. An illustration of a common-emitter amplifier's frequency response that is comparable to the one. The input signal amplitude remains maintained constant while the signal frequency is changed in this graph showing an amplifier's gain, AV, plotted versus frequency. If the gain, AV, is constant, the output signal must also be constant while the input signal's amplitude is constant. In the middle, the gain does not change. The gain decreases as the signal frequency rises at frequencies higher than fH, or the so-called high-frequency corner frequency. This is caused by parallel to RL capacitance in the circuit and in the device. At frequency fH, AV is downgraded by 3 dB from it's own mid-band frequency. The frequency at which AV has decreased to 0.707 of its midband value also corresponds to the 3 dB mark. fH for the amplifier ranges between 5 and 7 MHz. If the amplifier solely amplifies AC signals, AV will decrease when the signal frequency is decreased below fL, this same low-frequency corner. When the amplifier is indeed a DC amplifier, the midband values of AV will stretch down to zero frequency. The frequency at which AV is -3 dB (or 0.707) of its midband amplitude is known as fL, much as fH. The coupling capacitors and capacitors from across emitter resistors employed in AC amplifiers are to blame for the loss in gain.

Coupling Coupling, DC

Circuits may be cascaded—coupled together—to produce higher gain when a single circuit, like the one, is insufficient. Two amplifier stages are used in a DC amplifier, as shown in the coupling method. The first stage gain multiplied by the second stage gain results in the total benefit. One benefit of measuring amplifier gain using dB is that. The overall gain in dB may be calculated by adding the gain values for each step. Also shown is the impact on frequency response. The amplifier has continuous gain until the zero frequency with DC coupling. So because DC voltages combine from stage to stage, more attention must be given in the design to account for the correct operating voltages just on base, collector, and emitter.

Combining with Light

use light to couple. Light coupling allows for total isolation between stages 1 and 2. In the example, an LED whose light output is detected by a photo transistor has its current modulated by a transistor. A fiber-optic cable is a fairly simple option for the light medium. Consider the transistor characteristic curves, the sort of frequency response required, if operation is required down to the zero frequency, as well as whether more than small-signal operation was required when selecting an amplifier for an application.

Small vs. Large Signal

The NPN transistor's common-emitter characteristic curves. A "load line" for the 1 k load resistor utilized in the amplifier stage's design is a straight line drawn on the characteristic curves. It symbolizes the fluctuation in collector voltage that happens when base current changes cause changes in collector current. The load line is where operating point A is located. Increased base current results in increased voltage drop across the 1 k load resistor and lower collector voltage. The transistor would've been shorted and operate at point C if indeed the collector voltage was decreased to zero. The transistor is cutoff and the operational point is at B if the collector current is zero. The steady-state no-signal operating point is designated as A. The fluctuations in the collector current will indeed be 100 times (at least 50 times) higher, or 1 mA, when an input signal is provided that modifies the base current in small-signal increments of 0.010 mA either side of the operational point A. An input signal is given that varies IB between 0.04 mA to 0.08 mA, causing the collector voltage to swing 1V on either side of the working point A. As a consequence, the collector voltage ranges from 4V to 8V as well as the collector current varies between 4mA to 8mA. Although the output voltage swing is significantly bigger, the signal still seems to be linear and undistorted. The operating point just on load line runs into to the nonlinear region of the characteristic curves, point D, whereby distortion of an output waveform occurs when the operation of the amplifier switches to a "large-signal" mode and greater input base current change is provided. The distortion is shown. If linear functioning is needed, it is crucial for the application that perhaps the input signal avoids driving the amplifier's output into the distortion area (Figure 3.5).

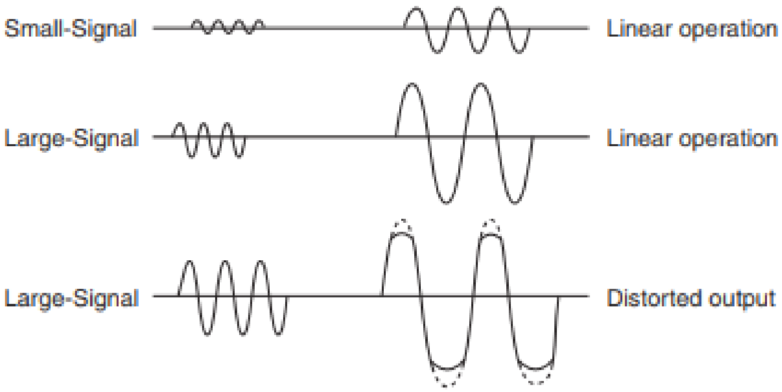


Figure 3.5: Representing the Small vs. Large Signal

Classes of Amplifiers

The classes of amplifier circuits that could be created are defined by the plot of characteristic curves, which is the same as before. The operational waveforms and load line operating points are shown. The Class A small-signal amplifier at point A is so named because it operates entirely linearly, reproducing the input exactly at the output. At point B on the load line, a Class B amplifier is in operation. When it functions, it is linear, but it only does so for 180 degrees of the input cycle. This is a crucial class for power amplifiers—amplifiers that need to provide a lot of current while also having big voltage fluctuations. An operational point on the load line for a Class AB amplifier is located among both Class A and Class B. In tuned amplifiers for communications networks as well as linear power amplifiers, it is utilized to get rid of crossover distortion. On the load line, a Class C amplifier works at a cutoff point where the transistor has to be forced into conduction by the input signal. Only a tiny amount of each input cycle is spent with collector current flowing. Resonant directly relates amplifiers often use Class C amplifiers to produce outputs across a constrained spectrum of frequencies, typically radio frequencies and higher (Figure 3.7).

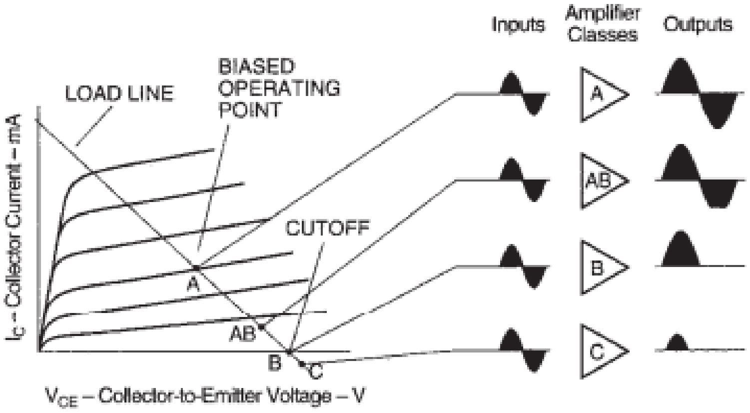


Figure 3.7: Characteristics of Amplifiers

Field-Effect Transistor Amplifiers

Field-effect transistors are also used in the construction of amplifiers. In, MOS transistor symbols were shown. Instead of a layer of metal over oxide over silicon, JFETs (junction field-effect transistors) may alternatively be produced using semiconductor junctions. They are available as P-channel or N-channel gadgets that work in depletion or enhancement modes. While enhancement mode transistors do not produce any drain-to-source current until a gate-to-source voltage is supplied, depletion mode transistors do so without any gate-to-source voltage. The most typical JFETS utilized for individual transistor amplifier stages were depletion mode JFETS. The majority of MOS transistors are enhancement mode components.

JFET Characteristic Curves

An N-channel with a depletion mode's characteristic curves. As the gate-to-source voltage, VGS, varies, the changes in the drain-to-source current, ID, are displayed against the drain-to-source voltage, VDS. However, keep in mind that for these curves, a variation in the voltage between gate to source causes the change throughout power from drain to source. The curves are created in the same manner as bipolar transistor curves. Similar to the bipolar transistor, a load line is drawn on all these characteristic curves to create an amplifier. Several significant aspects are recognized before the amplifier is developed. A voltage known as the "pinch-off" voltage exists between the gate and the source. For transistors operating in the enhancement mode, the gate-to-source voltage initiates the flow of drain-to-source current, while for devices operating inside the depletion mode, the gate-to-source voltage results in zero drain-to-source current.

The transistor is in the pinch-off mode whenever the drain-to-source voltage is higher than the gate-to-source voltage by both the pinch-off voltage. Inside the pinch-off mode, the field effect transistor's channel is blocked as well as the drain-to-source current, IDS, virtually stays constant for additional significant changes in the drain-to-source voltage, VDS. For depletion mode JFETs, the device will be functioning at point X and the drain current will indeed be IDSS when VGS = zero. Pinch-off voltage and IDSS were crucial characteristics that FET manufacturers provide (Figure 3.8).

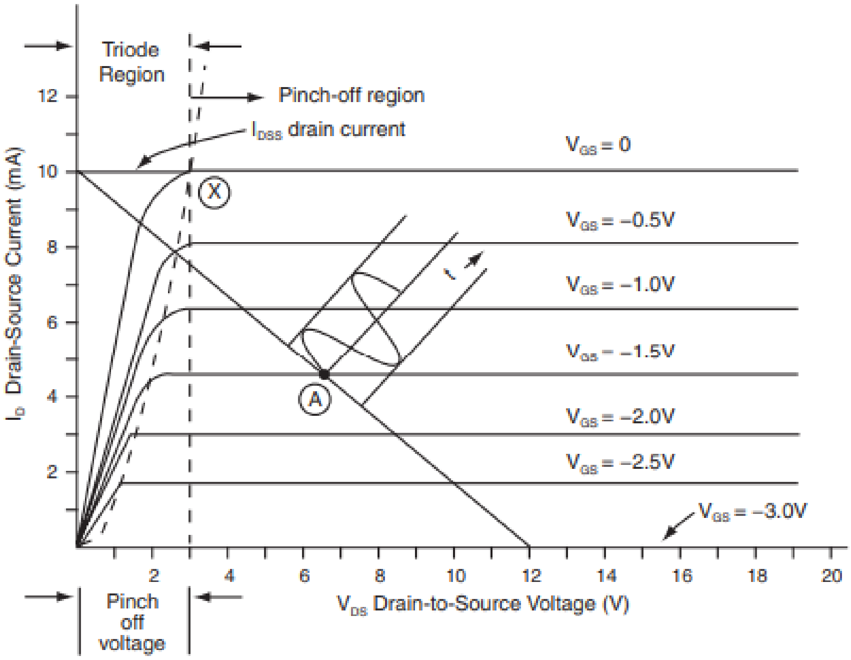


Figure 3.8: JFET Characteristic Curves

Operational Amplifiers

Operational amplifiers (op amps), a superb product made by integrated circuit makers, are available to designers of electronic circuits for signal conditioning sensor signals. There are several kinds and variations available for a broad range of applications. System designers who want amplification may utilize an op amp rather than designing a separate amplifier circuit. A direct-coupled amplifier known as a "op amp" is a device that was first employed in analog computers to carry out mathematical operations while resolving real-time control system issues. Op amps are DC amplifiers with a broad bandwidth, high gain, and high input and output impedance. The ability to alter the amplifier's properties using additional components is another important benefit.

A circuit that creates a stronger version of its input signal is referred to as an amplifier. However, as we shall see in this introductory to the amplifier lesson, there are several types of amplifier circuits since they are categorized based on their operational modes and circuit designs?

Tiny signal amplifiers are often employed in "Electronics" because of their capacity to transform a relatively small incoming signal, such as one from a sensor like a photo device, into a significantly larger output signal to, for instance, operate a relay, light, or loudspeaker

Operational amplifiers, small signal amplifiers, large signal amplifiers, and power amplifiers are only a few of the several types of electrical circuits that fall under the category of amplifiers. The magnitude of the signal, whether big or little, the amplifier's physical design, and how it processing the input signal—specifically, the interaction between the input signal as well as current flowing through the load—determine an amplifier's categorization.

The type or classification of an Amplifier is given in the following table.

Introduction to the Amplifier – Classification Amplifier

Type of Signal	Type of Configuration	Classification	Frequency of Operation
Small Signal	Common Emitter	Class A Amplifier	Direct Current (DC)
Large Signal	Common Base	Class B Amplifier	Audio Frequencies (AF)
	Common Collector	Class AB Amplifier	Radio Frequencies (RF)
		Class C Amplifier	VHF, UHF and SHF Frequencies

A basic box or block called an amplifier may be conceived of as having an amplifying device, which could be a bipolar transistor, field effect transistor, or operational amplifier. These devices have two input terminals with two output terminals, with ground serving as the common terminal.

The three fundamental characteristics of a perfect signal amplifier are input resistance (RIN), output resistance (ROUT), and amplification (also known as gain or gain amplification) (A). No matter how complex an amplifier circuit is, the link between these three features may still be shown using a generic amplifier model (Figure 3.9).

Ideal Amplifier Model

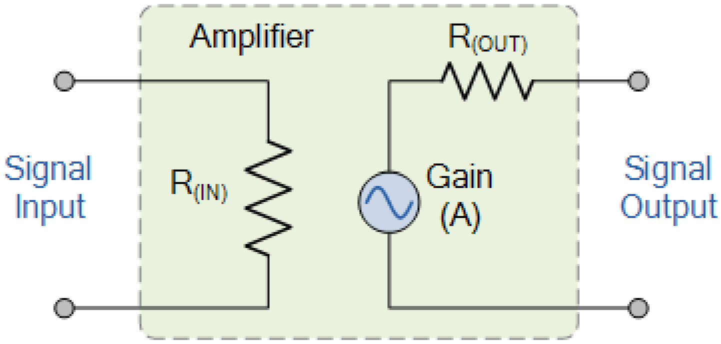


Figure 3.9: Ideal Amplifier Model

The Gain of the amplifier is the amplified differential between the input and output signals. Gain is essentially a measurement of how much the input signal is "amplified" by the amplifier. For instance, the gain of the amplifier would be "50" if the input current was 1 volts and the output was 50 volts. In other words, a 50-fold increase in the input signal has indeed been made. Gain is the name of this growth.

Simply dividing the output by the input results in amplifier gain. Gain is a ratio with no units, however it is often represented by the letter "A" for amplification in electronics. In such case, an amplifier's gain is simply computed as "output signal divided by input signal.”.

Amplifier Gain

The connection between the signal measured somewhere at output and the signal measured there at input is often referred to as the admission to the amplifier gain. Depending upon the amount being measured, there seem to be three distinct types of amplifier gains that may be measured: voltage gain (Av), current gain (Ai), and power gain (Ap). Examples of these various gains are shown below.

Amplifier Gain of the Input Signal, as shown in Figure 3.10

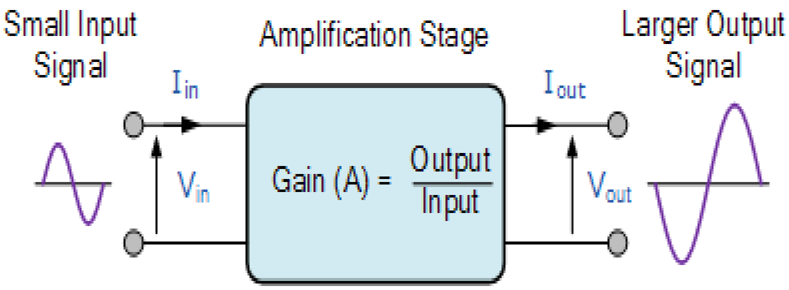


Figure 3.10: Amplifier Gain of the Input Signal

Voltage Amplifier Gain

$$Voltage\,Gain\,(A_V) = \frac{Output\ Voltage}{Input\ Voltage} = \frac{Vout}{Vin}$$

Current Amplifier Gain

$$Current\,Gain\,(A_i) = \frac{Output\ Current}{Input\ Current} = \frac{Iout}{Iin}$$

Power Amplifier Gain

$$Power\,Gain\,(A_P) = A_V\ x\ A_i$$

Remember that you may divide the power gained at the output by the power obtained there at input for the Power Gain. Additionally, the subscripts v, I and p are utilized to indicate the kind of signal gain being employed when computing an amplifier's gain.Decibels may also be used to describe the power gain (Ap) or power level of the amplifier (dB). The Bel (B) is a base ten logarithmic unit of measurement without any units. Since the Bel is an excessively big unit of measurement, Decibels, with one decibel equaling one tenth (1/10th) of a Bel, is used in its place. We may use the following formulae to get the gain of the amplifier in decibels, or dB.

Voltage Gain in dB: $a_v = 20*\log(Av)$

Current Gain in dB: $a_i = 20*\log(Ai)$

Power Gain in dB: $a_p = 10*\log(Ap)$

Note that although the voltage and current gains were 20 times the common log of the outputs to input ratio, the DC power gain of the an amplifier is equivalent to 10 times that ratio. However, thanks to the log scale, 20dB does not have double the strength of 10dB.

Additionally, inside the amplifier, a positive dB number denotes gain and a negative dB value denotes loss. For instance, an amplifier gain of +3dB means the output signal has "doubled," or increased by 2, whereas an amplifier gain of -3dB means the signal has "halved," or decreased by 5, or suffered a loss.

When using 0 dB as the highest output value, the -3dB point of such an amplifier is known as the half-power point.

Overview of the Amplifier Case No. 1

Find the voltage, current, and power gain about an amplifier with a 1 mA input signal at 10 mV and a 10 mA output signal at 1 v. additionally, quantify all three advances in decibels (dB).

The Various Amplifier Gains:

$$A_V = \frac{\text{Output Voltage}}{\text{Input Voltage}} = \frac{1}{0.01} = 100$$

$$A_i = \frac{\text{Output Current}}{\text{Input Current}} = \frac{10}{1} = 10$$

$$A_p = A_V \times A_i = 100 \times 10 = 1{,}000$$

Amplifier Gains given in Decibels (dB):

$$a_v = 20\log A_v = 20\log 100 = 40\,\text{dB}$$

$$a_i = 20\log A_i = 20\log 10 = 20\,\text{dB}$$

$$a_p = 10\log A_p = 10\log 1000 = 30\,\text{dB}$$

The amplifier's voltage gain, (Av), current gain, (Ai), and power gain, (Ap) are all 100, 10, and 1,000, respectively.

Generally, based on their power or voltage gain, amplifiers may be split into two main categories. Pre-amplifiers, instrumentation amplifiers, and other devices fall within the category of small signal amplifiers. Small signal amplifiers are made to boost extremely low signal voltage levels from sensors or audio signals that are just a few micro-volts (V) in magnitude.

The second kind is referred to as a large signal amplifier, and examples include power switching amplifiers and audio power amplifiers. Big signal amplifiers are designed to switch enormous load currents, such as those powering loudspeakers, or magnify large input voltage signals.

Chapter 4

An Introduction to the Power Amplifier's Amplifier

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Because they often transform a low input voltage into a high output voltage, tiny signal amplifiers are also known as "Voltage" amplifiers. When large switching currents are needed, such as when an amplifier circuit is needed to feed a loudspeaker or operate a motor, power amplifiers are needed.

A "Power Amplifier" (sometimes referred to as a big signal amplifier) is primarily responsible for supplying power to the load. As we learned above, this power is produced as a result of the voltage and current delivered to the load, with both the output signal power being larger than the input signal power. To put it another way, a power amplifier increases the strength of the input signal, resulting in these kinds of amplifier circuits are employed in the output stages of audio amplifiers to drive loudspeakers.

The fundamental operation of the power amplifier is to transform the DC power obtained from the power source into such an AC voltage signal sent to the load. Despite the high amplification, the efficiency of a conversion from the input of the DC power source towards the output of the AC voltage signal is often low.

We would get a 100% efficiency rating from the ideal amplifier, or at the very least, the power "IN" and "OUT" would be equal. However, in practice, this is impossible since some power is wasted as heat and the amplifier itself uses energy while amplifying sounds. The effectiveness of an amplifier is then shown as:

Amplifier Efficiency

$$Efficiency\ (\eta) = \frac{Power\ delivered\ to\ the\ Load}{Power\ taken\ from\ the\ Supply} = \frac{P_{OUT}}{P_{IN}}$$

Ideal Amplifier

From our consideration of an ideal amplifier's gain, or voltage gain, above, we may identify the following characteristics:

- For a range of input signal levels, the amplifier's strength, (A), ought to stay constant.
- Frequency has no impact on gain. All signals need to be amplified by the same precise amount.
- The output signal cannot be made noisier by the amplifier's gain. Any noise present in the input signal should be eliminated.
- The gain produced by the amplifier must be steady over a long period of time and should not be impacted by variations in temperature, resulting in excellent temperature stability.

Classes of Electronic Amplifiers

By comparing the characteristics of a input and output signals and timing how long after the input signal the current flows in the output circuit, it is possible to categorize an amplifier either as a voltage or a power amplifier.

In the Common Emitter Transistor lesson, we learned that the transistor needed some kind of "Base Biasing" in it to function inside its "Active Region." The input signal was given a tiny Base Bias voltage addition that enabled the transistor to faithfully duplicate the input waveform at its output without introducing any signal loss.

Amplification modes other than those for complete waveform reproduction may be used with amplifiers by adjusting the location of the Base bias voltage. Different operating ranges and operational modes that are classified according to their categorization may be generated by adding a Base bias voltage to the amplifier. Amplifier Class is the most common name for these several modes of operation.

According to their operating modes and circuit layouts, audio power amplifiers are categorized alphabetically. Different classes of operation, such as class "A," class "B," class "C," class "AB," etc., are used to identify amplifiers. These various amplifier classes vary from having a non-linear output but high efficiency to having an output that is nearly linear but has a poor efficiency.

The kind of operation is decided by the usage of the amplifying circuit; no class of operation is "better" or "worse" compared to any other class. For each kind or class of amplifier, there seem to be typical maximum conversion efficiencies, with the following being the most popular: Class A Amplifier - has a low efficiency of less than 40% but strong signal reproduction and linearity.

Class B amplifiers have a theoretical maximum efficiency of roughly 70% and are twice as effective as class A amplifiers since they only conduct (and use power for) 50% of the incoming signal.

Class AB amplifiers reproduce signals less accurately than Class A amplifiers while having an efficiency rating in the middle of Class A and Class B amplifiers.

The most effective amplifier class is the Class C amplifier, however distortion is quite severe since only a tiny amount of the input signal is amplified, and as a result, the output signal is significantly dissimilar to the input signal. Amplifiers of the Class C category reproduce signals the poorest.

Overview of the Amplifier Amplifier Class A

A class-An amplifier's fundamental design makes for a useful introduction to the amplifier circuit. The whole waveform of the input signal is accurately replicated at the amplifier's output terminal when it operates as a class a amplifier because the transistor is correctly biased inside its active area.

This implies that the cut-off or saturation zones of the switching transistor are never reached. As a consequence, as seen below, the AC input signal is properly "centered" between the amplifier's top and lower signal limits.

Class A Amplifier Output Waveform, as shown in Figure 4.1:

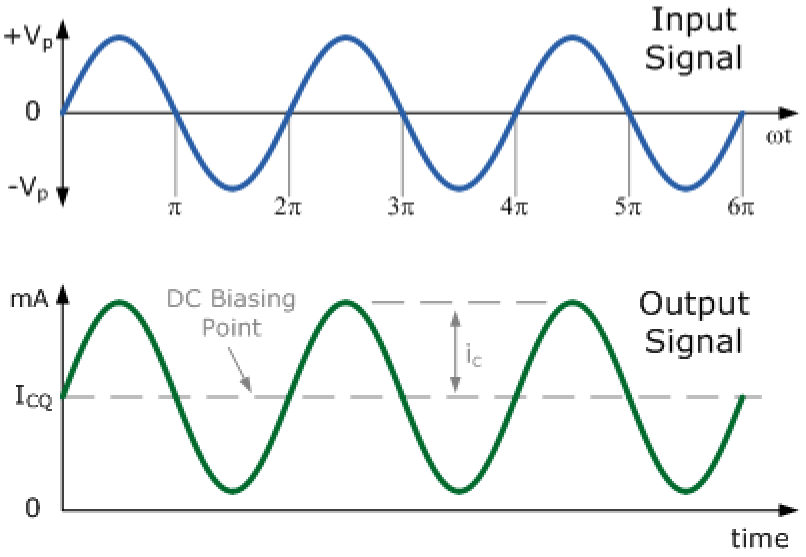

Figure 4.1: Class A Amplifier Output Waveform

The output transistor in a Class-A amplifier design always has a continuous DC biasing current (ICQ) running through it, even when there is no input signal present, thanks to the central biasing arrangement and the utilization of the identical switching transistor for the both half of the output waveform. In other words, its output transistors are permanently in an idle state and never "OFF."

Due to the Class-A type of operation's often relatively poor conversion of the DC supply power towards the AC signal power given to the load, it is rather inefficient.

A Class-A amplifier needs some kind of heat sinking since the output transistor might get very heated due to this centered biasing position, even though there is no input signal present. The transistor's collector current (ICQ), which is used for DC biasing, is equal to the collector load current. Because the majority of this DC power is transferred to heat, a Class-A amplifier is highly inefficient.

Amplifier - Class B Amplifier Introduction

The Class-B amplifier, in contrast to the Class-A amplifier mode of operation above, amplifies each half of the output waveform using two complementary transistors (either an NPN as well as a PNP or an NMOS and a PMOS).

While the other transistor conducts for the opposing or opposite half of the signal waveform, each transistor only participates for one half of the signal waveform. This implies that each transistor amplifies only 50% of the input signal since it spends half of its activity in the active zone and the other half in the cut-off region.

Unlike a class-A amplifier, a class-B amplifier does not have a direct DC bias voltage. Instead, the transistor only conducts whenever the input signal is higher than the base-emitter voltage (VBE), which is around 0.7 volts for silicon transistors. As a result, there is no output when there is no input signal. Compared to the preceding Class-A design, which is shown below, the amplifier efficiency is increased since only half of the input signal is exhibited at the amplifier's output.

Class B Amplifier Output Waveform, as shown in Figure 4.2:

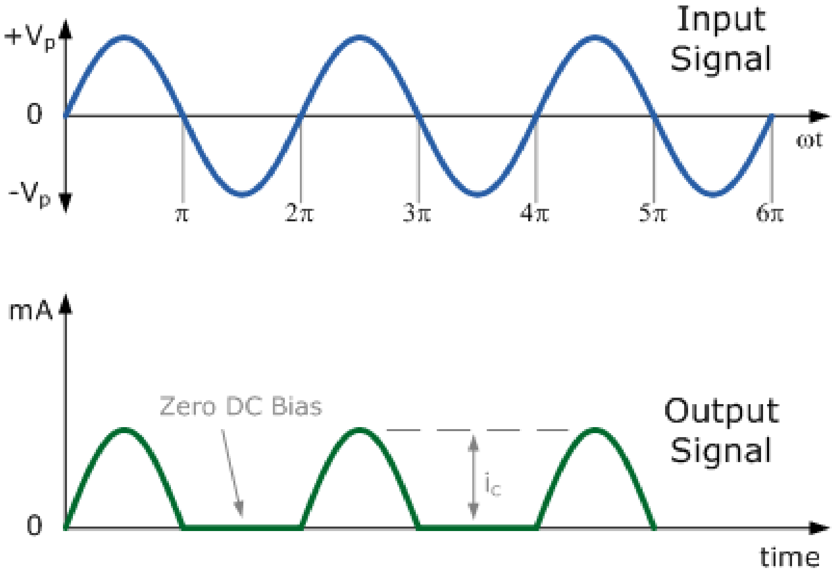

Figure 4.2:Class B Amplifier Output Waveform

Since the base-emitter voltage of a Class-B amplifier is higher than the 0.7 volt forward voltage drop needed for a typical bipolar transistor to begin conducting, the output transistors must begin to conduct both the positive and negative halves of the waveform.

As a result, the bottom portion of the output waveform, which is below this 0.7v region, won't be precisely replicated. When VBE > 0.7V, this causes one transistor to switch "OFF" while waiting for the second to become "ON," distorting the output waveform in the process. As a consequence, there will be a minor amount of distortion in the output waveform just at zero voltage cross over point. Crossover Distortion is the name given to this kind of distortion, which is discussed further in this section.

A Brief Introduction to the Class AB Amplifier

The Class-AB Amplifier strikes a balance between the aforementioned Class-A and Class-B designs. Class-AB operation still employs two complementary transistors inside the output stage, but when there is no input signal, a very little biasing voltage is given to the bases of each transistor to bias them toward their cut-off region.

The class-B configuration's inherent crossover distortion is removed when an input signal causes the transistor to function normally inside its active area. When there is no input signal, a tiny biasing Collector current (ICQ) would flow through to the transistor, although it is typically considerably smaller than for the Class-A amplifier design.

This means that for slightly longer than half of the input waveform, each transistor was conducting and "ON." Comparing to a pure Class-A design above, the Class-AB amplifier arrangement's modest biasing enhances the amplifier circuit's predictability and efficiency.

Class AB Amplifier Output Waveform (Figure 4.3):

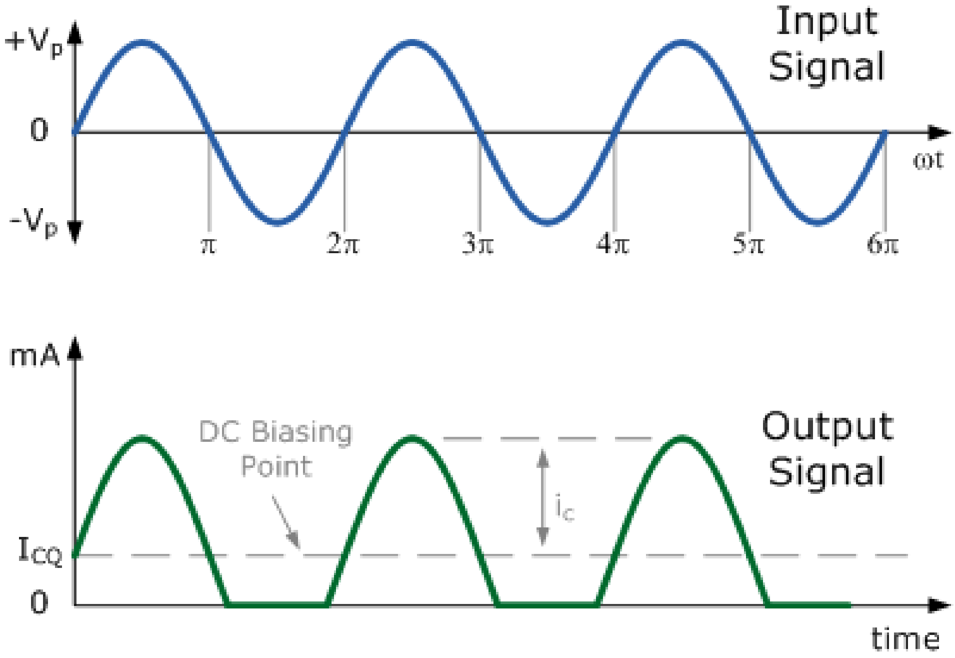

Figure 4.3: Class AB Amplifier Output Waveform

The class of operation of the an amplifier is crucial when constructing amplifier circuits since it influences the amount of transistor prejudicing needed for operation and also the maximum amplitude of a input signal.

The quantity of the input signal that the output transistor conducts, in addition to the efficiency and indeed the amount of power which the switching transistor both uses and wastes as heat, are all factors considered when classifying amplifiers. The following table provides a comparison of the most popular amplifier classes (Table 4.1).

Table 4.1: Power Amplifier Classes

Class	A	B	C	AB
Conduction Angle	360°	180°	Less than 90°	180 to 360°
Position of the Q-point	Centre Point of the Load Line	Exactly on the X-axis	Below the X-axis	In between the X-axis and the Centre Load Line
Overall Efficiency	Poor 25 to 30%	Better 70 to 80%	Higher than 80%	Better than A but less than B 50 to 70%
Signal Distortion	None if Correctly Biased	At the X-axis Crossover Point	Large Amounts	Small Amounts

Poorly built amplifiers, particularly Class "A" varieties, could additionally need bigger power transistors, more costly heat sinks, cooling fans, or even a bigger power supply to produce the additional wasted power the amplifier needs. Any electrical circuit that has power from transistors, resistors, or any other component transformed into heat is inefficient and will lead to an early breakdown of the device.

So why use a Class A amplifier when a Class B amplifier with a greater efficiency rating of over 70% is better if its efficiency is less than 40%? In essence, a Class A amplifier produces an output that is significantly more linear and has linearity across a wider frequency response even though it uses a lot of DC power.

There are several kinds of amplifier circuits, each with their own benefits and drawbacks, as we have seen in this lesson on the introduction to amplifiers.

We'll examine the transistor amplifier circuit known as a common emitter amplifier in the next lesson on amplifiers. Due to their substantial increases in voltage, current, and power in addition to their superior input/output properties, the majority of transistor amplifiers are comprised of the Common Emitter, or CE, type circuit.

An AC input signal that alternates between such a positive value and a matching negative value is amplified by transistor amplifiers.

The transistor must therefore be able to function between these two maximum or peak values, hence a method of "presetting" a common emitter amplifier circuit configuration is necessary. A technique called biasing may be used to do this.

Biasing plays a crucial role in the design of amplifiers because it determines the transistor amplifier's ideal operating point when it is ready to accept signals, minimizing output signal distortion.

Additionally, we may view every potential operating point of the transistor, from completely "ON" to fully "OFF," and within which the quiescent operating point or Q-point of a amplifier can be identified, by using a static or DC load line drawn onto to the output characteristic curves of an amplifier.

Any tiny signal amplifier's objective is to amplify the entirety of the input signal with the least amount of distortion conceivable to the output signal, or, to put it another way, the output signal must be a perfect replication of the input signal, only larger (amplified).

When used as an amplifier, the operational quiescent point must be carefully chosen to achieve minimum distortion.

This is the amplifier's actual DC working point, and a good biasing scheme may locate it wherever along the load line.

The ideal location for this Q-point is as near to the load line's center as is practically achievable, resulting in Class A amplifier operation, where Vce = 1/2Vcc. Take into account the Common Emitter Amplifier circuit below.

The Common Emitter Amplifier Circuit (Figure 4.4):

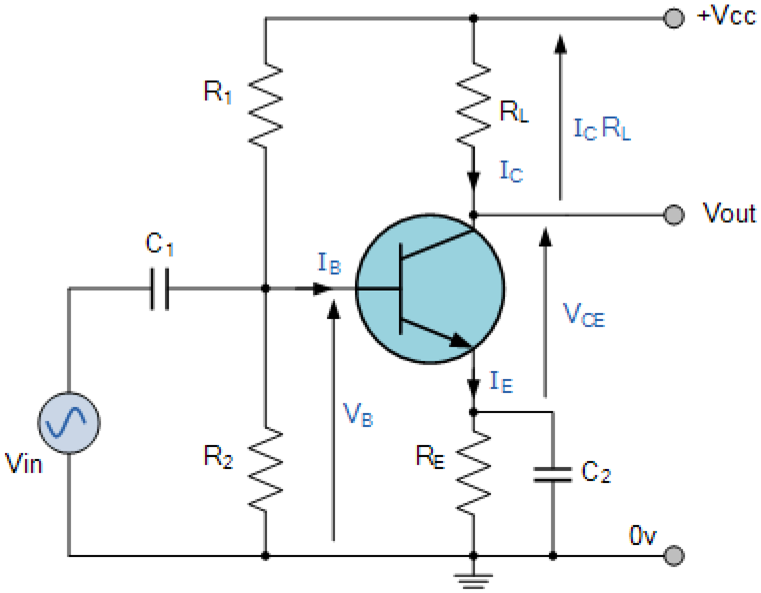

Figure 4.4: Common Emitter Amplifier Circuit

What is known as "Voltage Divider Biasing" is used in the single stage common emitter amplifier circuit described. Two resistors are used as a potential divider chain across the source in this form of biasing configuration, with their centers delivering the necessary Base bias voltage towards the transistor. Bipolar transistor amplifier circuit designs often include voltage divider biasing (Figure 4.5).

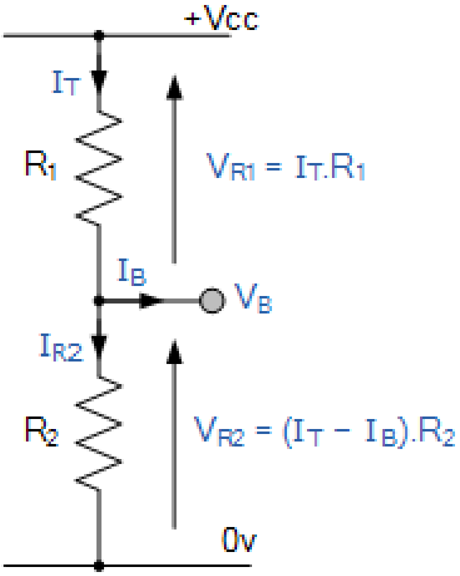

Figure 4.5:The Voltage Divider Biasing

By maintaining the Base bias at such a constant stable voltage level, this approach of biasing the transistor significantly eliminates the impacts of fluctuating Beta, providing for the greatest stability.

The potential divider network made consisting of the two resistors, R1, R2, and the power source voltage Vcc, as depicted with the current flowing both through resistors, determines the quiescent Base voltage (Vb).

The current will therefore be given as I = Vcc/RT and the overall resistance will then be equal to R1 + R2. The Base voltage (Vb) is maintained constant at a value underneath the supply voltage by both the voltage level created at the junction of a resistors R1 and R2.

The supply voltage is divided in proportion towards the resistance by the potential divider networks utilized in the common emitter amplifier circuit. The straightforward voltage divider formula shown below may be used to quickly compute this bias reference voltage:

Transistor Bias Voltage

$$V_B = \frac{V_{CC} R_2}{R_1 + R_2}$$

The highest Collector current, Ic, at full "ON" (saturation), Vce = 0, when the transistor is turned on is determined by the same supply voltage, (Vcc). The transistor's Collector current, Ic, and DC current gain, Beta, are used to calculate the Base current, Ib.

Beta Value

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

The forward current gain of a transistor in the common emitter configuration is determined by the transistor's beta value, which is commonly written as hFE in datasheets. Beta is an electrical characteristic included during transistor manufacturing.

A minor change inside the Base current will result in a big change in the Collector current since Beta (hFE) has no units and is a fixed ratio of something like the two currents, Ic and Ib.

One more thing about Beta. The Beta value of transistors with the same kind and component number will vary greatly. For instance, the DC current gain Beta value of the BC107 NPN bipolar transistor ranges from 110 to 450. (data sheet value). Therefore, even if two BC107 npn transistors may have Beta values of 110 and 450, respectively, they are both BC107 transistors. This is due to the fact that Beta (), rather than the transistor's functionality, is an intrinsic property of the transistor's design.

The Emitter voltage, Ve, will deviate from the Base voltage by one junction voltage drop because the Base/Emitter connection is forward-biased. Ohm's Law may be used to quickly compute the emitter current, Ie, if the voltage across the emitter resistor is available. Given that the Collector current, Ic, and Emitter current have values that are almost identical.

Common Emitter Amplifier Example No1

A common emitter amplifier circuit has a supply voltage of 12 volts and a load resistance of 1.2 k. Assuming Vce = 0, determine the maximum Collector current (Ic) that will flow through the load resistor whenever the transistor is completely "ON" (saturation). Additionally, determine the value of the emitter resistor, RE, assuming there is a 1 volt voltage drop across it. Determine the values of each additional resistor in the circuit assuming a typical NPN silicon transistor.

$$I_{C_{(MAX)}} = \frac{V_{CC} - V_{RE}}{R_L} = \frac{12 - 1}{1200} = 9.2\text{mA}$$

$$V_{CE} = 0 \ (\text{Saturation})$$

When Vce = 0, this sets point "A" on the characteristic curves' vertical axis for collector current. Since there is no current that flows through either resistor RE or RL while the transistor is totally "OFF," there isn't any voltage drop across either of those. Consequently, the supply voltage, Vcc, is equal to the voltage drop from across transistor, Vce. This places point "B" on the characteristics curves' horizontal axis.

The Collector typically resides halfway down the load line between zero volts as well as the supply voltage, or (Vcc/2) since the quiescent Q-point of a amplifier is typically with zero input signal supplied to the Base. As a result, the Collector charge at the amplifier's Q-point will be shown as:

$$Ic_{(Q)} = \frac{\frac{12-1}{2}}{1200} = \frac{5.5}{1200} = 4.58\text{mA}$$

The straight line equation created by this static DC load line has the slope -1/(RL + RE) and intersects the vertical Ic axis at the a location equal to Vcc/(RL + RE). The mean value of Ib determines the actual location of the Q-point on the DC load line.

Given that the transistor's base current, Ib, and collector current, Ic, are both equal towards the transistor's DC gain (Beta), multiplied by the base current, we can calculate the transistor's armature voltage, Ib, by assuming that the transistor has a beta value of 100 (one hundred is indeed a reasonable approximate amount for reduced power signal transistors):

$$\beta = \frac{I_C}{I_B}$$

$$\therefore I_B = \frac{I_C}{\beta} = \frac{4.58\text{mA}}{100} = 45.8\mu\text{A}$$

It is typical to feed the Base Bias Voltage from either the primary supply rail (Vcc) via a dropping resistor, R1, as opposed to having a separate Base bias supply.

Now that R1 and R2 can be selected, an appropriate quiescent base current of 45.8 A or 46 A, rounded to the closest integer, may be obtained. In order to prevent the voltage divider network from being overloaded by the Base current flow, the current that flows through into the potential divider circuit must be substantially larger than the actual Base current, Ib.

A value along with at least 10 times Ib travelling through into the resistor R2 is a common rule of thumb. When the base/emitter voltage of a silicon transistor, Vbe, is set at 0.7V, the value of R2 is given as:

$$R_2 = \frac{V_{(RE)} + V_{(BE)}}{10 \times I_B} = \frac{1 + 0.7}{458 \times 10^{-6}} = 3.71\text{k}\Omega$$

The current flowing across resistor R1 inside the divider network must've been 11 times the value of a Base current if indeed the current flowing through resistor R2 equals 10 times the Base current. Thus, IR2 plus Ib.

R1 may be computed as follows:

Since the voltage accross resistor R1 is equal to Vcc - 1.7v (VRE + 0.7 for silicon transistor) which really is equivalent to 10.3V:

$$R_1 = \frac{V_{CC} - \left(V_{(RE)} + V_{(BE)}\right)}{11 \times I_B} = \frac{12 - 1.7}{504 \times 10^{-6}} = 20.45\text{k}\Omega$$

Ohm's Law makes it simple to determine the Emitter resistor's RE value. Combining the Base current, Ib, with the Collector current, Ic, to get the current flowing through RE:

$$I_E = I_C + I_B = 4.58\text{mA} + 45.8\mu\text{A} = 4.63\text{mA}$$

There is a 1 volt voltage drop around across resistor, RE, which is connected between the transistor's Emitter wire and ground.

Consequently, the Emitter resistor's value, RE, is determined as:

$$R_E = \frac{V_{RE}}{I_E} = \frac{1\text{v}}{4.63\text{mA}} = 216\Omega$$

So, for our example above, the preferred values of the resistors chosen to give a tolerance of 5% (E24) are:

$$R_1 = 20\text{k}\Omega, \; R_2 = 3.6\text{k}\Omega, \; R_L = 1.2\text{k}\Omega, \; R_E = 220\Omega$$

The values of the components that we just determined above may then be added to their original Common Emitter Amplifier circuit.

Completed Common Emitter Circuit (Figure 4.6)

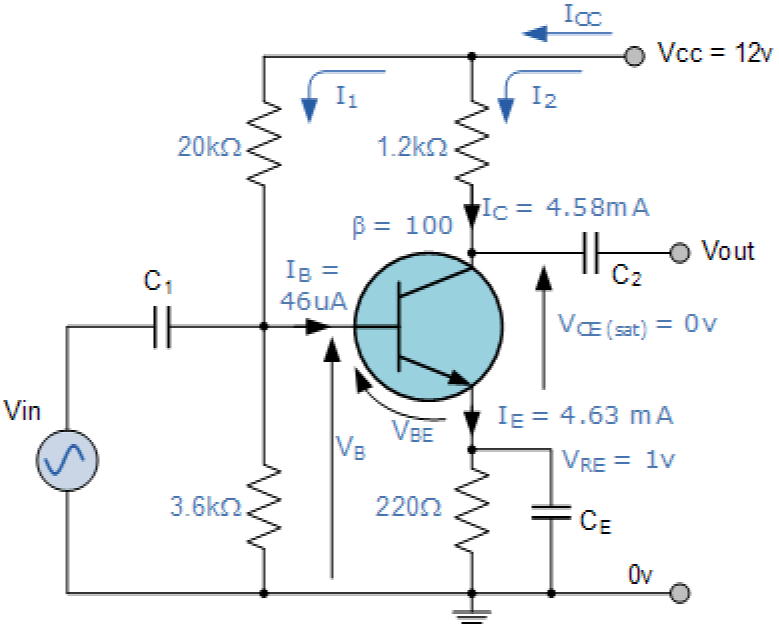

Figure 4.6: Common Emitter Circuit

Amplifier Coupling Capacitors

The coupling capacitors C1 and C2 are used in Common Emitter Amplifier circuits to isolate the AC signals from of the DC biasing voltage. As a result, the capacitors would only carry AC signals & block any DC components, ensuring that the bias conditions established for the circuit to work properly is not impacted by any subsequent amplifier stages. The biasing of the subsequent stages is then applied over the output AC signal. CE, which is a bypass capacitor as well, is a part of the emitter leg circuit.

For DC biasing situations, this capacitor is essentially an open circuit component, which means that the inclusion of the capacitor has no impact on the biasing voltages and voltages, preserving strong Q-point stability.

However, owing to its reactance, this parallel-connected bypass capacitor inadvertently creates a short circuit towards the emitter resistor during high frequency signals. Thus, its load simply consists of RL and a very minimal internal resistance, which maximizes voltage gain. The bypass capacitor's value, CE, is typically selected to achieve a reactance that is at most 1/10th RE's value at the lowest operational signal frequency.

Curves for Output Characteristics

Good thus far, I suppose. For our simple common emitter amplifier circuit, designers can now create a set of curves that plot the Collector current, Ic, versus the Collector/Emitter voltage, Vce, with various values of Base current, Ib.

The "Output Characteristic Curves" are used to depict how the transistor will behave across its dynamic range. To depict all of the transistors potential operating positions, a static and DC load line is put onto the curves for the 1.2k load resistor RL.

Point "B" on the line represents Vce equaling the supply voltage Vcc when the transistor is turned "OFF." The load resistor, RL, which is point "A" on the line, also controls the collector current whenever the transistor is completely "ON" and saturated.

Point Q on the load line, which stands for the Quiescent point or Q-point of the amplifier, is where they computed previously from the DC gain of the transistor which the Base current necessary for the mean position of the transistor were 45.8 A. Without affecting the operating point, researchers could simply simplify things for ourselves and round this number to precisely 50 A.

Output Characteristics Curves (Figure 4.7):

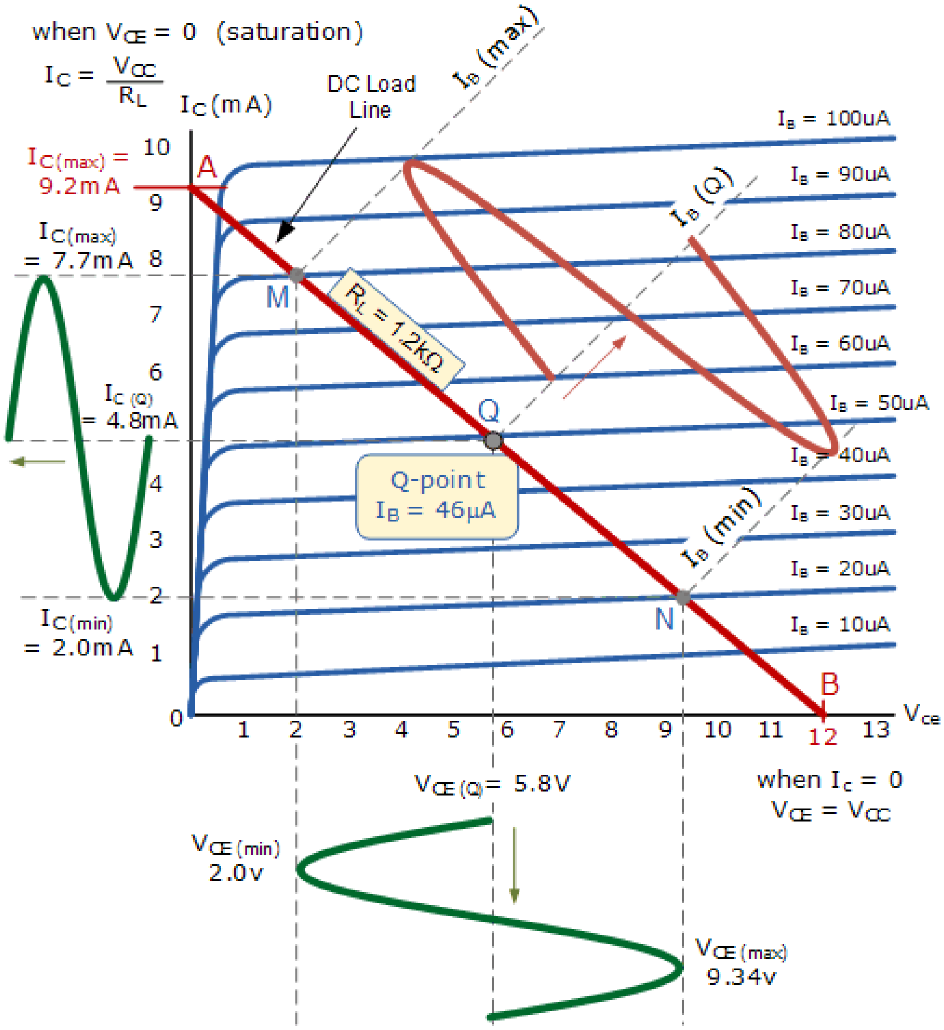

Figure 4.7: Output Characteristics Curves

Humans may determine the Base current Q-point at Point Q on the load line, which is Ib = 45.8 or 46 A. The maximum and least base current peak swings that will cause a proportionate change in the collector current, Ic, without degrading the output signal must be determined.

The peak swings of Base current that were already evenly spaced throughout the load line may be found when the load line passes through the various Base current values upon that DC characteristics curves. These values are shown on the line as points "N" & "M," respectively, with a minimum and maximum Baseline current of 20 A and 80 A.

As long as they are evenly spaced apart from Q, these locations, "N" and "M," may be located anywhere on the load line that we choose. With no distortion to the output signal, this gives us such a theoretical maximum incoming signal toward the Base terminal of 60 A peak-to-peak and 30 A peak

The transistor will be driven past point "N" and into its "cut-off" zone or beyond point "M" and into the saturation area by any input signal that has a base current larger than this amount, causing distortion in the output signal known as "clipping."

The instantaneous quantities of Collector current and related values of Collector-emitter voltage may well be projected from the load line using locations "N" and "M" as an example. As can be observed, the collector current and the collector-emitter voltage are in anti-phase (-180o).

The Collector-emitter voltage, also known as the output voltage, reduces from its constant state value of 5.8 volts to 2.0 volts when the Base current Ib changes in some kind of a positive direction between 50 A to 80 A. Afterward, one stage. Since a rise in Base voltage results in a drop in Vout and a decrease throughout Base voltage results in an increase in Vout, Common Emitter Amplifiers are called "Inverting Amplifiers." The output signal is therefore 180 degrees out of phase with the input signal.

Emitter Voltage Gain Typically

The ratio of the variation in the input voltage to that same change in output voltage is known as the voltage gain of a common emitter amplifier. Then, VB is Vin and VL is Vout. However, voltage gain also is equal to the inverse of the ratio of the signal impedance in the emitter to that in the collector, and is denoted by:

$$\text{Voltage Gain} = \frac{\text{Vout}}{\text{Vin}} = \frac{\Delta V_L}{\Delta V_B} = -\frac{R_L}{R_E}$$

As we previously explained, the bypass capacitor begins to short out the emitter resistor as the ac signal frequency rises because of its reactance. When RE = 0, the gain is unlimited at high frequencies.

The bipolar transistor does, however, have a tiny internal resistance known as r'e built itself into the Emitter region. A little resistor sign is often shown within the larger transistor symbol to symbolize the internal resistance that the semiconductor material of a transistor provides to the passage of current through it.

According to transistor data sheets, this same internal resistance of the a small signal bipolar transistor is determined as the product of 25mV and Ie, where 25mV is the internal voltage drop throughout the emitter junction layer. Therefore, this resistance value will indeed be equal to for with us common emitter amplifier race track above:

$$r'_e = \frac{25\text{mV}}{I_E} = \frac{25\text{mV}}{4.58\text{mA}} = 5.5\Omega$$

This internal Emitter leg resistance will indeed be connected in series with the external Emitter resistor, RE, so that it may be included in the calculation for the transistor's real gain:

$$\text{Voltage Gain} = -\frac{R_L}{(R_E + r'_e)}$$

The overall resistance inside the emitter leg for low frequency signals is equal to RE + r'e. High gain is produced when the bypass capacitor grounds out the emitter resistance at high frequencies, leaving just the internal resistance r'e in the emitter leg.

The gain of the circuitry at both low and high transmission frequencies is thus obtained for our common emitter amplifier circuitry above as:

Amplifier Gain at Low Frequencies

$$\text{Gain} = -\frac{R_L}{(R_E + r'_e)} = -\frac{1200}{220+5.5} = -5.32$$

Amplifier Gain at High Frequencies

$$\text{Gain} = -\frac{R_L}{r'_e} = -\frac{1200}{5.5} = -218$$

Since the reaction capacitance of the capacitor (XC) is large at extremely low input signal frequency, the external emitter resistance, RE, has an impact on voltage gain, dropping it to, throughout this example, 5.32. The voltage gain of the amplifier, in this case 218 in this example, rises as a result of the reactance of something like the capacitor shorting out RE (RE = 0) whenever the input frequency band is extremely high.

One other thing to note is that the voltage gain is unaffected by the transistor's current gain beta, hFE, and solely depends just on quantities of the collector terminal, RL, and emitter resistance, (RE + r'e).

Now can now summarize all the values we determined for our common emitter amplifier circuit for both the simple example above, and they are (Table 4.2):

Table 4.2:common emitter amplifier circuit values

	Minimum	Mean	Maximum
Base Current	20µA	50µA	80µA
Collector Current	2.0mA	4.8mA	7.7mA
Output Voltage Swing	2.0V	5.8V	9.3V
Amplifier Gain	-5.32		-218

Chapter 5

Common Emitter Amplifier

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Finally, a summary. The Collector circuit of the Common Emitter Amplifier circuit has a resistor. The voltage output of a amplifier is created by the current passing throughout this resistor. This resistor's value is set to have an output voltage that is halfway down its load line there at amplifier's Q-point, or quiescent operating point.

Two resistors act as a potential divider network that bias the base of the transistor utilized in a common emitter amplifier. By maintaining the Base bias at such a constant steady voltage, this sort of biasing arrangement significantly lessens the impacts of fluctuating Beta, (), and is often employed in the construction of bipolar transistor amplifier circuits. The most stability is produced by this kind of biasing.

The voltage gain may be changed to -RL/RE by adding a resistor to the emitter leg. The voltage gain achieved by the amplifier is not infinite when there is no external Emitter resistance because the Emitter leg has a very modest internal resistance called r'e. This internal resistance has a value of 25mV/IE.

The Junction Field Effect Amplifier, also known as the JFET Amplifier, will be discussed in the next lesson on bipolar transistor amplifiers. The JFET is used in a single stage amplifier circuit, similar to the transistor, thereby making it easier to comprehend. There are various distinct types of field effect transistors that we may use, however the junction field effect transistor, or JFET, is the most straightforward to comprehend. Its very high input impedance makes it perfect for amplifier circuits.

JFET Common Source Amplifier

In comparison to common-emitter BJT amplifiers, the common source JFET amplifier only has significant advantage: the FET seems to have an extremely high input impedance. This, combined with a low noise output, makes the FET the perfect choice for use in operational amplifiers that need very low input voltage signals. Bipolar transistors are used to create transistor amplifier circuits like the conventional emitter amplifier, but field effect transistors may also be used to create tiny signal amplifiers. The configuration of an amplifier circuit centered on a junction field effect transistor, also known as a "JFET," (for this tutorial, an N-channel FET), or even a metal oxide silicon FET, or "MOSFET," uses the exact same principles as the bipolar transistor circuit employed in the Class-A amplifier circuit humans looked at within the previous tutorial.

In order to properly bias the JFET amplifier circuit, a suitable quiescent point, also known as a "Q-point," must first be identified. The majority of FET devices have single amplifier designs with common-source (CS), common-drain (CD), source-follower (SF), and common-gate (CG) options.

These three JFET amplifier designs are equivalent to the bipolar transistor's common-emitter, emitter-follower, and common-base arrangements. Since the Common Sources JFET Amplifier is the most often used JFET amplifier design, we will examine it in this lesson on FET amplifiers.

Think about the Common Source JFET Amplifier Circuit below.

Common Source JFET Amplifier (Figure 5.1)

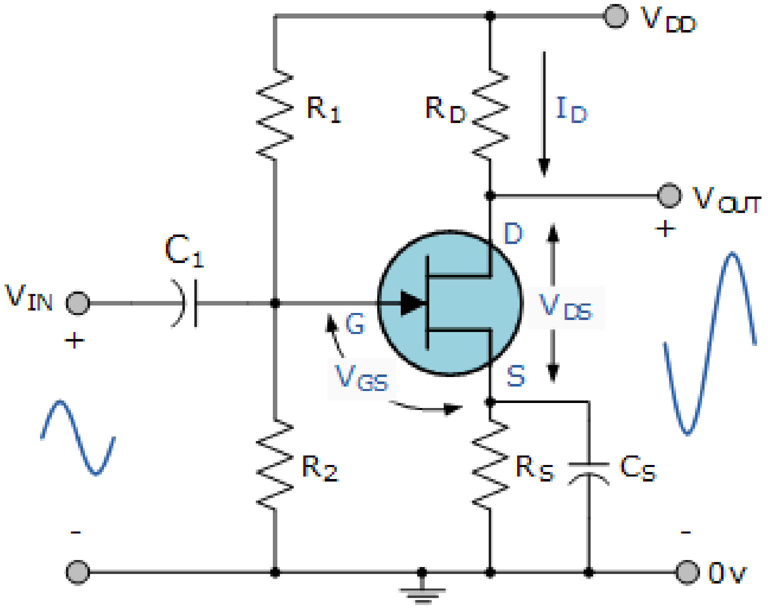

Figure 5.1: Common Source JFET Amplifier

The N-channel JFET in the amplifier circuit might alternatively be an equivalent N-channel depletion-mode MOSFET as that the circuit design would remain the same with just the FET's connection to the common source changed. Through into the potential divider network created by resistors R1 and R2, the JFET modulation index Vg is biased to function in its saturation zone, which is analogous to the bipolar junction transistor's active area.

The junction FET requires almost minimal input gate current, which enables the gate to be viewed as an open circuit, in contrast to a bipolar transistor circuit (Table 5.1). No input characteristic curves are thus necessary. In the following table, we may contrast the JFET with the bipolar junction transistor (BJT).

Table 5.1: JFET to BJT Comparison

Junction FET	Bipolar Transistor
Gate, (G)	Base, (B)
Drain, (D)	Collector, (C)
Source, (S)	Emitter, (E)
Gate Supply, (V_G)	Base Supply, (V_B)
Drain Supply, (V_{DD})	Collector Supply, (V_{CC})
Drain Current, (I_D)	Collector Current, (I_C)

A negative gate voltage in relation to the source is needed to modulate or regulate the drain current since the N-Channel JFET is a depletion mode device and is typically "ON." As long as a constant water goes through the JFET regardless of the absence of an input power available when Vg maintains a reverse bias of a gate-source pn junction, this negative voltage may be produced either by biasing from an independent level of voltage or by a self biasing mechanism.

In our simple example, a potential divider network includes as the biasing, enabling the input signal to result in both a voltage fall at the gate and a voltage increase at the gate with a sinusoidal signal. The DC gate biasing voltage Vg is stated as follows because any reasonable pair of resistor values in the right ratios will provide the right biasing voltage:

$$V_G = \frac{V_{DD} R_2}{R_1 + R_2} = V_{DD}\left(\frac{R_2}{R_1 + R_2}\right)$$

Noting that this equation only establishes the ratio of a resistors R1 and R2, we must increase the value systems of these resistors as much as possible in order to make the most of the JFET's extremely high input impedance and lower power dissipation within in the circuit. Values in the range of 1M to 10M are typically used.

The gate terminal as well as the zero volts rail are where the common source JFET amplifier's input signal (Vin) is applied (0v). The JFET functions in its "Ohmic zone," operating like a linearly resistive device, when a constant gate voltage Vg is supplied. The load resistor, Rd, is part of the drain circuit. This load resistance develops the output voltage, Vout.

By including a resistor, Rs, in the source lead and passing the same drain current through it, the common source JFET amplifier's efficiency may be increased. Resistor Rs is also employed to control the "Q-point" of JFET amplifiers.

A voltage drop equivalent to Rs*Id is created across this resistor when the JFET is completely "ON," bringing the source terminal's potential over 0 volts or ground. Given the requisite reverse biasing state all across gate resistor, which is created by the voltage drop between Rs caused by the drain current, R2 produces negative feedback.

Consequently, to maintain the reverse bias of the gate-source junction, the source voltage, Vs, would have to be larger than the gate voltage, Vg. This voltage output is thus represented as:

$$V_S = I_D \times R_S = V_G - V_{GS}$$

Then the Drain current, Id is also equal to the Source current, Is as “No Current” enters the Gate terminal and this can be given as:

$$I_D = \frac{V_S}{R_S} = \frac{V_{DD}}{R_D + R_S}$$

Compared to a fixed voltage biasing circuit, this potential divider biasing circuit enhances the stability of a common source JFET operational amplifier when powered by a single DC supply. Inside the common emitter bipolar transistor operational amplifier, the emitter resistor but also capacitor serve much the same purpose as the sources by-pass resistor with capacitor, namely to maintain adequate stability and avoid a decline in the voltage gain loss. Nevertheless, more supply voltage is lost across Rs as a result of the stabilised quiescent gate voltage.

The source by-pass capacitor typically has a value in farads exceeding 100 uF and will be polarized. As a result, the capacitor's impedance value is substantially lower—less than 10% of the device's electrical characteristics, or gm, or transfer coefficient, gain—value. At high frequencies, the by-pass capacitor practically creates a short circuit, effectively connecting the source to ground.

A common - emitter JFET amplifier's fundamental design and features are very similar to those of a common emitter amplifier. A DC load line is created by connecting the points representing the drain current, Id, and supply voltage, Vdd, keeping in mind that when Id = 0: (Vdd = Vds) and when Vds = 0: (Id = Vdd/RL) respectively. As a result, the load line is the point at where the curves connect at the Q-point.

Common Source JFET Amplifier Characteristics Curves (Figure 5.2)

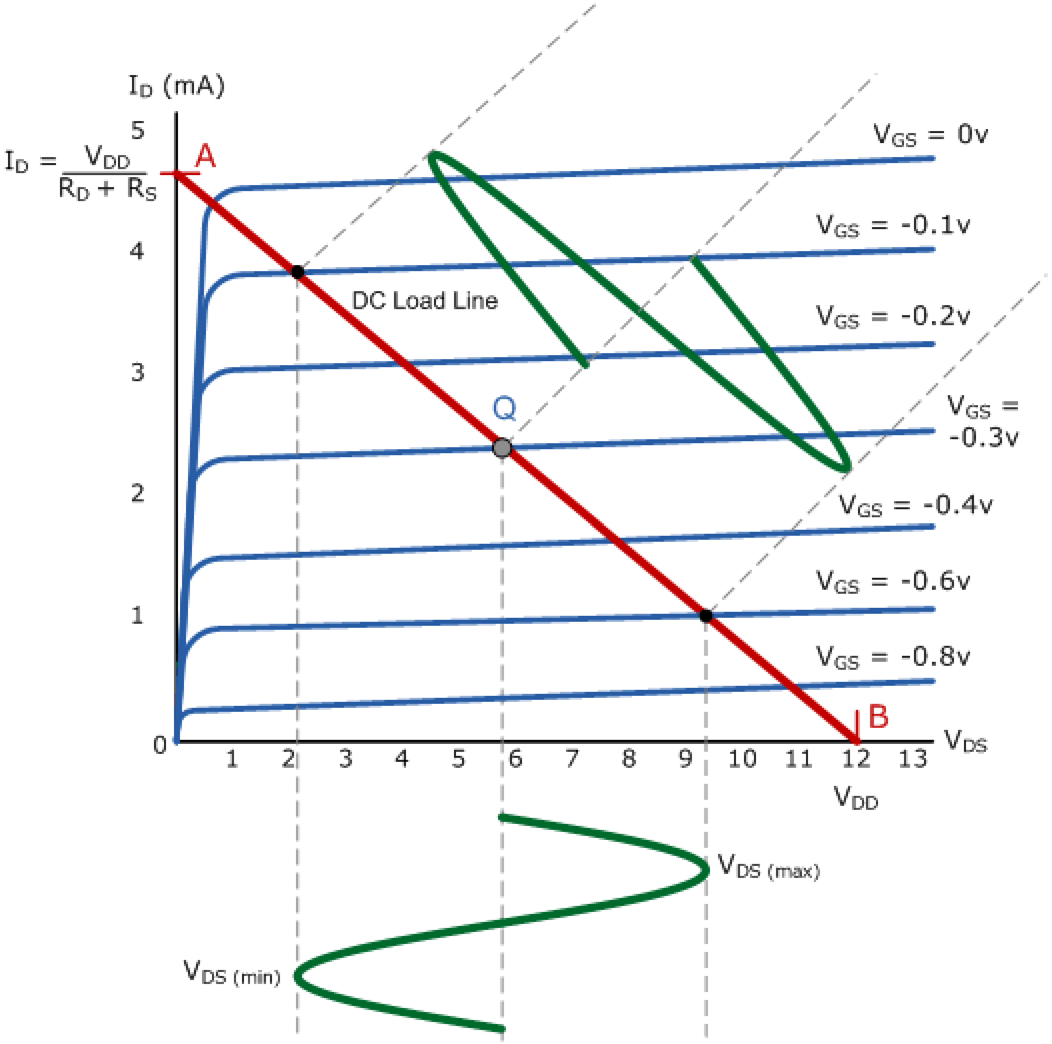

Figure 5.2: Common Source JFET Amplifier Characteristics Curves

The DC load line for something like the common source JFET amplifier generates a straight line solution whose gradient is provided as: -1/(Rd + Rs), and it crosses the vertical Id axis near point A equal to Vdd/(Rd + Rs). This is similar to the common emitter bipolar circuit. Point B, which is equal to the supply voltage, Vdd, marks the location where the opposite end of the load line crosses this same horizontal axis.

The mean value of Vg, which is biased negatively since the JFET is a depletion-mode device, determines the actual location of the Q-point on the DC load line, which is typically located at the midpoint of a load line (for class-A operation). The output of both the Common Source JFET Amplifier is 180o out of phase with the input signal, much like the bipolar common emitter amplifier.

The need of negatively biasing Depletion-mode JFETs is one of their key drawbacks. In the event that this bias fails for whatever reason, the gate-source voltage may grow and become positive, increasing the drain current and ultimately causing the drain voltage, Vd, to fail.

These devices run hot because to the high quiescent quasi - steady drain current and high channel resistance, Rds(on), of the junction FET, necessitating the need of an extra heatsink. However, by switching to enhancement-mode MOSFET devices, the majority of the issues brought on by the use of JFETs may be significantly alleviated.

When compared to an analogous JFET, MOSFETs, or Metal Oxide Semiconductor FETs, have substantially greater input impedances and lower channel resistances. Additionally, the biasing configurations for MOSFETs vary, and until we bias them positively for N-channel transistors and negatively for P-channel devices, no outlet current will flow. At that point, we effectively have a fail-safe transistor.

Gains in JFET Amplifier Current and Power

As have previously said, the very high gate impedance, Rg, causes the input current, Ig, of a central denominator JFET amplifier to be exceedingly low. Because of this, a common source JFET amplifier has a very excellent ratio between its input and outputting impedances and will have a very high current gain Ai for any output current, IOUT.

Because of this, common source JFET amplifiers were particularly advantageous for use as voltage or impedance balancing circuits. The power gain, Ap, is likewise quite high since power is equal to voltage times current (P = V*I) and output voltages are typically many millivolts or even volts.

In the next lesson, we'll examine how improper biasing of a transistor amplifier may amplitude distortion attributable to clipping, as well as the effects of frequency and phase distortions distortion, on the output signal.

Distortion in Amplifiers

A signal amplifier needs some kind of DC bias on its foundation or gate terminal in order to function properly without amplification distortion of the output voltage. The amplifier needs a DC bias to be able to magnify the input signal throughout its whole cycle with the bias "Q-point" set as close to the load line's center as feasible.

The bias Q-point setting will result in a "Class-A" type amplification setup, with the "Common Emitter" or "Common Source" configuration for bipolar transistors or unipolar FET transistors, respectively, being the most popular configurations.

The ratio of the amplifier's peak output value towards its peak input value (Output Input) determines the amount of power, voltage, or current gain (amplification) that is delivered.

The output signal, however, could not be an exact representation of the original incoming signal waveform if they construct our amplifier circuit poorly, place the biasing Q-point on the load line incorrectly, or apply a big input signal towards the amplifier. In other words, the amplifier will experience amplifier distortion, which is a typical problem. A typical emitter amplifier circuit is shown below.

Common Emitter Amplifier

The output signal waveform may very well be distorted because: Incorrect biasing levels may prevent amplification from occurring during the whole signal cycle.

The amplifier transistors' supply voltage may be capped by the amplifiers' transistors due to an excessively big input signal.

Over the whole frequency range of inputs, the signal amplification could not be a linear signal.

This indicates that some kind of amplifier distortions has happened during the process of amplification of the signal waveform.

The primary purpose of amplifiers is to transform weak voltage input signals into considerably stronger output signals.

As a result, at all input frequencies, the output signal is continually changing by a quantity or factor known as gain multiplied either by input signal. As we previously saw, this multiplicand is known as the transistor's beta value.

The predicted location of the bias Q-point of the a bipolar amplifier relies on the identical Beta value for any and all transistors, which is a significant drawback for common emitter or perhaps even common source types transistor circuits.

However, owing to the inherent material properties, this Beta value will differ for transistors of the same kind. In other words, the Q-point once per transistor isn't always the same as that of the Q-point for another transistor that are the same type.

The amplifier will then experience amplifier distortion since it is not linear, which causes amplitude distortion.

The impact of amplifier distortion may be reduced with careful selection of the transistor and attempting to influence components.

Distortion In An Amplifier Caused By Amplitude Distortion

When the frequency waveform's peak values are attenuated, distortion results from a change in the Q-point, and amplification may not occur throughout the entire signal cycle. The output waveform's non-linearity is seen below.

Correct Biasing-Induced Amplitude Distortion

Erroneous prejudice

The output waveform should then be larger than the input waveform if the biasing point of the transistors is accurate (amplified). The output waveform will resemble the one on the right, with both the negative half of a output waveform "cut-off" or clipped, when there is inadequate bias and the Q-point is located in the bottom half of the load line. The output waveform will resemble the one shown on the left with both the positive half "cut-off" or clipped when there is too much bias as well as the Q-point is in the top half of the load line.

Additionally, when the voltage level is too low, the transistor does not completely conduct during the negative portion of the cycle, causing the supply voltage to control the output. The positive part of the cycle saturates the transistor whenever the bias is too high, and the output almost disappears.

It is still possible therefore for output waveform to become distorted even with the proper biasing voltage level set because of a strong input signal being amplified by the circuit's gain. Regardless of whether the bias is accurate, the output voltage signal exhibits clipping in both the positive and negative portions of the waveform and no longer resembles a sine wave. Clipping, a sort of amplitude distortion brought on by "over-driving" the amplifier's input, is the cause of this distortion.

The peak (+ve half) and trough (-ve half) portions of the waveform signal flatten out or are "Clipped-off" when the input amplitude is too high, forcing the output waveform signals to exceed maximum power supply voltage rails. The maximum value that the input signal must be constrained to a level that will prevent such clipping effect in order to avoid it, as seen above.

Clipping-Induced Amplitude Distortion

An amplifier circuit's efficiency is significantly decreased by amplitude distortion. These "flat tops" of a distorted output waveform, which may be the result of improper biasing or input overdrive, have no bearing on the output signal's intensity at the required frequency. Having said all of that, a few well-known rock bands and guitarists really like their signature sound to be severely distorted or "overdriven" by severely clipping the output waveform to both the +ve and -ve power supply rails. Additionally, increasing the clipping on a sinusoid can cause the amplifier to become so distorted that the output waveform will ultimately approximate a "square wave" shape, which may be employed in electrical or digital synthesizer circuits. We have shown that for a DC signal, the amplifier's amount of gain may change with the signal's amplitude, but for an AC signal, other forms of amplifier distortion, such as frequency distortion as well as phase distortion, can also occur in amplifier circuits.

Frequency distortion causes amplifier distortion

Another kind of amplifier distortion known as frequency distortion happens in transistor amplifiers when the amount of amplification fluctuates with frequency. The majority of the input signals that even a practical amplifier would amplify include a number of other frequencies termed harmonics superimposed on the needed signal waveform, known as the "Fundamental Frequency," as well as the required signal waveform itself. These harmonics often have a negligible or no impact on the output waveform since their amplitudes are a small portion of the fundamental's. However, if these harmonic overtones grow in amplitude relative to the fundamental frequency, the output waveform may become distorted. Think about the waveform below as an example:

Harmonic-induced frequency distortion

In the aforementioned example, a second harmonic signal is added to the fundamental frequency to create the input waveform. On the right, the final output waveform is shown. The output signal is distorted by the fundamental frequency when it interacts with the second harmonic. Since harmonics are several times the fundamental frequency, a second harmonic was employed in our straightforward example. As a result, the harmonic's frequency, 2* or 2, is twice that of the fundamental. Third harmonics would thus be 3 and 4 and so forth. Harmonic frequency distortion is a constant risk in amplifier circuits with reactive components like capacitance or inductance.

Phase distortion causes amplifier distortion.

When there is a delay between the original signal as well as its appearance at the output, a non-linear semiconductor amplifier will experience phase distortion, also known as delay distortion. The difference between the harmonic and the fundamentals will result in the phase angle delay as a consequence, if the phase change between both the input as well as the output is zero at the fundamental frequency. Within the amplifier's bandwidth, this delay time will gradually rise with frequency and be dependent on the amplifier's design. Think about the waveform below as an example:

Delay-induced Phase Distortion

Most practical amplifiers, with the exception of high-end audio amplifiers, will exhibit some degree of amplifier distortion, which combines amplitude distortion with both frequency distortion and phase distortion.

Unless the distortion of the amplifier is extreme or severe, it usually has little impact on the functioning or output sound of the amplifier in the majority of applications, such as audio amplifiers as well as power amplifiers. We shall examine the Class A Amplifier in the next session on amplifiers. The most prevalent output stage for amplifiers, class A amplifiers are perfect for usage in audio high power applications.

Amplifier in Class A

The widespread emitter class—

As we learned in the previous lessons, an amplifier is mostly employed as "small signal amplifiers" because it is intended to create a significant output voltage swing from such a relatively tiny input signal voltage of just a few millivolts.

However, power amplifiers are necessary for these kinds of applications when huge switching currents are required, such as when an amplifier is needed to drive a loudspeaker or a robot's motor.

The primary purpose of a power amplifier, commonly referred to as a "big signal amplifier," is to transmit power, because it is the result of the interaction between voltage and current, to the load. A power amplifier is essentially the same as a voltage amplifier with the exception that the load resistance associated with the output is often low, such as a loudspeaker of 4 or 8, which causes large currents to flow through the transistor's collector.

The output transistor(s) used mostly for power amplifier output stages, such as the 2N3055, must have greater voltage and power ratings than the standard ones used for tiny signal amplifiers, such as the BC107, due to these large load currents.

The "conversion efficiency" of the amplifier is primarily important to us because we want to be able to provide the load with the highest AC power while using the least amount of DC power from the supply.

However, one of the primary drawbacks of power amplifiers, particularly the Class A amplifier, is that a significant amount of power is wasted as heat due to huge currents, which results in a relatively poor overall conversion efficiency. As seen below, the percentage efficiency of an amplifier is calculated by dividing the total DC power drawn from the supply source by the r.m.s. output power dissipated in the load.

Power Amplifier Efficiency, as shown in Figure 5.3

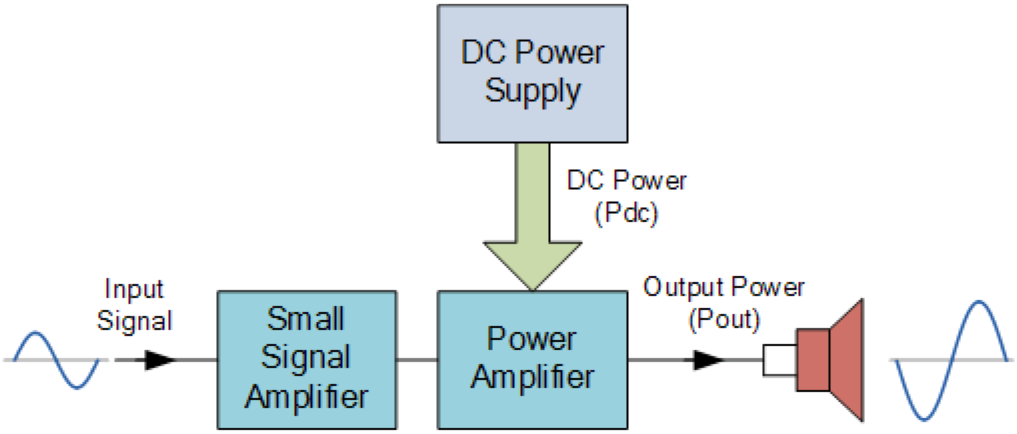

Figure 5.3: Power Amplifier Efficiency

$$\eta\% = \frac{P_{OUT}}{P_{DC}} \times 100$$

Where: % is the amplifier's efficiency.

Pout is the output power that is sent to the load by the amplifier.

The DC power drawn from the supply is known as Pdc.

It is crucial for a power amplifier's power supply to be well-designed in order to provide the most continuous power towards the output signal.

Amplifier in Class A

The Class A Amplifier is the most often used arrangement for power amplifiers. The Class A amplifier is the most basic kind of power amplifier that generates an inverted output using a single switching semiconductor in the conventional common emitter circuit design that we have seen before. The transistor is always biased "ON" to conduct for the duration of one full cycle of the input signal waveform, resulting in the least amount of distortion and the highest possible output signal amplitude.

Since there can be no crossovers or switch-off distortion towards the output waveform even within the negative second half of the cycle, the Class A Amplifier arrangement is the best operating condition. A single power transistor or two coupled power transistor pairs may be used in the Class A power amplifier output stages to distribute the high load current. A Class A amplifier circuit is shown below.

Single Stage Class-A Amplifier Circuit, as shown in Figure 5.4:

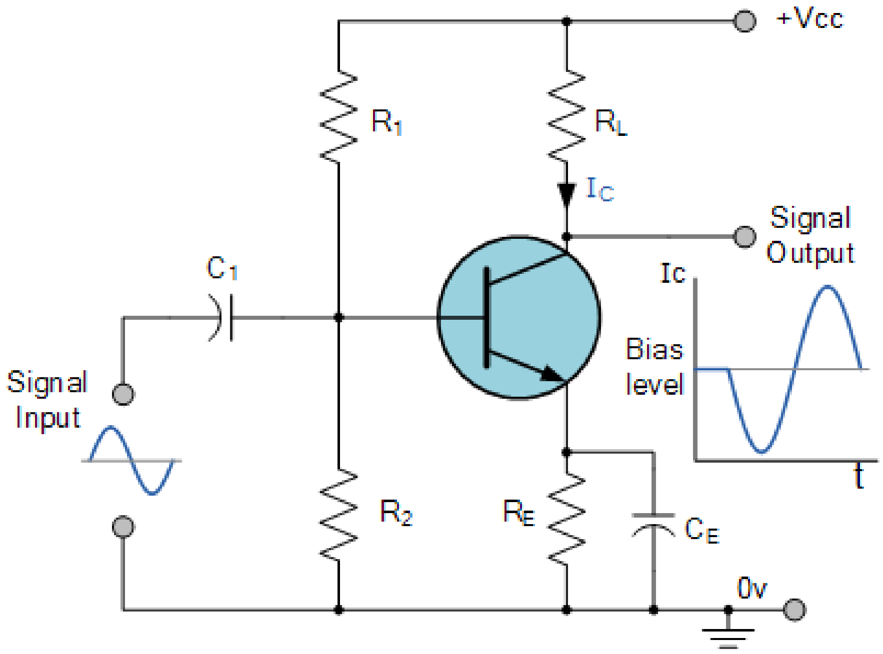

Figure 5.4: Single Stage Class-A Amplifier Circuit

The simplest Class A power amplifier circuit is the following. The output stage of the device is a single-ended transistor, and the resistive load is connected directly towards the Collector terminal. Whenever the transistor becomes "ON," it limits the potential for negative output by sinking the output current via the Collector, which inevitably causes a voltage drop across the Emitter resistance.

This kind of circuit has a very poor efficiency (less than 30%), producing little power outputs while using a lot of the DC power source. Large heatsinks are required again for output transistors of a Class A amplifier stage since the load current is always the same even in the absence of an input signal.

But swapping out the single output transistor with just a Darlington transistor is another straightforward technique to boost the circuit's ability to handle current while also gaining more power. These kinds of electronics primarily consist of a tiny "pilot" transistor and a bigger "switching" transistor in a single package. These devices have the major benefit of having an appropriately high input impedance as well as a relatively low output impedance, which reduces power loss and, subsequently, heat generation inside the switching device.

Darlington Transistor Configurations (Figure 5.5)

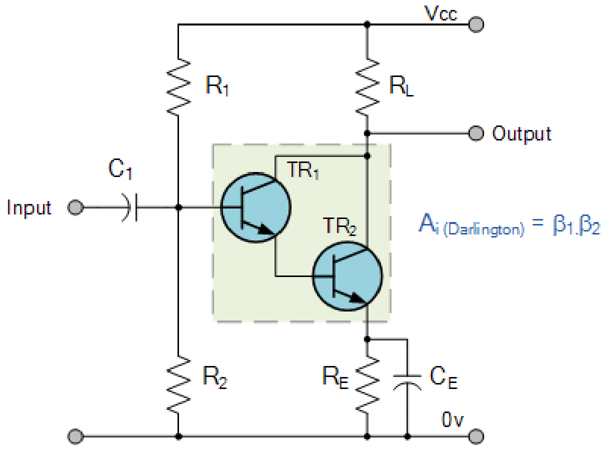

Figure 5.5: Darlington Transistor Configurations

The present gain overall In comparison to a circuit using a single transistor, a Darlington device may achieve extremely high beta () values and large collector currents by multiplying the two transistors' separate gains. It is possible to construct the circuit with a transformer linked directly in the Collector circuit to create a circuit known as a Transformer Coupled Amplifier in order to increase the complete power efficiency of a Class A amplifier. By matching the capacitance of the load with the amplitude of the amplifier's output that use the transformers turns ratio (n), the transformer increases the efficiency of both the amplifier. An illustration of this is shown below.

Chapter 6

Amplifier Circuit

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Due to changes in the base current, overall magnetic flux inside the transformer core falls as the Collector current, Ic, is decreased down below the quiescent Q-point established by the base bias voltage. This results in an induced emf throughout the transformer primary windings. When the collector voltage is at its lowest, this produces an instantaneous collector voltage to increase to a value that is double the supply voltage, or 2Vcc, and a maximum collector current of twice Ic. Consequently, the following formula may be used to determine this sort of Class A amplifier configuration's efficiency (Figure 6.1).

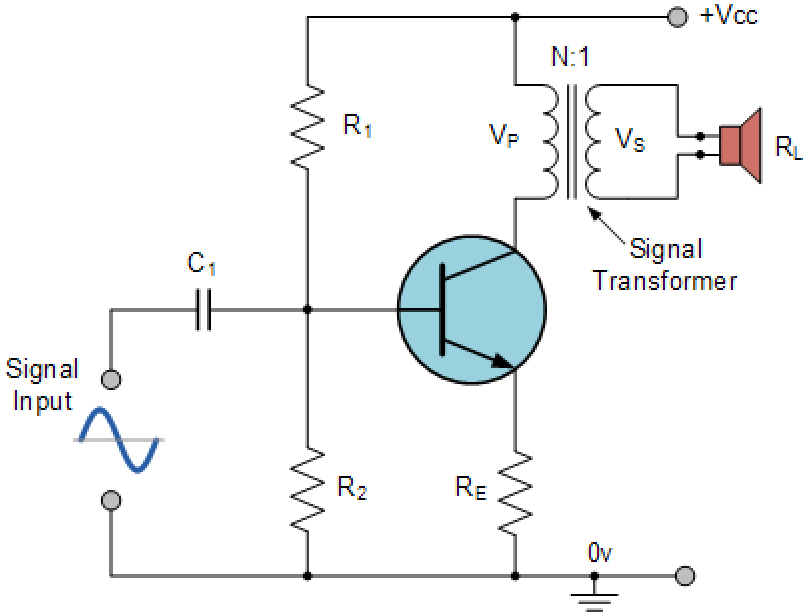

Figure 6.1: Transformer-coupled Amplifier Circuit

The r.m.s. Collector voltage is given as:

$$V_{CE} = \frac{V_{C(max)} - V_{C(min)}}{2\sqrt{2}} = \frac{2V_{CC} - 0}{2\sqrt{2}}$$

The r.m.s. Collector current is given as:

$$I_{CE} = \frac{I_{C(max)} - I_{C(min)}}{2\sqrt{2}} = \frac{2I_{C} - 0}{2\sqrt{2}}$$

The r.m.s. Power delivered to the load (Pac) is therefore given as:

$$P_{ac} = V_{CE} \times I_{CE} = \frac{2V_{CC}}{2\sqrt{2}} \times \frac{2I_C}{2\sqrt{2}} = \frac{2V_{CC}\,2I_C}{8}$$

The average power drawn from the supply (Pdc) is given by:

$$P_{dc} = V_{CC} \times I_C$$

and therefore the efficiency of a Transformer-coupled Class A amplifier is given as:

$$\eta_{(max)} = \frac{P_{ac}}{P_{dc}} = \frac{2V_{CC}\,2I_C}{8V_{CC}I_C} \times 100\%$$

By matching the load's impedance towards the output impedance of the amplifier, an output transformer increases the efficiency of the amplifier. The majority of commercially available Class-A type power amplifiers are of this construction, and class-A amplifier efficiencies of up to 40% are achievable by utilizing an output or signal transformer with just an appropriate turns ratio.

It is advisable to avoid using inductive components with amplifier switching circuits since the transformer is indeed an inductive device owing to its windings and core, and any back emfs it generates might harm the transistor if it is not well protected.

The added cost and needed size of both the audio transformer is another significant drawback of this sort of transformer linked class A amplifier circuit.

The sort of "Class" or classification assigned to an amplifier mostly relies on the conduction angle, or the fraction of the input waveform cycle that the transistor is conducting, which would be measured as a percentage of 360o. whereas in other amplifier classes each transistor conducts throughout a smaller conduction angle, the conduction angle in the Class A amplifier is complete 360o or 100% of a input signal.

Using two complementary transistors inside the output stage having one being an NPN or N-channel type and the other being a PNP or P-channel (the complement) type linked in what is known as a "push-pull" arrangement allows for higher power output and efficiency compared to the Class A amplifier.

Another form of audio amplifier circuit that we will examine in the next lesson is this type of power amplifier setup, which is often referred to as a Class B Amplifier.

Amplifying class B

It is possible to create the power amplifier circuit that has two transistors in its output stage in order to increase the complete power efficiency of the preceding Class A amplifier by decreasing the lost power in the form of heat. As a result, a push-pull amplifier arrangement, sometimes referred to as a Class B amplifier, is produced.

Push-pull amplifiers employ two "complementary" or matching transistors, one of which is of the NPN type while the other of which is of the PNP type. Both power transistors receive the same input signal at the exact same time, which is of equal amplitude but of the opposite phase. This results in the "two-halves" of the input waveform been put back together on the output terminal by one transistor amplifying just one half, or 180o, of the input waveform cycle, and the second transistor amplifying some other half, or remaining 180o, of a input waveform cycle.

Then, for this kind of amplifier circuit, the conduction angle is just 180o, or 50% of both the input signal. This sort of circuit is often referred to as a "push-pull" amplifier, although it is more commonly known as a class B amplifier. An example of a class B amplifier is illustrated below.

Class B Push-pull Transformer Amplifier Circuit (Figure 6.2):

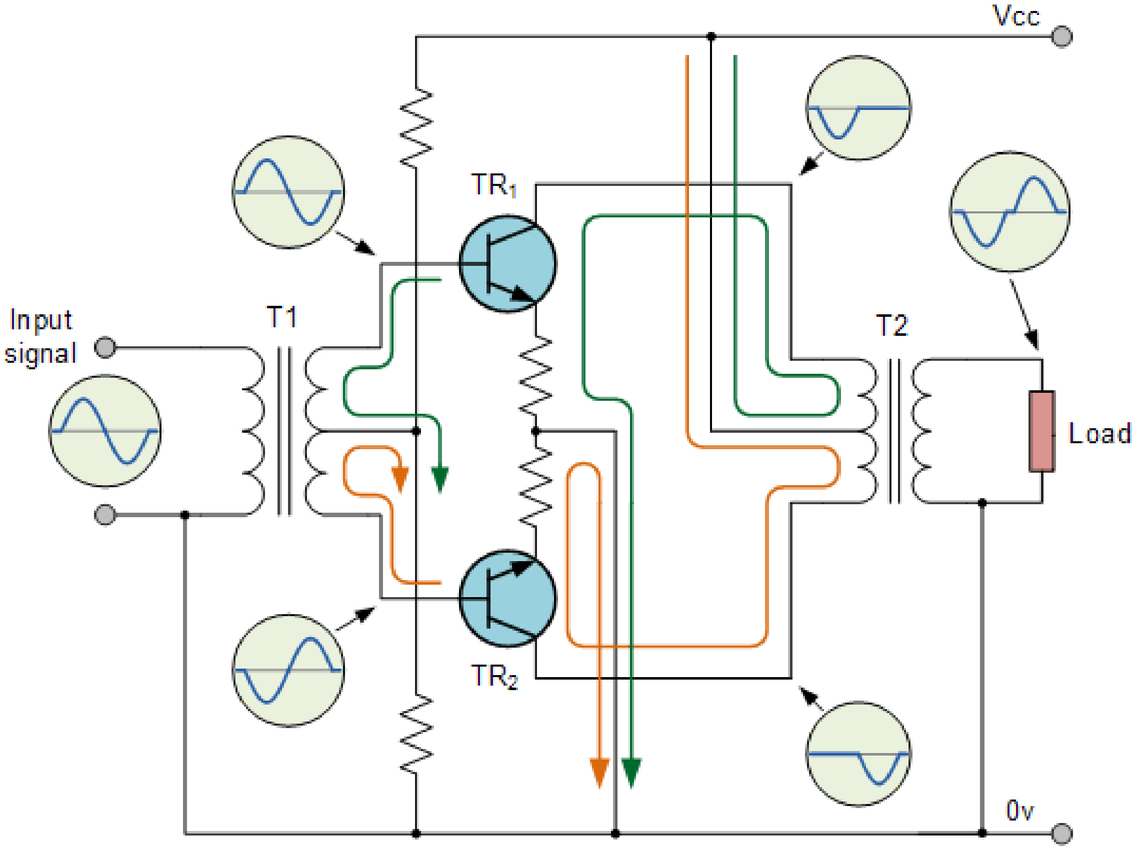

Figure 6.2: Class B Push-pull Transformer Amplifier Circuit

A balanced center-tapped input transformer is used in the circuit above to create a typical Class B amplifier. This transformer divides the incoming waveform message into two equal halves that are 180 degrees out of phase with one another. The two signals are recombined to enhance the power to the load using a center-tapped transformer here on output. Both NPN transistors with coupled emitter terminals are being used in this kind of transformers push-pull amplifier circuit.

In this case, the output voltage and current are reduced to zero by sharing the load current between both the two power transistor devices because it fluctuates between one device and another throughout the signal cycle. As a consequence, the output waveform currently oscillates in both directions, from zero to double the quiescent current, lowering dissipation. This has the result of almost tripling the amplifier's efficiency, which now stands at around 70%.

Each transistor transmits the typical quiescent current flowing, the magnitude of which is defined by the bases bias that is located at the cut-off point, assuming that there is no input signal. The likelihood of distortion is reduced if the transformer is precisely center tapped, in which case the two collector currents will stream in the opposite directions (the ideal situation), and the transformer core won't get magnetized.

The transistor base inputs are "anti-phase" against one another when an input signal is received from across secondary of a driver transformer T1, as shown. As a result, if the base current of TR1 goes positive, going to drive the transistor in and out of heavy energy transfer, its collector current is increased, but at the same moment, the base current of TR2 will increase further negatively into cut-off, and its collector current will decrease by an equal amount, and vice versa. Because of this push-pull action, negative half are amplified through one transistor while positive two strands amplified by the other transistor.

The two output half-cycles are combined to produce a sine wave in the output transformer's main winding, which further appears across the load, since these alternating currents, unlike DC, are Additive.

Since the transistors are driven at the cut-off in a Class B amplifier, there is zero DC bias throughout operation. As a result, each transistor simply conducts whenever the input signal is larger than the base-emitter voltage. As a result, with zero input, there is also zero output and also no power consumption. Therefore, as illustrated below, the Class B amplifier's real Q-point is located on the Vce portion of the load line.

Class B Output Characteristics Curves (Figure 6.3):

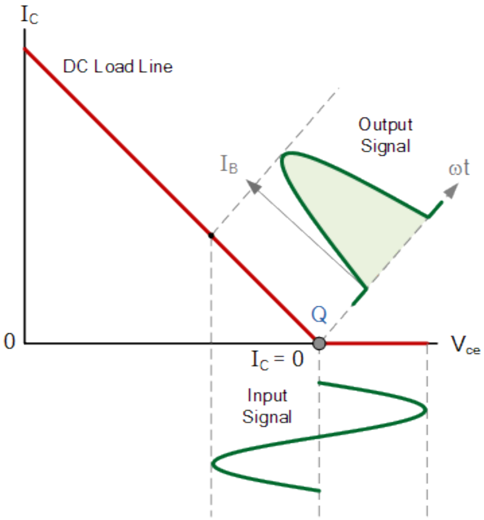

Figure 6.3: Class B Output Characteristics Curves

In contrast to Class A amplifier stages, which require significant base bias and generate a lot of heat even in the absence of an input signal, Class B amplifier stages have the major advantage of having no current flowing through the transistors whenever they are in their quiescent state (i.e., without an input signal). As a result, no power is lost in the output transistors as well as transformer whenever there is no signal present. As a consequence, practically all contemporary push-pull amplifiers operate in this Class B mode since their total conversion efficiency () is higher than that of the comparable Class A amplifier, with efficiencies of up to 70% attainable.

Push-Pull Amplifier without Transformer

The Class B amplifier circuit described above has many drawbacks, chief among them being the high cost of construction due to the usage of balanced center-tapped transformers in its design. A other kind of Class B amplifier, known as a complementary-symmetry Class B amplifier, on the other hand, is transformer less and instead uses complementary or corresponding pairs of power transistors. Since transformers are not required, the amplifier circuit is substantially smaller for the same amount of output and the output signal's quality is not affected by stray magnetic effects or transformer distortion. Below is an illustration of a "transformer less" Class B amplifier circuit.

Transformer less Output Stage (Figure 6.4)

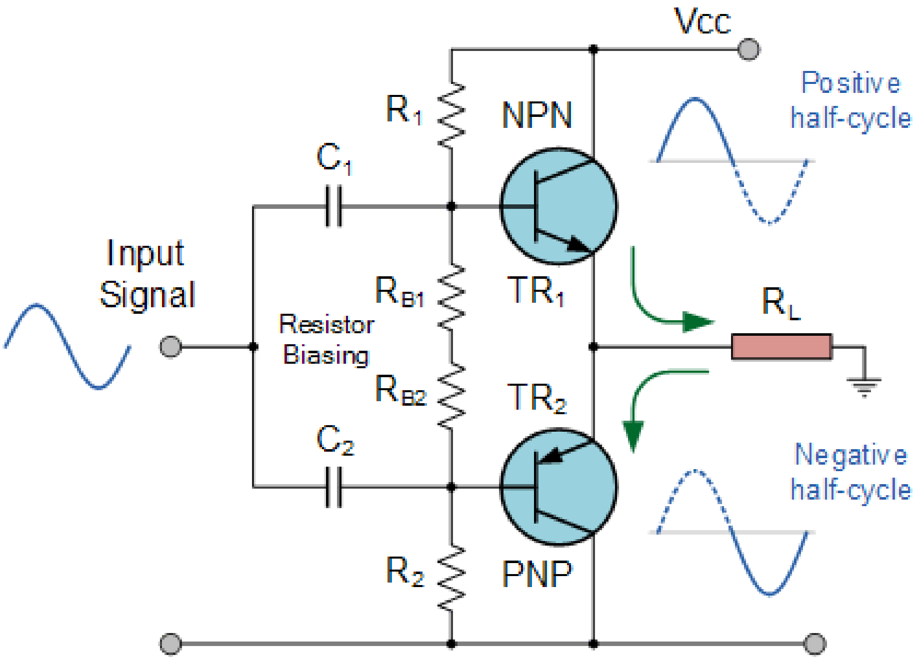

Figure 6.4: Transformer less Output Stage

Although Class B amplifiers have a higher gain than Class A types, one of the primary drawbacks of class B type push-pull amplifiers would be that they experience an effect that is well-known. The Class B amplifier circuit shown above employs complementary transistors with each half of the waveform. Hopefully, we may recall from our Transistors lectures that a bipolar transistor requires around 0.7 volts (measured from base to emitter) to begin conducting. The output transistors really aren't "pre-biased" to a "ON" state of operation inside a pure class B amplifier. This means that even though the transistors are specially matched pairs, the transistors do not stop as well as start conducting exactly at the zero crossover point during the transition from the two transistors (when they are switching over from yet another transistor to the other), so the portion of the output waveform below this 0.7 volt window will not be accurately reproduced. The output transistors for the positive and negative halves of the waveform will each have a 0.7 volt region where they are not conducting. As a consequence, both transistors are switched "OFF" at the exact same moment. In a Class B amplifier, adding two modest voltage sources to bias both transistors at a position just above their cut-off point is a straightforward technique to get rid of crossover distortion. We would then have what is known as a Class AB amplifier circuit as a result. However, it would be impossible to add more voltage sources towards the amplifier circuit, thus silicon diodes with PN-junctions are employed to give the extra bias.

The Class AB Amplifier

If so many of us are to swap out the two voltage divider biasing resistors attached to the base terminals of both the transistors and two silicon Diodes, we would know that somehow a silicon bipolar transistor needs the base-emitter voltage to be higher than 0.7v in order to begin conducting. The forward potential difference of the diodes would therefore be the same as the biasing voltage given to the transistors. These photodiodes are often referred to as compensating or biasing diodes, and they are selected to match the properties of the corresponding transistors. The circuit below displays biasing of a diode (Figure 6.5).

Class AB Amplifier

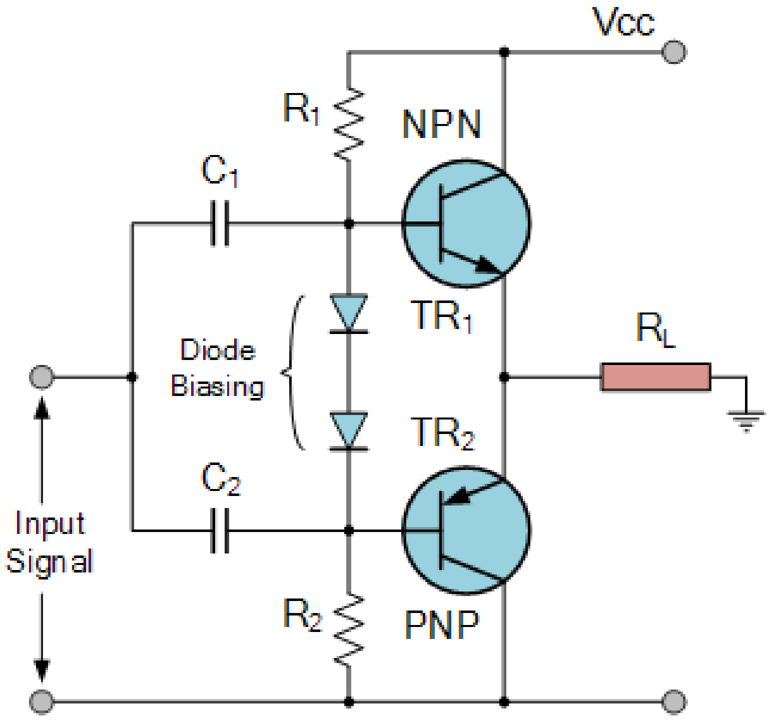

Figure 6.5: Class AB Amplifier

A compromise between the Class A and Class B topologies is the Class AB amplifier circuit. Even in the absence of an input signal, the extremely low diode biasing voltage enables both transistors to marginally conduct. Pure Class B amplifier designs include crossover distortion, but with an input signal waveform, the transistors will perform normally in their active area and any such distortion will be eliminated.

When there is no input signal, a negligible collector current will flow, but it will be far less than in a Class A amplifier setup. This indicates that depending on the amount of extra biasing used, the transistor will be "ON" for between 50% and 100% of the input signal or 180° to 360° of the waveform, depending on the amount of additional biasing employed. By connecting more diodes in series, the diode biasing voltage that is already present at the transistor base terminal may be multiplied.

High-power applications like audio power amplifiers and PA systems substantially favor Class B amplifiers over Class A designs. Using Darlington transistor pairs rather than single transistors in the output circuitry of a Class B push-pull amplifier may significantly increase its current gain (Ai), similar to the class-A amplifier design. Examining crossover distortion's impacts on Class B amplifier circuits in further detail and finding strategies to mitigate them.

Amplifier Crossover Distortion

The inaccurate replication of an input signal at an amplifier's output is known as distortion. Push-pull amplifiers experience crossover distortion of the output waveform around its zero crossover point because of its two-stage construction. We've seen that the Class-A amplifier configuration's poor full power efficiency rating as a result of being biased around its center Q-point is one of its key drawbacks.

However, we also know that by simply switching the amplifier's output stage to a Class B push-pull arrangement, we can enhance the amplifier and almost double its efficiency. The majority of contemporary Class B amplifiers are transformerless or complementary versions with two transistors in their output stage, which is wonderful from an efficiency standpoint.

Due to their special zero cut-off biasing configuration, push-pull amplifiers have one key basic issue in which the two transistors do not come together completely at the output of both sides of the waveform. Due to this issue, the output wave form is "distorted" to some extent when the signal "crosses-over" from one transistor to the other at the zero voltage point. As a consequence, a problem known as Crossover Distortion is created.

As the waveform crosses over from one half to the other, crossover distortion causes a zero voltage "flat spot" or "deadband" on the output wave shape. The cause of this is that there is a little delay between the first transistor going "OFF" and the second transistor becoming "ON" because the transition time between the transistors while they are switching over from one to the other does not finish or start precisely at the zero crossover point. Due to the delay, both transistors turn "OFF" simultaneously, resulting in the output wave pattern that is seen below Figure 6.6.

Crossover Distortion Waveform

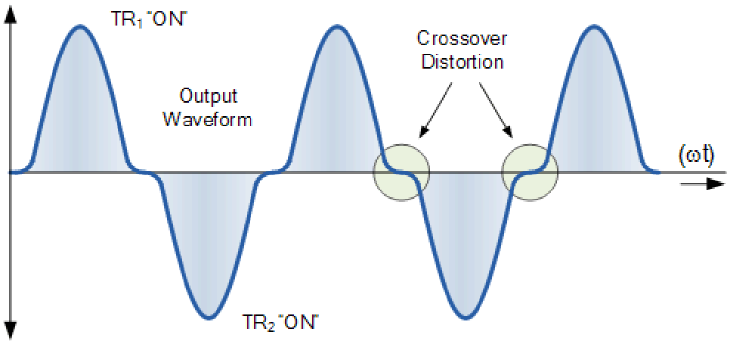

Figure 6.6: Class AB Amplifier

We must assume that each transistor begins to conduct when its base to emitter voltage rises a little above the zero in order to ensure that the output waveform is not distorted. However, humans know that this is not the case because, for silicon bipolar transistors, this same base-emitter voltage must reach at least 0.7 volts before the transistor begins to conduct due to the forward diode voltage drop of a base-emitter pn-junction, producing this flat spot. As illustrated below, this crossover distortion impact also lowers the output waveform's total peak to peak value, which lowers the maximum power output.

Non-Linear Transfer Characteristics (Figure 6.7)

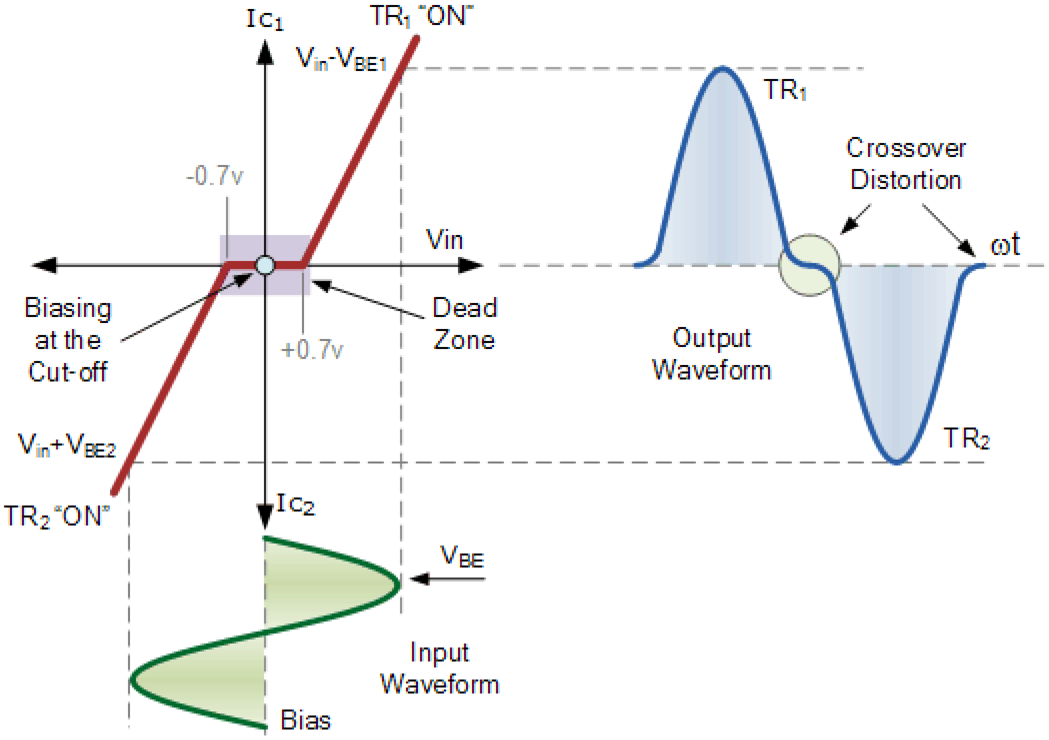

Figure 6.7: Non-Linear Transfer Characteristics

Since the input voltage is often relatively high, this effect is less noticeable for larger input signals, but it may be more severe for smaller input signals, resulting in audio distortion in the amplifier.

Pre-biasing Crossover Distortion Reduction

By applying a slight forward foundation bias voltage towards the bases of the pmos transistors through the use of the input transformer's center-tap, the problem of crossing distortion can be greatly reduced.

As a result, the transistors are no longer prejudiced at the negligible cut-off point but rather are "Pre-biased" at a level determined by the new biasing voltage.

Push-pull Amplifier with Pre-biasing (Figure 6.8)

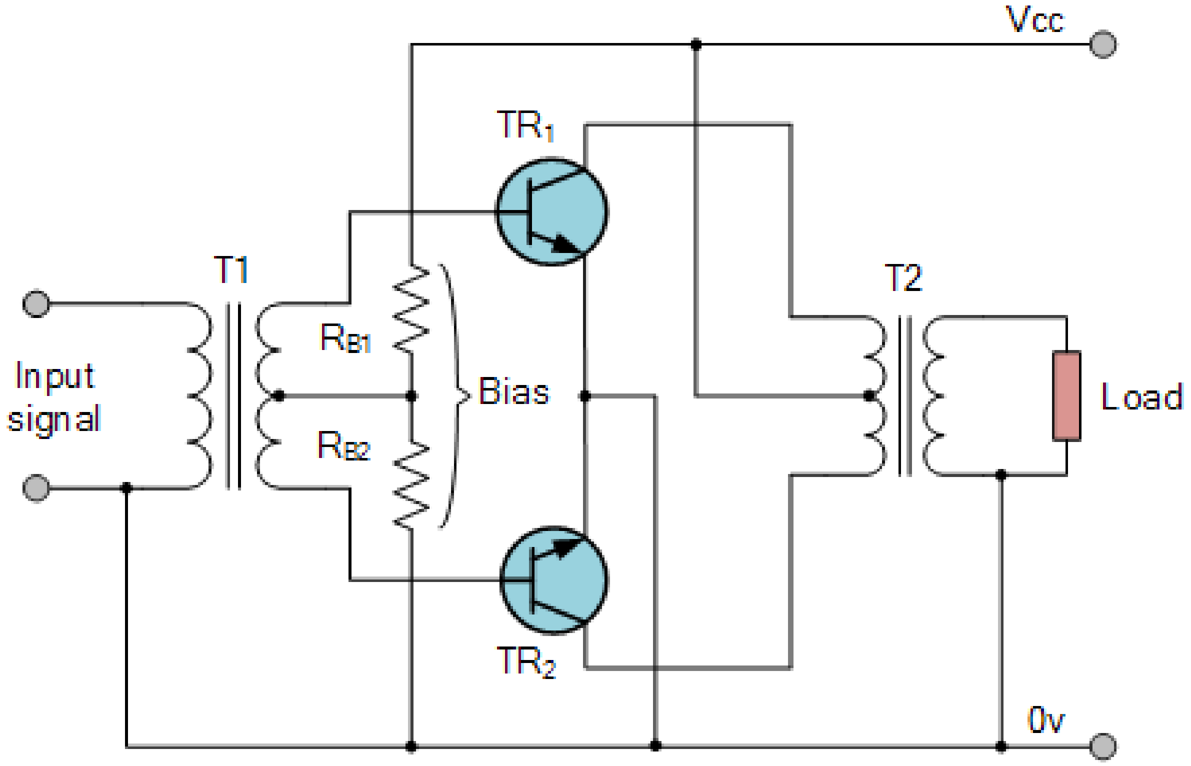

Figure 6.8: Push-pull Amplifier with Pre-biasing

Because both transistors are all now biased just a little bit over their initial cut-off point, this kind of resistor pre-biasing allows one transistor to turn "ON" precisely at the same moment that the other transistor goes "OFF."

To turn the transistors "ON," their bias voltage is required to be least twice as high as the standard base to emitter voltage.

Transformer less amplifiers that employ complementary transistors may also use this pre-biasing by simply substituting the two potential divider resistors using biasing diodes, as illustrated below.

Pre-biasing with Diodes (Figure 6.9)

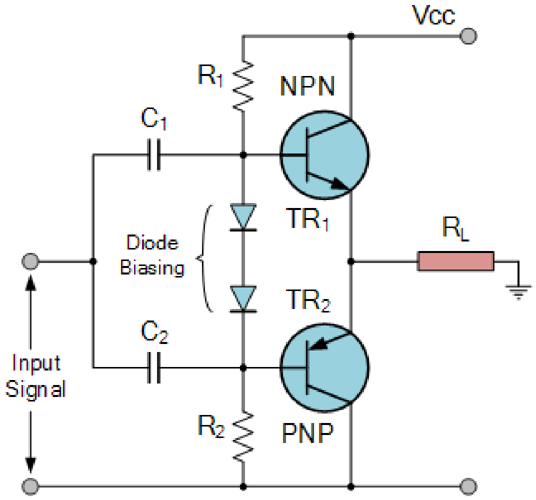

Figure 6.9: Pre-biasing with Diodes

This pre-biasing voltage, whether used in a transformer-based or transformerless amplifier circuit, does have the effect of moving the amplifiers' Q-point beyond the original cut-off point, having allowed each transistor to operate through its active region for a little more than half or 180 degrees of each half cycle. Alternatively stated, 180o + Bias. By connecting more diodes in series, the diode biasing voltage that is already present at the transistor base terminal may be multiplied. After that, a circuit known as a Class AB amplifier is created, and its biasing setup is shown below.

Class AB Output Characteristics (Figure 6.10)

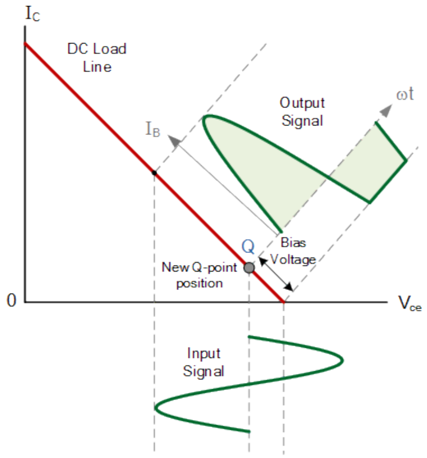

Figure 6.10: Class AB Output Characteristics

Summary of Crossover Distortion

In conclusion, Crossover Distortion occurs in Class B amplifiers due to biasing at the amplifier's cut-off point. Consequently, when the waveform crosses the zero axis, BOTH transistors are turned "OFF" at the same moment. This crossover distortion may be considerably decreased or even totally removed by adding a modest base bias voltage, either by utilizing a resistive potential divider circuit or diode biasing, and getting the transistors to the point of being barely turned "ON."

Another sort or class of amplifier circuit, known as a Class AB Amplifier, is created by applying a biasing voltage. The biasing level applied to the output transistors is what differentiates a pure Class B amplifier from an enhanced Class AB amplifier. Diodes have many benefits over resistors, one of which is that their PN-junctions can account for changes in the transistors' temperature.

Since the Class AB amplifier is simply a Class B amplifier with additional "Bias," we may state with accuracy that it is as follows:

Class A Amplifiers: Since they are biased in the middle of the load line, there is no crossover distortion.

Large quantities of crossover distortion in Class B amplifiers are caused by biasing at the cut-off point.

Class AB Amplifiers - If the biasing level is adjusted too low, some crossover distortion may occur. There are a variety of high efficiency amplifier classes related to switching amplifier designs that employ various switching strategies to decrease power loss and boost efficiency, in addition to the three amplifier classes mentioned above. To lessen power loss and distortion, several of these amplifier designs include RLC resonators or power distribution voltages. Summary of Amplifiers Typically, we think of amplifiers as the audio amplifiers found in the stereos, CD players, and radios we use at home. Although we examined the amplifier circuit that uses a single bipolar transistor as illustrated below in this section on amplifiers, there are other types of transistor amplifier circuitry that we might employ.

Typical Single Stage Amplifier Circuit (Figure 6.11)

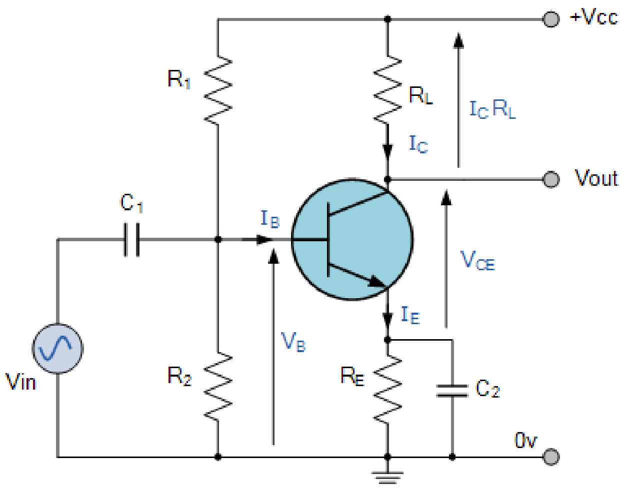

Figure 6.11: Typical Single Stage Amplifier Circuit

Amplifiers: Small Signal Amplifiers Summary

Voltage amplifiers are another name for small signal amplifiers.

Input Resistance, Output Resistance, and Gain are the three basic characteristics of voltage amplifiers.

The gain of a tiny signal amplifier refers to how much the input signal is "Amped" by the amplifier.

Gain, which has no units but is denoted by the letter (A), is a ratio of output divided by input. The most common forms of transistor gain are voltage gain (Av), current gain (Ai), and power gain (Ap)

Decibels, or simply dB, may be used to indicate the amplifier's power gain.

In a Class A type amplifier, DC Base Biasing is necessary in order to amplify all of the input signal without any distortion.

Halfway up the load line, DC Bias places the amplifier's Q-point.

Because of this DC Base biasing, the amplifier uses energy even when there is no input signal.

Because of the non-linear nature of transistor amplifiers, an erroneous bias setting will result in significant distortion of the output waveform.

Due to clipping, which is a kind of amplitude distortion, an input signal that is too big will result in significant distortion.

Saturation cutting or Cut-off clipping will result from the Q-incorrect point's placement on the load line.

The most popular general-purpose voltage amplifier circuitry employing a bipolar junction transistor is indeed the Common Emitter Amplifier design.

The most prevalent general-purpose voltage amplifier circuit employing a Junction Field Effect Transistor is indeed the Common Source Amplifier arrangement (Table 6.1).

Table 6.1: BJT Amplifier to JFET Amplifier Comparison

Parameter	Common Emitter Amplifier	Common Source Amplifier
Voltage Gain, (A_V)	Medium/High	Medium/High
Current Gain, (A_i)	High	Very High
Power Gain, (A_P)	High	Very High
Input Resistance, (R_{in})	Medium	Very High
Output Resistance, (R_{out})	Medium/High	Medium/High
Phase Shift	180^o	180^o

Amplifiers: Large Signal Amplifiers Summary

Power amplifiers are another name for large signal amplifiers.

Power amplifiers may be further classified into a number of Classes, such as:

1. Class A Amplifiers, in which the output device operates during the whole input cycle.
2. Class B Amplifiers: In these amplifiers, the output device conducts for just 50% of the input cycle.
3. Class AB Amplifiers: These amplifiers conduct the output device for more than 50% but much less than 100% of a input cycle.

A perfect power amplifier would provide the load with all of the available DC power.

The most popular kind of power amplifier, Class A amplifiers, only have an efficiency rating of the less than 40%.

Class B amplifiers are about 70% more efficient that Class A amplifiers but have substantial distortion levels.

Class B amplifiers are very energy-efficient in the absence of an input signal.

The "Push-pull" output stage layout may significantly minimize distortion.

But simple push-pull because to their cut-off point biasing, Class B Power Amplifiers may generate significant amounts of Crossover Distortion.

This crossover distortion may be reduced by pre-biasing resistors or diodes.

Transformers or complementary semiconductors may be used to create Class B Power Amplifiers at their output stage.

Chapter 7

Resistance of Emitters

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Any amplifier's goal is to maintain a constant DC biased input voltage while amplifying just the appropriate AC signal. This is accomplished by raising the bias stabilization of the amplifier using an emitter resistance linked to the emitter terminal of a transistor.The automated biasing necessary for a common emitter amplifier is provided by an emitter resistance, which is used to accomplish this stabilization. Consider the simple amplifier circuit below to help better clarify this.

Basic Common Emitter Amplifier Circuit (Figure 7.1)

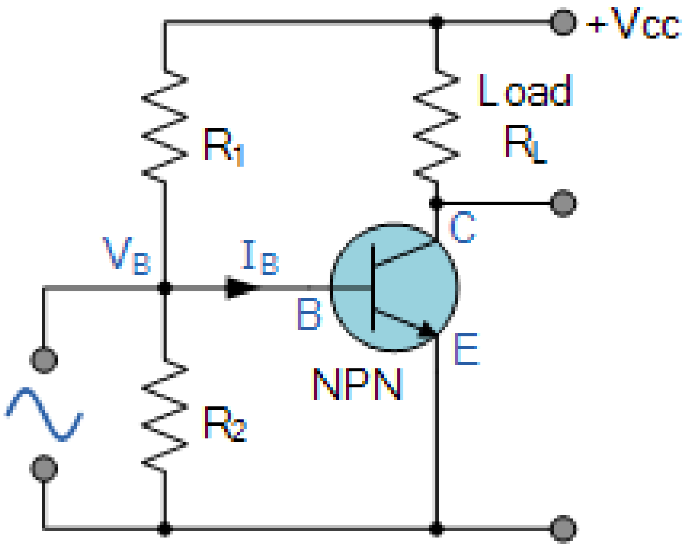

Figure 7.1: Basic Common Emitter Amplifier Circuit

A voltage divider network is used in the common emitter amplifier circuit depicted to bias the transistors' bases, and this arrangement is a relatively typical one for bipolar transistor amplifiers. The fact that a significant amount of current goes into the transistor base in this circuit is a crucial component.

The base voltage of the transistor, VB, is maintained at a constant level and is proportional to the supply voltage, VCC, by the voltage at the junction of the two biasing resistors, R1 and R2. Keep in mind that VB represents the voltage drop across R2 as measured from base to ground. The base current (Ib) of this "class-A" type amplifier circuit is usually intended to be less than 10% of the current passing through the biasing resistor R2. Therefore, the base current, IB, will be about one tenth of this, or 10, if we need a quiescent collector current of 1mA, for instance. Therefore, at least 10 times this amount, or 100, must be the current flowing through resistor R2 of the potential divider network. The stability of a voltage divider is its main benefit. The base voltage, Vb, maybe readily determined using the straightforward voltage divider formula as the voltage divider created by R1 and R2 is only weakly loaded.

Voltage Divider Equation (Figure 7.2)

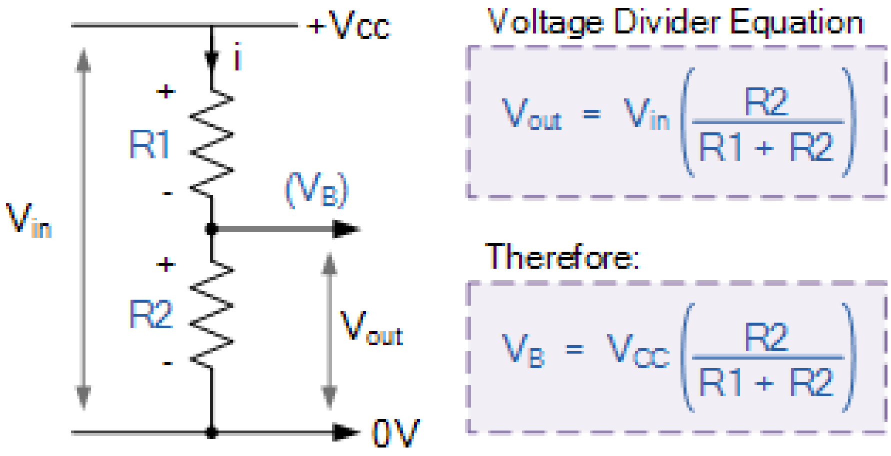

Figure 7.2: Voltage Divider Equation

The voltage divider networks is really not loaded either by base current in this sort of biasing setup because it is too tiny, therefore any variations in the supply voltage Vcc will likewise cause a corresponding change in the voltage level on the base. The transistor's base bias or Q-point then has to be stabilized by some means.

Emitter Resistance Stabilization (Figure 7.3)

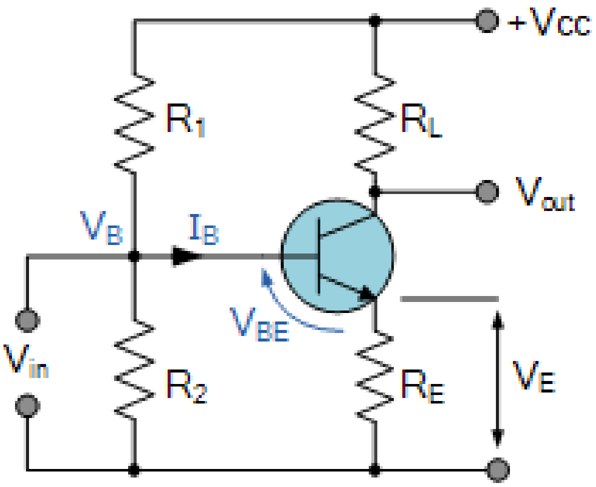

Figure 7.3: Emitter Resistance Stabilization

By including a single resistor inside the transistor's emitter circuit as illustrated, the bias voltage for the amplifier may be stabilized. The Emitter Resistance, or RE, is the name of this resistance. The inclusion of this emitter resistor causes the transistor's emitter terminal to be slightly above ground potential, as determined by the Ohms Law equation VE = IE x RE, rather than grounded either at zero volt potential. IE stands for actual emitter current.

Now, for a constant load resistance, the transistor's collector current Ic grows as the supply voltage Vcc rises. The voltage drop across RE will rise if the collector current rises since the corresponding emitter current should rise as well. Because VB = VE + VBE, this causes a proportionate rise in base voltage.

The divider resistors R1 and R2 maintain the base voltage constant, lowering the DC voltage upon that base relative towards the emitter Vbe by a corresponding amount. This reduces the base current drive and prevents the collector current from further growing. If the supply voltage plus collector current attempt to fall in value, the same thing happens. In other words, by using negative feedback to counteract any attempted change in collector current with a corresponding change in base bias voltage, the addition of this emitter terminal resistance helps to control the transistors' base biasing and enables the circuit to stabilize at a particular level.

The value of RE should also be as low as feasible since a portion of the supply is dropped across it, allowing the highest voltage to be created across the load resistance, RL, and ultimately the output. Its value must be just right, however, or the circuit instability risk will recur. The following equation is used to get the current flowing through into the emitter resistor:

Emitter Resistance Current

$$I_E = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E}$$

The voltage drop across in this emitter resistance is often calculated as follows as a rule of thumb: VB - VBE, or one-tenth (1/10th) of the supply voltage, Vcc. Typically, the voltage across the emitter resistor is between 1 and 2 volts, whichever is lower. Since the AC voltage gain has become equal to: RL / RE, it is also possible to determine the value of a emitter resistance, RE, from the gain.

Examples of Emitter Resistance No. 1

The properties of a typical emitter amplifier are as follows: = 100, Vcc = 30V, and RL = 1k. Calculate the resistance of the emitter if the amplifier circuit utilizes one to increase stability. The amplifier's ICQ (quiescent current) value:

$$I_{CQ} = \frac{\frac{1}{2}Vcc}{R_L} = \frac{15V}{1k\Omega} = 15mA$$

$$I_B = \frac{I_{CQ}}{\beta} = \frac{15mA}{100} = 150\mu A$$

The voltage drop across the emitter resistance is generally between 1 and 2 volts, so lets assume a voltage drop, V_E of 1.5 volts.

$$V_B = V_E + V_{BE} = 1.5V + 0.7V = 2.2\,\text{Volts}$$

$$R_2 = \frac{V_B}{10 \times I_B} = \frac{2.2}{10 \times 150\mu A} = 1.47k\Omega$$

$$R_1 = \frac{Vcc - V_B}{11 \times I_B} = \frac{30 - 2.2}{11 \times 150\mu A} = 16.67k\Omega$$

$$I_E = I_{CQ} + I_B = 15mA + 150\mu A = 15.15mA$$

$$R_E = \frac{V_E}{I_E} = \frac{1.5V}{15.15mA} = 100\Omega$$

The final common emitter circuit is then described as, "The value of the Emitter Resistance needed for the amplifier circuit as given as: 100:

Final Common Emitter Amplifier (Figure 7.4)

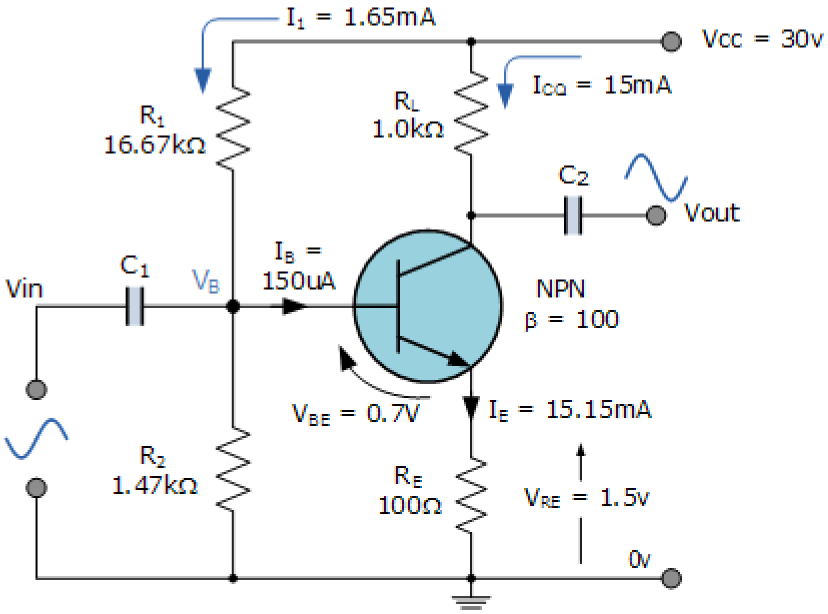

Figure 7.4: Final Common Emitter Amplifier

The gain of the amplifier stage can also be found if so required and is given as:

$$\text{Gain},(A) = \frac{R_L}{R_E} = \frac{1k\Omega}{100\Omega} = 10$$

Emitter By-pass Capacitor

The emitter resistor, RE, serves two purposes in the basic series feedback circuit above: DC negative feedback for steady biasing and AC negative feedback enabling signal permeability and voltage gain specification. But since the emitter impedance is a feedback resistor, changes in the emitter current caused by the AC input signal will likewise cause a reduction in the amplifier's gain (Figure 7.5).

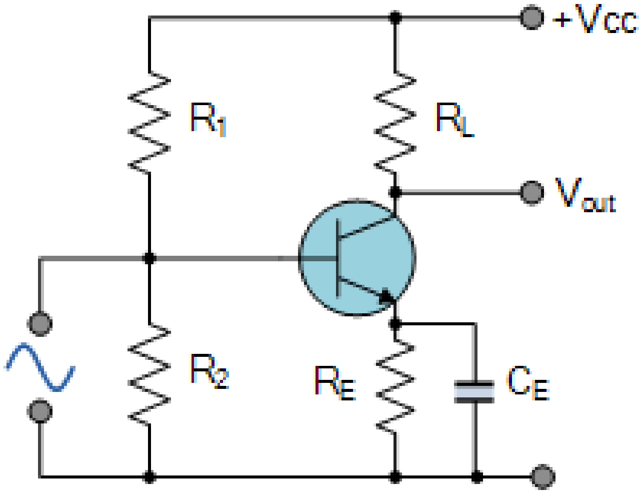

Figure 7.5: Emitter By-pass Capacitor

An "Emitter Bypass Capacitor," CE, is connected throughout the emitter resistance as indicated to solve this issue. By-passing (thus its name), this bypass capacitor enables the resonant frequency of a amplifier to fail at a predetermined cut-off frequency, c. Due to its nature as a capacitor, the bypass capacitor has no effect on the biased voltages and currents since it appears to the DC bias as an open circuit. This capacitor's reactance, XC, will be extraordinarily high at low frequencies throughout the entire frequency range of the amplifier, creating a negative feedback loop and lowering the amplifier's gain. At the lowest cut-off frequency, the value of this bypass capacitor CE is typically set to produce a capacitive reactance of, at most, one-tenth (1/10th) of the amount of the emitter resistor RE. After that, assuming that 100 Hz is the lowest information frequency that has to be amplified the bypass capacitor CE's value is determined as:

Emitter Bypass Capacitor

$$X_C = 1/10^{\text{th}} R_E \text{ at } f_{3dB} = 0.1 \times 100\Omega = 10\Omega$$

$$C_E = \frac{1}{2\pi f_{3dB} X_C} = \frac{1}{2\pi \times 100 \times 10} = 160\mu F$$

Then for our simple common emitter amplifier above the value of the emitter bypass capacitor connected in parallel with the emitter resistance is: 160μF

Split Emitter Amplifier

While the bypass capacitor, CE, counteracts the effects of beta uncertainty and aids in controlling amplifier gain, one of its key drawbacks is that at high frequencies, the reactance of the capacitor drops so low that it practically shorts out all the emitter resistance, RE as even the frequency rises. Because RE is shorted out as a consequence, the capacitor's reactance allows for very little AC feedback control at high frequencies, which further causes the transistor's AC voltage gain to grow significantly and push the amplifier into saturation. Splitting the emitter resistance into two halves as indicated is a simple method of adjusting the amplifiers gain throughout the entire operational frequency range.

Split Emitter Resistors

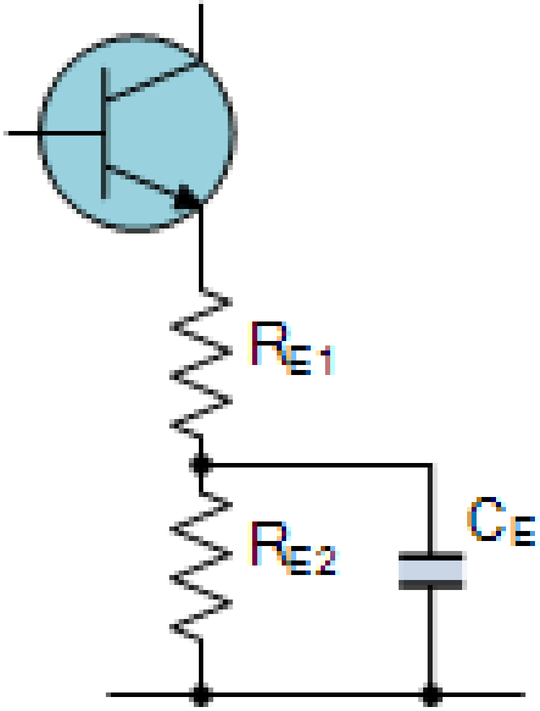

Figure 7.7:Split Emitter Resistors

In order to create a voltage divider network inside the emitter leg, the resistor in the emitter leg was divided into two halves, RE1 and RE2, with both the by-pass capacitor parallel connected from across lower resistor (Figure 7.7). When determining the signal characteristics, the higher resistor, RE1, which has the same value as previously but is not bypassed by the capacitor, must be taken into account. When determining signal parameters, the lower resistor RE2, which is linked in parallel with both the capacitor, is taken into account as zero ohms since it shorts out at high frequencies. The fact that we can regulate the amplifier's AC gain throughout the whole spectrum of input frequencies is a benefit in this situation. At lower AC frequencies, the emitter resistance is simply RE1, the same that it was in the original unbypassed circuit above, while at DC, the emitter resistance is equal to RE1 + RE2, and at higher AC frequencies, it is only RE1. What is resistor RE2's value then? The DC voltage gain necessary at the frequencies lower cut-off point will determine that, I suppose. We previously stated that the gain of the aforementioned circuit was equal to RL / RE, which for the aforementioned common emitter circuit was determined to be 10 (1k/100). The benefit, however, will now be equal to RL / (RE1 + RE2) at DC. The value of an emitter resistor, RE2, is given as follows if we choose a DC gain of let's say 1 (one):

Split-emitter Resistor, R_{E2}

$$\text{DC Gain}, \left(A_{dc}\right) = \frac{R_L}{\left(R_{E1} + R_{E2}\right)} = \frac{1k\Omega}{100 + R_{E2}} = 1$$

$$\therefore\ R_{E2} = \left(\frac{R_L}{A_{dc}} - R_{E1}\right) = \frac{1k\Omega}{1} - 100 = 900\Omega$$

With RE1 = 100 and RE2 = 900, respectively, yielding a DC gain of 1 (one). Note that at 10, the AC gain will remain constant.

Consequently, depending on the operating frequency, a split-emitter amplifier has voltage gain and input impedance values that fall halfway between those of a completely bypassed emitter amplifier and an unbypassed emitter amplifier.

Summary of Emitter Resistance

In conclusion, manufacturing tolerances, differences in supply voltage, and operating temperature may all affect how much a transistor's current amplification parameter,, varies from one device to the next of the same kind and part number.

Therefore, a biasing circuit which will stabilize the operational Q-point and make the DC collector current, IC, independent of beta is required for a common emitter class-A amplifier circuit. The installation of an Emitter Resistance, RE inside the emitter leg to provide stabilization may help to lessen the impact of on the magnitude of the emitter current.

Typically, a voltage drop of between one and two volts is stated over this emitter resistance. A proper bypass capacitor, CE placed in parallel with the emitter resistor to increase AC gain, or a split-emitter voltage divider network, which minimizes DC gain and distortion, may completely bypass the emitter resistor. Based on its capacitive reactance (XC) values at the lowest signal frequency, this capacitor's value may be calculated.

Classes of Amplifiers

Different amplifier designs exist. Between amplifier classes, there is a major difference in how their output stages are set up and work. Linearity, signal gain, efficiency, and power output are the primary operational qualities of an ideal amplifier, however in practical amplifiers, there is always a trade-off between these various features.

In order to drive a loudspeaker load, massive signal or power amplifiers are typically utilized in the output stages for audio amplifier systems. The impedance of a typical loudspeaker ranges from 4 to 8, hence a power amplifier has to be able to provide the high peak currents needed to drive the speaker's low impedance.

A way for differentiating the electrical properties of various amplifier types is by "class," and as a result, amplifiers are categorized in accordance with their circuit design and mode of operation.

The word used to distinguish between the various amplifier kinds is then amplifier classes.

The amount of a output signal that fluctuates inside the amplifier circuit throughout one cycle of operation when triggered by a sinusoidal input signal is represented by amplifier classes.

The efficiency of an amplifier may vary from being completely linear (for use in high-fidelity signal amplification) to being completely non-linear (where an accurate signal replication is not as necessary) while others are a balance between the two.

Amplifier classes may often be divided into two categories. The first are the classically regulated conduction angle amplifiers that make up the more popular amplifier classes A, B, AB, and C. These amplifiers are classified as either "fully-ON" or "fully-OFF" depending on how long their conduction state lasts over a given section of the output waveform.

The second group of amplifiers are the more recent so-called "switching" amplifier classes, such as D, E, F, G, S, and T, which continuously switch the signal across "fully-ON" and "fully-OFF" while pushing the output hard into the saturation and cut-off zones of transistors.

Class A, B, AB, and C audio amplifiers are the most often built amplifier classes. In in order to keep things simple, they will focus on these classes of amplifiers in greater depth below.

Classes of Class A Amplifiers

Class A amplifiers employ only one output switching transistor (Bipolar, FET, IGBT, etc.) in their amplifier architecture, making them the most prevalent form of amplifier topology. This single output transistor may conduct current throughout the whole input cycle because it is biased around the Q-point in the center of its load line and never pushed into its cut-off or saturation areas. One of the biggest drawbacks of a class-A topology is that its output transistor never goes "OFF."

Class "A" amplifiers are regarded as the finest class of amplifier design because, when constructed properly, they have great linearity, high gain, and minimal levels of signal distortion. Class-A amplifiers are perhaps the finest sounding of all the amplifier classes listed here, and as a result, they are employed in high-fidelity operational amplifier designs even though they are seldom used with high power amplifier applications owing to thermal power supply constraints.

Class A Amplifier

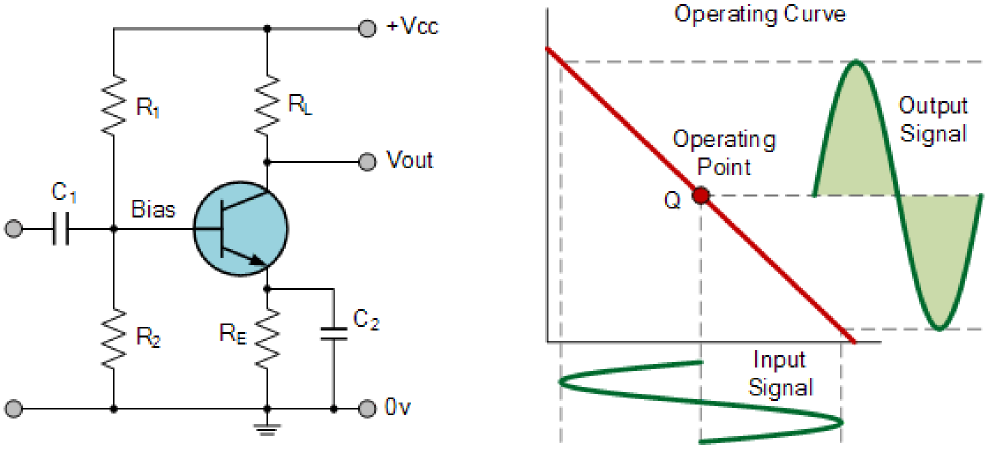

Figure 7.8: Class A Amplifier

The output stage of a class A amplifier is biased "ON" (conducting) constantly in order to obtain excellent linearity and gain (Figure 7.8). The zero signal idle current in the output stage must therefore be equal to or higher than the greatest load current needed (often a loudspeaker) to create the biggest output signal for an amplifier to be categorized as "Class A."

A single output device in a class A amplifier conducts across the whole output waveform while it works in the linear region of its characteristic curves. A current source is therefore equivalent to the class A amplifier.

The base (or gate) DC biasing voltage of the transistor should be carefully set to guarantee good functioning and minimum distortion since a class A amplifier works in the linear area. But because the output device is always "ON," current is continually being carried, which signifies a steady loss of power in the amplifier.

Class A amplifiers are unsuitable for high-power amplifications because to their continual loss of power, very high heat production, and extremely poor efficiency of just around 30%. The power supply has to be properly designed and filtered to prevent amplifier hum and noise owing to the amplifier's high idle current. More efficient amplifier classes have therefore been created as a result of Class A amplifiers' poor efficiency and overheating issues.

Classes of Class B Amplifiers

In order to address the efficiency and heating issues of the prior class A amplifier, class B amplifiers were created. The output stage of the basic class B amplifier is set up in a "push-pull" configuration, with two complementary transistors—either bipolar or FET—for each half of the waveform. As a result, each transistor component amplifies just half of the output waveform.

The class B amplifier has a far greater efficiency than the class A amplifier since it has no DC base bias current because its quiescent current is zero, resulting in a modest dc power. However, the linearity of a switching device is the price paid for the increase in efficiency.

Class B Amplifier

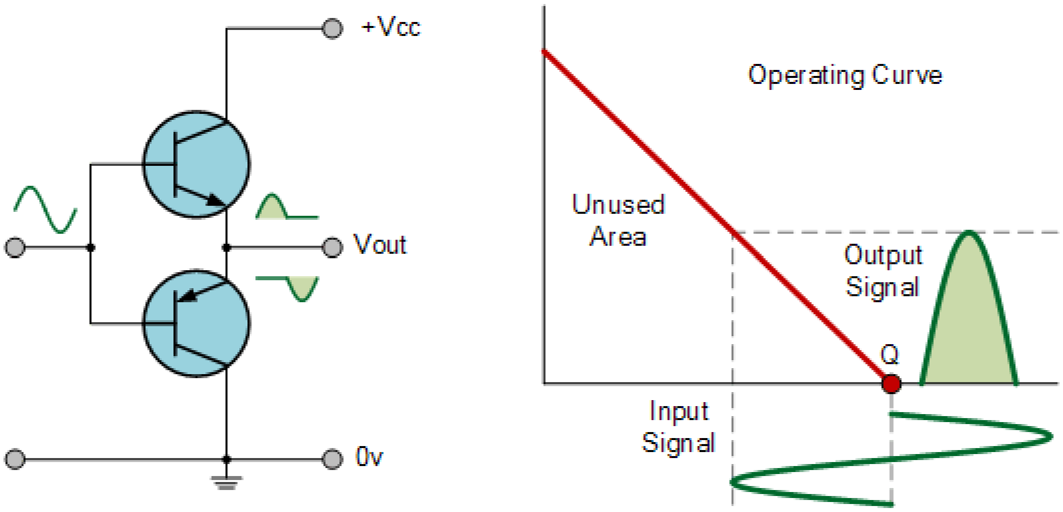

Figure 7.9: Class B Amplifier

The positive biased transistor conducts whenever the input signal is positive, whereas the negative biased transistor is turned "OFF." The positive transistor switches "OFF" when the input signal becomes negative, while the negatively biased transistor switches "ON" and conducts the negative component of the signal. As a result, the transistor only operates during the positive or negative half of the input signal's cycle (Figure 7.9).

The output stage has devices for both parts of the signal waveform, so the two halves are used together to produce the full linear output waveform. Then we can see that each cmos technology device of the class B amplifier conducts through one quarter or 180 degrees of both the output waveform in strict time alternation.

Although this push-pull amplifier design is around 50% more efficient than Class A, it has the drawback of introducing distortion at the waveform's zero-crossing point because of the transistors' dead band of input base voltages between -0.7V and +0.7V. As we recall from the lesson, a bipolar transistor must have a base-emitter voltage of around 0.7 volts in order to begin conducting. After that, until this voltage is surpassed, the output transistor in a class B amplifier is not "biased" to a "ON" state of operation. This implies that the class B amplifier is inappropriate for applications requiring precision audio amplifiers since the portion of the waveform that falls within this 0.7 volt window will not be precisely reproduced. Class AB amplifiers were created to combat this zero-crossing distortion, also referred to as crossover distortion.

Classes of Class AB Amplifiers

The Class AB Amplifier, as its name indicates, combines the "Class A" and "Class B" types of amplifiers that we have just examined. One of the most often utilized varieties of audio power amplifier design at the moment is the AB classification of amplifier. The class AB amplifier is an adaptation of the class B amplifier as previously described, with the exception that both devices are permitted to conduct simultaneously around the waveforms crossover point, hence removing the crossover distortion issues of the prior class B amplifier.

To bias the two transistors just above their cut-off point, a very tiny bias voltage is often used, typically between 5 and 10% of the quiescent current. The conducting device, whether bipolar or FET, will then remain "ON" for more than a half-cycle but for a much less period of time than a complete cycle of the input signal. As a result, each push-pull transistor in a class AB amplifier circuit conducts for significantly shorter time than a complete cycle of conduction in class A but somewhat longer than a half cycle of conduction in class B.

In other words, depending on the selected bias point, the conduction angle of a class AB amplifier ranges from 180o to 360o as indicated.

Class AB Amplifier

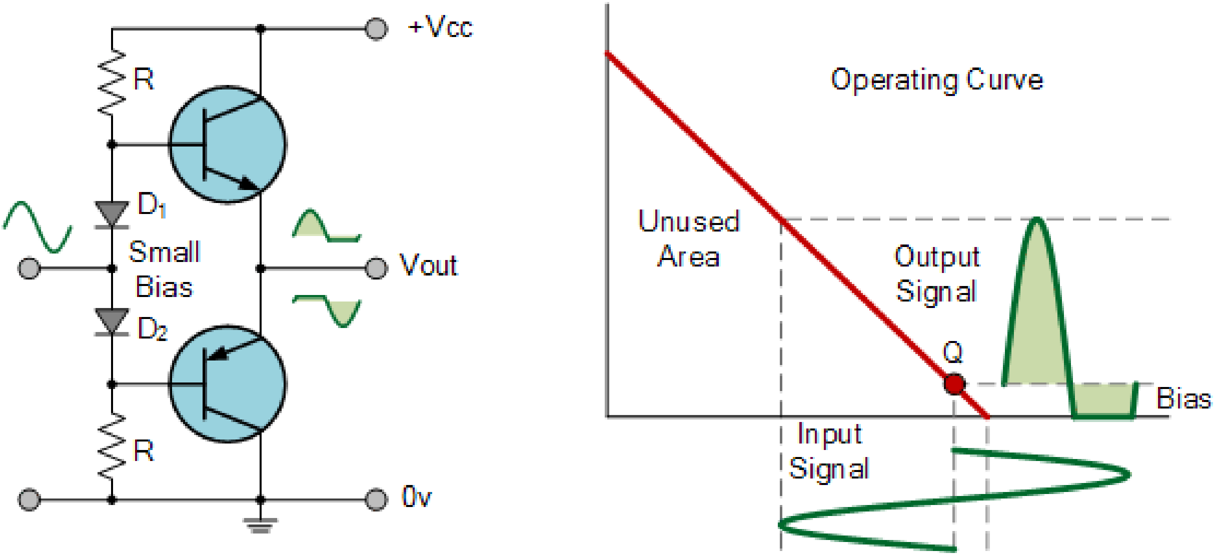

Figure 7.10: Class AB Amplifier

The benefit of this low bias voltage, which is supplied by series diodes or resistors, is that it eliminates crossover distortion while avoiding the drawbacks of the class A amplifier design. With conversion efficiencies of roughly 50% to 60%, the class AB amplifier is a nice middle ground between class A and class B in terms of efficiency and linearity (Figure 7.10).

Classes of Class C Amplifiers

Of the amplifying classes listed here, the Class C Amplifier Design offers the most efficiency but the worst linearity. The amplitude and phase of the output signals are linearly connected to those of the input signals, making the preceding classes, A, B, and AB, considered linear amplifiers. The transistor is idle at the cut-off point, but the class C amplifier is strongly biased so that the output current is zero for more than one-half of the input sinusoidal signal cycle. In other words, the transistor's conduction angle is much lower than 180 degrees, often in the 90 degree range.

While this method of biasing the transistors increases the amplifier's efficiency by around 80%, the output signal is severely distorted as a result. Class C amplifiers are thus not appropriate for use as audio amplifiers.

Class C Amplifier

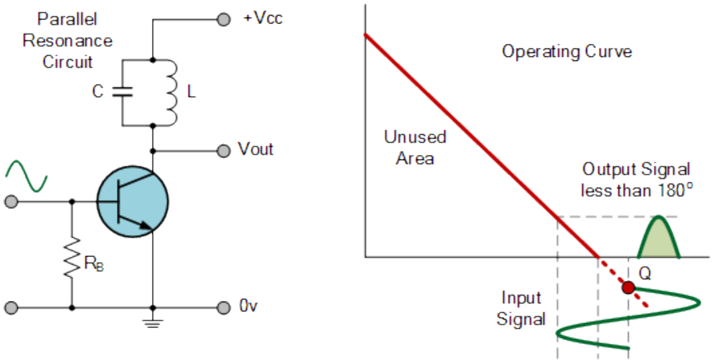

Figure 7.11:Class C Amplifier

Class C amplifiers are frequently used in high frequency sinusoidal waveform oscillators and some types of radio frequency amplifiers despite their significant audio distortion because the pulses of current they produce at their output can be transformed into complete sine waves of a specific frequency through the use of LC resonant circuits in their collector circuit.

Summary of Amplifier Classes

The categorization of an amplifier is then determined by the amplifier's quiescent DC operating point (Q-point). The amplifier will function as a class a amplifier if the Q-point is placed halfway down the load line of the characteristic curve. The amplifier becomes a class AB, B, or C amplifier by lowering the Q-point on the load linConsequently, the amplifier's class of operation in relation to its DC operating point may be expressed as:

Amplifier Classes and Efficiency

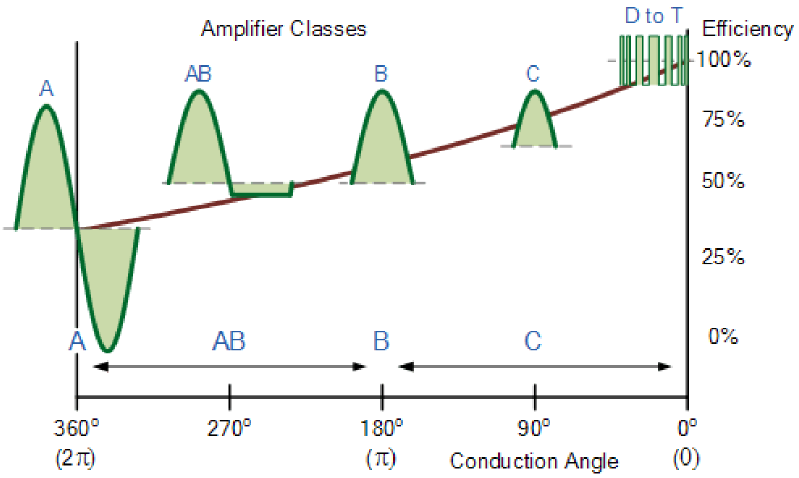

Figure 7.12: Amplifier Efficiency

There are a variety of high efficiency amplifier classes related to switching amplifier designs that employ various switching strategies to decrease power loss and enhance efficiency in addition to audio amplifiers. Some of the below-listed amplifier class designs include RLC resonators, various power supply voltages, or digital DSP (digital signal processing) type amplifiers that employ pulse width modulation (PWM) switching methods to decrease power loss (Figure 7.12).

Class D Amplifier - Other Popular Amplifier Classes A non-linear switching amplifier or PWM amplifier is essentially what a Class D audio amplifier is. Since current is exclusively pulled via the on transistor, there is never a time during a cycle when the voltage and current waveforms overlap. This allows class-D amplifiers to potentially achieve 100% efficiency.

Class-F amplifiers increase output and efficiency by transforming the output waveform into a square wave utilizing harmonic resonators in the output network. If infinite harmonic tuning is applied, Class-F amplifiers are capable of high efficiency of more than 90%.

Class G amplifiers provide upgrades to the standard class AB amplifier architecture. As the input signal changes, Class G employs a number of power supply rails of different voltages and automatically alternates between them. The average power usage and, therefore, power loss from wasted heat are reduced by this continual switching.

Class I Amplifier: The class I amplifier samples the same input waveform with both sets of complementary downstream switching devices placed in a parallel push-pull arrangement. Similar to a class B amplifier, one device switches the dc component of the waveform while the other changes the negative half. The switching devices are simultaneously switched ON and OFF when there is no input signal provided, or when a signal crosses the zero crossing point, with a 50% PWM switching frequency canceling out any high frequency impulses. The output of the affirmative switching device's duty cycle is raised to generate the positive half of a output signal, while the duty cycle of the negative active switch is lowered to achieve the opposite result. The class I amplifier is referred to as a "interleaved PWM amplifier" when it operates at switching frequencies more than 250 kHz because the two switching signal currents are stated to be interleaved at the output.

Class S power amplifiers are non-linear switching mode amplifiers that function similarly to class D amplifiers. A delta-sigma modulator transforms analog input signals into digital square wave pulses that are then amplified by the class S amplifier to enhance output power before being demodulated by a band pass filter. Efficiency levels of 100% are feasible since the digital signal of this switching amplifiers is always completely "ON" or "OFF" (theoretically zero power dissipation).

Amplifier Class T - Another sort of digital switching amplifier architecture is the class T amplifier. Due to the availability of digital signal processing (DSP) chips and multi-channel virtual surround amplifiers, class T amplifiers are starting to gain popularity as an audio amplifier design. By converting analog data into digital pulse width modulated (PWM) messages for amplification, class T amplifiers increase the efficiency of the amplifier. Class T amplifier designs combine the power efficiency of a class D amplifier with the low distortion signal levels of a class AB amplifier.

Here, we've seen a variety of amplifier classifications, from linear power amplifiers to non-linear switching amplifiers, and we've seen how each class of amplifier varies along the load line of the amplifier. According to the conduction angle, the class AB, B, and C amplifiers may be described as follows Table 7.1:

Table 7.1: Amplifier Class by Conduction Angle

Amplifier Class	Description	Conduction Angle
Class-A	Full cycle 360° of Conduction	$\theta = 2\pi$
Class-B	Half cycle 180° of Conduction	$\theta = \pi$
Class-AB	Slightly more than 180° of conduction	$\pi < \theta < 2\pi$
Class-C	Slightly less than 180° of conduction	$\theta < \pi$
Class-D to T	ON-OFF non-linear switching	$\theta = 0$

Transistor Biasing

A bipolar transistor's steady state performance heavily relies on the parameters of its base current, collector voltage, but also collector current. Because poor transistor biasing will lead to distorted output, the transistor must be appropriately biased around its operating point in order to function as a linear amplifier. The choice of bias resistors with load resistors to give the proper input current but also collector voltage conditions is necessary to establish the right operating point. A bipolar transistor's proper biasing point, whether NPN or PNP, often falls between the two states of operation when it is either "fully-ON" or "fully-OFF" itself along the DC load line. The "Quiescent Operating Point," or Q-point for short, is this core operating point. A bipolar transistor is considered to be working as a Class-A amplifier when the bias is set such that the Q-point is about in the center of its operational range, or halfway between cut-off and saturation. With this mode of operation, the input signal swings throughout one full cycle while the output voltage fluctuates about the amplifier's Q-point without introducing distortion. This means that the output is accessible during the whole 360o of the input cycle.

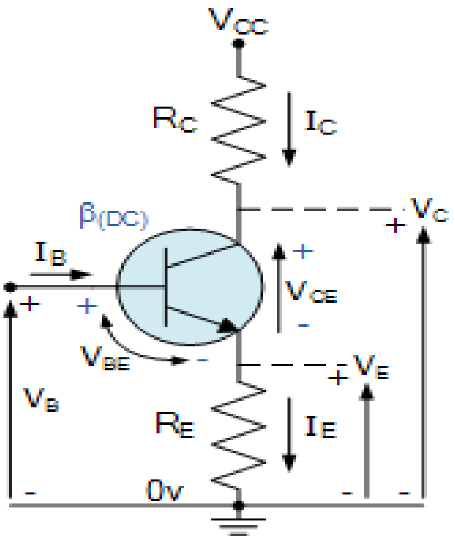

Figure 7.13: Transistor Biasing

But first, let's refresh our memories on a simple single transistor circuit and its voltages and currents, as illustrated on the left, before we begin to consider the many transistor biasing arrangements that can be feasible (Figure 7.13).

By adjusting the transistor's Collector current (IC) to a constant and steady state value without applying any external input signals to the transistor's Base, the "DC Bias level" serves to appropriately establish the transistor's Q-point.

The values of both the circuit's DC supply voltage (Vcc) and any biasing resistors connected towards the transistors' Base terminal determine this steady-state or DC operating point. The correct usage of coupling and bypass capacitors will assist prevent any biasing currents from previous transistor stages altering the bias conditions of the subsequent transistor stage since the transistors' base bias currents were steady-state DC currents. Common-base (CB), common-collector (CC), and common-emitter (CE) transistor designs may all employ base bias networks. We will examine the various biasing setups possible for a Common Emitter Amplifier in this straightforward lesson on transistor biasing.

Chapter 8

Typical Emitter Biasing of Transistors

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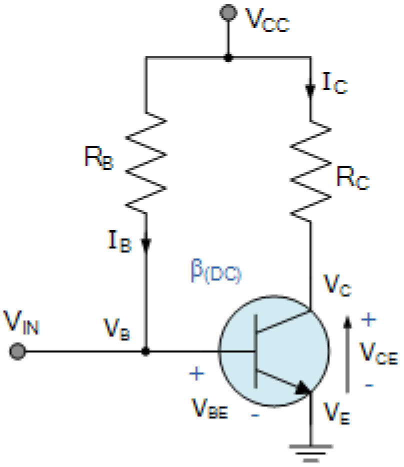
With the self-biasing of the emitter-bias circuit, one or more biasing resistors are used to configure the initial DC values again for three transistor currents (IB), (IC), and (IC). This is one of the most often used biasing circuits for transistor circuits (IE). Beta Dependent and Beta Independence are the two types of bipolar transistor biasing that are most often used. The biasing configuration for one transistor may not always be the same for another transistor since their beta values may change. Transistor bias voltages are highly reliant on transistor beta, (), therefore this may not always be the case. A single feed-back resistor or a straightforward voltage divider network may both be used to provide the necessary biasing voltage for transistor biasing.

Here are five possibilities for transistor base bias using a single source (Vcc).

Fixed Base Biasing a Transistor (Figure 8.1)



$$V_C = V_{CC} - (I_C R_C)$$
$$V_{CE} = V_C - V_E$$
$$V_E = 0v$$
$$V_B = V_{BE}$$
$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$
$$I_C = \beta_{(DC)} I_B$$
$$I_E = (I_C + I_B) \cong I_C$$

Figure 8.1: Fixed Base Biasing a Transistor

The circuit shown is referred to as a "fixed base bias circuit" since the operating point of the transistors also needs to be stable because the base current of the transistors, IB, is constant for specific values of Vcc. Using a fixed current bias, this four resistor biasing connection is utilized to create the transistor's initial functioning area. As the steady-state conditions of operation is a consequence of the transistor's beta value, this form of transistor inherently biased arrangement is likewise beta dependent. As a result, the biasing point will vary widely for transistors with the same type because their characteristics won't be precisely the same.

By using the current limiting resistor RB to deliver the necessary positive base bias voltage, the transistor's emitter diode is forward biased. The forward base-emitter voltage drop, assuming a typical bipolar transistor, would be 0.7V. If so, (VCC - VBE)/IB, wherein IB is defined as IC/, is the value of RB. The biasing voltages and currents using this single resistor kind of biasing configuration are not constant throughout transistor operation and might fluctuate greatly. Additionally, the operating point of the transistor may be negatively impacted by its operating temperature.

Collector Feedback Biasing (Figure 8.2)

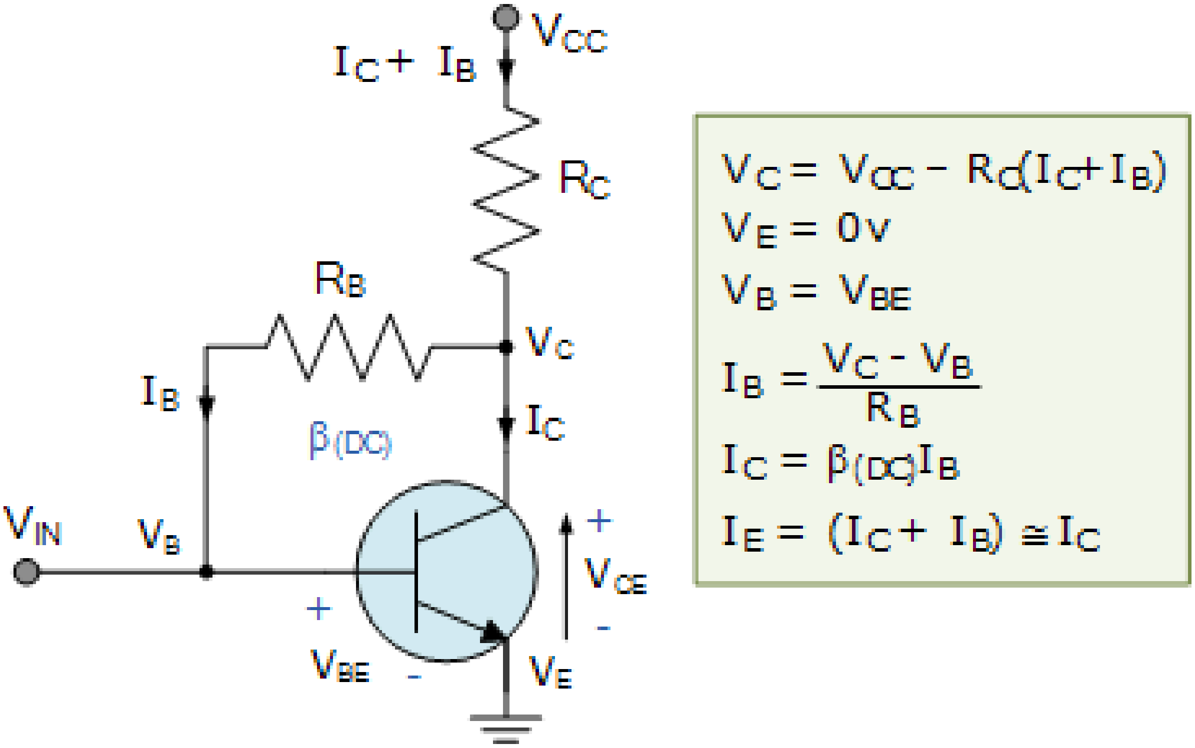


Figure 8.2: Collector Feedback Biasing

Another beta dependent biasing technique, the self-biasing collector feedback design calls for two resistors to provide the transistor with the required DC bias. Regardless of the amount of Beta (), the transistor is always biased in the active area thanks to the collector to base feedback design. Since the collector voltage VC is used to calculate the DC base bias voltage, stability is high.

Instead of being linked to the supply voltage rail, Vcc, in this circuit, the base bias resistor, RB, is connected to the transistor's collector, C. Consequently, if the collector current rises, the collection voltage falls, lowering the base drive and causing the collector current to fall automatically to maintain the transistors Q-point constant. Because there is direct feedback from the output terminal towards the input terminal through the resistor, RB, this technique of collector feedback biasing results in negative feedback all around the transistor. Since the voltage drop from across load resistor, RL, is what determines the biasing voltage, an increment in the load current will result in a greater voltage drop across RL and a corresponding decrease in the collector voltage, VC. The base current, IB, will decrease in accordance with this impact, returning IC to normal in the process. When the transistor's collector current decreases, the opposite response will likewise take place. The transistors' stability utilizing this form of feedback bias network is typically excellent for most amplifier designs, hence this technique of biasing is known as self-biasing..

Dual Feedback Transistor Biasing (Figure 8.3)

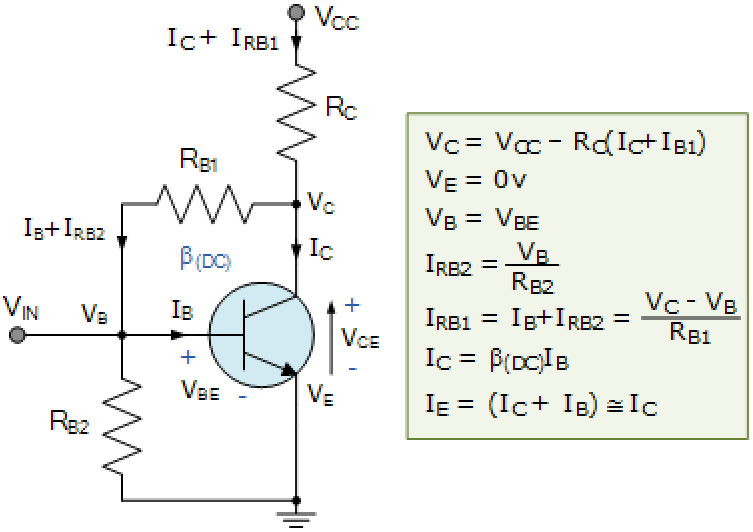


Figure 8.3: Dual Feedback Transistor Biasing

By boosting the current flowing through into the base biasing resistors, adding an extra resistor to the base bias networks of the preceding arrangement increases stability with regard to changes in Beta ().

The collector current, IC, is typically adjusted to 10% of the current flowing through RB1. Naturally, it also has to be higher than the base current needed to achieve the minimal value of Beta.

One benefit of this kind of self-biasing design is that the two resistors simultaneously give automatic biasing and R feedback.

Emitter Feedback Configuration (Figure 8.4)

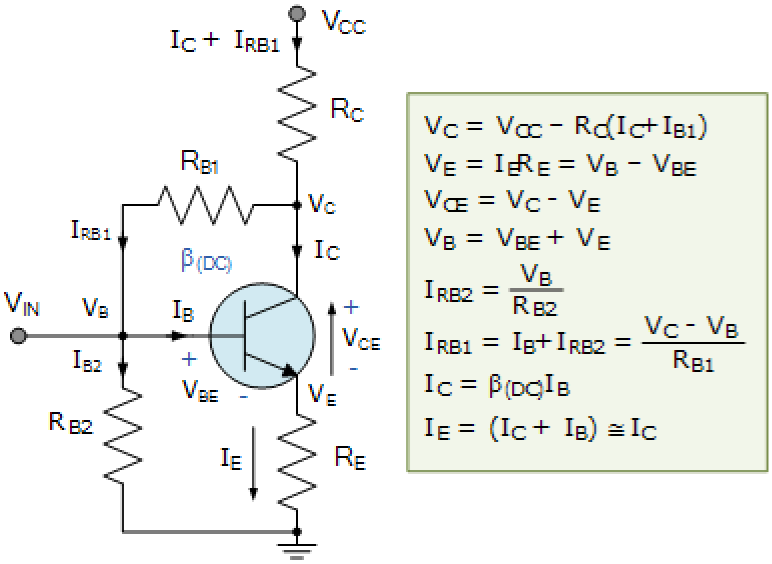
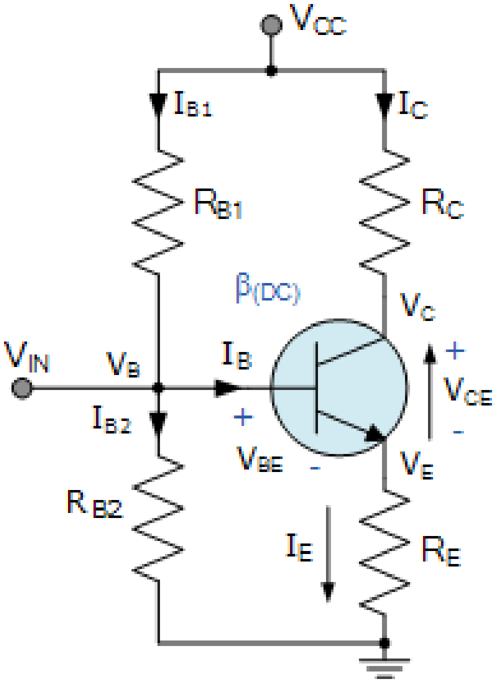


Figure 8.4: Emitter Feedback Configuration

This kind of transistor biasing setup, also known as self-emitter biasing, employs base-collector and emitter feedback that will further stabilize the collector current. This is due to the fact that the resistors RB1 and RE, as well as the transistor's base-emitter junction, are all actually wired in series with the supply voltage, VCC. The drawback of this emitter feedback setup is that the bottom resistor connection limits output gain. The current flowing through into the feedback resistor, RB1, is determined by the collector voltage and results in "degenerative feedback." The voltage drop across RE caused by the current coming from the emitter, IE (which is an combination of IC + IB), reverse biased the base-emitter junction. As a result, as the collector current rises, the voltage drop I*RE likewise increases as the emitter current grows. IB immediately decreases because the base-emitter junction is reverse biased by the polarity of this voltage. As a result, the emitter current increased less than it would have if the self biasing resistor hadn't been there. The voltage dropped throughout the emitter resistor RE should be around 10% of VCC, and the current that flows through the resistor RB1 should be 10% of the collector current IC. In light of this, comparatively low power supply voltages are optimal for this sort of transistor biasing setup.

Voltage Divider Transistor Biasing (Figure 8.5)



$$V_C = V_{CC} - R_C I_C = (V_E + V_{CE})$$
$$V_E = I_E R_E = V_B - V_{BE}$$
$$V_{CE} = V_C - V_E = V_{CC} - (I_C R_C + I_E R_E)$$
$$V_B = V_{BE} + V_E = V_{RB2} = \left(\frac{R_{B2}}{R_{B1} + R_{B2}}\right) V_{CC}$$
$$I_{B2} = \frac{V_B}{R_{B2}}$$
$$I_{B1} = I_B + I_{B2} = \frac{V_{CC} - V_B}{R_{B1}}$$
$$R_B = \frac{R_{B1} \times R_{B2}}{R_{B1} + R_{B2}} \qquad I_B = \frac{V_B - V_{BE}}{R_B + (1+\beta) R_E}$$
$$I_C = \beta_{(DC)} I_B$$
$$I_E = I_C + I_B = \frac{V_E}{R_E}$$

Figure 8.5: Voltage Divider Transistor Biasing

Here, a voltage divider network is used to bias the common emitter transistor design to improve stability. The two resistors, RB1 and RB2, create a voltage or potential divider network across the supply, and their center point junction is linked to the transistor's base terminal as indicated, giving this biasing arrangement its name.

The most common transistor biasing setup is this voltage divider biasing design. The voltage that has built up across resistor RB2 is what forward biases the transistor's emitter diode. Furthermore, because the biasing voltages established at the transistors' base, emitter, and collector terminals are independent of the values of the external circuit, voltage divider network biasing renders the transistor circuit immune to variations in beta. We only use the voltage divider formula for resistors in series to get the voltage created across resistor RB2 and, therefore, the voltage supplied to the base wire. In comparison to resistor RB1, the voltage drop across resistor RB2 is often substantially lower. It is obvious that the voltage across RB2 will be equal to the transistor's base voltage, VB, with respect to ground.

In order to ensure that the voltage divider current and variations in Beta are not impacted, the biasing current via resistor RB2 is often adjusted to 10 times the value of the necessary base current IB. Establishing a recognized quiescent operating point, or Q-point, for the bipolar transistor to function effectively and provide an undistorted output signal is the aim of transistor biasing.

With realistic biasing circuits that use either a two or four-resistor bias network, proper DC biasing of the transistor also sets its first AC working area. The Q-point is denoted in bipolar transistor circuits by (VCE, IC) for NPN transistors or (VEC, IC) for PNP transistors. The collector current as a function of temperature and Beta () is often used to evaluate the stability of the base bias network and therefore the Q-point. Here, we've taken a quick look at five distinct resistive network designs for "biasing a transistor."

However, by connecting silicon diodes, zener diodes, or active networks to the transistor's base terminal, we may also bias a transistor. If desired, we could also power the transistor with a dual voltage supply and bias it appropriately.

A transistor amplifier's input impedance, also known as ZIN or input resistance, is a crucial design factor. As a result, amplifiers may be classified according to respective effective input and output impedances, as well as their power but also current ratings.

When cascading various amplifier stages together following one another to reduce signal distortion in the amplification circuit, an amplifier's impedance value is particularly crucial for circuit analysis. An amplifier's input impedance is what the source driving the amplifier's input "sees," according to Wikipedia.

If it is set too low, it may negatively load the stage before it and may impact its frequency response overall output signal level. Common emitter and common collector amplifier circuits, however, often have high input impedances in most applications.

Some amplifier designs, like the common collector amplifier circuit, have high input and low output impedances by virtue of their construction alone. In situations where an amplifier's input impedance is smaller than desired, the output impedance of something like the preceding phase can be adjusted to compensate, or if this is not possible, buffer amplifier stages may be required. Amplifiers can now have high input impedance, output impedance, and practically any arbitrary gain.

An amplifier circuit must also feature current amplification (Ca) in addition to voltage amplification (Av) (Ai). An amplifier circuit should also be capable of power amplification (Ap). An amplifier circuit must also include other qualities like high input impedance (ZIN), low output impedance (ZOUT), and some degree of bandwidth in addition to these three crucial ones (Bw). The "ideal" amplifier will have an infinite input impedance and a zero output impedance in either case.

Input and Output Impedance, as shown in Figure 8.6:

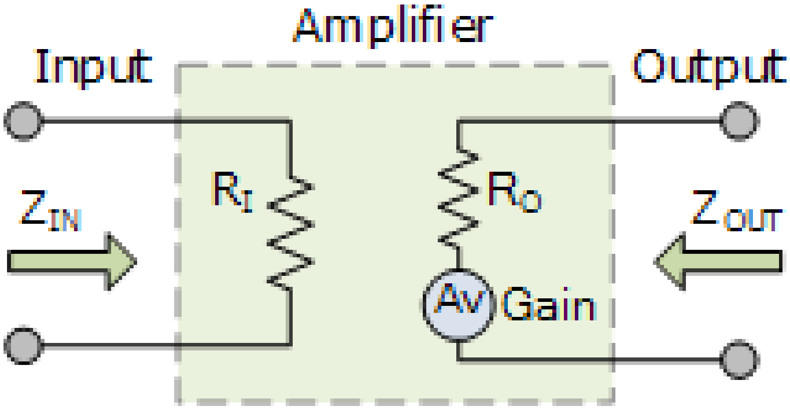


Figure 8.6: Input and Output Impedance

An amplifier may be compared to a "black box" in many aspects, with two input terminals and two output connections as depicted. In order to determine the DC set point but also operating parameters of an amplifier, this concept offers a straightforward h-parameter model of the transistor. In actuality, the input and the output share a terminal that represents ground or zero volts. These terminals have an output impedance, ZOUT, and an input impedance, ZIN, when viewed from the outside in. The proportion of voltage to current flowing into or out of these terminals determines the input and output susceptibility of an amplifier. Whereas the output impedance may change depending on the load impedance, RL from across output terminals, the input impedance may be influenced by the source supply powering the amplifier. Alternating currents (AC) are often used for the input signals being amplified, and the amplifier circuit acts as a load by connecting Z to the source. An amplifier's input impedance ranges from a few tens of ohms (Ohms) for bipolar transistor circuitry to several thousand ohms (Kilo-ohms k) to millions of ohms (Mega-ohms M) for FET transistor circuits. The related electrical characteristics of the amplifier circuit may be represented when a signal source and load are linked to an amplifier, as illustrated.

Output and Input Impedance Model (Figure 8.7)

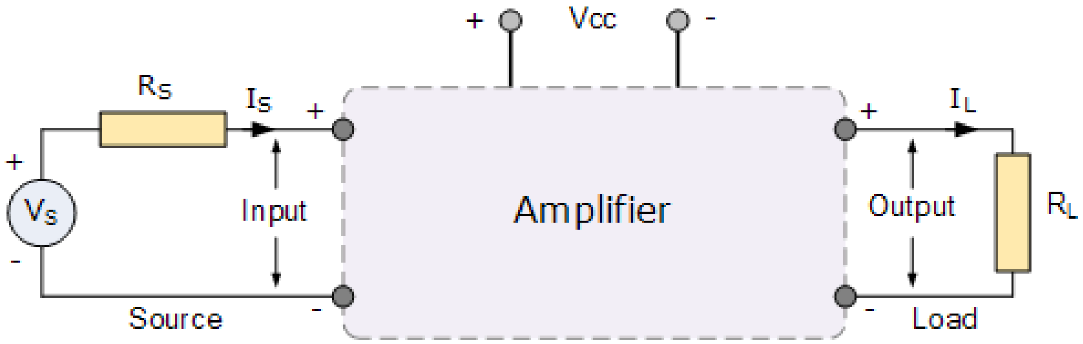


Figure 8.7: Output and Input Impedance Model

Where RL is the load resistance attached from across output, RS is the input impedance of both the signal source, and VS is the signal voltage. By examining the connections between the amplifier's source and load, we may further develop this concept. When a signal sources is connected to an amplifier, the supply "sees" the amplifier's input impedance, Zin, as a load. Similar to this, the amplifier detects the input voltage, Vin, across the input impedance, Zin. Then, as illustrated, the amplifier's input may be modeled as a straightforward voltage divider circuit.

Amplifier Input Circuit Model (Figure 8.8)

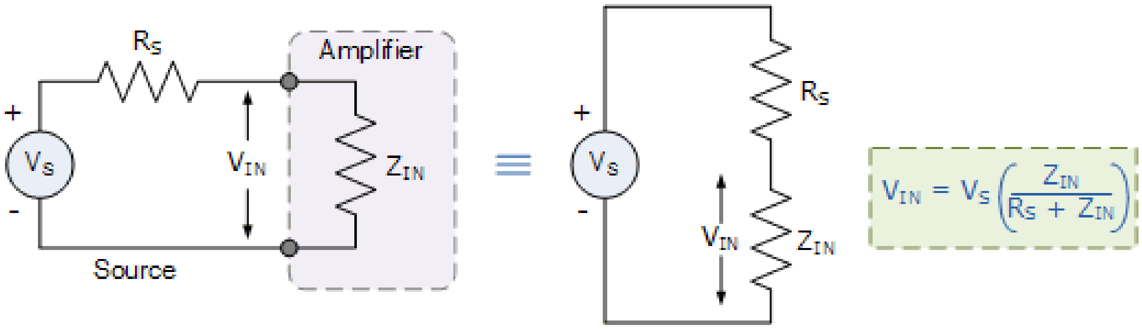


Figure 8.8: Amplifier Input Circuit Model

The amplifier's output impedance follows the same logic. When an amplifier's output is coupled with a load resistance (RL), the amplifier serves as the source that powers the load. As a result, as indicated, the source voltage and source impedance for something like the load are automatically converted from the output voltage and impedance.

Amplifier Output Circuit Model

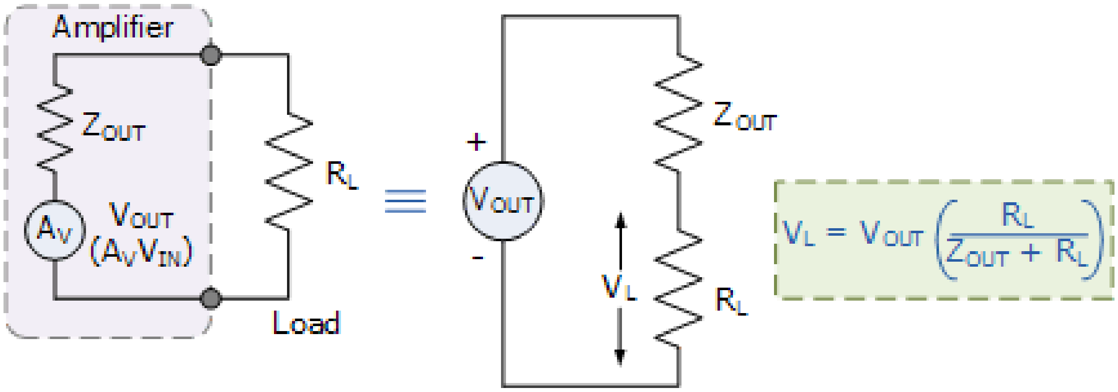


Figure 8.9: Amplifier Output Circuit Model

Then it becomes clear that an amplifier's input and output properties may both be modeled as a straightforward voltage divider network. The amplifier itself may be set up as a common base, common collector, or common emitter (emitter grounded) arrangement. We will examine the previously mentioned bipolar transistor linked in a common emitter configuration in this lesson (Figure 8.9).

Amplifying emitters in common

A potential divider network is used in the so-called traditional common emitter arrangement to bias the transistors' base. The transistor operating point is set to conduct in the forward active mode by the biasing resistors and the power supply Vcc.

The voltage on the Collector is the same as the supply voltage, Vcc, when there is no signal current flowing into the Base (transistor in cut-off). When a signal current flows into the base, it flows through the collector resistor (Rc), causing a voltage drop across it and a corresponding drop in the collector voltage.

The polarity is then reversed since the direction of change in the Collector voltage is then the opposite of the direction of change in the Base voltage. As a result, the common emitter arrangement amplifies the voltage across the collector to generate a high voltage and a clearly defined DC voltage level, as illustrated, with resistor RL acting as the load across the output..

Single Stage Common Emitter Amplifier (Figure 8.10)

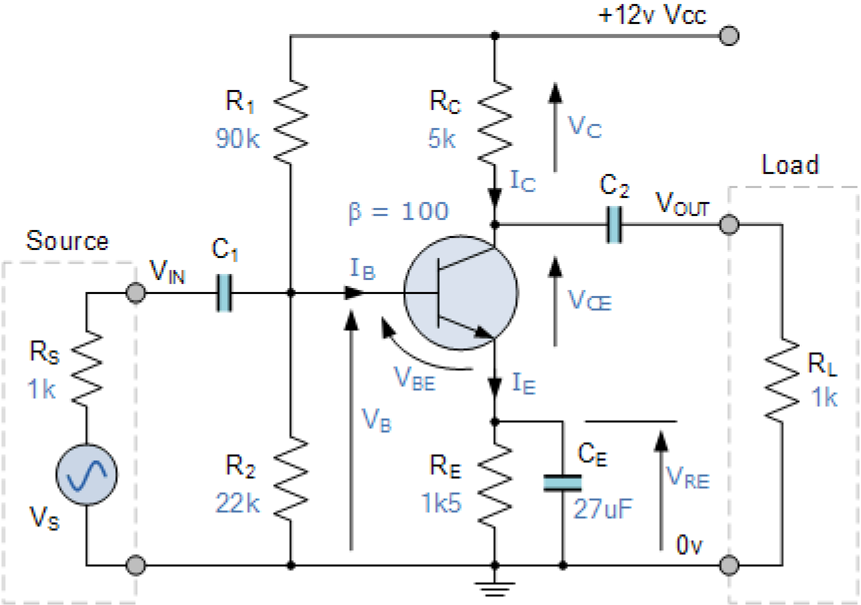


Figure 8.10: Single Stage Common Emitter Amplifier

A quick review will help us better understand how the amplifier's values were determined so that we can use the above circuit to determine the amplifier's input impedance. Hopefully by this point, we have been able to calculate the values of the resistors needed for the transformer to continue operating in the middle of its linear active region, known as the quiescent point or Q point. To identify the operating point of the transistor, let's first make a few basic assumptions regarding the single stage common emitter amplifier circuit. Circuit above. The corner or breaking frequency of a amplifier is provided as: -3dB = 40Hz. The voltage drop from across emitter resistor is given as VRE = 1.5V, the quiescent current is given as IQ = 1mA, and the current gain (Beta) of the NPN transistor is given as 100 (= 100).

We may state that: IC = IE = IQ = 1mA because the quiescent current, which does not have an input signal, passes via the Collector and Emitter of the transistor. Inferring from Ohm's Law:

$$R_E = \frac{V_{RE}}{I_E} = \frac{1.5V}{1mA} = 1500\Omega \text{ or } 1.5k\Omega$$

For maximal output signal swing between peak-to-peak around the center point without output signal clipping, the voltage drop from across Collector resistor, Rc, will be half of Vcc - VRE when the transistor is fully-ON (saturation).

$$V_{RC} = \frac{V_{CC} - V_{RE}}{2} = \frac{12 - 1.5}{2} \cong 5V$$

$$\therefore R_C = \frac{V_{RC}}{I_C} = \frac{5}{1mA} = 5k\Omega$$

Keep in mind that -RC/RE may be used to determine the amplifier's DC no signal voltage gain. Also take note of the voltage gain's negative value, which results from the output signal's inversion of the original input signal.

The Base-Emitter junction of an NPN transistor functions as a forward-biased diode since it is forward biased, therefore the Base voltage (Ve + 0.7V) will be 0.7 volts higher than the Emitter voltage. As a result, the voltage across the Base resistor R2 will be:

$$V_{R2} = V_{RE} + V_{BE} = 1.5 + 0.7 = 2.2V$$

If the two biasing resistors are already given, we can also use the following standard voltage divider formula to find the Base voltage Vb across R2.

$$V_{R2} = V_{CC}\left[\frac{R_2}{R_1 + R_2}\right]$$

According to the information provided, the quiescent current is 1mA. As a result, the transistor is biased using a 1mA collector current across the Vcc, or 12 volt supply. As Ic = *Ib, the Collector voltage is inversely proportional to the Base current. If the transistor's DC current gain, Beta (), is 100, the base current flowing through into transistor will be:

$$\beta = 100 = \frac{Ic}{Ib} \qquad \therefore Ib = \frac{Ic}{\beta} = \frac{1mA}{100} = 10\mu A$$

The voltage divider network of R1 and R2 creates the DC bias circuit, which establishes the DC operating point. In order to create the voltage across the 12 volt supply, Vcc, which was previously predicted to be at 2.2 volts for the base voltage, we must determine the appropriate ratio of R1 to R2.

Typically, the current flowing through into the lower resistor, R2, is 10 times more than the DC current going into the Base for a conventional emitter amplifier circuit's normal voltage divider DC biasing network. Consequently, the resistor's value, R2, may be computed as:

$$I_{R2} = 10 \times Ib = 10 \times 10\mu A = 100\mu A$$

$$R_2 = \frac{V_{R2}}{I_{R2}} = \frac{2.2V}{100\mu A} = 22k\Omega$$

The supply voltage less the base bias voltage will be the voltage applied across resistor R1. Additionally, the higher resistor R1 in the series chain must carry both the current of R2 and the transistor's real Base current, Ib, assuming resistor R2 carries 10 times normal Base current. Alternatively, 11 times the Base power as shown.

$$V_{R1} = V_{CC} - V_B = 12 - 2.2 = 9.8V$$

$$I_{R1} = I_{R2} + I_B = 100\mu A + 10\mu A = 110\mu A$$

$$\therefore R_1 = \frac{V_{R1}}{I_{R1}} = \frac{9.8V}{110\mu A} = 90k\Omega$$

The reactance Xc of the Emitter bypass capacitor for a common emitter amplifier is typically one tenth (1/10th) the magnitude of the Emitter resistor, RE, at the cut-off frequency point.

A 40Hz -3dB corner frequency was specified in the amplifier's specs, thus the value of the capacitor CE is computed as:

$$\text{at } 40Hz, \quad X_C = \frac{1}{10} \times R_E = \frac{1500}{10} = 150\Omega$$

$$C_E = \frac{1}{2\pi f X_C} = \frac{1}{2\pi.40.150} = 27\mu F$$

Our common emitter amplifier circuit's input and output impedances, as well as the values of both the coupling capacitors C1 and C2, can now be calculated thanks to the values we previously set for it.

Model for a Simple Emitter Amplifier

ZIN = VIN/IIN is the universal formula for calculating the input impedance of any circuit. The transistor's DC operating "Q" point is determined by the DC bias circuit. As an open circuit, the input capacitor C1 prevents any externally provided DC voltage.

The circuit's input impedance (ZIN) will be exceedingly high at DC 0Hz. Capacitors operate as short circuits during high frequencies and pass the AC input signal, but when an AC signal is delivered to the input, the properties of the circuit change.

ZIN = REQ||(RE+ re) is the generalized formula again for AC input impedance of an amplifier staring into the base. Where re seems to be the internal signal resistance of the backward biased Emitter layer and REQ is the equivalent resistance to ground (0 v) of a biasing network from across Base.

We may then redraw the common emitter circuit above while follows if we short off the 12 volt power supply, Vcc to ground since Vcc looks as a short to AC signals.:

Chapter 9

Amplifier Circuit Model

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The transistor is then shown to have a number of resistors linked in parallel across it with their supply voltage shorted. We may redraw the above circuit to define overall input impedance of a amplifier as by focusing just on the input side of the transistor amplifier and considering capacitor C1 as a short circuit to AC signals (Figure 9.1):

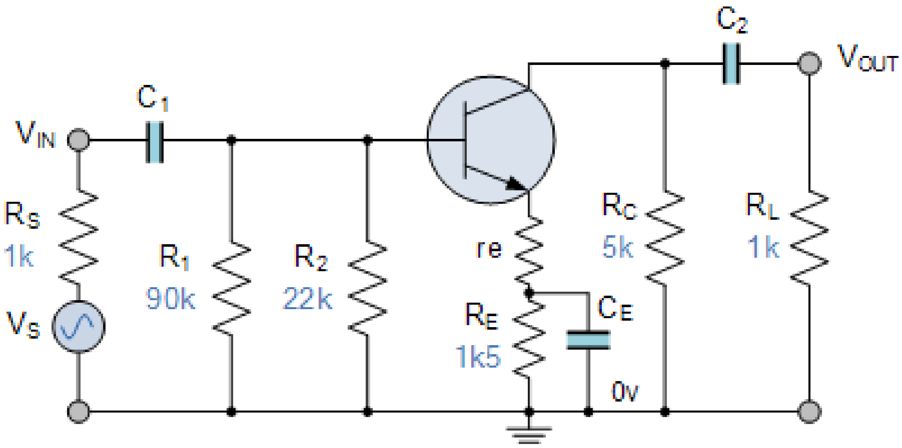

Figure 9.1: Amplifier Circuit

Input Impedance of Amplifier

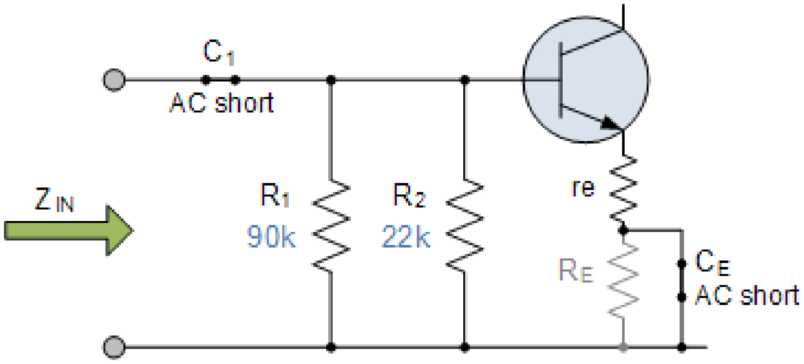

Figure 9.2: Input Impedance of Amplifier

The internal signal resistance of a emitter layer is defined in the previous lesson as being equivalent to the product of 25mV Ie, where 25mV represents the internal volt drop and IE = IQ (Figure 9.2). The Emitter diode's equivalent AC resistance value, re, for our amplification circuit above is thus given as:

Emitter Leg Signal Resistance

$$re = \frac{25mV}{I_E} = \frac{25mV}{1mA} = 25\Omega$$

Where the internal resistor re is connected in series with the emitter. The base impedance of the transistor will be equal to *re since Ic/Ib =.

Be aware that the value has become: (RE+ re) considerably raising the amplifier's input resistance if bypass capacitor CE is not incorporated into the design of the amplifier.

The input impedance of a common-emitter amplifier, ZIN, is indeed the input impedance "seen" by the AC source powering the amplifier in our case since the bypass capacitor, CE, is included. This input impedance is computed as:

Input Impedance Equation

$$Z_{IN} = R_1 \,||\, R_2 \,||\, \beta(re)$$

$$\frac{1}{Z_{IN}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{\beta(re)}$$

$$\frac{1}{Z_{IN}} = \frac{1}{90k} + \frac{1}{22k} + \frac{1}{100 \times 25}$$

$$\therefore Z_{IN} = 2190\Omega, \text{ or } 2.2k\Omega$$

The input impedance of the amplifier, as measured into the input terminal, is 2.2 k. If the source signal's impedance is known—it is supplied as 1 k in our straightforward example above—this value may be added to or summed with ZIN as necessary.

However, let's pretend for a moment that CE, the bypass capacitor, is not connected to our circuit. Without it, the amplifier's input impedance would be higher.

Since the resistor won't be shorted at high frequencies, the equation would remain unchanged other than for the addition of RE to the (RE+ re) portion of the equation.

The amplifier circuit's non-CE unbypassed input impedance will then be:

Input Impedance without Bypass Capacitor

$$Z_{IN} = R_1 \,||\, R_2 \,||\, \beta(R_E + re)$$

$$\frac{1}{Z_{IN}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{\beta(R_E + re)}$$

$$\frac{1}{Z_{IN}} = \frac{1}{90k} + \frac{1}{22k} + \frac{1}{100(1500+25)}$$

$$\therefore\ Z_{IN} = 15842\Omega,\ \text{or}\ 15.8k\Omega$$

The input impedance of the circuit is therefore dramatically changed by the presence of the Emitter leg bypass capacitor, dropping from 15.8k without it to 2.2k with it in our example design. We'll see later that the gain of the amplifiers is likewise increased by the inclusion of this bypass capacitor, CE.

We used the assumption that the capacitors in the circuit had infinite impedance (Xc=) for DC biasing currents and zero impedance (Xc = 0) for AC signal currents when doing our calculations to determine the input impedance of the amplifier.

We can utilize this figure of 2.2k to determine the value of the input coupling capacitor, C1, needed at the stated cut-off frequency point, which was previously set as 40Hz, now that we are aware of the bypassed input impedance of the amplifier circuit. Therefore:

Input Coupling Capacitor Equation

$$C_1 = \frac{1}{2\pi f_{3dB} Z_{IN}} = \frac{1}{2\pi(40Hz)(2.2k\Omega)} = 1.8uF$$

We can now extract an equation for the output impedance of the amplifier in a manner similar to how they did for the input impedance of the single stage common emitter amplifier circuit before.

Impedance at the Amplifier's Output

The impedance (or resistance) which the load observes while "looking back" into the amplifier whenever the input is zero is known as the output impedance of an amplifier. The generalized formula for the output impedance may be written as ZOUT = VCE/IC, using the same logic as we did for the input impedance.

However, since the two resistors are linked in series across Vcc, the signal current flowing inside the Collector resistor, RC, also flows inside the Load resistor, RL. However, if we simply consider the transistor amplifier's output side and regard the output coupling capacitor C2 as just a short circuit to AC signals, we can redisplay the circuit above to characterize the amplifier's output impedance as:

Output Impedance of Amplifier (Figure 9.3)

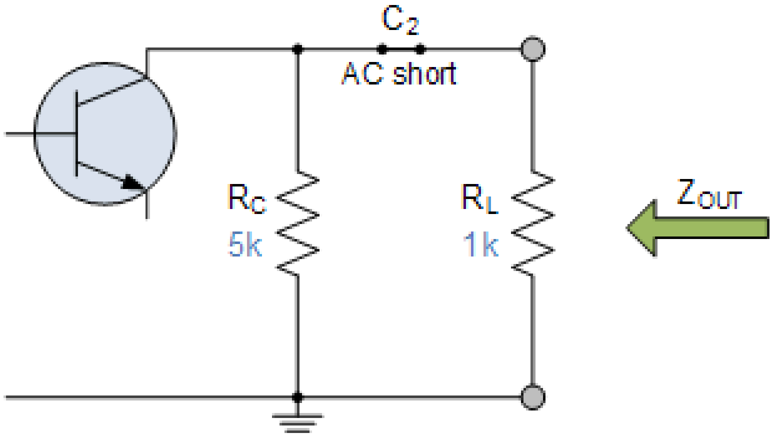

Figure 9.3: Output Impedance of Amplifier

Then we can see that the amplifiers output impedancee is equal to R_C in parallel with R_L giving us an output resistance of:

Output Impedance Equation

$$Z_{OUT} = R_C \,||\, R_L$$

$$\frac{1}{Z_{OUT}} = \frac{1}{R_C} + \frac{1}{R_L}$$

$$\frac{1}{Z_{OUT}} = \frac{1}{5k} + \frac{1}{1k} = 0.0012$$

$$\therefore\ Z_{OUT} = 833\Omega$$

Be aware that the load resistance is linked across the transistor, resulting in the value of 833. The output impedance of a amplifier would've been equal to the Collector resistor, RC, only if RL were to be removed.

We can determine the value of a output coupling capacitor, C2, at the 40Hz cut-off frequency point now that we know the output impedance of our amplifier circuit from above.

Output Coupling Capacitor Equation

$$C_2 = \frac{1}{2\pi f_{3dB} Z_{OUT}} = \frac{1}{2\pi(40Hz)(833\Omega)} = 4.7uF$$

Once again, the load resistor RL might be included or not when determining the value of coupling capacitor C2.

Emitter Voltage Gain Typically

Av = ROUT/REMITTER, where ROUT seems to be the output impedance as observed in the Collector leg and REMITTER is equivalent to the equivalent resistance inside the Emitter leg with or without the bypass capacitor attached, is the formula for the voltage gain of a common emitter circuit.

(RE+ re) is unconnected when the bypass capacitor CE is used..

$$A_V = \frac{R_{OUT}}{R_E + re} = \frac{833\Omega}{1.5k\Omega + 25\Omega} = 0.546$$

And with the bypass capacitor C_E connected, (re) only.

$$A_V = \frac{R_{OUT}}{re} = \frac{833\Omega}{25\Omega} = 33.3$$

The voltage gain, Av, of our common emitter circuit is thus dramatically changed from 0.5 to 33 by the addition of the bypass capacitor in the amplifier design. Additionally, it demonstrates that when the bypass capacitor shorts the external emitter resistor at high frequencies, the common emitter gain does not reach infinity but rather reaches the limiting value of ROUT/re.

Additionally, we have observed that the input impedance decreases with increasing gain, dropping from 15.8 k without it to 2.2 k with it. Most amplifier circuits may benefit from an increase in voltage gain at the price of a lower input impedance.

Summary of Input Impedance

This article demonstrated how to short off the supply voltage and consider the voltage divider biasing circuit as just a series of parallel resistors to determine the input impedance of either a common emitter amplifier.

As the AC input signal modifies the bias on the transistor's base, which controls the current flow through the transistors, the impedance "seen" looking into the divider network (R1||R2) is often significantly smaller than the impedance seen looking straight into the transistor's Base, (RE+ re).

The transistor may be biased in a variety of ways. Since each input impedance equation and value is unique, there are several useful single transistor amplifier circuits. Consider adding Rs in series with the base bias resistors (Rs + R1||R2) if you need the input impedance of the whole stage in addition to the source impedance.

The collector resistance in parallel with both the load resistor (RC||RL) determines a common emitter stage's output impedance; if they are not connected, the output impedance is only RC. The amplifier's voltage gain, Av, is dependent on RC/RE.

By shorting out all the emitter resistor, RE, at high frequencies and leaving just the signal emitter resistance, re inside the emitter leg circuit, the emitter bypass capacitor, CE, may provide the emitter an AC route to ground.

As a consequence, the voltage gain of the amplifier rises (from 0.5 to 33) with an increase in signal frequency. The amplifier's input impedance value is reduced as a result, going from 18.5 k to 2.2 k, as illustrated.

When the bypass capacitor is removed, the voltage gain of the amplifier lowers, Av rises, and ZIN rises. A "split-emitter" amplifier circuit, which is a compromise between an unbypassed and a completely bypassed amplifier circuit, is one technique to retain a set amount of gain and input impedance. It is made by connecting an extra resistor in series with CE. Keep in mind that the output impedance of the amplifier is unaffected by the presence or absence of this bypass capacitor.

The transfer characteristics of an amplifier in reference to the relationship between the output current, Ic, and the input current, Ib, may thus be defined in part by the input and output impedances of the amplifier. A series of output characteristic curves for an amplifier may be visually constructed with the aid of knowledge about the amplifier's input impedance.

Response to Frequency

Electronic circuits having the qualities of both amplification and filtration—hence their names—amplifiers and filters are frequently employed and create a frequency response that falls between an upper and lower band.

While filters change the amplitude and/or phase properties of an electrical signal with regard to its frequency, amplifiers provide gain. Due to the employment of resistor, inductor, or capacitor networks (RLC) in the design of these amplifiers and filters, there is a significant correlation between the utilization of these reactive elements and the frequency response properties of the circuit.

It is believed that AC circuits run at a set frequency, such as 50 Hz or 60 Hz, when working with them. However, an AC or sinusoidal input signal with a constant amplitude but a variable frequency, such as those present in amplifier and filter circuits, may also be used to test the behavior of a linear AC circuit. This thus makes it possible to study such circuits using frequency response analysis.

Depending on the circuit's design parameters, the frequency response of an electric or electronic circuit enables us to see precisely how the output gain (also known as the magnitude response) and the phase (also known as the phase response) changes at a specific single frequency, or over a whole range of different frequency range from 0Hz, (d.c.), to many thousands of megahertz (MHz).

The gain of a circuit or system, which is the ratio of the magnitude of its output signal to that of its input signal, Output/Input, is often shown against a frequency range over which the circuitry or system is intended to function. Knowing the gain (or loss) of the circuit at each frequency point then allows us to assess how effectively (or inadequately) the circuit can discriminate between signals of various frequencies.

A graphical illustration of magnitude (gain) versus frequency () may be used to show the frequency range of a specific frequency dependant circuit. The vertical axis, which represents the voltage output or gain, is often represented as a linear scale with decimal divisions, whereas the horizontal frequency axis is typically displayed on a logarithmic scale. The y-axis may consequently contain positive and negative values since a system gain might be either positive or negative.

The Logarithm, or "log" for short, is the power by which the base number must be increased to get that number in electronics. Then, in a Bode plot, every decade of frequencies (e.g., 0.01, 0.1, 1, 10, 100, 1000, etc.) is evenly placed onto the x-axis thanks to the logarithmic x-axis scale's graduation in log10 divisions. The antilogarithm, sometimes known as "antilog," is the logarithm's polar opposite.

Bode plots, which are diagrammatic representation of frequency response curves, are sometimes referred to as semi-logarithmic graphs because they have a logarithmic x-axis and a linear y-axis (log-lin plot), as illustrated.

Frequency Response Curve (Figure 9.4):

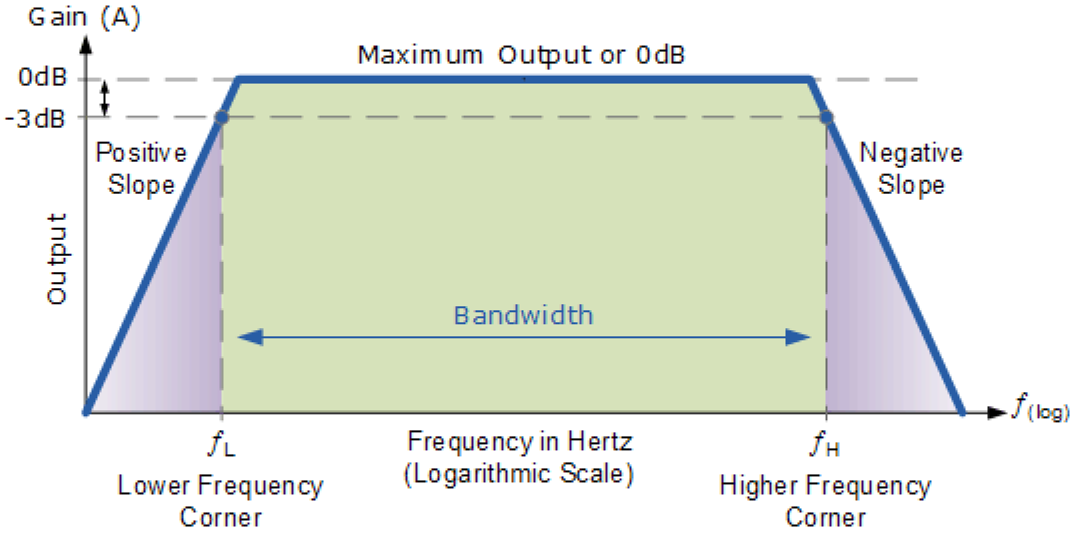

Figure 9.4: Frequency Response Curve

When we look at the range of frequencies throughout which the output (and gain) stay reasonably consistent, then recognize that the frequency response of any particular circuit is the variation in its behavior with changes in the input signal frequency. The circuit's bandwidth is the range of frequencies, large or small, between L and H. As a result, we can quickly calculate the voltage gain (in dB) for just about any sinusoidal input within a certain frequency range from this.The frequency response is shown logarithmically in the Bode diagram, as was already described. Over the whole auditory range of frequencies from 20 Hz to 20 kHz, the majority of contemporary audio amplifiers exhibit the same flat frequency response as seen above. The Bandwidth (BW) of an audio amplifier, which is mostly influenced by the circuit's frequency response, is the range of frequencies it can handle.The frequency points L and H correspond to the lower and upper cut-off frequencies, respectively, where the circuit's gain decreases at high and low frequencies. The -3dB (decibel) points on a frequency response curve refer to these positions. Therefore, the bandwidth was simply provided as:

$$\text{Bandwidth}, (BW) = f_H - f_L$$

A typical non-linear measure for measuring gain is the decibel (dB), which is 1/10th of a bel (B) and is defined as 20log10(A), where A is the decimal gain and is shown on the y-axis. The maximum output is represented by a magnitude function equal unity at zero decibels (0dB). In other words, there is no attenuation at about this frequency level, hence 0dB happens when Vout = Vin:

$$\frac{V_{OUT}}{V_{IN}} = 1, \qquad \therefore\ 20\log(1) = 0\text{dB}$$

The output lowers from 0 dB to -3 dB and keeps falling at a set rate at the two corner or cut-off frequencies points, as seen by the Bode curve above. The roll-off section of the frequency response curve refers to this decline or decrease in gain. This roll-off rate is specified as 20 dB/decade in all fundamental single order amplifier device filter circuits, which is comparable to a rate of 6 dB/octave. The ordering of the circuit is multiplied by these numbers.

The frequency during which the output gain is lowered to 70.71% of its highest value is defined by these -3dB corner frequency points. Then we can appropriately state that the frequency during which the system gain has decreased to 0.707 of its highest value is at the -3dB mark.

Frequency Response -3dB Point

$$-3\text{dB} = 20\log_{10}(0.7071)$$

Since the output power at these corner frequencies will indeed be half of its maximum 0dB value, the -3dB point is also known as the half-power point.

$$P = \frac{V^2}{R} = I^2 \times R$$

At f_L or f_H,

$$V \text{ or } I = 70.71\% \text{ of maximum or } 0.7071\text{max}$$

$$\text{If } R = 1, \text{ then } P = \frac{(0.7071 \times V)^2}{1} \text{ or } (0.7071 \times I)^2 \times 1$$

$$\therefore\ P = 0.5V \text{ or } 0.5I$$

The bandwidth (BW) of the frequency response curves may alternatively be described as the spectrum of frequencies between such two half-power points since the output power given to the load effectively "halves" at the cut-off frequency.

While we use 20log10(Av) and 20log10(Ai) for voltage and current gains, respectively, we use 10log10 for power gains (Ap). Noting that the decibel is a unit of the power ratio and not a measurement of the actual power level, the multiplication factor of 20 does not imply that it is twice as much as 10. Additionally, gain in dB has two possible values: positive and negative, with positive signifying gain and negative suggesting attenuation.

The next table will then show how voltage, current, and power gain relate to one another (Table 9).

Table 9.1: Decibel Gain Equivalents

dB Gain	Voltage or Current Gain $20\log_{10}(A)$	Power Gain $10\log_{10}(A)$
-6	0.5	0.25
-3	0.7071 or 1/√2	0.5
0	1	1
3	1.414 or √2	2
6	2	4
10	3.2	10
20	10	100
30	32	1,000
40	100	10,000
60	1,000	1,000,000

Operational amplifiers can have open-loop voltage gains, (A_{VO}) in excess of 1,000,000 or 100dB.

Frequency Response Summary

In this lesson, we've seen how an electrical circuit's frequency response determines the frequency range across which it functions. The change in gain, or the quantity of signal a device or circuit allows through with frequency, that characterizes a device or circuit's behavior throughout a given range of signal frequencies.

Bode plots may be used to solve design issues since they are graphical representations of the properties of the circuit's frequency response. Typically, the magnitude and phase components of the circuit's gain are shown separately on graphs with the logarithmic frequency scale running along the x-axis.

The frequency range between a circuit's top and lower cut-off frequencies is known as its bandwidth. The frequencies during which the power associated with the output drops to half its highest value are indicated by these cut-off or corner frequency points. Those half power points translate into a gain drop of 3 dB (0.7071) from its highest dB value.

The bandwidth or passband component of the circuit, which is flat and constant across a large range of frequencies, is a feature of the majority of amplifiers and filters known as a flat frequency response. Resonant circuits are made such that they can pass certain frequencies while blocking others. Their frequency response curves might resemble a sharp spike or point because their bandwidth is impacted by resonance, which relies on the Q of the circuit and results in a smaller bandwidth. They are built using resistors, inductors, and capacitors whose reactances change with frequency.

MOSFET Booster

Junction field effect transistors, or JFETs, may be used to create simple single stage amplifiers, as we saw in the last article on FET amplifiers. However, there are several field effect transistors that may be utilized to build an amplifier; in this lesson, we'll focus on the MOSFET Amplifier.

A great option for tiny signal linear amplifiers is the Metal Oxide Semiconductor Field Effect Transistor, or MOSFET, because of its exceptionally high input impedance and simple biasing. In contrast to the Bipolar Junction Transistor, a mosfet must operate in its saturation area in order to provide linear amplification. But like the BJT, it must also be biased toward a fixed Q-point in the middle.

MOSFET Transistor

The "channel" is the conductive area or passage that MOSFETS use to conduct electricity. By using an appropriate gate potential, we may expand or contract this conductive channel. By applying this gate voltage, an electric field is created around the gate terminal that influences the channel's electrical properties, giving the field-effect transistor its name.

To put it another way, humans can influence how the mosfet behaves by extending or "enhancing" its conductive channel between both the source and drain regions. This results in a particular kind of mosfet known as an n-channel Enhancement-mode MOSFET, that also simply means that no channel current will flow unless humans bias them positively here on gate (negatively for the p-channel).

Because there are significant differences between the properties of various mosfet kinds, each mosfet must be biased separately. The common source mosfet amplifier has to be biased at an appropriate quiescent value, much like with the bipolar transistor common emitter design. But first, let's review the mosfets' fundamental features and settings.

Enhancement N-channel MOSFET (Figure 9.5)

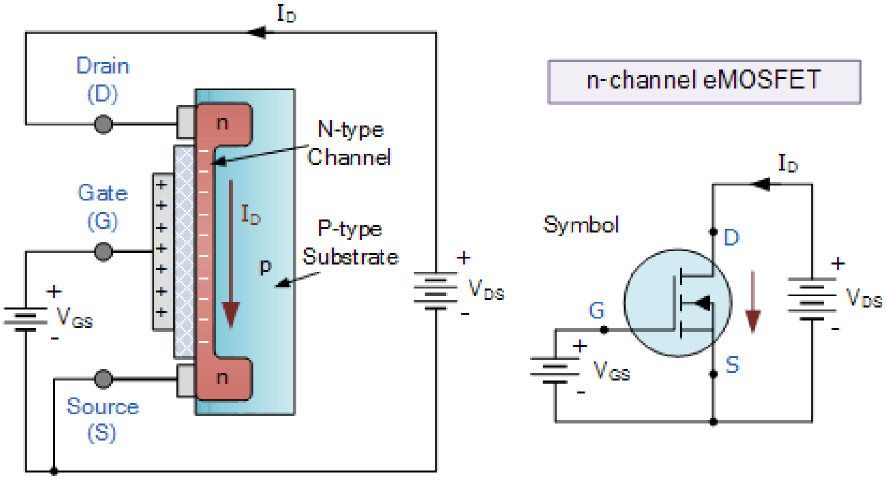

Figure 9.5: Enhancement N-channel MOSFET

A MOSFET has terminals labeled Drain, Source, and Gate, while a BJT has terminals labeled Collector, Emitter, and Base. This is one of the key distinctions between the two types of transistors.

The metal gate electrode of the MOSFET is electrically isolated from the conductive channel, giving it the alternate name of Insulated Gate Field Effect Transistor, or IGFET. Additionally, the MOSFET differs from the BJT in that there is no direct connection between both the gate and channel, unlike the base-emitter junction of the BJT.

We can see that the drain and source electrodes again for n-channel MOSFET (NMOS) above are n-type whereas the substrate semiconductor material is p-type. There will be positive supply voltage. Electrons in the p-type semiconductor substrate underneath the gate area are drawn to the gate terminal when it is biased positively.

The excessive number of free electrons inside the p-type substrate leads to the formation or growth of a conductive channel as the p-type region's electrical characteristics flip, thus converting the p-type substrate into an n-type material and enabling channel current to flow.

For the p-channel MOSFET (PMOS), the opposite is also true; a negative gate potential results in a buildup of holes beneath the gate area because they are drawn to the electrons on the outer surface of the metal gate electrode. As a consequence, a p-type conductive conduit is produced by the n-type substrate.

Therefore, for our n-type MOS transistor, the wider the conductive channel develops, the larger the buildup of electrons surrounding the gate area, and the more positive potential we apply to the gate. This improves the channel's electron flow, enabling more channel current to pass from the drain to the source and giving rise to the moniker "Enhancement MOSFET."

MOSFET Enhancement Amplifier

In contrast to Depletion type mosfets, which seem to be normally-on devices conducting whenever the gate voltage is zero, Enhancement MOSFETs, or eMOSFETs, may be classified as normally-off (non-conducting) devices since they only operate when a proper gate-to-source positive voltage is supplied.

However, an enhancement type mosfet has a minimum gate-to-source voltage, known as the threshold voltage VTH that must be provided to the gate before it begins to conduct enabling drain current to flow. This is due to the structure and mechanics of an enhancement type mosfet.

As a result, an enhancement mosfet is perfect for use in mosfet amplifier circuits because it does not conduct whenever the gate-source voltage, VGS, is less than the threshold voltage, VTH.

However, as the gates forward bias increases, this same drain current, ID (also widely recognized as drain-source current IDS), will also increase, much like a bipolar transistor.

You may think of the MOS conductive channel's features as a gate-controlled variable resistor. As a result, the gate-source voltage determines how much drain current flows through this n-channel. One of the various tests we can do with a mosfet is to create a transfer characteristics chart to demonstrate the i-v connection between the drain current as well as the gate voltage, as illustrated.

N-channel EMOSFET I-V Characteristics

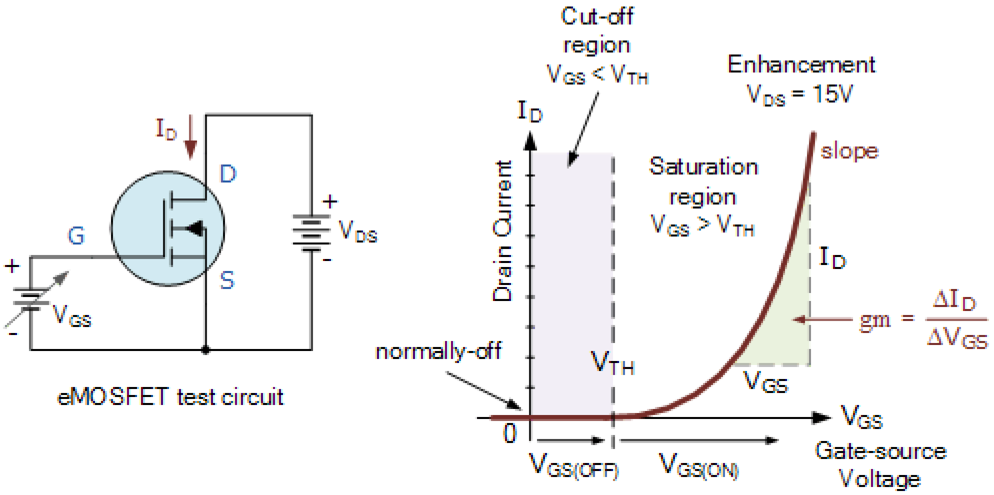

Figure 9.6: N-channel E-MOSFET I-V Characteristics

We may plot the numbers of drain current, ID with various values of VGS to generate a graph of a mosfets forward DC characteristics by connecting a fixed VDS drain-source voltage from across eMOSFET. These variables determine the transistor's transconductance, gm (Figure 9.6).

This transconductance connects the output current to the transistor gain represented by the input voltage. Therefore, with a constant value of VDS, the formula for the slope of a transconductance curve is given as gm = ID/VGS.

Consider a MOS transistor, for instance, which, at VGS = 3 v, passes a drain current of 2 mA and at VGS = 7 v, a drain current of 14 mA. Then:

$$gm = \frac{\Delta I_D}{\Delta V_{GS}} = \frac{(14-2)\times 10^{-3}}{7-3} = 3mS$$

The term "transfer conductance" (short for "transfer conductance") used to describe this ratio is "transconductance," as well as the unit used to express it is Siemens (S), which is expressed in amps per volt. A mosfet amplifier's voltage gain is inversely related to its transconductance and the size of its drain resistor.

Because the field effect surrounding the gate is inadequate to establish or "open" the n-type channel when VGS = 0, no current flows through the MOS transistor channel. The transistor is therefore operating as an open switch while in its cut-off zone. In other words, the n-channel eMOSFET is said to be normally-off when there is no gate voltage supplied, and this "OFF" state is represented by that of the broken channel lines in the eMOSFET symbol (unlike the depletion types that have a continuous channel line).

The field effect continues to improve the conductivity of the channel regions as we now steadily raise the positive gate-source voltage VGS, and there eventually comes a moment when the channel starts to conduct. The threshold voltage VTH is referred to as this location. VGS becomes more positive as we raise it, resulting in a broader conductive channel (reduced resistance) and an increase in ID as a consequence of the increased drain current. Remember that what a mosfetamplifier has a very high input impedance since the gate never transmits any current because it is electrically insulated from the channel.

As a result, the n-channel enhancement mosfet will operate in its cut-off mode whenever the gate-source voltage, VGS, is lower than its threshold voltage level, VTH, and anytime the channel conducts or saturates, respectively, when the VGS is greater than this threshold level. The drain current, ID, is determined by when the eMOS transistor is functioning in the saturation zone:

eMOSFET Drain Current

$$I_D = k\left(V_{GS} - V_{TH}\right)^2$$

Be aware that the conduction parameter (k) and threshold voltage (VTH) values differ from one eMOSFET to the next and cannot be physically modified. This is due to the fact that they are precise specifications pertaining to the material and device shape that are incorporated into the transistor during its manufacturing.

The properties of static transfer The right-hand curve is often parabolic (square law) in form before becoming linear. The slope or gradient of the curve for constant values of VDS is determined by the increase in drain current, ID for a given rise in gate-source voltage, VGS.

Then, it becomes clear that turning an improvement MOS transistor "ON" requires a progressive process, and that we must bias the MOSFET's gate terminal over its threshold level in order to utilize it as an amplifier.

We may do this in a variety of methods, such by utilizing two distinct voltage sources, drain feedback biasing, zener diode biasing, etc. Regardless of the biasing technique, you must make sure that perhaps the gate voltage is larger than VTH more positive than that of the source. We will use the already well-known universal voltage divider biasing circuit in the thismosfet amplifier lesson.

Chapter 10

DC MOSFET Biasing

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A common biasing method used to provide the necessary DC operating state for bipolar transistor amplifiers and mosfet amplifiers is the universal voltage divider biasing circuit. A bipolar transistor or a MOSFET may be biased from a single DC supply thanks to the voltage divider biasing network. To begin with, though, we must understand how to bias the gate of our mosfet amplifier.

Three separate operational areas are present in mosfet devices. The Ohmic/Triode area, Saturation/Linear region, and Pinch-off point are the names of these regions. A mosfet must be biased to run in its saturation area in order to produce a well-defined quiescent operating point, or Q-point, which is necessary for it to function as a linear amplifier. The DC values, ID, and VGS, which place the operating point in the middle of the mosfet's output characteristics curve, serve as the mosfet's Q-point.

The saturation area starts when VGS is over the VTH threshold level, as we've seen previously. Therefore, the MOSFET will behave as a linear amplifier if we add a modest AC signal that is overlaid on this DC bias at the gate input, as indicated.

E-MOSFET DC Bias Point

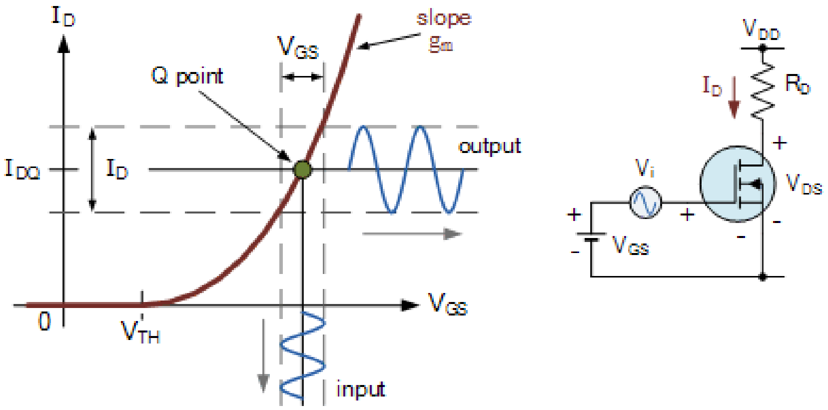

Figure 10.1: E-MOSFET DC Bias Point

The common-source NMOS circuit shown above demonstrates how a DC source is connected in series with the sinusoidal input voltage, Vi. The bias circuit will determine this DC gate voltage. When VGS and Vi are added together, the total gate-source voltage is obtained (Figure 10.1).

The gate voltage VGS, supply voltage VDD, and load resistance RD are all effects on the DC characteristics, and as a result, on the Q-point (quiescent point).

To produce the required drain current, which will determine the transistor's Q-point, the MOS transistor is biased inside the saturation area. The bias point travels up the curve, as indicated, as the instantaneous value of VGS rises, enabling a greater drain current to flow as VDS falls.

Similar to how the bias point moves down the curve when the instantaneous value of VGS falls (during the negative portion of the input sine wave), a smaller VGS causes a smaller drain current and an enhanced VDS.

The transistor must then be biased considerably beyond threshold level in order to guarantee that it remains in saturation during the whole sinusoidal input cycle in order to produce a wide output swing. The amount of gate bias and drain current we can employ, however, is limited. The Q-point should be situated about midway between the supply voltage VDD and the threshold voltage VTH to allow for the output's maximum voltage swing.

Let's take building a single stage NMOS common-source amplifiers as an example. The supply voltage, VDD, is +15 volts, and the eMOSFET's threshold voltage, VTH, is 2.5 volts. The DC bias point will therefore be 6 volts to the closest integer, or 15 - 2.5 = 12.5 volts.

The MOSFETS ID - VDS Features

As we have seen above, by maintaining a constant supply voltage (VDD) and raising the gate voltage (VG), we may create a graph of the mosfets' forward DC characteristics. But in order to fully understand how the n-type enhancement MOS transistor works in a mosfet amplifier circuit, it is necessary to show the output characteristics for various VDD and VGS values.

For an n-channel enhancement-mode MOS transistor, we may create a series of output characteristic curves that display the drain current, ID, for rising positive values of VG as illustrated.

N-type EMOSFET Characteristics Curves (Figure 110.2)

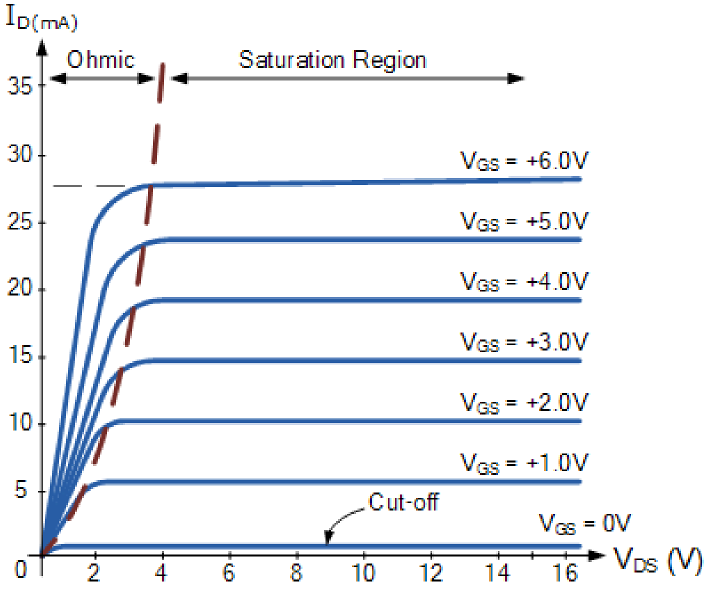

Figure 10.2: N-type EMOSFET Characteristics Curves

Noting that the polarity of the gate voltage would be flipped, a p-channel eMOSFET device would exhibit a very similar set of drain current characteristic curves.

Common Source MOSFET Amplifier in the Basic

In a previous section, we looked at creating the ideal DC working environment to bias the n-type eMOSFET. The mosfet circuit can function as a linear amplifier when a small time-varying signal is applied to the input under the right conditions, provided that the transistors Q-point is somewhere close to the center of the saturation region and the input current is small enough for the output to continue to stay linear. A simple mosfet amplifier circuit is shown below.

Basic MOSFET Amplifier

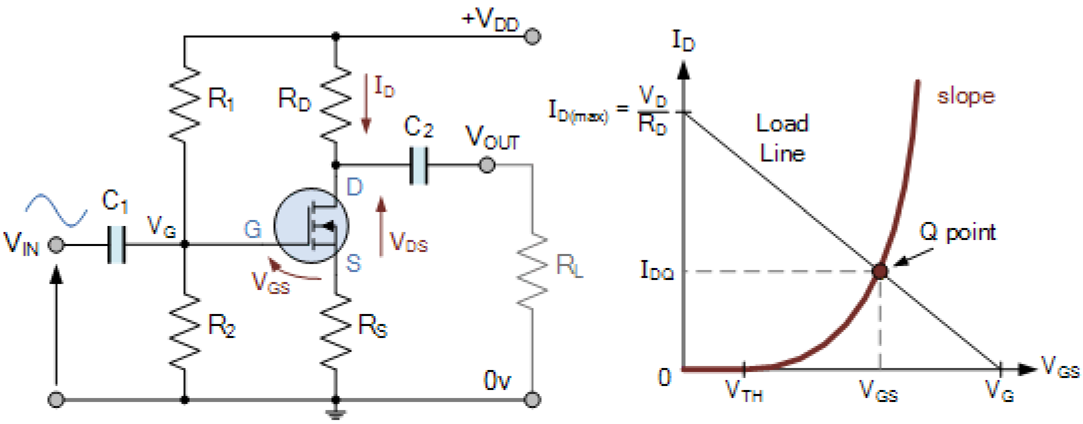

Figure 10.3: MOSFET Amplifier

In this straightforward enhancement-mode common source mosfet amplifier design, the gate voltage, VG, is produced by a resistor divider utilizing a single supply at the drain. We may make the following fundamental assumptions regarding the MOSFET amplifiers' DC working conditions based on the knowledge that a MOSFET does not allow current to pass into its gate terminal (Figure 10.3).

$$\begin{aligned} V_{DD} &= I_D R_D + V_{DS} + I_D R_S \\ &= I_D\left(R_D + R_S\right) + V_{DS} \end{aligned}$$

$$\therefore R_D + R_S = \frac{V_{DD} - V_{DS}}{I_D}$$

Then from this we can say that:

$$R_D = \frac{V_{DD} - V_D}{I_D} \quad \text{and} \quad R_S = \frac{V_S}{I_D}$$

and the mosfets gate-to-source voltage, V_{GS} is given as:

$$V_{GS} = V_G - I_S R_S$$

As we saw above, this gate-source voltage must be higher than the mosfet threshold voltage, or VGS > VTH, for the mosfet to function properly. The gate voltage, VG, is also identical since IS = ID:

$$V_{GS} = V_G - I_D R_S$$

$$\therefore \; V_G = V_{GS} + I_D R_S$$

$$\text{or} \;\; V_G = V_{GS} + V_S$$

We choose the appropriate values for the resistors R1 and R2 inside the voltage divider network to set the mosfet amplifier gate voltage to this value. Since "no current" flows through into gate terminal of a mosfet device, as we learned from the example above, the voltage division formula is as follows:

MOSFET Amplifier Gate Bias Voltage

$$V_G = V_{DD}\left(\frac{R_2}{R_1 + R_2}\right)$$

Remember that the ratio of the two bias resistors, R1 and R2, and not their actual values, are solely determined by this voltage divider equation. Additionally, it is preferable to increase the values of the these two resistors in order to decrease their I2*R power loss and raise the input resistance of the mosfet amplifier.

Amplifier of Class AB

Combining the benefits of the Class A amplifier with the Class B amplifier, the Class AB amplifier output stage results in a superior amplifier design.

In order to rebuild the whole 360o input waveform either with or without distortion, the output stage of both the Class B amplifier as well as the Class AB amplifier is made up of two transistors.

Any amplifier's goal is to provide an output that closely matches the characteristics of the source signal while being big enough to meet the demands of the load that is attached to it.

As we've seen, the power input of an amplifier is the product of a DC voltage and current drawn from the power source, but the power output is determined by the voltage and current supplied to the load (P = V*I).

The efficiency of the conversion from the DC power source to an AC power output is often low at less than 50%, despite the possibility of high Class A amplifier amplification (in which the output transistor conducts 100% of the time).

The collector current in each transistor flows for just 180o of the cycle if the Class A amplifier circuit is modified to function in Class B mode (where each transistor conducts only for 50% of the time). Although the DC-to-AC conversion efficiency is substantially better in this case, at around 75%, the crossover distortion of the output signal caused by the Class B arrangement may be undesirable.

A Class AB amplifier is a new form of amplifier circuit that combines the characteristics of the previous two classes to generate an amplifier with the high output efficiency of the Class B configuration and the low distortion of the Class A configuration.

The Class AB amplifier output stage thereby minimizes the issues of poor efficiency and distortion connected with Class A and Class B amplifiers while combining their benefits.

As previously stated, the Class AB Amplifier combines Classes A and B in that it functions as a class A amplifier for low power outputs but switches to a class b amplifier for high current outputs. Pre-biasing the two transistors in the amplifier's output stage allows for this activity.

Due to pre-biasing and current output, each transistor will conduct between 180 and 360 percent of the time. The output stage of the amplifier then functions as a Class AB amplifier.

Let's first compare the output signals for the various amplifier operating classes.

Comparison of the Different Amplifier Classes (Figure 10.4)

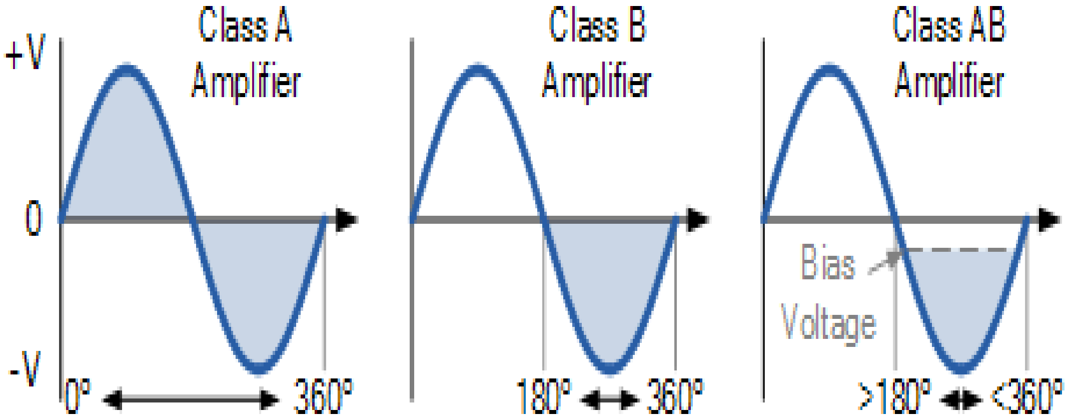

Figure 10.4: Comparison of the Different Amplifier Classes

Thus, the following definition applies to all amplifier classes:

Class A: The amplifier's single output transistor is operational throughout the whole 360o of the input waveform's cycle.

Class B: The two output transistors of a amplifier only operate for 180 degrees of the input waveform.

Class AB: The two output transistors of something like the amplifier conduct between 180 and 360 degrees of the input waveform.

Class A Amplifier Operation

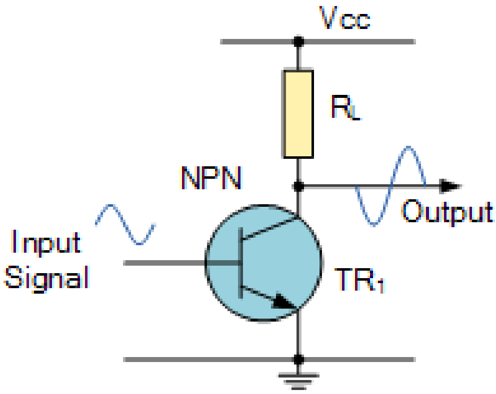

Figure 10.5: Class A Amplifier Operation

The switching transistor's Q-point lies in the center of the output characteristic load line and within the linear zone for Class A amplifier operation. This enables the transistor could conduct for a full 360 degrees, allowing the output signal to vary over the input signal's whole cycle.The fundamental benefit of Class A is that it reduces distortion since the output signal will constantly be an identical replica of the input signal. However, it has a low efficiency because, even in the absence of an input signal to amplify, an appropriate DC quiescent current must constantly flow through into the switching transistor in order to bias another transistor in the middle of the load line.

Class B Amplifier Operation

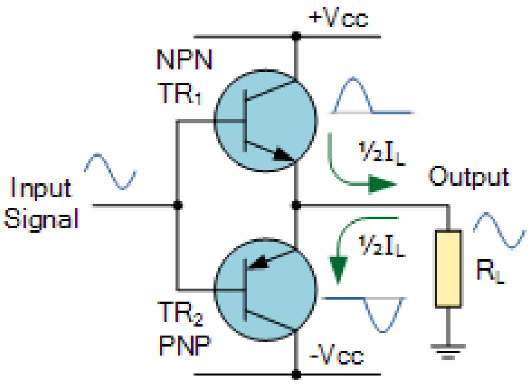

Figure 10.6: Class B Amplifier Operation

Two complementary switching transistors are utilized in Class B amplifier operation, with the Q-point (also known as the biasing point) of each transistor situated at its cut-off point.

As a result, one transistor may increase the signal over half of the input waveform, while the other transistor can increase the signal over the other half. At the load, these two amplified halves then are merged to create a complete waveform cycle. This complementary pair of NPN-PNP devices is sometimes referred to as a push-pull arrangement.

The overall efficiency of the a Class B amplifier is higher than a Class A amplifier because the cut-off biasing ensures that the quiescent current is zero whenever there is no input signal. As a result, no power is lost or squandered while the transistors are present in the quiescent state.

The output waveform is not a precise duplicate of the input waveform because the output signal is warped since the Class B amplifier was biased such that the output current passes through each transistor only for half of the input period. Every time the input signal crosses the zero line, this distortion happens, causing what is known as cross-over distortion when the two transistors flip "ON" one after the other.

The biasing point of the transistor should be placed slightly above cut-off to solve the distortion issue. We can build a Class AB amplifier circuit by biasing the transistor slightly beyond its cut-off point but significantly below the center Q-point of the class A amplifier. A Class AB amplifier's primary goal is to maintain the fundamental characteristics of a Class B amplifier while also enhancing its linearity by biasing every switching transistor just above threshold.

So tell us how to proceed. A typical Class B push-pull stage may be converted into a Class AB amplifier by biasing both switching transistors into mild conduction, even in the absence of an input signal. By more than 50% of the input cycle but less than 100%, both transistors will conduct concurrently for a very little portion of the input waveform thanks to this minor biasing arrangement. By using the proper biasing, the 0.6 to 0.7V (one forward diode volt drop) dead band that causes the crossover distortion effect in Class B amplifiers is significantly minimized. There are many techniques to pre-bias transistor devices, including by employing a voltage divider network, a preset voltage bias, or a series linked diode configuration.

Class AB Amplifier Voltage Biasing

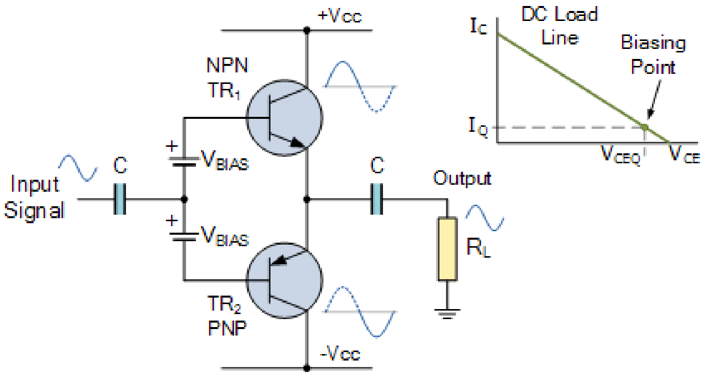

Figure 10.7: Class AB Amplifier Voltage Biasing

Here, the bases of TR1 and TR2 are applied with a sufficient fixed bias voltage to accomplish transistor biasing. The little quiescent collector current flowing through TR1 then combines with both the small quiescent collector current running through TR2 and enters the load at a region where both transistors are conducting.

When the input signal is positive, the base of transistor TR1 experiences an increase in voltage, which causes a corresponding rise in the positive output voltage. This rise in collector current via transistor TR1 sources current to the load, RL. However, any increase in TR1's conduction will result in an equal and opposite reduction in TR2's conduction during the positive half cycle since the voltage between the two bases is fixed and constant.

As a consequence, transistor TR2 finally shuts down, leaving transistor TR1—which is forward biased—to provide the load with all of the current gain. The converse happens for the negative half of the input voltage. That is, when the input signal grows increasingly negative, TR1 switches off and TR2 sinks the load current.

Then, humans can observe that both transistors are modestly conducting at zero input voltage (VIN) owing to their voltage biasing, but when the input voltage shifts more positively or negatively, one of the two transistors conducts more, either sourcing or sinking the load current.

The smooth and practically instantaneous switching between the two transistors significantly reduces the crossover distortion that plagues the Class B design. On the other hand, improper biasing may result in sudden spikes in crossover distortion when the two transistors flip over.

Each transistor may operate for more than half of the input cycle while the biasing voltage is fixed (Class AB operation). However, designing additional batteries into the amplifier's output stage is not particularly feasible. Utilizing a resistive voltage divider network is one extremely straightforward and straightforward method of generating two fixed biasing voltages to provide a steady Q-point close to the transistors cut-off.

Amplifier Resistor Biasing

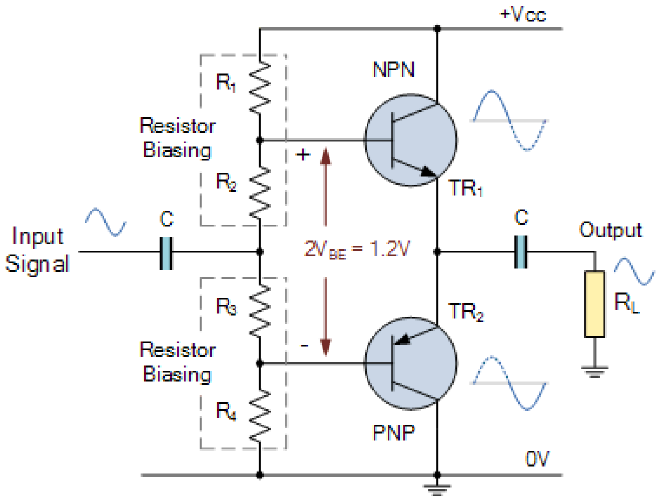

Figure 10.8: Amplifier Resistor Biasing

According to Ohm's law, a voltage drop develops across a resistor when a current flows through it. As a result, we may build a voltage divider network that generates a set of fixed voltages at the values of our choice by connecting two or more resistors in series across a source voltage (Figure 10.9).

In that transistors TR1 and TR2 conduct during the opposing half cycles of the input waveform, the fundamental circuit is analogous to the voltage biasing circuit discussed above. In other words, TR1 conducts when VIN in is positive, and TR2 conducts when VIN in is negative.

To provide the necessary resistive biasing, the four resistances R1 to R4 are linked across the supply voltage Vcc. The right value of VBE is set at around 0.6V, and the two resistors R1 and R4 are selected to put the Q-point slightly above cut-off. As a result, the voltage dips over the resistive network bring the bases of TR1 and TR2 to approximately 0.6V and -0.6V, respectively. the total voltage drop across the biasing resistors R2 and R3 is therefore close to 1.2 volts, which is the amount needed to completely switch on each transistor. The quiescent collector current, ICQ, should have a value of zero if the transistors are biased slightly above cut-off. Additionally, the VCEQ voltage drop across each switching transistor will be close to half of Vcc since the two switching transistors are really linked in series across the supply.

While a Class AB amplifier's resistive biasing theoretically works, a transistor's collector current is very sensitive to variations in its base biasing voltage, VBE. Finding the right resistor combination inside the voltage divider network may be challenging since the cut-off points of the two complementary transistors may not be the same. Utilizing an adjustable resistor to provide the proper Q-point as demonstrated is one approach to get around issue.

Adjustable Amplifier Biasing

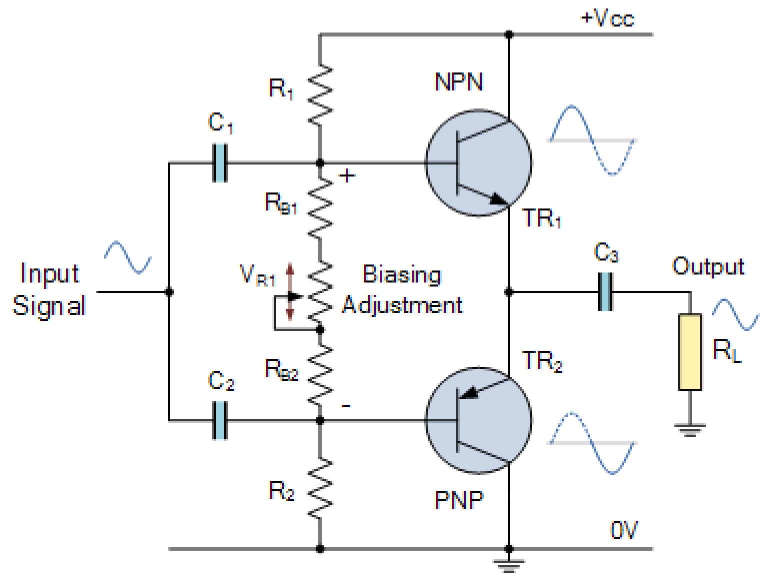

Figure 10.10: Adjustable Amplifier Biasing

Both transistors may be biased toward conduction using a variable resistor or potentiometer. So that their outputs are balanced and no quiescent current flows into the load, transistors TR1 and TR2 are then biased using RB1-VR1-RB2 (Figure 10.10).

The biasing voltages and the input signal that is supplied to the bases of both transistors through the capacitors C1 and C2 are overlaid. Because they came from VIN, both signals applied to each base had the identical frequency and amplitude.

Because the potentiometer may be changed to compensate, the basic amplifier circuit does not need to utilize complementary transistors with precisely matching electrical properties or an exact resistor ratio inside the voltage divider network. This is a benefit of the adjustable biasing design.

The resistive biasing of a Class AB amplifier, whether fixed or adjustable, may be very sensitive to temperature fluctuations since resistors are passive devices that transform electrical power into heat as a result of their power rating. Each transistor's quiescent collector current may alter unfavorably if the biasing resistors' (or transistors') operational temperature fluctuates even little. Using diode biasing to replace the resistors may help solve this temperature-related issue.

Amplifier Diode Biasing

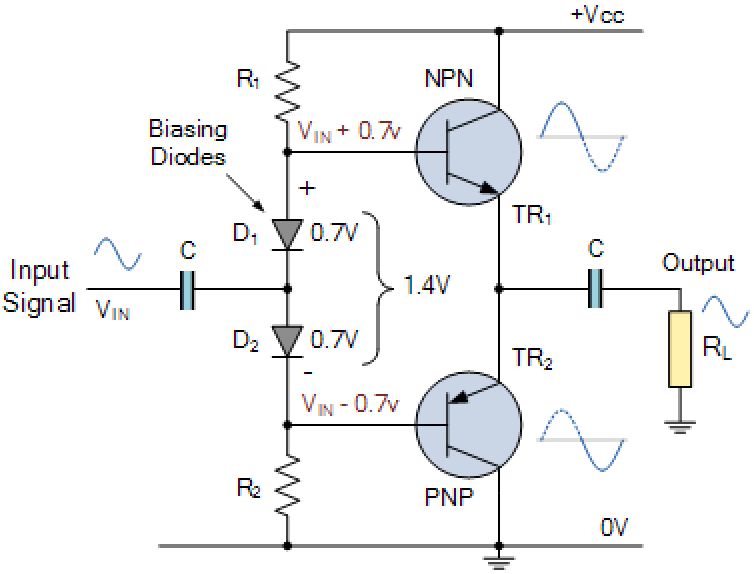

Figure 10.11: Amplifier Diode Biasing

A pair of standard forward biased diodes may be used in the amplifier's biasing setup as illustrated to account for any temperature-related variations in the base-emitter voltage (VBE), even if using biasing resistors may not completely fix the temperature issue (Figure 10.11).

Through the series circuit of R1-D1-D2-R2, a modest constant current flows, causing voltage dips that are symmetrical on each side of the input. The point between the two diodes is at 0 volts when there is no input signal voltage provided. The forward bias voltage drop across the diodes, which is applied to the base-emitter junctions of the switching transistors, is around 0.7V as current flows through the chain.

As a result, the voltage drop between the diodes biases the bases of transistors TR1 and TR2 to about 0.7 and -0.7 volts, respectively. In order to bias the two bases above cut-off, the two silicon diodes provide a continuous voltage drop of around 1.4 volts between them.

Due to their proximity to the transistors, the diodes' temperature increases along with that of the circuit. By redirecting part of the transistor's base current, the voltage across the PN junction of the diode falls, stabilizing the transistor's collector current.

The current flowing in the diodes and the current flowing in the transistors will be the same, forming what is known as a current mirror, if the electrical parameters of the diodes and those of the transistor base-emitter junction are closely matched. By creating the necessary Class AB functioning and compensating for temperature changes, this current mirror's action eliminates crossover distortion.

Modern integrated circuit amplifiers make it simple to do diode biasing since the switching transistor and diode are both built on the same chip, as in the well-known LM386 audio power amplifier IC. This indicates that the characteristic curves for each of them across a large temperature range are the same, enabling thermal stabilization of the quiescent current.

A Class AB amplifier output stage's biasing is often changed to fit a specific amplifier application. In Class B operation, the amplifier's quiescent current is set to zero to reduce power consumption. In Class AB operation, the amplifier's quiescent current is set to run at a very low level to reduce crossover distortion.

The input signal is directly linked to the bases of the switching transistors in the Class AB biasing examples above by use of capacitors. But adding a simple common-emitter driver stage to a Class AB amplifier would help us increase the output stage of the amplifier a little bit further, as shown.

Class AB Amplifier Driver Stage

The requisite DC biasing current flowing through the diodes is created by transistor TR3 acting as a current source. As a result, Vcc/2 is set as the output quiescent voltage. The base of TR3 is driven by the input signal, which also serves as an amplifier stage for driving the bases of TR1 and TR2. As previously, the positive half of the input cycle drives TR1, while TR2 is off, and the negative half of the input cycle drives TR2, while TR1 is off.

Just as there are several variants and alterations that may be made to a basic amplifier output circuit, there are numerous methods to construct a power amplifier's output stage.An effective amount of output power (both current and voltage) must be delivered to the connected load by a power amplifier with a respectable level of efficiency. The Class A or Class B operating modes of the transistor(s) may be used to do this.Using a symmetrical Class B output stage built from complementary NPN and PNP transistors is one technique to run an amplifier with a respectable degree of efficiency. As we saw above, a circuit like this is referred to as a Class AB amplifier.

By having the two transistors both switch off for a short duration of each cycle, it is feasible to eliminate any crossover distortion with a proper quantity of forward biasing.

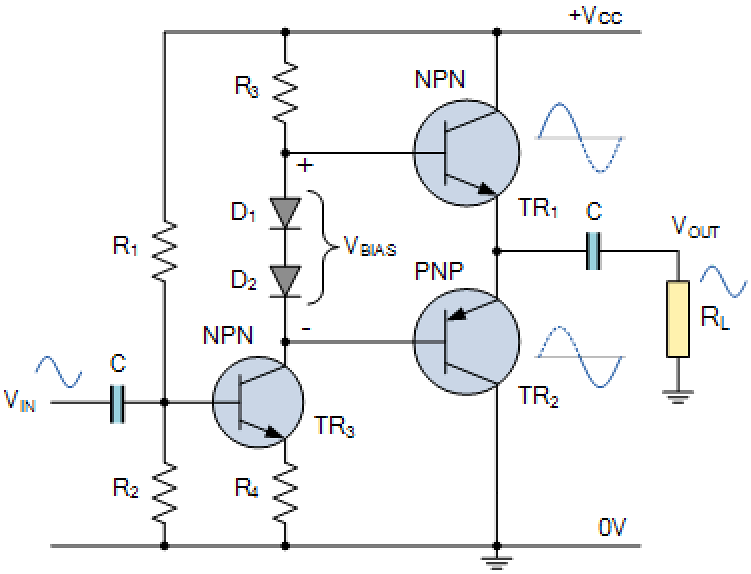

Figure 10.12: Class AB Amplifier Driver Stage

After putting everything together, we can create the straightforward Class AB power amplifier circuit illustrated, which has a frequency response of around 20Hz to 20kHz and can output approximately one watt into 16 ohms.

Chapter 11

Class AB Amplifier

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Here, students have seen that the bias of a Class AB amplifier causes the output current to run for more than a half cycle of the input waveform but less than one complete cycle. Class AB amplifiers employ two switching transistors as part of a complementary output stage, with each transistor conducting on opposing half-cycles of the input waveform before being merged at the load. This implementation is quite similar to the usual Class B arrangements.Thus, it is possible to significantly smooth the output waveform during the zero crossover period and lower the crossover distortion associated with the Class B amplifier design by allowing both switching transistors to conduct current simultaneously for a relatively brief amount of time. The conduction angle is thus larger than 180 degrees but far less than 360 degrees.

As a result of the little quiescent current required to bias the transistors just above cut-off, a Class AB amplifier architecture is somewhat less efficient than a Class B amplifier while being more efficient than a Class A amplifier. However, poor biasing might result in crossover distortion spikes that worsen the situation.

Nevertheless, Class AB amplifiers, which have minimal crossover distortion and strong linearity identical to the Class A amplifier design, are among the most popular audio power amplifier designs because of their combination of respectable efficiency and high-quality output.

Amplifier with a Common Collector

Another form of bipolar junction transistor (BJT) layout is the common collector amplifier, in which the input signal is supplied to the base terminal and the output signal is obtained from the emitter terminal. As a result, both the output and the input circuits share the collector terminal. Due to the fact that the collector termination is effectively "grounded" or "earthed" by the power supply, this arrangement type is known as Common Collector (CC).

The connected load resistor is transferred from the customary collector terminal, which is labeled RC, to the emitter terminal, where it is labeled RE, in the common collector (CC) configuration, which is in many respects the reverse of the common emitter (CE) design.

In situations when a high impedance input source must be linked to a low impedance output load needing a high current gain, the common collector or grounded collector design is often utilized. Think about the following typical collector amplifier circuit.

Common Collector Amplifier using an NPN Transistor (Figure 11.1)

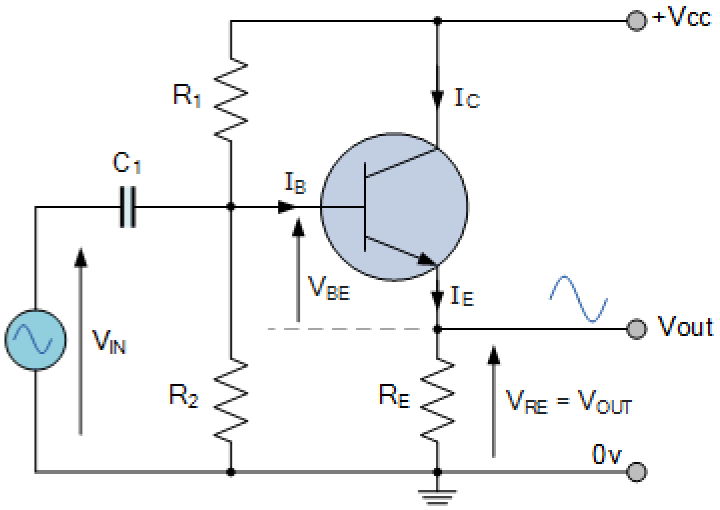

Figure 11.1: Common Collector Amplifier using an NPN Transistor

A straightforward voltage divider network made up of the resistors R1 and R2 is utilized to bias the NPN transistor into conducting. The base voltage, VB, may be readily computed using the straightforward voltage divider method as this voltage divider only slightly loads the transistor.

Voltage Divider Network

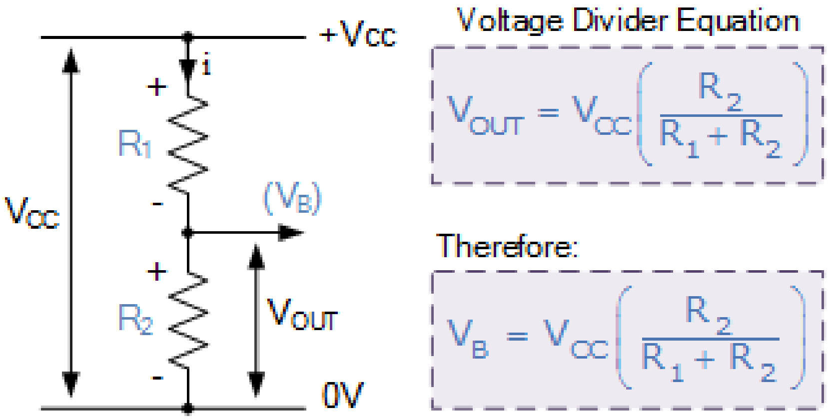

Figure 11.2: Voltage Divider Network

Any collector current will cause a voltage drop throughout the emitter resistor RE when the transistor's collector terminal is directly connected to VCC and has no collector resistance (RC = 0).

The output voltage, VOUT, is represented by the same voltage drop, VE, in the common collector amplifier circuit (Figure 11.2).

A maximum unclipped output voltage is possible if the DC voltage drop across RE is equal to half overall supply voltage, VCC, which makes the transistor's quiescent output voltage lie somewhere in the center of the characteristic curves. As a result, IB and the transistors' current gain, Beta, have a significant impact on the choice of RE.

A considerably greater collector current, IC, flows because the base-emitter pn-junction is forward biased, boosting transistor activation as base current flows through the connection to the emitter. As a result, the emitter current (IE) is a mixture of the base current and the collector current. The emitter current, on the other hand, is about equal towards the collector current since the base current is so much less than the collector current. Therefore IE IC

The input signal is supplied to the transistor's base terminal, just as in the common emitter (CE) amplifier design, and as we just said, the output signal of the amplifier is obtained from the emitter emitter terminal. However, because the transistor's base and its emitter terminal are separated by a single forward biased pn-junction, any input signal provided to the base would instead go straight through the junction towards the emitter. As a result, the applied input current at the base is in phase with the output signal at the emitter.

This particular transistor configuration also was known as a "Emitter Follower" circuit because the emitter output "follows" or tracks each and every voltage changes towards the base input signal with the exception of remaining 0.7 volts (VBE) below the base voltage. This is because the amplifier's output signal is taken from beyond the emitter load. As a result, there is no phase difference between both the input and output signals since VIN and VOUT are in phase.

Nevertheless, the pn-junction of the emitters effectively functions as a forward biased diode, and then for small AC input signals, this emitter diode junction has a serious opposition given by: r'e = 25mV/Ie, where the 25mV is the junction's thermal voltage at room temperature (25oC) and Ie is the emitter current. As a result, the emitter resistance lowers proportionally as the emitter current rises.

The base current that passes through in this internal base-emitter junction resistance also passes via the emitter resistor, RE, which is linked externally. Due to the series connection of these two resistances, they function as a potential divider network and cause a voltage drop. The magnitude of the amplifier's output voltage is thus smaller than that of its input voltage since r'e has a very low value and RE has a considerably greater value, which is typically in the kilohms (k) range.

However, in practice, the output voltage's magnitude (peak to peak) often ranges between 98 and 99% of the input voltage, which is sufficiently near in most instances to be regarded as unity gain.

Using the voltage divider formula as illustrated, we can get the common collector amplifier's voltage gain, VA, assuming that the base voltage, VB, is indeed the input voltage, VIN.

Common Collector Amplifier Voltage Gain

$$V_{OUT} = \frac{V_{IN} \times R_E}{r'_e + R_E}$$

Thus :

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{I_e \times R_E}{I_e\left(r'_e + R_E\right)}$$

Since R_E is much greater than r'_e $(r'_e + R_E) \cong R_E$

and the two emitter currents, I_e cancel, thus:

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{R_E}{R_E} \cong 1$$

As a result, the common collector amplifier could indeed increase voltage, and for obvious reasons, the common collector amplifier circuitry is sometimes referred to as a voltage follower circuit. A non-inverting unity voltage gain amplifier is what the common collector circuit is since the output signal gradient approximation the input and is in phase with the input.

Impedance of a Common Collector Input

The common collector amplifier does not perform well as a voltage amplifier because, as we have seen, its frequency response voltage gain is roughly equal to one (AV 1); however, because of its high input (ZIN) and low output (ZOUT) impedances, which provide isolation between an input signal source and an impedance load, it performs well as a voltage buffer circuit.

The common collector amplifier also offers current gain (Ai) as long as it is conducting, which is a helpful feature. That is, it may respond to a minor change in its base current, IB, by passing a huge current that flows from the collector to the emitter. Keep in mind that because there is no RC, this DC current merely observes RE. If RE is tiny, the DC current is just VCC/RE, which may be substantial.

Consider the fundamental emitter follower or common collector amplifier arrangement shown below:

Common Collector Amplifier Configuration (Figure 11.3)

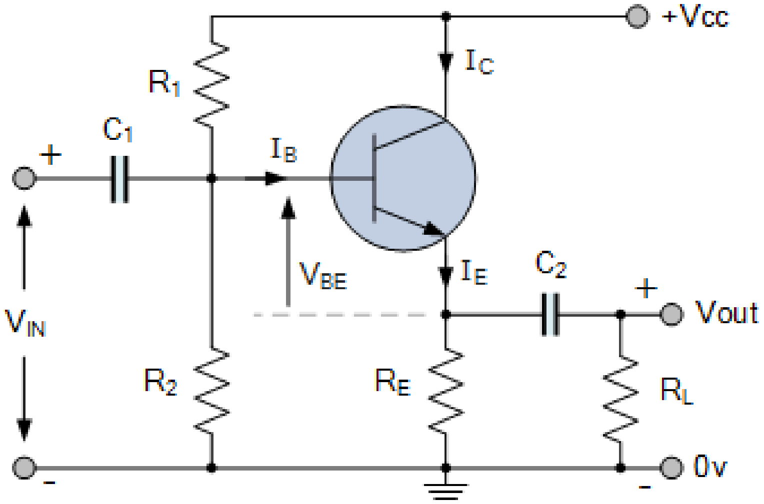

Figure 11.3: Common Collector Amplifier Configuration

For AC analysis of the circuit, the capacitors are shorted and V_{CC} is shorted (zero impedance). Thus the equivalent circuit is given as shown with the biasing currents and voltages given as (Figure 11.4):

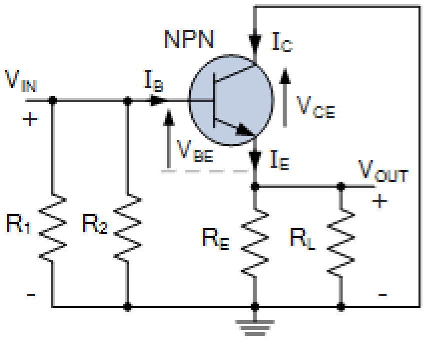

Figure 11.4: Common Collector Amplifier Configuration-zero impedance

$$R_B = R_1 \parallel R_2$$

$$R_e = R_E \parallel R_L$$

$$\beta = \frac{I_C}{I_B} \quad \therefore I_C = \beta I_B$$

$$I_E \approx I_C = \beta I_B$$

$$V_{IN} = V_B = V_{BE} + V_E$$

The Input Impedance, Z_{IN} of the common collector configuration looking into the base is given as:

$$Z_{IN} = R_{BIAS} \parallel Z_{base} \qquad \text{Where: } Z_{base} = \frac{V_b}{i_b}$$

$$\text{But: } V_b = i_e\left(R_e + r'_e\right), \quad i_e = i_c + i_b \quad \text{and } i_c = \beta i_b$$

$$\text{So: } Z_{base} = \frac{V_b}{i_b} = \frac{i_e\left(R_e + r'_e\right)}{i_b} = \frac{\left(i_c + i_b\right)\left(R_e + r'_e\right)}{i_b}$$

$$= \frac{\left(\beta \cancel{i_b} + \cancel{i_b}^{1}\right)\left(R_e + r'_e\right)}{\cancel{i_b}} = \left(\beta + 1\right)\left(R_e + r'_e\right)$$

However, because Beta, is often considerably larger than 1 (typically over 100), the formula of: + 1 may be simplified to simply Beta, as multiplying by 100 is essentially equivalent to multiplying by 101. Thus:

Common Collector Amplifier Base Impedance

$$Z_{base} = \beta(R_e + r'_e)$$

Where r'e is the ac resistance of the emitter-base diode, Re is the corresponding emitter resistance, and is the transistor's current gain. Note that the transistor's base impedance may be written as simply: *Re since the sum of Re is often considerably higher than the equivalent resistance of the diode, r'e (kilo-ohms opposed to a few ohms).

It's interesting to note that while the load resistor RL and the emitter leg resistor RE are parallel linked, the value of one of them might affect the transistor's input base impedance, ZIN(base).

While the aforementioned equation provides the input impedance as seen through the transistor's base, it does not provide the actual input impedance that the original signal would experience as seen through the whole amplifier circuit. In order to do so, we must take into account the voltage divider biasing network's two resistors. Thus:

Common Collector Amplifier Input Impedance

$$Z_{IN} = R_{BIAS} \parallel Z_{base}$$

$$\text{Where :} \; R_{BIAS} = R_B = R_1 \parallel R_2$$

$$\therefore \; Z_{IN} = R_B \parallel \beta(R_e + r'_e)$$

Chapter 12

Common Base Amplifier

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The input is supplied to the emitter terminal of the BJT transistor for a common base amplifier, and the output is obtained from the collector terminal.

Another bipolar junction transistor (BJT) design is the common base amplifier, which gets its name from the fact that the transistor's base terminal serves as a common terminal for both input and output signals (CB). Despite being less prevalent as an amplifier than the more well-liked common emitter or common collector arrangements, the common base configuration is nonetheless used because of its distinct input/output properties.

The input signal must be supplied to the emitter terminal of the common base configuration in order for it to function as an amplifier, and the output must be obtained from the collector terminal. Because the transistor is a three-layer, two-pn-junction device, it must be properly biased in order for it to function as a common base amplifier. As a result, the emitter current is also the input current and the collector current is also the output current. In other words, the base-emitter junction is biased forward.

Take a look at the fundamental common base amplifier arrangement below.

Common Base Amplifier using an NPN Transistor (Figure 12.1):

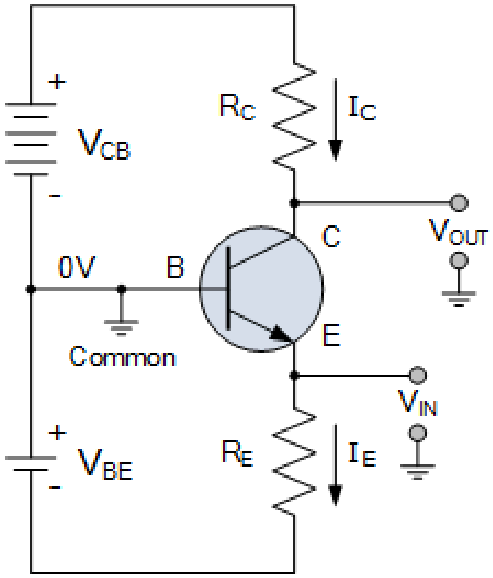

Figure 12.1: Common Base Amplifier using an NPN Transistor

The output variables are therefore related to the collector current IC and the collector-base voltage, VCB, whereas the input variables are related to the emitter current IE and the base-emitter voltage, VBE.

Since the input current, I, and the emitter current, IE, are inversely correlated, any changes to the input signal will also result in changes to the collector current, IC. Ai is specified as iOUT/iIN for a common base amplifier configuration called current gain, which is itself calculated by the formula IC/IE. Alpha, (), is the name given to the current gain for a CB arrangement.

Because the emitter current in a BJT amplifier is always bigger than the collector current (IE = IB + IC), the amplifier's current gain () must be less than one (unity), because IC is always less than IE by the amount of IB. Consequently, the CB amplifier reduces the current, with average alpha values falling between 0.980 and 0.995.

The equations for alpha,, and beta may be obtained by demonstrating the electrical relationships between the three transistor currents, as illustrated.

$$I_E = I_B + I_C$$

$$\text{Alpha}, (\alpha) = \frac{I_C}{I_E} \quad \text{and} \quad \text{Beta}, (\beta) = \frac{I_C}{I_B}$$

$$\therefore I_C = \alpha \times I_E = \beta \times I_B$$

$$\text{thus:} \quad \alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{1 - \alpha}$$

Amplifier Current Gain

$$A_i = \frac{i_{OUT}}{i_{IN}} = \frac{\beta}{\beta + 1} \cong 1$$

The value of Alpha would be expressed as follows: 100/101 = 0.99 if the Beta value of a typical bipolar junction transistor is 100.

Gain in Amplifier Voltage

The common base amplifier must be able to function as a voltage amplifier since it cannot function as a current amplifier (Ai 1) The ratio of VOUT/VIN, or the collector voltage VC towards the emitter voltage VE, determines the voltage gain for something like the common base amplifier. Alternatively, VOUT = VC and VIN = VE

The output voltage must thus be a function of IC because, according to Ohm's Law, VRC = IC*RC, the output voltage VOUT is formed across the collector resistance, RC. Therefore, any change to IE will also result in a change to IC.

Then, given a typical base amplifier arrangement, we may state that:

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{V_C}{V_E} \cong \frac{I_C \times R_C}{I_E \times R_E}$$

As I_C/I_E is alpha, we can present the amplifiers voltage gain as:

$$A_V = \alpha\frac{R_C}{R_E} = A_i\left[\frac{R_C}{R_E}\right]$$

As a result, the voltage gain roughly corresponds to the relationship between the collector resistance and the emitter resistance. However, a bipolar junction transistor has a single pn-diode junction between the base and emitter terminals that results in a property known as the dynamic emitter resistance, abbreviated as R'e (Figure 12.2).

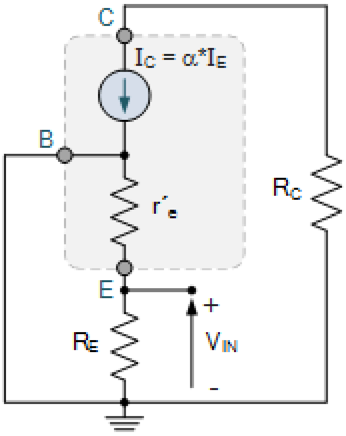

Figure 12.2: Gain in Amplifier Voltage

The effective small-signal resistance (r'e) of the emitter diode junction for AC input signals is given by: r'e = 25mV/IE, wherein IE is the emitter current and 25mV is the temperature coefficient of the pn-junction. As a result, the emitter resistance will drop proportionally as the emitter current rises.

Along with the externally attached emitter resistor, RE, some of the input current passes via this internal base-emitter junction resistance and into the base. These two resistances were linked in parallel for small-signal analysis.

The size of the amplifier's voltage gain fluctuates dynamically with various amounts of emitter current since the amount of r'e is relatively tiny and RE is typically considerably greater, often in the kilohms (k) range.

The real voltage gain of the common base amplifier will therefore be if RE >r'e:

$$A_V = \alpha\frac{R_C}{r'e} = A_i\left[\frac{R_C}{r'e}\right]$$

The voltage gain equation is simplified to only IC + IE since the current gain is almost equal to one:

$$A_V = \frac{R_C}{r'e}$$

As a result, the emitter-base junction's dynamic impedance would indeed be 25mV/1mA = 25 if, for instance, 1mA of current were to flow through it. With a collector load resistance of 10 k, the income from the sale, or AV, would be 10,000/25, or 400 volts. The more current that passes through the junction, the lower its dynamic resistance and the greater the voltage gain.

The greater the load resistance, the larger the voltage gain of the amplifier. Nevertheless, it would be unusual for a real common base amplifier circuit to employ a load resistor higher than 20 k, with typical voltage gain values ranging from roughly 100 to 2000 depending on the amount of RC. The power gain and voltage gain of the amplifier are almost equal.

There is no phase inversion between both the emitter and the collector since the voltage gain of the common base amplifier depends on the ratio of these two resistive values. As a result, the input and output waveforms are "in-phase," demonstrating the non-inverting amplifier architecture of the common base amplifier.

Gain in Amplifier Resistance

The ratio of the input and the output impedances in the common source amplifier circuit, which gives birth to the basic property known as the amplifier's Resistance Gain and makes amplification feasible, is one of the circuit's important features. As was said previously, the output is drawn from the collector while the input is linked to the emitter.

There are two potential parallel resistive routes between the input and ground terminal. One is grounded by the emitter resistance and RE, while the other is grounded through the base terminal and r'e. As a result, we may state that ZIN = RE||r'e while gazing at the emitter with the base grounded.

However, since the internal dynamic emitter resistance, r'e, dominates the equation and the dynamic emitter resistance, r'e, is just slightly larger than RE (r'eRE), the equation results in a low input impedance that is about equal to r'e.

As a result, with the common base design, the input impedance is relatively low and may vary between 10 and 200 ohms depending on the source impedance, which is determined by the RS connected to the emitter terminal. One of the primary causes of the common base amplifier circuit's restricted use as a single stage amplifier is its low input impedance.

However, depending on the collector resistance used to regulate the voltage gain and the linked external load resistance, RL, the CB amplifier's output impedance may be considerable. ZOUT = RC||RL is the result of connecting a load resistance across the amplifier's output terminal, which essentially connects it in parallel with the collector resistance.

However, if the collector resistance RC dominates the parallel equation and the output impedance ZOUT is small, it will become about equivalent to RC. This will happen if the externally connected load resistance, RL, is much higher than the collector resistance, RC. The output impedance for a common base setup would thus be ZOUT = RC when looking back into the collector terminal.

The common base circuit functions nearly like an ideal current source, receiving the input current from either the low input impedance side and transferring it to the high output impedance side since the output impedance of the amplifier able to look back into the collector terminal might potentially be quite big. In contrast to the common-collector (CC) design, which is known as a voltage follower, the common base transistor configuration also was known as a current buffer or power follower configuration.

Summary of Common Base Amplifier

The Common Base Amplifier has a current gain (alpha) of around one (unity), as we have seen in this article, but it may also have a very high voltage gain, with common values ranging from 100 to over 2000 dependent on the value of the collector load resistor RL employed.

Additionally, we have shown that while the amplifier circuit's input impedance is relatively low, its output impedance might be quite large. Additionally, we said that the common base amplifier somehow doesn't reverse the input signal since it is configured as a non-inverting amplifier.

The common base amplifier arrangement is very helpful in audio and radio frequency applications due to its input-output impedance characteristics as a current buffer to complement a low-impedance originator to a high-impedance load or as a single stage amplifier in a cascoded or multi-stage configuration whereby a amplifier stage is used to drive another.

Phasing Separator

A phase splitter circuit divides a single input signal into two output signals that are identical in amplitude but in phase with one another. Another sort of bipolar junction transistor (BJT) structure is the phase splitter, which divides a single sinusoidal input signal into two independent outputs that are 180 electrical degrees out of phase with one another. A transistor phase splitter's input signal is applied to the base terminal, and two output signals are obtained—one from the collector terminal and the other from the emitter terminal. Thus, the transistor phase splitter is a dual output amplifier that generates 180° out of phase complementary outputs from it's own collector and emitter terminals. We have already examined the fundamental components of a single-transistor phase splitter circuit in other courses, so this is nothing new. A common emitter amplifier's and a common collector amplifier's traits are combined in the phase splitter, phase-inverter circuit. The phase splitter circuit is forward biased to function as a linear class-A amplifier to minimize output signal distortion, much as the CE amplifier and CC amplifier circuits.

But first, let's brush up on our understanding of the common emitter (CE) and common collector (CC) amplifier circuit designs.

Amplifying emitters in common

The most popular linear amplifier architecture is the common emitter circuit with voltage divider biasing because it is simple to comprehend and bias. The output signal is drawn from across the load resistance, RL, which is connected between the collector as well as the positive supply rail, VCC, as illustrated. The input signal is applied to the base terminal. In light of this, the emitter is shared by the input and output circuits. The fundamental feature of the Common Emitter (CE) arrangement is that it is an inverting amplifier creating a phase reversal of 180o between the input signal and the output signals in addition to providing voltage amplification dictated by the ratio of: RL/RE. The circuit is biased such that the quiescent current injected into the base, IB puts the collector terminal voltage at about half the supply voltage value, allowing the device to function as a class-A amplifier. To ensure that the transistor is properly biased and producing the most pure output signal possible, the ratio of resistors R1 and R2 is selected.

Amplifier with a Common Collector

With the collector shared by the input and output circuits, the common collector amplifier employs a single transistor in a common collector design. As indicated, the transistor's base terminal receives the input signal, while its emitter terminal receives the output. Since there is no need for a collector resistor since the output signal is obtained from across the emitter resistor, RE, the collector terminal is coupled directly to the supply rail, VCC. As the output signal follows the input signal, this kind of amplifier design is often referred to as an emitter follower or a voltage follower.

The input signal immediately travels from the base-emitter junction to the output, making the Common Collector (CC) arrangement a non-inverting amplifier. As a result, the output and input are "in-phase." As a result, it has a voltage gain that is just under one (unity). The transistor of the common collector amplifier is biased using just a voltage divider network to half the supply voltage to offer it adequate stabilization for its DC working circumstances, similar to the prior common emitter arrangement.

Configuration of a phase splitter

We can build a transistor circuit that generates two output signals that are equal in magnitude but reversed with respect to one another if humans combine the configuration of a common emitter amplifier and that of the common collector amplifier but also take the outputs from both the collector and emitter terminals at the same time. Inverting and non-inverting outputs are generated by the Phase Splitter using a single transistor, as illustrated.

Using an NPN transistor as a phase splitter

As previously stated, the common emitter amplifier's voltage gain is defined as the ratio of RL to RE, or -RL/RE (the minus sign indicates an inverting amplifier). The voltage gain of a common emitter stage would be equal to -1 or unity if we were to make the values of these two resistors equal (RL = RE).

The two output signals—one from the collector and one from the emitter—will be identical in amplitude but 180 degrees out of phase because the common collector, emitter follower amplifier circuit has a non-inverting voltage gain that is inherently close to unity (+1). Because of this, the unity gain transistor phase splitter circuit may be used to provide complementary or anti-phase inputs to a class-B push-pull power amplifier or another amplifier stage. The voltage divider network that is connected between the supply rail and ground must be selected to produce the proper stabilizing of the DC conditions for something like the output voltage swing from both the collector and emitter terminals producing symmetrical outputs in order for the circuit to function properly.

Summary of a transistor phase splitter

In this tutorial, we've seen how to combine a common emitter and common collector circuit to make a different kind of single transistor circuit that isn't really a CE amplifier or a CC amplifier but rather a phase splitter circuit that generates two voltages with the same amplitude but opposite phase. There are several techniques to build a dual output phase splitter circuit, including the use of differential amplifiers and operational amplifiers. Sometimes it is required to have two signals that are both equal in amplitude but are 180o out-of-phase with one another. However, the one transistor phase splitter circuit design is the simplest to construct and comprehend. The two complementary (inverted and non-inverted) outputs of the single transistor phase splitter circuit are taken from the collector and emitter terminals of the transistor, respectively, and it is biased to function as a class A amplifier. Each output's gain setting has to be 1 for proper operation. As one transistor is ON and the other is OFF, single transistor phase splitter circuits are helpful for driving Class-B push-pull amplifiers, center-tapped transformer for inverters, or totem-pole outputs for motor control.

Conversions from analog to digital and from digital to analog

Let's take another look at the binary numbering system seen in Figure 5-1a as this chapter starts to establish a knowledge of converting an input analog signal to digital codes or translating digital codes to analog signals. Figure 1-5 had an illustration similar to this one. It is reiterated here to draw attention to the weighted value assigned to a digit's location in a binary numbering system. Remember that a binary number consists of binary digits (bits) at each of its digit positions. The only possible values for a bit are 0 or 1. The binary digit value of 1 or 0 multiplied by the weighted value of the digit position yields the weighted value for each digit position. The digit position has a weighted position value if the bit is a 1, and a weighted position value of 0 if the bit is a 0. The sum of all the weighted position values is the binary number's overall value. The binary digit weighted digit position value grows by two times over the digit value to the right, as shown in Figure 5-1a.

The design of digital-to-analog converters (DACs) and analog-to-digital converters must take this into consideration (ADCs). For instance, the weighted digit position value of the most significant bit (MSB) of the 8-bit binary integer shown in Figure 5-1a is 128. This is half of an 8-bit binary integer with a total value of 256. Also take note that the weighted digit position value for the next rightmost digit (the 7th bit) is 64, which is equal to half the MSB value. As the bit position is shifted to the right, the weighted digit position value is decreased by half, continuing all the way to the least significant bit (LSB). The design of DACs and ADCs relies on determining if the input quantity value exceeds the MSB value and, if so, whether it exceeds the MSB value plus the weighted digit position value of the next bit. If so, is it more than the sum of the values of the bits that came before it plus the weighted digit position value of the bit that comes after it? Up until the input is less than the total of the weighted values, the procedure is repeated.

Then, the weighted position value of the previous digit is not added but set equal to zero, the weighted position value of the subsequent bit to the right is added, and the sum is once again checked. Until the value is established or the LSB's value is included, which indicates that the evaluation is finished, this procedure continues. In other words, the digit values are added or set to zero as the digit positions from MSB to LSB are assessed, and when the LSB is reached, the evaluation is complete. This is how the input value is checked.

Binary Number Equivalent in Decimal

The A-to-D and D-to-A processes both depend on understanding a binary number's decimal counterpart. The assessment method is summarized in Figure 5-1b. It demonstrates how the decimal value is calculated by summing all of the bit values and multiplying the binary digit weighted position value by the bit value at each bit position.

Digital ADC Codes

The first step in discussing ADCs and DACs is to look at the codes that an ADC produces in response to an analog input signal. A 4-bit analog-to-digital converter is shown in Figure 5-2b as producing digital codes. It produces an analog signal as it rises from 0 to 15/16 of full size, resulting in 16 codes of four bits each. The coding is altered by a digital bit when the signal rises by 1/16 of the entire scale. The digital code produced by the ADC changes to reflect the amplitude of the analog signal at the moment the signal was sampled as the analog signal, seen in Figure 5-2a, changes in amplitude over time. This is seen by superimposing Figure 5-2a's analog signal over Figure 5-2b's ADC transfer curve. The sample points are shown and numbered from 1 to 16, and they match the sampling points against time in Figure 5-2a. Figure 5-2c lists the digital codes produced at each sample location in Figure 5-2b. The digital code created at a certain sample is the code that is closest to the amplitude that the signal has just overtaken but is still too little to generate the next code step. At the ADC's output, these codes from the sample points are shown in order to characterize the analog signal. Depending on the ADC, the digital codes may be displayed at predetermined periods set by a timing network either all at once in parallel or one bit at a time in series.

Digital-to-Analog Converters (ADC)

Figure 5-3's input section is an analog-to-digital converter (ADC). The counting ADC in Figure 5-8 was among the first ADCs. A binary counter that counts pulses from a central clock makes up the device. Two components—a DAC and a latch—are given the binary output from the counter. Each unit contains the necessary number of input or output bit lines to handle the ADC's needed bit count. The DAC is visible in the loop. The debate of the DAC arose first because to this. One input of a comparator receives an analog voltage generated by the binary code fed to the DAC. The second comparator input is the analog input voltage that will be transformed into a digital output. A digital 1 will result from the comparator when the input from the DAC is less than the analog input; a low voltage will result from the comparator when the input from the DAC is equal to or higher than the analog input (a digital 0). The latch is activated to lock in the binary values from the bit lines of the counter when the comparator output changes from a high signal to a low level. The binary code that corresponds to the value of the analog input voltage is what comes out of the latch as a result. This is how the A to D process works. The counter is restarted with a value of 0. As a consequence, the DAC output is zero. The comparator output will be a 1 if Vin, the analog input voltage, is positive. The output of the DAC will rise in steps, each a small positive voltage, as the clock advances the counter. The counter keeps counting and raises the DAC output voltage until it exceeds Vin if the DAC output is less positive than Vin. The comparator is triggered by this, and when it outputs 0, the binary code is latched at the output of the ADC and the counter is reset. The comparator output changes to a 1 when the counter is reset to zero, signaling that the ADC is prepared for another conversion. The conversion time of the counting ADC is one of its drawbacks. The amount of time needed for conversion may reach 2n - 1 clock cycles, where n is the number of bits in the ADC's binary output (Figure 12.3).

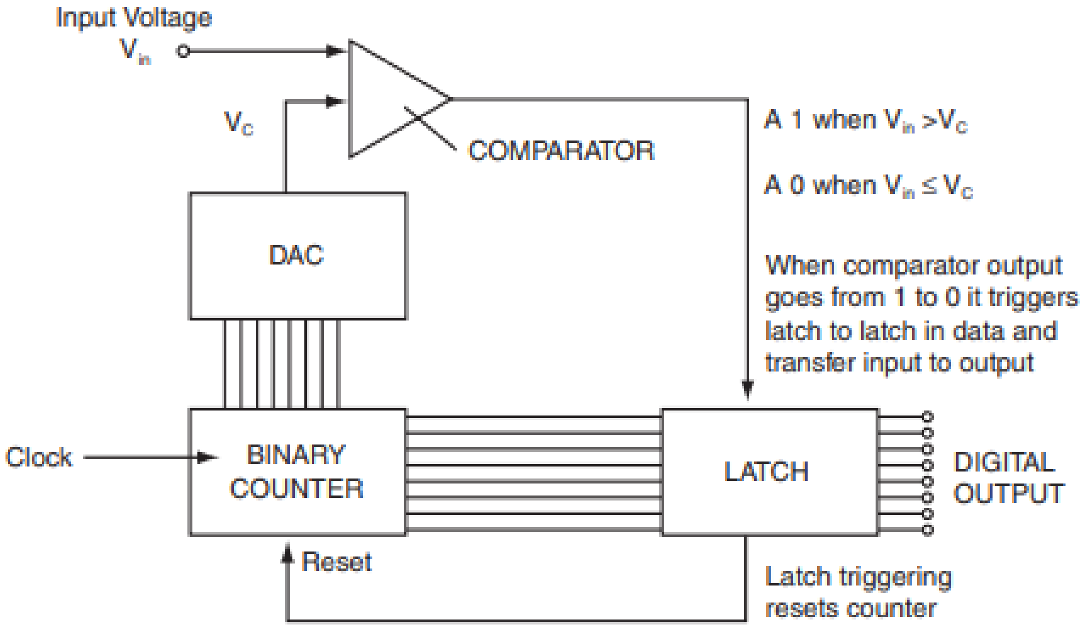

Figure 12.3: Digital-to-Analog Converters (ADC)

Successive Approximation Register (SAR)

ADC Utilizing a Successive Approximation Register (SAR) ADC reduces conversion time. The SAR, one of the most widely used ADCs, is constructed by substituting the counter from Figure 5-8 with logic, register, and latch circuits, as illustrated in Figure 5-9. The SAR may have resolutions of up to 16 bits and conversion durations ranging from 100 S to 1 S. The SAR was created using bipolar, CMOS, and both of these semiconductor technologies. Because the requisite performance can be reached for a reasonable price, the SAR seems to be the preferred design for the conversion time needed. Additionally, precision may be exchanged for system throughput (speed); however, increasing speed reduces accuracy. The SAR's name comes from comparing the output of a DAC with a binary-weighted code as its input to the input analog voltage repeatedly. Setting the MSB of the SAR's input to the DAC from a 1 initiates the conversion process. The remaining bits are all set to 0. This results in an analog voltage at the DAC output that is equivalent to 50% of the DAC's full-scale range. The DAC output is juxtaposed to the analog input voltage at the comparator, just as with the counting ADC. The comparator output is a 1 as well as the SAR MSB is left at a 1, and the next most significant bit supplied to the DAC is set to a 1 if the input voltage is higher than the DAC voltage. The output from the DAC will now comprise one-half plus another one-quarter to complete three-quarters of the DAC's full-scale range with the MSB and the next significant bit set to a 1.

As long as the comparator output is a 1, this sequence, which is shown in Figure 5-9b, keeps setting the next most important thing to a 1 (all other bits are zero). As long as the input voltage is higher than the DAC output, the comparator output will be a 1 each time a binary-weighted voltage is appended by the DAC to its output—one eighth, one sixteenth, one thirty-second, and so on. The comparator output changes to 0 when changing the next significant bit to 1, which causes the input voltage to just be lower than the DAC output. By changing the final significant bit from a 1 to a 0, this causes the DAC output to drop below the input voltage (Figure 12.4). The DAC output is raised once again at the same time as the next most important bit is set to 1, but this time simply a fraction of a voltage increment—say let's one thirty-second—instead of the one-sixteenth that was added there at bit before. Figure 5-9b depicts this. Up until all bits are checked and the closest approximation is discovered, the successive approximation process continues. As a consequence, depending on the outcome of the comparison between the DAC output and the input voltage, the SAR output bit is either set to a 1 or a 0, respectively. Figure 5-9b's final digital code is 11101010. In comparison to the counting ADC, the time required to transform the analog input voltage to a digital output is n clock cycles. The digital output code will be the SAR output after n clock cycles, as shown in Figure 5-9b, after all the bits have been checked and set. As each comparison is conducted, the output may be taken in parallel or moved out. This is also another benefit of the SAR ADC.

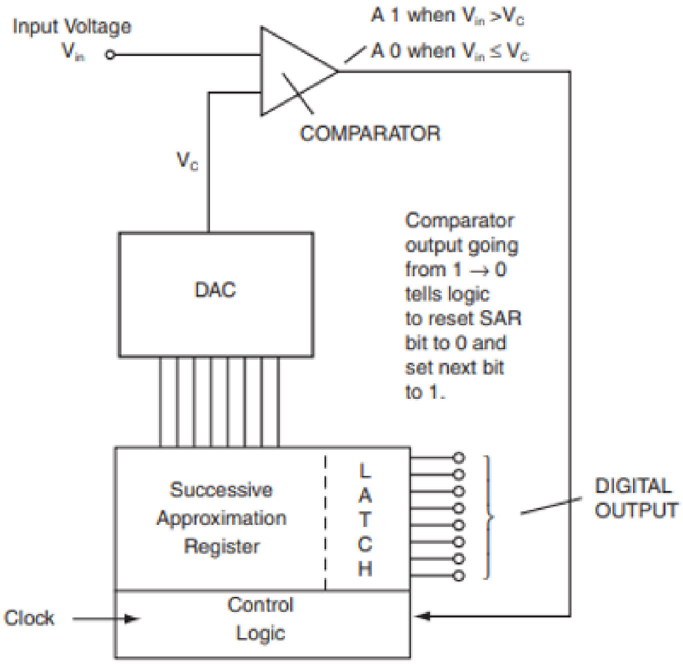

Figure 12.4: Successive Approximation Register

Capacitor Charge-Redistribution ADC

Figure 5-10 depicts the block diagram of a hybrid resistor-tree, capacitor charge redistribution ADC. It comprises of a charge-redistribution capacitor bank conversion circuit that processes K bits of the ADC output and a resistor-tree conversion circuit that processes M bits of the ADC output. The switching logic for setting individual bits in the SAR, the switch settings for the resistor tree, and the switch settings for the capacitor bank are all provided by the control logic, which is synchronized by the clock. Similar to the procedure previously outlined for the SAR ADC, a bit is compared by a comparator, and the result of that comparison is given to the SAR, which sets the bit for the ADC output. Between employing an all-capacitor charge redistribution circuit and a completely resistor-tree circuit, the hybrid DAC is a compromise. The conversion rates of the capacitor-charge redistribution are sluggish (Figure 12.5);

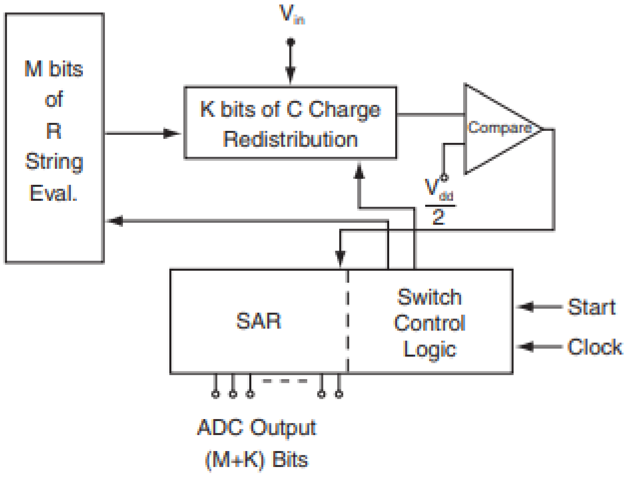

Figure 12.5: Capacitor Charge-Redistribution ADC

The resistor-tree circuit consumes more IC space but converts data more quickly, particularly as the ADC output bit count rises. Resistors use more space in integrated circuits than capacitors.

Operation ADC

The input analog voltage is recorded as a quantity of charge on a bank of capacitors in the hybrid ADC. The binary-weighted capacitors can handle up to K bits of the digital code that has to be transformed. A resistor tree conversion is used to convert the remaining bits (equivalent to M). Both the K bit and the M bit conversions using the resistor tree depend heavily on the charge on the capacitors, whose stays constant during the conversion. For instance, M = 5 and K = 3 in Figure 5-11 result in the conversion of five bits using the resistor tree and three bits using the binary weighted capacitors. The three least important bits are the K bits, whereas the M bits are the five most significant (Figure 12.6).

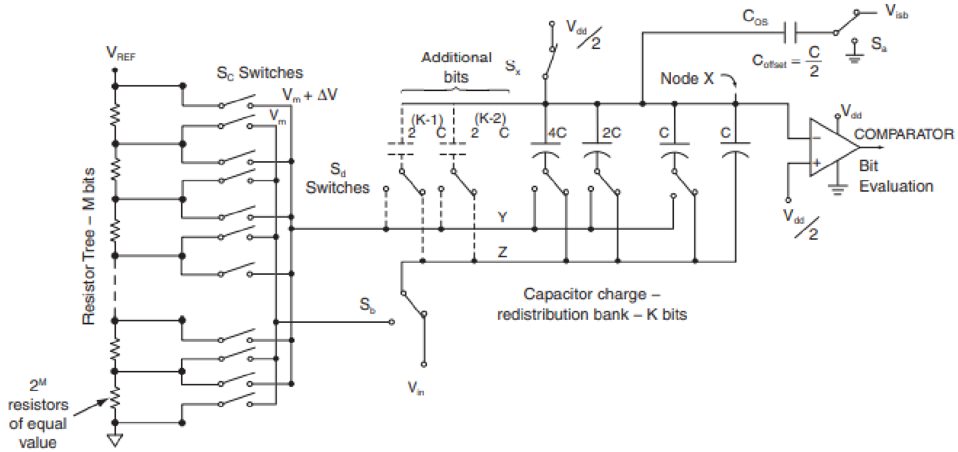

Figure 12.6: Operation ADC

Converting the M Bits

Beginning with the data collecting period shown in Figure 5-11, the conversion procedure begins. Switch Sa is linked to Vlsb, switch Sx is connected to VDD/2, and switch Sb is associated with the input analog voltage, Vin. Because the bottom end of the capacitors is linked to Node Z, the binaryweighted capacitor bank will charge to VDD/2 - Vin. The bank has a 2KC total capacitance. Charged to VDD/2 - Vlsb is the offset capacitor COS, which is equivalent to C/2. There is now no comparison since the comparator's two inputs are both linked to VDD/2. As illustrated in Figure 5-12, Sx opens at the end of the data collection period, Sb switches from Vin and is linked to the Vm line of a resistor tree, and Sa is connected to ground. The voltage at Node X is crucial to every conversion since it supplies the comparator's negative input. The comparator's positive input is wired to VDD/2. The comparator output will be a 1 if Node X's value is less than VDD/2 and a 0 if it is larger than VDD/2. Similar to the SAR ADC, the control logic picks the tap from the resistance tree that corresponds to one-half of the full-scale range for Vm when Sb is connected towards the resistor tree. The voltage at Node X is thus measured against VDD/2. The MSB of the output digital code from of the SAR is set to 1 if the voltage of Node X is less than VDD/2. The output bit of a SAR is set to zero if the voltage of Node X is higher than VDD/2. The MSB is now fully evaluated and is either set to a 1 or a 0 (Figure 12.7).

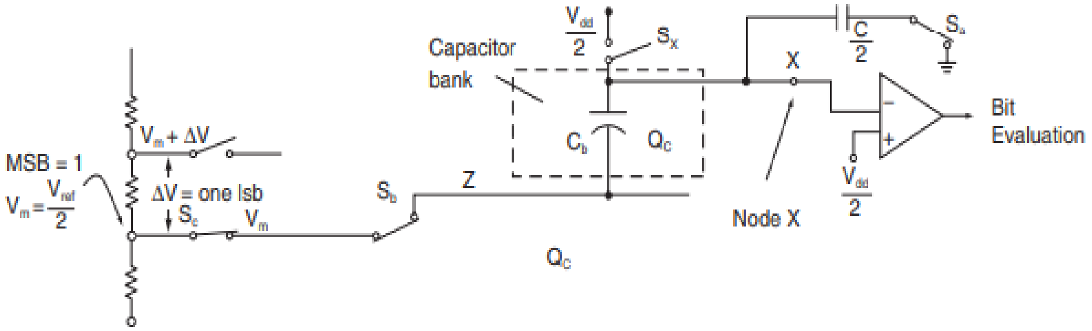

Figure 12.7: Converting the M Bits

The next significant bit will be evaluated by the control logic. The subsequent significant bit is set to 1. The SAR will choose the matching value of Vm from the resistor tree to feed the Node Z line linked to the capacitor bank in combination with the MSB value of a 1 or 0. The constant charges on the capacitor bank are redistributed as a result of the changed voltage value on the Z line, which also affects the voltage at Node X. The second-most significant bit is changed to a 1 or a 0 based on the comparison's outcome when the new Node X voltage is compared to VDD/2. After evaluating M bits, the bit evaluation procedure is complete. As a consequence, the M bits of the output SAR code are set. The voltage of Node X will be an accurate representation of the values of the five most important bits in the SAR output digital code at the conclusion of the M bit evaluations.

K Bits conversion

The evaluation now switches to the shunt capacitors circuit to evaluate the K bits, the last three prominent bits of a digital output code, while keeping the Node X voltage value constant. By moving the ends of the capacitors in each bit position, one bit placement at a time, to the Y line, the K bits are evaluated. The voltage of the resistor tree connection that the Y line is connected to (Vm + v) is one significant bit higher than the voltage of the Z line. According to Figure 5-13, the three K least significant bits are examined starting with the most significant bit. The Y line is linked to the capacitor's end, which in this instance has a value of C. The voltage at Node X is altered by the redistribution of charge on the capacitors. The end of the capacitor is switched back to the Z line if Node X is less than VDD/2; otherwise, the bit is set to a 0 and the capacitor end is left connected to the Y line. If Node X is larger than VDD/2, the capacitor bit is set to a 1. The voltage on capacitor C is added to the resistor network value to get the voltage at Node X when the bit is set to 1. By altering its Sd switch and connecting it with the Y line, the control logic flips the end of the subsequent binary-weighted capacitance of the subsequent least significant bit. With the replacement capacitor, which is now 2C in value, the charge is redistributed, causing a corresponding change in the voltage at Node X. The output is either set to a 1 or a 0, depending on whether the Node X voltage is greater than or equal to VDD/2. The end of the capacitor is once again returned to the Z line using switch Sd if the bit is set to a 0. Until all K bits have been analyzed and the final SAR digital code has been sent from the SAR, the procedure is repeated.

The Fastest Conversions

Flash ADCs enable conversions at the fastest possible speeds. The utilization of simultaneous comparisons between the analog input voltage and references produced by a resistor string enables the high speed. In Figure 5-14, a flash ADC's schematic diagram is shown. There are 2n - 1 reference voltages and 2n - 1 comparators needed for an n-bit flash converter. As a result, 255 comparators are needed for an 8-bit flash converter and 1023 comparators are needed for a 10-bit flash converter. The speed advantage comes at a hefty cost, including high cost, high power consumption, and enormous silicon area for the ICs. The converting procedure is rather easy. Each comparator's negative input is coupled to a pair of reference voltages that are one LSB apart in value. Each comparator's plus input is coupled to the analog input voltage. At each comparator, a comparison is done simultaneously. The comparator outputs a 0 if the input analog value on the plus input is lower than the reference voltage here on minus input. If the input analog voltage is higher than the reference value, the comparator's output will be a 1. Each comparator outcome is simultaneously delivered to the decoder, whose output is stored in a latch as an n-bit wide code. All input analog voltages that are above their respective resistor-string reference voltages will result in comparator outputs of 1, and all inputs that are below those reference voltages will result in comparator outputs of 0. For a given n-bit code that corresponds to the value of a input analog voltage, the resulting digital code into to the decoder produces the corresponding binary output code.

Sample and Hold and Filters

Test and Hold A to D conversions are also involved in the following two tasks. Sample and hold is one; filtering is the other. As shown in Figure 5-15, sample and hold does exactly what it says on the tin. In order to sample the input analog signal, switch S1 briefly closes before charging C1. The input voltage is then held by C1 until the ADC can process the data. That a capacitor that loses charge between samples would introduce mistakes into the sampling process is presumably evident. Similarly, switches with changing contact resistance change how long the capacitors need to charge and increase mistakes. So, the important components of sample and hold circuits are quick switches and high-quality capacitors. The majority of sample and hold circuits are now built straight into the ADC, when before they were only accessible separately. In actuality, a sample and hold is not required in the hybrid resistor-tree capacitor charge-distribution ADC. It is included into the circuit design as part of a cost-saving measure (Figure 12.8).

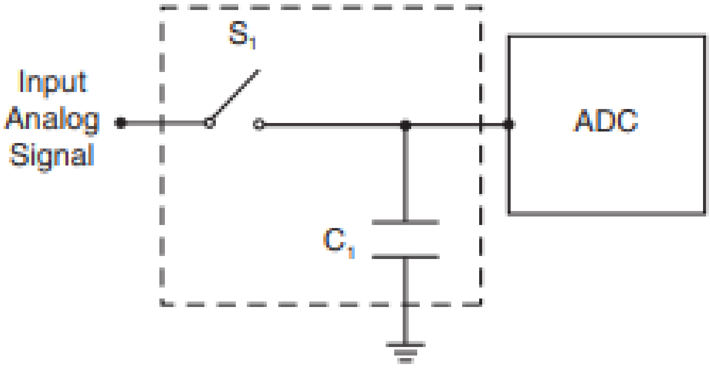

Figure 12.8: Sample and Hold and Filters

Filtering

It is used to restrict signals' bandwidth. As a result, it can do things like smooth out the input signal, get rid of spikes in the noise, restrict the high frequency response, choose certain signal frequencies, and so on. Their particular use in DAC systems is shown in Figure 5-16b. Step-like signals may be produced by the DAC. Filtering is used to eliminate the signal's step character and produce a smooth analog signal. The majority of filters are made specifically for each application. General filters are often not the answer since they are chosen to regulate a particular demand of the system. For the application, the filters must be specified specifically. The filter must be selected for the individual system in the DAC system example in Figure 5-16b. Instead of a jerky, jagged output, the signal that eventually manifests must be a smooth, continuous signal throughout time. The output of the ADC conversion and the DAC conversion is a highly precise reproduction of the input signal seen in Figure 12.9.

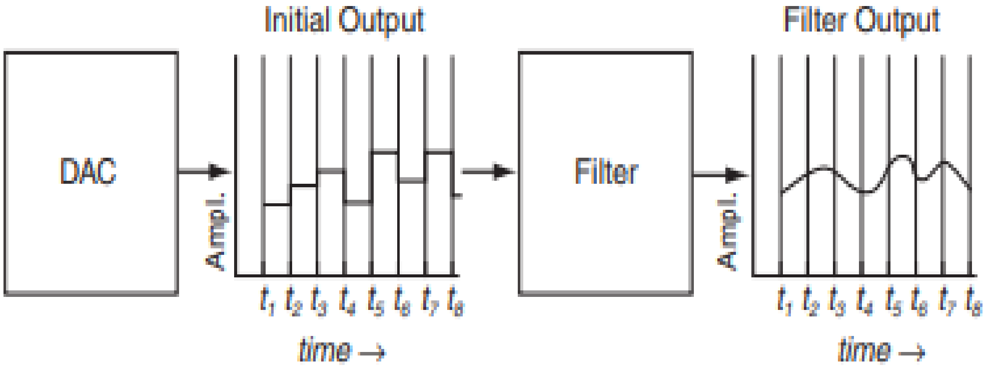

Figure 12.9: Output of ADC conversion

Digital System Processing

It is explained how a digital signal is processed in order to alter, compute, manipulate, change its shape, or route it to certain channels. To complete a job that has been assigned by the application that is being fulfilled, one or more of these processing activities may be required. The whole system is built to do a job, and the digital processor is a crucial component.

Digital Computer or Digital Processor

The digital processor inputs, stores, processes, and outputs digital signals, as the name suggests. Some of the processes controlled by the instructions in the application software include performing logical or mathematical calculations, changing the format of the signal, storing data temporarily or more permanently, decoding signals for display, and outputting signals. The fundamental design of a digital processor, often known as a digital computer, is seen in Figure 6-1. The central processing unit (CPU), which controls and decides how actions are carried out, is the primary brain of the system. Instructions are the binary-coded digital signals that inform the digital processor which operation to carry out. Every digital processor is built to carry out a certain set of instructions. The digital processor will carry out a different action as a result of each instruction in the set. For instance, a command may direct the digital processor to read a digital signal from a certain input. Alternately, a command might direct the CPU to temporarily store the input signal or to store it more permanently in memory. A different instruction could send a digital signal that has been processed by the CPU to a certain output after being applied. Additionally, a processor may be instructed to do a logical operation (such as ANDing two binary values), an arithmetic action (such as adding two binary numbers), or even a subtractive operation. A program is what we refer to as a set of sequential instructions that the processor is given (Figure 12.10).

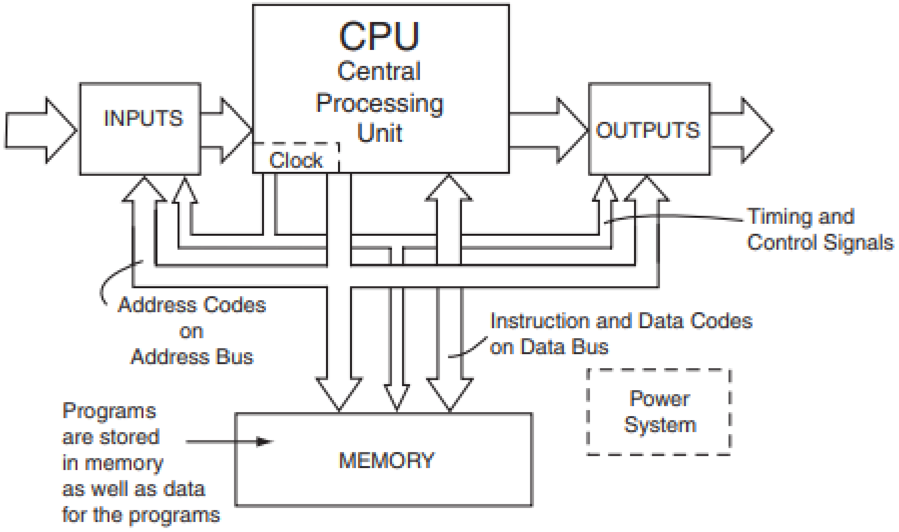

Figure 12.10: Digital Computer

Program for a digital computer

A program is the sequential arrangement of instructions for a digital processor to carry out a series of actions in a certain order to complete a job. A program's set of instructions is memorized and called upon whenever the desired job is needed. A separate software is necessary whenever a different job is called for.

The instructions of a program are sent from memory to the CPU through the data bus after being placed in memory at certain locations and often in order. It is comparable to a house with a specific address. The address is used by the post office to deliver mail. The addresses of the instructions in memory are also different. The CPU sends the address of the program's initial instruction to memory through the address bus whenever a specific job is required. The CPU tells the memory to read the instruction after locating it in memory using the address, and it is then transmitted to the CPU through the data bus. The guided operation is carried out by the CPU after decoding the instruction. The program addresses, locates the next instruction in memory, sends it to the CPU, and the CPU executes it.

Bus for Address, Instruction, and Data

Addresses are sent across the address bus and are used to find instructions in memory as well as to identify specific inputs and outputs. Addressing a specific input causes the CPU to choose that input to receive input data; addressing a specific output causes the CPU to send data to that output for transmission to the subsequent function. Addresses may also be used in other ways. The data A and the data B must be provided to the CPU before the operations may be carried out when an instruction asks for an arithmetic operation (or other operations that need specific information), such as ADD A and B. Data A and B are kept in a different part of memory from the program that is being run, along with additional data needed for the program. Similar to instructions, Data A and Data B were addressed across the address bus before being retrieved and transferred to the CPU. The data bus, often known as the instruction/data bus, is used to transfer both data and instructions from memory to the CPU.

Rhythm and Command

As seen in Figure 6-1, all CPU activities, including all address, instruction, and data transfers, take place in a predetermined order that is defined by timing and control signals obtained from the CPU's clock. A circuit that emits a sequence of repeating pulses that happen at a predetermined frequency or frequencies is the clock. The quick rise and fall periods of the clock pulses allow circuits to be activated on either edge, precisely timing the functioning of the circuits. The leading edge of the pulses is referred to as the rise time, and the following edge as the fall time. The timing of clock signals must be precise. As a consequence, phase-locked loops (PLLs) or, for the highest precision, quartz crystal oscillators are used to create them. When electrically energized, quartz crystals of a certain cut and size will vibrate at a very specific frequency. The CPU and the associated overall system are accurately controlled by the clock signals in terms of information transfers, manipulations, and storage.

Energy Systems

A whole, individual power system powers every digital processor. As the circuits frequently change states, sophisticated mechanisms are needed for the distribution of the supply voltages and the necessary currents. These systems must be controlled to maintain voltage fluctuation within strict bounds. Bypass capacitors are often used at crucial junctions to keep voltages within limits even while considerable amounts of current are transferred down the supply lines. The necessity for heat sinks and cooling air distribution has risen along with integrated circuit density as watts/in2 dissipation rises. As an IC's circuit density rose, complementary MOS (CMOS) technology took the lead in changing the circuit type from bipolar to MOS (metal-oxide-semiconductor) and CMOS (complementary MOS), which decreased power dissipation per circuit function. The supply voltages for circuit operation have been lowered from 5V to 3V and now 1.8V to once again minimize power consumption per function as density has continued to rise. Even with the decrease in voltage levels, the strict control criteria are still in place.

Representations of Digital Signals

Binary bits may typically represent numbers, letters, characters, and instructions in digital information. It is displayed a 4-bit binary code that may represent 16 distinct things. The 16 separate entities may be either eight positive numbers from +0 to +7 and eight negative numbers from -0 to -7, or they can be the numbers from 0 to 15 (1st column) (2nd column). The MSB of the code, as previously mentioned, is utilized to determine if a number is positive or negative. The six special punctuation letters and the digits 0 to 9 may also be identified using the 16 distinct codes (3rd column). Alternately, 16 distinct codes might be used to denote 16 distinct instructions (8th column). The code must have more bits in order to recognize more letters and symbols. As an example, a 7-bit code is used by The American Standard Code for Information Interchange (ASCII), which is briefly referenced in Chapter 1 and presented in its entirety in Chapter 8. For a total of 128 characters, it recognizes 52 upper- and lower-case alphabetic letters, 10 digits from 0 to 9, 34 special data transmission and Teletype instructions, and 32 more special characters. The 52 upper- and lower-case alphabetic letters as well as additional unique symbols that are designated in the ASCII code are shown in columns 4, 5, 6, and 7 of Figure 6-5. The previously stated column 3 is also utilized in the ASCII coding. Column 3 has bits 5, 6, and 7 at 110, whereas columns 4, 5, and 6 have them at 001, 011, and 111, respectively, to complete the 7-bit code. The identities of the 16 codes transform to new letters, numerals, or symbols when the 5, 6, and 7 bit combinations change.

Signals for timing, clocks, and controls

As previously mentioned, a computer program is a set of instructions that must be followed in order for a digital processor to complete a job that is specified by the program. The timing and control signals cause these actions to take place in the specified order at certain predetermined times. Instructions specify how electrical circuits should work inside each step to carry out the tasks requested by the program. The timing and control signals regulate the timing of the instructions and the timing of the circuit's functioning.

Clock

The clock is the brain of the timing circuits. Typically, a crystal-controlled oscillator that produces signals at very exact frequencies serves as its source. The signal output of this device is made up of rectangular pulses with very quick rising and falling edges. Figure 6-6a depicts an example of a typical pulse. The clock pulse's rising and falling edges provide accurate timing for managing the operation of electrical circuits. The clock may have several phases, as illustrated in Figure 6-6a, or it may just have one set of pulses, like phase 1(1). For the control of circuits, the extra phases provide more timing signals. As shown in Figure 6-6a, some of the clock-controlled circuits begin operation on the rising edge of the pulse, while other circuits initiate operation on the falling edge. These options for triggering circuits provide a variety of customizable ways to time the functioning of electrical circuits.

Figure 6-6b illustrates the timing of an electrical circuit using a gated latch. The electrical device shown is referred to as a gated latch. Digital data is temporarily stored there. The clock and the binary signal D (which may be either 1 or 0) serve as the gated latch's inputs. The results are the outputs Q and Q', which are complimentary to one another if Q = 1 or 0 respectively. Only when a signal has been "clocked in," or after the clock has appeared and the D signal has been timed in, is it stored in the latch and shown on Q. As shown in Figure 12.11, a clock signal schedules the change into the latch such that Q only changes when D changes. The latch gets its name from the fact that it is an electrical circuit used for temporary storage and latches onto and holds onto data. Data is gated in at a certain moment thanks to the gated latch.

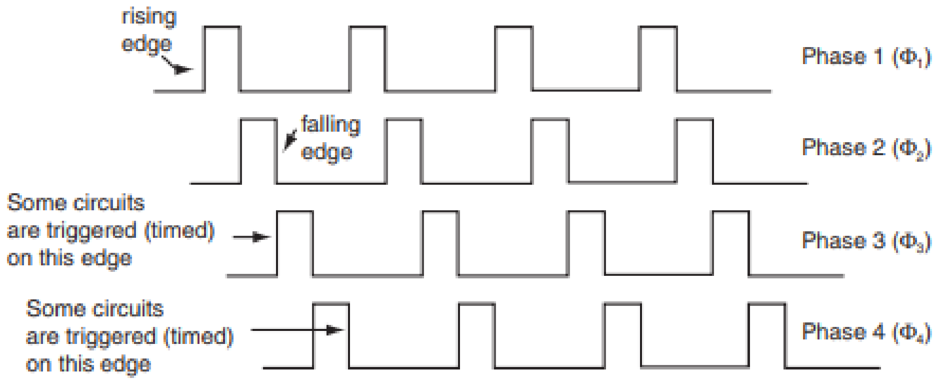

Figure 12.11: clock signal

AND Gate Control

In Figure 6-6c, another example of performing detection is shown. Here, a control signal is timed using a 2-input AND gate. A memory is instructed to read data from memory by the control signal needed. Before the memory received the control signal, it had already received and decoded the address of the information. To provide the memory read signal at a certain moment, an AND gate is used. The truth table demonstrates that for the AND gate's output to be a 1, both of its inputs must be 1. The output is a 0 if either or both of the inputs are 0. When the memory read signal is connected to the AND gate's A input and reads 1, the memory is being read. However, until the clock signal is a 1, the control signal needed to properly instruct the memory to read will not appear on the AND gate's output. As a consequence, the clock's accurate time is used to read data from the memory. The read signal overlaps the clock signal at the input of the AND gate and may move around a lot in regard to the clock while still being timed appropriately. The output of the AND gate, in this instance the memory read pulse, turns out to have the same width as the clock pulse. The versatility of the timing and control signals is increased by the possibility of various phases in a clock. Phase 2 may be utilized by the clock in Figure 6-6b, whereas Phase 4 may be used by the clock in Figure 6-6c. This displays the adaptability a designer has when timing the system circuits as was previously described.

Interrupts

An interrupt is a signal that activates a digital processor at erratic or unexpected periods. The interrupt signal indicates that it instructs the digital processor to perform something else in place of what it was previously doing. A STOP signal forces the processor to stop whatever it is doing. Depending on when the CPU has to be turned off, it often happens at odd times. Or maybe the

CPU is executing a program and needs input signals. The input circuits alert the digital processor to the presence of the inputs when they are accessible. The CPU receives an interrupt as a result, stops what it's doing, and enters the data. The processor resumes where it left off after the data has been entered. The CPU records the location of the processor at the time of the interrupt. Identical behavior is seen at the outputs. The software mandates that the CPU output data to an external device. The CPU picks an output and addresses the I/O. When the output is prepared, the output circuits notify the CPU by sending an interrupt. The processor that is being interrupted shifts to a procedure to produce the data. The processor goes back to the program position just after the place where it was paused once the transfer to the output is finished. A digital processor's reaction to an interrupt may determine how it is used. Some processors react to interruptions extremely rapidly so that the overall speed of running their application and finishing a job is not impacted. While certain processors may be sluggish to react to interrupts, if an application relies heavily on interrupts, the processor's overall performance will be significantly affected. The fastest the CPU can complete the job is significantly constrained. Some digital processors don't react to interrupts randomly or unpredictably; instead, they only do so when they wish to. The majority of contemporary digital processors react swiftly to sporadic and unforeseen interruptions.

Status bits

The state of check bits, also known as status bits, is used to generate the control signals that drive digital processors. In a register, status bits are kept. A register, for instance, saves 16 bits since it is made up of a series of latches that are connected in a chain. The majority of registers keep track of the total amount of bits in each word utilized by the digital system. There are several differences in the status register. Each bit in the register is relatively independent of the other bits, and it stores a range of distinct bits. Numerous bits are separately set, and the values of many of them rely on the outcome of certain processor operations. Digital information passes through a digital processor as one of three different bit combinations: an 8-bit character code, a 16-bit instruction code, or a 32-bit address code. The bits' values—either a 1 or a 0—must be recognized by circuits that identify and decode the digital information and operate accordingly to decode the information. As previously mentioned, the processor follows a program that consists of a sequence of instructions. Each instruction has a certain amount of bits, as well as a specific code. Over the data bus, the instructions are sent from memory to the CPU. The instructions are temporarily stored in the instruction register within the processor so that the instruction decoder circuits may decipher them. The decoder analyzes the bits and determines the step that has to be taken by the processor in order to carry out the command. Computer programs are written by humans. The computer must be given instructions in a language that people can comprehend, but the computer must obey those instructions in digital codes that it can decipher. The human language must be translated into digital codes that the computer (processor) can comprehend. Machine code is the kind of digital code that a machine can comprehend. A machine-language program is a computer program created in machine code.

Questionnaire

- What is analog electronics?
- How to analysis an analog signals?
- What are Analog Components and Circuitry?
- What are Basic Functions for Analog-to-Digital Conversion?
- What are procedure Transducing the Signal?
- Define the Electromagnetic Spectrum?
- What are Application and Design of Analog Systems?
- What are Passive Components of analog electronics?
- How to measure Amplifier Frequency Response?
- How to measure small signal versus large signal?
- How many Classes of Amplifiers?
- What are JFET Characteristic Curves?