SEMESTER – I

19PHP102 ELECTRONIC DEVICES AND CIRCUITS 4H – 4C

Instruction Hours / week: L: 4 T: 0 P: 0 **Marks:** Internal: **40** External: **60** Total: **100**

End Semester Exam: 3 Hours

Course Objectives

- This paper contains details of basic electronic components, their characteristics and applications in the construction of different electronic instruments.
- Other than ordinary transistors and diodes special devices are also explained.
- To give an idea about the basics of electronics and electronic devices, which is very important for knowing the basics of any modern instrument.

Course Outcomes (COs)

1. Students will be able to build, design and analyze analog to digital converter.
2. Students will be able to design digital and analog systems.
3. Ability to understand the basic operation and working of different diodes like FET, MOSFET, CMOS, etc.
4. To understand the high frequency application of diodes.

UNIT I- ELECTRONIC DEVICES

Transistor Biasing and Stabilization with design problems, h-parameters and their applications in transistor circuit analysis for CE, CB and CC configurations; FET and MOSFETs: Characteristics and Biasing, Design of biasing circuits, Design and analysis of amplifiers, SCR, UJT, DIAC, TRIAC (construction & working).

UNIT II- ANALOG DEVICES

Frequency response of amplifiers General concepts; bode plot; low frequency response: BJT and FET amplifiers; miller effect capacitance; high frequency response of BIT amplifiers; hybrid pie model: short circuit current gain, cut off frequency, and current gain with resistive load; high frequency response of FET amplifiers; frequency response of multistage amplifiers; square wave testing, Numerical problems.

UNITIII - ANALOG CIRCUITS

Analysis of compound configurations Cascade connection; Cascade connection; Darlington connection; Bootstrapping principle; Bootstrapped Emitter Follower; Bootstrapped Darlington Emitter Follower; Feedback pair; . CMOS circuits; Current source circuits; Current mirror circuits; Differential amplifier circuits; Numerical problems.

UNIT IV- POWER AMPLIFIERS

Introduction, Series-fed Class A amplifier, Transformer coupled class A amplifier, Class B amplifier operation, Class B amplifier distortion, Power transistor heat sinking, Class C and Class D amplifiers, Numerical problems.

UNIT V- NETWORK THEORY

Mesh and node analysis Kirchhoff's voltage and current law, Network Theorems- Thevein's theorem, Norton's theorem, Superposition Theorem, Maximum power transfer theorem, Problems based on network theorems

SUGGESTED READINGS

1. Boyle L. stad and Louis Nashelsky, 10th edition, 2013, Electronic devices and circuit theory, Prentice-Hall of India,Delhi.
2. Millman and Halkias, 48th reprint, 2008, Integrated electronics, Tata McGraw-Hill, New Delhi.
3. Malvino A.P., Electronics Principles, 10th edition, 2013, Tata McGraw Hill, New Delhi
4. Mottershed, 1st edition, 2002, Electronic devices and circuits : An introduction, Prentice-Halloflndia, New Delhi.
5. M. S. Ghausi1st edition, 2013, Electronic devices and circuits, CBS.
6. Donald L. Schilling, Charles Belove, 3rd edition, 2009, Electronic circuits discrete and integrated, Tata McGraw-Hill, New Delhi.
7. Millman and Grabel, 2nd edition, 2001, Microelectronics; Tata McGraw-Hill, New Delhi.
8. T.F. Bogart and J.S. beasely and G. Rico, 5th edition, 2000, Electronic devices and circuits, Prentice hall; New Delhi.Hall of India .
9. A.Nagoor Kani, 1st edition, 2014, Circuit theory, RBA publications.

UNIT I

Electronic Devices and Applications - Transistor Biasing and Stabilization with design problems, h-parameters and their applications in transistor circuit analysis for CE, CB and CC configurations; FET and MOSFETs: Characteristics and Biasing, Design of biasing circuits, Design and analysis of amplifiers, Numerical problems.

ELECTRONIC DEVICES AND APPLICATIONS

Semiconductor devices are electronic components that exploit the electronic properties of semiconductor materials, principally silicon, germanium, and gallium arsenide, as well as organic semiconductors. Semiconductor devices have replaced thermionic devices (vacuum tubes) in most applications. They use electronic conduction in the solid state as opposed to the gaseous state or thermionic emission in a high vacuum.

Semiconductor devices are manufactured both as single discrete devices and as integrated circuits (ICs), which consist of a number—from a few (as low as two) to billions—of devices manufactured and interconnected on a single semiconductor substrate, or wafer.

Semiconductor materials are useful because their behavior can be easily manipulated by the addition of impurities, known as doping. Semiconductor conductivity can be controlled by the introduction of an electric or magnetic field, by exposure to light or heat, or by the mechanical deformation of a doped monocrystalline grid; thus, semiconductors can make excellent sensors. Current conduction in a semiconductor occurs via mobile or "free" electrons and holes, collectively known as charge carriers. Doping a semiconductor such as silicon with a small amount of impurity atoms, such as phosphorus or boron, greatly increases the number of free electrons or holes within the semiconductor. When a doped semiconductor contains excess holes it is called "p-type", and when it contains excess free electrons it is known as "n-type", where p (positive for holes) or n (negative for electrons) is the sign of the charge of the majority mobile charge carriers. The semiconductor material used in devices is doped under highly controlled conditions in a fabrication facility, or fab, to control precisely the location and concentration of p- and n-type dopants. The junctions which form where n-type and p-type semiconductors join together are called p–n junctions.

Diode

A semiconductor diode is a device typically made from a single p–n junction. At the junction of a p-type and an n-type semiconductor there forms a depletion region where current conduction is inhibited by the lack of mobile charge carriers. When the device is forward biased (connected with the p-side at higher electric potential than the n-side), this depletion region is diminished, allowing for significant conduction, while only very small current can be achieved when the diode is reverse biased and thus the depletion region expanded.

Exposing a semiconductor to light can generate electron–hole pairs, which increases the number of free carriers and thereby the conductivity. Diodes optimized to take advantage of this phenomenon are known as photodiodes. Compound semiconductor diodes can also be used to generate light, as in light-emitting diodes and laser diodes

Transistor

Bipolar junction transistor

Bipolar junction transistors are formed from two p–n junctions, in either n–p–n or p–n–p configuration. The middle, or base, region between the junctions is typically very narrow. The other regions, and their associated terminals, are known as the emitter and the collector. A small current injected through the junction between the base and the emitter changes the properties of the base-collector junction so that it can conduct current even though it is reverse biased. This creates a much larger current between the collector and emitter, controlled by the base-emitter current.

Field-effect transistor

Another type of transistor, the field-effect transistor, operates on the principle that semiconductor conductivity can be increased or decreased by the presence of an electric field. An electric field can increase the number of free electrons and holes in a semiconductor, thereby changing its conductivity. The field may be applied by a reverse-biased p–n junction, forming a junction field-effect transistor (JFET) or by an electrode insulated from the bulk material by an oxide layer, forming a metal–oxide–semiconductor field-effect transistor (MOSFET).

The MOSFET, a solid-state device, is the most used semiconductor device today. The gate electrode is charged to produce an electric field that controls the conductivity of a "channel" between two terminals, called the source and drain. Depending on the type of carrier in the channel, the device may be an n-channel (for electrons) or a p-channel (for holes) MOSFET. Although the MOSFET is named in part for its "metal" gate, in modern devices polysilicon is typically used instead.

Semiconductor materials

By far, silicon (Si) is the most widely used material in semiconductor devices. Its combination of low raw material cost, relatively simple processing, and a useful temperature range makes it currently the best compromise among the various competing materials. Silicon used in semiconductor device manufacturing is currently fabricated into boules that are large enough in diameter to allow the production of 300 mm (12 in.)wafers.

Germanium (Ge) was a widely used early semiconductor material but its thermal sensitivity makes it less useful than silicon. Today, germanium is often alloyed with silicon for use in very-high-speed SiGe devices; IBM is a major producer of such devices.

Gallium arsenide (GaAs) is also widely used in high-speed devices but so far, it has been difficult to form large-diameter boules of this material, limiting the wafer diameter to sizes significantly smaller than silicon wafers thus making mass production of GaAs devices significantly more expensive than silicon.

Other less common materials are also in use or under investigation.

Silicon carbide (SiC) has found some application as the raw material for blue light-emitting diodes (LEDs) and is being investigated for use in semiconductor devices that could withstand very high operating temperatures and environments with the presence of significant levels of ionizing radiation. IMPATT diodes have also been fabricated from SiC.

Various indium compounds (indium arsenide, indium antimonide, and indium phosphide) are also being used in LEDs and solid state laser diodes. Selenium sulfide is being studied in the manufacture of photovoltaic solar cells.

The most common use for organic semiconductors is Organic light-emitting diodes.

Semiconductor device application:

All transistor types can be used as the building blocks of logic gates, which are fundamental in the design of digital circuits. In digital circuits like microprocessors, transistors act as on-off switches; in the MOSFET, for instance, the voltage applied to the gate determines whether the switch is on or off.

Transistors used for analog circuits do not act as on-off switches; rather, they respond to a continuous range of inputs with a continuous range of outputs. Common analog circuits include amplifiers and oscillators.

Circuits that interface or translate between digital circuits and analog circuits are known as mixed-signal circuits.

Power semiconductor devices are discrete devices or integrated circuits intended for high current or high voltage applications. Power integrated circuits combine IC technology with power semiconductor technology, these are sometimes referred to as "smart" power devices. Several companies specialize in manufacturing power semiconductors.

TRANSISTOR BIASING AND STABILIZATION WITH DESIGN PROBLEMS

Transistor Biasing

Transistor Biasing is the process of setting a transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor.

A transistors steady state of operation depends a great deal on its base current, collector voltage, and collector current and therefore, if a transistor is to operate as a linear amplifier, it must be properly biased to have a suitable operating point.

Establishing the correct operating point requires the proper selection of bias resistors and load resistors to provide the appropriate input current and collector voltage conditions. The correct biasing point for a bipolar transistor, either NPN or PNP, generally lies somewhere between the two extremes of operation with respect to it being either “fully-ON” or “fully-OFF” along its load line. This central operating point is called the “Quiescent Operating Point”, or Q-point for short.

When a bipolar transistor is biased so that the Q-point is near the middle of its operating range, that is approximately halfway between cut-off and saturation, it is said to be operating as a Class-A amplifier. This mode of operation allows the output current to increase and decrease around the amplifiers Q-point without distortion as the input signal swings through a complete cycle. In other words, the output current flows for the full 360^o of the input cycle.

So how do we set this Q-point biasing of a transistor? – The correct biasing of the transistor is achieved using a process know commonly as Base Bias.

The function of the "DC Bias level" or "no input signal level" is to correctly set the transistors Q-point by setting its Collector current (I_C) to a constant and steady state value without an input signal applied to the transistors Base.

This steady-state or DC operating point is set by the values of the circuits DC supply voltage (Vcc) and the value of the biasing resistors connected the transistors Base terminal.

Since the transistors Base bias currents are steady-state DC currents, the appropriate use of coupling and bypass capacitors will help block bias current setup for one transistor stage affecting the bias conditions of the next. Base bias networks can be used for Common-base (CB), common-collector (CC) or common-emitter (CE) transistor configurations. In this simple transistor biasing tutorial we will look at the different biasing arrangements available for a Common Emitter Amplifier.

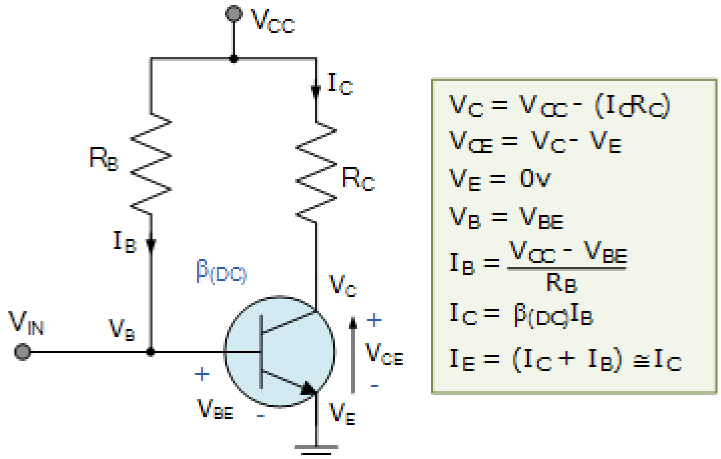
Base Biasing a Common Emitter Amplifier

One of the most frequently used biasing circuits for a transistor circuit is with the self-bias of the emitter-bias circuit where one or more biasing resistors are used to set up the initial DC values of transistor currents, (I_B), (I_C) and (I_E).

The two most common forms of transistor biasing are: Beta Dependent and Beta Independent. Transistor bias voltages are largely dependent on transistor beta, (β) so the biasing set up for one transistor may not necessarily be the same for another transistor. Transistor biasing can be achieved either by using a single feed back resistor or by using a simple voltage divider network to provide the required biasing voltage.

The following are five examples of transistor Base bias configurations from a single supply (Vcc).

Fixed Base Biasing a Transistor



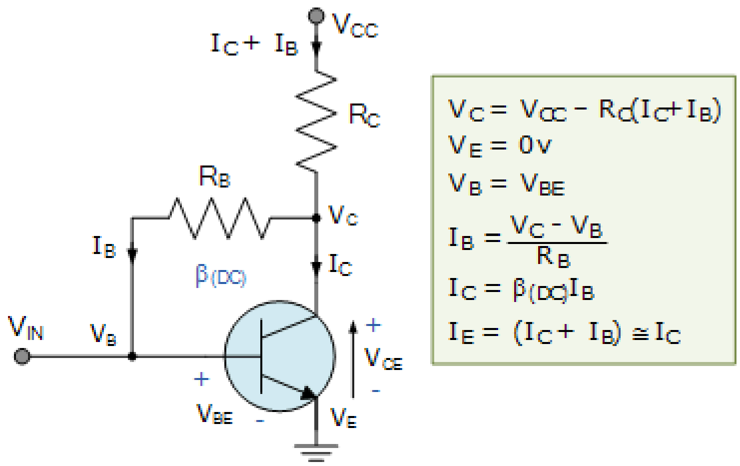
The circuit shown is called as a "fixed base bias circuit", because the transistors base current, I_B remains constant for given values of Vcc, and therefore the transistors operating point must also remain fixed. This two resistor biasing network is used to establish the initial operating region of the transistor using a fixed current bias.

This type of transistor biasing arrangement is also beta dependent biasing as the steady-state condition of operation is a function of the transistors beta β value, so the biasing point will vary over a wide range for transistors of the same type as the characteristics of the transistors will not be exactly the same.

The emitter diode of the transistor is forward biased by applying the required positive base bias voltage via the current limiting resistor R_B. Assuming a standard bipolar transistor, the forward base-emitter voltage drop will be 0.7V. Then the value of R_B is simply: $(V_{CC} - V_{BE})/I_B$ where I_B is defined as I_C/β.

With this single resistor type of biasing method the biasing voltages and currents do not remain stable during transistor operation and can vary enormously. Also the temperature of the transistor can adversely affect the operating point.

Collector Feedback Biasing a Transistor



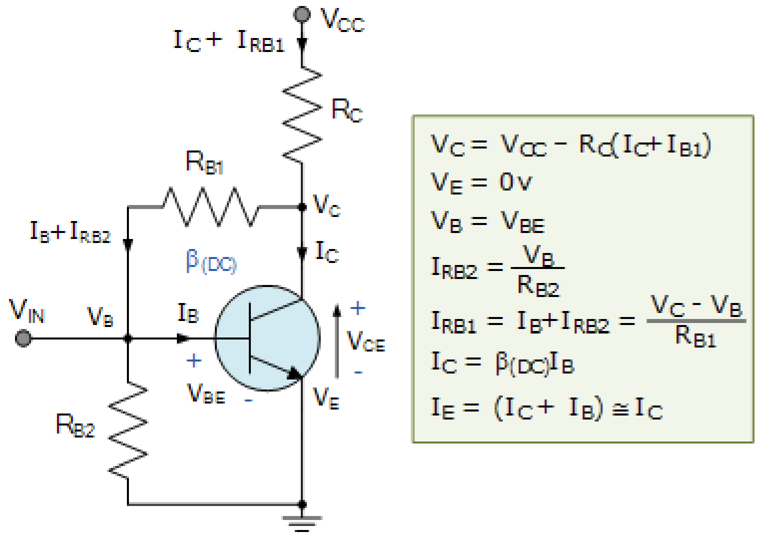
This self biasing collector feedback configuration is another beta dependent biasing method that requires only two resistors to provide the necessary DC bias for the transistor. The collector to base feedback configuration ensures that the transistor is always biased in the active region regardless of the value of Beta (β) as the DC base bias voltage is derived from the collector voltage, V_C providing good stability.

In this circuit, the base bias resistor, R_B is connected to the transistors collector C, instead of to the supply voltage rail, Vcc. Now if the collector current increases, the collector voltage drops, reducing the base drive and thereby automatically reducing the collector current to keep the transistors Q-point fixed. Then this method of collector feedback biasing produces negative feedback as there is feedback from the output to the input through resistor, R_B.

The biasing voltage is derived from the voltage drop across the load resistor, R_L. So if the load current increases there will be a larger voltage drop across R_L, and a corresponding reduced collector voltage, V_C which will cause a corresponding drop in the base current, I_B which in turn, brings I_C back to normal.

The opposite reaction will also occur when transistors collector current becomes less. Then this method of biasing is called self-biasing with the transistors stability using this type of feedback bias network being generally good for most amplifier designs.

Dual Feedback Transistor Biasing

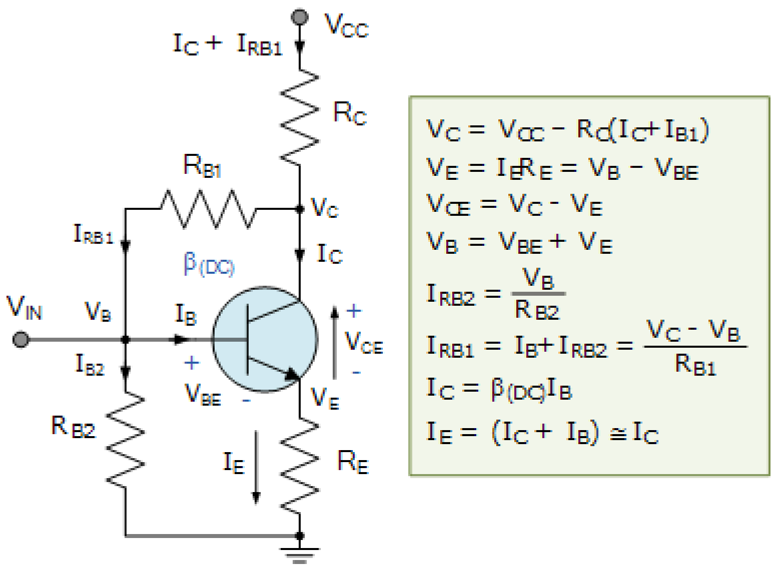


Adding an additional resistor to the base bias network of the previous configuration improves stability even more with respect to variations in Beta, (β) by increasing the current flowing through the base bias resistors.

The current flowing through R_{B1} is generally set at a value equal to about 10% of collector current, I_C. Obviously it must also be greater than the base current required for the minimum value of Beta, β.

One of the advantages of this type of self biasing configuration is that the resistors provide both automatic biasing and Rf feedback at the same time.

Transistor Biasing with Emitter Feedback



This type of transistor biasing configuration, often called self-emitter biasing, uses both emitter and collector-base feedback to stabilize the collector current even more as resistors R_B and R_E as well as the emitter-base junction of the transistor are all effectively connected in series with the supply voltage, V_{CC}.

The downside of this emitter feedback configuration is that the output has reduced gain because of the base resistor connection as the collector voltage determines the current flowing through the feedback resistor, R_B producing what is called “degenerative feedback”.

The current flowing from the emitter, I_E (which is a combination of I_C + :I_B) causes a voltage drop to appear across R_E in such a direction, that it forward biases the emitter-base junction.

So if the emitter current increases, voltage drop IR_E also increases. Since the polarity of this voltage reverse biases the emitter-base junction, I_B automatically decrease. Therefore the emitter current increase less than it would have done had there been no self biasing resistor.

Resistor values are generally set so that the voltage drop across emitter resistor R_E is approximately 10% of V_{CC} and the current flowing through resistor R_{B1} is 10% of the collector current I_C.

H-PARAMETERS AND THEIR APPLICATIONS IN TRANSISTOR CIRCUIT ANALYSIS FOR CE, CB AND CC CONFIGURATION:

Hybrid Parameters:- Every linear circuit having input and output terminals can by analyzed by four parameters (one is measured in ohm, one in mho and two dimension less) Since these parameters have mixed dimensions they are called hybrid parameters or h parameters. Consider the linear circuit having input voltage output voltage, input current ( ) output current ( ). Here the input current and output voltage are taken as independent variables where output current and input voltage are taken as dependent variable.

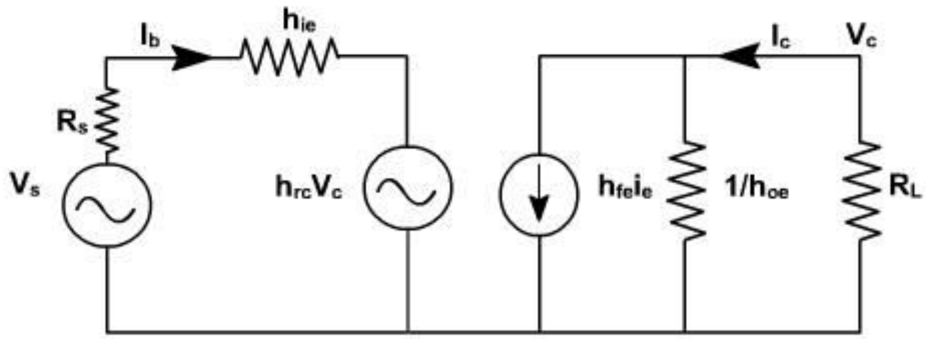
Hybrid model of a transistor in different mode of connections:- A transistor is actually a three-terminal device. However any of the terminals is used in common with both output and input. Thus virtually it has two input and two output terminals. Therefore it can be modeled by a two port hybrid model. The hybrid model can be applied to explain the operation of a transistor, only when it acts as a small-signal low frequency amplifier. The h-parameter model assumes two factors (i) linear variables (ii) absence of reactance. These are satisfied only if the above conditions are maintained. Generally to the notations of h-parameters a second subscript is induced to designate the circuit configuration. i.e. represents the CE,CB,CC configuration of the transistor.

Common emitter hybrid model:

In most practical cases it is appropriate to obtain approximate values of A_V , A_i etc rather than calculating exact values. How the circuit can be modified without greatly reducing the accuracy. Fig. 4 shows the CE amplifier equivalent circuit in terms of h-parameters Since 1 / h_{oe} in parallel with R_L is approximately equal to R_L if 1 / h_{oe} >> R_L then h_{oe} may be neglected. Under these conditions.

$I_c = h_{fe} I_B$.

$h_{re} v_c = h_{re} I_c R_L = h_{re} h_{fe} I_b R_L$.



FET - CHARACTERISTICS AND BIASING

Unlike BJTs, thermal runaway does not occur with FETs, as already discussed in our blog. However, the wide differences in maximum and minimum **transfer characteristics** make I_D levels unpredictable with simple fixed-gate bias voltage. To obtain reasonable limits on quiescent drain currents I_D and drain-source voltage V_{DS}, source resistor and potential divider bias techniques must be used. With few exceptions, MOSFET bias circuits are similar to those used for **JFET**s. Various FET biasing circuits are discussed below:

Fixed Bias

C bias of a FET device needs setting of gate-source voltage V_{GS} to give desired drain current I_D. For a JFET drain current is limited by the saturation current I_{DS}. Since the FET has such a high input impedance that no gate current flows and the dc voltage of the gate set by a voltage divider or a fixed battery voltage is not affected or loaded by the FET.

Fixed dc bias is obtained using a battery V_{QG}. This battery ensures that the gate is always negative with respect to source and no current flows through resistor R_G and gate terminal that is I_G =0. The battery provides a voltage V_{GS} to bias the N-channel JFET, but no resulting current is drawn from the battery V_{GG}. Resistor R_G is included to allow any ac signal applied through capacitor C to develop across R_G. While any ac signal will develop across R_G, the dc voltage drop across R_G is equal to I_G R_G i.e. 0 volt.

The gate-source voltage V_{GS} is then

$V_{GS} = – v_G – v_s = – v_{GG} – 0 = – V_{GG}$

The drain -source current I_D is then fixed by the gate-source voltage as determined by equation. This current then causes a voltage drop across the drain resistor R_D and is given as $V_{RD} = I_D R_D$ and output voltage, $V_{out} = V_{DD} – I_D R_D$

Self-Bias.

This is the most common method for biasing a JFET. Self-bias circuit for N-channel JFET is shown in figure.

Since no gate current flows through the reverse-biased gate-source, the gate current $I_G = 0$ and, therefore,$v_G = i_G R_G = 0$

With a drain current I_D the voltage at the S is

$V_s= I_D R_s$

The gate-source voltage is then

$V_{Gs} = V_G – V_s = 0 – I_D R_s = – I_D R_s$

So voltage drop across resistance R_s provides the biasing voltage V_{Gg} and no external source is required for biasing and this is the reason that it is called self-biasing.

The operating point (that is zero signal I_D and V_{DS}) can easily be determined from equation and equation given below :

$V_{DS} = V_{DD} – I_D (R_D + R_S)$

Thus dc conditions of JFET amplifier are fully specified. Self biasing of a JFET stabilizes its quiescent operating point against any change in its parameters like transconductance. Let the given JFET be replaced by another JFET having the double conductance then drain current will also try to be double but since any increase in voltage drop across R_s, therefore, gate-source voltage, V_{GS} becomes more negative and thus increase in drain current is reduced.

Potential-Divider Biasing

A slightly modified form of dc bias is provided by the circuit shown in figure. The resistors R_{Gl} and R_{G2} form a potential divider across drain supply V_{DD}. The voltage V_2 across R_{G2} provides the necessary bias. The additional gate resistor R_{Gl} from gate to supply voltage facilitates in larger adjustment of the dc bias point and permits use of larger valued R_S.

The gate is reverse biased so that $I_G = 0$ and gate voltage

$V_G =V_2 = (V_{DD}/R_{G1} + R_{G2}) *R_{G2}$

And

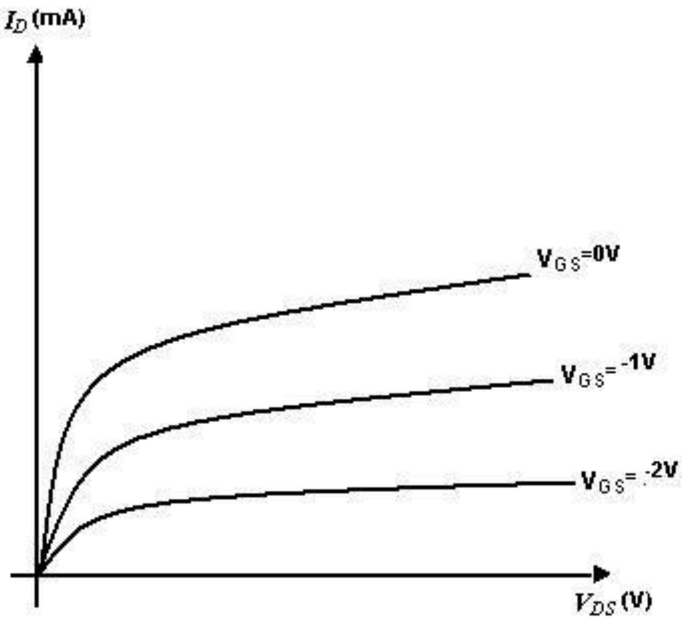
$V_{GS} = v_G – v_s = V_G – I_D R_s$

The channel of a FET is doped to produce either an n-type semiconductor or a p-type semiconductor. The drain and source may be doped of opposite type to the channel, in the case of enhancement mode FETs, or doped of similar type to the channel as in depletion mode FETs. Field-effect transistors are also distinguished by the method of insulation between channel and gate. Types of FETs include:

- The JFET (junction field-effect transistor) uses a reverse biased p–n junction to separate the gate from the body.
- The MOSFET (metal–oxide–semiconductor field-effect transistor) utilizes an insulator (typically SiO_2) between the gate and the body.
- The MNOS (metal–nitride–oxide–semiconductor) transistor utilizes an nitride-oxide layer insulator between the gate and the body.
- The DGMOSFET (dual-gate MOSFET) is a FET with two insulated gates.
- The DEPFET is a FET formed in a fully depleted substrate and acts as a sensor, amplifier and memory node at the same time. It can be used as an image (photon) sensor.
- The FREDFET (fast-reverse or fast-recovery epitaxial diode FET) is a specialized FET designed to provide a very fast recovery (turn-off) of the body diode.
- The HIGFET (heterostructure insulated gate field-effect transistor) is now used mainly in research.
- The MODFET (modulation-doped field-effect transistor) uses a quantum well structure formed by graded doping of the active region.
- The TFET (tunnel field-effect transistor) is based on band-to-band tunneling.
- The IGBT (insulated-gate bipolar transistor) is a device for power control. It has a structure akin to a MOSFET coupled with a bipolar-like main conduction channel. These are commonly used for the 200–3000 V drain-to-source voltage range of operation. Power MOSFETs are still the device of choice for drain-to-source voltages of 1 to 200 V.
- The HEMT (high-electron-mobility transistor), also called a HFET (heterostructure FET), can be made using bandgap engineering in a ternary semiconductor such as AlGaAs. The fully depleted wide-band-gap material forms the isolation between gate and body.

- The ISFET (ion-sensitive field-effect transistor) can be used to measure ion concentrations in a solution; when the ion concentration (such as H^+, see pH electrode) changes, the current through the transistor will change accordingly.
- The Bio FET (Biologically sensitive field-effect transistor) is a class of sensors/biosensors based on ISFET technology which are utilized to detect charged molecules; when a charged molecule is present, changes in the electrostatic field at the Bio FET surface result in a measurable change in current through the transistor. These include EnFETs, ImmunoFETs, GenFETs, DNAFETs, CPFETs, BeetleFETs, and FETs based on ion-channels/protein binding.
- The MESFET (metal–semiconductor field-effect transistor) substitutes the p–n junction of the JFET with a Schottky barrier; and is used in GaAs and other III-V semiconductor materials.
- The NOMFET is a nanoparticle organic memory field-effect transistor.
- The GNRFET (graphene nanoribbon field-effect transistor) uses a graphene nanoribbon for its channel.
- The VeSFET (vertical-slit field-effect transistor) is a square-shaped junction less FET with a narrow slit connecting the source and drain at opposite corners. Two gates occupy the other corners, and control the current through the slit.
- The CNTFET (carbon nanotube field-effect transistor).
- The OFET (organic field-effect transistor) uses an organic semiconductor in its channel.
- The DNAFET (DNA field-effect transistor) is a specialized FET that acts as a biosensor, by using a gate made of single-strand DNA molecules to detect matching DNA strands.
- The QFET (quantum field effect transistor) takes advantage of quantum tunneling to greatly increase the speed of transistor operation by eliminating the traditional transistor's area of electron conduction.

DRAIN CHARACTERISTICS

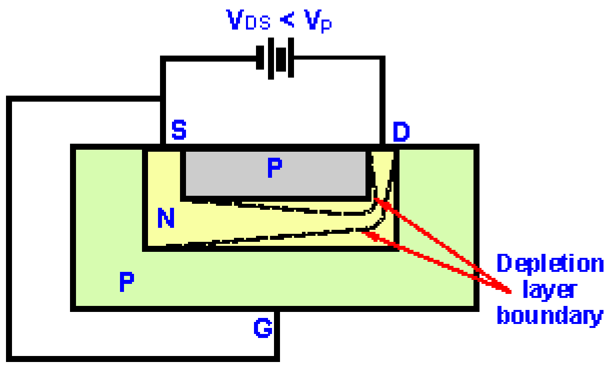


DESIGN OF BIASING CIRCUITS:

The electric field to control the current is applied to a third electrode known as a gate.

As it is only the electric field that controls the current flowing in the channel, the device is said to be voltage operated and it has high input impedance, usually many megohms. This can be a distinct advantage over the bipolar transistor that is current operated and has much lower input impedance.

The external field on the gate may serve to deplete the channel of carriers, in which case the FET is known as a depletion mode FET, or it may serve to enhance the carriers in the channel when it is known as an enhancement mode FET.



MOSFET – METAL OXIDE FET

Junction Field Effect Transistor (JFET), there is another type of Field Effect Transistor available whose Gate input is electrically insulated from the main current carrying channel and is therefore called an Insulated Gate Field Effect Transistor or IGFET. The most common type of insulated gate FET which is used in many different types of electronic circuits is called the Metal Oxide Semiconductor Field Effect Transistor or MOSFET for short.

The IGFET or MOSFET is a voltage controlled field effect transistor that differs from a JFET in that it has a "Metal Oxide" Gate electrode which is electrically insulated from the main semiconductor n-channel or p-channel by a very thin layer of insulating material usually silicon dioxide, commonly known as glass.

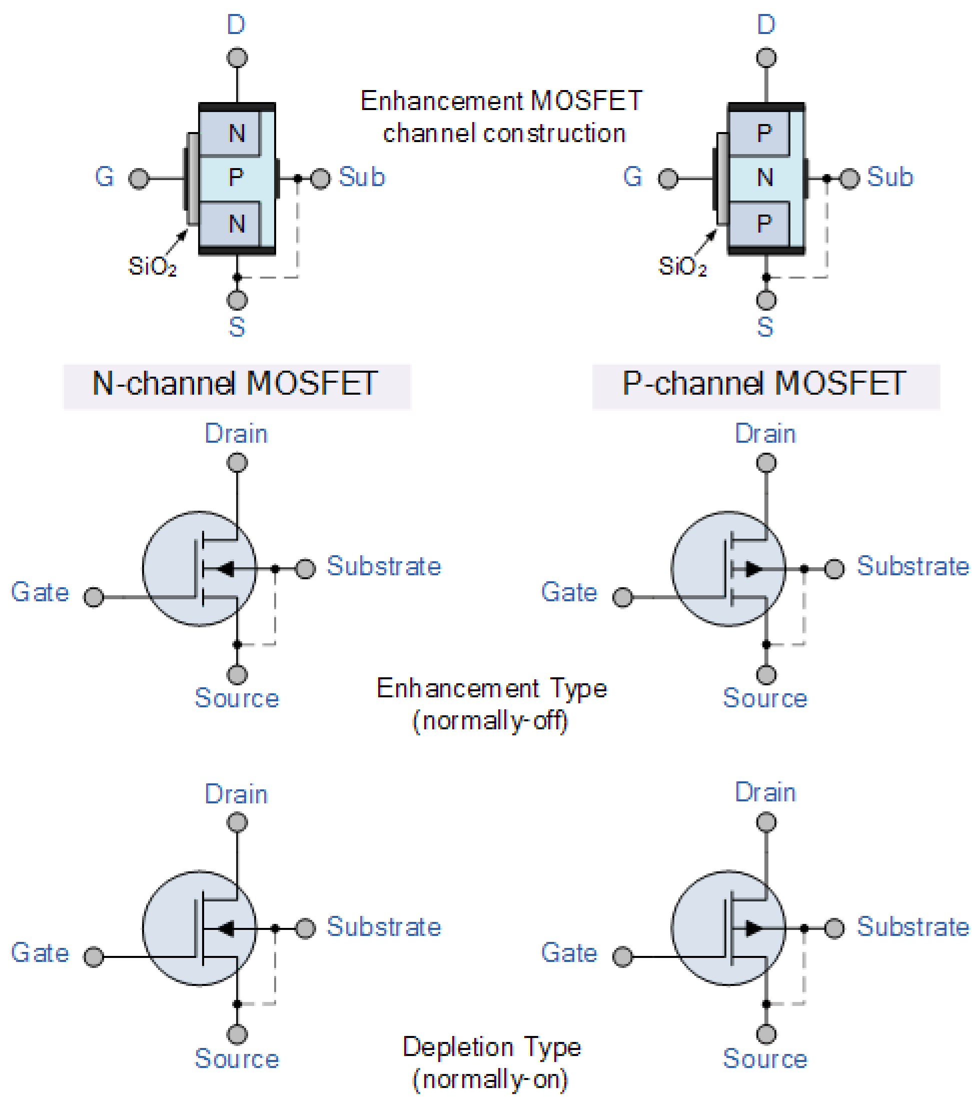
This ultra thin insulated metal gate electrode can be thought of as one plate of a capacitor. The isolation of the controlling Gate makes the input resistance of the MOSFET extremely high way up in the Mega-ohms (MΩ) region thereby making it almost infinite.

As the Gate terminal is isolated from the main current carrying channel "NO current flows into the gate" and just like the JFET the MOSFET also acts like a voltage controlled resistor were the current flowing through the main channel between the Drain and Source is proportional to the input voltage. Also like the JFET, the MOSFETs very high input resistance can easily accumulate large amounts of static charge resulting in the MOSFET becoming easily damaged unless carefully handled or protected.

Like the previous JFET tutorial, MOSFETs are three terminal devices with a Gate, Drain and Source and both P-channel (PMOS) and N-channel (NMOS) MOSFETs are available. The main difference this time is that MOSFETs are available in two basic forms:

- Depletion Type – the transistor requires the Gate-Source voltage, (V_{GS}) to switch the device "OFF". The depletion mode MOSFET is equivalent to a "Normally Closed" switch.
- Enhancement Type – the transistor requires a Gate-Source voltage, (V_{GS}) to switch the device "ON". The enhancement mode MOSFET is equivalent to a "Normally Open" switch.

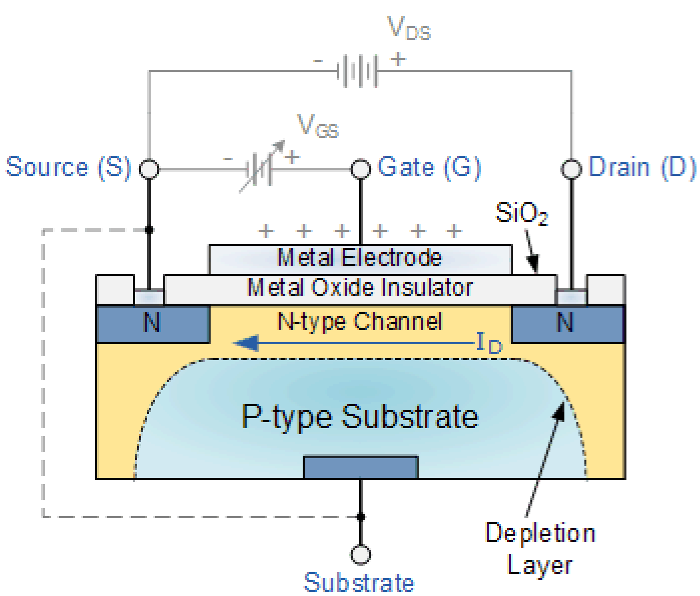
The symbols and basic construction for both configurations of MOSFETs are shown below.



The four MOSFET symbols above show an additional terminal called the Substrate and is not normally used as either an input or an output connection but instead it is used for grounding the substrate. It connects to the main semiconductive channel through a diode junction to the body or metal tab of the MOSFET. Usually in discrete type MOSFETs, this substrate lead is connected internally to the source terminal. When this is the case, as in enhancement types it is omitted from the symbol for clarification.

The line between the drain and source connections represents the semiconductive channel. If this is a solid unbroken line then this represents a "Depletion" (normally-ON) type MOSFET as drain current can flow with zero gate potential. If the channel line is shown dotted or broken it is an "Enhancement" (normally-OFF) type MOSFET as zero drain current flows with zero gate potential. The direction of the arrow indicates whether the conductive channel is a p-type or an n-type semiconductor device.

Basic MOSFET Structure and Symbol



The construction of the Metal Oxide Semiconductor FET is very different to that of the Junction FET. Both the Depletion and Enhancement type MOSFETs use an electrical field produced by a gate voltage to alter the flow of charge carriers, electrons for n-channel or holes for P-channel, through the semiconductive drain-source channel. The gate electrode is placed on top of a very thin insulating layer and there are a pair of small n-type regions just under the drain and source electrodes.

We saw in the previous tutorial, that the gate of a junction field effect transistor, JFET must be biased in such a way as to reverse-bias the pn-junction. With a insulated gate MOSFET device no such limitations apply so it is possible to bias the gate of a MOSFET in either polarity, positive (+ve) or negative (-ve).

This makes the MOSFET device especially valuable as electronic switches or to make logic gates because with no bias they are normally non-conducting and this high gate input resistance means that very little or no control current is needed as MOSFETs are voltage controlled devices. Both the p-channel and the n-channel MOSFETs are available in two basic forms, the Enhancement type and the Depletion type.

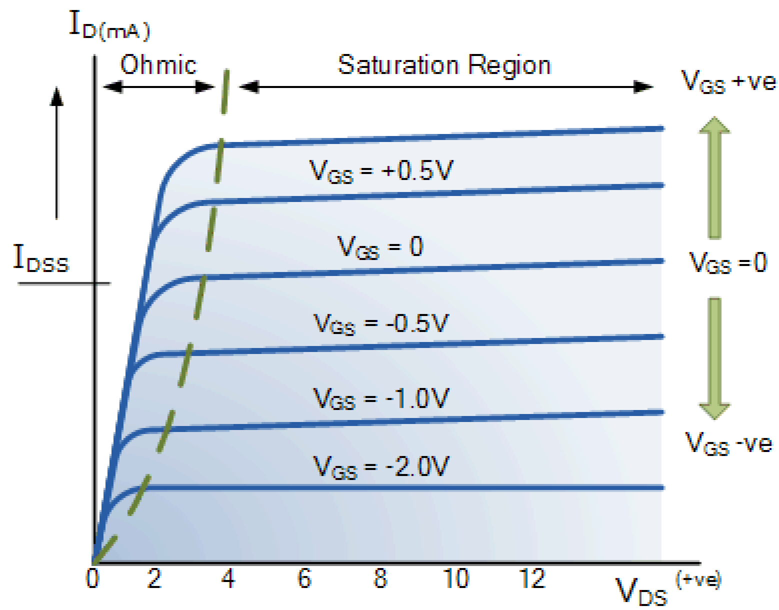
Depletion-mode MOSFET

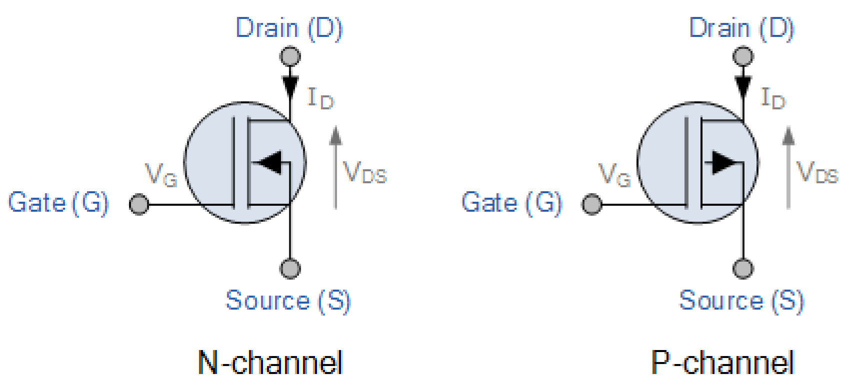
The Depletion-mode MOSFET, which is less common than the enhancement mode types is normally switched "ON" (conducting) without the application of a gate bias voltage. That is the channel conducts when $V_{GS} = 0$ making it a "normally-closed" device. The circuit symbol shown above for a depletion MOS transistor uses a solid channel line to signify a normally closed conductive channel.

For the n-channel depletion MOS transistor, a negative gate-source voltage, $-V_{GS}$ will deplete (hence its name) the conductive channel of its free electrons switching the transistor "OFF". Likewise for a p-channel depletion MOS transistor a positive gate-source voltage, $+V_{GS}$ will deplete the channel of its free holes turning it "OFF".

In other words, for an n-channel depletion mode MOSFET: $+V_{GS}$ means more electrons and more current. While a $-V_{GS}$ means less electrons and less current. The opposite is also true for the p-channel types. Then the depletion mode MOSFET is equivalent to a "normally-closed" switch.

Depletion-mode N-Channel MOSFET and circuit Symbols





The depletion-mode MOSFET is constructed in a similar way to their JFET transistor counterparts were the drain-source channel is inherently conductive with the electrons and holes already present within the n-type or p-type channel. This doping of the channel produces a conducting path of low resistance between the Drain and Source with zero Gate bias.

Enhancement-mode MOSFET

The more common Enhancement-mode MOSFET or eMOSFET, is the reverse of the depletion-mode type. Here the conducting channel is lightly doped or even undoped making it non-conductive. This results in the device being normally "OFF" (non-conducting) when the gate bias voltage, V_{GS} is equal to zero. The circuit symbol shown above for an enhancement MOS transistor uses a broken channel line to signify a normally open non-conducting channel.

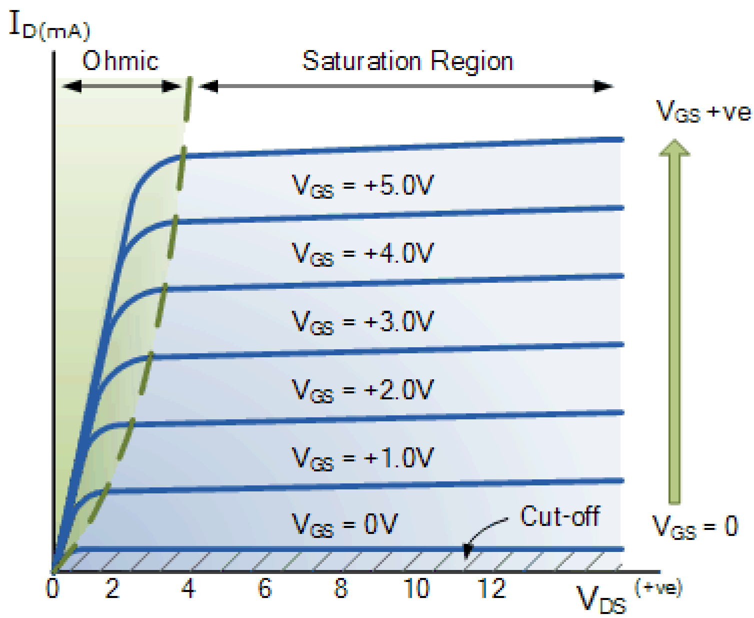
For the n-channel enhancement MOS transistor a drain current will only flow when a gate voltage (V_{GS}) is applied to the gate terminal greater than the threshold voltage (V_{TH}) level in which conductance takes place making it a transconductance device.

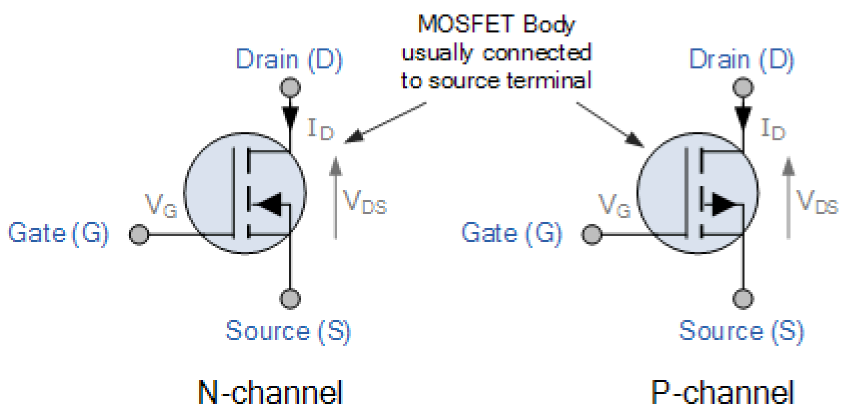
The application of a positive (+ve) gate voltage to a n-type eMOSFET attracts more electrons towards the oxide layer around the gate thereby increasing or enhancing (hence its name) the thickness of the channel allowing more current to flow. This is why this kind of transistor is called an enhancement mode device as the application of a gate voltage enhances the channel.

Increasing this positive gate voltage will cause the channel resistance to decrease further causing an increase in the drain current, I_D through the channel. In other words, for an n-channel enhancement mode MOSFET: $+V_{GS}$ turns the transistor "ON", while a zero or $-V_{GS}$ turns the transistor "OFF". Then, the enhancement-mode MOSFET is equivalent to a "normally-open" switch.

The reverse is true for the p-channel enhancement MOS transistor. When $V_{GS} = 0$ the device is "OFF" and the channel is open. The application of a negative (-ve) gate voltage to the p-type eMOSFET enhances the channels conductivity turning it "ON". Then for a p-channel enhancement mode MOSFET: $+V_{GS}$ turns the transistor "OFF", while $-V_{GS}$ turns the transistor "ON".

Enhancement-mode N-Channel MOSFET and Circuit Symbols





Enhancement-mode MOSFETs make excellent electronics switches due to their low "ON" resistance and extremely high "OFF" resistance as well as their infinitely high input resistance due to their isolated gate. Enhancement-mode MOSFETs are used in integrated circuits to produce CMOS type Logic Gates and power switching circuits in the form of as PMOS (P-channel) and NMOS (N-channel) gates. CMOS actually stands for Complementary MOS meaning that the logic device has both PMOS and NMOS within its design.

DESIGN AND ANALYSIS OF AMPLIFIERS

Amplifier is the generic term used to describe a circuit which increases its input signal, but not all amplifiers are the same as they are classified according to their circuit configurations and methods of operation.

In “Electronics”, small signal amplifiers are commonly used devices as they have the ability to amplify a relatively small input signal, for example from as sensor such as a photo-device, into a much larger output signal to drive a relay, lamp or loudspeaker for example.

There are many forms of electronic circuits classed as amplifiers, from Operational Amplifiers and Small Signal Amplifiers up to Large Signal and Power Amplifiers. The classification of an amplifier depends upon the size of the signal, large or small, its physical configuration and how it processes the input signal that is the relationship between input signal and current flowing in the load.

Classification of Amplifiers

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

Amplifiers can be thought of as a simple box or block containing the amplifying device, such as a transistor, FETor Op Amp, which has two input terminals and two output terminals (ground being common) with the output signal being much greater than that of the input signal as it has been “Amplified”.

Generally, an ideal signal amplifier has three main properties, Input Resistance or (Rin), Output Resistance or (Rout) and of course amplification known commonly as Gain or (A). No matter how complicated an amplifier circuit is, a general amplifier model can still be used to show the relationship of these three properties.

Ideal Amplifier Model:

The difference between the input and output signals is known as the Gain of the amplifier and is basically a measure of how much an amplifier “amplifies” the input signal. For example, if we have an input signal of 1 volt and an output of 50 volts, then the gain of the amplifier would be “50”. In other words, the input signal has been increased by a factor of 50. This increase is called **Gain**.

Amplifier gain is simply the ratio of the output divided-by the input. Gain has no units as its a ratio, but in Electronics it is commonly given the symbol “A”, for Amplification. Then the gain of an amplifier is simply calculated as the “output signal divided by the input signal”.

Power Amplifiers

The Small Signal Amplifier is generally referred to as a “Voltage” amplifier because they usually convert a small input voltage into a much larger output voltage. Sometimes an amplifier circuit is required to drive a motor or feed a loudspeaker and for these types of applications where high switching currents are needed Power Amplifiers are required.

As their name suggests, the main job of a “Power Amplifier” (also known as a large signal amplifier), is to deliver power to the load, and as we know from above, is the product of the voltage and current applied to the load with the output signal power being greater than the input signal power. In other words, a power amplifier amplifies the power of the input signal which is why these types of amplifier circuits are used in audio amplifier output stages to drive loudspeakers.

The power amplifier works on the basic principle of converting the DC power drawn from the power supply into an AC voltage signal delivered to the load. Although the amplification is high the efficiency of the conversion from the DC power supply input to the AC voltage signal output is usually poor.

The perfect or ideal amplifier would give us an efficiency rating of 100% or at least the power “IN” would be equal to the power “OUT”. However, in reality this can never happen as some of the power is lost in the form of heat and also, the amplifier itself consumes power during the amplification process.

Amplifier Classes

The classification of an amplifier as either a voltage or a power amplifier is made by comparing the characteristics of the input and output signals by measuring the amount of time in relation to the input signal that the current flows in the output circuit. We saw in the common emitter transistor tutorial that for the transistor to operate within its “Active Region” some form of “Base Biasing” was required. This small Base Bias voltage added to the input signal allowed the transistor to reproduce the full input waveform at its output with no loss of signal.

However, by altering the position of this Base bias voltage, it is possible to operate an amplifier in an amplification mode other than that for full waveform reproduction. With the introduction to the amplifier of a Base bias voltage, different operating ranges and modes of operation can be obtained which are categorized according to their classification. These various modes of operation are better known as Amplifier Class.

Audio power amplifiers are classified in an alphabetical order according to their circuit configurations and mode of operation. Amplifiers are designated by different classes of operation such as class “A”, class “B”, class “C”, class “AB”, etc. These different amplifier classes range from a near linear output but with low efficiency to a non-linear output but with a high efficiency.

No one class of operation is “better” or “worse” than any other class with the type of operation being determined by the use of the amplifying circuit. There are typical maximum efficiencies for the various types or class of amplifier, with the most commonly used being:

- Class A Amplifier – has low efficiency of less than 40% but good signal reproduction and linearity.
- Class B Amplifier – is twice as efficient as class A amplifiers with a maximum theoretical efficiency of about 70% because the amplifying device only conducts (and uses power) for half of the input signal.
- Class AB Amplifier – has an efficiency rating between that of Class A and Class B but poorer signal reproduction than class A amplifiers.
- Class C Amplifier – is the most inefficient amplifier class as only a very small portion of the input signal is amplified therefore the output signal bears very little resemblance to the input signal. Class C amplifiers have the worst signal reproduction.

Class A Amplifier Operation

Class A Amplifier operation is where the entire input signal waveform is faithfully reproduced at the amplifiers output as the transistor is perfectly biased within its active region, thereby never reaching either of its Cut-off or Saturation regions. This then results in the AC input signal being perfectly “centred” between the amplifiers upper and lower signal limits as shown below.

In this configuration, the Class A amplifier uses the same transistor for both halves of the output waveform and due to its biasing arrangement the output transistor always has current flowing through it, even if there is no input signal. In other words the output transistor never turns “OFF”. This results in the class A type of operation being very inefficient as its conversion of the DC supply power to the AC signal power delivered to the load is usually very low.

Generally, the output transistor of a Class A amplifier gets very hot even when there is no input signal present so some form of heat sinking is required. The direct current flowing through the output transistor (Ic) when there is no output signal will be equal to the current flowing through the load. Then a Class A amplifier is very inefficient as most of the DC power is converted to heat.

Class B Amplifier Operation

Unlike the Class A amplifier mode of operation above that uses a single transistor for its output power stage, the Class B Amplifier uses two complimentary transistors (either an NPN and a PNP or a NMOS and a PMOS) for each half of the output waveform. One transistor conducts for one-half of the signal waveform while the other conducts for the other or opposite half of the signal waveform. This means that each transistor spends half of its time in the active region and half its time in the cut-off region thereby amplifying only 50% of the input signal.

Class B operation has no direct DC bias voltage like the class A amplifier, but instead the transistor only conducts when the input signal is greater than the base-emitter voltage and for silicon devices is about 0.7 V. Therefore, at zero input there is zero output. This then results in only half the input signal being presented at the amplifiers output giving a greater amount of amplifier efficiency as shown below.

In a class B amplifier, no DC voltage is used to bias the transistors, so for the output transistors to start to conduct each half of the waveform, both positive and negative, they need the base-emitter voltage Vbe to be greater than the 0.7 V required for a bipolar transistor to start conducting.

Then the lower part of the output waveform which is below this 0.7 V window will not be reproduced accurately resulting in a distorted area of the output waveform as one transistor turns "OFF" waiting for the other to turn back "ON". The result is that there is a small part of the output waveform at the zero voltage cross over point which will be distorted. This type of distortion is called Crossover Distortion and is looked at later on in this section.

Class AB Amplifier Operation

The Class AB Amplifier is a compromise between the Class A and the Class B configurations above. While Class AB operation still uses two complementary transistors in its output stage a very small biasing voltage is applied to the Base of the transistor to bias it close to the Cut-off region when no input signal is present.

An input signal will cause the transistor to operate as normal in its Active region thereby eliminating any crossover distortion which is present in class B configurations. A small Collector current will flow when there is no input signal but it is much less than that for the Class A amplifier configuration.

This means then that the transistor will be “ON” for more than half a cycle of the waveform. This type of amplifier configuration improves both the efficiency and linearity of the amplifier circuit compared to a pure Class A configuration.

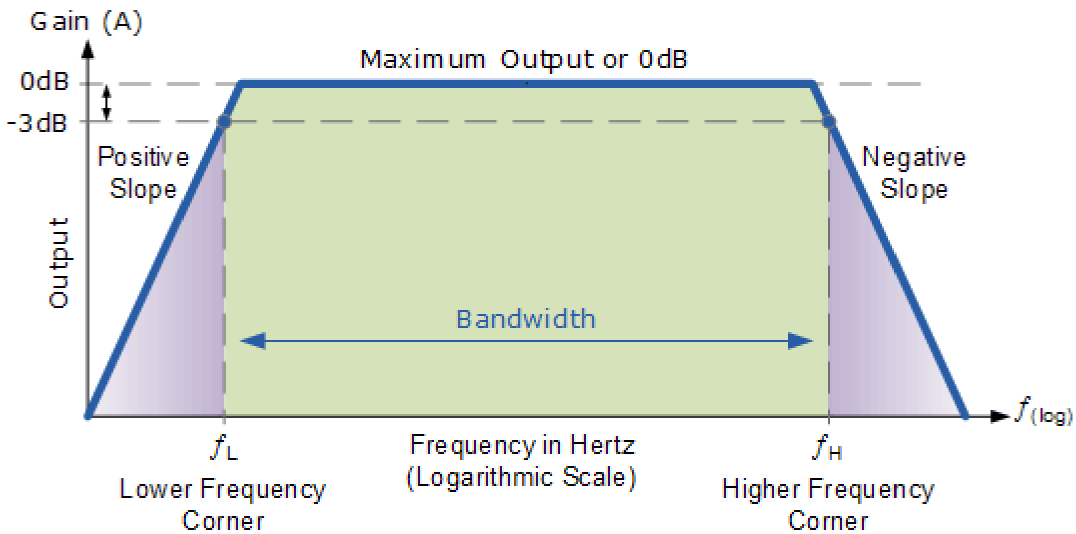
Class AB Output Waveform

The class of operation for an amplifier is very important and is based on the amount of transistor bias required for operation as well as the amplitude required for the input signal. Amplifier classification takes into account the portion of the input signal in which the transistor conducts as well as determining both the efficiency and the amount of power that the switching transistor both consumes and dissipates in the form of wasted heat.

UNIT II

Frequency response of amplifiers General concepts; bode plot; low frequency response: BJT and FET amplifiers; miller effect capacitance; high frequency response of BIT amplifiers; hybrid pie model: short circuit current gain, cut off frequency, and current gain with resistive load; high frequency response of FET amplifiers; frequency response of multistage amplifiers; square wave testing, Numerical problems.

FREQUENCY RESPONSE OF AMPLIFIERS – BODE PLOT



Amplifiers and filters are widely used electronic circuits that have the properties of amplification and filtration, hence their names.

Amplifiers produce gain while filters alter the amplitude and/or phase characteristics of an electrical signal with respect to its frequency. As these amplifiers and filters use resistors, inductors, or capacitor networks (RLC) within their design, there is an important relationship between the use of these reactive components and the circuits frequency response characteristics.

When dealing with AC circuits it is assumed that they operate at a fixed frequency, for example either 50 Hz or 60 Hz. But the response of a linear AC circuit can also be examined with an AC or sinusoidal input signal of a constant magnitude but with a varying frequency such as those found in amplifier and filter circuits. This then allows such circuits to be studied using frequency response analysis.

Frequency Response of an electric or electronics circuit allows us to see exactly how the output gain (known as the *magnitude response*) and the phase (known as the *phase response*) changes at a particular single frequency, or over a whole range of different frequencies from 0Hz, (d.c.) to many thousands of mega-hertz, (MHz) depending upon the design characteristics of the circuit.

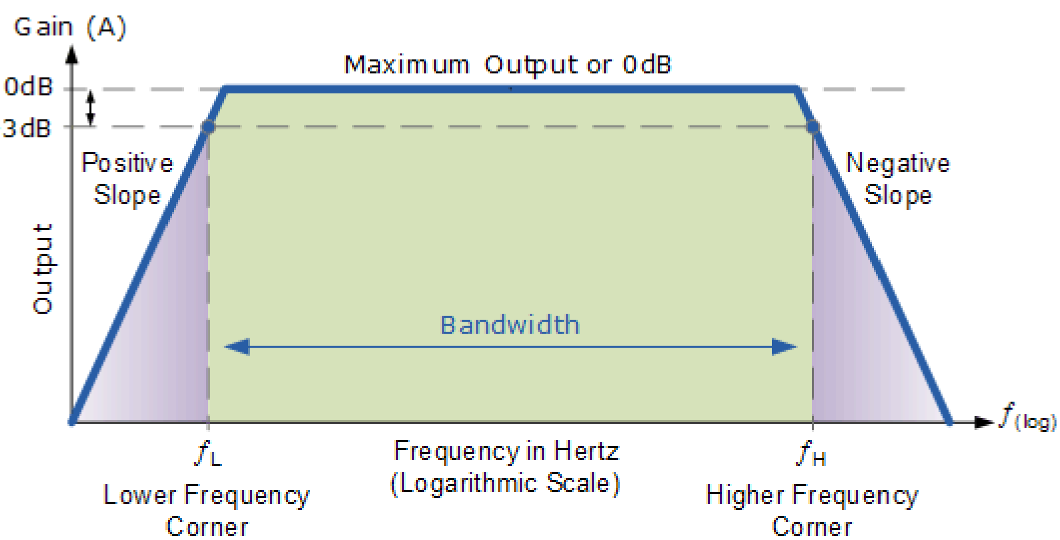
Generally, the frequency response analysis of a circuit or system is shown by plotting its gain, that is the size of its output signal to its input signal, Output/Input against a frequency scale over which the circuit or system is expected to operate. Then by knowing the circuits gain, (or loss) at each frequency point helps us to understand how well (or badly) the circuit can distinguish between signals of different frequencies.

The frequency response of a given frequency dependent circuit can be displayed as a graphical sketch of magnitude (gain) against frequency (f). The horizontal frequency axis is usually plotted on a logarithmic scale while the vertical axis representing the voltage output or gain, is usually drawn as a linear scale in decimal divisions. Since a systems gain can be both positive and negative, the y-axis can therefore have both positive and negative values.

In Electronics, the *Logarithm*, or "log" for short is defined as the power to which the base number must be raised to get that number. Then on a Bode plot, the logarithmic x-axis scale is graduated in $\log_{10}$ divisions, so every decade of frequency (e.g, 0.01, 0.1, 1, 10, 100, 1000, etc.) is equally spaced onto the x-axis. The opposite of the logarithm is the antilogarithm or "antilog".

Graphical representations of frequency response curves are called **Bode Plots** and as such Bode plots are generally said to be a semi-logarithmic graphs because one scale (x-axis) is logarithmic and the other (y-axis) is linear (log-lin plot) as shown.

Frequency Response Curve



Then we can see that the frequency response of any given circuit is the variation in its behaviour with changes in the input signal frequency as it shows the band of frequencies over which the output (and the gain) remains fairly constant. The range of frequencies either big or small between f_L and f_H is called the circuits bandwidth. So from this we are able to determine at a glance the voltage gain (in dB) for any sinusoidal input within a given frequency range.

As mentioned above, the Bode diagram is a logarithmic presentation of the frequency response. Most modern audio amplifiers have a flat frequency response as shown above over the whole audio range of frequencies from 20 Hz to 20 kHz. This range of frequencies, for an audio amplifier is called its Bandwidth, (BW) and is primarily determined by the frequency response of the circuit.

Frequency points f_L and f_H relate to the lower corner or cut-off frequency and the upper corner or cut-off frequency points respectively were the circuits gain falls off at high and low frequencies. These points on a frequency response curve are known commonly as the -3dB (decibel) points. So the bandwidth is simply given as:

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

The decibel, (dB) which is 1/10th of a bel (B), is a common non-linear unit for measuring gain and is defined as $20\log_{10}(A)$ where A is the decimal gain, being plotted on the y-axis. Zero decibels, (0dB) corresponds to a magnitude function of unity giving the maximum output. In other words, 0dB occurs when Vout = Vin as there is no attenuation at this frequency level and is given as:

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

We see from the Bode plot above that at the two corner or cut-off frequency points, the output drops from 0dB to -3dB and continues to fall at a fixed rate. This fall or reduction in gain is known commonly as the roll-off region of the frequency response curve. In all basic single order amplifier and filter circuits this roll-off rate is defined as 20dB/decade, which is an equivalent to a rate of 6dB/octave. These values are multiplied by the order of the circuit.

These -3dB corner frequency points define the frequency at which the output gain is reduced to 70.71% of its maximum value. Then we can correctly say that the -3dB point is also the frequency at which the systems gain has reduced to 0.707 of its maximum value.

Frequency Response -3dB Point

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

The -3dB point is also known as the half-power points since the output power at this corner frequencies will be half that of its maximum 0dB value as shown.

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

At f_L or f_H,

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

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

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

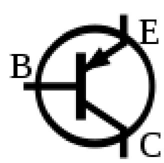
Therefore the amount of output power delivered to the load is effectively "halved" at the cut-off frequency and as such the bandwidth (BW) of the frequency response curve can also be defined as the range of frequencies between these two half-power points.

While for voltage gain we use $20\log_{10}$ (Av), and for current gain $20\log_{10}$ (Ai), for power gain we use $10\log_{10}$(Ap). Note that the multiplying factor of 20 does not mean that it is twice as much as 10 as the decibel is a unit of the power ratio and not a measure of the actual power level. Also gain in dB can be either positive or negative with a positive value indicating gain and a negative value attenuation.

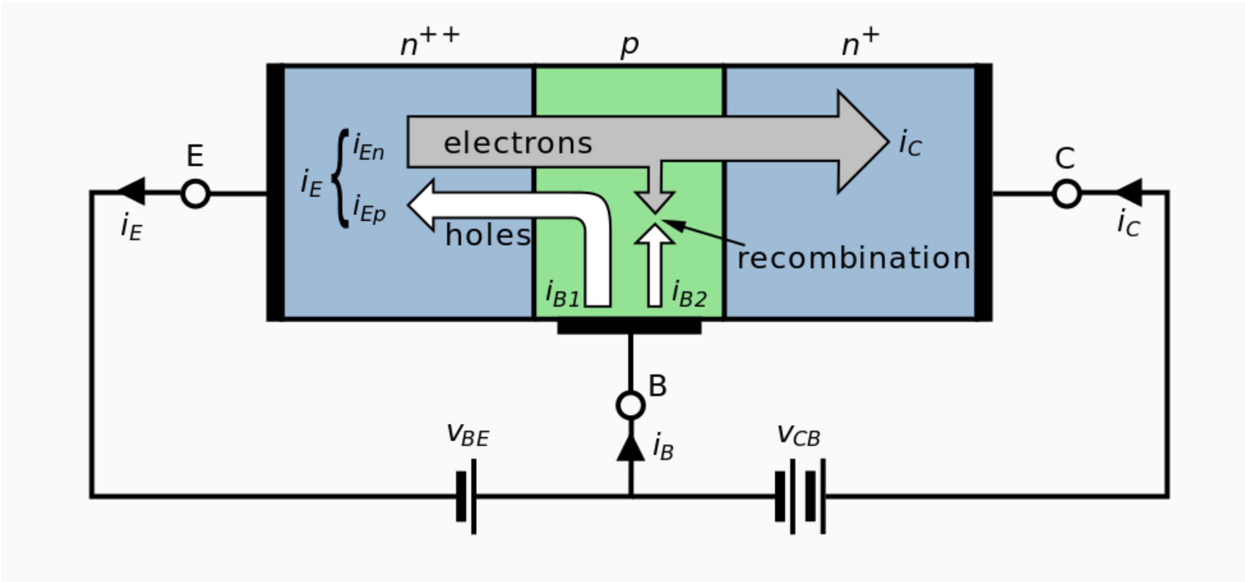
BJT AMPLIFIER:

A bipolar junction transistor (bipolar transistor or BJT) is a type of transistor that uses both electron and hole charge carriers. In contrast, unipolar transistors, such as field-effect transistors, only use one kind of charge carrier. For their operation, BJTs use two junctions between two semiconductor types, n-type and p-type.

BJTs are manufactured in two types, NPN and PNP, and are available as individual components, or fabricated in integrated circuits, often in large numbers. The basic function of a BJT is to amplify current. This allows BJTs to be used as amplifiers or switches, giving them wide applicability in electronic equipment, including computers, televisions, mobile phones, audio amplifiers, industrial control, and radio transmitters.



BJTs come in two types, or polarities, known as PNP and NPN based on the doping types of the three main terminal regions. An NPN transistor comprises two semiconductor junctions that share a thin p-doped anode region, and a PNP transistor comprises two semiconductor junctions that share a thin n-doped cathode region.



Large flow in a BJT is due to diffusion of charge carriers across a junction between two regions of different charge concentrations. The regions of a BJT are called emitter, collector, and base. A discrete transistor has three leads for connection to these regions. Typically, the emitter region is heavily doped compared to the other two layers, whereas the majority charge carrier concentrations in base and collector layers are about the same. By design, most of the BJT collector current is due to the flow of charges injected from a high-concentration emitter into the base where they are minority carriers that diffuse toward the collector, and so BJTs are classified as minority-carrier devices.

In typical operation, the base–emitter junction is forward biased, which means that the p-doped side of the junction is at a more positive potential than the n-doped side, and the base–collector junction is reverse biased. In an NPN transistor, when positive bias is applied to the base–emitter junction, the equilibrium is disturbed between the thermally generated carriers and the repelling electric field of the n-doped emitter depletion region. This allows thermally excited electrons to inject from the emitter into the base region. These electrons diffuse through the base from the region of high concentration near the emitter towards the region of low concentration near the collector. The electrons in the base are called minority carriers because the base is doped p-type, which makes holes the majority carrier in the base.

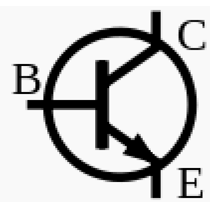
To minimize the percentage of carriers that recombine before reaching the collector–base junction, the transistor's base region must be thin enough that carriers can diffuse across it in much less time than the semiconductor's minority carrier lifetime. In particular, the thickness of the base must be much less than the diffusion length of the electrons. The collector–base junction is reverse-biased, and so little electron injection occurs from the collector to the base, but electrons that diffuse through the base towards the collector are swept into the collector by the electric field in the depletion region of the collector–base junction. The thin shared base and asymmetric collector–emitter doping are what differentiates a bipolar transistor from two separate and oppositely biased diodes connected in series.

A BJT consists of three differently doped semiconductor regions: the emitter region, the base region and the collector region. These regions are, respectively, p type, n type and p type in a PNP transistor, and n type, p type and n type in an NPN transistor. Each semiconductor region is connected to a terminal, appropriately labeled: emitter (E), base (B) and collector(C).

The base is physically located between the emitter and the collector and is made from lightly doped, high-resistivity material. The collector surrounds the emitter region, making it almost impossible for the electrons injected into the base region to escape without being collected, thus making the resulting value of α very close to unity, and so, giving the transistor a large β. A cross-section view of a BJT indicates that the collector–base junction has a much larger area than the emitter–base junction.

The bipolar junction transistor, unlike other transistors, is usually not a symmetrical device. This means that interchanging the collector and the emitter makes the transistor leave the forward active mode and start to operate in reverse mode. Because the transistor's internal structure is usually optimized for forward-mode operation, interchanging the collector and the emitter makes the values of α and β in reverse operation much smaller than those in forward operation; often the α of the reverse mode is lower than 0.5. The lack of symmetry is primarily due to the doping ratios of the emitter and the collector. The emitter is heavily doped, while the collector is lightly doped, allowing a large reverse bias voltage to be applied before the collector–base junction breaks down. The collector–base junction is reverse biased in normal operation. The reason the emitter is heavily doped is to increase the emitter injection efficiency: the ratio of carriers injected by the emitter to those injected by the base. For high current gain, most of the carriers injected into the emitter–base junction must come from the emitter.

NPN

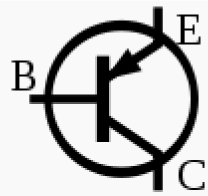


The symbol of an NPN BJT. A mnemonic for the symbol is "not pointing in".

NPN is one of the two types of bipolar transistors, consisting of a layer of P-doped semiconductor (the "base") between two N-doped layers. A small current entering the base is amplified to produce a large collector and emitter current. That is, when there is a positive potential difference measured from the emitter of an NPN transistor to its base (i.e., when the base is high relative to the emitter) as well as positive potential difference measured from the base to the collector, the transistor becomes active. In this "on" state, charge flows between the collector and emitter of the transistor. Most of the current is carried by electrons moving from emitter to collector as minority carriers in the P-type base region. To allow for greater current and faster operation, most bipolar transistors used today are NPN because electron mobility is higher than hole mobility.

A mnemonic device for the NPN transistor symbol is "not pointing in", based on the arrows in the symbol and the letters in the name.

PNP



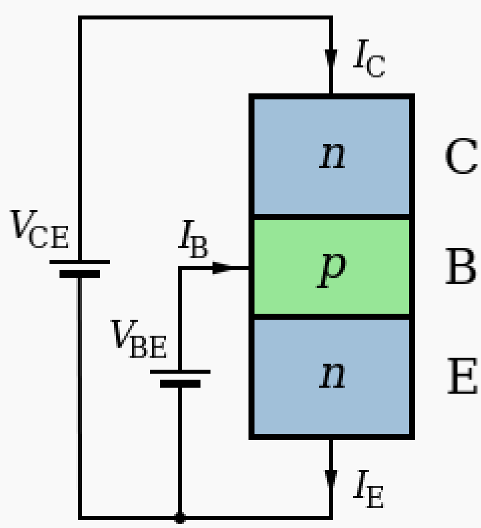
The symbol of a PNP BJT. A mnemonic for the symbol is "points in proudly".

The other type of BJT is the PNP, consisting of a layer of N-doped semiconductor between two layers of P-doped material. A small current leaving the base is amplified in the collector output. That is, a PNP transistor is "on" when its base is pulled low relative to the emitter. In a PNP transistor, emitter-base region is forward biased, so electric field and carriers will be generated. They should flow towards the base junction, but the base part is very thin and has low conductivity. The reverse-biased collector base part has generated holes. Thus, due to the electric field, carriers or electrons get pulled by the holes.

The arrows in the NPN and PNP transistor symbols are on the emitter legs and point in the direction of the conventional current when the device is in forward active mode.

A mnemonic device for the PNP transistor symbol is "pointing in (proudly/permanently)", based on the arrows in the symbol and the letters in the name.

Active-mode NPN transistors in circuits



Structure and use of NPN transistor.

The diagram shows a schematic representation of an NPN transistor connected to two voltage sources. To make the transistor conduct appreciable current (on the order of 1 mA) from C to E, V_{BE} must be above a minimum value sometimes referred to as the cut-in voltage. The cut-in voltage is usually about 650 mV for silicon BJTs at room temperature but can be different depending on the type of transistor and its biasing. This applied voltage causes the lower P-N junction to 'turn on', allowing a flow of electrons from the emitter into the base. In active mode, the electric field existing between base and collector (caused by V_{CE}) will cause the majority of these electrons to cross the upper P-N junction into the collector to form the collector current I_C.

The remainder of the electrons recombines with holes, the majority carriers in the base, making a current through the base connection to form the base current, I_B. As shown in the diagram, the emitter current, I_E, is the total transistor current, which is the sum of the other terminal currents, (i.e.,$I_E = I_B + I_C$).

In the diagram, the arrows representing current point in the direction of conventional current – the flow of electrons is in the opposite direction of the arrows because electrons carry negative electric charge. In active mode, the ratio of the collector current to the base current is called the DC current gain. This gain is usually 100 or more, but robust circuit designs do not depend on the exact value (for example see op-amp).

Active-mode PNP transistors in circuits:

Structure and use of PNP transistor:

The diagram shows a schematic representation of a PNP transistor connected to two voltage sources. To make the transistor conduct appreciable current (on the order of 1 mA) from E to C, must be above a minimum value sometimes referred to as the cut-in voltage. The cut-in voltage is usually about 650 mV for silicon BJTs at room temperature but can be different depending on the type of transistor and its biasing. This applied voltage causes the upper P-N junction to 'turn-on' allowing a flow of holes from the emitter into the base. In active mode, the electric field existing between the emitter and the collector (caused by) causes the majority of

these holes to cross the lower p-n junction into the collector to form the collector current . The remainder of the holes recombine with electrons, the majority carriers in the base, making a current through the base connection to form the base current, . As shown in the diagram, the emitter current, is the total transistor current, which is the sum of the other terminal currents (i.e.,$I_E = I_B + I_C$).

In the diagram, the arrows representing current point in the direction of conventional current – the flow of holes is in the same direction of the arrows because holes carry positive electric charge. In active mode, the ratio of the collector current to the base current is called the DC current gain.

FET AMPLIFIER:

An FET amplifier is an amplifier which uses one or more field-effect transistors (FETs). The main advantage of an FET used for amplification is that it has very high input impedance and low output impedance. These are two desirable features for an amplifier.

TYPES OF FET AMPLIFIER

There are three types of FET amplifiers depending upon the common terminal used as input and output. This is similar to a bipolar junction transistor (BJT) amplifier.

Common gate amplifier

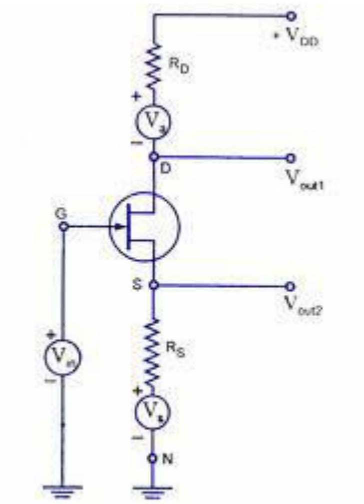
In a common gate amplifier, the gate terminal is common to both input and output.

Common source amplifier

In a common source amplifier, the source terminal is common to both input and output.

Common drain amplifier

In a common drain amplifier, the drain terminal is common to both input and output. It is also known as a "source follower"

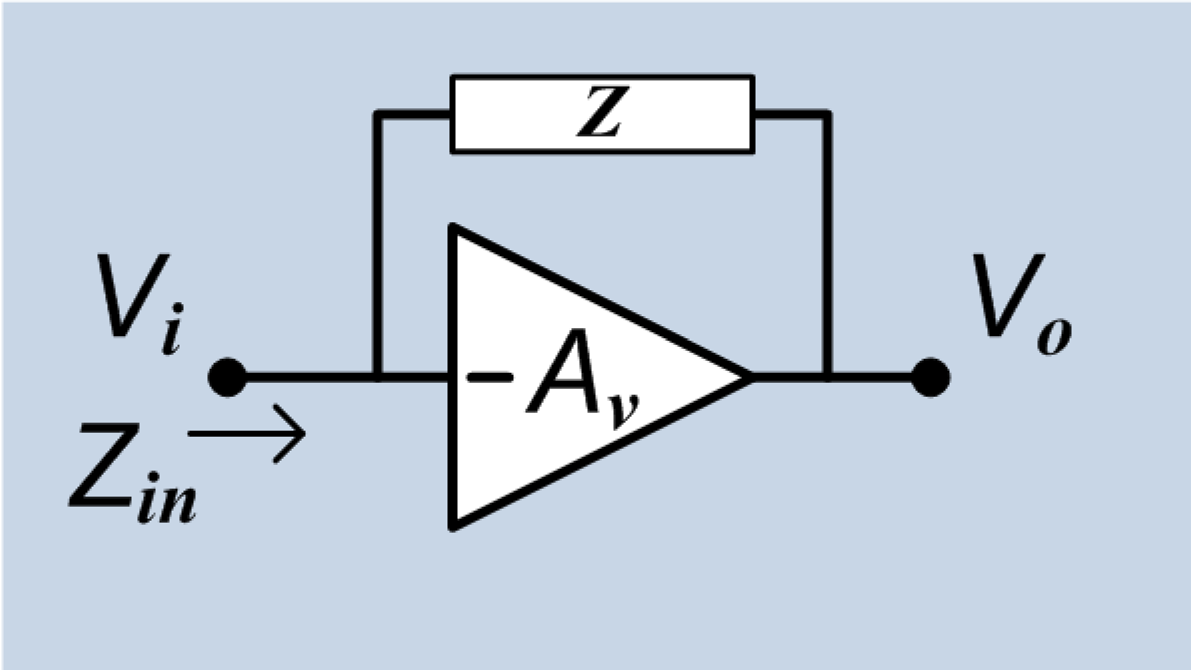


A Generalized FET Amplifier

MILLER EFFECT CAPACITANCE

In electronics, the Miller effect accounts for the increase in the equivalent input capacitance of an inverting voltage amplifier due to amplification of the effect of capacitance between the input and output terminals.

Although the term Miller effect normally refers to capacitance, any impedance connected between the input and another node exhibiting gain can modify the amplifier input impedance via this effect. These properties of the Miller effect are generalized in the Miller theorem. The Miller capacitance due to parasitic capacitance between the output and input of active devices like transistors and vacuum tubes is a major factor limiting their gain at high frequencies. Miller capacitance was identified in 1920 in triode vacuum tubes by John Milton Miller.



Any P-N junction can develop capacitance. This was mentioned in the chapter on diodes.

- In a BJT amplifier this capacitance becomes noticeable between: the Base-Collector junction at high frequencies in CE BJT amplifier configurations.
- It is called the Miller Capacitance.
- It effects the input and output circuits.

For any inverting amplifier, the input capacitance will be increased by a Miller effect capacitance sensitive to the gain of the amplifier and the inter-electrode (parasitic) capacitance between the input and output terminals of the active device.

High frequency Response of CE Amplifier

At high frequencies, internal transistor junction capacitances do come into play, reducing an amplifier's gain and introducing phase shift as the signal frequency increases. In BJT, CBE is the B-E junction capacitance, and CBC is the B-C junction capacitance. (output to input capacitance) At lower frequencies, the internal capacitances have a very high reactance because of their low capacitance value (usually only a few pf) and the low frequency value. Therefore, they look like opens and have no effect on the transistor's performance. As the frequency goes up, the internal capacitive reactance's go down, and at some point they begin to have a significant effect on the transistor's gain.

High frequency Response of CE Amplifier

When the reactance of C_{be} becomes small enough, a significant amount of the signal voltage is lost due to a voltage-divider effect of the source resistance and the reactance of Cbe.

When the reactance of C_{bc} becomes small enough, a significant amount of output signal voltage is fed back out of phase with the input (negative feedback), thus effectively reducing the voltage gain.

HYBRID-PI MODEL:

The hybrid-pi model is a popular circuit model used for analyzing the small signal behavior of bipolar junction and field effect transistors. Sometimes it is also called Giacoletto model because it was introduced by L.J. Giacoletto in 1969. The model can be quite accurate for low-frequency circuits and can easily be adapted for higher frequency circuits with the addition of appropriate inter-electrode capacitances and other parasitic elements.

The hybrid-pi model is a linearized three-terminal approximation to the transistor using the small-signal base-emitter voltage v_π and collector-emitter voltage v_{ce} as independent variables, and the small-signal base current i_b and collector current i_c as dependent variables.

A basic, low-frequency hybrid-pi model for the bipolar transistor is shown in the figure. The three transistor terminals are E = emitter, B = base, and C = collector. The base-emitter connection is through a resistor r_π, and the base current causes a small-signal voltage drop across it, v_π (the π notation is standard). Voltage v_π induces a small-signal collector current via the voltage-controlled current source with current $g_m v_\pi$, g_m is the transistor transconductance.

This three-terminal model can be viewed as a y-parameter two-port network, as shown in the next figure. However, to qualify as a port, current into and out of the two terminals of a port must be the same. To meet this requirement, a mathematical artifice is introduced of splitting of the emitter current into separate base and collector currents, which does not correspond to any physical phenomenon. If this two-port is inserted into a larger circuit, the input and output port conditions will be violated if the connected circuitry does not itself satisfy the port conditions. To elaborate: this four-terminal model of the bipolar transistor does not enforce the port conditions, it is only compatible with them if they are requested by the surrounding circuitry.

Equivalence to the three-terminal circuit is established using the relations $v_\pi = i_b r_\pi$ and $\beta = g_m r_\pi$. Thus, the dependent source current $g_m v_\pi = \beta i_b$, and is the same in both circuits.

SHORT CIRCUIT CURRENT GAIN

11.4 The Common-Emitter Short-Circuit-Current Frequency Response

The T model of Fig. 11.2 is applicable in the CE configuration if E is grounded, the signal is applied to B, and the load is placed between C and E. The CE short-circuit current gain A_{ie} is obtained by shorting the collector terminal C to E as indicated in Fig. 11.4.

Since $r_c' >> r_e$ and $C_e >> C_c$, we may omit the parallel elements r_c' and C_c, and then $I_L = \alpha_o I_1 = \alpha I_e$. But from KCL, $I_L = I_b + I_e$, so that $I_e(1-\alpha) = -I_b$. Finally,

$$A_{ie} = \frac{I_L}{I_b} = \frac{\alpha I_e}{I_b} = \frac{-\alpha(\omega)}{1-\alpha(\omega)} \qquad (11.16)$$

Using Eq. (11.4), A_{ie} may be put in the form

$$A_{ie} = \frac{-\beta_o}{1 + jf/f_\beta} \qquad (11.17)$$

where

$$\beta_o \equiv \frac{\alpha_o}{1-\alpha_o} \qquad (11.18)$$

and

$$f_\beta \equiv f_\alpha(1-\alpha_o) \qquad (11.19)$$

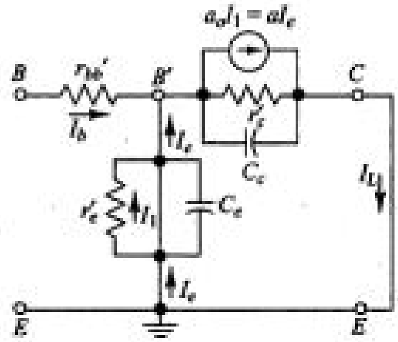


Fig. 11.4 *The T circuit in the CE configuration under short-circuit conditions.*

At zero frequency the CE short-circuit current amplification is $\beta_o = h_{fe}$ and the corresponding CB parameters is $\alpha_o = -h_{fb}$. Hence Eq. (11.18) is consistent with the conversion in Table 9.3.

The CE 3-dB frequency, or the beta cutoff frequency, is f_β (also designated f_{hfe} or $f_{\alpha e}$). From Eqs (11.18) and (11.19)

$$\beta_o f_\beta = h_{fe} f_\beta = \alpha_o f_\alpha \qquad (11.20)$$

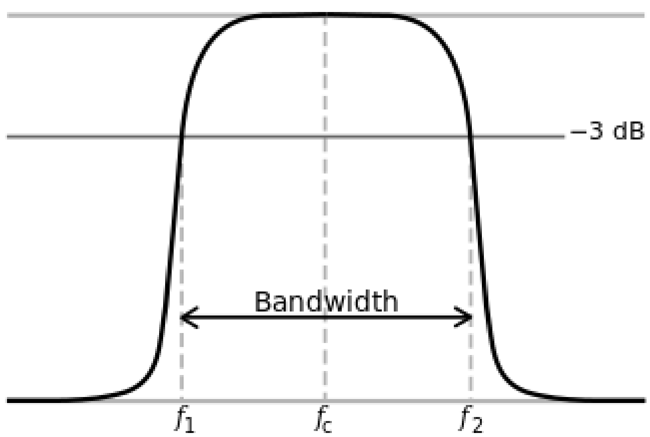
Since α_o is close to unity, the high-frequency response for the CE configuration is must worse than that for the CB circuit. However, the amplification for the CE configuration is much greater than that for the CB circuit. Note that the so-called *short-circuit-current gain-bandwidth product* (amplification times 3-dB frequency) is the same for both configurations.

CUTOFF FREQUENCY

In physics and electrical engineering, a cutoff frequency, corner frequency, or break frequency is a boundary in a system's frequency response at which energy flowing through the system begins to be reduced (attenuated or reflected) rather than passing through.

Typically in electronic systems such as filters and communication channels, cutoff frequency applies to an edge in alowpass, highpass, bandpass, or band-stop characteristic – a frequency characterizing a boundary between a passband and a stopband. It is sometimes taken to be the point in the filter response where a transition band and passband meet, for example, as defined by a 3 dB corner (a frequency for which the output of the circuit is −3 dB of the nominal passband value). Alternatively, a stopband corner frequency may be specified as a point where a transition band and a stopband meet: a frequency for which the attenuation is larger than the required stopband attenuation, which for example may be 30 dB or 100 dB.

In the case of a waveguide or an antenna, the cutoff frequencies correspond to the lower and upper cutoff wavelengths.



In electronics, cutoff frequency or corner frequency is the frequency either above or below which the power output of a circuit, such as a line, amplifier, or electronic filter has fallen to a given proportion of the power in the passband. Most frequently this proportion is one half the passband power, also referred to as the 3 dB point since a fall of 3 dB corresponds approximately to half power.

Sometimes other ratios are more convenient than the 3 dB point. For instance, in the case of the Chebyshev filter it is usual to define the cutoff frequency as the point after the last peak in the frequency response at which the level has fallen to the design value of the passband ripple. The amount of ripple in this class of filter can be set by the designer to any desired value, hence the ratio used could be any value.

In communications, the term cutoff frequency can mean the frequency below which a radio wave fails to penetrate a layer of the ionosphere at the incidence angle required for transmission between two specified points by reflection from the layer.

WAVEGUIDES:

The cutoff frequency of an electromagnetic waveguide is the lowest frequency for which a mode will propagate in it. In fiber optics, it is more common to consider the cutoff wavelength, the maximum wavelength that will propagate in an optical fiber or waveguide. The cutoff frequency is found with the characteristic equation of the Helmholtz equation for electromagnetic waves, which is derived from the electromagnetic wave equation by setting the longitudinal wave number equal to zero and solving for the frequency. Thus, any exciting frequency lower than the cutoff frequency will attenuate, rather than propagate. The following derivation assumes lossless walls. The value of c, the speed of light, should be taken to be the group velocity of light in whatever material fills the waveguide.

CURRENT GAIN WITH RESISTIVE LOAD

11.4.4. High Frequency Current Gain with Resistive Load

With a resistive load connected in the output, the high frequency equivalent circuit of a CE transistor amplifier has been shown in Fig. 11.23.

By using Miller's theorem the circuit of Fig. 11.24 can be modified as described below:

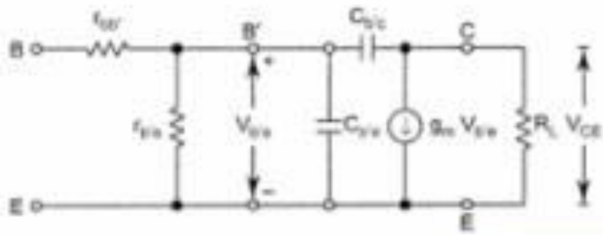


Fig. 11.23. *High frequency equivalent circuit with resistive load.*

Miller's Theorem

Miller's theorem states that if an impedance Z is connected between the input and output terminals of a network which provides a voltage gain. A_v an equivalent circuit that gives the same effect can be drawn by removing Z and connecting as impedance $Z_i = \frac{Z}{1-A}$ across the input and $Z_o = \frac{ZA}{A-1}$ across the output as shown in Fig. 11.24.

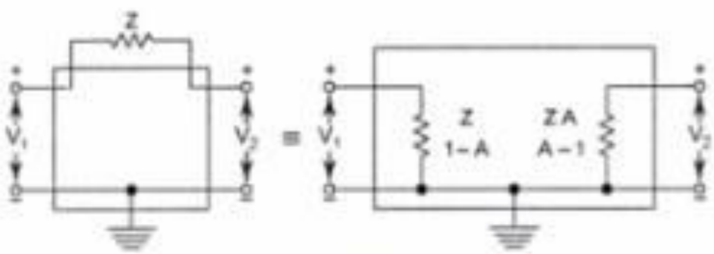


Fig. 11.24. *Miller's theorem.*

From Fig. 11.23, the voltage gain will be

$$A = \frac{V_{CE}}{V_{b'e}} = \frac{-g_m V_{b'e} R_L}{V_{b'e}}$$

or $\quad A = -g_m R_L$

or $\quad 1 - A = 1 - (-g_m R_L) = 1 + g_m R_L$

Since the impedance at the input gets decreased by a factor of $(1 - A)$, therefore, the capacitance will be increased by a factor of $(1 - A)$ or $1 + g_m R_L$.

The capacitance that is to be included in the output circuit will not make any significant change in the performance and may be neglected. This results in the modified equivalent circuit of Fig. 11.25.

The total input capacitance between B' and E is

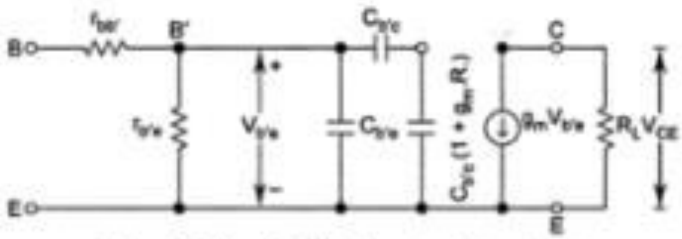


Fig. 11.25. *Modified equivalent circuit.*

$$C = C_{b'e} + (1 + g_m R_L)\, C_{b'c} \qquad \text{...(11.56)}$$

HIGH FREQUENCY RESPONSE OF FET AMPLIFIER:

The high frequency response of the FET is limited by values of internal capacitance, as shown in Figure 3(a). There is a measurable amount of capacitance between each terminal pair of the FET. These capacitances each have a reactance that decreases as frequency increases. As the reactance of a given terminal capacitance decreases, more and more of the signal at the terminal is bypassed through the capacitance.

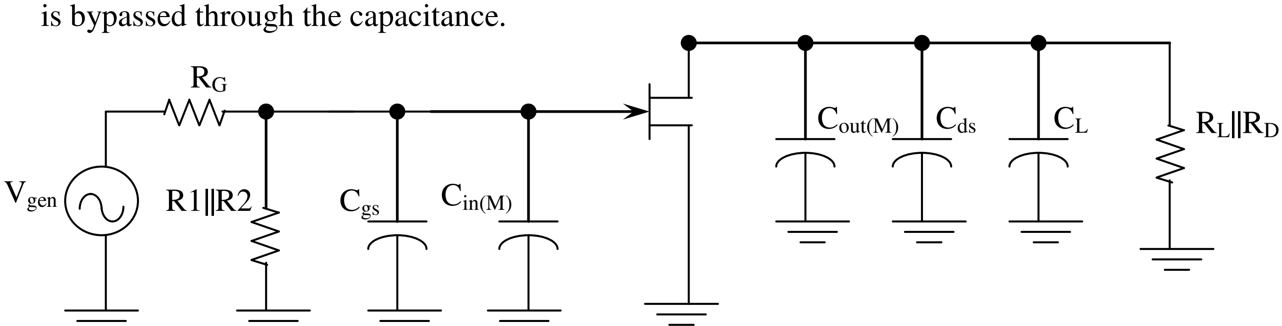


Figure 3(a): JFET amplifier with internal capacitors that affect the high frequency response.

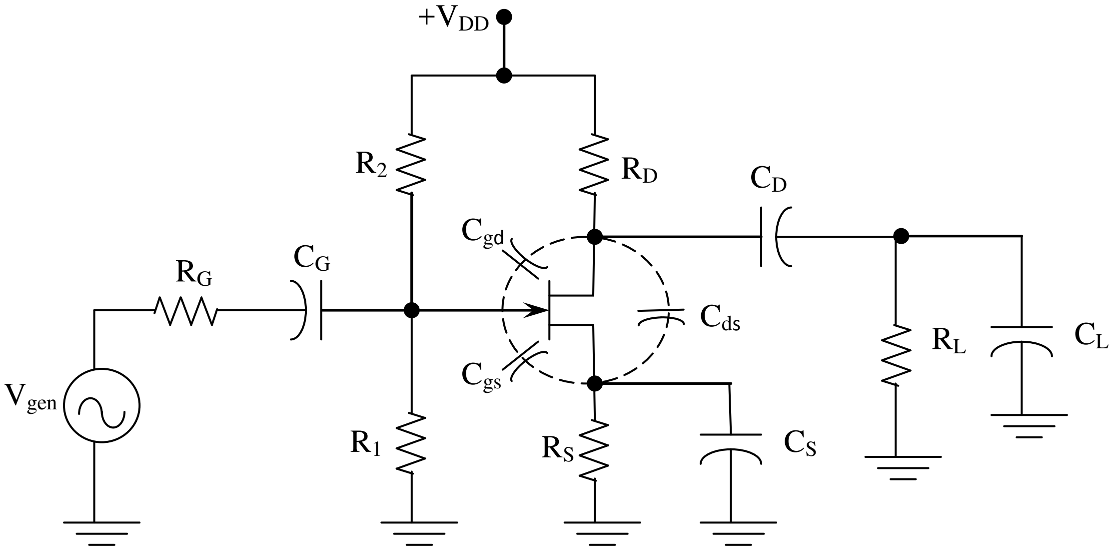
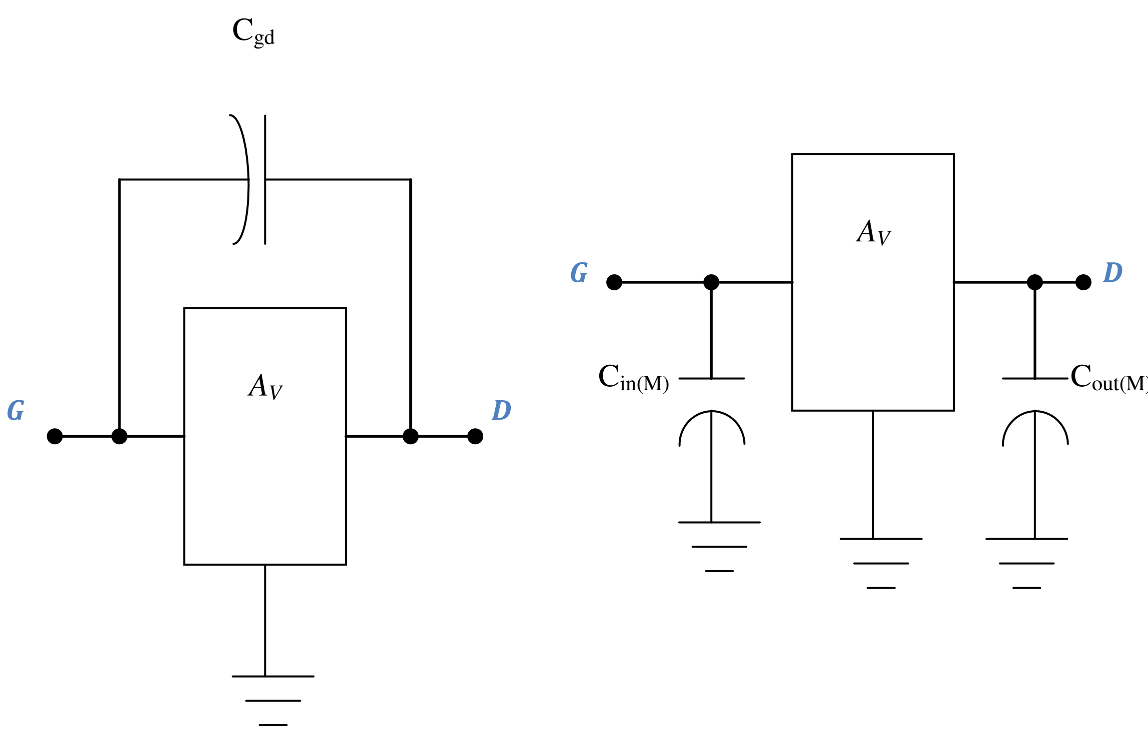


Figure 3(b): FET amplifier high frequency ac equivalent circuit.

The high frequency equivalent circuit for the FET amplifier in Figure 3(a) is shown in Figure 3(b), including all the terminal capacitance values. C_{gd} is replaced with the Miller equivalent input and output capacitance values given as

$$C_{in(M)} = C_{gd}(A_v + 1) \quad \text{and} \quad C_{out(M)} = C_{gd}\frac{A_v + 1}{A_v}$$



Miller equivalent circuit for a feedback capacitor.

Note the absence of capacitors C_G, C_D and C_S in Figure 3(b), which are all assumed to be short circuit at high frequencies. From this figure, the gate and drain circuit capacitance are given by

$$C'_G = C_{gs} + C_{in(M)} \quad \text{and} \quad C'_D = C_{out(M)} + C_{ds} + C_L$$

where C_L is the input capacitance of the following stage. In general the capacitance C_{gs} is the largest of the parasitic capacitances, with C_{ds} the smallest. The high cutoff frequencies for the gate and drain circuits are then given by

$$f_{HG} = \frac{1}{2\pi R'_{in} C'_G} \quad \text{and} \quad f_{HD} = \frac{1}{2\pi R'_L C'_D}$$

where $R'_{in} = R_G \parallel R_{in}$ and $R'_L = R_D \parallel R_L$. At very high frequencies, the effect of C'_G is to reduce the total impedance of the parallel combination of R_1, R_2 and C'_G in Figure 3(b). The result is a reduced level of voltage across the gate-source terminals. Similarly, for the drain circuit, the capacitive reactance of C'_D will decrease with frequency and consequently reduces the total impedance of the output parallel branches of Figure 3(b). It causes the output voltage to decrease as the reactance becomes smaller.

FREQUENCY RESPONSE OF MULTISTAGE AMPLIFIERS:

The voltage gain of an amplifier varies with signal frequency. It is because reactance of the capacitors in the circuit changes with signal frequency and hence affects the output voltage. The curve between voltage gain and signal frequency of an amplifier is known as frequency response. The gain of the amplifier increases as the frequency increases from zero till it becomes maximum at f r , called resonant frequency. If the frequency of signal increases beyond f r , the gain decreases. The performance of an amplifier depends to a considerable extent upon its frequency response. While designing an amplifier, appropriate steps must be taken to ensure that gain is essentially uniform over some specified frequency range. For instance, in case of an audio amplifier, which is used to amplify speech or music, it is necessary that all the frequencies in the sound spectrum (i.e. 20 Hz to 20 kHz) should be uniformly amplified otherwise speaker will give a distorted sound output.

SQUAREWAVE TESTING

Square-Wave Testing An important experimental procedure (called *square-wave testing*) is to observe with an oscilloscope the output of an amplifier excited by a square-wave generator. It is possible to improve the response of an amplifier by adding to it certain circuit elements, which then must be adjusted with precision. It is a great convenience to be able to adjust these elements and to see simultaneously the effect of such an adjustment on the amplifier ouput waveform. The alternative is to take data, after each successive adjustment, from which to plot the amplitude and phase responses. Aside from the extra time consumed in this latter procedure, we have the problem that it is usually not obvious which of the attainable amplitude and phase responses corresponds to optimum fidelity. On the other hand, the step response gives immediately useful information.

It is possible, by judicious selection of two square-wave frequencies, to examine individually the high-frequency and low-frequency distortion. For example, consider an amplifier which has a high-frequency time constant of 0.1 μs and a low-frequency time constant of 100 ms. A square wave of half period equal to several tenths of a microsecond, on an appropriately fast oscilloscope sweep, will display the rounding of the leading edge of the waveform and will not display the tilt. At the other extreme, a square wave of half period approximately 10 ms on an appropriately slow sweep will display the tilt, and not the distortion of the leading edge.

It should *not* be inferred from the above comparison between steady-state and transient response that the phase and amplitude responses are of no importance at all in the study of amplifiers. The frequency characteristics are useful for the following reasons. In the first place, much more is known generally about the analysis and synthesis of circuits in the frequency domain than in the time domain, and for this reason amplifier design is often done on a frequency-response basis. Second, it is often possible to arrive at least at a qualitative understanding of the properties of a circuit from a study of the steady-state response in circumstances where transient calculations are extremely cumbersome. Third, compensating an amplifier against unwanted oscillations (Chap. 13) is accomplished in the frequency domain. Finally, it happens occasionally that an amplifier is required whose characteristics are specified on a frequency basis, the principal emphasis being to amplify sinusoidal signals.

The high-frequency response of BJT and FET amplifier stages is treated in the next several sections. We concentrate on high-frequency behavior first because this is primary limitation in IC amplifiers. The results derived are applicable also to discrete-component stages. The low-frequency response characteristics of amplifiers is discussed subsequently.

UNIT III

Analysis of compound configurations Cascade connection; Cascade connection; Darlington connection; Bootstrapping principle; Bootstrapped Emitter Follower; Bootstrapped Darlington Emitter Follower; Feedback pair; . CMOS circuits; Current source circuits; Current mirror circuits; Differential amplifier circuits; Numerical problems.

COMPOUND CONFIGURATIONS

In the present chapter, we introduce a number of circuit connections that, although not standard common-emitter, common-collector, or common-base, are still quite important, being widely used in either discrete or integrated circuits. The cascade connection provides stages in series, while the cascode connection places one transistor on top of another. Both these connection forms are found in practical circuits. The Darlington connection and the feedback pair connection provide multiple transistors connected for operation as a single transistor for improved performance, usually with much larger current gain.

The CMOS connection, using both p-type enhancement and n-type enhancement MOSFET transistors in a very low-power operating circuit, is introduced in this chapter. Much of the newest digital circuitry uses CMOS circuits either to permit portable operation at very low battery power or to allow very high packing density in integrated circuits with lowest power dissipation in the small space used by an IC chip.

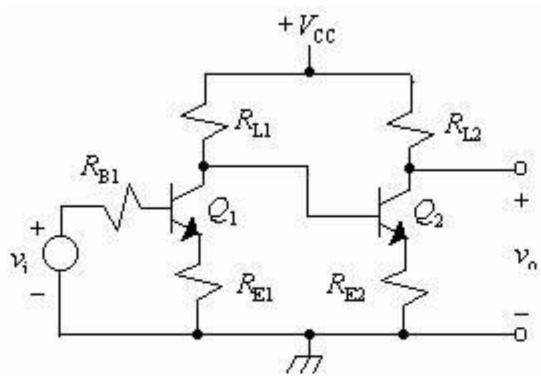
Both discrete circuits and integrated circuits use the current source connection. The current mirror connection provides constant current to various other circuits and is especially important in linear integrated circuits.

The differential amplifier is the basic part of operational amplifier circuits. The basic differential circuit connection and its operation are introduced in this chapter. Although placed at the end of the chapter, it is nevertheless a most important circuit connection. A bipolar-JFET circuit used in ICs is the BiFET connection, while the bipolar-MOSFET connection is called a BiMOS connection. Both of these are used in linear integrated circuits.

CASCADE AMPLIFIER

A cascade amplifier is any two-port network constructed from a series of amplifiers, where each amplifier sends its output to the input of the next amplifier in a daisy chain.

The complication in calculating the gain of cascaded stages is the non-ideal coupling between stages due to loading. Two cascaded common emitter stages are shown. Because the input resistance of the second stage forms a voltage divider with the output resistance of the first stage, the total gain is not the product of the individual (separated) stages



DARLINGTON CIRCUIT

The Darlington Pair is a useful circuit configuration for many applications within electronic circuits. This circuit configuration provides a number of advantages that other forms of transistor circuit are not able to offer and as a result it is used in many areas of electronics design.

The Darlington Pair also occasionally referred to as a super-alpha pair is renowned as a method for obtaining a very high level of current gain, using just two transistors. It is able to provide levels of gain that are not possible using single transistors on their own, but it may not be used in all circumstances because it does have a number of limitations.

The circuit may be used in the form of discrete components, but there are also very many integrated circuit versions often termed a Darlington transistor that may also be used. These Darlington transistor components may be obtained in a variety of forms including those for high power applications where current levels of many amps may be required.

The Darlington Pair has been in use for very many years. It was invented in 1953 by Sidney Darlington who was working at Bell Laboratories. He developed the idea of having two or three transistors in a single semiconductor chip, where the emitter of one transistor was connected directly to the base of the next, and all the transistors shared the same collector connection. In many ways the Darlington bore many of the hallmarks of the first integrated circuit patent, but it was too specific to the specific Darlington circuit itself to be considered as an integrated circuit.

ADVANTAGES:	DISADVANTAGES:
• Very high current gain • Very high input impedance for overall circuit • Darlington pairs are widely available in a single package or	• Slow switching speed • Limited bandwidth • Introduces a phase shift that can give rise to problems at certain frequencies in circuit using

ADVANTAGES:	DISADVANTAGES:
they can be made from two separate transistors • Convenient and easy circuit configuration to use	negative feedback • Higher overall base-emitter voltage = 2 x V_{be}. • High saturation voltage (typically around 0.7 V) which can lead to high levels of power dissipation in some applications

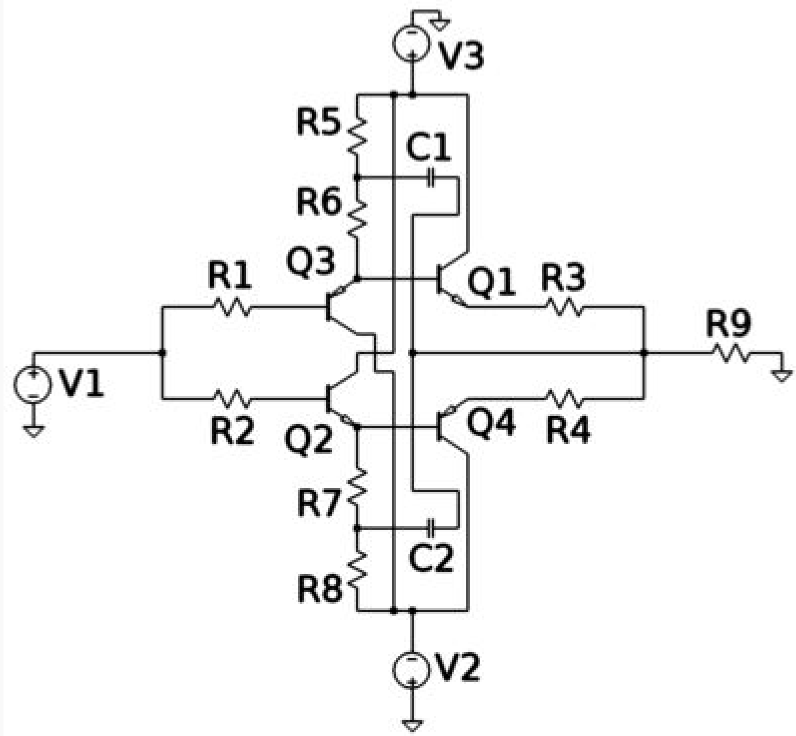
The Darlington pair transistor circuit configuration can be very useful in electronics circuit design. Although it has speed limitations, the circuit is nevertheless very useful in many areas where high levels of current gain are required, particularly for emitter follower style applications. Although the Darlington pair is most usually referred to by this name, the older name - the super-alpha pair may still be used on some occasions. Today, the term Darlington is the most widely used.

BOOTSTRAPPING PRINCIPLE:

In the field of electronics, a bootstrap circuit is one where part of the output of an amplifier stage is applied to the input, so as to alter the input impedance of the amplifier. When applied deliberately, the intention is usually to increase rather than decrease the impedance. Generally, any technique where part of the output of a system is used at startup is described as bootstrapping.

In the domain of MOSFET circuits, "bootstrapping" is commonly used to mean pulling up the operating point of a transistor above the power supply rail. The same term has been used somewhat more generally for dynamically altering the operating point of an operational amplifier (by shifting both its positive and negative supply rail) in order to increase its output voltage swing (relative to the ground). In the sense used in this paragraph, bootstrapping an operational amplifier means "using a signal to drive the reference point of the op-amp's power supplies". A more sophisticated use of this rail bootstrapping technique is to alter the non-linear C/V characteristic of the inputs of a JFET op-amp in order to decrease its distortion.

INPUT IMPEDANCE:



Bootstrap capacitors C1 and C2 in a BJT emitter follower circuit

In analog circuit designs a bootstrap circuit is an arrangement of components deliberately intended to alter the input impedance of a circuit. Usually it is intended to increase the impedance, by using a small amount of positive feedback, usually over two stages. This was often necessary in the early days of bipolar transistors, which inherently have quite a low input impedance. Because the feedback is positive, such circuits can suffer from poor stability and noise performance compared to ones that don't bootstrap.

Negative feedback may alternatively be used to bootstrap an input impedance, causing the apparent impedance to be reduced. This is seldom done deliberately, however, and is normally an unwanted result of a particular circuit design. A well-known example of this is the Miller effect, in which an unavoidable feedback capacitance appears increased (i.e. its impedance appears reduced) by negative feedback. One popular case where this is done deliberately is the Miller compensation technique for providing a low-frequency pole inside an integrated circuit. To minimize the size of the necessary capacitor, it is placed between the input and an output which swings in the opposite direction. This bootstrapping makes it act like a larger capacitor to ground.

DRIVING MOS TRANSISTORS

A N-MOSFET/IGBT needs a significantly positive charge ($V_{GS} > V_{th}$) applied to the gate in order to turn on. Using only N-channel MOSFET/IGBT devices is a common cost reduction method due largely to die size reduction (there are other benefits as well). However, using nMOS devices in place of pMOS devices means that a voltage higher than the power rail supply (V+) is needed in order to bias the transistor into linear operation (minimal current limiting) and thus avoid significant heat loss.

A bootstrap capacitor is connected from the supply rail (V+) to the output voltage. Usually the source terminal of the N-MOSFET is connected to the cathode of a recirculation diode allowing for efficient management of stored energy in the typically inductive load. Due to the charge storage characteristics of a capacitor, the bootstrap voltage will rise above (V+) providing the needed gate drive voltage.

A MOSFET/IGBT is a voltage-controlled device which, in theory, will not have any gate current. This makes it possible to utilize the charge inside the capacitor for control purposes. However, eventually the capacitor will lose its charge due to parasitic gate current and non-ideal (i.e. finite) internal resistance, so this scheme is only used where there is a steady pulse present. This is because the pulsing action allows for the capacitor to discharge (at least partially if not completely). Most control schemes that use a bootstrap capacitor force the high side driver (N-MOSFET) off for a minimum time to allow for the capacitor to refill. This means that the duty cycle will always need to be less than 100% to accommodate for the parasitic discharge unless the leakage is accommodated for in another manner.

SWITCH-MODE POWER SUPPLIES

In switch-mode power supplies, the regulation circuits are powered from the output. To start the power supply, a leakage resistance can be used to trickle-charge the supply rail for the control circuit to start it oscillating. This approach is less costly and more efficient than providing a separate linear power supply just to start the regulator circuit.

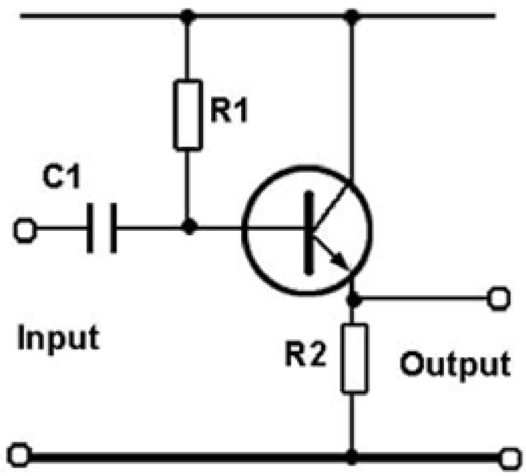
OUTPUT SWING

AC amplifiers can use bootstrapping to increase output swing. A capacitor (usually referred as bootstrap capacitor) is connected from the output of the amplifier to the bias circuit, providing bias voltages that exceed the power supply voltage. Emitter followers can provide rail-to-rail output in this way, which is a common technique in class AB audio amplifiers.

Digital integrated circuits

Within an integrated circuit a bootstrap method is used to allow internal address and clock distribution lines to have an increased voltage swing. The bootstrap circuit uses a coupling capacitor, formed from the gate/source capacitance of a transistor, to drive a signal line to slightly greater than the supply voltage.

THE EMITTER FOLLOWER



4.3.4 Emitter Follower

Common emitter amplifiers generally have a medium to high output impedance, the value depending mainly on the value of load resistor in the final stage of amplification. Many typical transducers, such as loudspeakers, relays, motors etc. are inductive devices having a low impedance of only a few ohms.

Connecting such devices to the output of a voltage amplifier with a load resistance of several thousand ohms will result in poor impedance matching with practically the whole of the output being developed across the load resistor instead of across the load. One answer to this problem is to reduce the output impedance by using an emitter follower, which is a single transistor connected in common collector mode.

Common Collector Mode

This configuration uses the collector lead as the common connection for input and output. In the circuit (Fig. 4.3.4) the input to the transistor is connected between base and ground, and the output is connected across the load resistor between emitter and ground. Remember that with the collector connected directly to the supply, the collector is at ground potential as far as AC is concerned, because of the presence of large decoupling capacitors connected between supply and ground.

The common collector amplifier is called an emitter follower because the output, taken from the emitter is in phase with and 'follows' the input voltage at the base. In fact the base and emitter voltages are almost identical so the emitter follower has a voltage gain of 1 (in practice, slightly less) because of the 100% negative feedback created by the emitter load resistor not being decoupled, as would be the normal case in a common emitter amplifier. This causes the full amplitude of the output signal to be fed back to the base, giving a closed loop gainβ of 1.

The emitter follower is therefore of no use as a voltage amplifier. It does however, have other very useful properties. Its current gain is large, and approximately equals the current gain (h_{fe}) of the transistor. The input impedance of the circuit is high, 100KΩ or more being typical, although this will depend to some extent on the value of the base bias resistor R1 in Fig. 4.3.4, which is in parallel with the input resistance of the transistor, but this shunting effect can be reduced by 'Bootstrapping'. The output impedance of the circuit is very low, typically in the region of 50Ω. Because of its use in matching relatively high output impedance voltage amplifiers to low impedance loads, the emitter follower may also be called a 'Buffer Amplifier'.

The Emitter Follower as a Voltage Regulator

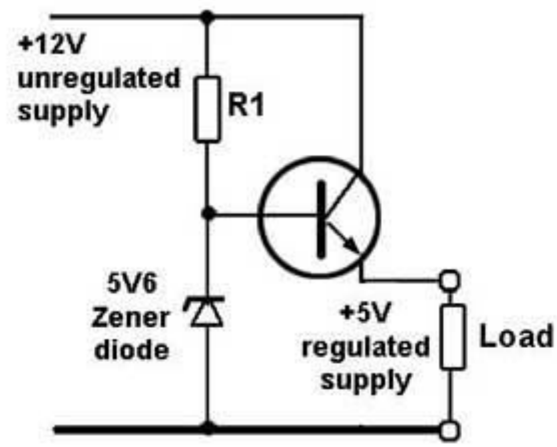


Fig. 4.3.5 Emitter Follower Voltage Regulator

Another use for the emitter follower is as a voltage regulator, and is useful in power supplies where a small voltage can be used to regulate a large current, as shown in Fig. 4.3.5. This circuit ensures that the regulated 5 volt supply remains at the correct voltage even if the 12 volt supply changes. An accurate five volts is also maintained for a range of currents drawn by the circuit being supplied. Regulation can be achieved just using a resistor and Zener diode combination but much higher currents can be handled when an emitter follower is used.

Notice in Fig.4.3.5 that the Zener diode has a voltage rating of 5V6 (meaning 5.6volts), this will maintain the base of the transistor at that voltage, and the emitter of the transistor at 0.6V below the base voltage, will be maintained at 5 volts. A small current maintaining the base voltage at 5.6V is therefore able to accurately control a much larger current flowing through the collector and emitter.

The emitter follower circuit is also the basis of many push-pull class B and class AB power output amplifier stages described in Amplifiers Module 5

The Emitter Follower Converted to a Darlington Pair

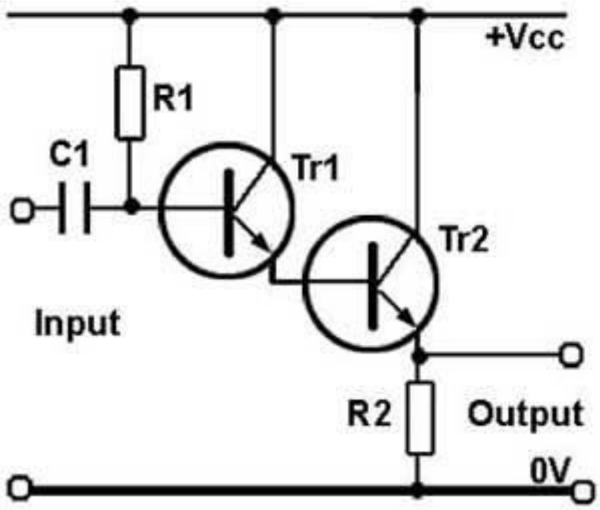


Fig. 4.3.6 The Darlington Pair

The effect of a high input impedance is to reduce the input current to the amplifier. If the input current for a given input voltage is reduced by whatever method, the effect is to increase the input impedance. The emitter follower has a high input impedance, but this may be reduced to an unacceptable level by the presence of the base bias resistor.

However another circuit, the compound or Darlington pair shown in Fig. 4.3.6 can greatly increase input impedance. By using one emitter follower (Tr1) to drive another (Tr2) the overall current gain becomes the product of the individual gains, $h_{fe}1 \times h_{fe}2$ and can be typically 1000 or more. This greatly reduces the signal current required by the base of Tr1 and thereby dramatically increases the input impedance.

The Darlington Pair using Common Emitter Amplifiers

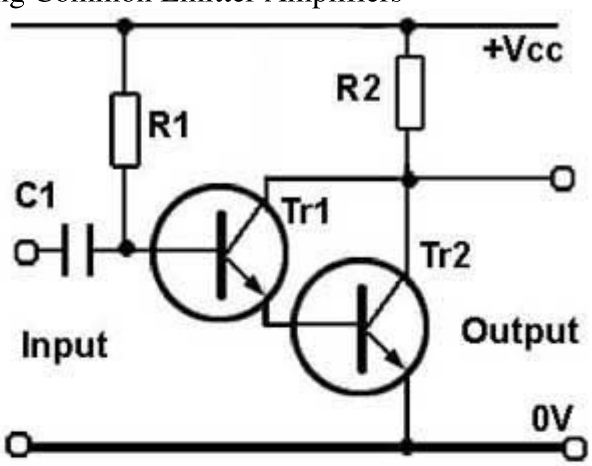


Fig. 4.3.7 Common Emitter Arrangement

The Darlington pair can also be used in common emitter mode, as shown in Fig. 4.3.7. Darlington transistors are also available as combined packages in both PNP and NPN types, complete with back emf protection diodes typically required when the Darlington configuration is used as a high current gain output device for switching high current inductive loads.

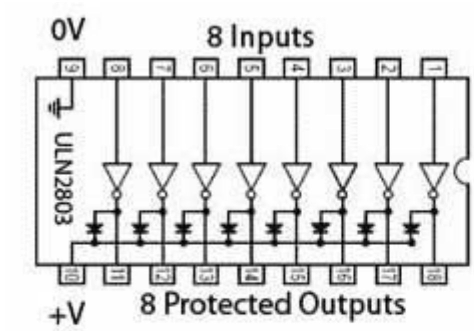


Fig. 4.3.8 The Darlington Integrated Circuit ULN2803

Darlington amplifiers are also available in integrated circuit form, such as the ULN2803, which contains eight high current, Darlington amplifiers with open collector outputs, for interfacing between TTL (5V) logic circuits and high current/high voltage (up to 500mA and 50V) devices. When pin 10 is connected to +V each output is diode protected for driving inductive loads against back e.m.f.

Bootstrapping

Bootstrapping (Using positive feedback to feed part of the output back to the input, but without causing oscillation) is a method of apparently increasing the value of a fixed resistor as it appears to A.C. signals, and thereby increasing input impedance. A basic bootstrap amplifier is shown in Fig. 4.3.8 where capacitor C_B is the ‘Bootstrap Capacitor’, which provides A.C. feedback to a resistor in series with the base. The value of C_B will be large, about 10 x the lowest frequency handled x the value of the series resistor ($10f_{min}R3$).

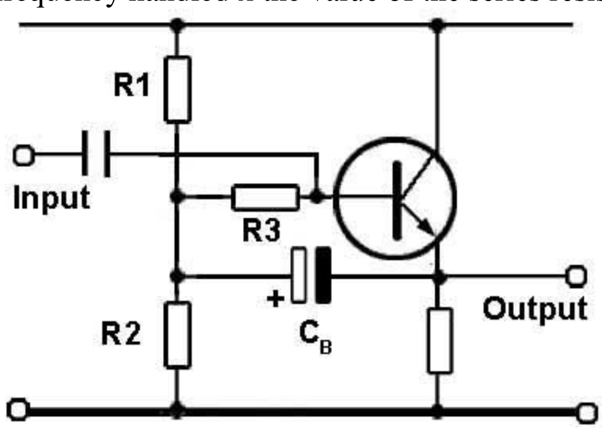


Fig. 4.3.8 Bootstrapping applied to an Emitter Follower

Although positive feedback is being used, which would normally cause an amplifier to oscillate, the voltage gain of the emitter follower is less than 1, which prevents oscillation.

In Fig. 4.3.8 the base of the emitter follower is biased from a potential divider via R3. By feeding the output waveform back to the left hand side of R3 the voltage at this end of R3 is made to rise and fall in phase with the input signal at the base end of R3.

Because the output waveform of the emitter follower is a slightly less amplitude than the base waveform (due to the less than 1 gain of the transistor) there will be a very small signal current waveform across R3. Such a small current waveform suggests a very small current is flowing; therefore the resistance of R3 must be very high, much higher than in fact it is. The input impedance of the amplifier has therefore been increased.

The effective A.C. value of R3 is increased by R3 ÷ $(1 - A_o)$ where A_o is the open loop gain of the amplifier.

For example a 47KΩ resistor with bootstrapping would appear to be:

$$\text{The bootstrap value of R3, } = R3_B = \frac{R3}{(1 - A_o)}$$

FEEDBACK PAIR

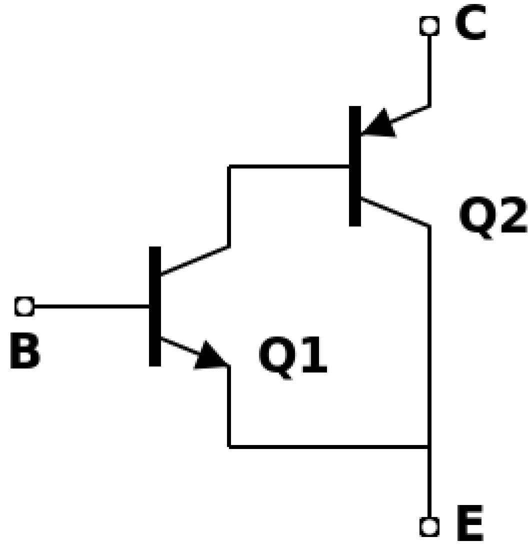
In electronics, the Sziklai pair (also known as a complementary feedback pair (CFP) or "compound transistor", and as a "pseudo-Darlington") is a configuration of two bipolar transistors, similar to a Darlington pair. In contrast to the Darlington arrangement, the Sziklai pair has one NPN and one PNP transistor, and so it is sometimes also called the "complementary Darlington". Current gain is similar to that of a Darlington pair, which is the product of the gains of the two transistors. The configuration is named for its early popularizer, George C. Sziklai.

In a typical application the Sziklai pair acts somewhat like a single transistor with the same type (e.g. NPN) as Q1 and with a very high current gain (β). The emitter of Q2 acts the role of a collector. Hence the emitter of Q2 is labeled "C" in the figure to the right. Likewise, in a typical application the collector of Q2 (also connected to the emitter of Q1) plays the role of an emitter and is thus labeled "E."

The figure at the right illustrates an NPN-PNP pair that acts like a single NPN transistor overall. By replacing Q1 with a PNP transistor and Q2 with an NPN transistor the pair will act like a PNP transistor overall. (Just exchange the two arrows in the figure to visualize the PNP-NPN pair.)

One advantage over the Darlington pair is that the base turn-on voltage is only about 0.6V or half of the Darlington's 1.2V nominal turn-on voltage. Like the Darlington, it can saturate only to 0.6V, which is a drawback for high-power stages.

As with a Darlington pair, a resistor (e.g., 100Ω–1kΩ) is usually connected between Q2's emitter and base to improve its turn-off time (i.e., its performance for high frequency signals).



Sziklai pairs are often used in the output stages of power amplifiers due to their advantages both in linearity and bandwidth when compared with more common Darlington emitter follower output stages. They are especially advantageous in amplifiers where the intended load does not require the use of parallel devices.

Sziklai pairs can also have the benefit of superior thermal stability under the right conditions. In contrast to the traditional Darlington configuration, quiescent current is much more stable with respect to changes in the temperature of the higher power output transistors vs the lower power drivers. This means that a Sziklai output stage in a class AB amplifier requires only that the bias servo transistor or diodes be thermally matched to the lower power driver transistors; they need not (and should not) be placed on the main heatsink. This potentially simplifies the design and implementation of a stable class AB amplifier, reducing the need for emitter resistors, significantly reducing the number of components which must be in thermal contact with the heatsink and reducing the likelihood to thermal runaway.

Optimal quiescent current in an amplifier using Sziklai pairs also tends to be much lower than in Darlington-based output stages, on the order of 10mA vs. 100mA or more for some emitter follower output stages. This means that idle power consumption is on the order of a few watts versus tens of watts for the same performance in many cases. This is a very compelling reason to use the Sziklai pair in cases were output power is moderate (25-100W), fidelity is critical and relatively low idle power consumption is desired.

Historically, designers frequently used the "quasi-complementary" configuration, which uses a Darlington push pair (i.e., two NPN transistors) and a Sziklai pull pair (i.e., one PNP and one NPN transistor). This configuration, which uses three NPN transistors and one PNP transistor, is advantageous because while the first transistors and the most common small signal transistors for decades were PNP Germanium devices, silicon PNP power transistors were slower to develop than and have historically been more expensive than their NPN counterparts. Alternately, if a germanium PNP device were used, it would have significantly different characteristics. In the Quasi-complimentary topology, the performance of the lower pull pair, which used a single NPN transistor, more closely matched the performance of the upper push pair, which consists of two NPN transistors and an identical power device.

While for decades the Quasi-complimentary output stage made sense, recently PNP and NPN power transistors have become roughly equally available and have more closely matched performance characteristics, and so modern audio power amplifiers often use equivalent topologies for both pairs, either both Darlington emitter follower or both Sziklai pair

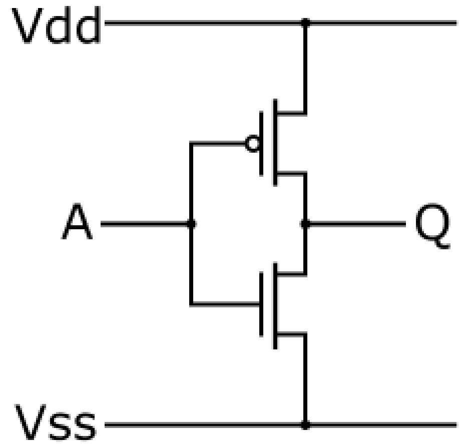
CMOS

Complementary metal–oxide–semiconductor (CMOS) /ˈsiːmɒs/ is a technology for constructing integrated circuits. CMOS technology is used in microprocessors, microcontrollers, static RAM, and other digital logic circuits. CMOS technology is also used for several analog circuits such as image sensors (CMOS sensor), data converters, and highly integrated transceivers for many types of communication. In 1963, while working for Fairchild Semiconductor, Frank Wanlass patented CMOS (US patent 3,356,858).

CMOS is also sometimes referred to as complementary-symmetry metal–oxide–semiconductor (or COS-MOS). The words "complementary-symmetry" refer to the fact that the typical design style with CMOS uses complementary and symmetrical pairs of p-typeand n-type metal oxide semiconductor field effect transistors (MOSFETs) for logic functions.

Two important characteristics of CMOS devices are high noise immunity and low static power consumption. Since one transistor of the pair is always off, the series combination draws significant power only momentarily during switching between on and off states. Consequently, CMOS devices do not produce as much waste heat as other forms of logic, for example transistor–transistor logic (TTL) or NMOS logic, which normally have some standing current even when not changing state. CMOS also allows a high density of logic functions on a chip. It was primarily for this reason that CMOS became the most used technology to be implemented in VLSI chips.

The phrase "metal–oxide–semiconductor" is a reference to the physical structure of certain field-effect transistors, having a metal gate electrode placed on top of an oxide insulator, which in turn is on top of a semiconductor material. Aluminium was once used but now the material is polysilicon. Other metal gates have made a comeback with the advent of high-k dielectric materials in the CMOS process, as announced by IBM and Intel for the 45 nanometer node and beyond.



MOS" refers to both a particular style of digital circuitry design and the family of processes used to implement that circuitry on integrated circuits (chips). CMOS circuitry dissipates less power than logic families with resistive loads. Since this advantage has increased and grown more important, CMOS processes and variants have come to dominate, thus the vast majority of modern integrated circuit manufacturing is on CMOS processes. As of 2010, CPUs with the best performance per watt each year have been CMOS static logic since 1976.

CMOS circuits use a combination of p-type and n-type metal–oxide–semiconductor field-effect transistor (MOSFETs) to implement logic gates and other digital circuits. Although CMOS logic can be implemented with discrete devices for demonstrations, commercial CMOS products are integrated circuits composed of up to billions of transistors of both types, on a rectangular piece of silicon of between 10 and 400 mm^2.

CMOS always uses all enhancement-mode MOSFETs

INVERSION:

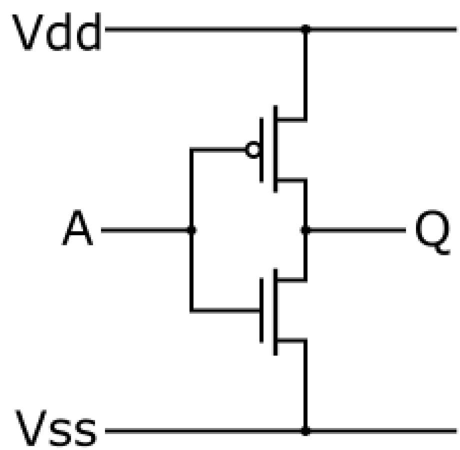
CMOS circuits are constructed in such a way that all PMOS transistors must have either an input from the voltage source or from another PMOS transistor. Similarly, all NMOS transistors must have either an input from ground or from another NMOS transistor. The composition of a PMOS transistor creates low resistance between its source and drain contacts when a low gate voltage is applied and high resistance when a high gate voltage is applied. On the other hand, the composition of an NMOS transistor creates high resistance between source and drain when a low gate voltage is applied and low resistance when a high gate voltage is applied. CMOS accomplishes current reduction by complementing every nMOSFET with a pMOSFET and connecting both gates and both drains together. A high voltage on the gates will cause the nMOSFET to conduct and the pMOSFET to not conduct, while a low voltage on the gates causes the reverse. This arrangement greatly reduces power consumption and heat generation. However, during the switching time, both MOSFETs conduct briefly as the gate voltage goes from one state to another. This induces a brief spike in power consumption and becomes a serious issue at high frequencies.

The image on the right shows what happens when an input is connected to both a PMOS transistor (top of diagram) and an NMOS transistor (bottom of diagram). When the voltage of input A is low, the NMOS transistor's channel is in a high resistance state. This limits the current that can flow from Q to ground. The PMOS transistor's channel is in a low resistance state and much more current can flow from the supply to the output. Because the resistance between the supply voltage and Q is low, the voltage drop between the supply voltage and Q due to a current drawn from Q is small. The output therefore registers a high voltage.

On the other hand, when the voltage of input A is high, the PMOS transistor is in an OFF (high resistance) state so it would limit the current flowing from the positive supply to the output, while the NMOS transistor is in an ON (low resistance) state, allowing the output from drain to ground. Because the resistance between Q and ground is low, the voltage drop due to a current drawn into Q placing Q above ground is small. This low drop results in the output registering a low voltage.

In short, the outputs of the PMOS and NMOS transistors are complementary such that when the input is low, the output is high, and when the input is high, the output is low. Because of this behavior of input and output, the CMOS circuit's output is the inverse of the input.

The power supplies for CMOS are called V_{DD} and V_{SS}, or V_{CC} and Ground (GND) depending on the manufacturer. V_{DD} and V_{SS} are carryovers from conventional MOS circuits and stand for the drain and source supplies. These do not apply directly to CMOS, since both supplies are really source supplies. V_{CC} and Ground are carryovers from TTL logic and that nomenclature has been retained with the introduction of the 54C/74C line of CMOS.



Duality

An important characteristic of a CMOS circuit is the duality that exists between its PMOS transistors and NMOS transistors. A CMOS circuit is created to allow a path always to exist from the output to either the power source or ground. To accomplish this, the set of all paths to the voltage source must be the complement of the set of all paths to ground. This can be easily accomplished by defining one in terms of the NOT of the other. Due to the De Morgan's laws based logic, the PMOS transistors in parallel have corresponding NMOS transistors in series while the PMOS transistors in series have corresponding NMOS transistors in parallel.

CURRENT MIRROR CIRCUIT:

A current mirror is a circuit block which functions to produce a copy of the current in one active device by replicating the current in second active device. An important feature of the current mirror is a relatively high output resistance which helps to keep the output current constant regardless of load conditions. Another feature of the current mirror is a relatively low input resistance which helps to keep the input current constant regardless of drive conditions. The current being 'copied' can be, and often is, a varying signal current. Conceptually, an ideal current mirror is simply an ideal current amplifier with a gain of -1. The current mirror is often used to provide bias currents and active loads in amplifier stages. Given a current source as the input, we convert the current (entering the current mirror) into a voltage and then use this voltage to control a current sink (the current exiting the mirror); as a result, we obtain a current sink (figure 11.1a). Conversely, given a current sink as the input, we convert the input current (exiting the current mirror) into a voltage and then use this voltage to control a current source (figure 11.1b); as a result, now we obtain a current source. We can generalize this basic current mirror structure in a first conclusion:

A current mirror consists of a current-to-voltage converter consecutively connected to a voltage-to-current converter.

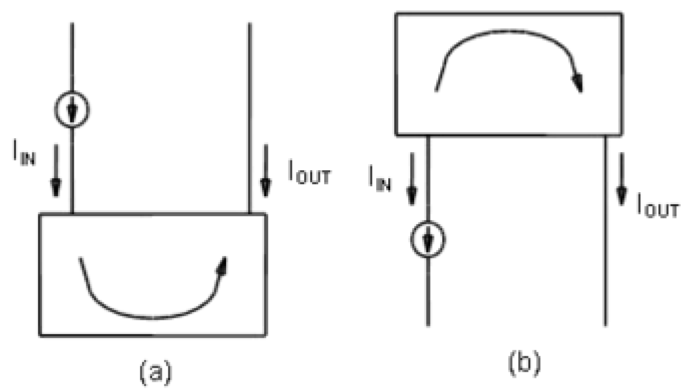


Figure 11.1, Current Mirror (a) Sink (b) Source

It should be noted that the two converters may have a linear relationship (for example where $V_{OUT} = I_{IN}R$ and $I_{OUT} = V_{IN}/R$) like a resistor but this linear relationship is not required. The converters might be non-linear devices having whatever transfer or I to V characteristics that may even depend on another quantity (such as temperature); the only requirement is the characteristics be the inverse of each other. For example, if the I to V converter implements a function $v = f(i)$ and the other represents the inverse function $i = f^{-1}(v)$ the whole function is $v = f(i) = f(f^{-1}(v))$. So, we can formulate the second conclusion: A current mirror consists of two consecutively connected converters that have inverse transfer functions.

An input stage to convert current to voltage

We need a configuration where our active element of choice, a transistor, serves as the desired current-to-voltage converter. However, the transistor is a unidirectional device, where for the BJT the base emitter voltage controls the collector current or for the FET the gate source voltage controls the drain current. Producing the opposite where the collector current controls the V_{BE} is not possible in the conventional use of the device as a common emitter amplifier. The solution is to incorporate negative feedback. In this case that means making the transistor adjust its base emitter or gate source voltage, V_{BE} or V_{GS}, so that the collector or drain current is $I_{IN} = (V_1 - V_{BE})/R$. For this purpose, we simply connect the collector to the base or gate to drain. This results in 100% parallel negative feedback (figure 11.2). As a result, with this reversed transistor, the collector current serves as the input quantity while the base-emitter voltage V_{BE} serves as the output quantity with a logarithmic transfer function. The input part of the simple BJT current mirror is just a bipolar transistor with 100% parallel negative feedback. Similarly, a diode connected enhancement mode MOS FET (gate tied to drain) will serve as a similar current to voltage converter with V_{GS} as the output quantity rather than V_{BE}.

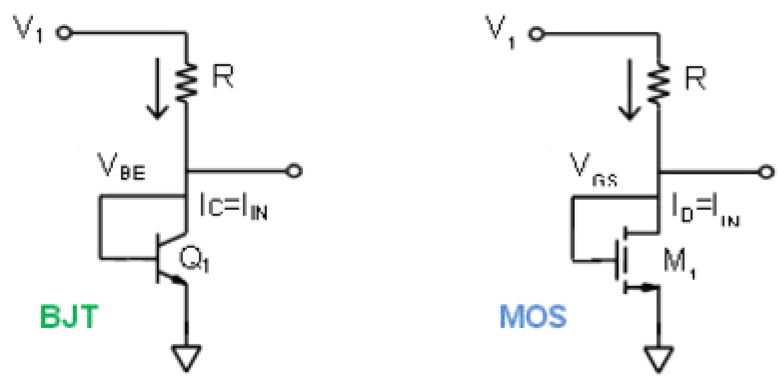


Figure 11.2, Current to Voltage Converter

An output stage to convert voltage to current

A bipolar transistor can be driven by a voltage or by a current. If we consider the base emitter voltage, V_{BE}, as the input and the collector current, I_C, as the output (figure 11.3), we can think of a transistor as a non-linear voltage-to-current converter having an exponential characteristic. The base can be directly driven by the voltage output of the I-to-V converter we just discussed. The collector provides the output terminal of our simple current mirror: The output V to I converter stage of the simple current mirror is just a transistor acting as a non-linear (exponential for BJT) voltage-to-current converter. Again if a MOS transistor were used for the input stage the output stage would be a MOS transistor with the gate serving as the voltage input and the drain as the current output.

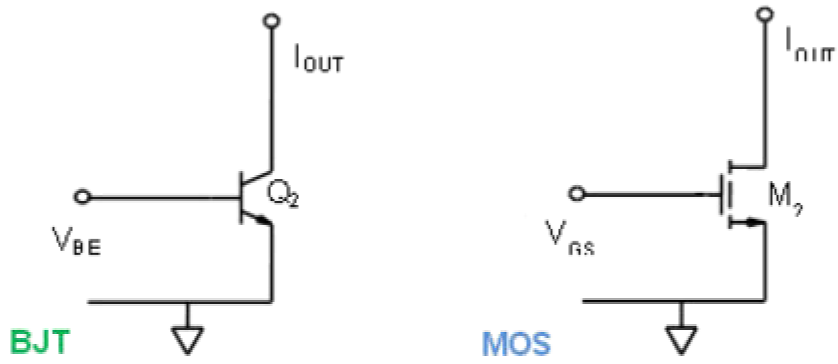


Figure 11.3, Voltage to Current Converter

CURRENT SOURCE:

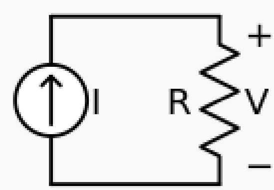


Figure 1: An ideal current source, I, driving a resistor, R, and creating a voltage V

A current source is an electronic circuit that delivers or absorbs an electric current which is independent of the voltage across it.

A current source is the dual of a voltage source. The term, constant-current sink, is sometimes used for sources fed from a negative voltage supply. Figure 1 shows the schematic symbol for an ideal current source, driving a resistor load. There are two types. An independent current source (or sink) delivers a constant current. A dependent current source delivers a current which is proportional to some other voltage or current in the circuit.

In circuit theory, an ideal current source is a circuit element where the current through it is independent of the voltage across it. It is a mathematical model, which real devices can only approach in performance. If the current through an ideal current source can be specified independently of any other variable in a circuit, it is called an independent current source. Conversely, if the current through an ideal current source is determined by some other voltage or current in a circuit, it is called a dependent or controlled current source. Symbols for these sources are shown in Figure 2.

The internal resistance of an ideal current source is infinite. An independent current source with zero current is identical to an ideal open circuit. The voltage across an ideal current source is completely determined by the circuit it is connected to. When connected to a short circuit, there is zero voltage and thus zero power delivered. When connected to a load resistance, the voltage across the source approaches infinity as the load resistance approaches infinity (an open circuit). Thus, an ideal current source, if such a thing existed in reality, could supply unlimited power and so would represent an unlimited source of energy.

No physical current source is ideal. For example, no physical current source can operate when applied to an open circuit. There are two characteristics that define a current source in real life. One is its internal resistance and the other is its compliance voltage. The compliance voltage is the maximum voltage that the current source can supply to a load. Over a given load range, it is possible for some types of real current sources to exhibit nearly infinite internal resistance. However, when the current source reaches its compliance voltage, it abruptly stops being a current source.

In circuit analysis, a current source having finite internal resistance is modeled by placing the value of that resistance across an ideal current source (the Norton equivalent circuit). However, this model is only useful when a current source is operating within its compliance voltage.

Passive current source:

The simplest non-ideal current source consists of a voltage source in series with a resistor. The amount of current available from such a source is given by the ratio of the voltage across the voltage source to the resistance of the resistor (Ohm's law; I = V/R). This value of current will only be delivered to a load with zero voltage drop across its terminals (a short circuit, an uncharged capacitor, a charged inductor, a virtual ground circuit, etc.) The current delivered to a load with nonzero voltage (drop) across its terminals (a linear or nonlinear resistor with a finite resistance, a charged capacitor, an uncharged inductor, a voltage source, etc.) will always be different. It is given by the ratio of the voltage drop across the resistor (the difference between the exciting voltage and the voltage across the load) to its resistance. For a nearly ideal current source, the value of the resistor should be very large but this implies that, for a specified current, the voltage source must be very large (in the limit as the resistance and the voltage go to infinity, the current source will become ideal and the current will not depend at all on the voltage across the load). Thus, efficiency is low (due to power loss in the resistor) and it is usually impractical to construct a 'good' current source this way. Nonetheless, it is often the case that such a circuit will provide adequate performance when the specified current and load resistance are small. For example, a 5 V voltage source in series with a 4.7 kilohm resistor will provide an approximately constant current of 1 mA ± 5% to a load resistance in the range of 50 to 450 ohm.

A Van de Graff generator is an example of such a high voltage current source. It behaves as an almost constant current source because of its very high output voltage coupled with its very high output resistance and so it supplies the same few microamperes at any output voltage up to hundreds of thousands of volts (or even tens of megavolts) for large laboratory versions.

Active current sources without negative feedback.

In these circuits the output current is not monitored and controlled by means of negative feedback.

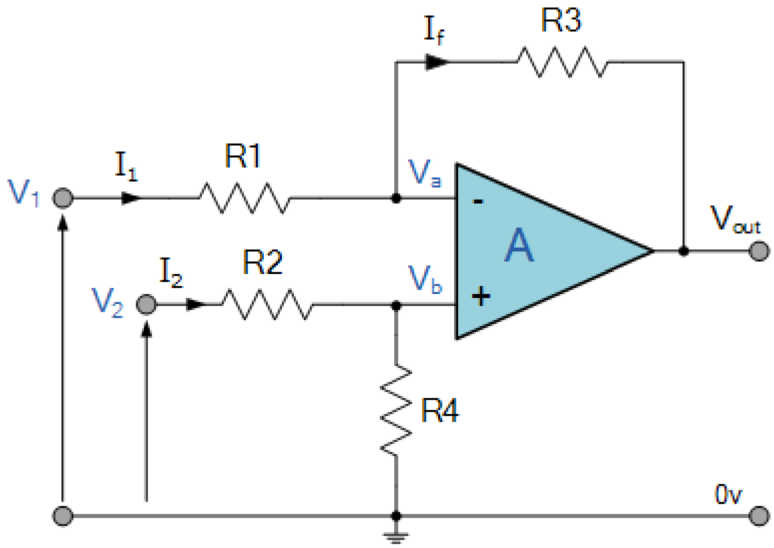
Current-stable nonlinear implementation. They are implemented by active electronic components (transistors) having current-stable nonlinear output characteristic when driven by steady input quantity (current or voltage). These circuits behave as dynamic resistors changing its present resistance to compensate current variations. For example, if the load increases its resistance, the transistor decreases its present output resistance (and vice versa) to keep up a constant total resistance in the circuit.

Active current sources have many important applications in electronic circuits. They are often used in place of ohmic resistors in analog integrated circuits (e.g., a differential amplifier) to generate a current that depends slightly on the voltage across the load.

The common emitter configuration driven by a constant input current or voltage and common source (common cathode) driven by a constant voltage naturally behave as current sources (or sinks) because the output impedance of these devices is naturally high. The output part of the simple current mirror is an example of such a current source widely used in integrated circuits. The common base, common gate and common grid configurations can serve as constant current sources as well.

THE DIFFERENTIAL AMPLIFIER

Thus far we have used only one of the operational amplifiers inputs to connect to the amplifier, using either the "inverting" or the "non-inverting" input terminal to amplify a single input signal with the other input being connected to ground.

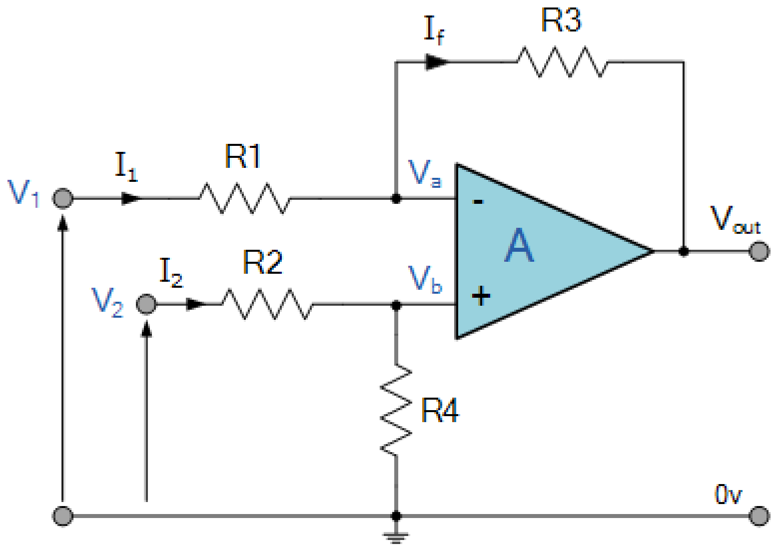


But as a standard operational amplifier has two inputs, inverting and no-inverting, we can also connect signals to both of these inputs at the same time producing another common type of operational amplifier circuit called a Differential Amplifier.

Basically, as we saw in the first tutorial about operational amplifier, all op-amps are "Differential Amplifiers" due to their input configuration. But by connecting one voltage signal onto one input terminal and another voltage signal onto the other input terminal the resultant output voltage will be proportional to the "Difference" between the two input voltage signals of V1 and V2.

Then differential amplifiers amplify the difference between two voltages making this type of operational amplifier circuit a Subtractor unlike a summing amplifier which adds or sums together the input voltages. This type of operational amplifier circuit is commonly known as a Differential Amplifier configuration and is shown below:

DIFFERENTIAL AMPLIFIER



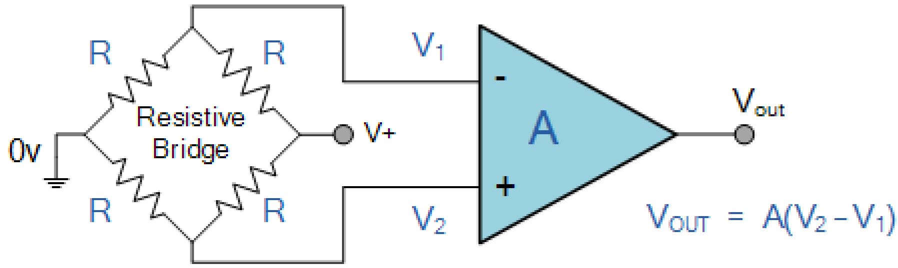
By connecting each input in turn to 0v ground we can use superposition to solve for the output voltage Vout. Then the transfer function for a Differential Amplifier circuit is given as:

When resistors, R1 = R2 and R3 = R4 the above transfer function for the differential amplifier can be simplified to the following expression:

If all the resistors are all of the same ohmic value, that is: R1 = R2 = R3 = R4 then the circuit will become a Unity Gain Differential Amplifier and the voltage gain of the amplifier will be exactly one or unity. Then the output expression would simply be Vout = V2 – V1. Also note that if input V1 is higher than input V2 the output voltage sum will be negative, and if V2 is higher than V1, the output voltage sum will be positive.

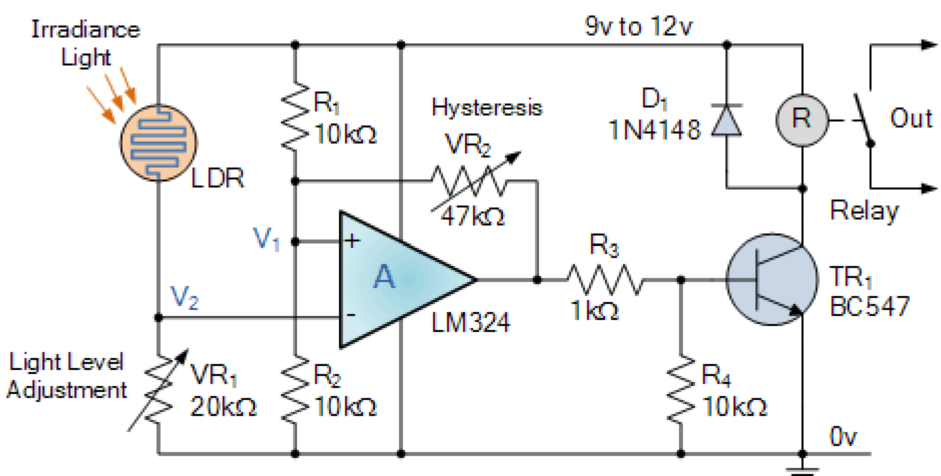
The Differential Amplifier circuit is a very useful op-amp circuit and by adding more resistors in parallel with the input resistors R1 and R3, the resultant circuit can be made to either "Add" or "Subtract" the voltages applied to their respective inputs. One of the most common ways of doing this is to connect a "Resistive Bridge" commonly called a Wheatstone Bridge to the input of the amplifier as shown below.

Wheatstone Bridge Differential Amplifier



The standard Differential Amplifier circuit now becomes a differential voltage comparator by "Comparing" one input voltage to the other. For example, by connecting one input to a fixed voltage reference set up on one leg of the resistive bridge network and the other to either a "Thermistor" or a "Light Dependant Resistor" the amplifier circuit can be used to detect either low or high levels of temperature or light as the output voltage becomes a linear function of the changes in the active leg of the resistive bridge and this is demonstrated below.

Light Activated Differential Amplifier



Here the circuit above acts as a light-activated switch which turns the output relay either "ON" or "OFF" as the light level detected by the LDR resistor exceeds or falls below some pre-set value. A fixed voltage reference is applied to the non-inverting input terminal of the op-amp via the R1 – R2 voltage divider network.

The voltage value at V1 sets the op-amps trip point with a feed back potentiometer, VR2used to set the switching hysteresis. That is the difference between the light level for "ON" and the light level for "OFF".

The second leg of the differential amplifier consists of a standard light dependant resistor, also known as a LDR, photoresistive sensor that changes its resistive value (hence its name) with the amount of light on its cell as their resistive value is a function of illumination.

The LDR can be any standard type of cadmium-sulphide (CdS) photoconductive cell such as the common NORP12 that has a resistive range of between about 500Ω in sunlight to about 20kΩ's or more in the dark.

The NORP12 photoconductive cell has a spectral response similar to that of the human eye making it ideal for use in lighting control type applications. The photocell resistance is proportional to the light level and falls with increasing light intensity so therefore the voltage level at V2 will also change above or below the switching point which can be determined by the position of VR1.

Then by adjusting the light level trip or set position using potentiometer VR1 and the switching hysteresis using potentiometer, VR2 an precision light-sensitive switch can be made. Depending upon the application, the output from the op-amp can switch the load directly, or use a transistor switch to control a relay or the lamps themselves.

It is also possible to detect temperature using this type of simple circuit configuration by replacing the light dependant resistor with a thermistor. By interchanging the positions of VR1 and the LDR, the circuit can be used to detect either light or dark, or heat or cold using a thermistor.

One major limitation of this type of amplifier design is that its input impedances are lower compared to that of other operational amplifier configurations, for example, a non-inverting (single-ended input) amplifier.

Each input voltage source has to drive current through an input resistance, which has less overall impedance than that of the op-amps input alone. This may be good for a low impedance source such as the bridge circuit above, but not so good for a high impedance source.

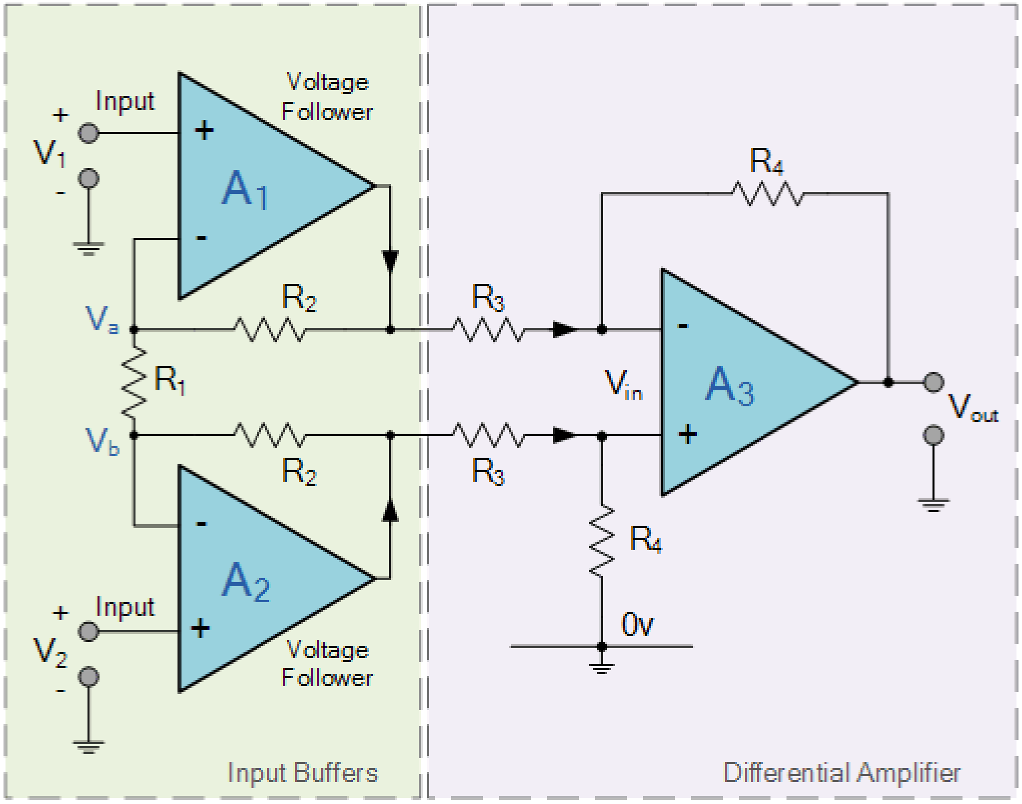
Instrumentation Amplifier

Instrumentation Amplifiers (in-amps) are very high gain differential amplifiers which have a high input impedance and a single ended output. Instrumentation amplifiers are mainly used to amplify very small differential signals from strain gauges, thermocouples or current sensing devices in motor control systems.

Unlike standard operational amplifiers in which their closed-loop gain is determined by an external resistive feedback connected between their output terminal and one input terminal, either positive or negative, "instrumentation amplifiers" have an internal feedback resistor that is effectively isolated from its input terminals as the input signal is applied across two differential inputs, V1 and V2.

The instrumentation amplifier also has a very good common mode rejection ratio, CMRR (zero output when V1 = V2) well in excess of 100dB at DC. A typical example of a three op-amp instrumentation amplifier with a high input impedance (Zin) is given below:

High Input Impedance Instrumentation Amplifier



The two non-inverting amplifiers form a differential input stage acting as buffer amplifiers with a gain of 1 + 2R2/R1 for differential input signals and unity gain for common mode input signals. Since amplifiers A1 and A2 are closed loop negative feedback amplifiers, we can expect the voltage at Va to be equal to the input voltage V1. Likewise, the voltage at Vb to be equal to the value at V2.

As the op-amps take no current at their input terminals (virtual earth), the same current must flow through the three resistor network of R2, R1 and R2 connected across the op-amp outputs. This means then that the voltage on the upper end of R1 will be equal to V1 and the voltage at the lower end of R1 to be equal to V2.

This produces a voltage drop across resistor R1 which is equal to the voltage difference between inputs V1 and V2, the differential input voltage, because the voltage at the summing junction of each amplifier, Va and Vb is equal to the voltage applied to its positive inputs.

However, if a common-mode voltage is applied to the amplifiers inputs, the voltages on each side of R1 will be equal, and no current will flow through this resistor. Since no current flows through R1 (nor, therefore, through both R2 resistors, amplifiers A1 andA2 will operate as unity-gain followers (buffers). Since the input voltage at the outputs of amplifiers A1 and A2 appears differentially across the three resistor network, the differential gain of the circuit can be varied by just changing the value of R1.

UNIT IV

Power amplifiers Introduction, Series-fed Class A amplifier, Transformer coupled class A amplifier, Class B amplifier operation, Class B amplifier distortion, Power transistor heat sinking, Class C and Class D amplifiers, Numerical problems.

INTRODUCTION TO POWER AMPLIFIERS:

An amplifier system consists of signal pick-up transducer, followed by a small signal amplifier(s), a large signal amplifier and an output transducer. A transducer is used to convert one form of energy into another type. For example a microphone is used to convert acoustical energy into electrical energy. Conversely, a loudspeaker is used to convert electrical energy into acoustical energy. A motor is a transducer that is used to convert electrical energy into mechanical energy.

The input transducer produces small electrical (typically voltage) signal, that needs sufficient amplification to operate some output device such as a loudspeaker, a servomotor, a solenoid or relay. The factors of prime interest in small signal voltage amplifiers are usually linearity and gain. Since the signal voltage and current from the input transducer is usually very small, the amount of power handling capacity and power efficiency are of slight concern. The functions of voltage amplifiers are to present a high resistance to the input transducer to minimize loading effects and to provide a large enough voltage signal to the large-signal amplifier stages to operate such output devices (loudspeaker, servomotor etc.). A large-signal amplifier must operate efficiently and be capable of handling large amounts of power-typically, a few watts to hundred of watts. Large signal amplifier that drives the output transducer demands even more consideration than the small-signal voltage amplifiers that we have focused so far. The factors of greatest concern to the large signal power amplifiers are the power efficiency of the circuit, the maximum amount of power that the circuit is capable of handling, and impedance matching to the output device.

Power amplifier is meant to raise the power level of the input signal. In order to get large power at the output, it is necessary that the input-signal voltage is large. That is why, in an electronic system, a voltage amplifier always precedes the power amplifier, also, that is why power amplifiers are called large-signal amplifiers.

In fact, power amplifier does not amplify power. What a power amplifier actually does is that it draws power from dc supply connected to the output circuit and converts it into useful ac signal power. The type of ac power available at the output terminals of the power amplifier is controlled by the input signal. Thus a power amplifier may be defined as a device that converts dc power and whose action is controlled by the input signal.

The transistors employed in power amplifiers are called power transistors. They differ from other transistors in the following respects.

(i) The base is made thicker to handle large currents i.e.in power amplifiers; transistors with comparatively smaller gain are used.

(ii) The area of collector region of a power transistor is made considerably larger in order to dissipate the heat developed in the transistor during operation. Moreover, heat sinks are used for improving the heat dissipation.

(iii) The emitter and base layers are heavily doped. The contact area between the base layers and base leads is in ring like form so that the area is increased. By doing so ohmic resistance between emitter and base is reduced and due to low resistance, small power is required at input.

CLASSIFICATION OF POWER AMPLIFIERS:

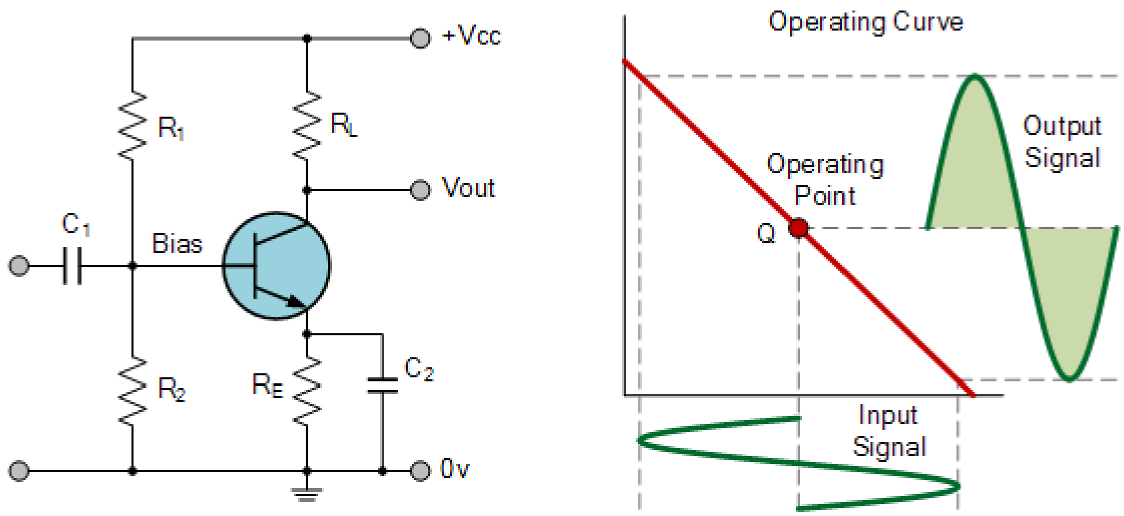
The power amplifiers are primarily divided into two categories

- Audio-power amplifiers – also called the small signal power amplifiers, raise the power levels of signals that have audio-frequency range (20 Hz- 20 kHz).
- Radio-power amplifiers – also called large signal power amplifiers raise the power level of signals that have radio frequency range. They amplify a specific frequency or narrow band of frequencies while rejecting all other frequencies.

Classification According To Mode of Operation

Transistor power amplifiers handle large signals. Many of them are driven so hard by the input large signal that collector current is either cut- off or is in saturation region during a large portion of the input cycle. So such amplifiers are generally classified according to their mode of operation. This classification is based on the amount of transistor bias and amplitude of the input signal. It takes into account the portion of the cycle for which the transistor conducts. They are classified as below:

Class A Amplifier:



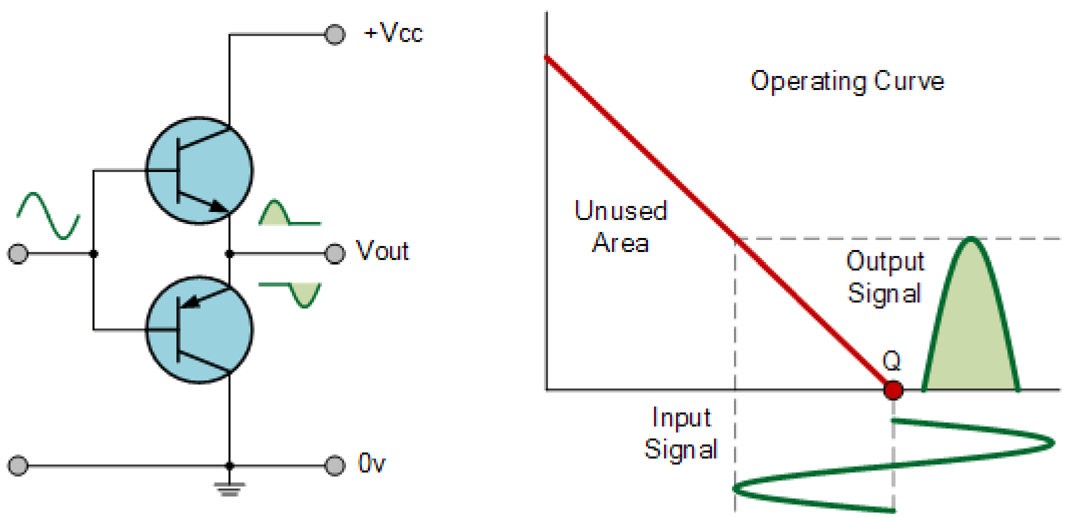
To achieve high linearity and gain, the output stage of a class A amplifier is biased "ON" (conducting) all the time. Then for an amplifier to be classified as "Class A" the zero signal idle current in the output stage must be equal to or greater than the maximum load current (usually a loudspeaker) required to produce the largest output signal.

As a class A amplifier operates in the linear portion of its characteristic curves, the single output device conducts through a full 360 degrees of the output waveform. Then the class A amplifier is equivalent to a current source.

Since a class A amplifier operates in the linear region, the transistors base (or gate) DC biasing voltage should by chosen properly to ensure correct operation and low distortion. However, as the output device is “ON” at all times, it is constantly carrying current, which represents a continuous loss of power in the amplifier.

Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplifications. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well filtered to avoid any amplifier hum and noise. Therefore, due to the low efficiency and overheating problems of Class A amplifiers, more efficient amplifier classes have been developed.

Class B Amplifier:



When the input signal goes positive, the positive biased transistor conducts while the negative transistor is switched “OFF”. Likewise, when the input signal goes negative, the positive transistor switches “OFF” while the negative biased transistor turns “ON” and conducts the negative portion of the signal. Thus the transistor conducts only half of the time, either on positive or negative half cycle of the input signal.

Then we can see that each transistor device of the class B amplifier only conducts through one half or 180 degrees of the output waveform in strict time alternation, but as the output stage has devices for both halves of the signal waveform the two halves are combined together to produce the full linear output waveform.

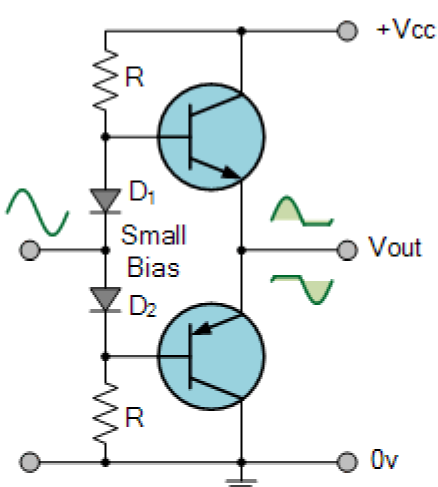
This push-pull design of amplifier is obviously more efficient than Class A, at about 50%, but the problem with the class B amplifier design is that it can create distortion at the zero-crossing point of the waveform due to the transistors dead band of input base voltages from -0.7V to +0.7.

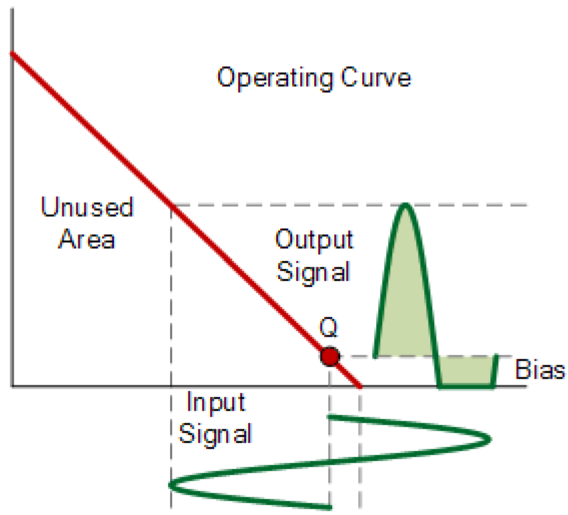
We remember from the Transistor tutorial that it takes a base-emitter voltage of about 0.7 volts to get a bipolar transistor to start conducting. Then in a class B amplifier, the output transistor is not “biased” to an “ON” state of operation until this voltage is exceeded.

This means that the part of the waveform which falls within this 0.7 volt window will not be reproduced accurately making the class B amplifier unsuitable for precision audio amplifier applications.

To overcome this zero-crossing distortion (also known as Crossover Distortion) class AB amplifiers were developed.

Class AB Amplifier





As its name suggests, the **Class AB Amplifier** is a combination of the “Class A” and the “Class B” type amplifiers we have looked at above. The AB classification of amplifier is currently one of the most common used types of audio power amplifier design. The class AB amplifier is a variation of a class B amplifier as described above, except that both devices are allowed to conduct at the same time around the waveforms crossover point eliminating the crossover distortion problems of the previous class B amplifier.

The two transistors have a very small bias voltage, typically at 5 to 10% of the quiescent current to bias the transistors just above its cut-off point. Then the conducting device, either bipolar of FET, will be “ON” for more than one half cycle, but much less than one full cycle of the input signal. Therefore, in a class AB amplifier design each of the push-pull transistors is conducting for slightly more than the half cycle of conduction in class B, but much less than the full cycle of conduction of class A.

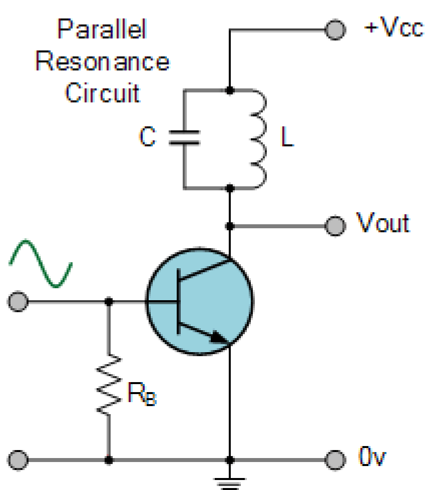
In other words, the conduction angle of a class AB amplifier is somewhere between $180^{o}$and 360^{o} depending upon the chosen bias point as shown.

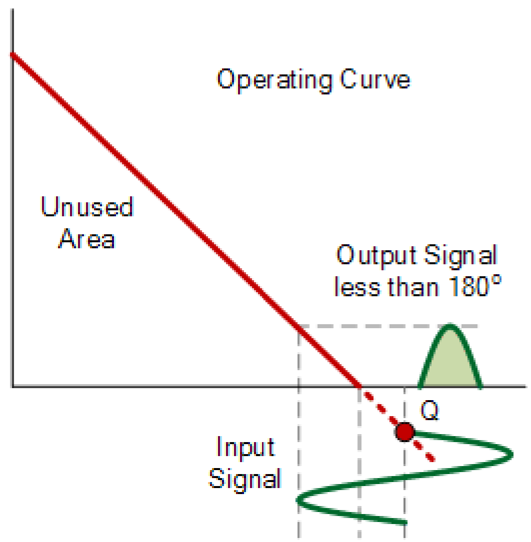
Class C Amplifier

The **Class C Amplifier** design has the greatest efficiency but the poorest linearity of the classes of amplifiers mentioned here. The previous classes, A, B and AB are considered linear amplifiers, as the output signals amplitude and phase are linearly related to the input signals amplitude and phase.

However, the class C amplifier is heavily biased so that the output current is zero for more than one half of an input sinusoidal signal cycle with the transistor idling at its cut-off point. In other words, the conduction angle for the transistor is significantly less than 180 degrees, and is generally around the 90 degrees area.

While this form of transistor biasing gives a much improved efficiency of around 80% to the amplifier, it introduces a very heavy distortion of the output signal. Therefore, class C amplifiers are not suitable for use as audio amplifiers.



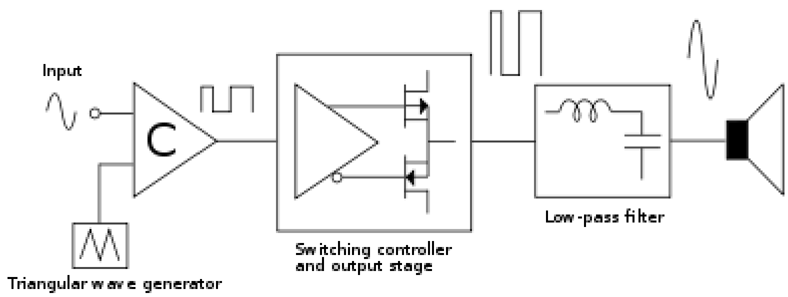


Due to its heavy audio distortion, class C amplifiers are commonly used in high frequency sine wave oscillators and certain types of radio frequency amplifiers, where the pulses of current produced at the amplifiers output can be converted to complete sine waves of a particular frequency by the use of LC resonant circuits in its collector circuit.

A class C power amplifier is biased for operation for less than 180 of the input signal cycle and will operate only with a tuned or resonant circuit which provides a full cycle of operation for the tuned or resonant frequency. Such power amplifiers are, therefore, employed in special areas of tuned circuits, such as radio or communications.

Class D Power Amplifiers

A class-D amplifier or switching amplifier is an electronic amplifier in which the amplifying devices (transistors, usually MOSFETs) operate as electronic switches, and not as linear gain devices as in other amplifiers. The signal to be amplified is a train of constant amplitude pulses, so the active devices switch rapidly back and forth between a fully conductive and nonconductive state. The analog signal to be amplified is converted to a series of pulses by pulse width modulation, pulse density modulation or other method before being applied to the amplifier. After amplification, the output pulse train can be converted back to an analog signal by passing through a passive low pass filter consisting of inductors and capacitors. The major advantage of a class-D amplifier is that it can be more efficient than analog amplifiers, with less power dissipated as heat in the active devices. Class D power amplifiers are designed to operate with digital or pulse type signals. Using digital techniques makes it possible to have a signal that varies over the entire cycle (using sample-and-hold-circuitry) to recreate the output from many pieces of input signal. The main advantage of class D power amplifiers is that it is on (using power) only for short intervals and the overall efficiency can practically be very high (above 90 degree).



POWER TRANSISTOR HEAT SINKING:

A **heat sink** (also commonly spelled heatsink) is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, thereby allowing regulation of the device's temperature at optimal levels. In computers, heat sinks are used to cool central processing units or graphics processors. Heat sinks are used with high-power semiconductor devices such as power transistors and optoelectronics such as lasers and light emitting diodes (LEDs), where the heat dissipation ability of the component itself is insufficient to moderate its temperature.

A heat sink is designed to maximize its surface area in contact with the cooling medium surrounding it, such as the air. Air velocity, choice of material, protrusion design and surface treatment are factors that affect the performance of a heat sink. Heat sink attachment methods and thermal interface materials also affect the die temperature of the integrated circuit. Thermal adhesive or thermal grease improve the heat sink's performance by filling air gaps between the heat sink and the heat spreader on the device. A heat sink is usually made out of copper and/or aluminium. Copper is used because it has many desirable properties for thermally efficient and durable heat exchangers. First and foremost, copper is an excellent conductor of heat. This means that copper's high thermal conductivity allows heat to pass through it quickly. Aluminium is used in applications where weight is a big concern. A heat sink transfers thermal energy from a higher temperature device to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water, refrigerants or oil. If the fluid medium is water, the heat sink is frequently called a cold plate. In thermodynamics a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction. The power supplies of electronics are not 100% efficient, so extra heat is produced that may be detrimental to the function of the device. As such, a heat sink is included in the design to disperse heat to improve efficient energy use.

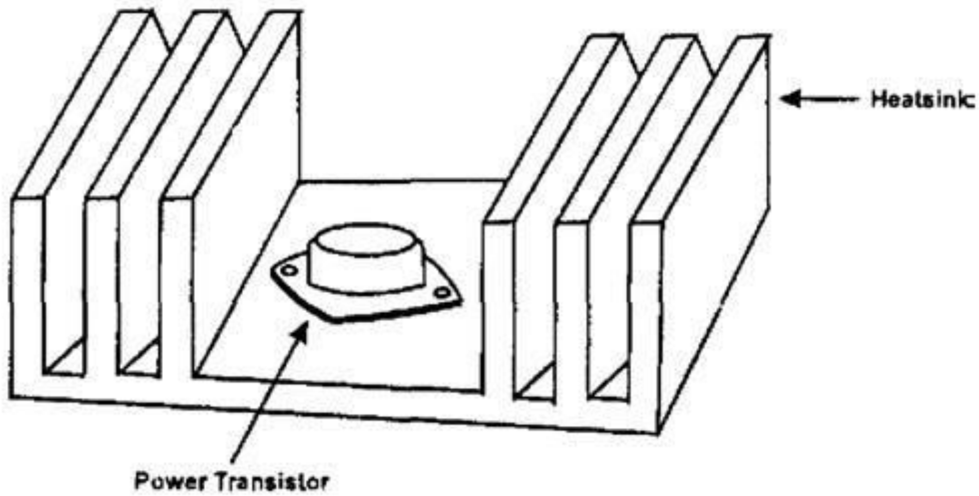
To understand the principle of a heat sink, consider Fourier's law of heat conduction. Fourier's law of heat conduction, simplified to a one-dimensional form in the *x*-direction, shows that when there is a temperature gradient in a body, heat will be transferred from the higher temperature

region to the lower temperature region. The rate at which heat is transferred by conduction is proportional to the product of the temperature gradient and the cross-sectional area through which heat is transferred.

HEAT SINKS USED IN POWER TRANSISTORS:

Heat sinks are used for power transistors as the power dissipated at their collector junction is large. If heat dissipation is not done, this will cause large increases in junction temperature. In a transistor, the collector to base junction temperature (temperature of surrounding air) rises or because of self-heating. The self-heating is due to the power dissipated at collector junction. This power dissipation at junction causes the junction temperature to rise, and this in turn increases the collector current which causes further increase in power dissipation. If the phenomenon continues then it may result in permanent damage of the transistor. This is known as thermal runaway. In power transistor or large signal transistors, the power to be dissipated at the collector causes junction temperature to rise to a high level. It is possible to increase the power handling capacity of the transistor if a device that can cause rapid conduction of heat away from the junction is used. Such a device is called a heat sink. A heat sink is a mechanical device. It is connected to the case of the semiconductor device. So it is providing a path for the heat transfer. The heat flows through the heat sink and is radiated to surrounding air.

If a heat sink is not used then all the heat has to he transferred from a transistor case to surrounding air causing case temperature to increase. If the power handled by the transistor is higher, then the case temperatures will he higher. The temperature of the two types of power transistor is Germanium: 100°C to 110°C Silicon : 150°C to 200°C Heat sinks increase the power rating (ie. power handling capacity) of a transistor by getting rid of the heat developed quickly. It is in the form of a sheet of metal. Since the power dissipation within a transistor is mainly due to power dissipated at collector junction, the collector (connected to the case of the transistor) is bolted on to metal sheet for faster radiation of heat. In this case, to prevent the collector from shorting to metal sheet, a thin mica washer is used between the two. Fig shows a heat sink. The heat now radiate more quickly because of increased surface area. Sometimes the transistor is connected to a large heat sink with fins causing more efficient removal of heat from the transistor. When heat flows out of a transistor, it passes through the case transistor and into the heat sink, which then radiates the heat into the surrounding air. The temperature of the transistor case T will be slightly higher than the temperature of the heat sink which in turn is slightly higher than the ambient temperature TA. Ambient Temperature: The heat produced at the junction passed through the transistor case (metal or plastic housing) are radiates to the surrounding air. The temperature of this air is known as the ambient temperature.


Heatsinic
Power Transistor

UNIT V

Network theory, mesh and node analysis Kirchhoff's voltage and current law, Network Theorems- Thevenin's theorem, Norton's theorem, Superposition Theorem, Maximum power transfer theorem, Problems based on network theorems

NETWORK THEORY

In electrical engineering, Network Theory is the study of how to solve circuit problems. By analyzing circuits, the engineer looks to determine the various voltages can currents with exist within the network.

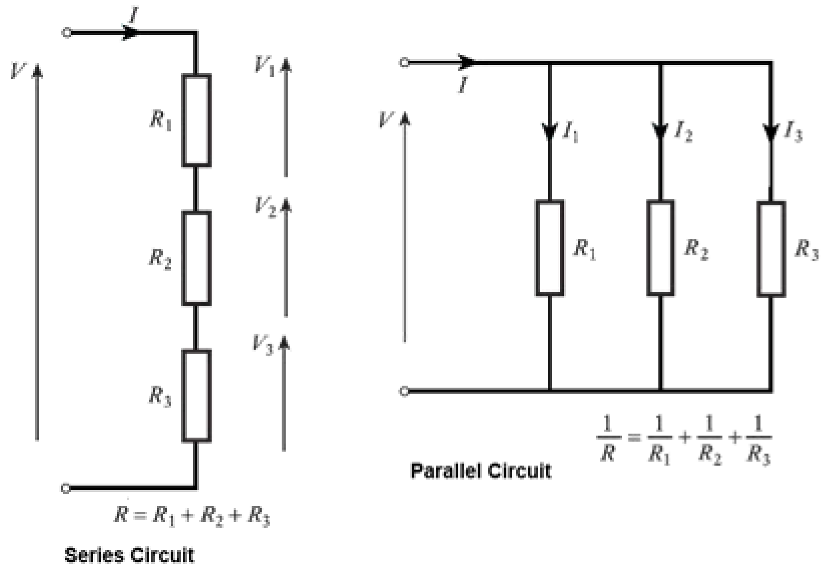
When looking at solving any circuit, a number of methods and theories exist to assist and simplify the process. This post briefly lists some of the more common network theories. Typically in network theory, we deal with linear and passive elements – most commonly:

- resistors add resistance, R to a circuit. The inverse of resistance (1/R) is the conductance, G.
- capacitors add capacitance, C to a circuit.
- inductors add inductance, L to a circuit.
- reactance, X is a product of having capacitance or inductance in an alternating current (ac) circuit. The inverse of reactance (1/X) is the susceptance, B.
- impedance, Z is the combination of resistance and reactance in an ac circuit. The invers of impedance (1/Z) is the admittance, Y.
- voltage source is a source of voltage within the circuit. An ideal voltage source contains no internal series resistance.
- current source is a source of current within a circuit. An ideal current source contains no internal parallel resistance.

Series and Parallel Circuits

The connecting of elements in series or parallel is probably the most basic type of network. In a series circuit the total resistance (or impedance) is the sum or resistances (or impedances). In a parallel the inverse of the total resistance (or impedance) is the sum of the inverses.

The voltage in a series circuit is the sum of voltages across each element, while the current is the same through each element. In a parallel circuit the voltage is the same across each element, whilst the current is inversely proportional to the resistance (or impedance) of each circuit.



Inductors follow the same law as resistors. That is in series the total inductance is the sum of individual inductances, while in parallel the inverse of the total is the sum of the inverses.

Capacitors are the opposite. In a series circuit the inverse of total capacitance is the sum of the inverses for each individual capacitor. For a parallel circuit the total capacitance is the sum of the individual capacitances.

MESH AND NODE ANALYSIS:

In electric circuits analysis, nodal analysis, node-voltage analysis, or the branch current method is a method of determining the voltage (potential difference) between "nodes" (points where elements or branches connect) in an electrical circuit in terms of the branch currents.

In analyzing a circuit using Kirchhoff's circuit laws, one can either do nodal analysis using Kirchhoff's current law (KCL) or mesh analysis using Kirchhoff's voltage law (KVL). Nodal analysis writes an equation at each electrical node, requiring that the branch currents incident at a node must sum to zero. The branch currents are written in terms of the circuit node voltages. As a consequence, each branch constitutive relation must give current as a function of voltage; an admittance representation. For instance, for a resistor, $I_{branch} = V_{branch} * G$, where G (=1/R) is the admittance (conductance) of the resistor.

Nodal analysis is possible when all the circuit elements' branch constitutive relations have an admittance representation. Nodal analysis produces a compact set of equations for the network, which can be solved by hand if small, or can be quickly solved using linear algebra by computer. Because of the compact system of equations, many circuit simulation programs (e.g. SPICE) use nodal analysis as a basis. When elements do not have admittance representations, a more general extension of nodal analysis, modified nodal analysis, can be used.

Method:

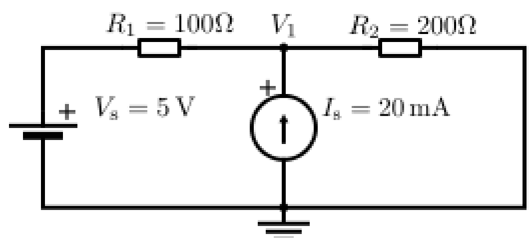
1. Note all connected wire segments in the circuit. These are the nodes of nodal analysis.
2. Select one node as the ground reference. The choice does not affect the result and is just a matter of convention. Choosing the node with the most connections can simplify the analysis. For a circuit of N nodes the number of nodal equations is N−1.
3. Assign a variable for each node whose voltage is unknown. If the voltage is already known, it is not necessary to assign a variable.
4. For each unknown voltage, form an equation based on Kirchhoff's current law. Basically, add together all currents leaving from the node and mark the sum equal to zero. Finding the current between two nodes is nothing more than "the node with the higher potential, minus the node with the lower potential, divided by the resistance between the two nodes."
5. If there are voltage sources between two unknown voltages, join the two nodes as a supernode. The currents of the two nodes are combined in a single equation, and a new equation for the voltages is formed.
6. Solve the system of simultaneous equations for each unknown voltage.

The only unknown voltage in this circuit is V_1. There are three connections to this node and consequently three currents to consider. The direction of the currents in calculations is chosen to be away from the node.

1. Current through resistor R_1: $(V_1 - V_S) / R_1$
2. Current through resistor R_2: V_1 / R_2
3. Current through current source I_S: $-I_S$

THE MESH METHOD:

The mesh method uses the mesh currents as the circuit variables. The procedure for obtaining the solution is similar to that followed in the Node method and the various steps are given below. 1. Clearly label all circuit parameters and distinguish the unknown parameters from the known. 2. Identify all meshes of the circuit. 3. Assign mesh currents and label polarities. 4. Apply KVL at each mesh and express the voltages in terms of the mesh currents. 5. Solve the resulting simultaneous equations for the mesh currents. 6. Now that the mesh currents are known, the voltages may be obtained from Ohm's law. A mesh is defined as a loop which does not contain any other loops. Our circuit example has three loops but only two meshes as shown on Figure 9. Note that we have assigned a ground potential to a certain part of the circuit. Since the definition of ground potential is fundamental in understanding circuits this is a good practice and thus will continue to designate a reference (ground) potential as we continue to design and analyze circuits regardless of the method used in the analysis. R1 R2 R3 R4 Vs + _ mesh1 mesh2 loop Figure 9. Identification of the meshes The meshes of interest are mesh1 and mesh2. For the next step we will assign mesh currents, define current direction and voltage polarities. The direction of the mesh currents I1 and is defined in the clockwise direction as shown on Figure 10. This definition for the current direction is arbitrary but it helps if we maintain consistence in the way we define these current directions. Note that in certain parts of the mesh the branch current may be the same as the current in the mesh. The branch of the circuit containing resistor is shared by the two meshes and thus the branch current (the current flowing through) is the difference of the two mesh currents. (Note that in order to distinguish between the mesh currents and the branch I2 R2 R2 6.071, Spring 2006. Chaniotakis and Cory 11 currents by using the symbol for the mesh currents and the symbol for the branch currents.) I i R1 R2 R3 R4 Vs + _ I1 I2 mesh1 mesh2 Figure 10. Labeling mesh current direction Now let's turn our attention in labeling the voltages across the various branch elements. We choose to assign the voltage labels to be consistent with the direction of the indicated mesh currents. In the case where a certain branch is shared by two meshes as is the case in our example with the branch that contains resistor the labeling of the voltage is done for each mesh consistent with the assigned direction of the mesh current. R2 In this, our first encounter with mesh analysis let's consider the each mesh separately and apply KVL around the loop following the defined direction of the mesh current. Considering mesh1. For clarity we have separated mesh1 from the circuit on Figure 11. In doing this, care must be taken to carry all the information of the shared branches. Here we indicate the direction of mesh current I2 on the shared branch. R1 R2 Vs + _ I1 I2 mesh1 + + _ _ Figure 11. Sub-circuit for mesh1



KIRCHOFFS CIRCUIT LAW

When two or more resistors are connected together in either series, parallel or combinations of both, and that these circuits obey Ohm's Law.

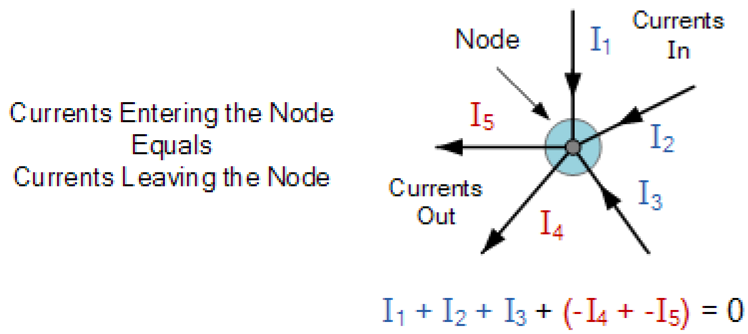
However, sometimes in complex circuits such as bridge or T networks, we cannot simply use Ohm's Law alone to find the voltages or currents circulating within the circuit. For these types of calculations we need certain rules which allow us to obtain the circuit equations and for this we can use Kirchhoff's Circuit Law.

In 1845, a German physicist, Gustav Kirchhoff developed a pair or set of rules or laws which deal with the conservation of current and energy within electrical circuits. These two rules are commonly known as: Kirchhoff's Circuit Laws with one of Kirchhoff's laws dealing with the current flowing around a closed circuit, Kirchhoff's Current Law, (KCL) while the other law deals with the voltage sources present in a closed circuit, Kirchhoff's Voltage Law, (KVL).

Kirchhoff's First Law – The Current Law, (KCL)

Kirchhoff's Current Law or KCL, states that the "total current or charge entering a junction or node is exactly equal to the charge leaving the node as it has no other place to go except to leave, as no charge is lost within the node". In other words the algebraic sum of ALL the currents entering and leaving a node must be equal to zero, $I_{(exiting)} + I_{(entering)} = 0$. This idea by Kirchhoff is commonly known as the Conservation of Charge.

Kirchhoff's Current Law



Here, the 3 currents entering the node, I_1, I_2, I_3 are all positive in value and the 2 currents leaving the node, I_4 and I_5 are negative in value. Then this means we can also rewrite the equation as;

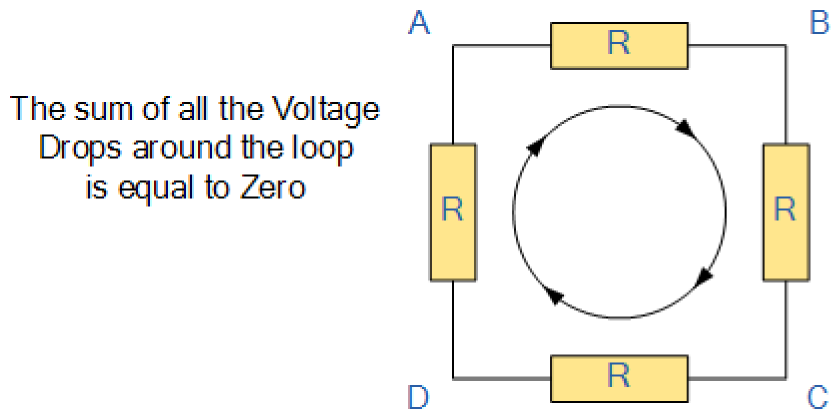
$I_1 + I_2 + I_3 - I_4 - I_5 = 0$

The term Node in an electrical circuit generally refers to a connection or junction of two or more current carrying paths or elements such as cables and components. Also for current to flow either in or out of a node a closed circuit path must exist. We can use Kirchoff's current law when analysing parallel circuits.

Kirchhoff's Second Law – The Voltage Law, (KVL)

Kirchhoff's Voltage Law or KVL, states that "in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop" which is also equal to zero. In other words the algebraic sum of all voltages within the loop must be equal to zero. This idea by Kirchhoff is known as the Conservation of Energy.

Kirchhoff's Voltage Law



$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

Starting at any point in the loop continue in the same direction noting the direction of all the voltage drops, either positive or negative, and returning back to the same starting point. It is important to maintain the same direction either clockwise or anti-clockwise or the final voltage sum will not be equal to zero. We can use Kirchhoff's voltage law when analysing series circuits.

When analysing either DC circuits or AC circuits using Kirchhoff's Circuit Laws a number of definitions and terminologies are used to describe the parts of the circuit being analysed such as: node, paths, branches, loops and meshes. These terms are used frequently in circuit analysis so it is important to understand them.

Common DC Circuit Theory Terms:

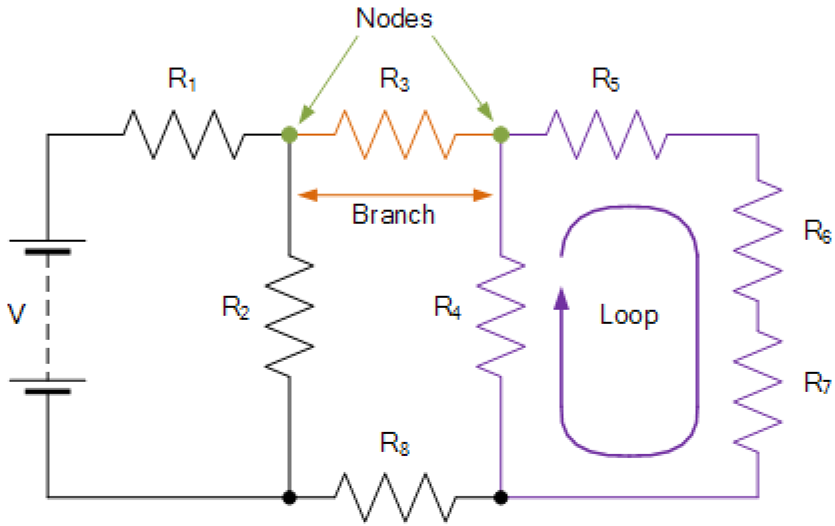
- Circuit – a circuit is a closed loop conducting path in which an electrical current flows.
- Path – a single line of connecting elements or sources.
- Node – a node is a junction, connection or terminal within a circuit were two or more circuit elements are connected or joined together giving a connection point between two or more branches. A node is indicated by a dot.
- Branch – a branch is a single or group of components such as resistors or a source which are connected between two nodes.
- Loop – a loop is a simple closed path in a circuit in which no circuit element or node is encountered more than once.
- Mesh – a mesh is a single open loop that does not have a closed path. There are no components inside a mesh.

Note that:

Components are said to be connected together in Series if the same current value flows through all the components.

Components are said to be connected together in Parallel if they have the same voltage applied across them.

A Typical DC Circuit



Application of Kirchhoff's Circuit Laws

These two laws enable the Currents and Voltages in a circuit to be found, ie, the circuit is said to be "Analysed", and the basic procedure for using Kirchhoff's Circuit Laws is as follows:

1. Assume all voltages and resistances are given. (If not label them V1, V2,… R1, R2, etc.)
2. Label each branch with a branch current. (I1, I2, I3 etc.)
3. Find Kirchhoff's first law equations for each node.
4. Find Kirchhoff's second law equations for each of the independent loops of the circuit.
5. Use linear simultaneous equations as required to find the unknown currents.

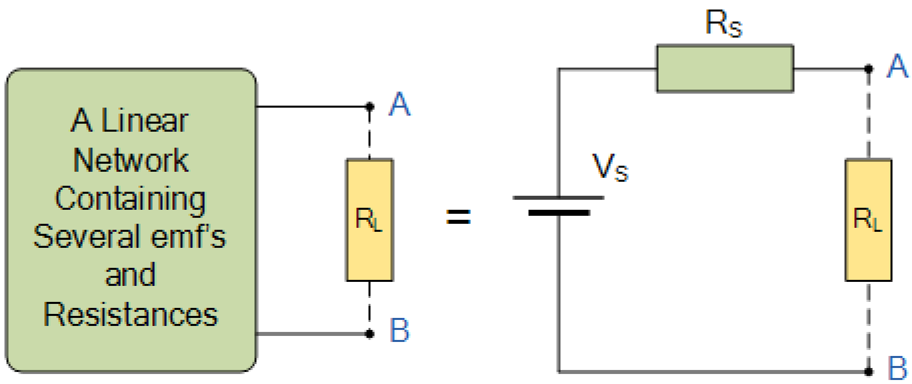
As well as using Kirchhoff's Circuit Law to calculate the various voltages and currents circulating around a linear circuit, we can also use loop analysis to calculate the currents in each independent loop which helps to reduce the amount of mathematics required by using just Kirchhoff's laws. In the next tutorial about DC circuits, we will look at Mesh Current Analysis to do just that.

THEVENIN'S THEOREM

Thevenin's Theorem states that "Any linear circuit containing several voltages and resistances can be replaced by just one single voltage in series with a single resistance connected across the load". In other words, it is possible to simplify any electrical circuit, no matter how complex, to an equivalent two-terminal circuit with just a single constant voltage source in series with a resistance (or impedance) connected to a load as shown below.

Thevenin's Theorem is especially useful in the circuit analysis of power or battery systems and other interconnected resistive circuits where it will have an effect on the adjoining part of the circuit.

Thevenin's equivalent circuit



As far as the load resistor R_L is concerned, any complex "one-port" network consisting of multiple resistive circuit elements and energy sources can be replaced by one single equivalent resistance Rs and one single equivalent voltage Vs. Rs is the source resistance value looking back into the circuit and Vs is the open circuit voltage at the terminals.

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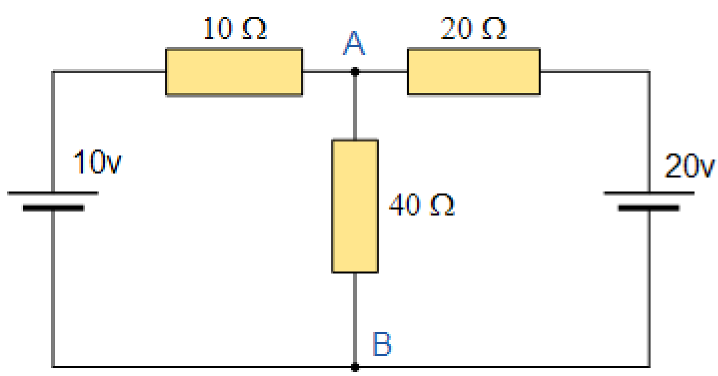
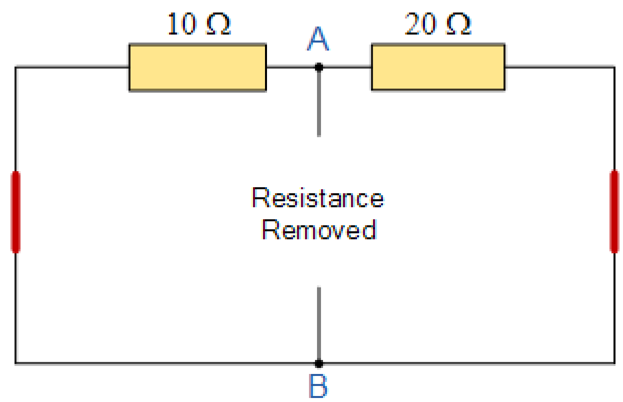


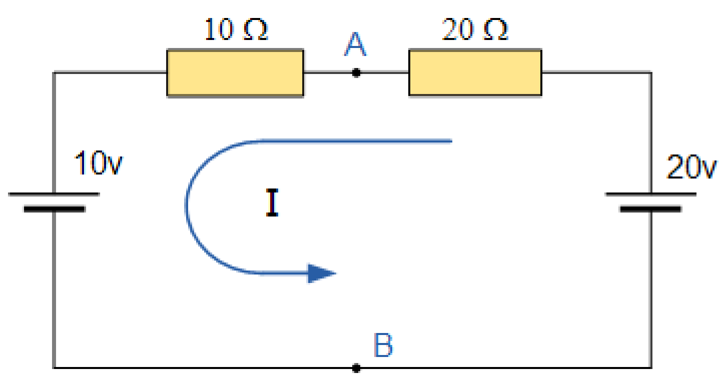
Firstly, to analyse the circuit we have to remove the centre 40Ω load resistor connected across the terminals A-B, and remove any internal resistance associated with the voltage source(s). This is done by shorting out all the voltage sources connected to the circuit, that is v = 0, or open circuit any connected current sources making i = 0. The reason for this is that we want to have an ideal voltage source or an ideal current source for the circuit analysis.

The value of the equivalent resistance, Rs is found by calculating the total resistance looking back from the terminals A and B with all the voltage sources shorted. We then get the following circuit.



The voltage Vs is defined as the total voltage across the terminals A and B when there is an open circuit between them. That is without the load resistor R_L connected.

Find the Equivalent Voltage (Vs)



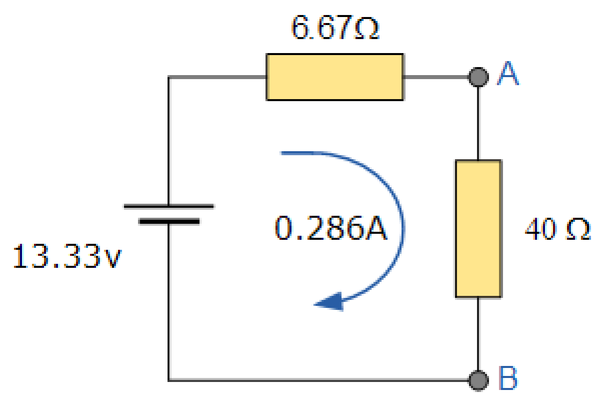
We now need to reconnect the two voltages back into the circuit, and as $V_S = V_{AB}$ the current flowing around the loop is calculated as:

$$I = \frac{V}{R} = \frac{20v - 10v}{20\Omega + 10\Omega} = 0.33\ amps$$

This current of 0.33 amperes (330mA) is common to both resistors so the voltage drop across the 20Ω resistor or the 10Ω resistor can be calculated as:

V_{AB} = 20 – (20Ω x 0.33amps) = 13.33 volts.
or
V_{AB} = 10 + (10Ω x 0.33amps) = 13.33 volts, the same.

Then the Thevenin's Equivalent circuit would consist or a series resistance of 6.67Ω'sand a voltage source of 13.33v. With the 40Ω resistor connected back into the circuit we get:



and from this the current flowing around the circuit is given as:

$$I = \frac{V}{R} = \frac{13.33v}{6.67\Omega + 40\Omega} = 0.286\ amps$$

which again, is the same value of 0.286 amps, we found using Kirchhoff's circuit law in the previous circuit analysis tutorial.

Thevenin's theorem can be used as another type of circuit analysis method and is particularly useful in the analysis of complicated circuits consisting of one or more voltage or current source and resistors that are arranged in the usual parallel and series connections.

While Thevenin's circuit theorem can be described mathematically in terms of current and voltage, it is not as powerful as Mesh or Nodal analysis in larger networks because the use of Mesh or Nodal analysis is usually necessary in any Thevenin exercise, so it might as well be used from the start. However, Thevenin's equivalent circuits of Transistors, Voltage Sources such as batteries etc, are very useful in circuit design.

Thevenin's theorem is another type of circuit analysis tool that can be used to reduce any complicated electrical network into a simple circuit consisting of a single voltage source, Vs in series with a single resistor, Rs.

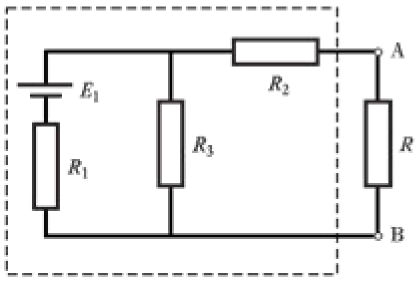
When looking back from terminals A and B, this single circuit behaves in exactly the same way electrically as the complex circuit it replaces. That is the i-v relationships at terminals A-B are identical.

The basic procedure for solving a circuit using Thevenin's Theorem is as follows:

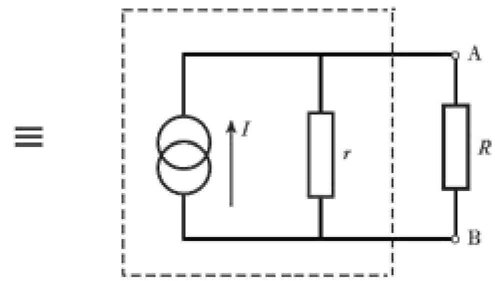
1. Remove the load resistor R_L or component concerned.
2. Find R_S by shorting all voltage sources or by open circuiting all the current sources.
3. Find V_S by the usual circuit analysis methods.
4. Find the current flowing through the load resistor R_L.

NORTON'S THEOREM

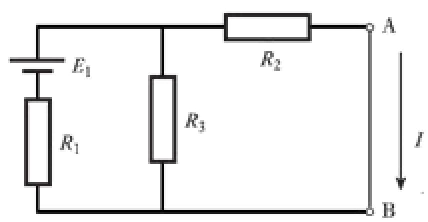
Norton's theorem states that any combination of network elements can be represented by a single current source and parallel resistor. The equivalent current is calculated by having the branch short circuited; while the resistor is calculated by having any voltage sources short circuited;



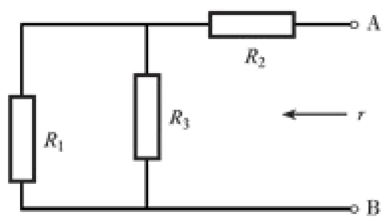
Original Network



Norton Equivalent

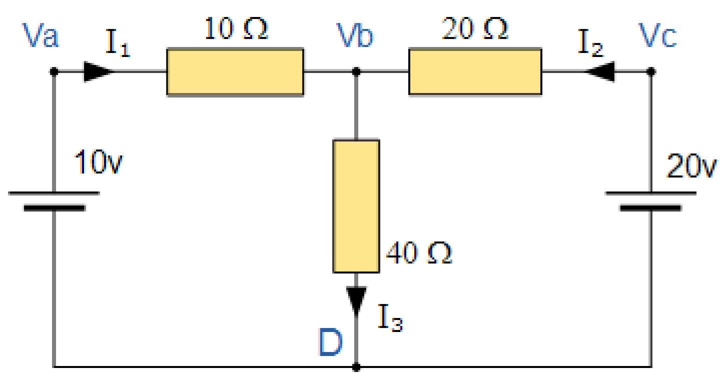


Calculation of I



Calculation of r

Nodal Voltage Analysis



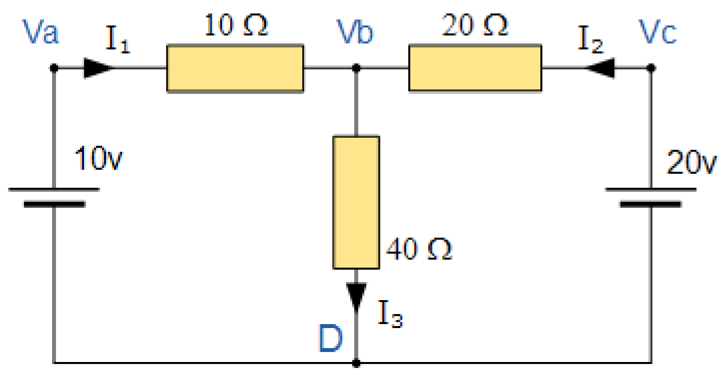
As well as using Mesh Analysis to solve the currents flowing around complex circuits it is also possible to use nodal analysis methods too. Nodal Voltage Analysis complements the previous mesh analysis in that it is equally powerful and based on the same concepts of matrix analysis. As its name implies, Nodal Voltage Analysis uses the “Nodal” equations of Kirchhoff’s first law to find the voltage potentials around the circuit.

So by adding together all these nodal voltages the net result will be equal to zero. Then, if there are “n” nodes in the circuit there will be “n-1” independent nodal equations and these alone are sufficient to describe and hence solve the circuit.

At each node point write down Kirchhoff’s first law equation, that is: “the currents entering a node are exactly equal in value to the currents leaving the node” then express each current in terms of the voltage across the branch. For “n” nodes, one node will be used as the reference node and all the other voltages will be referenced or measured with respect to this common node.

For example, consider the circuit from the previous section.

Nodal Voltage Analysis Circuit



In the above circuit, node D is chosen as the reference node and the other three nodes are assumed to have voltages, Va, Vb and Vc with respect to node D. For example;

$$\frac{(V_a - V_b)}{10} + \frac{(V_c - V_b)}{20} = \frac{V_b}{40}$$

As Va = 10v and Vc = 20v , Vb can be easily found by:

$$\left(1 - \frac{Vb}{10}\right) + \left(1 - \frac{Vb}{20}\right) = \frac{Vb}{40}$$

$$2 = Vb\left(\frac{1}{40} + \frac{1}{20} + \frac{1}{10}\right)$$

$$Vb = \frac{80}{7}V$$

$$\therefore I_3 = \frac{2}{7} \;\; or \;\; 0.286Amps$$

again is the same value of 0.286 amps, we found using Kirchhoff's Circuit Law in the previous tutorial.

From both Mesh and Nodal Analysis methods we have looked at so far, this is the simplest method of solving this particular circuit. Generally, nodal voltage analysis is more appropriate when there are a larger number of current sources around. The network is then defined as: [I] = [Y] [V] where [I] are the driving current sources, [V] are the nodal voltages to be found and [Y] is the admittance matrix of the network which operates on [V] to give [I].

The basic procedure for solving Nodal Analysis equations is as follows:

1. Write down the current vectors, assuming currents into a node are positive. ie, a (N x 1) matrices for "N" independent nodes.
2. Write the admittance matrix [Y] of the network where:
   - Y_{11} = the total admittance of the first node.
   - Y_{22} = the total admittance of the second node.
   - R_{JK} = the total admittance joining node J to node K.
3. For a network with "N" independent nodes, [Y] will be an (N x N) matrix and that Ynn will be positive and Yjk will be negative or zero value.
4. The voltage vector will be (N x L) and will list the "N" voltages to be found.

SUPERPOSITION THEOREM:

The superposition theorem for electrical circuits states that for a linear system the response (voltage or current) in any branch of a bilateral linear circuit having more than one independent source equals the algebraic sum of the responses caused by each independent source acting alone, where all the other independent sources are replaced by their internal impedances.

To ascertain the contribution of each individual source, all of the other sources first must be "turned off" (set to zero) by:

- Replacing all other independent voltage sources with a short circuit (thereby eliminating difference of potential i.e. V=0; internal impedance of ideal voltage source is zero (short circuit)).
- Replacing all other independent current sources with an open circuit (thereby eliminating current i.e. I=0; internal impedance of ideal current source is infinite (open circuit)).

This procedure is followed for each source in turn, then the resultant responses are added to determine the true operation of the circuit. The resultant circuit operation is the superposition of the various voltage and current sources.

The superposition theorem is very important in circuit analysis. It is used in converting any circuit into its Norton equivalent or Thevenin equivalent.

The theorem is applicable to linear networks (time varying or time invariant) consisting of independent sources, linear dependent sources, linear passive elements (resistors, inductors, capacitors) and linear transformers.

Superposition works for voltage and current but not power. In other words, the sum of the powers of each source with the other sources turned off is not the real consumed power. To calculate power we first use superposition to find both current and voltage of each linear element and then calculate the sum of the multiplied voltages and currents.

MAXIMUM POWER TRANSFER THEOREM

In electrical engineering, the maximum power transfer theorem states that, to obtain maximum external power from a source with a finite internal resistance, the resistance of the load must equal the resistance of the source as viewed from its output terminals. Moritz von Jacobi published the maximum power (transfer) theorem around 1840; it is also referred to as "Jacobi's law".

The theorem results in maximum power transfer, and not maximum efficiency. If the resistance of the load is made larger than the resistance of the source, then efficiency is higher, since a higher percentage of the source power is transferred to the load, but the magnitude of the load power is lower since the total circuit resistance goes up.

If the load resistance is smaller than the source resistance, then most of the power ends up being dissipated in the source, and although the total power dissipated is higher, due to a lower total resistance, it turns out that the amount dissipated in the load is reduced.

The theorem states how to choose (so as to maximize power transfer) the load resistance, once the source resistance is given. It is a common misconception to apply the theorem in the opposite scenario. It does not say how to choose the source resistance for a given load resistance. In fact, the source resistance that maximizes power transfer is always zero, regardless of the value of the load resistance.

The theorem can be extended to alternating current circuits that include reactance, and states that maximum power transfer occurs when the load impedance is equal to the complex conjugate of the source impedance.

- Maximum Power Transfer
- We have seen in the previous tutorials that any complex circuit or network can be replaced by a single energy source in series with a single internal source resistance, R_S. Generally, this source resistance or even impedance if inductors or capacitors are involved is of a fixed value in Ohm´s.
- However, when we connect a load resistance, R_L across the output terminals of the power source, the impedance of the load will vary from an open-circuit state to a short-circuit state resulting in the power being absorbed by the load becoming dependent on the impedance of the actual power source. Then for the load resistance to absorb the maximum power possible it has to be “Matched” to the impedance of the power source and this forms the basis of Maximum Power Transfer.
- The Maximum Power Transfer Theorem is another useful circuit analysis method to ensure that the maximum amount of power will be dissipated in the load resistance when the value of the load resistance is exactly equal to the resistance of the power source. The relationship between the load impedance and the internal impedance of the energy source will give the power in the load.

KARPAGAM ACADEMY OF HIGHER EDUCATION, COIMBATORE – 21
DEPARTMENT OF PHYSICS
CLASS: I M. Sc. PHYSICS BATCH: 2019 - 2020
ELECTRONIC DEVICES AND CIRCUITS (19PHP102)
MULTIPLE CHOICE QUESTIONS
QUESTIONS

UNIT I	CHOICE 1	CHOICE 2	CHOICE 3	CHOICE 4	ANSWER
A transistor has how many pn junctions?	1	2	3	4	2
In an npn transistor, the majority carriers in the emitter are	free electrons	holes	neither	both	free electrons
The barrier potential across each silicon depletion layer is	0V	0.3V	0.7V	1V	0.7V
The base of an npn transistor is thin and	Heavily doped	Lightly doped	Metallic	Doped by a pentavalent material	Lightly doped
The emitter of a transistor is generally doped the heaviest because it	has to dissipate maximum power	has to supply the charge carriers	is the first region of the transistor	must possess low resistance	has to dissipate maximum power
When a transistor is fully switched ON, it is said to be	shorted	saturated	open	cut-off	saturated
A FET consists of a	source	drain	gate	all the above	all the above
The extremely high input impedance of a MOSFET is primarily due to the	absence of its channel	negative gate-source voltage	depletion of current carriers	extremely small leakage current of its gate capacitor	extremely small leakage current of its gate capacitor
When a transistor is used as a switch, it is stable in which two distinct regions?	saturation and active	active and cutoff	saturation and cutoff	none of the above	saturation and cutoff
The term BJT is short for	base junction transistor	binary junction transistor	both junction transistor	bipolar junction transistor	bipolar junction transistor
What are the two types of bipolar junction transistors?	npn and pnp	pnn and nnp	ppn and nnp	pts and stp	npn and pnp
The magnitude of dark current in a phototransistor usually falls in what range?	mA	mA	nA	pA	nA
Junction Field Effect Transistors (JFET) contain how many diodes?	4	3	2	1	1
When not in use, MOSFET pins are kept at the same potential through the use of:	shipping foil	nonconductive foam	conductive foam	a wrist strap	conductive foam
A MOSFET has how many terminals?	2 or 3	3	4	3 or 4	3 or 4
A very simple bias for a D-MOSFET is called:	self biasing	gate biasing	zero biasing	voltage-divider biasing	zero biasing
Hybrid means	mixed	single	iunique	none of the above	mixed

There are __________ h- parameters of a transistor.	two	four	three	none of the above	four
The h- parameter approach gives correct results for	large signals only	small signals only	both small and large signals	none of the above	small signals only
If the operating point changes, the h-parameters of transistor	also change	do not change	may or may not change	none of above	also change
The dc load line on a family of collector characteristic curves of a transistor shows the	saturation region.	cutoff region.	active region.	all of the above	all of the above
A transistor data sheet usually identifies β_{DC} as	h_{re}.	h_{fe}.	I_C.	V_{CE}.	h_{fe}
When a transistor is used as a switch, it is stable in which two distinct regions?	saturation and active	active and cutoff	saturation and cutoff	none of the above	saturation and cutoff
For a silicon transistor, when a base-emitter junction is forward-biased, it has a nominal voltage drop of	0.7 V.	0.3 V.	0.2 V.	V_{CC}.	0.7 V
The value of β_{DC}	is fixed for any particular transistor.	varies with temperature.	varies with I_C.	varies with temperature and I_C.	varies with temperature and I_C.
The term BJT is short for	base junction transistor.	binary junction transistor.	both junction transistor.	bipolar junction transistor.	bipolar junction transistor
A BJT has an I_B of 50 µA and a βDC of 75; I_C is:	375 mA	37.5 mA	3.75 mA	0.375 mA	3.75 mA
A certain transistor has I_C = 15 mA and I_B = 167 µA; β_{DC} is:	15	167	0.011	90	90
For normal operation of a pnp BJT, the base must be _____ with respect to the emitter and _____ with respect to the collector.	positive, negative	positive, positive	negative, positive	negative, negative	negative, positive
A transistor amplifier has a voltage gain of 100. If the input voltage is 75 mV, the output voltage is:	1.33 V	7.5 V	13.3 V	15 V	7.5 V
A 35 mV signal is applied to the base of a properly biased transistor with an r'_e = 8 Ω and R_C = 1 kΩ. The output signal voltage at the collector is:	3.5 V	28.57 V	4.375 V	4.375 mV	4.375 V
What is the order of doping, from heavily to lightly doped, for each region?	base, collector, emitter	emitter, collector, base	emitter, base, collector	collector, emitter, base	emitter, collector, base
What are the two types of bipolar junction transistors?	npn and pnp	pnn and nnp	ppn and nnp	pts and stp	npn and pnp
Which of the following is true for an npn or pnp transistor?	$I_E = I_B + I_C$	$I_B = I_C + I_E$	$I_C = I_B + I_E$	none of the above	$I_E = I_B + I_C$
What is the ratio of I_C to I_B?	β_{DC}	h_{FE}	α_{DC}	either β_{DC} or h_{FE}, but not α_{DC}	either β_{DC} or h_{FE}, but not α_{DC}
What is the ratio of I_C to I_E?	β_{DC}	$\beta_{DC} / (\beta_{DC} + 1)$	α_{DC}	either $\beta_{DC} / (\beta_{DC} + 1)$ or α_{DC}, but not β_{DC}	either $\beta_{DC} / (\beta_{DC} + 1)$ or α_{DC}, but not β_{DC}
In what range of voltages is the transistor in the linear region of its operation?	$0 < V_{CE}$	$0.7 < V_{CE} < V_{CE(max)}$	$V_{CE(max)} > V_{CE}$	none of the above	$0.7 < V_{CE} < V_{CE(max)}$

What does DC vary with?	I_C	ºC	both I_C and ºC	$I_{C'}$, but not ºC	both I_C and ºC
What is (are) common fault(s) in a BJT-based circuit?	pens or shorts internal to the transistor	open bias resistor(s)	external opens and shorts on the circuit board	all of the above	all of the above
What is (are) general-purpose/small-signal transistors case type(s)?	TO-18	TO-92	TO-39	all of the above	all of the above
The magnitude of dark current in a phototransistor usually falls in what range?	mA	µA	nA	pA	nA
On the drain characteristic curve of a JFET for V_{GS} = 0, the pinch-off voltage is	below the ohmic area.	between the ohmic area and the constant current area.	between the constant current area and the breakdown region.	above the breakdown region.	between the ohmic area and the constant current area
For a JFET, the value of V_{DS} at which I_D becomes essentially constant is the	pinch-off voltage.	cutoff voltage.	breakdown voltage.	ohmic voltage.	pinch-off voltage
The value of V_{GS} that makes I_D approximately zero is the	pinch-off voltage.	cutoff voltage.	breakdown voltage.	ohmic voltage.	cutoff voltage
For a JFET, the change in drain current for a given change in gate-to-source voltage, with the drain-to-source voltage constant, is	breakdown.	reverse transconductance.	forward transconductance.	self-biasing.	forward transconductance
High input resistance for a JFET is due to	a metal oxide layer.	a large input resistor to the device.	an intrinsic layer.	the gate-source junction being reverse-biased.	the gate-source junction being reverse-biased
A dual-gated MOSFET is	a depletion MOSFET.	an enhancement MOSFET.	a VMOSFET.	either a depletion or an enhancement MOSFET.	either a depletion or an enhancement MOSFET
Which of the following devices has the highest input resistance?	diode	JFET	MOSFET	bipolar junction transistor	MOSFET
A self-biased n-channel JFET has a V_D = 6 V. V_{GS} = –3 V. Find the value of V_{DS}.	–3 V	–6 V	3 V	6 V	–6 V
A JFET data sheet specifies $V_{GS(off)}$ = –6 V and I_{DSS} = 8 mA. Find the value of I_D when V_{GS} = –3 V.	2 mA	4 mA	8 mA	none of the above	2 mA
A JFET data sheet specifies $V_{GS(off)}$ = –10 V and I_{DSS} = 8 mA. Find the value of I_D when V_{GS} = –3 V.	2 mA	1.4 mA	4.8 mA	3.92 mA	3.92 mA
The JFET is always operated with the gate-source pn junction _____ -biased.	forward	reverse	all of the above	none of the above	reverse
What three areas are the drain characteristics of a JFET (V_{GS} = 0) divided into?	ohmic, constant-current, breakdown	pinch-off, constant-current, avalanche	ohmic, constant-voltage, breakdown	none of the above	ohmic, constant-current, breakdown
What type(s) of gate-to-source voltage(s) can a depletion MOSFET (D-MOSFET) operate with?	zero	positive	negative	any of the above	any of the above
The _____ has a physical channel between the drain and source.	D-MOSFET	E-MOSFET	V-MOSFET	none of the above	D-MOSFET
All MOSFETs are subject to damage from electrostatic discharge (ESD).	TRUE	FALSE			TRUE
Midpoint bias for a D-MOSFET is I_D = _____, obtained by setting V_{GS} = 0.	I_{DSS} / 2	I_{DSS} / 3.4	I_{DSS}		I_{DSS}

In a self-biased JFET circuit, if $V_D = V_{DD}$ then ID = ______.	0	cannot be determined from information above			0
If V_D is less than expected (normal) for a self-biased JFET circuit, then it could be caused by a(n)	open R_G .	open gate lead.	FET internally open at gate.	all of the above	all of the above
The resistance of a JFET biased in the ohmic region is controlled by	V_D.	V_{GS}.	V_S.	V_{DS}.	
UNIT-II					
A coupling capacitor is	A dc short	An ac open	A dc open and an ac short	A dc short and an ac open	A dc open and an ac short
In a bypass circuit, the top of a capacitor is	An open	A short	An ac ground	A mechanical ground	An ac ground
The capacitor that produces an ac ground is called a	Bypass capacitor	Coupling capacitor	DC open	AC open	Bypass capacitor
The output voltage of a CE amplifier is	Amplified	Inverted	180° out of phase with the input	All of the above	All of the above
A common-gate amplifier is similar in configuration to which BJT amplifier?	common-emitter	common-collector	common-base	emitter-follower	common-base
A common-source amplifier is similar in configuration to which BJT amplifier?	common-base	common-collector	common-emitter	emitter-follower	common-emitter
An emitter-follower is also known as a	common-emitter amplifier	common-base amplifier	common-collector amplifier	Darlington pair	common-collector amplifier
When transistors are used in digital circuits they usually operate in the	active region	breakdown region	saturation and cutoff regions	linear region	saturation and cutoff regions
Which of the following elements are important in determining the gain of the system in the high-frequency region?	Interelectrode capacitances	Wiring capacitances	Miller effect capacitance	All of the above	All of the above
For audio systems, the reference level is generally accepted as _________.	1 mW	1 W	10 mW	100 mW	1 mW
What is the normalized gain expressed in dB for the cutoff frequencies?	–3 dB	+3 dB	–6 dB	–20 dB	–3 dB
Which of the following configurations does not involve the Miller effect capacitance?	Common-emitter	Common-base	Common-collector	All of the above	Common-base
When transistors are used in digital circuits they usually operate in the	Active region	Saturation and cutoff regions	Breakdown region	Linear region	Saturation and cutoff regions
A current ratio of IC/IE is usually less than one and is called	Omega	Beta	Theta	Alpha	Alpha
A transistor may be used as a switching device or as a:	Tuning device	Rectifier	Fixed resistor	Variable resistor	Variable resistor
Most of the electrons in the base of an NPN transistor flow:	Into the collector	Into the emitter	Out of the base lead	Into the base supply	Into the collector

The BJT is a ________ device. The FET is a ________ device.	Bipolar, bipolar	Bipolar, unipolar	Unipolar, bipolar	Unipolar, unipolar	Bipolar, unipolar
The Bode plot is applicable to	All phase network	Minimum phase network	Maximum phase network	Lag lead network	Minimum phase network
For any inverting amplifier, the impedance capacitance will be ________ by a Miller effect capacitance sensitive to the gain of the amplifier and the interelectrode capacitance.	Unaffected	Increased	Decreased	None of the above	Decreased
Which of the following configurations does not involve the Miller effect capacitance?	Common-emitter	Common-base	Common-collector	All of the above	Common-base
For the common-emitter amplifier ac equivalent circuit, all capacitors are	effectively shorts.	effectively open circuits.	not connected to ground.	connected to ground.	effectively shorts
For a common-emitter amplifier, the purpose of the emitter bypass capacitor is	no purpose, since it is shorted out by R_E.	to reduce noise.	to despike the supply voltage.	to maximize amplifier gain.	to maximize amplifier gain
For a common-emitter amplifier, the purpose of swamping is	to minimize gain.	to reduce the effects of r'_e	to maximize gain.	no purpose.	to reduce the effects of r'_e
An emitter-follower is also known as a	common-emitter amplifier.	common-base amplifier.	common-collector amplifier.	Darlington pair.	common-collector amplifier
In a common-base amplifier, the input signal is connected to the	base.	collector.	emitter.	output.	emitter
The differential amplifier produces outputs that are	common mode.	in-phase with the input voltages.	the sum of the two input voltages.	the difference of the two input voltages.	the difference of the two input voltages
The differential amplifier has	one input and one output.	wo inputs and two outputs	two inputs and one output.	one input and two outputs.	two inputs and two outputs
The dc emitter current of a transistor is 8 mA. What is the value of r_e?	320 Ω	13.3 kΩ	3.125 Ω	5.75 Ω	3.125 Ω
An emitter-follower amplifier has an input impedance of 107 kΩ. The input signal is 12 mV. The approximate output voltage is (common-collector)	8.92 V	112 mV	12 mV	8.9 mV	12 mV
A Darlington pair amplifier has	high input impedance and high voltage gain.	low input impedance and low voltage gain.	a voltage gain of about 1 and a low input impedance.	a low voltage gain and a high input impedance.	a low voltage gain and a high input impedance
You have a need to apply an amplifier with a very high power gain. Which of the following would you choose?	common-collector	common-base	common-emitter	emitter-follower	common-emitter
What is the most important r parameter for amplifier analysis?	r_b'	r_c'	r_e'	none of the above	r_e'
A common-emitter amplifier has _____ voltage gain, _____ current gain, _____ power gain, and _____ input impedance.	high, low, high, low	high, high, high, low	high, high, high, high	low, low, low, high	high, high, high, low
To analyze the common-emitter amplifier, what must be done to determine the dc equivalent circuit?	leave circuit unchanged	replace coupling and bypass capacitors with opens	replace coupling and bypass capacitors with shorts	replace V_{CC} with ground	replace coupling and bypass capacitors with opens
When the bypass capacitor is removed from a common-emitter amplifier, the voltage gain	increases.	decreases.	has very little effect.		decreases
A common-collector amplifier has _____ input resistance, _____ current gain, and _____ voltage gain.	high, high, low	high, low, low	high, low, high		high, high, low

A Darlington pair provides beta _____ for _____ input resistance.	multiplication, decreased	multiplication, increased	division, decreased		multiplication, increased
The total gain of a multistage amplifier is the _____.	sum of individual voltage gains	sum of dB voltage gains	none of the above		sum of dB voltage gains
What is r_e equal to in terms of *h* parameters?	h_{re} / h_{oe}	$(h_{re} + 1) / h_{oe}$	$h_{ie} – (h_{re} / h_{oe})(1 + h_{fe})$	h_{fe}	h_{re} / h_{oe}
The advantage that a Sziklai pair has over a Darlington pair is	higher current gain.	out voltage is needed to tur	higher input impedance.	higher voltage gain.	less input voltage is needed to turn it on.
What is the device in a transistor oscillator?	LC tank circuit	Biasing circuit	Transistor	Feedback circuit	Transistor
When the collector supply is 5V, then collector cut off voltage under dc condition is	20 V	10 V	2.5 V	5 V	5 V
The common base (CB) amplifier has a ______ compared to CE and CC amplifier.	Lower input resistance	Larger current gain	Larger voltage gain	Higher input resistance	Lower input resistance
When a FET with a lower transconductance is substituted into a FET amplifier circuit, what happens?	The current gain does not change	The voltage gain decreases	The circuit disamplifies	The input resistance decreases	The voltage gain decreases
At zero signal condition, a transistor sees______ load.	dc	ac	both dc and ac	resistive	dc
What is the gain of an amplifier with negative feedback if the feedback factor is 0.01?	10	1,000	100	500	100
The current gain of an emitter follower is	Equal to 1	Greater than 1	Less than 1	Zero	Less than 1
The current in any branch of a transistor amplifier that is operating is	ac only	the sum of ac and dc	the difference of ac and dc	dc only	the sum of ac and dc
An ideal differential amplifiers common mode rejection ratio is	Infinite	Zero	Unity	Undetermined	Infinite
An open fuse circuit has a resistance equal to	Zero	Unity	At least 100Ω at standard	Infinity	Infinity
What is the purpose of dc conditions in a transistor?	To reverse bias the emitter	To forward bias the emitter	To set up operating point	To turn on the transistor	To set up operating point
The ac variations at the output side of power supply circuits are called _______.	Ripples	Pulses	Waves	Filters	Ripples
What is the purpose of the emitter capacitor?	To forward bias the emitter	To reduce noise in the amplifier	To avoid drop in gain	To stabilize emitter voltage	To avoid drop in gain
A common emitter circuit is also called ________ circuit.	Grounded emitter	Grounded collector	Grounded base	Emitter follower	Grounded emitter
The output signal of a common-collector amplifier is always	Larger than the input signal	In phase with the input signal	Out of phase with the input signal	Exactly equal to the input signal	In phase with the input signal
Calculate the ripples of the filter output if a dc and ac voltmeter is used and measures the output signal from a filter circuit of 25 VDC and 1.5 V_{rms}	5%	10%	50%	6%	6%

What is the ideal maximum voltage gain of a common collector amplifier?	Unity	Infinite	Indeterminate	Zero	Unity
The output power of a transistor amplifier is more than the input power due to additional power supplied by	Transistor	Collector supply	Emitter supply	Base supply	Collector supply
When a transistor amplifier feeds a load of low resistance, its voltage gain will be	Low	Very high	High	Moderate	Low
The capacitors are considered _________ in the ac equivalent circuit of a transistor amplifier.	Open	Partially open	Short	Partially short	Short
For highest power gain, what configuration is used?	CC	CB	CE	CS	CE
What is the most important characteristic of a common collector amplifier?	High input voltage	High input resistance	High output resistance	Its being an amplifier circuit	High input resistance
Which of the item below does not describe a common emitter amplifier?	High voltage gain	High current gain	Very high power gain	High input resistance	High input resistance
CC configuration is used for impedance matching because its	Input impedance is very high	Input impedance is very low	Output impedance is very low	Output impedance is zero	Input impedance is very high
Which of the following is the other name of the output stage in an amplifier?	Load stage	Audio stage	Power stage	RF stage	Power stage
When amplifiers are cascaded	The gain of each amplifier is increased	A lower supply voltage is required	The overall gain is increased	Each amplifier has to work less	The overall gain is increased
Ina common emitter amplifier, the capacitor from emitter to ground is called the	Coupling capacitor	Bypass capacitor	Decoupling capacitor	Tuning capacitor	Bypass capacitor
A class A power amplifier uses ________ transistor(s).	Two	One	Three	Four	One
What is the maximum collector efficiency of a resistance loaded class A power amplifier?	50%	78.50%	25%	30%	25%
What is the maximum collector efficiency of a transformer coupled class A power amplifier?	30%	80%	45%	50%	50%
Class C amplifiers are used as	AF amplifiers	Small signal amplifiers	RF amplifiers	IF amplifiers	RF amplifiers
Find the voltage drop developed across a D' Arsonval meter movement having an internal resistance of 1 kΩ and a full deflection current of 150uA.	150 μV	150 mV	150 V	200 mV	150 mV
If the capacitor from emitter to ground in a common emitter amplifier is removed, the voltage gain	Increases	Decreases	Becomes erratic	Remains the same	Decreases
Comparatively, power amplifier has _______ β.	Large	Very large	Small	Very small	Small
The driver stage usually employs ________ amplifier.	Class A power	Class C	Push-pull	Class AB	Class A power
The push-pull circuit must use ______ operation.	Class A	Class B	Class C	Class AB	Class B

A complementary-symmetry amplifier has	One PNP and one NPN transistor	Two PNP transistors	Two NPN transistors	Two PNP and two NPN transistors	One PNP and one NPN transistor
Power amplifiers generally use transformer coupling because transformer coupling provides	Cooling of the circuit	Distortionless output	Impedance matching	Good frequency response	Impedance matching
The output transformer used in a power amplifier is a/an _______ transformer	1:1 ratio	Step-down	Step-up	Isolation	Step-down
UNIT III					
An emitter follower has a voltage gain that is	Much less than one	Approximately equal to one	Greater than one	Zero	Approximately equal to one
The input impedance of the base of an emitter follower is usually	Low	High	Shorted to ground	Open	High
The ac base voltage of an emitter follower is across the	Emitter diode	DC emitter resistor	Load resistor	Emitter diode and external ac emitter resistance	Emitter diode and external ac emitter resistance
The output voltage of an emitter follower is across the	Emitter diode	DC collector resistor	Load resistor	Emitter diode and external ac emitter resistance	Load resistor
The differential amplifier has	one input and one output	two inputs and two outputs	two inputs and one output	one input and two outputs	two inputs and one output
The differential amplifier produces outputs that are	common mode	in-phase with the input voltages	the sum of the two input voltages	the difference of the two input voltages	the difference of the two input voltages
Which factor does not affect CMOS loading?	Charging time associated with the output resistance of the driving	Discharging time associated with the output	Output capacitance of the load gates	Input capacitance of the load gates	Output capacitance of the load gates
Which transistor element is used in CMOS logic?	FET	MOSFET	Bipolar	Unijunction	MOSFET
A Darlington pair is used for	low distortion	high frequency range	high power gain	high current gain	high current gain
What is the effect of cascading amplifier stages?	increase in the voltage gain and increase in the bandwidth	increase in the voltage gain and reduction in the bandwidth	decrease in the voltage gain and increase in the bandwidth	increase in the voltage gain and reduction in the bandwidth	increase in the voltage gain and reduction in the bandwidth
An open-drain gate is the CMOS counterpart of ________.	an open-collector TTL gate	a tristate TTL gate	a bipolar junction transistor	an emitter-coupled logic gate	an open-collector TTL gate
Which factor does not affect CMOS loading?	Charging time associated with the output resistance of the driving	Discharging time associated with the output	Output capacitance of the load gates	Input capacitance of the load gates	Output capacitance of the load gates
The decibel gain of a cascaded amplifier equals to	product of individual gains	sum of individual gains	ration of stage gains	product of voltage and current gains	sum of individual gains
The most desirable feature of transformer coupling is its	higher voltage gain	wide frequency range	ability to provide impedance matching between stages	ability to eliminate hum from the output	ability to provide impedance matching between stages
A transformer coupled amplifier would give	maximum voltage gain	impedance matching	maximum current gain	larger bandwidth	impedance matching
One of the advantages of a Darlington pair is that it has enormous ____________ transformation capacity.	Voltage	current	impedance	power	impedance

Bootstrapping is used in emitter follower configurations to	stabilize the voltage gain against process variations	increase current gain	reduce the output resistance	increase the input resistance	increase the input resistance
Cascading amplifier stages to obtain a high gain is best done with	common emitter stages	common base stages	common collector stages	a combination of successive common base and common emitter	
Which of the following is a concern when using CMOS type devices?	mechanical shock	electrostatic discharge	fan out	under voltage	
The original CMOS line of circuits is the	5400 series	4000 series	74C00 series	74HCOO series	
Which of the following is a concern when using CMOS type devices?	mechanical shock	electrostatic discharge	fan out	under voltage	electrostatic discharge
Which of the following is not a solution to interface problems between CMOS and TTL?	pull-up resistor	pull-down resistor	level-shifter	buffer	pull-down resistor
Which of the following is not a common logic family used today?	RTL	ECL	TTL	CMOS	RTL
The output current for a LOW output is called a(n)	exit current.	sink current.	ground current.	fan-out.	sink current.
Which of the following are not characteristics of TTL logic gates?	Totem-pole output	Bipolar transistors	CMOS transistors	Multiemitter transistors	CMOS transistors
A family of logic devices designed for extremely high speed applications is called	NMOS.	ECL.	PMOS.	TTL.	ECL.
Unused inputs on TTL, AND, and NAND gates	degrade the gate's noise immunity.	if left open will have the same effect as HIGH inputs.	should be tied HIGH.	All of the above are correct.	All of the above are correct.
The lower transistor of a totem-pole output is OFF when the gate output is	HIGH.	malfunctioning.	LOW.	over driven.	HIGH.
The input transistor on a TTL circuit is unusual in that it has	multiple bases.	no collector.	no base.	multiple emitters.	multiple emitters.
The difference between VOH and VIH voltages is known as	input margin.	noise margin.	output differential.	input level.	noise margin.
Te maximum output voltage recognized as a LOW by a TTL gate is	2.0 V.	0.8 V.	2.4 V.		
The upper transistor of a totem-pole output is OFF when the gate output is	logic 1.	malfunctioning.	HIGH.	LOW.	LOW.
The major advantage of TTL logic circuits over CMOS is	lower propagation delay.	the ability to output higher voltages.	more modern design.	very low power consumption	lower propagation delay.
The maximum current for a HIGH output on a standard TTL gate is	-10 µA.	-400 µA.	-1 µA.	-10 mA.	-400 µA.
The maximum current for a LOW output on a standard TTL gate is	16 µA.	40 mA.	100 µA.	16 mA.	16 mA.
The major advantage of CMOS logic circuits over TTL is	very low power consumption	the ability to produce several output voltage levels.	lower propagation delay.	much higher propagation delay.	very low power consumption.

The abbreviated designation for input current with a LOW input is	VIH.	IIH.	IIL.	IOL.	IIL.
Fan-out for a typical TTL gate is ________.	10	4	50	100	10
In order to interface an FPGA with an external device, you must set the value of the	sink current.	external power supply.	source current.	all of the above	all of the above
The abbreviated designator for a LOW output voltage is	VOH.	VIL.	VOL.	VIH.	VOL.
The lower transistor of a totem-pole output is saturated when the gate output is	HIGH.	LOW.	malfunctioning.	over driven.	LOW.
The abbreviation TTL means	transistor-transceiver latch.	three-transistor logic.	two-transistor logic.	transistor-transistor logic.	transistor-transistor logic.
Typical TTL HIGH level output voltage is	0.3 V.	5.0 V.	3.4 V.	4.8 V.	3.4 V.
The standard 74XX TTL IC family was originally developed in the	1970s.	1960s.	1950s.	1940s.	1960s.
The minimum output voltage recognized as a HIGH by a TTL gate is	0.8 V.	2.4 V.	5.0 V.	2.0 V.	2.4 V.
An open-collector TTL gate	can sink current but cannot source current.	can source current but cannot sink current.	cannot source or sink current.	can sink more current than a standard TTL gate.	can sink current but cannot source current.
The minimum input voltage recognized as a HIGH by a TTL gate is	0.8 V.	2.4 V.	2.0 V.	5.0 V	2.0 V.
Which of the following digital IC logic families is most susceptible to static discharge?	RTL	ECL	MOS	TTL	MOS
Each input on a TTL gate is connected to the transistor's	base.	collector.	gate.	emitter.	emitter.
The time it takes for an input signal to pass through internal circuitry and generate the appropriate output effect is known as	propagation delay.	rise time.	fan-out.	fall time	propagation delay.
In a common emitter, unbypassed resister provides	voltage shunt feedback	current series feedback	Negative voltage feedback	positive current feedback	voltage shunt feedback
The bandwidth of an RF tuned amplifier is dependent on		Q –factor of the tuned i/p circuit	Quiescent operating point	Q-factor of the o/p and i/p circuits as well as quiescent operating point	Q –factor of the tuned o/p circuit
Negative feedback in an amplifier	Reduces gain	Increase frequency & phase distortion	Reduces bandwidth	Increases noise	Reduces gain
An amplifier without feedback has a voltage gain of 50, input resistance is 1 KΩ & Output resistance of 2.5KΩ.The input resistance of the current-shunt negative feedback amplifier using the above amplifier with a feedback factor of 0.2 is	1/11KΩ	1/5KΩ	5KΩ	11KΩ	1/5KΩ
The fan out of a MOS logic gate is higher than that of TTL gates because of its	Low input impedance	high output impedance	Low output impedance	High input impedance	High input impedance
Transformer coupling can be used in ___________ amplifiers	Only power	Only voltage	Either power or voltage	Neither power nor voltage	Either power or voltage

When negative current feedback is applied to an amplifier, its output impedance	increases	remains unchanged	decreases	becomes zero	increases
The quiescent current of a FET amplifier is	IDS	id	ID	Id	ID
The total decibel voltage gain of two cascaded voltage amplifier where individual voltage gains are 10 and 100 is	20	60	800	1000	60
The frequency response of the combined amplifier can be compared with	An OR gate	A negative feedback amplifier	A positive filter	An AND gate	An AND gate
Minimum interference with frequency response can be given by	Direct coupling	RC coupling	Transformer coupling	Instrumentation and control	Direct coupling
The impedance of a load must match the impedance of the amplifier so that	Minimum power is transferred to the load	The efficiency can be maintained at low level	The signal-to-noise ratio is maximized	Maximum power is transferred to the load	Maximum power is transferred to the load
The ratio output rms power in watts to the input dc power in watts in the different amplifier class is called _________.	Gain	Amplification factor	Efficiency	Phase power	Efficiency
Consider a zener diode with a slope resistance of 10 Ω in series with a 90 Ω resistor fed from a dc supply containing a ripple voltage of 20mV peak-to-peak. Compute for the ripple voltage in load	1 mV p-p	2 mV p-p	1 V p-p	6mV p-p	2 mV p-p
The ________ of a common collector configuration is unity	Voltage gain	Current gain	Power gain	Input impedance	Voltage gain
Transmit time is the time taken by the electrons on holes to pass from	Emitter to collector	Collector to emitter	Base to emitter	Base to collector	Emitter to collector
For BJT power transistors, the collector terminal is always connected to the transistor's case	for easy circuit connection.	to prevent shorts.	because the collector terminal is the critical terminal for heat	because the collector terminal is located nearest the case.	because the collector terminal is the critical terminal for heat dissipation
Quiescent power is the power dissipation of a transistor	with no signal input.	with no load.	under full load.	along the dc load line.	with no signal input
A class B amplifier operates in the linear region for	slightly more than 180° of the input cycle.	360° of the input cycle.	slightly less than 180° of the input cycle.	much less than 180° of the input cycle.	slightly less than 180° of the input cycle
In a class AB amplifier, if the V_{BE} drops are not matched to the diode drops or if the diodes are not in thermal equilibrium with the transistors, this can result in	a current mirror.	diode separation.	crossover distortion.	thermal runaway.	thermal runaway
Which amplifier is commonly used as a frequency multiplier?	class A	class B	class C	all of the above	class C
The least efficient amplifier among all classes is	class B.	class A.	class AB.	class C.	class B
A class A amplifier has a voltage gain of 30 and a current gain of 25. What is the power gain?	30	25	1.2	750	750
You have an application for a power amplifier to operate on FM radio frequencies. The most likely choice would be a _____ amplifier.	class A	class B	class C	class AB	class C
A class A amplifier with R_C = 3.3 kΩ and R_E = 1.2 kΩ has a V_{CC} = 20 V. Find $I_{C(sat)}$.	4.4 mA	6.1 mA	16.7 mA	20 mA	4.4 mA
A class C amplifier has a tank circuit in the output. The amplifier is conducting only 28°. The output voltage is	0 V.	a dc value equal to V_{CC}.	a sine wave.	a square wave with a frequency determined by the tank.	a sine wave.

In practice, the efficiency of a capacitively coupled class A amplifier is about _____%.	25	40	70	10	10
The Q-point is at cutoff for class _____ operation.	A	B	C	AB	B
Class _____ amplifiers are normally operated in a push-pull configuration in order to produce an output that is a replica of the input.	A	B	C	AB	AB
The maximum efficiency of a class B amplifier is _____ percent.	50	25	70	79	79
A class _____ amplifier is biased slightly above cutoff and operates in the linear region for slightly more than 180º of the input cycle.	A	B	C	AB	AB
Which class of amplifier operates in the linear region for only a small part of the input cycle?	A	B	C	AB	C
The principal advantage(s) of MOSFETs over BJTs is (are)	their biasing networks are simpler.	their drive requirements are simpler.	they can be connected in parallel for added drive capability.	all of the above	all of the above
The principal advantage(s) of BJTs over MOSFETs is (are) that	voltage drop across the transistor is important.	they are not as prone to ESD.	both of the above	none of the above	both of the above
The class _____ amplifier is biased below cutoff.	A	AB	B	C	B
UNIT-IV					
For Class-B operation, the collector current flows for	The whole cycle	Half the cycle	Less than half a cycle	Less than a quarter of a cycle	Half the cycle
Transformer coupling is an example of	Direct coupling	AC coupling	DC coupling	Impedance coupling	AC coupling
Class-C amplifiers are almost always	Transformer-coupled between stages	Operated at audio frequencies	Tuned RF amplifiers	Wideband	Tuned RF amplifiers
Heat sinks reduce the	Transistor power	Ambient temperature	Junction temperature	Collector current	Junction temperature
Which type of power amplifier is biased for operation at less than 180º of the cycle?	Class A	Class B or AB	Class C	Class D	Class C
What is the maximum efficiency of a class A circuit with a direct or series-fed load connection?	90%	78.50%	50%	25%	25%
The Q-point is at cutoff for class ________ operation.	A	B	C	AB	B
Which of the following is (are) power amplifiers?	Class A	Class B or AB	Class C or D	All of the above	All of the above
The output of a class-B amplifier	is distortion free	consists of positive half cycle only	is like the output of a full wave rectifier	comprises short duration current pulses	consists of positive half cycle only
Crossover distortion occurs in _________ amplifiers.	push-pull	class A	class B	class AB	push-pull

The main use of a class C amplifier is	as an RF amplifier	as stereo amplifier	in communication sound equipment	as distortion generator	as an RF amplifier
The decibel is a measure of	power	voltage	current	sound level	sound level
The output stage of a multistage amplifier is also called	Mixer stage	Power stage	Detector stage	F stage	Power stage
___________ coupling is generally employed in power amplifiers	Transformer	RC	direct	Impedance	Transformer
The maximum efficiency of resistance loaded class A power amplifier is	5%	50%	30%	25%	25%
Class ________ power amplifier has the highest collector efficiency	C	A	B	AB	B
Power amplifiers handle ________ signals compare to voltage amplifiers.	Small	Very small	Large	None of the above	Large
In class B operation, at what fraction of VCC should the level of VL(p) be to achieve the maximum power dissipated by the output transistor?	0.5	0.636	0.707	1	0.636
In class A operation, the operating point is generally located _______ of the d.c. load line.	At cut off point	At the middle	At saturation point	None of the above	At the middle
The output transformer used in a power amplifier is a _________ transformer.	1:1 ratio	Step-up	Step-down	None of the above	Step-down
For BJT power transistors, the collector terminal is always connected to the transistor's case	for easy circuit connection.	to prevent shorts.	because the collector terminal is the critical terminal for heat	because the collector terminal is located nearest the case.	because the collector terminal is the critical terminal for heat dissipation
Quiescent power is the power dissipation of a transistor	with no signal input.	with no load.	under full load.	along the dc load line.	with no signal input
A class B amplifier operates in the linear region for	slightly more than 180° of the input cycle.	360° of the input cycle.	slightly less than 180° of the input cycle.	much less than 180° of the input cycle.	slightly less than 180° of the input cycle
In a class AB amplifier, if the V_{BE} drops are not matched to the diode drops or if the diodes are not in thermal equilibrium with the transistors, this can result in	a current mirror.	diode separation.	crossover distortion.	thermal runaway.	thermal runaway
Which amplifier is commonly used as a frequency multiplier?	class A	class B	class C	all of the above	class C
The least efficient amplifier among all classes is	class B.	class A.	class AB.	class C.	class B
A class A amplifier has a voltage gain of 30 and a current gain of 25. What is the power gain?	30	25	1.2	750	750
You have an application for a power amplifier to operate on FM radio frequencies. The most likely choice would be a _____ amplifier.	class A	class B	class C	class AB	class C
A class A amplifier with R_C = 3.3 kΩ and R_E = 1.2 kΩ has a V_{CC} = 20 V. Find $I_{C(sat)}$.	4.4 mA	6.1 mA	16.7 mA	20 mA	4.4 mA
A class C amplifier has a tank circuit in the output. The amplifier is conducting only 28°. The output voltage is	0 V.	a dc value equal to V_{CC}.	a sine wave.	a square wave with a frequency determined by the tank.	a sine wave.

In practice, the efficiency of a capacitively coupled class A amplifier is about _____%.	25	40	70	10	10
The Q-point is at cutoff for class _____ operation.	A	B	C	AB	B
Class _____ amplifiers are normally operated in a push-pull configuration in order to produce an output that is a replica of the input.	A	B	C	AB	AB
The maximum efficiency of a class B amplifier is _____ percent.	50	25	70	79	79
A class _____ amplifier is biased slightly above cutoff and operates in the linear region for slightly more than 180º of the input cycle.	A	B	C	AB	AB
Which class of amplifier operates in the linear region for only a small part of the input cycle?	A	B	C	AB	C
The principal advantage(s) of MOSFETs over BJTs is (are)	their biasing networks are simpler.	their drive requirements are simpler.	they can be connected in parallel for added drive capability.	all of the above	all of the above
The principal advantage(s) of BJTs over MOSFETs is (are) that	voltage drop across the transistor is important.	they are not as prone to ESD.	both of the above	none of the above	both of the above
The class _____ amplifier is biased below cutoff.	A	AB	B	C	B
Power amplifiers primarily provide sufficient power to an output load, typically from _____ to _____.	a few kW, tens of kW	500 W, 1 kW	100 W, 500 W	a few W, tens of W	a few W, tens of W
The main feature(s) of a large-signal amplifier is (are) the _____.	circuit's power efficiency	maximum amount of power that the circuit is capable of	impedance matching to the output	All of the above	All of the above
In _____ power amplifiers, the output signal varies for a full 360º of the cycle.	class A	class B or AB	class C	class D	class A
In class B power amplifiers, the output signal varies for _____ of the cycle.	360º	180º	between 180º and 360º	less than 180º	180º
_____ amplifiers have the highest overall efficiency.	Class A	Class B or AB	Class C	Class D	Class D
Class D operation can achieve power efficiency of over _____.	90%	78.50%	50%	25%	90%
The beta of a power transistor is generally _____.	more than 200	100 to 200	less than 100	0	less than 100
A form of class A amplifier having maximum efficiency of _____ uses a transformer to couple the output signal to the load.	90%	78.50%	50%	25%	50%
The reflected impedance seen from one side of the transformer to the other side is _____.	N_1/N_2	$(N_1/N_2)^2$	$(N_1/N_2)^{1/3}$	$N_1 \times N_2$	$(N_1/N_2)^2$
In a class A transformer-coupled power amplifier, _____ winding resistance of the transformer determine(s) the dc load line for the circuit.	the ac	the dc	both the ac and dc	neither the ac nor dc	the dc
The slope of the ac load line in the class A transformer-coupled transistor is _____.	$-1/R_L$ (load resistor)	$1/(a^2R_L)$	$-1/(a^2R_L)$	$1/R_L$	$-1/(a^2R_L)$

The amount of power dissipated by the transistor is the _____ of that drawn from the dc supply (set by the bias point) and the amount delivered to the ac load.	product	difference	average		difference
A class A amplifier dissipates _____ power when the load is drawing maximum power from the circuit.	the least	about the same	the most	None of the above	the least
In a class A transformer-coupled amplifier, the _____ the value of V_{CEmax} and the _____ the value of V_{CEmin}, the _____ the efficiency to (from) the theoretical limit of 50%.	larger, smaller, farther	larger, smaller, closer	smaller, larger, closer	None of the above	larger, smaller, closer
In class B operation, the current drawn from a single power supply has the form of _____ rectified signal.	a full-wave	a half-wave	both a full-wave and a half-wave	None of the above	a full-wave
The highest efficiency is obtained in class B operation when the level of $V_L(p)$ is equal to _____.	$0.25V_{CC}$	$0.50V_{CC}$	V_{CC}	$2V_{CC}$	V_{CC}
_____ transistors can be used to build a class B amplifier.	npn and pnp	nMOS and pMOS	Both npn and pnp or nMOS and pMOS	None of the above	Both npn and pnp or nMOS and pMOS
The complementary Darlington-connected transistor for a class B amplifier provides _____ output current and _____ output resistance.	higher, higher	higher, lower	lower, lower	lower, higher	higher, lower
The fundamental component is typically _____ any harmonic component.	larger than	the same as	smaller than	None of the above	larger than
In Fourier technique, any periodic distorted waveform can be represented by _____ the fundamental and all harmonic components.	multiplying	subtracting	dividing	adding	adding
Improvement in production techniques of power transistors have _____.	produced higher power ratings in small-sized packaging	increased the maximum transistor breakdown voltage	provided faster-switching power transistors	All of the above	All of the above
The greater the power handled by the power transistor, _____ the case temperature.	the higher	the lower	there is no change in	None of the above	the higher
The _____ has the hottest temperature in a power transistor.	heat sink	case	junction	None of the above	junction
A heat sink provides _____ thermal resistance between case and air.	a high	a low	the same	None of the above	a low
A _____ power amplifier is limited to use at one fixed frequency.	class A	class B or AB	class C	class D	class C
Which of the following is (are) power amplifiers?	Class A	Class B or AB	Class C or D	All of the above	All of the above
By how much does the output signal vary for a class AB power amplifier?	360º	180º	Between 180º and 360º	Less than 180º	Between 180º and 360º
Which type of power amplifier is biased for operation at less than 180º of the cycle?	Class A	Class B or AB	Class C	Class D	Class C
Which type of amplifier uses pulse (digital) signals in its operation?	Class A	Class B or AB	Class C	Class D	Class D
Which of the power amplifiers has the lowest overall efficiency?	Class A	Class B or AB	Class C	Class D	Class A
Which of the following describe(s) a power amplifier?	It can handle large power.	It can handle large current	It does not provide much voltage gain.	All of the above	All of the above

_____ amplifiers primarily provide sufficient power to an output load to drive a speaker from a few watts to tens of watts.	Small-signal	Power	None of the above	All of the above	Power
The main features of a large-signal amplifier is the circuit's _______.	power efficiency	naximum power limitation	ance matching to the output	All of the above	All of the above
Class AB operation is _____ operation.	similar to class A	similar to class B	similar to class C	d. None of the above	None of the above
Which operation class is generally used in radio or communications?	A	B	AB	C	Class C
Categorize the power efficiency of each class of amplifier, from worst to best.	A, B, AB, D	A, AB, D, B	A, AB, B, D		A, AB, B, D
What is the maximum efficiency of a class A circuit with a direct or series-fed load connection?	90%	78.50%	50%	25%	25%
What is the ratio of the secondary voltage to the primary voltage with the turn ratio in the winding	N_2/N_1	$(N_1/N_2)2$	$(N_1/N_2)1/3$	$N_1 \times N_2$	N_2/N_1
Calculate the effective resistance seen looking into the primary of a 20:1 transformer connected to an 8- Ω load.	3.2 kΩ	3.0 kΩ	2.8 kΩ	1.8 kΩ	3.2 kΩ
What transformer turns ratio is required to match an 8-speaker load so that the effective load resistance seen at the primary is 12.8 k?	20:01	40:01:00	50:01:00	60:01:00	40:01:00
Calculate the efficiency of a transformer-coupled class A amplifier for a supply of 15 V and an output of V(p) = 10 V.	25%	33.30%	50%	78.50%	33.30%
The maximum efficiency of a transformer-coupled class A amplifier is _____.	a. 25%	b. 50%	c. 78.5%	d. 63.6%	50%
What is the maximum efficiency of a class B circuit?	a. 90%	b. 78.5%	c. 50%	d. 25%	78.50%
How many transistors must be used in a class B power amplifier to obtain the output for the full cycle of the signal?	0	1	2	3	2
In class B operation, at what fraction of V_{CC} should the level of $V_L(p)$ be to achieve the maximum power dissipated by the output transistor?	0.5	0.636	0.707	1	0.636
Class B operation is provided when the dc bias leaves the transistor biased just off, the transistor turning on when the ac signal is applied.	TRUE	FALSE			TRUE
Calculate the efficiency of a class B amplifier for a supply voltage of V_{CC} = 20 V with peak output voltage of $V_L(p)$ = 18 V. Assume R_L = 16 Ω.	78.54%	75%	70.69%	50%	70.69%
Which of the following is (are) the disadvantage(s) of a class B complementary-symmetry circuit?	eds two separate voltage sou	ssover distortion in the ou	f one transistor off and the o	All of the above	All of the above
Which of the push-pull amplifiers is presently the most popular form of the class B power amplifier?	Quasi-complementary	Transformer-coupled	Complementary-symmetry	None of the above	Quasi-complementary
nMOS and pMOS transistors can be used for class B.	TRUE	FALSE			TRUE
Calculate the harmonic distortion component for an output signal having fundamental amplitude of 3 V and a second harmonic amplitude of 0.25 V.	a. 3.83%	b. 38.3%	c. 83.3%	d. 8.33%	8.33%

Which of the following instruments displays the harmonics of a distorted signal?	Digital multimeter	Spectrum analyzer	Oscilloscope	Wave analyzer	Spectrum analyzer
Which of the following instruments allows more precise measurement of the harmonic components of a distorted signal?	a. Digital multimeter	b. Spectrum analyzer	c. Oscilloscope	d. Wave analyzer	Wave analyzer
What is the maximum temperature rating for silicon power transistors?	50º to 80º	100º to 110º	150º to 200º	250º to 300º	150º to 200º
Which of the power amplifiers is not intended primarily for large-signal or power amplification?	Class A	Class B or AB	Class C	Class D	Class C
Determine what maximum dissipation will be allowed for a 70-W silicon transistor (rated at 25ºC) if derating is required above 25ºC by a derating factor of 0.6 W/ºC at a case temperature of 100º.	25 W	30 W	35 W	40 W	25 W
A silicon power transistor is operated with a heat sink (θ_{SA} = 1.5ºC/W). The transistor, rated at 150 W (25ºC), has θ_{JC} = 0.5º C/W, and the mounting insulation has θ_{CS} = 0.6 ºC/W. What is the maximum power that can be dissipated if the ambient temperature is 50ºC and T_{Jmax} = 200 ºC?	61.5 W	60.0 W	57.7 W	55.5 W	57.7 W
Which of the following transistors has been quite popular as the driver device for class D amplification?	BJT	FET	UJT	MOSFET	MOSFET
UNIT V					
Kirchhoff's Voltage Law states that the total voltage around a closed loop must be	0	½	1	2	0
The algebraic sum of _______ in a network of conductors meeting at a point is zero.	Voltages	currents	Resistances	Inductances	currents
Maximum power transfer theorem is also known as	Jacobi's law	Thompson's law	Phillips law	Jackson's law	Jacobi's law
The ________ theorem is a way to determine the currents and voltages present in a circuit that has multiple sources.	Norton	Super position	Thevenin	Maximum power transfer	Super position
The concept on which Superposition theorem is based is	reciprocity	duality	non-linearity	linearity	linearity
Kirchhoff s law is applicable to	passive networks only	a.c. circuits only	d.c. circuits only	both a.c. as well d.c. circuits	both a.c. as well d.c. circuits
For maximum transfer of power, internal resistance of the source should be	equal to load resistance	less than the load resistance	greater than the load resistance	none of the above	equal to load resistance
Kirchhoffs current law is applicable to only	junction in a network	closed loops in a network	electric circuits	electronic circuits	junction in a network
Kirchhoff's voltage law is related to	junction currents	battery emfs	IR drops	both b & c	both b & c
Superposition theorem can be applied only to circuits having	resistive elements	passive elements	non-linear elements	linear bilateral elements	linear bilateral elements
The concept on which superposition theorem is based on	reciprocity	duality	non-linearity	linearity	linearity
Which of the following is non-linear circuit parameter?	Inductance	condenser	wire wound resistor	transistor	Inductance

Node analysis can be applied for	planar networks	Non-planar networks	Both a & b	electric networks	Both a & b
Mesh analysis is applicable for	planar networks	Non-planar networks	Both a & b	electric networks	planar networks
The superposition theorem is applicable to	voltage only	current only	current and voltage	current, voltage and power	current, voltage and power
Kirchhoff's current law is applicable only to	junction in a network	closed loops in a network	electric circuits	electronic circuits	junction in a network
Maximum power output is obtained from a network when the load resistance is equal to the output resistance of the network as seen from the terminals of the load".The above statement is associated with	Millman's theorem	Thevenin's theorem	Superposition theorem	Maximum power transfer theorem	Maximum power transfer theorem
Kirchhoffs current law is applicable to only	junction in a network	closed loops in a network	electric circuits	electronic circuits	junction in a network
Superposition theorem is based on	Reciprocity	duality	non-linearity	Linearity	Linearity
The Norton current is sometimes called the	shorted-load current	open-load current	Thevenin current	Thevenin voltage	shorted-load current
Kirchhoff s current law states that	net current flow at the junction is positive	Hebraic sum of the currents meeting at the junction is zero	no curreht can leave the junction without some current entering it.	total sum of currents meeting at the junction is zero	Hebraic sum of the currents meeting at the junction is zero
According to Kirchhoffs voltage law, the algebraic sum of all IR drops and e.m.fs. in any closed loop of a network is always	negative	ositive	determined by battery e.m.fs	zero	zero
Kirchhoffs current law is applicable to only	junction in a network	closed loops in a network	electric circuits	electronic circuits	junction in a network
Kirchhoffs voltage law is related to	junction currents	battery e.m.fs.	IR drops	both (b) and (c)	both (b) and (c)
Superposition theorem can be applied only to circuits having	resistive elements	passive elements	non-linear elements	linear bilateral elements	linear bilateral elements
The concept on which Superposition theorem is based is	eciprocity	duality	non-linearity	linearity	linearity
Thevenin resistance Rth is found	by removing voltage sources along with their internal	by short-circuiting the given two terminals	between any two 'open' terminals	between same open terminals as for Etk	between same open terminals as for Etk
An ideal voltage source should have	large value of e.m.f.	small value of e.m.f.	zero source resistance	infinite source resistance	zero source resistance
For a voltage source	terminal voltage is always lower than source e.m.f.	terminal voltage cannot be higher than source e.m.f.	the source e.m.f. and terminal voltage are equal		terminal voltage cannot be higher than source e.m.f.
To determine the polarity of the voltage drop across a resistor, it is necessary to know	value of current through the resistor	direction of current through the resistor	value of resistor	e.m.fs. in the circuit	direction of current through the resistor
"Maximum power output is obtained from a network when the load resistance is equal to the output resistance of the network as seen from the terminals of the load". The above statement is associated with	Millman's theorem	Thevenin's theorem	Superposition theorem	Maximum power transfer theorem	Maximum power transfer theorem
"Any number of current sources in parallel may be replaced by a single current source whose current is the algebraic sum of individual source currents and source resistance is the parallel combination of individual source resistances". The above statement is associated with	Thevenin's theorem	Millman's theorem	Maximum power transfer theorem	None of the above	Millman's theorem

"In any linear bilateral network, if a source of e.m.f. E in any branch produces a current I in any other branch, then same e.m.f. acting in the second branch would produce the same current / in the first branch".The above statement is associated with	compensation theorem	superposition theorem	reciprocity theorem	none of the above	reciprocity theorem
Which of the following is non-linear circuit parameter ?	Inductance	Condenser	Wire wound resistor	Transistor	Inductance
A capacitor is generally a	bilateral and active component	active, passive, linear and nonlinear component	linear and bilateral component	non-linear and active component	linear and bilateral component
"In any network containing more than one sources of e.m.f. the current in any branch is the algebraic sum of a number of individual fictitious currents (the number being equal to the number of sources of e.m.f.), each of which is due to separate action of each source of e.m.f., taken in order, when the remaining sources of e.m.f. are replaced by conductors, the resistances of which are equal to the internal resistances of the respective sources". The above statement is associated with	Thevenin's theorem	Norton's theorem	Superposition theorem	None of the above	Superposition theorem
Kirchhoff s law is applicable to	passive networks only	a.c. circuits only	d.c. circuits only	both a.c. as well d.c. circuits	both a.c. as well d.c. circuits
Kirchhoff s law is not applicable to circuits with	lumped parameters	passive elements	distributed parameters	non-linear resistances	distributed parameters
Kirchhoff s voltage law applies to circuits with	nonlinear elements only	linear elements only	linear, non-linear, active and passive elements	linear, non-linear, active,passive, time varying as wells as time-in-	linear, non-linear, active, passive, time varying as wells as time-in-variant elements
The resistance LM will be	6.66 Q	12 Q	18Q	20Q	6.66 Q
For high efficiency of transfer of power, internal resistance of the source should be	equal to the load resistance	ess than the load resistanc	more than the load resistance	none of the above	less than the load resistance
Efficiency of power transfer when maximum transfer of power c xurs is	100%	80%	75%	50%	50%
If resistance across LM in Fig. 2.30 is 15 ohms, the value of R is	10 Q	20 Q	30 Q	40 Q	30 Q
For maximum transfer of power, internal resistance of the source should be	equal to load resistance	less than the load resistance	greater than the load resistance	none of the above	equal to load resistance
If the energy is supplied from a source, whose resistance is 1 ohm, to a load of 100 ohms the source will be	a voltage source	a current source	both of above	none of the above	a voltage source
The circuit whose properties are same in either direction is known as	unilateral circuit	bilateral circuit	irreversible circuit	reversible circuit	bilateral circuit
In a series parallel circuit, any two resistances in the same current path must be in	series with each other	parallel with each other	series with the voltage source.'	parallel with the voltage source	series with each other
The circuit has resistors, capacitors and semi-conductor diodes. The circuit will be known as	non-linear circuit	linear circuit	bilateral circuit	none of the above	non-linear circuit
A non-linear network does not satisfy	superposition condition	homogeneity condition	both homogeneity as well as superposition condition	homogeneity, superposition and associative condition	both homogeneity as well as superposition condition
An ideal voltage source has	zero internal resistance	open circuit voltage equal to the voltage on full load	terminal voltage in proportion to current	terminal voltage in proportion to load	zero internal resistance
A network which contains one or more than one source of e.m.f. is known as	linear network	non-linear network	passive network	active network	passive network

The superposition theorem is applicable to	linear, non-linear and time variant responses	linear and non-linear resistors only	linear responses only	none of the above	linear responses only
Which of the following is not a nonlinear element ?	Gas diode	Heater coil	Tunnel diode	Electric arc	Tunnel diode
Application of Norton's theorem to a circuit yields	equivalent current source and impedance in series	equivalent current source and impedance in parallel	equivalent impedance	equivalent current source	equivalent current source and impedance in series
Millman's theorem yields	equivalent resistance	equivalent impedance	equivalent voltage source	equivalent voltage or current source	equivalent voltage or current source
The superposition theorem is applicable to	voltage only	current only	both current and voltage	current voltage and power	current voltage and power
Between the branch voltages of a loop the Kirchhoff s voltage law imposes	non-linear constraints	linear constraints	no constraints	none of the above	linear constraints
A passive network is one which contains	only variable resistances	only some sources of e.m.f. in it	only two sources of e.m.f. in it	no source of e.m.f. in it	no source of e.m.f. in it
A terminal where three on more branches meet is known as	node	terminus	combination	anode	node
Which of the following is the passive element ?	Capacitance	Ideal current source	Ideal voltage source	All of the above	Capacitance
Which of the following is a bilateral element ?	Constant current source	Constant voltage source	Capacitance	None of the above	Capacitance
A closed path made by several branches of the network is known as	branch	loop	circuit	junction	loop
A linear resistor having 0 < R < °o is a	current controlled resistor	voltage controlled resistor	both current controlled and voltage controlled resistor	none of the above	both current controlled and voltage controlled resistor
A star circuit has element of resistance R/2. The equivalent delta elements will be	R/6	fi?	2R	4R	fi?
A delta circuit has each element of value R/2. The equivalent elements of star circuit with be	RIG	R/3	2R	3R	RIG
In Thevenin's theorem, to find Z	all independent current sources are short circuited and independent voltage sources are open circuited	all independent voltage sources are open circuited and all independent	all independent voltage and current sources are short circuited	all independent voltage sources are short circuited and all independent current sources are open circuited	all independent voltage sources are short circuited and all independent current sources are open circuited
While calculating Rth in Thevenin's theorem and Norton equivalent	all independent sources are made dead	only current sources are made dead	only voltage sources are made dead	all voltage and current sources are made dead	all independent sources are made dead
The number of independent equations to solve a network is equal to	the number of chords	the number of branches	sum of the number of branches and chords	sum of number of branches, chords and nodes	the number of chords
The superposition theorem requires as many circuits to be solved as there are	sources, nodes and meshes	sources and nodes	sources	nodes	