Forward biased diode:

An ideal diode acts like a closed switch when forward biased and an open switch when reverse biased. 1st approximation calculations assume an ideal diode. 2nd approximation calculations take into account the voltage drop across the diode. 3rd approximation calculations additionally take into account bulk resistance.

Voltage Drop  silicon diode .7V  germanium diode .3V
Bulk Resistance  $r_B = \Delta E/\Delta I$

A digital multimeter won’t measure the resistance on a diode due to insufficient voltage. The diode check function of a digital multimeter reads the knee voltage. The knee voltage is the voltage at which a forward biased diode begins to conduct.

Diode Ratings:
- PIV  Reverse Breakdown Voltage
- $I_f$  Forward Current Limit
- $I_s$  Saturation Current - minority carrier current of a reverse-biased diode
- $R_f$  Forward Resistance
- $V_k$  Knee Voltage

Light Emitting Diode When forward-biased, free electrons combine with holes near the junction. As they move from an area of higher energy to lower energy, they emit radiation. Assume 2V drop unless specified.

Schottky Diode has almost no charge storage, so can switch on and off much faster than an ordinary diode. Has metallic/silicon junction; low power handling; .25V offset voltage; used for high frequencies.

Varactor is a silicon diode optimized for its variable capacitance when reverse-biased. Used for tuning frequency-dependent equipment.

Zener Diode is designed to operate in the breakdown region; used for voltage regulation.

Avalanche Effect Reverse voltage exceeds the breakdown voltage and the minority carriers are given enough energy to dislodge valence electrons from their orbits. These free electrons then dislodge others.

Zener Effect The electric field becomes strong enough across the junction of a heavily-doped reverse-biased diode to pull valence electrons from their shells. For breakdown voltages below 5V, the Zener effect dominates, above 6V the avalanche effect dominates.

Second Approximation for a Zener Diode

$$I_z = \frac{V_{in} - V_z}{R_s + R_z}$$

$V_z$  zener voltage
$R_{z}$  zener resistance
$R_s$  source resistance

Zener Resistance is the small series resistance of a zener diode when it operates in the breakdown region.

$$\Delta V_{out} = \Delta I_z R_z$$

Half-Wave Rectifier:

$$V_{dc} = \frac{V_p}{\pi} = \frac{V_{rms} \sqrt{2}}{\pi}$$

diode reverse voltage:  $PIV = V_p$
diode forward current:  $I_{diode} = I_{dc}$

Half-Wave Rectifier With Capacitor Filter:

$$V_{dc} = V_p = V_{rms} \sqrt{2}$$

Full-Wave Rectifier:

$$V_{dc} = \frac{V_p}{\pi} = \frac{V_{rms} \sqrt{2}}{\pi}$$

diode reverse voltage:  $PIV = V_p$
diode forward current:  $I_{diode} = \frac{1}{2} I_{dc}$

V$_p$ is the voltage across the full secondary winding)

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Full-Wave Rectifier With Capacitor Filter:

\[ V_{dc} = \frac{1}{2}V_p = \frac{1}{2}V_{rms}\sqrt{2} \]

Bridge Rectifier:

- diode reverse voltage: \( PIV = V_p \)
- diode forward current: \( I_{diode} = \frac{1}{2}I_{dc} \)

Bridge Rectifier With Capacitor Filter:

Further refined to include the effect of ripple voltage:

\[ V_{dc} = V_p = V_{rms}\sqrt{2} \]
\[ V_{dc} = V_p - \frac{V_{rip}}{2} \]

Ripple Formula for a capacitor-input filter

\[ V_{rip} = \frac{I_{dc}}{fC} \]

Bias: difference in potential between base and emitter.

DC Alpha:

\( \alpha_{DC} = \frac{I_C}{I_E} \)
\( \alpha_{DC} = \frac{\beta_{DC}}{\beta_{DC} + 1} \)

DC Beta:

\( \beta_{DC} = \frac{I_C}{I_B} \) (usually 50 – 300)

The four operating regions of a transistor are saturation, active, cutoff, and breakdown.

DC and AC Load Lines, Q Point

The DC Load Line is a graph representing all possible dc operating points of the transistor for a specific load resistor. \( V_{CE} \) is the x-axis and \( I_C \) is the y-axis. The equation is \( V_{CE} = V_{CC} - I_cR_C \). The horizontal intercept will be the supply voltage \( V_{CC} \) and the vertical intercept will be the collector current when the transistor is saturated, i.e. the collector/emitter is considered a closed switch.

The Q Point is the operating point of the transistor, usually located near the middle of the DC Load Line.

AC Load Line. The Q point moves along the AC load line. Steeper than the DC load line.

AC Compliance - maximum peak to peak AC output voltage without clipping. AC Compliance is calculated by finding the smaller of the following:

- Cutoff Clipping:
  \[ PP = 2I_Cr_L \]
- Saturation Clipping:
  \[ PP = 2V_{CEQ} \]

When the Q point is centered on the DC load line, cutoff clipping occurs first because the AC load line is always steeper than the DC load line.

DC Compliance is the DC voltage range over which the transistor can operate; in other words \( V_{CC} \).

\[
\begin{align*}
I_E &= I_B + I_C \\
V_{CE} &= V_{CC} - I_Cr_C
\end{align*}
\]
Voltage Divider Bias: The Base Bias circuit above is usually impractical in linear circuits because the Q point is unpredictable due to variations in $\beta_{DC}$. The Voltage Divider Bias shown at right solves this problem. When $\beta_{DC}$ is known, $I_E$ may be calculated as:

$$I_E \equiv \frac{V_B - V_{BE}}{R_E + (R_2/R_1)/\beta_{dc}}$$

But when $R_E >> \frac{R_1 | R_2}{\beta_{dc}}$,

the equation may be reduced to: $I_E \equiv \frac{V_B - V_{BE}}{R_E}$

1) Calculate the voltage at the base
2) The emitter voltage is .7 less than the base
3) Calculate $I_E$
4) $I_C \equiv I_E$
5) Calculate voltage drop across $R_C$

When designing the voltage divider bias amplifier, the current through the voltage divider should be at least 10 times the current through the base. To center Q on the DC load line, $V_{CE}$ will be $.5V_{CC}$, $V_E$ will be about .1$V_{CC}$.

To center Q on the AC load line, use the formula:

$$I_{CQ} = \frac{V_{CC}}{R_C + R_E + r_L}$$

Other Biasing Methods:

AC Emitter Resistance of a Transistor:

$$r_e' = \frac{25mV}{I_E}$$

AC Beta: Called $\beta$ as opposed to $\beta_{dc}$ (DC Beta). Referred to as $h_{fe}$ as opposed to $h_{FE}$ for DC Beta.

CE Characteristics:
Output is out of phase with input
High voltage gain is possible
May be used with a swamping resistor to stabilize the voltage gain
In a matched load condition, $R_L = R_C$

AC Input Impedance of CE Amplifier:

$$z_{in} = R_1 | R_2 | \beta r'_e$$

Swamping Resistor
to desensitize a CE amplifier to changes in $r'_e$, a resistor $r_s$ is added between the emitter and ac ground. This stabilizes the amount of gain, but also reduces it.

Heavy Swamping
The value of $r_s$ is much larger than the value of $r'_e$:

$$A = \frac{r_s}{r'_e}$$

AC Input Voltage when a source resistor (a resistor in series with the input) is present.

AC Load Resistance, $r_s$, $r_c$, or $r_{acc}$, is the parallel combination of all AC paths from collector to ground. Remember the battery and capacitors are considered shorts.

AC Power delivered to the load (class A amplifier):

$$P_L = \frac{V_L^2}{R_L}$$

Quiescent Power Dissipation of a transistor:

$$P_{dq} = V_{CEQ} I_{CQ}$$

Efficiency of a stage:

$$\eta = P_{L(max)} \times 100\%$$

Total Current Drain is the voltage divider current plus the collector current:

$$I_{CC} = I_1 + I_{CQ}$$

Cascaded Stages Gain:

$$A = A_1 A_2 A_3$$

Cascaded Stages
The AC load resistance of one stage is affected by the impedance of the following stage:

$$r_L = R_C z_{in}$$

AC Resistance of a Diode:
where $I$ is the dc current through the diode. To a second approximation, consider the .7V drop across the diode in calculating the value $I$.

$$r_{ac} = \frac{25mV}{I}$$
CC Characteristics:
- Voltage gain < 1
- High input impedance
- AC output is in phase
- Low-distortion
- Has power gain
- Can be placed at the output of a CE amplifier to reduce output loading and thereby increase the gain.

Input Impedance (high) of a CC:

AC Voltage Gain of a CC is slightly less than 1:

\[
A = \frac{r_L}{r_e + r'_e}
\]

AC Power Gain of a CC:

\[
G = \beta \frac{r_L}{r_e + r'_e} = \beta A \approx \beta
\]

AC Output Power of a CC:

\[
P_{\text{out}} = i_e^2 r_L
\]

The Darlington Amplifier consists of cascaded CC’s for a very large increase in input impedance.

The Zener Follower is a voltage regulator circuit that offers improved load handling over the zener regulator. Voltage output is .7V less than the value of the zener diode.

CB Characteristics:
- Low input impedance
- Large voltage gain
- AC output in phase
- Useful at high frequencies
- Not as popular as CE or CC
- A differential amplifier is a CB driven by a CE

Field Effect Transistors

Metal Oxide Silicon Field Effect Transistors

Enhancement-type MOSFET

Depletion-type MOSFET

MOSFET’s do not have thermal runaway.

Gate may be positive or negative