EEE118: Electronic Devices and Circuits

Lecture XIV

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Review

- Considered several transistor switching circuits for AC including,
  - Half wave single transistor switch
  - Full wave two transistor switch
  - Bridge full wave single transistor switch
- Introduced the H-bridge as a circuit commonly used to drive electrical machines from a DC supply.
- Considered the effects of inductance in the load of a transistor switch in terms of rate of change of current and provided a diode as an alternate current pathway.
- Applied the parallel diode approach to the H bridge and considered four states of operation.

Outline

Transistors in Amplifying Applications

An Amplifier is...

an electronic component, circuit or subsystem which can accept an input signal and output it at a higher *power* level with minimal distortion.

This is different from a transformer which can only increase voltage or current at the expense of decreasing the other. Total power out is always slightly less than total power in. Amplifiers have three figures of "gain"

- Voltage Gain
- Current Gain
- Power Gain

Some more specialist types of amplifier accept an input current and produce an output voltage (transimpedance) or accept an input voltage and produce an output current (transconductance).

Gain

is the ratio of the output variable (voltage, current or power) to the input (voltage, current or power)

Input Impedance

is the ratio of the input voltage to the input current (apply Ohm's law at the input)

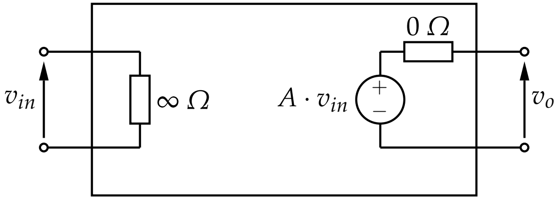
Output Impedance

is the ratio of the Output voltage to the Output current (apply Ohm's law at the output)

An amplifier must possess voltage gain and current gain in order to have power gain ($P = I\,V \ldots$).

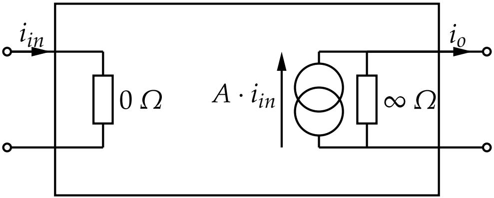
Voltage Amplifiers

- Used at low frequencies (below 30 MHz).
- Gain is $\frac{\text{output voltage}}{\text{input voltage}}$ in which case its units are $\frac{\text{volts}}{\text{volts}}$ i.e. unit-less.
- Should have infinite input impedance i.e. draw no current into its input terminals from the signal source.
- Should have zero output impedance i.e. be able to source an infinite current to the load.



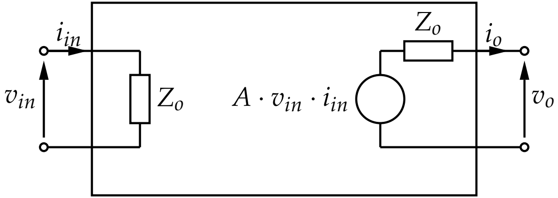
Current Amplifiers

- Used at low frequencies (below 30 MHz).
- Gain is $\frac{\text{output current}}{\text{input current}}$ in which case its units are $\frac{\text{amps}}{\text{amps}}$ i.e. unit-less.
- Should have zero input impedance i.e. can draw infinite current into its input terminals (no signal voltage at the input).
- Should have infinite output impedance i.e. be able to source an infinite voltage to the load.



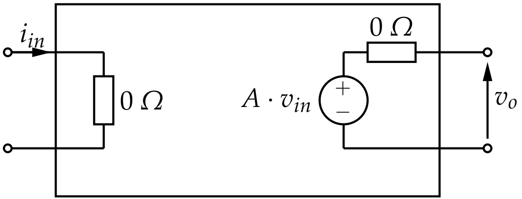
Power Amplifiers

- Used at high frequencies (above 30 MHz) in impedance matched systems where the system has a "characteristic impedance", Z_o (often 50 or 70 Ω)
- Gain is $\frac{\text{output power}}{\text{input power}}$ in which case its units are $\frac{\text{watts}}{\text{watts}}$ i.e. unit-less.
- Should have input impedance equal to Z_0.
- Should have output impedance equal to Z_0.



Transimpedance Gain

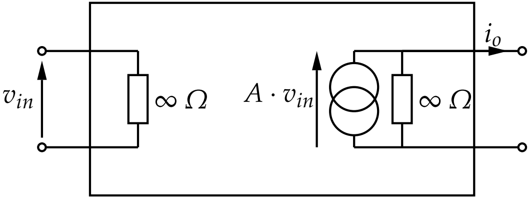
is the ratio of the output voltage to the input current, Gain is measured in Volts per Amp and therefore has the units of Ohms. Input impedance is low and output impedance is low.



This kind of amplifier is sometimes called a current to voltage converter - esp. in DAC/ADC applications. A resistor is a kind of voltage to current or current to voltage converter so it's not difficult to see why the gain of this type of amplifier should have units of Ohms.

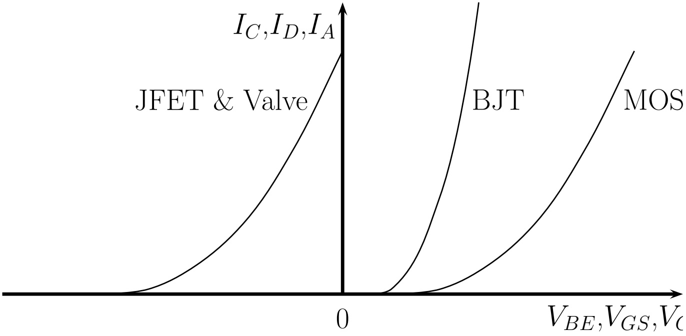
Transconductance Gain

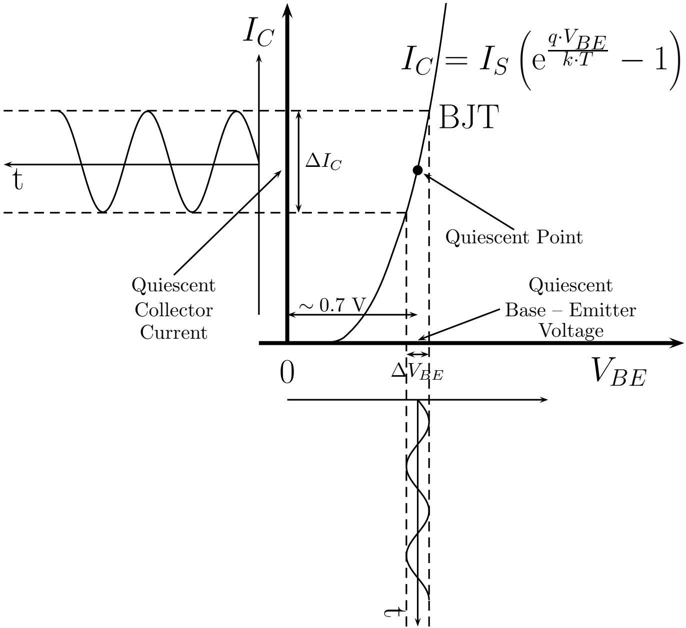
is the ratio of output current to the input voltage, there gain is measured in Amps per Volt and therefore has the units of Siemens or 1/Ohms. Input impedance is high and output impedance is high. **Transconductance is the fundamental mechanism by which transistors operate.**



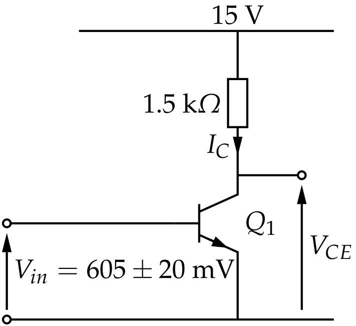
Transistors may be used to make voltage, current, power, transimpedance and transconductance amplifiers.

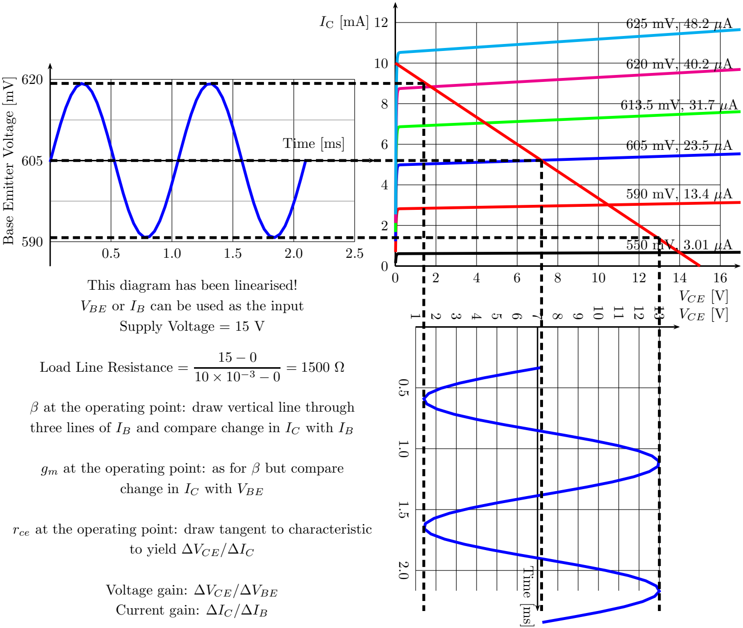
- Bipolar transistors, MOSFETs, JFETs and Valves are all modelled as transconductance devices.
- The relationship between the input voltage and output current is defined by the transconductance characteristics.
- If signals are a small change around an average or quiescent value (often zero) the amplifier will be strongly non-linear.




I_C
$I_C = I_S \left(e^{\frac{q \cdot V_{BE}}{k \cdot T}} - 1 \right)$
BJT
ΔI_C
t
Quiescent Point
Quiescent
Collector
Current
Quiescent
Base – Emitter
Voltage
~ 0.7 V
0
ΔV_{BE}
V_{BE}
t

- Prior to the invention of the BJT all amplifier stages were designed "graphically" using a copy of the characteristics, a pencil, ruler and a slide rule.
- Much can be appreciated about a stage by using the characteristics to design it, however this is not generally done for BJTs nowadays.
- Consider the circuit opposite. Ignore the necessity of biasing for now.
- We can graphically compute the small signal parameters and gain of the stage. β, g_m, r_{be}, voltage and current gain.





This diagram has been linearised!

V_{BE} or I_B can be used as the input

Supply Voltage = 15 V

$$\text{Load Line Resistance} = \frac{15-0}{10\times10^{-3}-0} = 1500\ \Omega$$

β at the operating point: draw vertical line through three lines of I_B and compare change in I_C with I_B

g_m at the operating point: as for β but compare change in I_C with V_{BE}

r_{ce} at the operating point: draw tangent to characteristic to yield $\Delta V_{CE}/\Delta I_C$

Voltage gain: $\Delta V_{CE}/\Delta V_{BE}$

Current gain: $\Delta I_C/\Delta I_B$

- A small signal voltage at the input controls a larger signal current at the output.
- To ensure reasonable linearity, the transistor must be biased to pass a constant quiescent (no signal) current.
- Signals are superimposed onto the quiescent point.
- The relationship between ΔI_C and ΔV_{BE} is called the small signal transconductance (g_m).
- Since the collector current expression is not linear g_m depends on the choice of quiescent point and on the amplitude of the signal.
- Usually it is assumed that ΔV_{BE} is sufficiently small that g_m is constant at the quiescent value i.e. the circuit is assumed linear.
- Usually, the collector current flows through a resistor, which converts the output signal current into a voltage.

An input voltage of,

$$V_{in} = V_{B_Q} \pm \frac{\Delta V_{BE}}{2} \qquad (1)$$

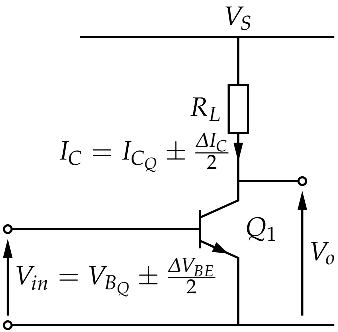
will give rise to a current change of,

$$I_C = I_{C_Q} \pm g_m \frac{\Delta V_{BE}}{2} \qquad (2)$$

note,

$$g_m = \frac{\Delta I_C}{\Delta V_{BE}} \qquad (3)$$

for a BJT.



This will give rise to a change in collector voltage of,

$$V_O = V_S - I_C R_L \qquad (4)$$

$$V_O = V_S - I_{C_Q} R_L \mp g_m R_L \frac{\Delta V_{BE}}{2} \qquad (5)$$

$$V_O = V_S - I_{C_Q} R_L \mp g_m R_L \frac{\Delta V_{BE}}{2} \tag{6}$$

$$V_O = V_{O_Q} \pm \frac{\Delta V_O}{2} \tag{7}$$

where V_{O_Q} the the quiescent output voltage, i.e.,

$$V_{O_Q} = V_S - I_{C_Q} R_L \tag{8}$$

and $\frac{\Delta V_O}{2}$ is the component of the output voltage due to the signal. i.e.

$$\frac{\Delta V_O}{2} = -g_m R_L \frac{\Delta V_{BE}}{2} \tag{9}$$

It is possible to estimate the voltgae gain of the amplifier as,

$$\Delta V_O = -g_m R_L \cdot \Delta V_{BE} \tag{10}$$

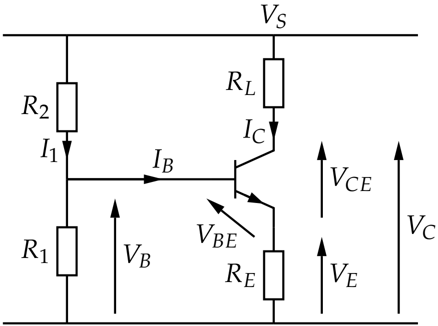
$$\frac{\Delta V_O}{\Delta V_{BE}} = -g_m R_L \tag{11}$$

Some Key Conclusions

1. Because the bias conditions V_{B_Q} and I_{C_Q} and V_{O_Q} do not appear in the gain expression, the gain of the amplifier can be found without *directly* considering the biasing conditions. Note that g_m is a function of I_{C_Q} however, so the gain is indirectly influenced by the choice of quiescent point.
2. The gain is negative. This means that the output signal is 180° out of phase with the input signal. When the input signal is increasing towards a maximum, the output signal is decreasing towards a minimum.

Point 1 allows the calculation of biasing voltages and currents (the quiescent conditions) without having to calculate what will happen to the signal voltages and currents. This is a considerable simplification.

A Tale of Two Biasing Circuits: Circuit One



Circuit 1.

Both circuits aim to control the collector current. In both cases this is achieved by the used of negative feedback.

In this circuit V_B is defined by V_S, R_1 & R_2 and is also formed from $V_E + V_{BE}$.

If V_E is large compared to any changes in V_{BE}, due to temperature or device variation for example, then V_E and therefore I_C are quite constant. Control of I_C has been taken away from the transistor and is now defined by circuit parameters (resistances) which can be easily and repeatably controlled.

Working Out the Biasing Conditions

Assume, I_B is negligible, $V_{BE} = 0.7\ V$, $h_{FE} >> 1 \therefore I_C \approx I_E$ Using potential division,

$$V_B = V_S \frac{R_2}{R_1 + R_2} \quad (12)$$

$$V_B = V_E + 0.7 \quad (13)$$

by Kirchhoff's Voltage Law,

$$V_B = V_E + V_{BE} \quad (14)$$

$$I_E \approx I_C = \frac{V_E}{R_E} = \frac{V_B - 0.7}{R_E} = \frac{1}{R_E}\left[V_S \frac{R_2}{R_1 + R_2} - 0.7\right] \quad (15)$$

also by Kirchhoff's Voltage Law,

$$V_C = V_S - I_C R_L \quad (16)$$

Review

- Introduced some terminology (gain, bias, input, output impedance).
- Introduced three ideal amplifiers in terms of their gain and input and output impedance.
- Considered what happens to signals when applied to an un-biased transistor
- Shown that biasing allows linear operation of an amplifier.
- Derived the voltage gain of a simple transistor amplifier with bias.
- Noted that the biasing terms and signal terms can be separated
- Introduced one of two biasing circuits, which operate using negative feedback, to control collector current nearly independently of device parameters and temperature.