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A simple model for the bipolar transistor using a 0.6 volt ideal diode, controlled current source, and re.

In the CE BJT, small base current controls large collector current. In the simple model, a 0.6 voltage drop across the diode is **used for low current applications, and a 0.7 volt drop across the diode is used for medium to high current applications.** The ideal diode is located between the base and emitter. Small signal input on the base is equal to the small signal output at the emitter, Ve. Output from Ve is non-inverting with unity gain minus DC offset from diode drop. Output from Vc is inverting. Current in the collector is **I*c* =** B **I*b*.** Current in the base is essentially zero. Current in the left "tuning" branch of the 4-resistor bias circuit is approximately 10 times collector current. Recall Shockley's equation: **Ie = Ies * e ^ Vbe / Vt** *where* **Vt = 26 mV** *and where* **I*es* = "saturation current" = 10 ^ -12 -> 10 ^ -17 A** (Hambley, p. 213).
The **gain** of a simple model CE BJT inverting amplifier (Vc = Vout) is ***Av* = *-Rc / Re*. Gain when re is the only emitter resistor:** Our gain is limited in a simple CE BJT circuit because we cannot make Re too small, as ***Re*** controls the ***DC feedback, as such: Vbe up -> Ve up -> Ie up -> ideal diode reverse biased/conducts less current -> Ie back down.*** To take advantage of the BJT's high gain capabilities and still keep the DC bias of the circuit stable, we **separate the AC and DC emitter resistors by** adding an RC branch "***Reac"*** parallel to the emitter resistor. When we add this branch, the gain is **Av = Rc / Re*ac* + ~~Re*dc*~~.** Re*dc* >>> Re*ac*. This means that so little current will go down the "dc" branch that **we need not consider *Redc*.** Since Re*ac* is separated completely from the DC operations and DC bias of the circuit, Re*ac* can be relatively large, and hence we can exploit the BJT's full high-gain capabilities. ***Once the separate "Reac RC branch" is added parallel to (common) emitter, gain is simplified to gain = gmRL, or, gain = [1/re] Rl.***

Transconductance (gm): Transconductance in a bipolar transistor is programmable by altering Ic, the collector current. Transconductance is often referred to as the "sensitivity" of a circuit: "for a small change in gate current, what is the change in output voltage?" Transconductance multiplied by resistance = "dimensionless gain." Hence, the units of gm are the reciprocal of resistance, or **g*m* = 1/r*e* and r*e* = 1/g*m*.** Transconductance ***gm for BJT's*** is a known industry-quantity of **g*m* = 38 * Ic. How to set gm and 1/gm for specific values: Current-controlled variable gain** is a feature of the bipolar transistor. Both gm and little re are controlled by the collector current. Set gm for a specific value using ***gm = 38 * Ic***.
"Little re" is a small internal resistance inside of the emitter, and in series with Re. Using Ohm's law: **re = Vt / Ic** where Vt = kT / q; so **little re = 26mV/ Ic**. **Little re** keeps the gain from going to infinity. **Gain when Re and re are the emitter resistors:** Recall the inverting amplifier gain equation ***Av = -Rc / Re***. If Re approaches zero, we have ***infinite gain.*** This problem is resolved by the existence of **little re**, or the internal resistance of the emitter. Hence, ***Av = - Rc / Re + re*** (inverting Vc out).

Separating the AC signal and DC circuits using DC blocking capacitors: A capacitor in series with a source behaves like a high pass filter. DC has a frequency of zero; the **DC blocking capacitor** blocks (filters out) all DC voltage ***components***. VCC is a DC Bias voltage to tune the circuit to its quiescent point and DC operating ideal characteristics. **DC blocking capacitors set frequency response:** Capacitance is set using a corner (cutoff) frequency ***w = 2 pi f.*** In a high pass filter, corner frequency is set lower than the desired frequency response; vice versa for low pass filters. A good **corner frequency** to use for high pass filter is 15.7Hz. Before capacitance is set, the **equivalent ac resistance** looking into the input, for Cin, and the equivalent ac resistance looking into the output, for Cout, must be calculated. Generally the **equivalent resistance** looking into the input is R1 || R2 || B Re, and this Req << lowest R in this equation. Equivalent resistance looking into the output is just Rc. Recall that = B 100.
Calculating capacitance is ***w = 1 / RC;*** to calculate Cin, R is equivalent ac resistance looking in; to calculate Cout, R is just Rc.

Common Emitter : Vce Design Constraint
The circuit design must meet this minimum threshold voltage drop across transistor of 0.2V in order to be a current controlled current source operating in the active region (s).
"Collector current is independent of collector-to-emitter voltage, so long as Vce > 0.2V." (Hambley, p. 214). Therefore the voltage between the collector and the emitter, aka the voltage drop across the transistor, does not affect the collector current so long as that voltage drop across the transistor is at least 2/10 of a volt. This is a "threshold voltage" of sorts. The bipolar junction's base current **I*b*** is very responsive to small changes in base-emitter voltage **V*be.* That small change in base current I*b* results in a relatively large change in collector current I*c*,** due to dependency **I*c* =** B **I*b*. *The BJT functions as a switch,*** with the base as the controlling entity. **The base current is the current-controlling region**, but the base current's variation will

rely on the base voltage, aka the small signal input voltage. ***The threshold voltage Vce > 0.2V*** is in regards to the minimum current (voltage) required through (over) the base (base-emitter ideal diode) in order to forward bias the transistor's emitter (diode) junction. **A more common sense way to say that is that the voltage drop across the transistor must be at least 0.2V, or transistor won't be DC-biased or "turned on."**

There are three stages of operation for the BJT: Note Vce minimum design requirements for drop across BJT:
CUTOFF REGION: Vce < 0.2V threshold voltage. Transistor = open circuit.
• no current • Vbe < 0.6V (emitter-base junction is reverse biased) • Recall shaded area on BJT plot
If Vce is greater than Vbe, the collector junction is reverse biased.
SATURATION REGION: Due to increase in Vbe: Vce ~ 0.2V threshold voltage. Transistor appears as short circuit. Vce has JUST reached threshold voltage. ***• Recall shaded area on BJT plot***
• Vce ~ 0.2V. This is called "Vce is at the saturation voltage." Vce has just reached it.
Vbe > 0.6V (emitter-base junction is forward biased)
FORWARD ACTIVE REGION: Linear Amplification. Vce > 0.2V and Vcc < Vce.
The supply voltage must be above the voltage drop across the transistor ***Vce***, and comfortably so for ***centering*** design purposes.
• Recall active area on BJT plot

Load line calculations for the BJT: Quiescent point bias design : Vgs is to a MOSFET plot as Ib is to a BJT plot.
• Plot Ic versus Vce • Use load line equation Vcc = IcRc + Vc + Ve **• Ic max = Vcc / Rc + Re**

Common base: for when we want electronic impedance match. Reverse isolation is used when we don't want to "see" what is on the output. You are driving the circuit from the output but only "looking" at the input. 50 ohm impedance. Small signals, and an input that's isolated from the output, and we define the input impedance. **Common emitter: for when we want lots of voltage gain. Common collector: for when we want lots of current into the load.**

COMMON EMITTER 4-R BIAS CIRCUIT DESIGN SEQUENCE: **1. Pick Vcc** **2. Pick Vc if Rc not given:** 0V < Vc < Vcc **If given Rc, pick the voltage drop over Rc:** *VdropRc = IcRc,* **that will give you Vc:** *Vc = Vcc - VdropRc.* ***<u>VC IS Q POINT OUTPUT.</u>*** **3. Ve:** Set *0.1V < Ve < 1V.* Ve is DC feedback **4. Vbe (or Vin):** Vbe - Vdropdiode = Ve **5. Re:** Ohm's law: Re = Ve / Ic **6. Find Ibias** = 1/10 * Ic **and Ib** = 1/100 Ic **7. Find R1 and R2:** Ohm's law: Vcc = ibias(R1+R2) or voltage divider V1 = Vcc (R1 / R1 + R2) **8. Find gm. gm of BJT = 38 Ic. Recall that re = 1/gm.** **9. Find gain = - Rc / Re.** **10. little re** and calculate that into actual gain = -Rc / Re + re. Is this close to step 7? Find % of variation here. **9. Design frequency response:** Find equivalent ac resistances, and capacitances. **10.** Note that with additional "Reac RC branch", gain is just gain = gmRL.	"COMMON" refers to whatever is grounded and not connected to either input or output. **Common base:** 1. Use same exact CE circuit, but input is now through emitter, base is grounded, and collector is output just as before. Vin on emitter has a Cin and looks symmetrical with Cout on collector ("horizontal branches"). 2. Voltage divider for R1 and R2. V1 ~ Vcc/2, *for now.* 3. Ve = V1 - diode drop. 4. Vc is still the q point. Vcc - Ve = Vc. 5. Input impedance is super low like 5-10 ohms, output Z is super high. Zout ~ source / beta of transistor. 6. 1 / 2 pi RCin = corner frequency 7. Vc is still Q point 8. Input current is essentially what output current is due to super low impedance of input on "Ve" 9. Voltage swings cleanly from Vcc to zero 10. RF applications **Common collector "Emitter follower:"** 1. Make a new branch in parallel with Re. Put another R on. 2. Put a C in between the two, up top (in series with both). 3. Vout is across this second R in the second branch you just added.

An important overview of the bipolar junction transistor should always include that the desired mode of operation is always the linear mode, when a large enough voltage drop across the transistor is part of the inherent circuit design, as well as a significant design constraint.