Simple Introduction to Transistor (BJT) Amplifier
Bipolar Junction Transistor

- Made out of n-type and p-type silicon
- There are two “flavors” of BJT’s
  - pnp & npn

Fig. 28.6 from *Electrical Engineering Uncovered*

Note: Current Directions Shown are Arbitrary!!

To Learn More!! EECE 332 (Semiconductors) “Why do they work?”
BJT Operation

- Recall FET: current flow controlled by the gate voltage
- BJT: current flow controlled by the base current
  - Acts like a current amplifier
    - But… with the right circuitry around it can also be a voltage amplifier

Conceptual Model of npn Transistor

- Base Current deflects current meter
- Meter linked to variable R
  - Controls the Collector current
- Voltage supply between C & E provides large Collector current controlled by small Base current

Fig. 28.4 from Electrical Engineering Uncovered
BJT Water Model

• While this electrical conceptual model is good… we can also use a water model

  Base Current Spins Small Turbine (Turbines: no friction & no momentum)

  Regulator (like scuba tank’s) ensures that current flows only due to the turbine’s “suck”… not the pressure difference between C-E

  Large Turbine spins @ same rate as small one… BUT larger size causes more water to flow

  Must exceed Diode “drop” before base current flows

Fig. 28.5 from Electrical Engineering Uncovered
Current Gain of BJT

- So… the main characteristic of a BJT is its current gain (called $\beta$… also called $h_{FE}$) Typical $\beta$: 50 – 200
- In our water model… $\beta$ is set by the relative size of the two turbines
- **Warning**… a designer’s knowledge of $\beta$ is almost always imprecise!!!!
  - That seems to limit the usefulness… but can be handled through proper circuit design
- **Emitter Current** = (Collector Current) + (Base Current)

$$I_E = I_B + I_C$$

Removal

Shown opposite book’s direction!!

$$= I_B + \beta I_B$$

$$= (\beta + 1) I_B$$
Main Rules of npn BJT Operation

1. The B-E voltage must be at a “diode drop” of 0.7V
   – If not… no base current flows… and no collector current flows
   – So… if not, the transistor is “cut off”

2. Collector must be more positive w.r.t. emitter

3. Can’t exceed certain maximum values on $I_B$, $I_C$, & $V_{CE}$

4. When rules 1 – 3 are obeyed, $I_C = \beta I_B$

From *The Art of Electronics*, by Horowitz and Hill, Cambridge University Press
Biasing a Typical BJT Amplifier

Before we can use a BJT as an amplifier we need to “set it up for use”… called biasing the transistor

1. Voltage Divider makes this 1.7V
   \[20V \times \frac{10}{110 + 10} = 1.67V\]

Assumes that current into base is negligibly small

2. Diode drop makes this 1 V

3. Ohms law sets emitter current
   \[1.0V / 1000\Omega = 1mA\]

4. Ohms law says 10V across \(R_C\), putting the collector at \(V_C = 10\) V
   \[1mA \times 10k\Omega = 10V\]

Now we can “inject” the signal we want to amplify
Injecting Signal to a BJT Amplifier

The Input $v_{in}$ typically wiggles around a level of 0 VDC. But we want to make the base voltage wiggle around the 1.7 VDC level. Roughly… Because the cap is like an open circuit to a DC voltage it keeps these two different “DC center values” from “working against” each other… But it passes the input wiggles to the base!!
Gain Analysis of BJT

1. A small wiggling $v_{\text{in}}$ causes a small wiggle $\Delta V_B$ here in $V_B$ centered around 1.7 V

2. The small wiggle at the base causes the same amount of wiggle here around 1V… $\Delta V_E = \Delta V_B$. That causes a wiggling emitter current $\Delta I_E$ around 1mA

3. The collector current wiggles about the same amount: $\Delta I_C \approx \Delta I_E$. Causes the collector voltage to wiggle around 10V… But $V_C$ goes down when $V_B$ goes up (inversion!!)

\[ \Delta I_E = \frac{\Delta V_B}{R_E} \]
\[ \Delta V_{R_C} \approx -R_C \Delta I_E = -R_C \frac{\Delta V_B}{R_E} \]
\[ \frac{\Delta V_C}{\Delta V_B} = -\frac{R_C}{R_E} \]

Note that the transistor’s current gain, $\beta$, has no direct effect on the gain… a good design!
BJT Amplifier in Real Life

Guitar distortion boxes work (in part) by amplifying the guitar signal before it reaches the actual amplifier… this overdrives the amplifier to give more distortion than it would otherwise.

Partial Circuit for the Boss DS-1 Distortion Box for Guitar
From Pedal Power Column by Robert Keeley, in Musician’s Hotline Magazine