Transistors as Switches

When a bipolar junction transistor (BJT) used in circuit, function determined by the device's characteristic curves.

Output curves dictate the range of collector-emitter voltage (Vce) for variations in collector current Ic.

For use as amplifier, biasing arranged so that linear part of output curves (the almost horizontal sections) used.

If circuit uses transistor as switch, biasing arranged to operate on regions of the output curves known as **saturation** and **cut-off**.

Figure 1 shows plot of collector current vs. voltage between current and emitter. :This figure shows a characteristic curve.

Active devices are transistors and tubes. They all have characteristic curves. Find the linear portion when designing an amplifier, for maximum fidelity, and bias so that the amplifier operation stays within the linear portion.

Cut-off

Yellow shaded area represents cut-off region (shown as backslashes in Diagram 1).

How does this apply in video? Diagram 2 has a video signal that is inverted (upside-down). How does this happen? Going through a common emitter configuration causes a 180 degree phase shift (this is the inversion). Use the cut-off: anything below certain level is cut off, anything above is passed through. For example, can bias transistor so that only the sync pulses get through (diagram 3); this is Class C amplification and the circuit is called a **sync separator**.

Set the dynamic point or Q point of the transistor, where it is conducting. The resistors at the base that form the voltage divider sets the biasing voltage of the base.

At the cut-off region, the operating conditions of the transistor are zero input base current, zero output collector current, and maximum (*supply rail*) collector voltage (since IR drop is zero because there is no output collector current).

Transistors have a base-to-emitter voltage of 0.6 to 0.8. This minimum voltage enables current flow in the transistor between emitter and collector. Small-signal amplifier transistors typically have a voltage of 0.7 volts.

Need load resistor between positive voltage and the collector in order to turn current flow into voltage. This is due to the IR drop across the resistor. By controlling the current through the transistor, we control the output voltage due to E=IR, where I is the collector current and R is the load resistor.

The signal path is used as the reference for voltage.

Can't look at a transistor circuit and tell what the transistor parameters are. Must look at the spec sheet or do your own experiments. Schematics will offer clues we will see later.

Saturation

Saturation is when the IR drop consumes all of the supply voltage, so the voltage at the collector is zero. In figure 1, it is the small portion marked by horizontal lines on the left side, next to the y axis.

A sync separator is really a switch. It's designed to either conduct or block current flow. Choice of bias point sets this up.

In saturation, the BJT will be biased so that the maximum amount of base current is applied, resulting in maximum collector current flow and minimum collector emitter voltage. Maximum I_C and minimum V_{CE}. The transistor is acting like a closed switch, a short circuit.

You don't have to go to saturation to get zero volts at the collector, since all you have to do is supply enough IR drop by supplying enough current and choosing the correct resistor value. However, circuits designed to switch go all the way to the transistor's saturation point to provide maximum assurance that an open circuit will occur, since resistor values can change with temperature and age.

In both cut-off and saturation, minimum power is dissipated in the transistor. This is because either voltage is zero (saturation) or current is zero (cut-off), and P = EI. So, we can get by with fairly small transistors in switching circuits. In dimming circuits, this is a different story since some of that power has to be dissipated somewhere else, and the transistor does this job. Must be rated at a power of half of the light bulb at least. The voltage regulators in our power supplies get warm because they dissipate the voltage/current to regulate the voltage.

Load Line

Knowing circuit load current and operating voltage, load line can be constructed.

Imagine a transistor designed to switch a 20 mA load and the supply voltage of 5VDC.

When transistor is off (the switch is open), I_C is zero and V_{CE} is 5VDC (the supply voltage). This is point A on figure 1.

On figure 1 – the diagonal line from A and B is the load line. A is at cut-off and B is at saturation.

When transistor is on, Ic will be 20mA, V_{CE} will be close to zero (this is point B on figure 1).

The line is called the **load line** and shows the transistor can be operated anywhere on this line by choice of bias current. For use as a switch, the device must work in the saturation and cutoff regions of the output curve. The bias current should be designed to work with the minimum value of H_{FE} (gain/beta) for the given transistor. A good spec sheet will give a range for the gain; always design using the minimum gain in case you get a transistor that only meets minimum spec.

BJT Switch Calculations

BJT with 5VDC supply, designed to switch 5V 20mA lamp on and off.

Transistor chosen from a batch with variations in H_{FE} from100 to 500. This is a general purpose transistor. Can choose a transistor with a smaller gain range, but will be more expensive. The gain range is over the lifetime of the product (multiple batches).

Switching configuration is for common emitter. Bias circuit in Figure 4.

Find a value for R_B (base resistor) to work with any transistor in the same gain group (100-500). Choose the minimum current gain so that any transistor we put in there won't just turn on the lamp half way and then the transistor would be dissipating IR.

Collector current is 20mA; the required base current is? $H_{FE} = I_C / I_B$, and $I_B = I_C / H_{FE}$ therefore 20mA / 100 = 200 microamps (0.2 mA) base current.

The lamp resistance is 250 ohms (5V / 20 mA).

There is 4.4 V across the base resistor (5V / 0.2 mA).

Finding the value of R_B. V_{IN} is 5V, the base-emitter voltage of transistor. V_{BE} is 0.6V then 4.4V is developed across R_B. R_B = E / I = 4.4 / 0.2 mA = 22K ohms.

A transistor with a gain higher than or equal to 100 will easily work and light the lamp. The V_{CE} will be very low (around 0.1V), and the power dissipated in the transistor is also low.

$I_C * V_{CE}$ = 2mW (milliwatt), and almost full power is developed in the load.

Summarize

Will always know load current your circuit needs. Use minimum value of H_{FE} for transistor found in data sheet. Calculate bias current to reach this minimum value.

Points to Note

Current gain (H_{FE}) lower in some power transistors at very high load currents.

The V_{BE} which varies between individual devices should be taken as the highest value. This is generally 0.6 or 0.7 V with small signal transistors, can be as high as 0.8 on some power transistors.

In saturation, a heat sink rarely required as little power is developed in the transistor.

Heat Sink

Transistor innards thermally connected to its case. Heat sink mounted to a transistor. Usually has fins. Heat conducts through metal, metal radiates the heat. Heat sink takes advantage of the heat traveling through the metal. Sink cools and allows more heat to travel from the device to the sink.

However, in power supply or other circuit where a transistor may be required to control large variations in current and voltage, then significant power may be developed.

If the power dissipation of the device is exceeded then it will be destroyed. In practice, allow for the worst combination of currents and voltages and calculate accordingly. For fuses, double the rating (e.g., use a 2A fuse for a circuit normally carrying 1A). Transistors are similar.

Lab

Switch circuit around to be a common emitter circuit, using a beta of 100,. Calculate to have 5 volt swings (cutoff to saturation) and hook up the circuit that way. TTL load should be negligible (we'll go into a Schmitt trigger NAND gate). Use 20mA for the current.