18. Transistors - Notes

TOPIC 1: Transistors in general

Two most popular types of transistors

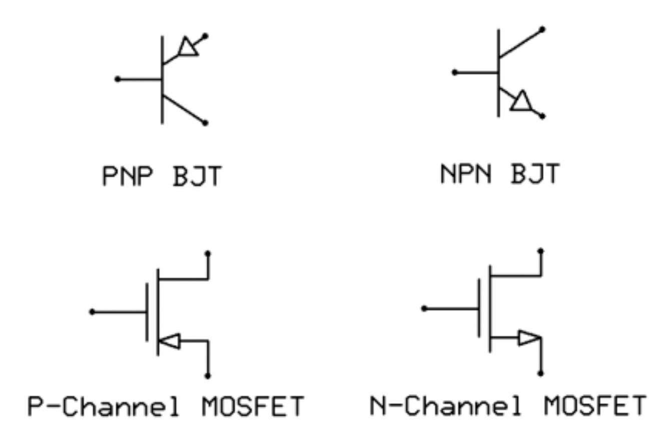
1. Bipolar Junction Transistor (BJT)
    - 3 leads; Base (B), Collector (C), and Emitter (E).
    - Two main types, PNP and NPN.
    - The base current controls how much collector current can flow.
    - The Base-Emitter "junction" is just like a diode and has a 0.7V drop when forward biased (that is when there is something to supply the current to that junction).
    - Rated in many ways, but the most important ratings are:
        1. Maximum current able to flow between the collector and emitter.
        2. Maximum voltage that can be applied to the collector and emitter before current will flow when the transistor is off.
        3. Voltage drop from the collector to the emitter.
        4. Maximum speed at which the transistor will turn on and off.
        5. The current gain (called Beta) which is a measure of the ratio of the collector current to the base current, $I_c = \beta I_b$.
        6. 2. Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
        7. 3 leads; Gate (G), Drain (D), Source (S). (compared to the BJT, the gate is like the base, the drain is like the collector, and the source is like the emitter).

2. Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
    - Two main types, P-channel and N-channel.
    - Has a threshold voltage (voltage from gate to source) from 2-4V.
    - The gate voltage controls the amount of drain current that can flow.
    - Rated in many ways, but the most important ratings are:
        1. Maximum current able to flow between the drain and the source.
        2. Maximum voltage that can be applied to the drain before current will flow when the transistor is off.
        3. Voltage drop from the drain to the source.
        4. Maximum speed at which the transistor will turn on and off.

Two most popular uses of transistors

1. Amplification – Transistor is used to amplify an electrical signal.
2. Switch – Transistor is used to turn a circuit on and off electrically.

TOPIC 2: Transistor Symbols



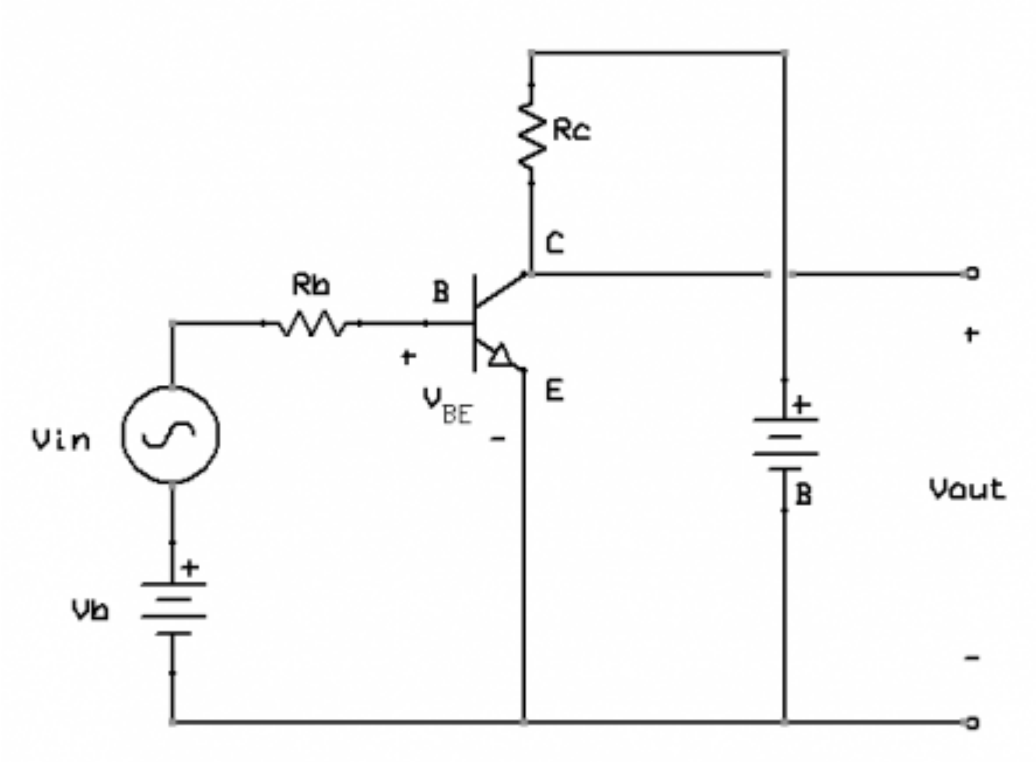
TOPIC 3: Transistors as Amplifiers

An amplifier is a circuit that takes a voltage signal (typically an AC voltage at multiple frequencies) and multiplies it by a gain to form a new voltage signal. Ideally, the amplifier affects all frequencies equally and all input voltages equally. Because of limitations of the transistor the amplifier will not perform the same above certain frequencies and above certain input voltages. Different transistors will act differently, but herein we will assume that we are operating inside the window if which the transistor will operate as ideal.

As an amplifier the transistor has a gain called Beta (β). The relationship is $I_c = \beta I_b$. That is to say, the current through the collector of the transistor is proportional to the current in the base and is larger by a factor of β. Normal values for β range from 100 to 250. If β=150 and the base current was 10μA then the collector current would be 1.5mA.

The BJT can be the center of three common types of amplifiers, the Common Base Amplifier, the Common Emitter Amplifier, and the Common Collector Amplifier. The name comes from the lead of the transistor that is not connected to either the input or output of the amplifier. There are many types of amplifiers but they are typically built around or as a combination of these three types.

Let's look at the "Common Emitter Amplifier" and calculate each piece of the circuit.



Example: If $V_b = 3V$, $V_{BE} = 0.7$ V, Rb = 100k, Rc = 3k, $\beta = 100$, and B = 10Vdc, find the output voltage and plot it alongside the input voltage when V_{in} is an AC waveform of amplitude 1V.
Start with the DC analysis (remove any AC voltage sources and replace them with a wire):

1. KVL says that $V_b = V_{Rb} + V_{BE}$ therefore, $3 = V_{Rb} + 0.7$ and $V_{Rb} = 2.3V$

2. I_b is the current flowing into the base, but also flows through Rb. Therefore $I_b = V_{Rb} / R_b = 0.023mA$

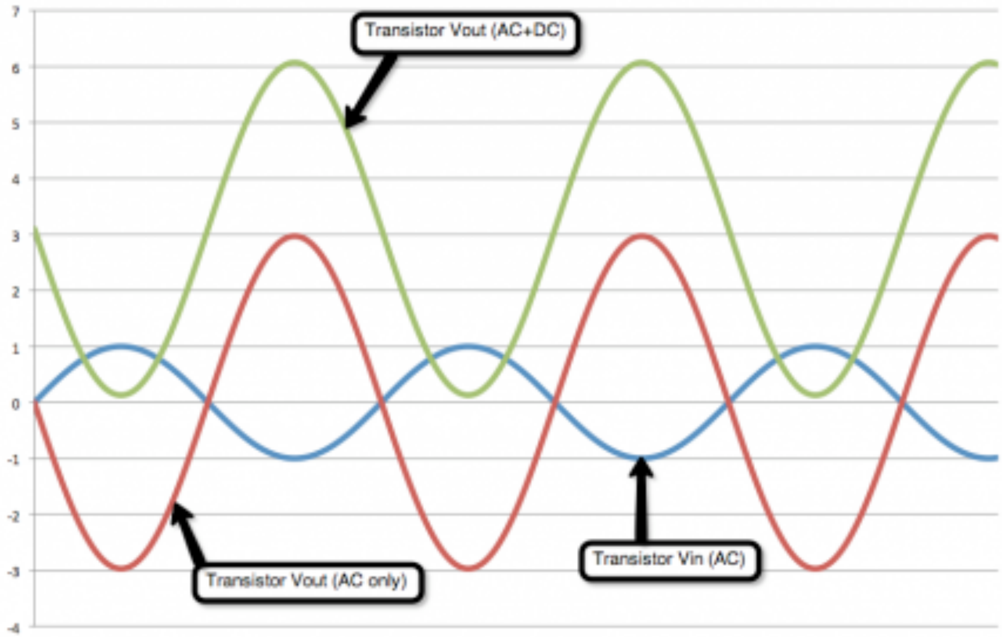
3. $I_c = \beta I_b$ therefore, $I_c = 2.3mA$

4. $V_c = B - (I_c \times Rc) = 10 - (0.0023 \times 3000) = 3.1Vdc$

Now on to the AC analysis (remove any DC voltage sources and replace them with a wire):

Voltage Gain = $\frac{V_{out}}{V_{in}} = \frac{-\beta R_c}{\beta \frac{V_T}{I_C} + R_b}$ = -2.97 V/V

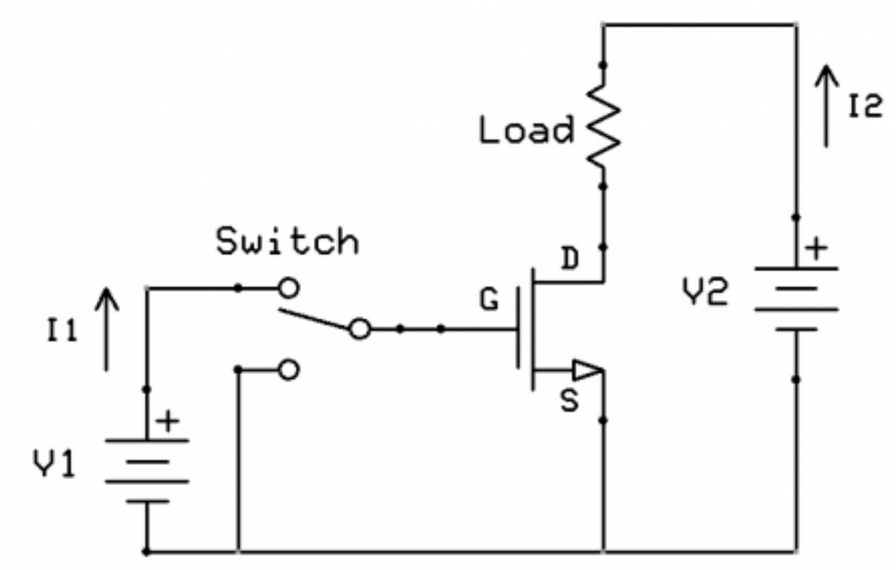
Total output voltage $V_{out} = V_{in}$ x Gain + V_c. If the input voltage was an AC waveform with amplitude of 1V the output would be an AC waveform (180 degrees out of phase because of the negative gain) with amplitude of 2.97V and a DC offset of 3.1V.



Common Emitter Amplifier Waveforms

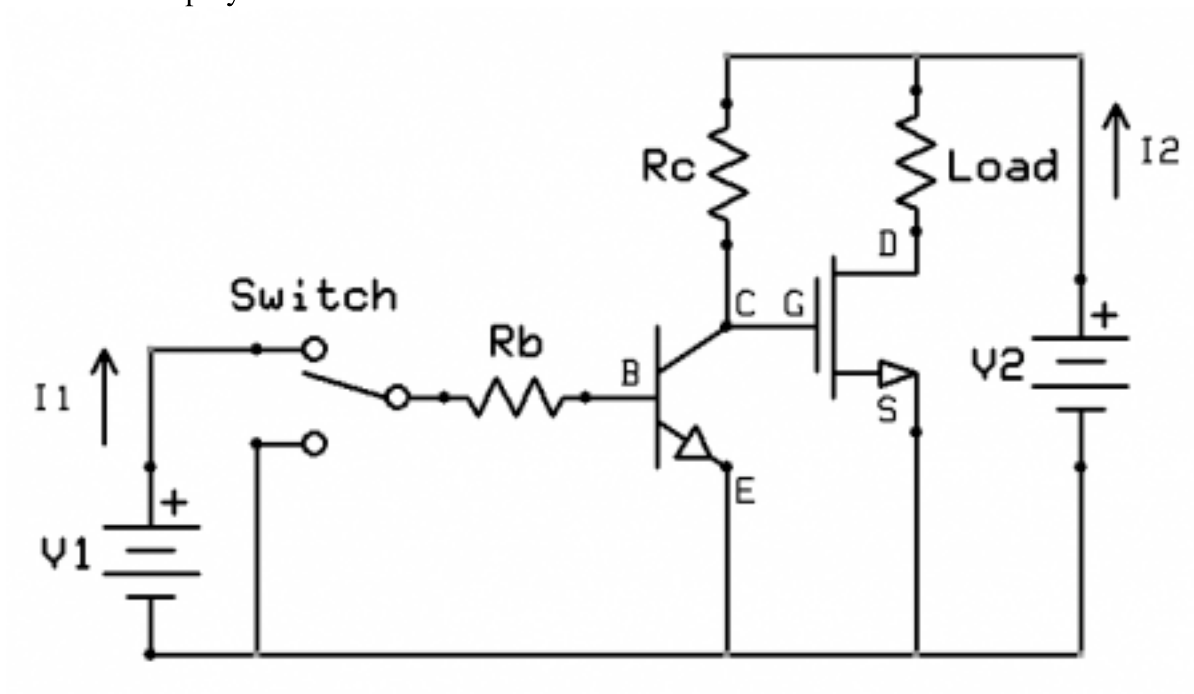
TOPIC 4: Transistors as Switches

Many times a large current flow in a circuit needs to be turned on and off by using a small amount of current. A transistor can function as this switch. Commonly a MOSFET is used as the transistor however, a BJT can complete the task as well. Below is the circuit that will accomplish this task.



In this circuit a small voltage, shown as coming from a power supply V1, is supplying power to the gate of the MOSFET. If this voltage is higher than the MOSFET's threshold voltage than the MOSFET will "turn on" (allow current to flow through from drain to source). This current only gets to the gate when the switch is connected to V1. When the switch is connected to ground (or the negative side of the power supply) the threshold voltage is not exceeded and the MOSFET is not on and current cannot flow through the transistor.

However, the voltage V1 must be above 4V to insure that the switch will work as the threshold voltage of the MOSFET can range from 2-4V. Sometimes this isn't possible to insure. For example many microcontrollers (small computers on a chip) supply output voltage of 3.3V and are used to turn on circuits exactly like that above, in place of the switch. Since we cannot guarantee 4V with a 3.3V microcontroller we must use another circuit that employs both the BJT and MOSFET.



In this case we have added what looks like a Common Emitter Amplifier without an AC voltage input. Here, if the current through the base of the transistor is zero (that is Rb is connected to ground) then the current through the collector is zero and the voltage drop across the resistor is zero which means that Vc = V2. This causes the MOSFET to turn on as there is a voltage between the gate and the source higher than the threshold voltage. However, if the current through the base is not zero then the current in the collector is not zero and the voltage drop across Rc is equal to V2 and Vc is zero therefore the MOSFET is off.

Be careful with this circuit because it operates in reverse logic. If the switch is connected to V1 then the MOSFET is off and I2=0 but when the switch is connected to ground the MOSFET is on and I2>0.

You should now be prepared to answer the following questions:

1. The three leads of the BJT are ___________.
2. In the BJT, ____________ controls how much collector current flows.
3. The threshold voltage in a MOSFET ranges from ___________.
4. In the MOSFET, __________ controls how much drain current can flow.
5. The collector current in a BJT is measured to be 3.4mA and the value of β=125. What is the base current?
6. A common emitter amplifier has a base resistor of 27.2k Ohms and a collector resistor of 3.4k Ohms. β=100, Vb=2V, B=18V, and Vin is an AC waveform with an amplitude of 0.5V. Find Ib, Ic, Vbe, Vc, gain, Vout AC amplitude.
7. A MOSFET is used as a switch with a load resistor of 10 Ohms and the voltage drop from the drain to the source is measured at 0.15V. The current flowing through the drain is 350mA. What is V2?
8. The switch voltage (V1) is only 1V therefore the designer decides to add a BJT into the circuit so that the MOSFET can be switched as discussed in the lecture. The base resistance is 45k Ohms and β=150. What is the minimum value we can select for Rc if V2 is 8V?
9. In a BJT/MOSFET switch circuit V1=2.2V, V2=12V, β=200, Rb=300k Ohms, and Rc=9k Ohms. In the lab the circuit worked but because the gate voltage of the MOSFET is only 3V when this circuit was mass-produced many of the units did not work. What should be changed?