## The Differential amplifier - An Intuitive Look

We will now take a look at a very versatile amplifier circuit called the *differential amplifier*. This amplifier is at the heart of many analog integrated circuits. We will look at the circuit only close enough to get a good intuitive feel for how it works and what it can do.



The differential amplifier operates by *amplifying the difference* between two separate inputs. These inputs are marked above as Vin1 and Vin2. Note that the amplifier is symmetrical about a center line going through the 5ma current source. For the sake of this explanation, we will consider the 5mA current source to be "not quite" ideal. In this case, it means that the current source is only able to drive its upper terminal to zero volts when attempting to force a minimum of 5mA to flow to ground. However, it will never allow more than 5mA to flow no matter how much base current is forced into Q1 andQ2.

To understand the operation of the amplifier, we will assume that Vin1 and Vin2 are equal in magnitude. Within the operating region for the amplifier, this will cause equal base and emitter currents to flow through each transistor. Since the current source will not allow more than 5mA of current to flow, the current through rc1 and rc2 will be exactly 2.5ma. This causes a potential of 2.5 volts to appear at Vc1 and Vc2. At this operating point, the amplifier currents and voltages are balanced. Note that if we increase both Vin1 and Vin2 equal amounts, Vo1 and Vo2 remain unchanged. Thus *the amplifier does not respond to identical changes in Vin1 and Vin2*. (also known as a common-mode signal).

Imagine now that Vin2 is held constant and Vin1 is increased slightly resulting in increased base current in Q1. This current is magnified by the beta of Q1 resulting in a greatly increased current through rc1. However, the 5mA current source will only allow a maximum of 5mA. If Vin1 increases only a little bit (depending on beta of course) it will cause 5mA to flow through rc1. Since Vin2 did not increase, Q1 will consume all the current capacity of the current source. This will cause the current through rc2 to drop to zero. Thus Vo2 will rise to Vcc and Vo1 will drop to zero.

Therefore we see that *the differential amplifier responds when Vin1 and Vin2 change relative to each other and does not depend on their absolute voltages* (within the operating region for the amplifier). Note also that the differential amplifier will have a 180 degree phase difference

in its outputs as the inputs change.

The differential amplifier allows us to detect and amplify the difference between two signals. When it is built in an integrated circuit, this amplifier can achieve a very high level of matching between the components allowing it to detect very, very small differences between the inputs. (on the order of tens of microvolts) When used as a linear amplifier, this circuit is often called an *Op Amp*, which is short for *Operational Amplifier*.

The differential amplifiers two independent inputs allows a comparison not against only ground like the emitter-base junction of a BJT could but against a user selectable input voltage. This lends the differential amplifier to another specialized task, called a *comparator*. The comparator is an difference amplifier that is optimized to compare two input voltages and give an output that is either "on" or "off" instead of a linear output. Below we see one way in which we could build a comparator. (greatly simplified)



The differential input stage is as before. However an output stage has been added. With the 1.8V zener diode in the emitter of Q3, a base to ground voltage of (0.7 + 1.8) = 2.5 volts will be right at the threshold of turning Q3 "on". If Vin1 exceeds Vin2 by a small amount the output terminal would go to zero volts. If Vin2 exceeds Vin1 by a small amount the output terminal would go to Vcc.

We can then use the comparator to sense the difference between two input voltages and give us an output that is either zero or some other voltage of our choosing. It is important to note that the output terminal is uncommitted. For the output to ever rise to some voltage, we must provide an external resistor to that potential, so that when Q3 goes off, the resistor will "pullup" the output terminal to the voltage desired.