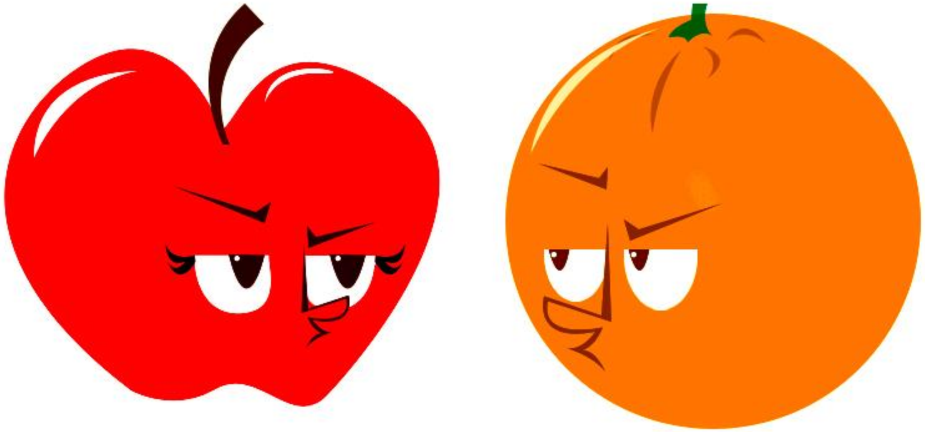
The New England Radio Discussion Society electronics course (Phase 4)



What's the difference?

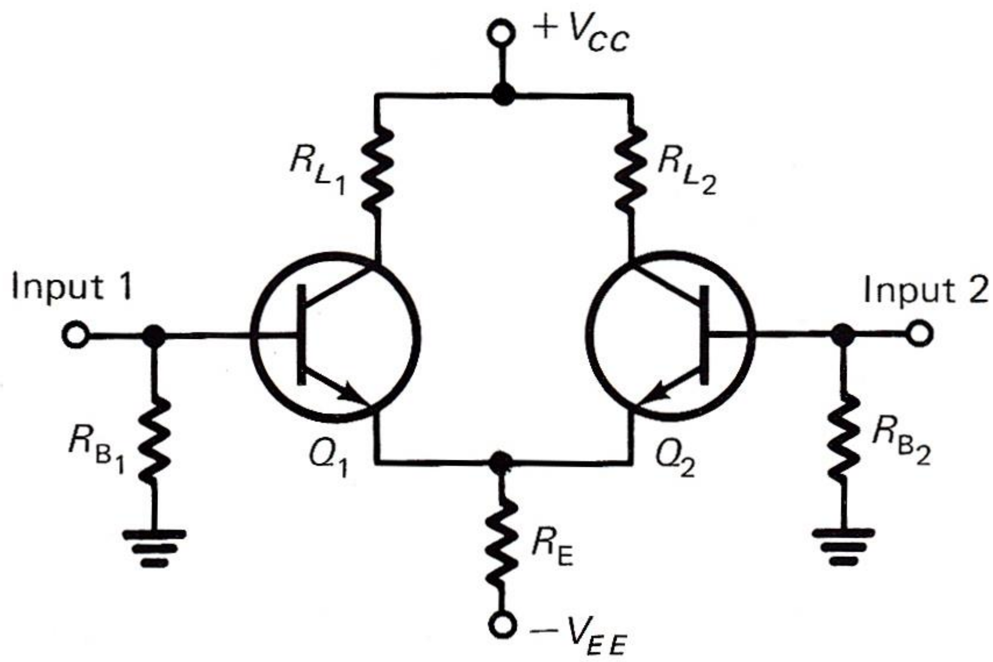
AI2Q – February 2017

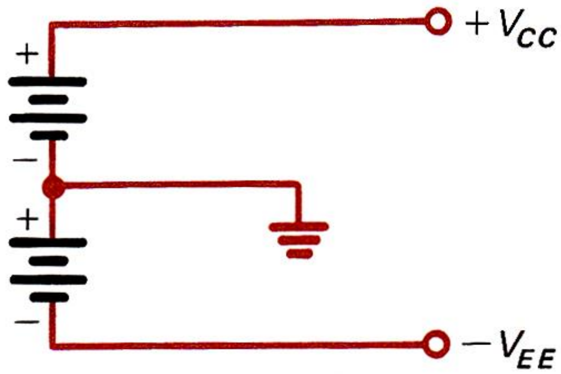
An amplifier can be designed to respond to the <u>difference</u> between two signals.

These types of amplifiers have two inputs, and are called *differential amplifiers*, or *diff-amps*.

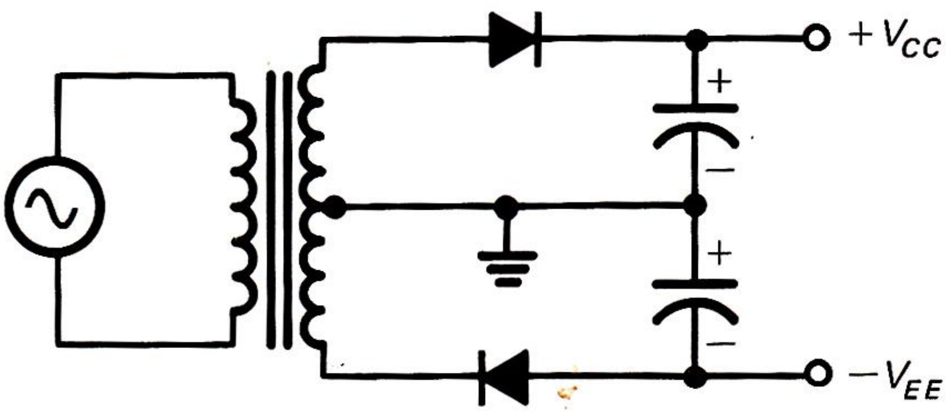
A diff-amp usually requires two power sources of opposite polarity.

For BJTs these are called V_{CC} and V_{EE}.

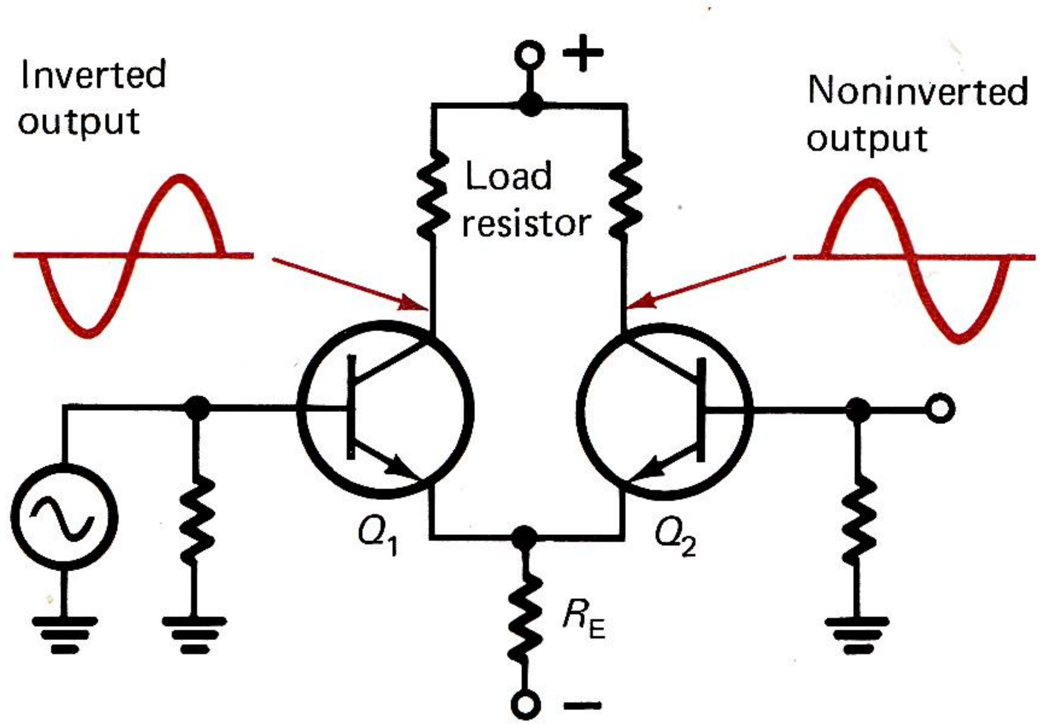




Two voltages of opposite polarity are typically used to power a differential amplifier.



You can drive a diff-amp from one input. However, an output signal will appear at both collectors.

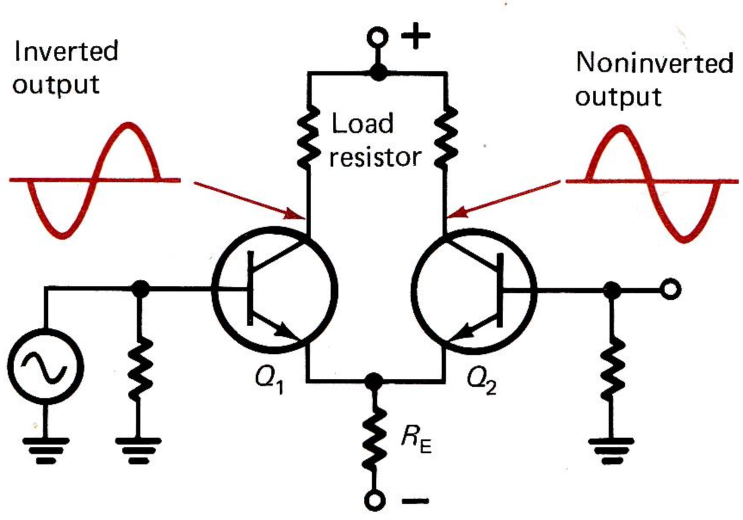


Assume an input signal drives the base of Q1 positive. Q1 conducts more heavily, so its collector goes less positive, and the signal is inverted. Now, what happens at Q2?

(1) As Q1 gets turned on harder the current through the common emitter resistor increases. This increases the IR drop across the emitter resistor.

(2) The emitters of both xstrs go positive. That has the same effect as making the base of Q2 less positive (more negative).

(3) Q2 now conducts less current. That means there's a lower voltage drop across Q2's collector load resistor. It's collector goes positive, towards the V_{CC} rail.



The result is a non-inverted output signal at the collector of Q2.

Way cool, eh?

The 2-transistor differential amplifier therefore can deliver <u>two</u> simultaneous signals. One is inverted and the other is non-inverted.

You can also call these signals *in-phase* and *out-of-phase*. The choice of terminology is up to you!

You can also use a differential amplifier to generate a *differential* output.

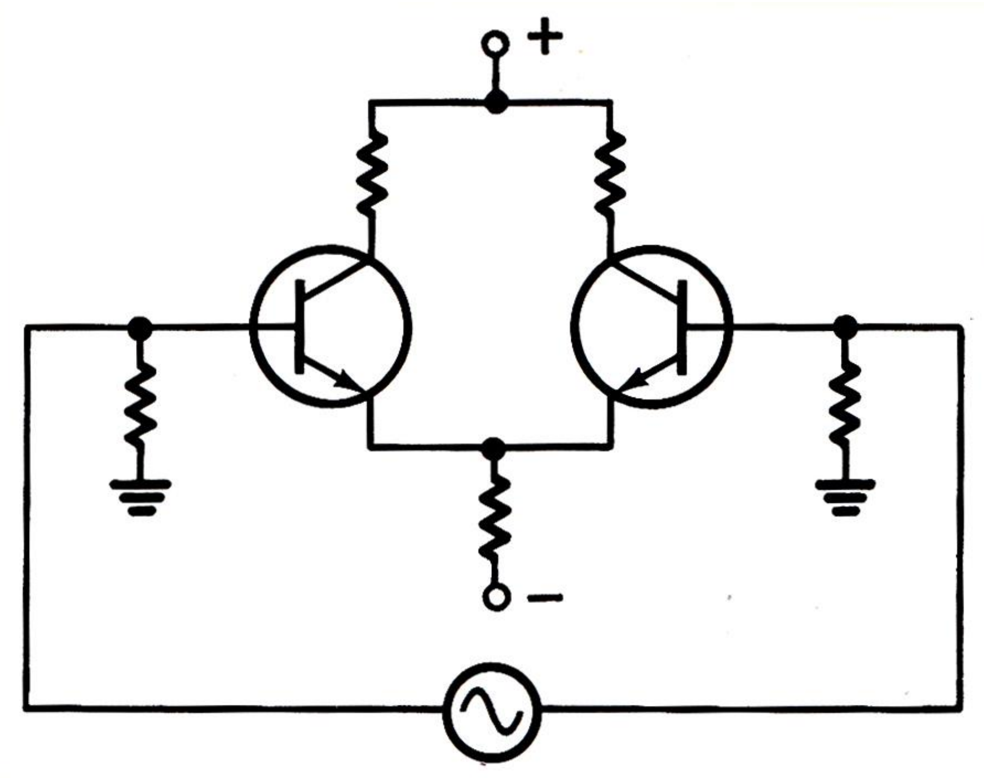
In this case the output would be taken from the collector of Q1 to the collector of Q2 (between them).

The differential output has twice the swing of either single-ended output.

For example, if Q1's collector has gone 2V negative and Q2's collector has gone 2V positive, the difference is

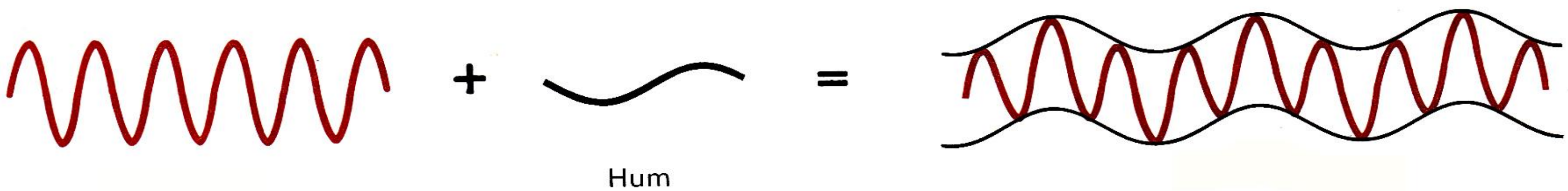
$$(+2) – (-2) = 4 \text{ V}$$

The diff-amp amplifier circuit can also be driven *differentially*. In that case the circuit would look like this:



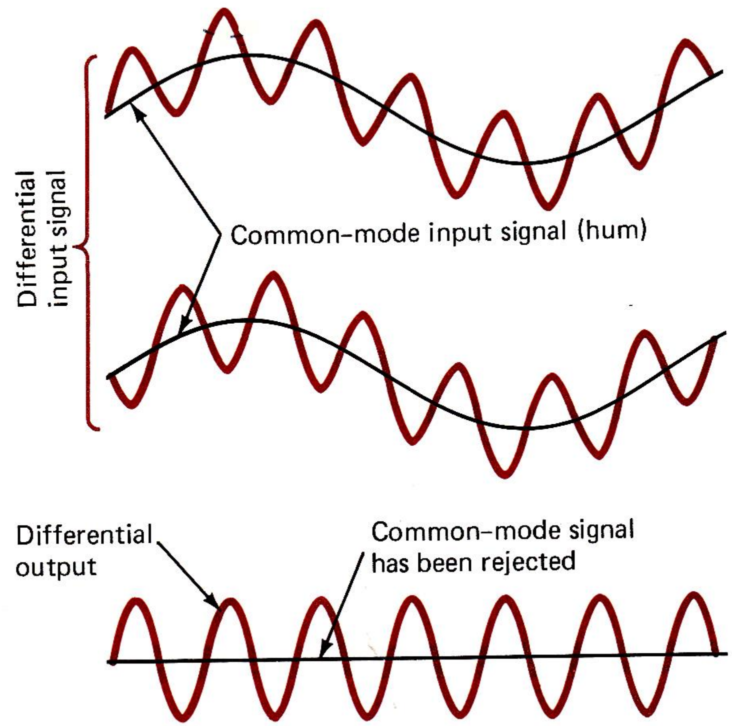
The differentially driven diff-amp can be used to cancel noise!

For example, you have a good signal but with some bothersome hum on it (the hum is added to the signal). Yuk.



If the hum is common to both inputs (it's in-phase on both) it will not affect the differential output.

The hum is rejected!



Noise that is common to both inputs is called a *common-mode* signal. No diff-amp is perfectly balanced, so some common-mode signal will appear at the amp's output.

The diff-amp's ability to reject this signal is quantified by what's called the *common-mode rejection ratio*, or *CMRR*.

CMRR is defined as the ratio of the voltage gain of the diff-amp for differential signals to the voltage gain of the diff-amp from common-mode signals.

$$\text{CMRR} = \frac{A_{V(\text{dif})}}{A_{V(\text{com})}}$$

where $A_{V(\text{dif})}$ = voltage gain of amplifier for differential signals

$A_{V(\text{com})}$ = voltage gain of amplifier for common-mode signals

Let's take an example: assume that a common-mode signal is 1V in amplitude.

The diff-amp isn't perfect, so let's say the 1V signal produces a 0.05V signal at the amp's output.

Let's calculate the common-mode gain $A_{V(com)}$

$$A_{V(com)} = \frac{\text{signal out}}{\text{signal in}} = \frac{0.05\ \text{V}}{1\ \text{V}} = 0.05$$

Now let's assume the differential input signal is 0.1V and that is amplified to produce a substantial 10V output signal.

The differential voltage gain $A_{V(dif)}$ is therefore 100:

$$A_{V(\text{dif})} = \frac{\text{signal out}}{\text{signal in}} = \frac{10\ \text{V}}{0.1\ \text{V}} = 100$$

The common-made rejection ratio is 2000, from

$$\text{CMRR} = \frac{100}{0.05} = 2000$$

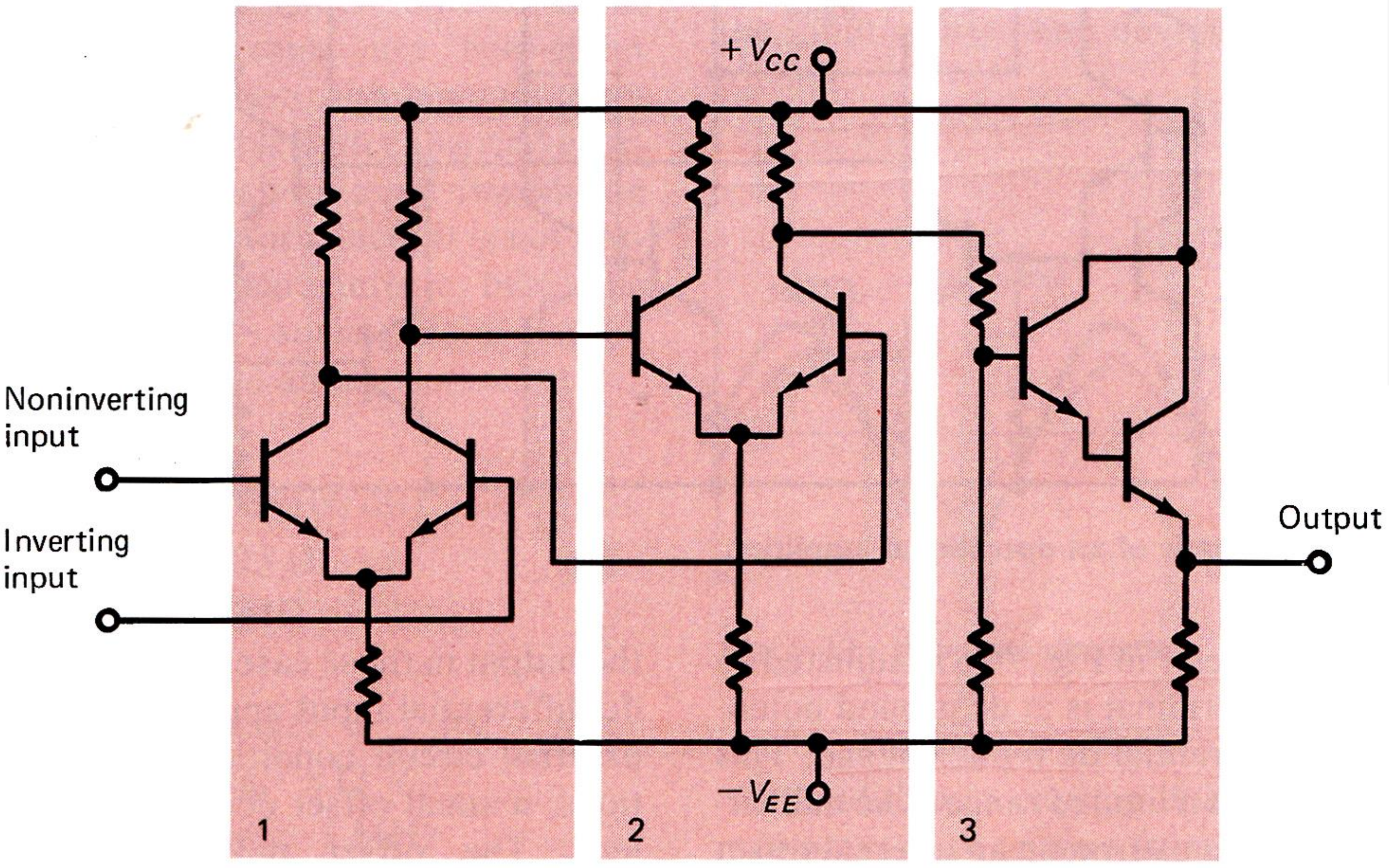
That means our diff-amp exhibits 2000 times as much gain for the differential signal as it does for a common-mode noise signal.

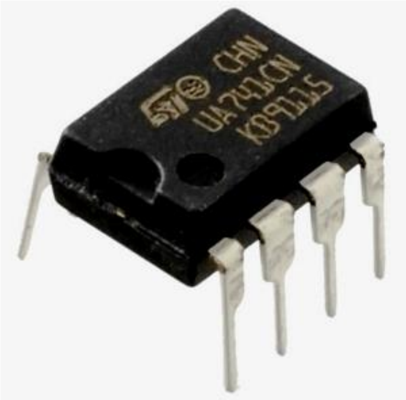
The ratio is typically expressed on datasheets in dB. i.e.

$$\text{CMRR}_{(\text{dB})} = 20 \times \log 2000 = 66 \text{ dB}$$

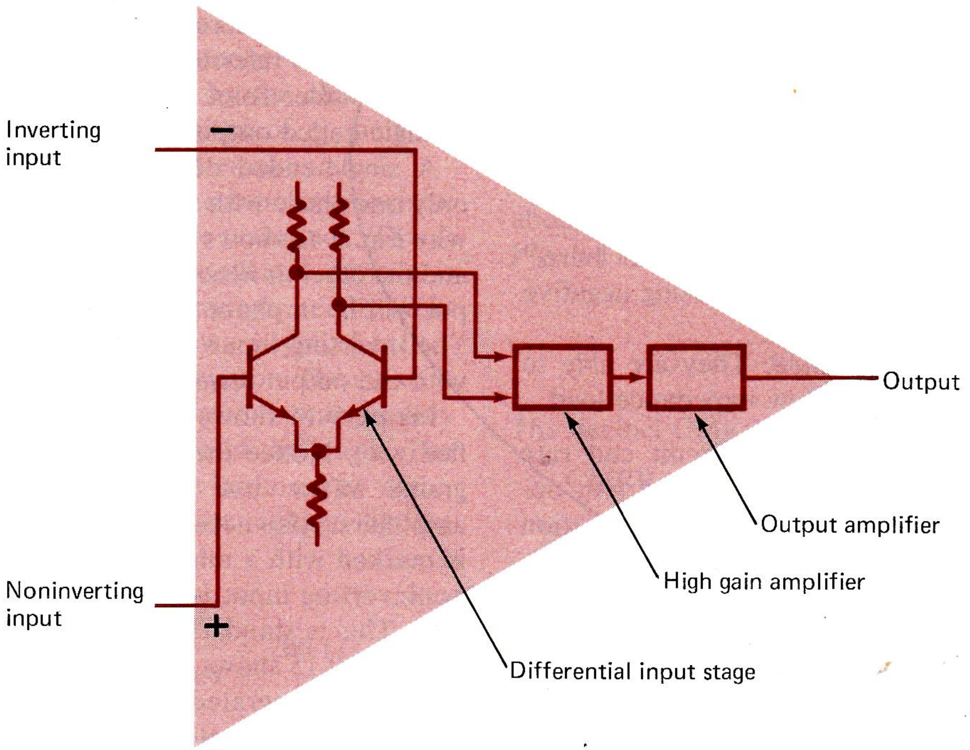
That is a very good CMRR spec.

***Operational amplifiers*, affectionately known as *op-amps*, using differential input stages, are available as *integrated circuits*, or *IC*s.**

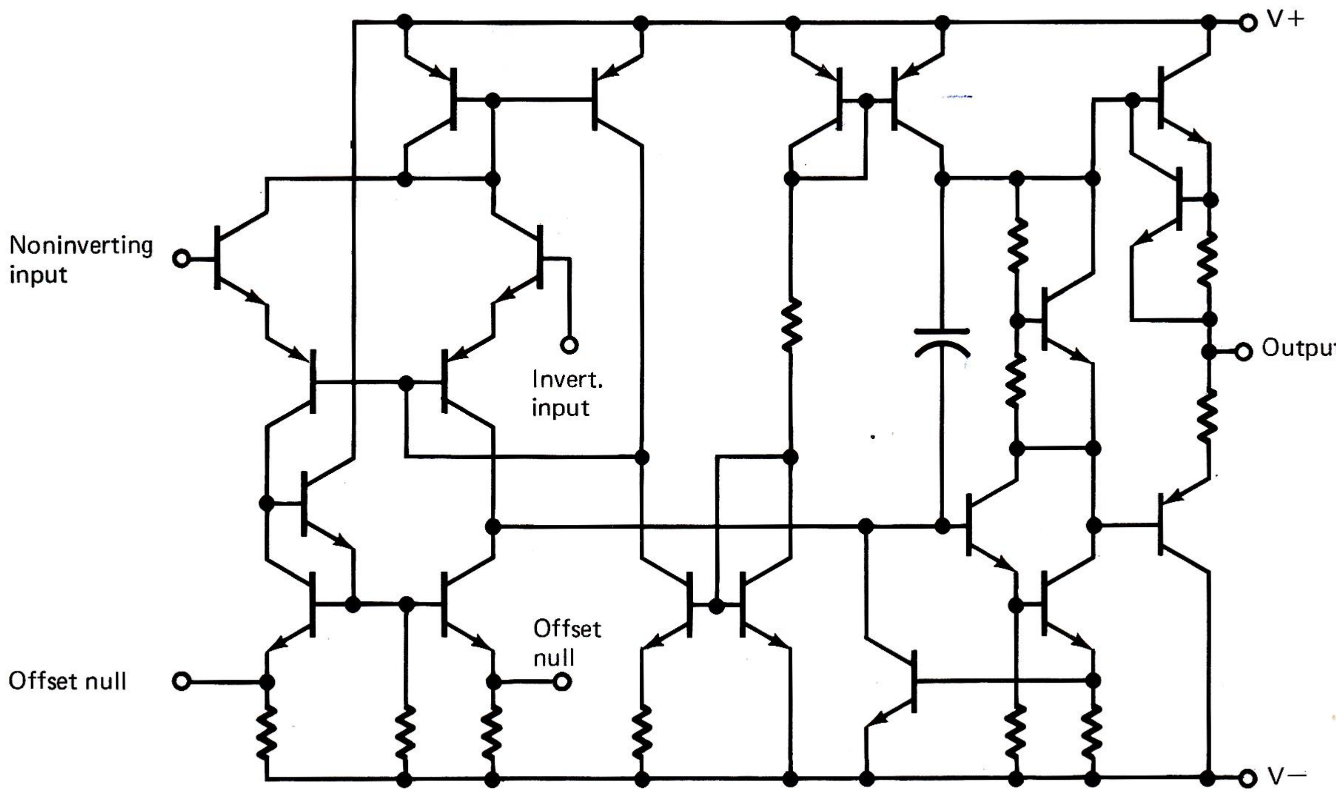




Here's a simplified diagram of the internals of an op-amp IC. It is a partial block diagram.

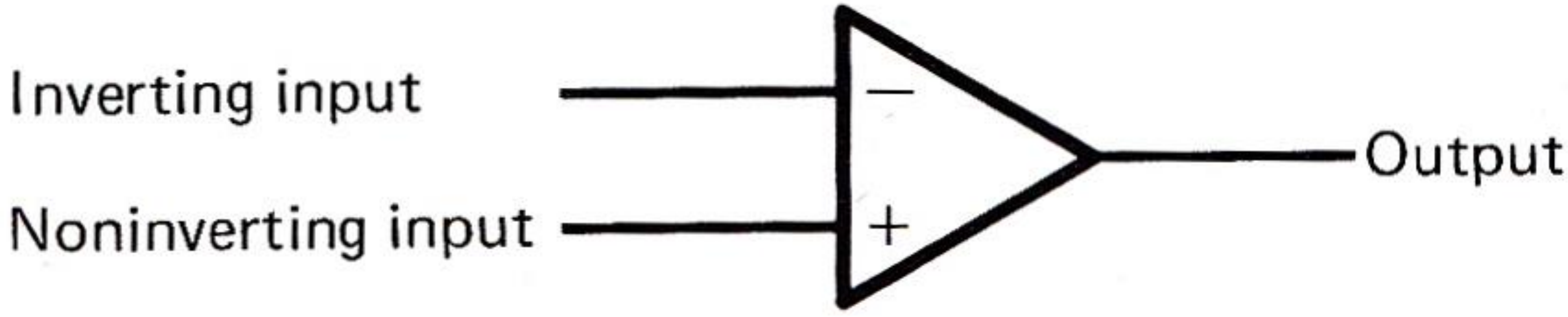


Here's an example of the internal "wiring" of an actual op-amp chip. All of this circuitry is contained on one silicon substrate. Note the internal resistors, and even an internal capacitor. Also, there are two "null" connections, or pins.



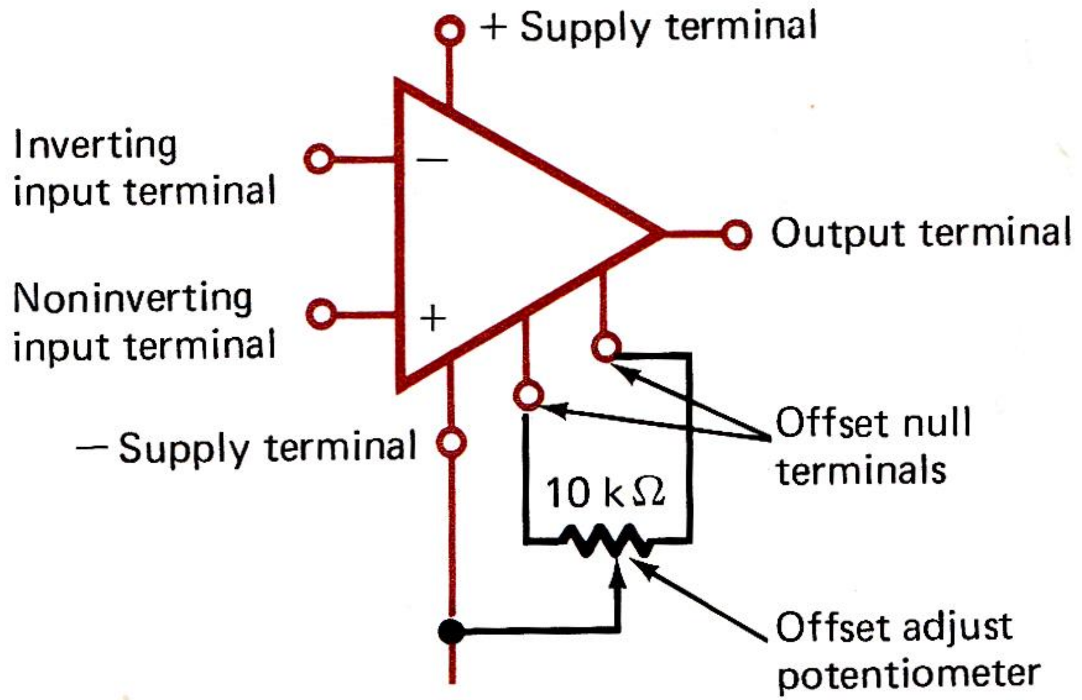
Looking at the innards of an op-amp is a nifty exercise, but it pays to simplify.

Here's the symbol for an op-amp that's most often used in overall schematic diagrams of *systems*.



Sometimes drawings will include positive and negative power-source terminals as well. Actual devices also often show part numbers and pin numbers.

The op-amp's "null" terminals can be connected to an external potentiometer, in order to carefully null out any slight, but possibly bothersome, *offset voltage* that might appear at the output. This adjustment is done with no differential DC input voltage applied.



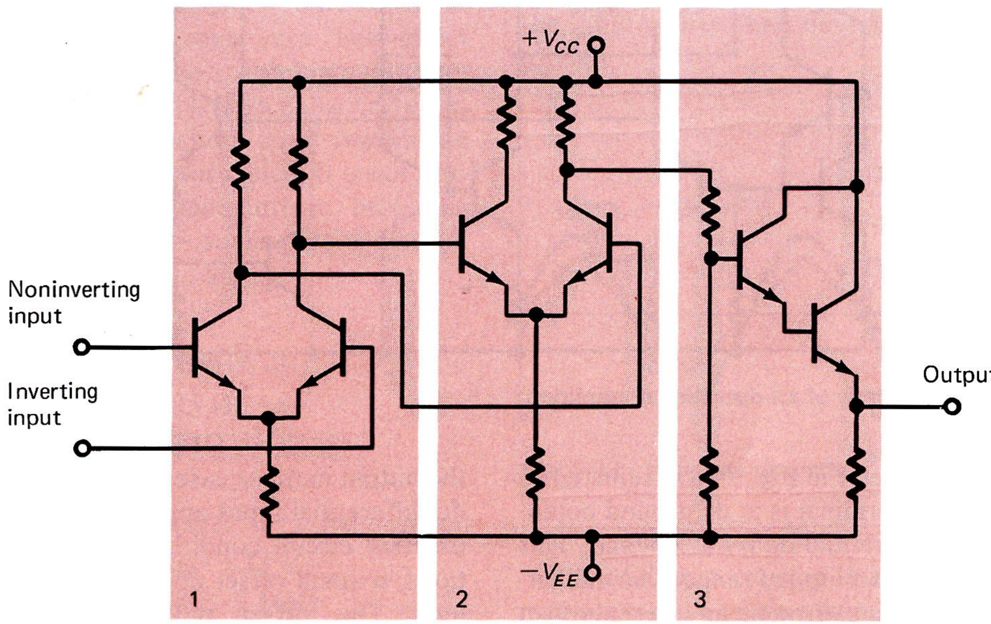
With no input signal the op-amp's output ideally should be zero volts.

Again, op-amps reject noise and hum. That characteristic is called *common-mode rejection*.

BJT-based op-amps also exhibit high input-impedance. What's more, FET-based op-amps have very high input-impedance specs.

Op-amps also have very low output-impedance specs.

Note the emitter-follower stage in Block 3 in our example.



Op-amp applications!

Until next time, 73
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