TRANSISTOR AMPLIFIERS 2.0

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INTRODUCTION

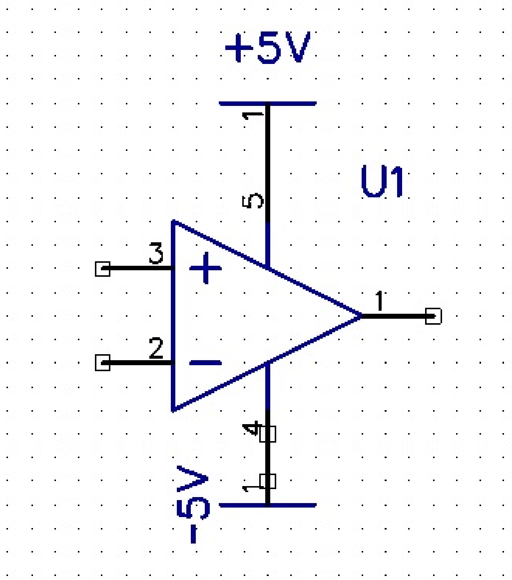
The goal of this short series of articles is to help you understand how a simple transistor amplifier – using a simple transistor such as the dirt cheap 2N3904 – can be a microphone preamp, or even a wide band RF amplifier, with just pennies worth of additional components mounted near it and a 9volt battery.

We'll take this step by step.

AN IDEAL AMPLIFIER

Transistors are terribly variable from one to another even if they are the same part number. A 2N3904 is a very common NPN transistor, but if you pick up three of them, they may have widely varying current gains (beta, or Hfe) – one may be 100, another 150 and another 250. How do we ever make a microphone preamplifier when the gain of the device can be so variable?

To answer this question, we first consider a mythical, "perfect" or "ideal" amplifier. We use this schematic to capture the idea:



Our mythical perfect amplifier has the expected power connections, to +5 V and to ground, and it has an OUTPUT (in this case, pin 1) and TWO INPUTS. The gain of this amplifier is infinite and the input impedance is also infinite – it consumes zero power from the input, and can produce infinite output power.

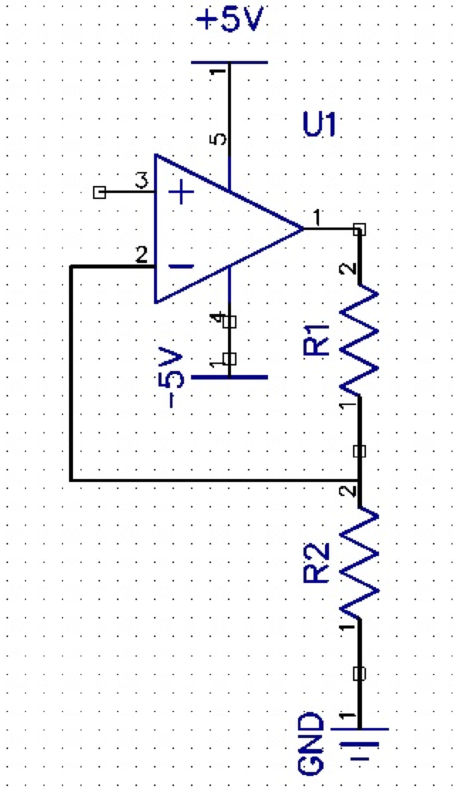
If you put a tiny positive voltage on the + (non-inverting) input (pin 3 above) the output voltage of this infinite gain amplifier will zoom upwards all the way to its limit – 5 V. If instead you put a tiny positive voltage on the - (inverting) input (pin 2 above) the output voltage will zoom downwards all the way to its limit – 5 volts.

If you short both inputs together, the output will go right to 0 volts.

Pretty cool amplifier, huh? (They actually make a pretty good imitation of this, and you can buy them for pennies....but more on that, later.)

Now...lets design a simple circuit where we take tiny bit of the OUTput and feed it back toward the input (“negative feedback”) and watch what happens:

NEGATIVE FEEDBACK



Lets assume that R2 is 1000 ohms, and R1 is 9000 ohms – so that whatever the output voltage is, 1/10 (10%) will be fedback to inverting input of our perfect amplifier.

Now realize that if there is ANY appreciable difference in voltage between the + and – inputs of this perfect amplifier, the output will ZOOM either upwards or downwards – so for all practical purpose, the ONLY time the amplifier stays put is when the + and – inputs have reached exactly the same voltage.

How does this circuit then respond if we give it a 0.1 volt positive input at the + (non-inverting) input? That will drive the output WAY UPWARDS – but then 1/10 of the output shows up at the inverting (-) input and that tends to drive it back DOWNWARDS –

The system will stabilize precisely when the two inputs are both at 0.1 volt – which occurs when the output is exactly 1 volt. At that point, 10% of the output 1.0 volt is fed to the inverting input (-) or 0.1 volts – and the input and output reach exactly the same voltage and the circuit comes to rest – with an amplification of exactly 10X.

An input of 0.1 volts DC has caused an output of 1.0 Volts – a gain of 10.

And in general, this perfect feedback amplifier will always have a gain that is precisely controlled by the ratio of

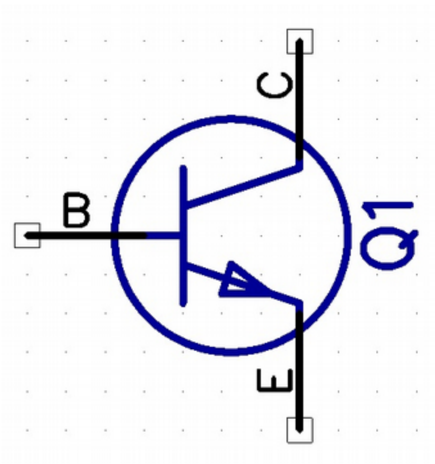
R2 / (R1+R2).

The gain will be exactly the inverse of this,

GAIN = (R1 + R2) / R2

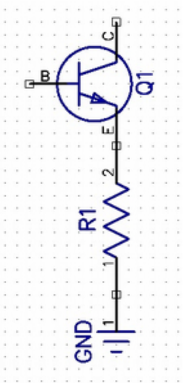
Now.... How do we apply this to a single transistor amplifier?

LOOKING CLOSELY AT A NPN TRANSISTOR



The transistor, when looked at like a small signal AC amplifier as we did in the previous lesson, responds precisely to the voltage DIFFERENCE between the Emitter and the Base. If the Base voltage goes UP a bit, versus the emitter, then the transistor will draw more current. So the INPUTS of the transistor, which looked at like an amplifier, are not the base and ground – they are the base and the **emitter**!

Let's put a resistor between the emitter and ground and examine what that resistor ends up doing – it does something very nice for us!



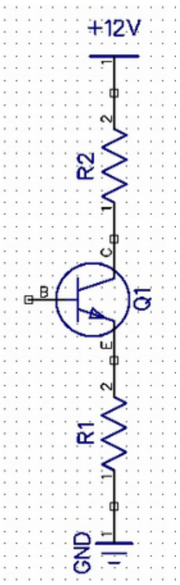
Suppose we put a bit of higher voltage on the base (versus ground). The voltage the transistor sees between its base and emitter terminals (its real "input") will have to go up a bit, because at least some of the voltage will end up there, and thus the transistor will conduct more heavily. But that will drive more current through R1 – increasing the voltage drop across R1 (by Ohm's Law) – and that means the voltage at the emitter will INCREASE somewhat --- and guess what, that DECREASES the effective input voltage (Base minus emitter) that the transistor sees!

This is an important point, so stop for a moment and be sure you see it.

That resistor, R1, has basically given us NEGATIVE FEEDBACK. It causes the emitter voltage to move in response to an increasing base input voltage...in such a way as to decrease the effectiveness of the input change. That’s negative feedback!

And we can use it to set a stable circuit gain, almost the same way as we did with the perfect amplifier we started this lesson with.

GAIN CONTROLLED AMPLIFIERS



Remember, for the moment we are ignoring the DC biasing of our transistor amplifier (that's for another lesson). We assume everything has been set up so that the transistor is happy, within its linear range (neither cut-off (no current flow) nor saturated (conducting as heavily as it can).

So from this happy quiescent bias state, in the above circuit lets assume R2 is 10K and R1 is 1K and lets have a transistor with a beta of "very large" (like > 500). And lets assume the input impedance of that transistor itself is somewhere within an order of magnitude of R1 = 1000 ohms, so that at least SOME of any input voltage (versus ground) will show up across the base-to-emitter input of the transistor itself.

Lets assume that we apply an input of 100 millivolts higher (versus ground) on the base terminal. What happens?

The 100 millivolts signal tries to increase the base current by as much as

I = E/R = 0.1 volt / 1000 ohms = 0.1 mA

But since the gain our transistor is "very large" like 500, this results in a VERY large increase in the collector current – and all that current has to course through the transistor and down through the emitter resistance also --- and it might have gotten to be as large as 500 * 0.1 mA more current = 50 mA more current --- but....

That if it happened would have raised the emitter voltage by 50 mA * 1000 ohms = FIFTY VOLTS!!!

Now that just can't happen!!! It would create such huge negative feedback (by driving the emitter to such a higher voltage that the input signal would be completely obliterated) –

So we can begin to realize that actually what will happen is that the current will increase only enough so that the input voltage change is pretty close to obliterated.....

In other words, the emitter voltage is going to increase by just about the same amount due to increased current carried by the transistor – the emitter voltage is going to increase by 100 millivolts! So that the transistor at its input sees a very very small change (we can't tell exactly how small but it might be only 1/10 of milivolt for example) from the 100 mV that came in from the stage or microphone input.

Thus the current in R1 is going to increase by almost

delta I = V/R = 100 millivolts / 1000 ohms = 0.1 mA

So the collector current – which makes up MOST of the emitter current, because the gain of this transistor is so high – is going to increase practically speaking by 0.1 mA

But that means the voltage drop across that 10K ohm resistor in the collector circuit is going to increase by:

V = I * R = 0.1 mA * 10,000 = 1 volt

Wow! Our 0.1 volt input change has resulted in an output change (in the opposite direction) of 1 volt – for an (inverted) gain of 10.

And now we have a small signal AC amplifier with a gain of 10. Most transistor amplifiers work exactly this way – they invert the signal. So if you put a 2nd stage after the 1st stage and invert it again, you end up with even more gain, and the same phase as you started with (if that is important to you)

So...the AC gain of a typical common-emitter amplifier is basically equal to

$$\text{GAIN} = \frac{\text{collector resistor}}{\text{emitter resistor}} = \frac{R2}{R1}$$

And this works any time we have a transistor that has some "excess gain." So in general, to design a transistor amplifier all we do is pick a transistor with a pretty high gain (the 2N3904 has a lot of gain!) and we set the AC gain of the stage by picking the ratio of the collector resistor to the emitter resistor.

Now…the exact VALUE of those resistors has a lot to do with the DC biasing of the stage – which we'll get to in a later lesson.