Diploma of Audio Production **Name________________**

Analogue Fundamentals (Audio Knowledge)

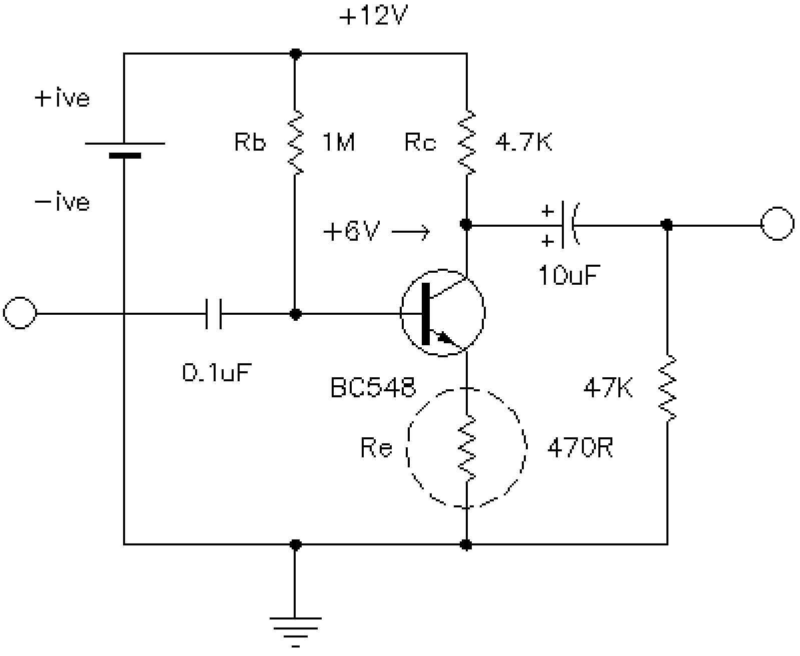
More on Semiconductors and simple applications

Module 14

Topic 1: A better analogue transistor amplifier circuit
Topic 2: Phase in circuits
Topic 3: Op-amps
Topic 4: The basic logic transistor circuit

Topic 1. A better analogue transistor amplifier circuit

We can improve the performance of this simple device by including a very important technique called "feedback" Feedback can be negative or positive depending on what we want the circuit to do.



In this circuit we have included a resistor (Re) in the emitter to ground connection. This means that when the current flow increases in the transistor due to a positive signal, a voltage drop occurs across Re, and this raises the voltage at the emitter causing the base-emitter voltage to ***reduce***. It effectively ***reduces the amplification*** factor of the transistor. This is called **'negative feedback'**.

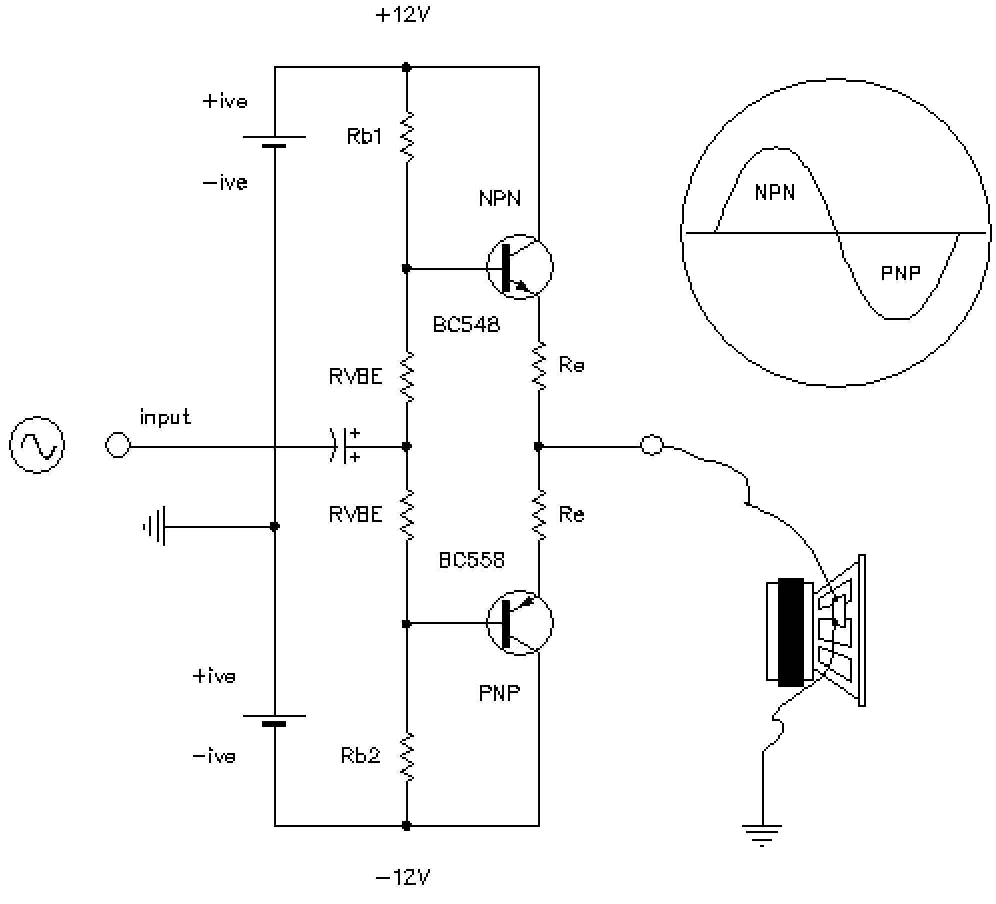
The really fantastic effect of this is that if there are artifacts in the output that were ***not*** present in the input, they are greatly eliminated. It effectively cancels distortion. The voltage gain of the circuit can now be calculated pretty much on the ratio of the resistors Rc & Re because they are carrying a series current.

So Av ≈ Rc/Re which = 4700/470 = 10. The formula for the gain of an **inverting amplifier** with –ive feedback is in fact:

$$A_V f = \frac{R_f}{R_2}$$

… where $A_V f$ is the voltage gain with feedback, R_f is the feedback resistor (in this case R_C), and the dividing resistor to ground is R_2 (in this case R_e).

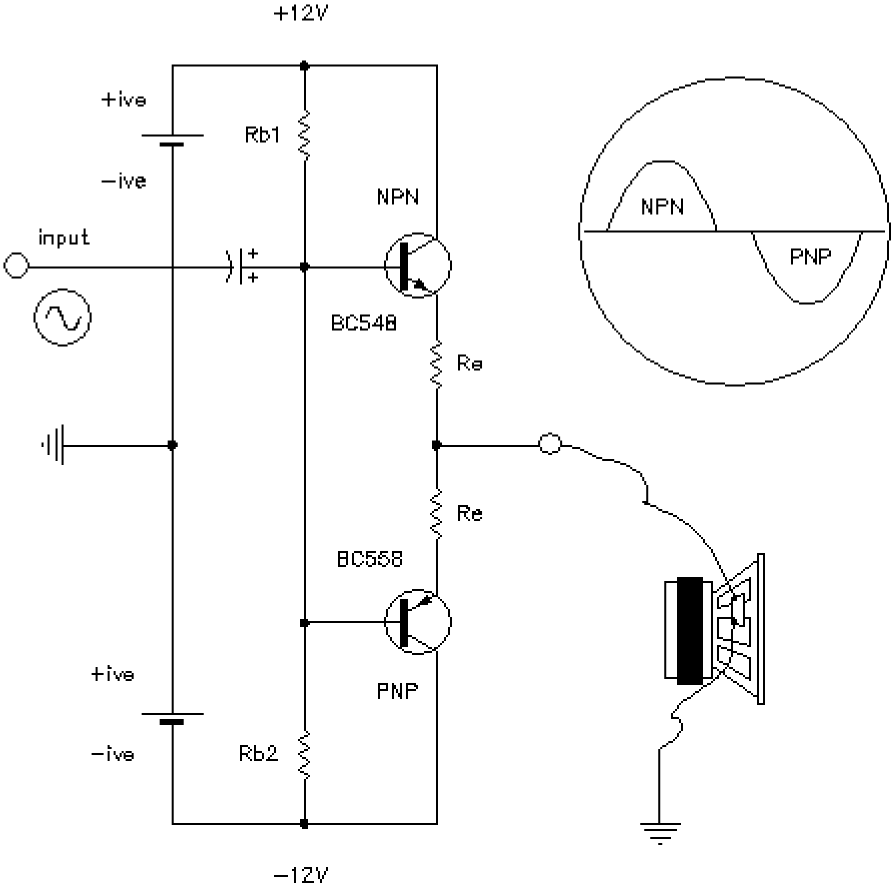
Most high power amplifiers use what is called a “Push-Pull” arrangement. To do this we add another transistor of the opposite type (a ‘P’ type) and allow each half of the wave to be handled by one transistor at a time. The NPN one will conduct with a positive voltage on the collector; the PNP will conduct with a negative supply on its collector.



When the top (NPN) conducts, the bottom (PNP) is turned off & visa versa. The transistors complete the circuit by conducting the + & - DC supply’s current through the loudspeaker, to earth and to the middle of the two batteries. Because the two batteries are earthed in the mid point of the + & - 12V, the two emitters of the transistors are at 0V with reference to earth. Most modern amplifiers use this system in one form or another.

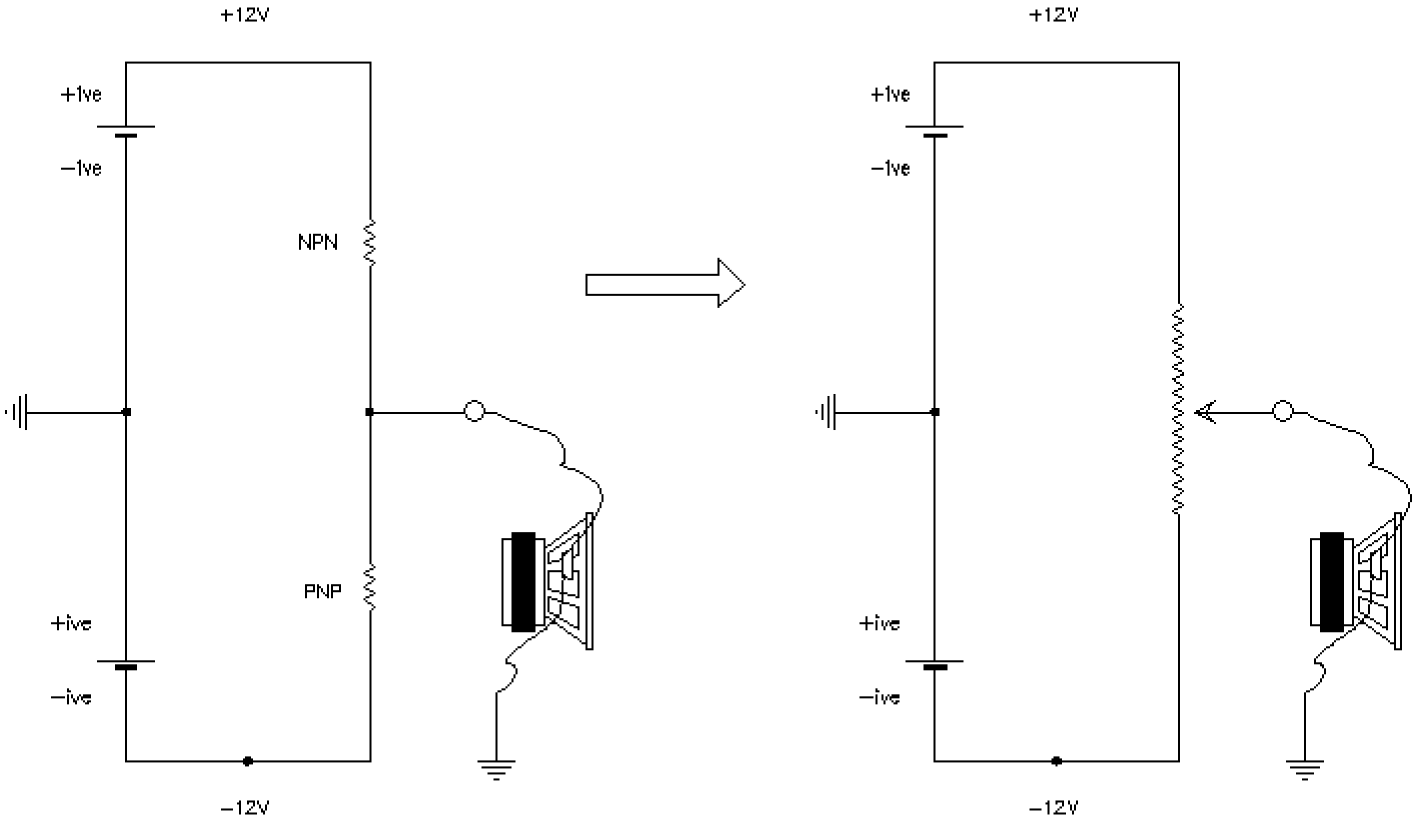
The resistors R_{B1} R_{VBE} & R_{B2} are there to supply a **‘bias’** to the two base/emitter junctions of the transistors. It is a series resistance circuit where the values would be chosen to give about 1.2 volts over the two base-emitter junctions (about 0.6 each) to enable the transistors to be just turned on – ready to go when a signal comes in, but not too much to overheat!! Note also that because the signal to the speaker is coming from the emitters of the two transistors, it is “in phase” with the input signal, or ‘non-inverted’, and the voltage gain (**A_V**), is actually slightly less than 1.

If we removed the forward biasing resistors on the transistors, the output would look more like this:



The waveform becomes distorted because it the input signal has to reach a certain voltage before the transistors ‘turn on’ and conduct. This distortion is called “**crossover distortion**”. Crossover distortion creates a lot of bad odd harmonic artefacts (3rd, 5th, 7th, 9th etc) that the human ear finds objectionable and harsh. Audio push-pull designs generally operate in **Class ‘AB’** mode where a certain amount of current is required to keep the power transistors turned on and ready for their part of the cycle. This greatly reduces the switching on distortion, but also means the transistors dissipate more heat.

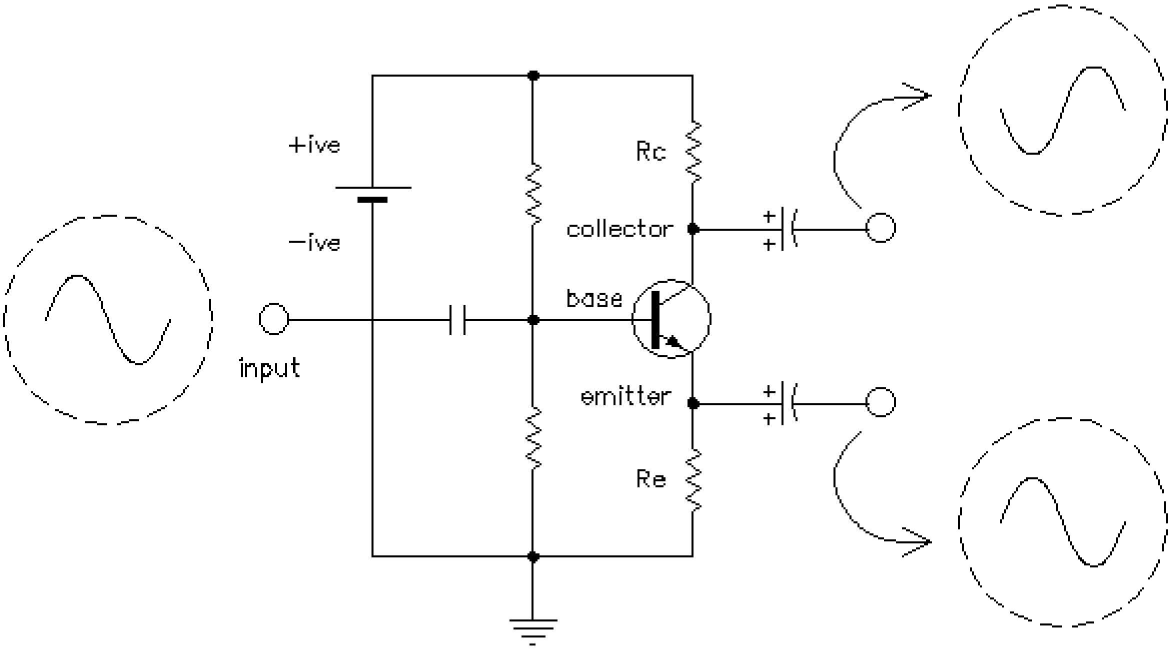
The equivalent circuit of a push-pull amp can be seen as two variable resistors conducting current from the power source to the load; they effectively shunt the + & - power supplies back and forth in synch with the input signal:



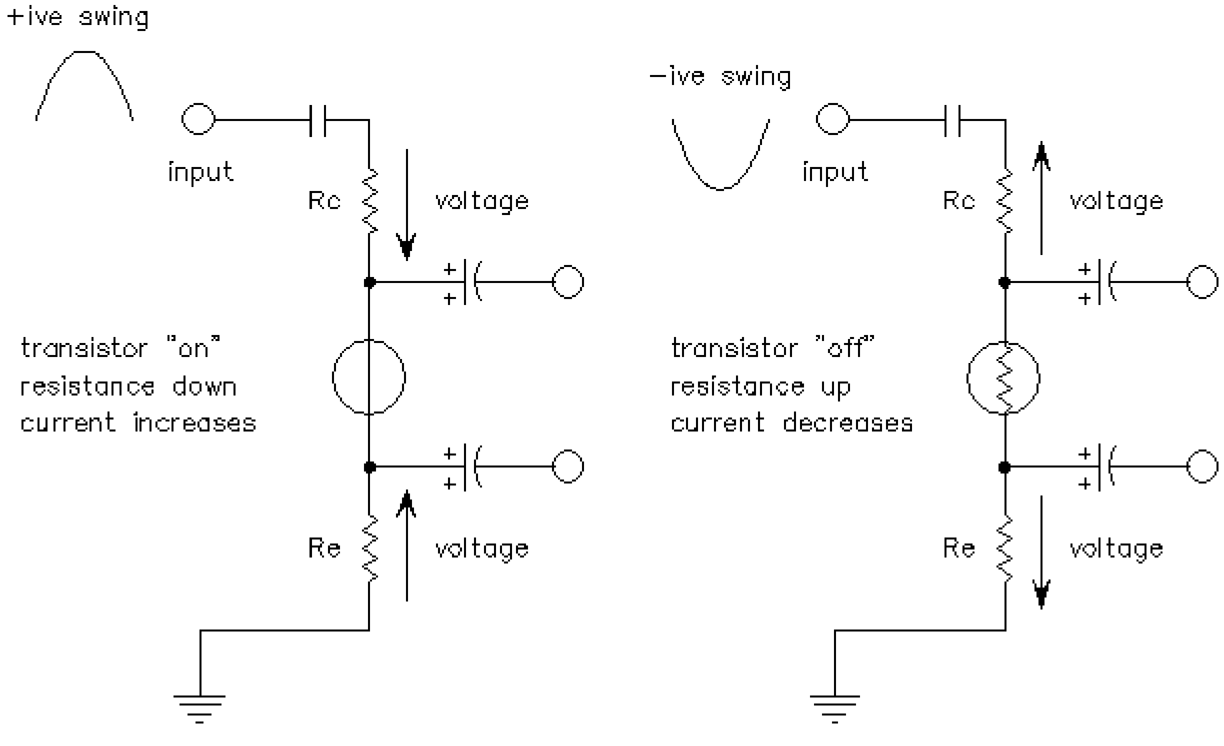
Push-pull designs are much more efficient than the simple “single ended” type of circuit we looked at before, which as you may recall, has a high amount of current flowing all the time. However single ended class ‘A’ power amplifiers are popular with some audiophiles because although fairly inefficient, and high in harmonic distortion, they don’t produce crossover distortion like a push-pull design. Most pre-amplifier circuits in audio use class ‘A’ designs because they enable the transistors (or valves) to operate in a way that produce the most pure (linear) signals. Because the amount of power used in small signal circuits is small, heat & power efficiency is not a big issue.

Topic 2: Phase in circuits

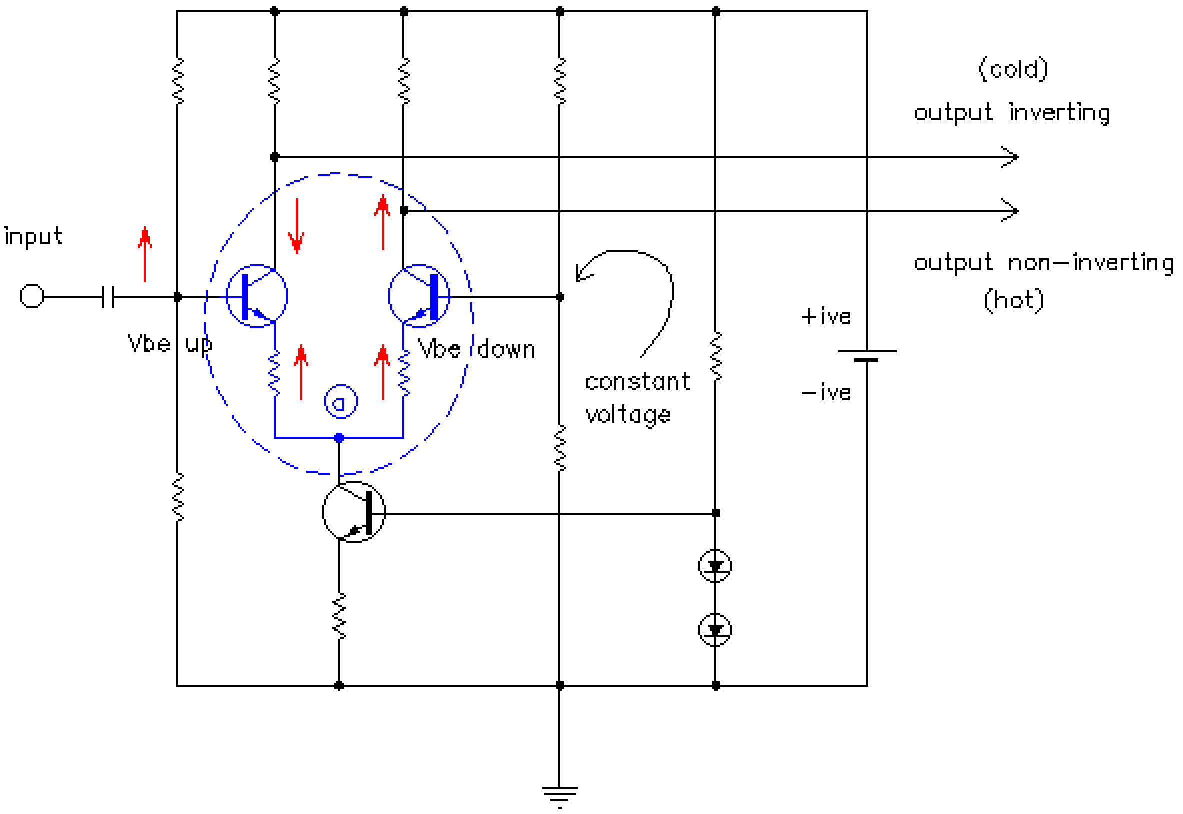
The little circuit below has two outputs: One in phase with the signal, and one 180º out of phase. If you think of it in terms of Ohms Law you will see why. When the transistor has a +ive input, it “turns on” and the increasing current through Rc causes an increasing voltage drop which ***lowers*** the voltage output. So the output from Rc is “inverted” i.e. 180º out of phase with the input signal. At exactly the same time, the same +ive input reduces the effective resistance of the transistor, and the voltage rises at the emitter – so the output from Re is in phase with the input - **non-inverting**.



The equivalent circuit would look like the one below:



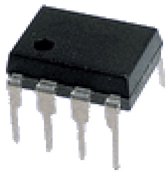
A much better way of splitting phase is to use what is called a **"Differential Amplifier"**, sometimes called a "Long Tailed Pair". This gives a much more linear output because the difference in the amplification characteristic of one transistor is ***mirrored*** in opposition by the other one in the pair. When one transistor is conducting due to the input signal, it causes the other one to turn off, and visa versa. This happens because they are sharing the same emitter current source.

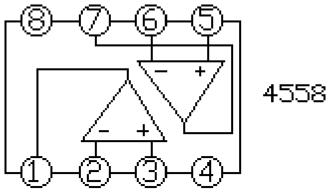


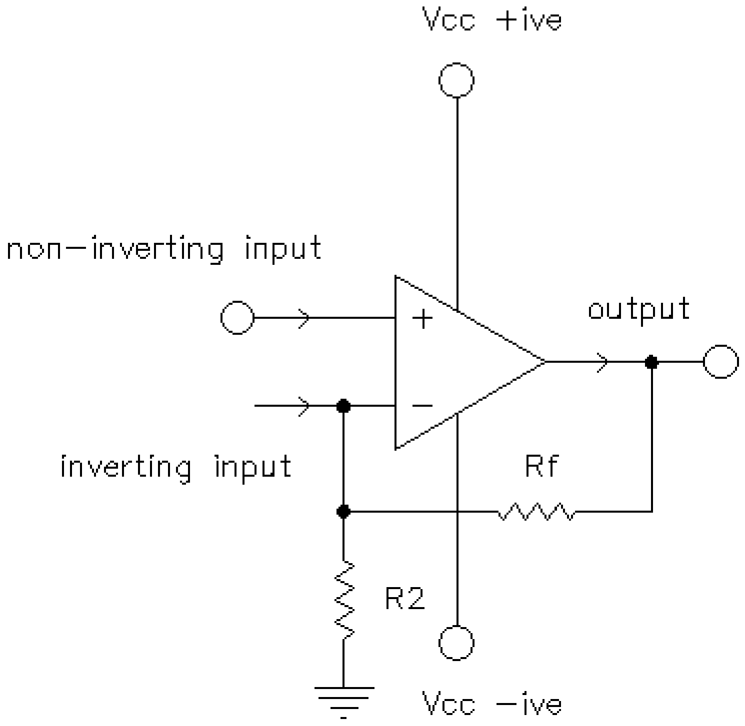
When the transistor (on the left) with the input signal is turned on, it raises the voltage at the point '@' (Ohms Law!). This reduces the **V_{BE}** of the transistor on the right (who's base voltage is held constant), and turns it off – so the voltage at output goes up. So the action of the two is 180° out of phase. This cancels the problem that most amplifying devices like transistors don't amplify the same amount throughout their operating currents and voltages. They are not particularly linear in their operation. Most high quality pre-amp and pre-driver stages in audio circuits and Op-amps (see below) use this sort of arrangement.

Topic 3: Op-amps

Most modern analogue devices such as mixing desks use integrated circuits, which are complex circuits, put on a single wafer or chip. Operational amplifiers are highly useful signal amps that are high performance, and can be used in a variety of applications. They utilise DC coupled circuitry; that is, they don’t have capacitors coupling the various stages inside. They have very wide frequency response, very high “open loop” voltage gain (> 100,000 is typical). Open Loop gain is the gain of the op-amp before the application of negative feedback, referred to as $\mathbf{A_{V\,OL}}$. They have inverting and non-inverting inputs, and run with a +ive and –ive supply of typically 5 ⇨ 18V DC.







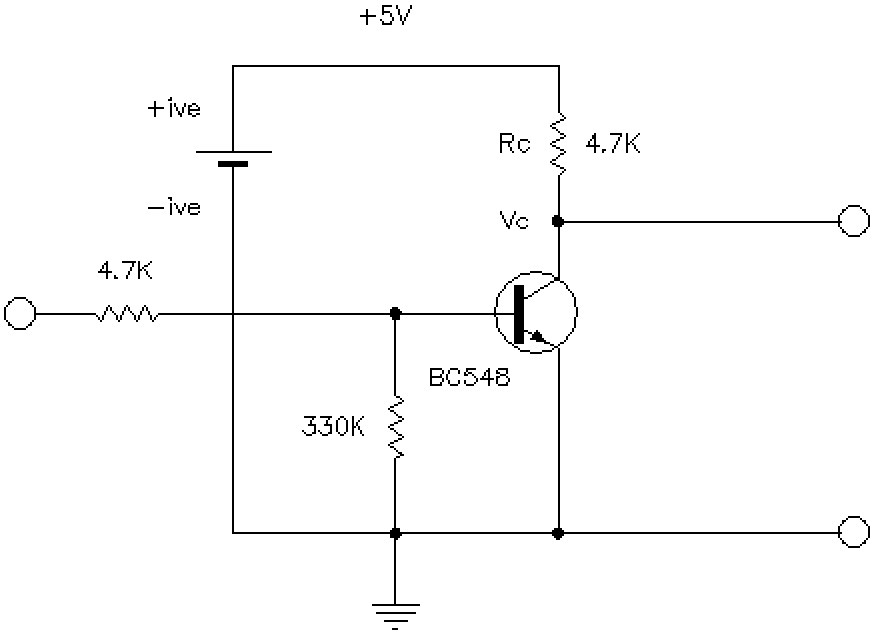
Because they have such high gain and wide frequency response, they are very useful with simple feedback circuits such as filters and so on. In this diagram the op-amp is being used with a “non-inverting” output, and the –ive input is being used for negative feedback. The formula for the gain with feedback is:

$$\mathbf{A_V}\boldsymbol{f} = \mathbf{1 + \frac{R_{\boldsymbol{f}}}{R_2}}$$

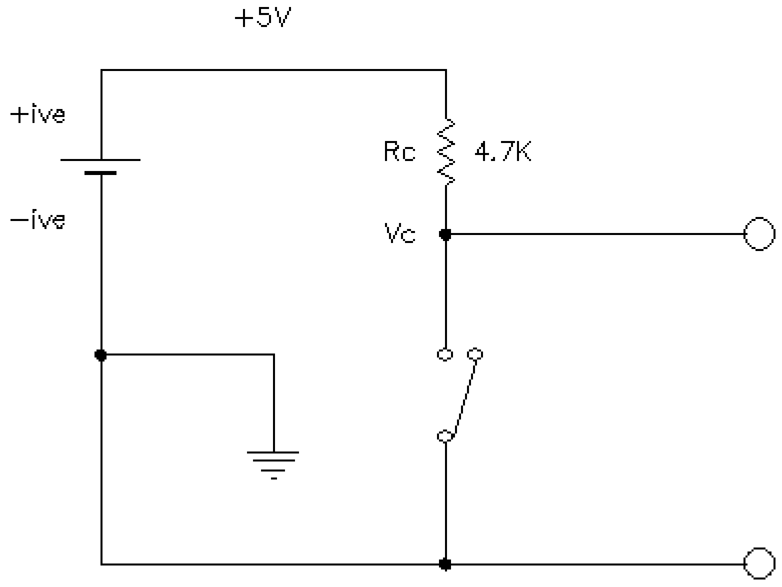
E.g. If $\mathbf{R}_{\boldsymbol{f}}$ was 10K Ω and $\mathbf{R_2}$ 1K Ω $\mathbf{A_{V\boldsymbol{f}}} =$ 1 + 10/1 which = 11. So if you put $1V_{PK}$ in you would get 11 * V_{PK} out (* providing the chip had sufficient +&- supplies).

Topic 4: The basic logic transistor circuit

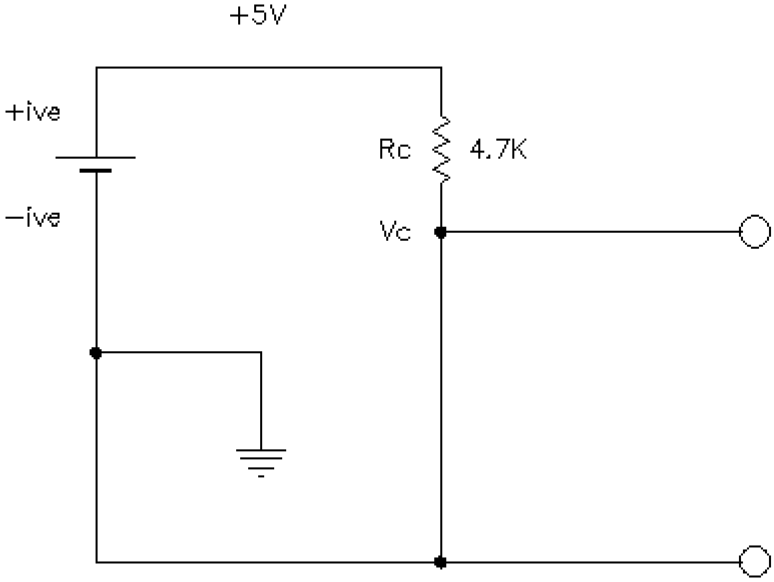
The little circuit below has a different function to that of an analogue amplifier. This is a switch circuit – it has just two basic modes; output +5V & output 0V. In the world of digital +5V = logic '1', and 0V = logic '0'.



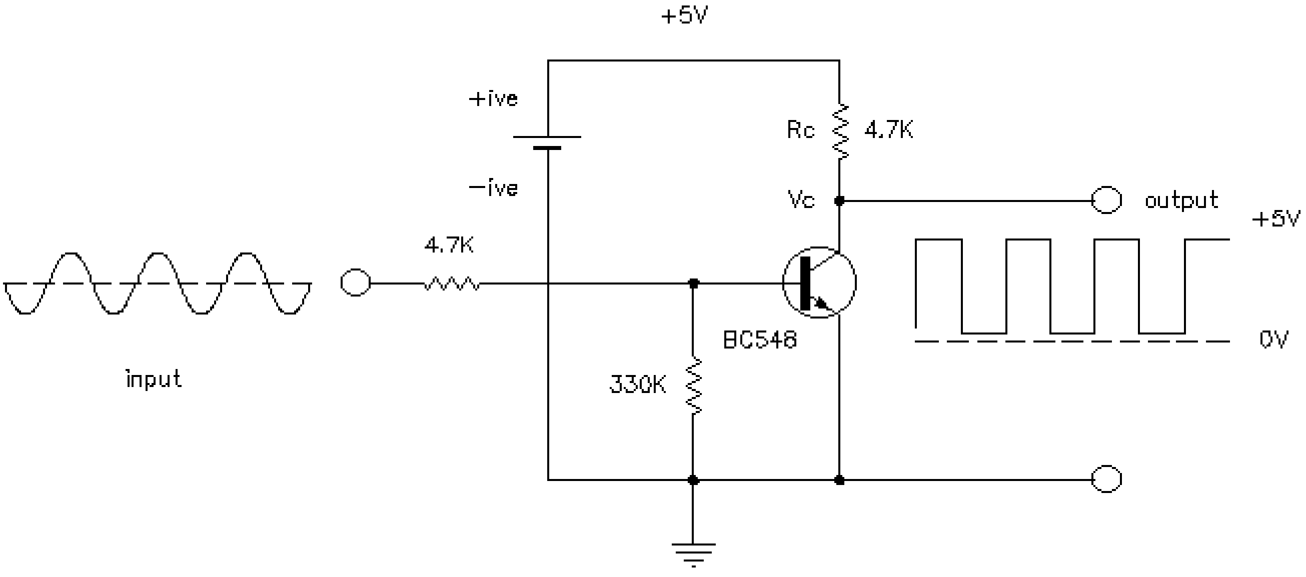
As you can see, there is a high value resistor connected from the base of the transistor to ground. This means that with no input, the base of the transistor is held down to ground (0V), and the transistor is switched 'off'. Because no current flows through Rc from Vcc (+5V) to ground, the voltage ***drop*** across the resistor Rc will be, using Ohms Law **V = IR** ≈ 0. This means that Rc will pass through the full +5V from V_{CC}. The equivalent circuit would look like this:



If a voltage is applied to the input through the 4.7K resistor, it causes a small current to flow through the base-emitter junction of the transistor. This causes the transistor to “turn on” and become like a closed switch. Using the principal of a series voltage divider the circuit would then look like the diagram below:

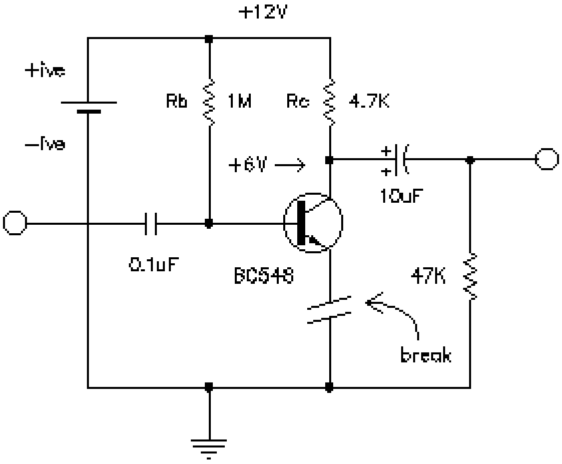


As you can see, the output voltage would be pretty much 0V, because the transistor is acting like a switch and shorting to earth. All the +5V will be dropped over Rc and the earth side will be at ground potential = 0V. So, depending on the input, this circuit just switches between two states. One of the characteristics of a transistor used in this manner is that, because it is either on or off, it behaves like a resistor which switches between very high, and very low resistance. Hence, the heat dissipated across the transistor is minimal. Because **P = IR^2**, when the transistor is “off”, **I** is virtually zero and **IR^2 ≈ 0**. When the transistor is switched on, its resistance **R** is very low, so **IR^2 ≈ 0.** If we stick a sine wave into a circuit like this, what comes out is close to a square wave. This is called a saturation amplifier because it is like a switch – ‘on’ or ‘off’.



Questions:

1. What effect on the output would a break in the connection have on the little single ended circuit below (due to damage say)? Assume it is being fed with a sine wave to the input.



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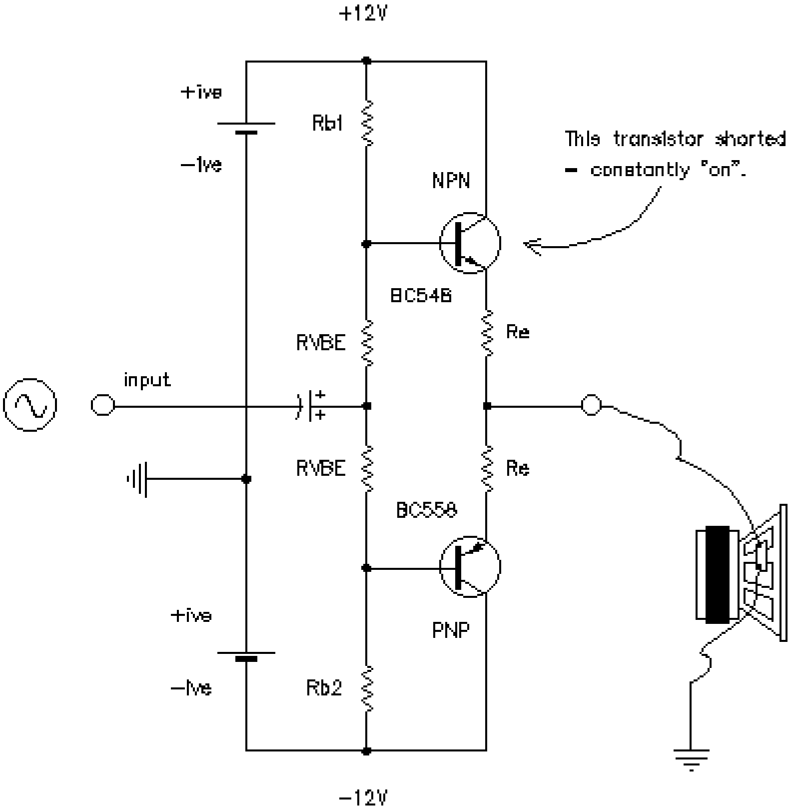
2. What effect would the output of this push-pull circuit be into the speaker if the top transistor was 'shorted out' (due to damage say)?



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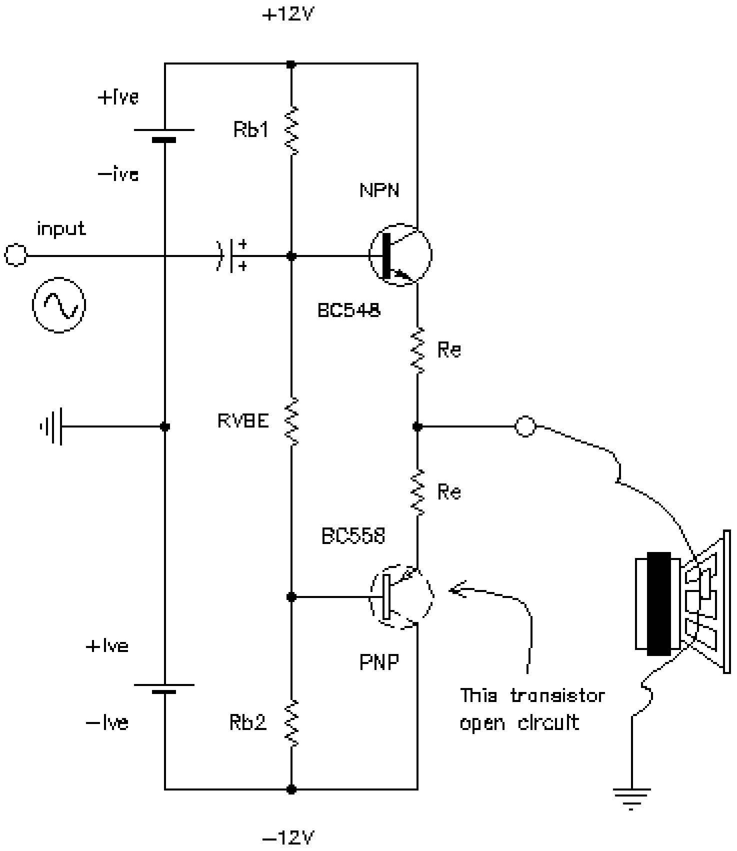
3. What effect would the output of this push-pull circuit be into the speaker if the bottom transistor was ‘open circuit’ (due to damage say)?



4. What do you think would the *approximate* theoretical maximum RMS power available in the push-pull amplifier circuit below given that the power supply voltages available are + & - 12V DC, and the speaker is 8Ω?