The Transistor Amplifier

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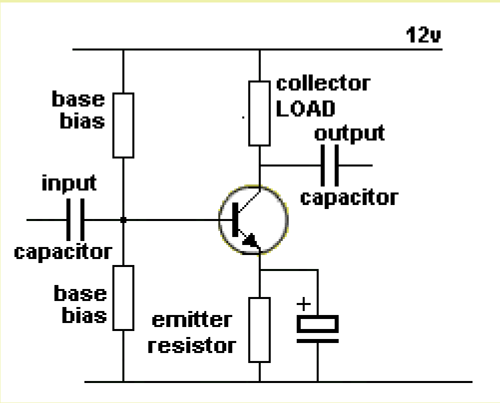
This article is in response to all the **YouTube** videos from instructors who don't have a clue about how to design a transistor stage and are just teaching RUBBISH. You will see what we means when you go through this discussion. You cannot design a stage unless you know the current-capability of the previous stage and the input impedance of the stage that follows.

STARTING

A small-signal stage is a Self-biased Common Emitter Stage. It should be designed to pass 0.1mA. The next stage can be an H-Bridge Stage passing 1mA and then an Emitter-Follower stage capable of delivering 100mA or more.
Start by selecting a collector load resistor to pass 0.1mA and then experiment with a base-bias resistor to create half-rail voltage on the collector.

The stage we are going to study is called a COMMON-EMITTER self-biased stage. More accurately it is called a "small-signal" CE amplifier.

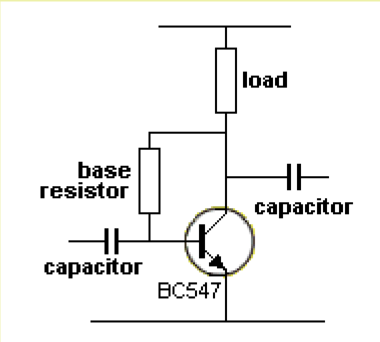
There are two ways to layout the components:
The H-Bridge:



H-bridge circuit

The H-Bridge uses more components and requires more current. It can have a fixed gain but the self-biased stage seems to have an overall gain of 70, no matter what the gain of the transistor. So it is universal. I have not covered the H-Bridge as it offers no benefit and just requires more components and takes more current.

The **self-biased stage:**
It uses 2 resistors, called the **base bias** resistor and **collector load** resistor: This circuit will work from 3v to more than 9v.



Self-biased stage

The value of the resistors are chosen so the collector is about half rail voltage. This allows the transistor to deliver a signal nearly equal to the value of the rail voltage to the following stage.
We are not going to use any mathematics or equations. But we are going to give suitable values so you can experiment.
A small-signal amplifier stage has a load current from 0.1mA to 1mA - NOT 10mA
A small-signal amplifier stage has a gain of 50 to 70. NOT 10.

The stage is called an **AC STAGE** or **AC amplifier** as the input and output have capacitors so the stage is not affected by any other voltages. It is separate and isolated from the voltages on the previous and next stage. It generates its own set of voltages.

The value of the input and output capacitors depend on the frequency you are amplifying and the values of 22n for the input capacitor and 100n for the output capacitor are good for experimenting at audio frequencies.
With the values we have chosen, the stage will produce a gain of 70 and this means the amplitude of the signal will increase 70 times with an input signal of 20mV.
The output signal will be about 1400mV when the stage is connected to a following stage with medium impedance.
The stage we are designing will operate on a supply of 3v to 12v and generally have a load current of 0.1mA to 1mA. With higher currents you can get background noise.
This noise is generated in the resistors and the transistor and if a high current is passed in an electret microphone the noise is like bacon and eggs being cooked. A higher current is wasteful and shows you don't know how to design a stage.

You cannot work out the gain of the stage with any formulae or mathematics. You just have to accept this value from the many experiments we have conducted and the hundreds of modules and circuits we have made and sold: (over 300,000).
Sitting down with pen and paper and mathematics show your complete lack of understanding of electronics. Transistors have enormous gain variations and can operate

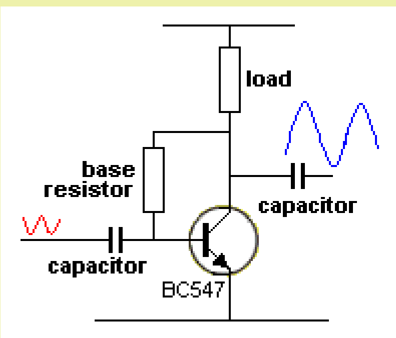
completely differently than expected. They have hidden zener features and current limitations and power dissipations and losses, you never expect.

A Little bit of Background

The self-biased stage is actually the stage we are referring to. It has a base-bias resistor of about 1M or more and it puts almost no load on the incoming signal.
The H-Bridge can be designed with high biasing values but generally puts a higher load on the previous stage.
Electret microphones, dynamic microphones, pick-up coils and some Light Dependent Resistors deliver a very small current and that's why the self-biased stage is used.

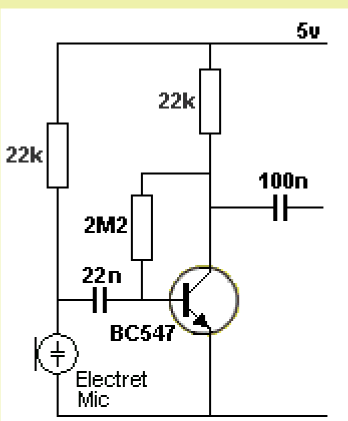
How the stage works and why you only get a gain of 70.

When a rising input signal enters the base, the transistor amplifies this about 200 times and the collector voltage falls. The current through the base-bias resistor falls and it reduces the effect of the incoming signal. That's why the transistor does not get the full effect and the gain is not as high as expected.
When the input signal falls, the transistor is turned off and the collector voltage rises. But now the base-bias resistor supplies more current to the base to turn it ON and this works against what the signal is trying to do. The end result is a gain of 70.
The following diagram shows the input signal is falling and at the same time the output signal is larger but rising. They are "out of phase" with each other.



The output is "OUT OF PHASE" with the input

The following circuit shows an electret microphone connected to the input of the self-biased stage and the component values to get a gain of 70.



Component values and

Connecting an electret microphone

Matching the impedance of the electret microphone to the input of the amplifier.

This is something you cannot work out. You just have to take my advice.
The LOAD for the microphone stage is 22k. The input of the self-biased stage is about 3k to 5k as this is the effect of the base-emitter junction.
You can see these two values are an enormous mismatch and that's why we get the figure of 70 for the gain of the circuit.
The 22n also produces a considerable loss in the transfer of the signal and you can get a CRO to see the losses.

When you see the signal on the electret is 20mV, this voltage is not passed to the base of the transistor as a voltage. It is converted into a current.
What happens is this: The electret turns off a small amount and the voltage rises 20mV. This rise is passed through the coupling capacitor to the base of the transistor.
The current associated with this rise is passed to the base of the transistor. The current is determined by the value of the load resistor on the microphone. There is no way we know how much current is associated with this rise as the capacitor is charging at the same time and removing some of the energy. Whatever current is detected by the transistor is amplified 200 times and some of the effect of this is delivered to the output capacitor and to the next stage. But the output capacitor and the next stage absorbs some of the energy that the transistor is able to deliver and that's why, in the end, the result we see is a gain of about 70.

INPUT - OUTPUT CAPACITORS

The value of an output capacitor should be 10 times larger than the input capacitor because the output will be handling a higher current and the resistors around this part of the circuit will be much lower than the value of resistors on the input.

3 simple questions:

1. If the transistor in a self-biasing stage is replaced with one having higher gain, what will happen to the collector voltage?

2. If the base-bias resistor in a self-biased stage is increased, what will happen to the collector voltage?

3. What is the ratio of input to output capacitor values?

As you can see, the real way the circuit works is completely different to anything that has been explained in any text book. Unless you know how a circuit works, you cannot find and fix a problem.

Answers:
1. The collector voltage will fall. 2. The collector voltage will rise 3. Output capacitor is 10 times larger.

THE TRUTH

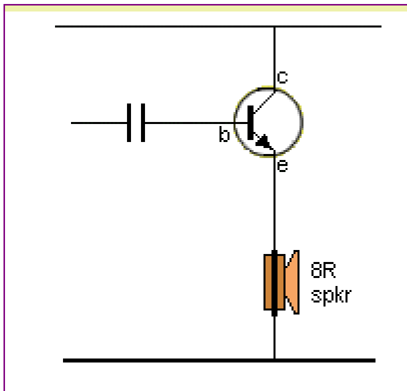
Now we come to the truth.
You cannot design a circuit without knowing the characteristics of the stage before and after the self-biased stage you are designing.
All the instructors on YouTube don't have a clue about designing a stage. They have **never**

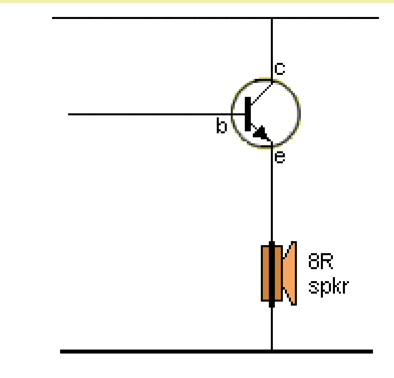
designed a circuit in their life.
The effectiveness of an input signal depends on its CURRENT-CAPABILITY. In other words, the IMPEDANCE of the signal - the strength of the signal being supplied by the electret microphone stage.
You will notice the electret microphone does not "drive" the signal into the self-biased stage, but the microphone turns OFF and the current IT DOES NOT TAKE is passed to the stage via the LOAD resistor, through the capacitor to the base we are designing.
It's a bit like you earning $1,000 a week and you spend as much as you want and the odd change at the end of the week is given to your family to buy food. They won't get much.
And the amplifier does get much either. It only gets a 20mV rise via a 22k resistor. This energy passes through a capacitor that absorbs 30% (as it gets charged during this time).
There is very little left for the transistor amplifier.
The incoming signal sees the base of the transistor as a 5k resistor (resistance - impedance).
In simple terms the 22k becomes 40k (due to the losses incurred by the capacitor) and now it is passed into 5k. This becomes an enormous voltage mismatch and that's why we can only deal with it as an "energy package."
But if the 22k load resistor was 1k, a lot more energy would be transferred. That's why you really cannot make any calculation because you don't know the real impedance of the base-emitter junction and you don't know how much energy it gets.
The same applies with the output.
If the stage (following the one we are designing), is removed, the amplitude of the signal on the collector of the self-biased transistor may be as high as 2,000mV. But when the following stage is connected, it will drop to 1,400mV or even lower.
This is because the base-emitter junction of the following stage and the effect of the output capacitor create a voltage-divider with the collector load resistor.
So, the gain of the stage we are designing depends on the input impedance of the stage that follows.
We can increase the gain by reducing the value of the load resistor on the collector and reducing the value of the base-bias resistor so the stage sits at half-rail voltage but it draws a higher current. Or we can reduce the impedance of the input of the stage that follows.

But this is only half the story. You cannot start to design a stage until you know: "**what you are driving into**." You need to know the input impedance of the stage that will follow.
That's why none of the videos on the web have any value.
They are just a JUNK presentation.

I have seen so many videos on YouTube with instructors following each other with descriptions of how to design the stage.
In fact ALL OF THEM ARE WRONG
You design the stage BACKWARDS.
The 3 critical components are the EMITTER RESISTOR, THE LOAD and the OUTPUT CAPACITOR.
These 3 components will decide the output swing.
If the LOAD is directly coupled to the emitter, the circuitry is simple.
But when the output is coupled via a capacitor (electrolytic) the output will be affected by the surrounding components.
What most instructors fail to take into account is the DISCHARGING of the capacitor and the second cycle will fail to perform.
That's why taking only mathematics into the equation will give you a failed design. You have to know how the circuit works to create one that works.

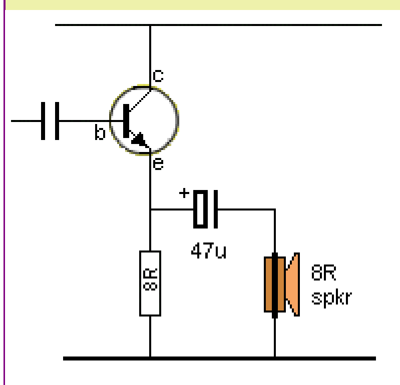
An **emitter-follower** stage is also called a **common collector** stage and it puts very little load on the stage that is driving and it drives into a very low impedance load.
In other words it has a very high impedance input and a very low impedance output.





The input needs to have an amplitude equal to rail voltage and only requires about 1/100th the current into the load. We say the transistor is a **driver transistor** and the stage is an **output stage**.

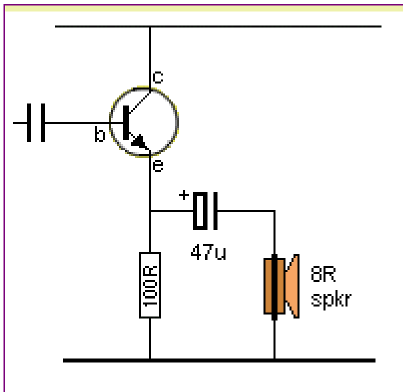
This is the ideal way to drive a LOAD. It is called **DIRECT COUPLING.**
When the base is raised, the emitter follows with about 100 to 200 times more strength.
You need a lot of "strength" (current) through the coil of the speaker to move the cone and create a loud sound.



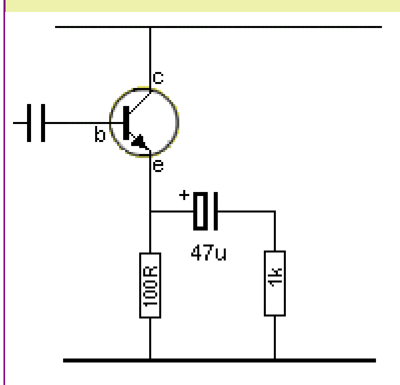
The circuit has NO LOSSES. There are no other components and thus NO LOSSES.
If the input signal remains HIGH, full current will flow through the coil of the speaker but it will not make any sound and just get hot. That's the disadvantage of this circuit. The input must be oscillating at all times.

If the input has the possibility of remaining HIGH, the solution is to add a capacitor to the input. But it will introduce LOSSES. These losses can be from 1% to 99%With the capacitor, the current flows through the coil of the speaker when the input signal is rising and slightly less flows when the input signal is falling.
If it stays HIGH, current will stop flowing through the coil of the speaker because the capacitor will charge and the base voltage will drop to almost zero.
This means you have full control of the current through the voice-coil when the input signal is oscillating or when it is stationary, and the speaker will never get hot.
But you will have less control over the current when the signal is falling. because the capacitor is charging and some of the amplitude of the input signal is being lost.
When the next cycle is delivered, the capacitor is partially charged because there is no component to discharge the capacitor. The base emitter junction allows the capacitor to discharge to about 0.7v, but this value remains on the capacitor. And the capacitor may not have time to fully discharge due to the frequency of the input signal and an even higher charge may be present.

To reduce these problems, this is the next improvement to the circuit.
The speaker is now **AC coupled** to the output of the emitter-follower. This means it is **capacitor-coupled**.
The load resistor is 8R, the speaker is 8R and a large capacitor is added to transfer as much energy as possible.
The resistance (capacitive Reactance) of 47u at 2kHz is only 2 ohms and it will have little effect on the transfer of energy.
Now we have a surprising advantage. The capacitor becomes a miniature battery and it gets charged when the input is rising and when the input falls, the positive lead of the 47u sees a falling voltage and the other lead of the capacitor falls about the same amount. This pushes a negative voltage through the voice coil and makes the cone move in the opposite direction. All the energy in the 47u is transferred to the speaker to produce a louder effect.

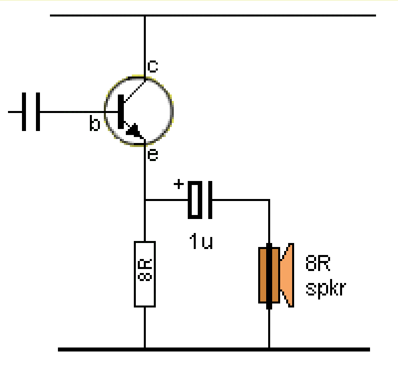


We have actually produced almost twice the amplitude of the signal into the speaker.
This feature is so important that we will cover it in more detail.
Suppose the emitter is pulled HIGH. During this time the capacitor will charge and the charging current will actually flow from the 0v rail and up through the speaker to the capacitor. We have to describe it this way so you understand what is happening. When the emitter is as high as possible, the capacitor will be fully charged and the current through the speaker will drop to zero.
The base voltage starts to fall and the transistor does not deliver as much current through the 8R resistor. But the 47u is fully charged and it is like a miniature battery. Replace it with a battery symbol to see what is happening.
Suppose the 8R had 10 volts across it and the capacitor (battery) has 6v. The energy in the capacitor (battery) will start to flow through the voice coil and as the voltage across the 8R resistor reduces, the positive of the electrolytic starts to fall and and this makes the negative lead fall and not only will it fall by the voltage in the capacitor but by the 10v across the 8R. This current creates magnetic flux in the opposite direction and pushes the cone in the opposite direction and the speaker sees a waveform that is larger than the input waveform.
Putting this phenomena another way, the charging current through the speaker puts a positive on the top of the speaker. When the capacitor is discharging, the speaker is effective "flipped over" and the top terminal of the speaker is below the 0v rail and becomes negative.



Now we look at fitting different (wrong) value component to the output.
If we fit a high value resistor as the LOAD, This is what happens:
The output becomes a closed-loop with the capacitor as a battery and passing current through 8R and 100R in series.
You can see the current will be a lot less than the circuit above where the resistance is 16R.
But in the circuit above, the voltage across each component will be about 50%. In this circuit the voltage across the speaker will be about 10%. So the energy will fall from 50% to 10%. This is called a miss-match.

This arrangement creates a miss-match because the circuit is required to deliver a lot of current through the 100R load resistor, whereas the 1k is only going to use 10% of the current.



The coupling capacitor is too small. We said the 47u has a capacitive reactance of 2 ohms. The 1u will be 100 ohms.
It will charge very quickly during a cycle and all the rise in voltage from the transistor will be lost in the capacitor. The speaker will get almost nothing.
And it will have very little energy to provide reverse voltage to the speaker. The result will be absolutely zero output from the speaker.

INPUT IMPEDANCE OF THE EMITTER FOLLOWER STAGE

The input impedance (resistance) of an emitter-follower stage is about 100 times greater than the resistor connected to the emitter. Basically we say it is the gain of the transistor. So, if the gain is just 20, the input impedance will be 20 times greater.
Why worry about accurate figures when the transistor can alter considerably with the current flow? You just have to know approximately what to expect.
That's why we say it puts very little load on the previous stage.
Don't forget, the previous stage is a MEDIUM CURRENT STAGE and has DRIVING CAPABILITY.

THE INPUT CAPACITOR

The input capacitor has an effect on the maximum voltage into the emitter-follower stage. The signal before the capacitor will be nearly rail voltage and the capacitor will charge slightly during the signal-rise and reduce the effect of the emitter-follower stage.
You don't need any complex mathematics but an understanding of how to work out approximate values.
We said 1u has a value of 100 ohms at the mid frequency we are amplifying and if the output is 100mA, the input will be about 1mA.
Doing a simple DC calculation of 1mA through 100R will produce a voltage of V=IR = .001 x 100 = 0.1v In other words, the loss will be almost zero. All the AC calculations will be a lot less.
I am against doing complex calculations because the gain of the transistor may be 200 or as low as 50, and nothing will get you closer to an actual value.

SUMMARY

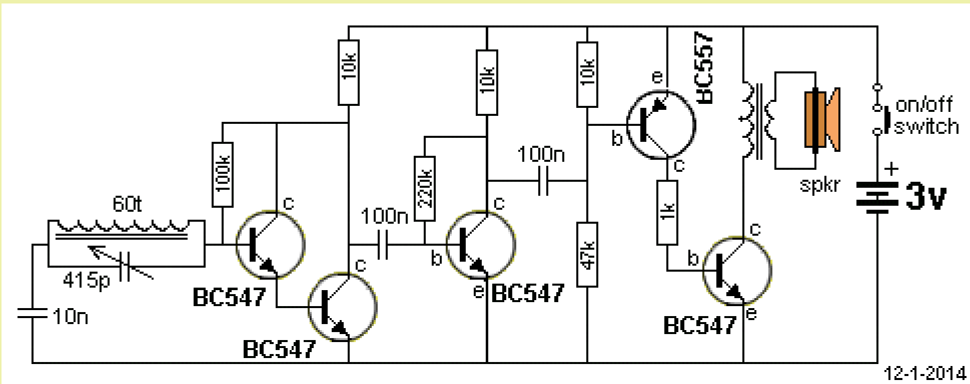
You can see the output components have a very big effect on the transfer of energy and the electrolytic actually improves the performance due to it providing a **REVERSE VOLTAGE**.
Once you have worked out the necessary output components to provide the maximum transfer of energy, you can decide on the type of driver transistor and the AC input coupling capacitor.
None of this has ever been covered in any text books.

That's why all text books, University courses, YouTube channels and demonstrations fail to mention these extremely important facts because none of them have made, tested and fixed any of the circuits they are talking about.

Designing actually works in . . . REVERSE . . . . BACKWARDS.
You can also think of it as working from BASICS - - - WORKING from the START.
Working from the BEGINNING. Working from the ELEMENTS.
And only advancing very slowly in small steps and stages until the project works perfectly .
That is how I design projects and modules that no-one else in the world has designed. It

looks simple in the end, but getting there is an art.
It might take longer but it is the ONLY WAY.

We are now going to discuss combining (connecting) (interfacing) one stage with another.



Here is a circuit that may look complex, but it shows exactly what we are talking about.
It is an AM radio of 1980.
The signal from the tuned circuit may be 10uV and 1uA and the first transistor of the Darlington Pair improves this by a factor of about 100.
The Darlington configuration turns two transistors into a single transistor with enormous gain.
It puts very little load on the tuned circuit and does not affect its ability to tune distant stations. This stage is connected to the next stage with 100n capacitor and the output of the second stage is connected to a driver/output that has a low input impedance. The main purpose of the final section (consisting of two transistors) is to amplify the current to drive the speaker transformer.
These are all the things we are discussing and the circuit is/was a practical example of an AM radio, in the days when AM sold millions of "Pocket Radios."

Normally, one stage is connected to next with a capacitor and most of the calculations are done by determining the resistance (capacitive resistance - called capacitive reactance) of the capacitor at a specified frequency.
But no-one has explained what is actually going on with this connection and why this interfacing is very inefficient. The only reason why most circuits work is due to the high gain of the transistors and even though the biasing and coupling of stages removes a large amount of energy, the final result of two stages is quite impressive.

The first thing you have to understand is this: The transistor in the first stage does not "push" or "drive" energy to the next stage.
When the transistor turns OFF, the voltage on the collector LOAD rises and this rise, associated with the current that can be supplied by the load resistor is passed to the next stage.
For instance, when a 10k resistor has 5v across it, the current capability of the resistor will be 0.5mA.   But if the stage is sitting at mid rail, this current is 0.25mA.
As the collector voltage rises, the voltage across the load resistor reduces to say 1v, and the current capability reduces to 0.1mA
You can see the real current from the stage is a lot less than expected.
What we are talking about is a package of energy from one stage to the next. This has never been discussed before and that's why no-one understands how "combining stages" works.

Of course it is much better to DIRECTLY COMBINE STAGES, but this is sometimes not possible and other times it requires a lot of circuit design.
This packet of energy is transferred to the next stage via a capacitor and the capacitor will always have a voltage across it as one stage is at mid-voltage and the other will have a low voltage on the base.
As the voltage on the load resistor decreases, less and less current is available from the load resistor and this means the capacitor gets charged slower and slower.
But at the same time it gets charged and so the rise on the top plate of the capacitor does not pull the bottom plate as high. So a lot of the energy goes into charging the capacitor and the following stage does not see much of the energy.
When the transistor in the stage we are studying is turned ON, the voltage on the load resistor increases and the voltage across the coupling capacitor reduces and the capacitor is put into a "discharging condition." If you slowly reduce the voltage on the top of the capacitor, it will discharge by delivering its energy into the base of the transistor. But as soon as the voltage on the lower plate of the capacitor reaches 0.55v, the current into the base ceases as the base does not accept any current when the base falls below 0.55v.
This means you might still have voltage (and energy) across the capacitor that has not been removed and when the next cycle takes place, the capacitor is already partially charged.
This means the capacitor will not be able to transfer the same amount of energy as in the first cycle and that's why the capacitor becomes such a poor transfer component. A resistor between base and zero volt rail will improve this is the answer to why they have been included.
And that's why you will find some of your circuits DON'T WORK AT ALL.
The only reason why the circuits work AT ALL is due to the high gain of the transistor and all these losses bring the final gain of many stages to about 70.
You have to be able to visualise this action to see why your circuit is not performing as well as expected. Especially when high currents are involved.
Most data sheets show transistor gain at 1mA or 10mA. When you increase this to 100mA, the gain drops considerably. That's why NOTHING can be calculated.

It is pointless doing any calculations as you have no idea of the gain you will get from each transistor or the value of the current-capability of the input signal or the impedance of the stage that follows.
If I could design a circuit with pen and paper, I would be a multimillionaire.
Things can work out much better than expected or not work at all. And it's when they don't work, that skill comes in - something that no University course has ever touched-on, because they have never had to design ANYTHING.
There is no skill in designing a circuit. The skill is getting it to WORK.

MORE ON THE H-BRIDGE

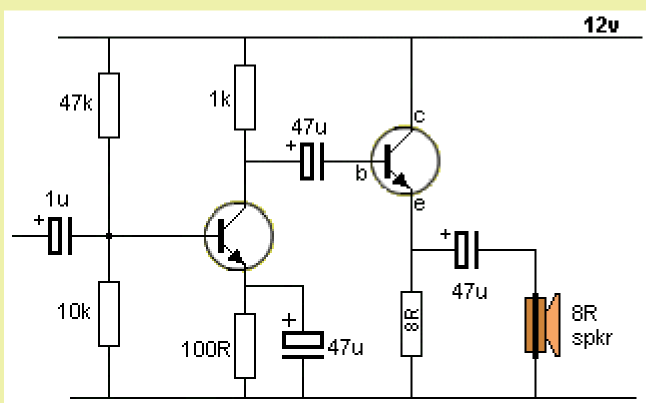
I did not want to go further into discussing the H-Bridge but the instructors on YouTube are so incompetent at designing this stage that I want to cover the steps you need to follow so you see how inept the instructors are.
You cannot design a stage UNTIL you get some external values. They have NEVER designed a circuit in their life and their approach is completely impractical and shows no understanding.

The first thing you need to find out is the impedance of the stage you are driving as it will affect all the values of the H-Bridge stage.
This is also called the input impedance and/or the base-emitter impedance or some value in the range of 500 ohms to 5,000 ohms.
The self-bias stage we are designing is called a small-signal stage but what this really means it is a **low current stage**.
It can be from 0.1mA to 5mA.
You cannot design the stage and then connect it to a following stage as the output of the

self-biased common emitter stage will be reduced and you will be very disappointed.

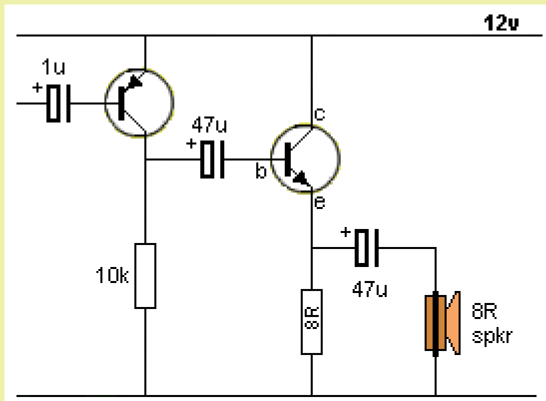
The collector LOAD resistor has to be equal or less than the impedance (resistance) of the following stage.
That's because the load resistor delivers the amplitude and if it has the same resistance, only about 50% of amplitude will be delivered. This is because the collector resistor and the coupling capacitor and the input impedance of the following stage forms a voltage divider.
But we cannot make any predictions because the real way to look at the transfer from one stage to the other is via ENERGY TRANSFER. And this involves analysing the circuit.
Next you need to work out the value of the emitter resistor and base-bias resistors to get the transistor to sit with the collector at mid-rail.
The bleed-current through the base resistors can ne 1/100th the collector current.
Next you need to work out the value of the emitter-bypass capacitor (electrolytic) to give a gain of 50 to 70 for the stage (to make it worthwhile). To do this you need to know the frequency you will be amplifying.
Normally it is at least 1/10th the resistance of the emitter resistor. If the emitter resistor is 1k, the capacitive reactance of the by-pass electrolytic should be 100 ohm at the desired frequency.
Next you need to know the current-capability of the input signal and it has to be at least 1/50th the collector current of the stage we are designing..
This is just the beginning of the parameters you need to start designing.
If you think the values are acceptable, I would not even waste my time doing any calculations.
Time is far too valuable.
Build the circuit and adjust the values to get the required results.
You can try working out the values mathematically and when you build the circuit you will see how incorrect your values were.

Here is a typical problem.



We have two stages. Each stage has been correctly designed with the first stage allowing the collector voltage to rise to 12v and fall to almost zero when the stage is not connected to the emitter-follower stage.
In other words we have full rail voltage amplitude and we know the emitter-follower stage has a high impedance.
But the term "high impedance is relative. It has 100 times higher impedance than the 8R load.
This might not be a high impedance as far as the first stage is concerned.
We have already mentioned the first stage does not "push" energy to the second stage.
The transistor turns OFF and the 1k load resistor passes energy to the emitter-follower.
When the transistor turns OFF, a voltage-divider is formed with the 1k, the 47u electrolytic

and the input impedance of the emitter follower.
The 47u is about 2 ohms and the input of the emitter-follower is 800 ohms.
Let's say it is 1k and 1k. This means half rail voltage will appear on the base and thus the emitter follower will only rise to 6v. We know the speaker will receive up to twice this swing but if you are expecting something like 24v, you will be mistaken.
The two stages have not been correctly matched and even though the first stage is taking more than 10mA, it is not only the current-flow that has to be correct, but the value of the collector LOAD.
Matching these two stages involves a PNP stage:



The first stage uses a PNP transistor and it can raise the voltage to 12v and when it is turned OFF, the voltage will fall to 0v. The next thing you have to work on is discharging the 47u on the collector of the PNP transistor.

That's a topic for another discussion.
If you want to see the solution . . . click **HERE**

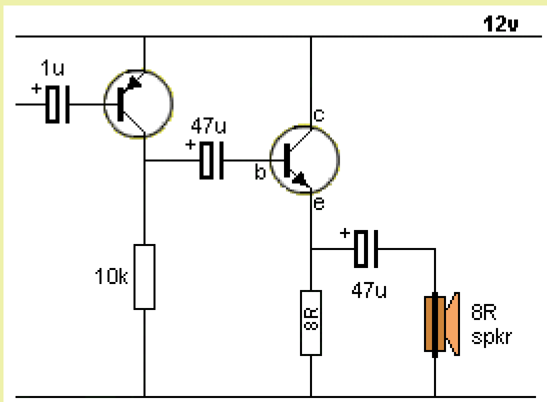
All circuits work on the principle of VOLTAGE DIVISION. Components are "dividing up" the available voltage and that is how and why I can "see" a circuit working. The real way to lean and understand "circuit design" is completely different from any lecture, text book or discussion.
You have to be "guided" into seeing a circuit working and see that a particular circuit WILL NOT WORK. This does not involve mathematics. It does not involve calculations, other than a simple understanding.

Here's what you need to remember:
1mA flowing through a 1k resistor will produce a voltage drop of 1 volt.
From there, you just multiply and divide:
10mA will produce a voltage drop of 10 volt.
1mA through 10k will produce a voltage drop of 10v.
Similarly: A 1k resistor on a 10v supply will pass 10mA.
10k on 10v will pass 1mA
And once you remember the above, you continue with voltage division.
A 10k and 10k in series on 10v will produce 5v at the join.
1k and 1k on 10v will produce 5v at the join.
3k3 and 3k3 and 3k3 in series on 10v will produce 3v3 and 6v6 at the joins.

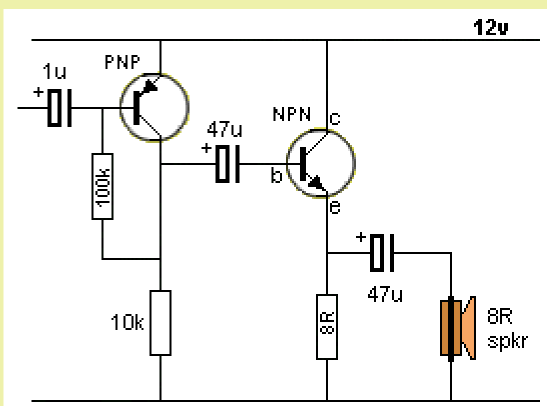
And there is another area of electronics that Universities do not cover. **It's how to fix things.**
All my projects include a section: IF IT DOES NOT WORK.   I teach how to fix a project.

Universities don't cover this topic because they have absolutely no idea how to fix anything. That's why the piece of paper they hand you at the end of 4 years is ABSOLUTELY WORTHLESS. One University graduate came for a job application and said: Oh, I don't do soldering !!!

The whole idea of adding stages is to increase the amplitude of the signal and its current-capability.
Eventually you will want the signal to drive a load and this will require a large amplitude but most important is its current capability.
We can go from one microamp to 5 amp capability and this is 5,000,000:1
If a stage has a gain of 100, this will require a minimum of 4 stages.
But you cannot add stages without the high-energy output signal entering the supply rail and passing back to the first stage where one or two microvolts will enter the first stage and get amplified to produce a hum or tone that cannot be prevented.
This is called **MOTORBOATING** or feedback and is a major problem when you have more than 2 stages of amplification.
We will now be up to 3 stage, from this 2-stage circuit:

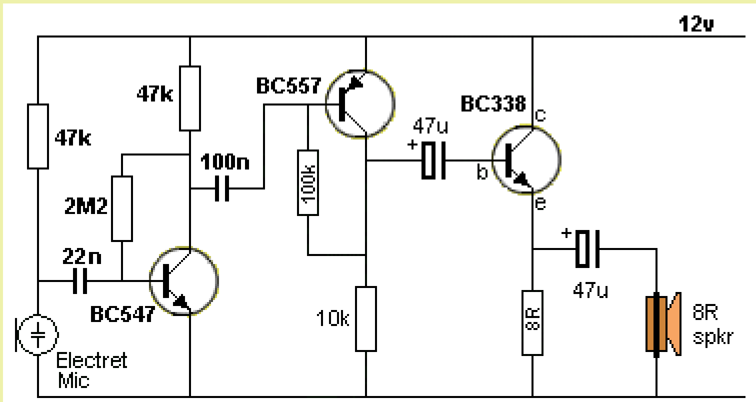


But first we have to convert the PNP stage into a self-biased arrangement:



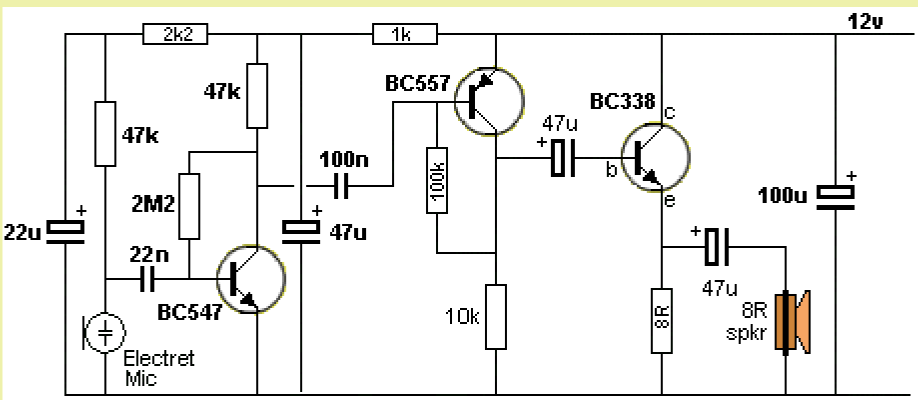
Adding the 100k will allow the PNP stage to sit at mid-rail and give the output stage a fair chance of driving full-scale.
You now have an input signal that can be based at the 0v rail and can be as small as 1v, with a current-capability less than 0.1mA.
We have converted the LOAD requirement from 150mA and 12v amplitude into 2mA requirement at 12v amplitude via the output stage and the first stage has changed the

requirement from 2mA to 0.1mA and 1v amplitude.
No mathematics, no calculations, no transistor gain, no worries and no frustration.
You just have to know what each stage does.
You need one more stage to connect an electret microphone as they deliver about 20mV and less than 0.1mA.
Here is the pre-amplifier stage:



This circuit will produce a lot of motorboating as the output is not separated (isolated) from the input. Build it and see what we mean.

Two stages of separation are needed:

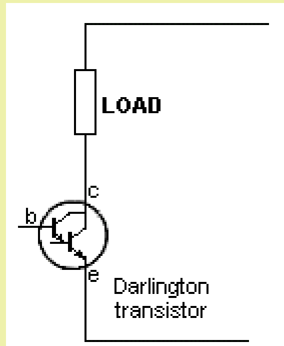


The 100u across the power supply will reduce the ripple from the output stage>
The1k and 47u will reduce the ripple on the supply rail from entering the first stage.
The 2k2 and 22u will reduce ripple on the supply rail from entering the electret microphone.

THE OUTPUT TRANSISTOR

You may be tempted to use a Darlington transistor in the output as it has a very high gain.
But there are two fact that you need to know.
Normally the data sheet for a Darlington transistor shows the gain to be more than 1,000 and if you design the circuit around this value, you may be in for a shock.
Sometimes the transistor will not perform successfully and it could be due to the fact that the collector-emitter voltage drops to such a low value that the base is equal or higher than the collector and the upper transistor does not perform as a normal transistor. This means only the lower transistor is working and the gain will be 100 to 200.
The other problem with Darlington transistors is the voltage across the collector-emitter

junction. It can be as high as 2v to 3v and the transistor will get much hotter than expected. A normal output transistor will have a collector-emitter voltage in the range 0.2v to 0.4v when fully turned ON.



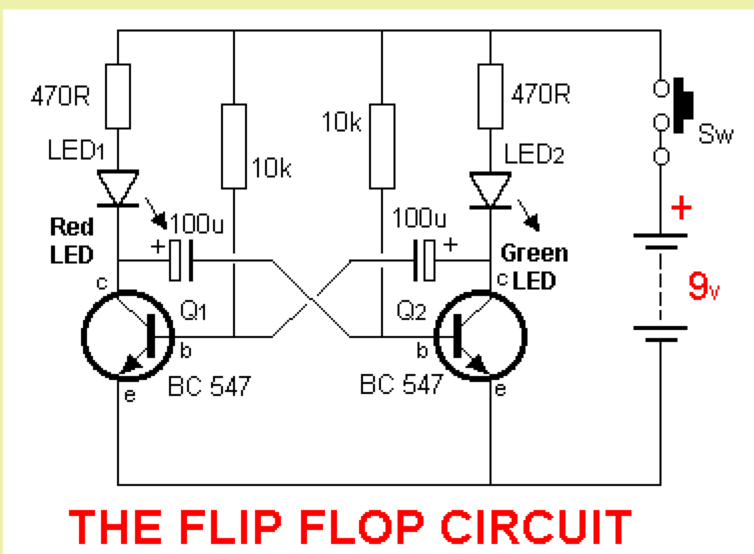
SUMMARY

All these circuits are CURRENT AMPLIFIERS (current increasers). At the same time the voltage will be increased, but the main requirement is to amplify the current from the input device.
The electret microphone will produce a voltage-swing of about 10mV to 20mV and when this voltage is rising the electret mic is turning OFF and the 47k is delivering the current to the first transistor stage.
You can work out the current or realise the output of the first stage is also controlled by a 47k load resistor so the current from the electret mic will not be increased very much but the voltage will be increased from say 10mV to 3v. That's 300 times increase and you will have to test the circuit to see if this occurs.
We now have the first stage capable of turning ON the second stage via 100n capacitor and we may get a swing of 6v to drive the emitter-follower output stage. We will need about 2mA to do this and the speaker will see almost twice this swing due to the effect of the 47u connected to the output (as described previously).
The requirement is to build the circuit and measure the voltages with no input signal. You can then adjust the component values to get the output you want.
Notice: We have not used any mathematics, because it is quicker and easier to change a component and get an actual result than waste time on speculating.

The Transistor Multivibrator

THE FLIP FLOP

The most difficult electronic component to understand is the transistor. That's because it has so many modes of operation and reacts differently when it is passing a small current and then a high current.
We are going to cover one of the cleverest circuits. It has features that guarantee its operation and it has NEVER been described fully in any text book or lecture. It is called the FLIP FLOP or MULTIVIBRATOR or SQUARE-WAVE OSCILLATOR or ASTABLE MULTIVIBRATOR.
Although the circuit is very simple, its operation is very complex and two terms have to be introduced to describe its operation. These two terms have never been mentioned before. That's because no-one has dealt into the depths of its operation.
The two transistors are just amplifiers. But because they are cross-coupled, one amplifier is controlled by the other and then the first amplifier is controlled by the second.
But when one stage turns on the other, it just does not turn it ON FULLY, but turns it on EVEN HARDER than it needs to and this allows it to pass a very high current and makes the transistor a very good conductor. This extra "turn-on" is called SUPER-SATURATION. and allows loads such as globes and motors to be connected as loads.
The other feature of the circuit is called REGENERATION.
One transistor starts to turn ON the other and this effect is passed to the first transistor and allows it to turn on the other EVEN MORE. This "runs around the circuit" very quickly 1,000 times or more and in the end, one transistor is turned on VERY HARD with more base current than it needs and it becomes SUPER SATURATED. The other transistor is fully turned off.
Because the transistors do not work within the parameters of any data sheet, we do not need any mathematics to explain how the circuit works. Just an understanding of the brilliance of the inventor of the circuit.
This was not the first flip-flop circuit to be invented. The other ones were very complex and were a complete failure. As the voltage of the supply dropped, they stopped working and they did not supersaturate the transistors.



The two wires in the middle of the circuit do not touch. That's why we say the circuit is "cross coupled." One side is connected to the other and the second stage is connected to the first.
All the components and the transistors will have slightly different values and one transistor

will start to turn ON when the switch is closed.
Suppose the second transistor starts to turn ON via the 10k base resistor and the voltage on the collector drops a small amount. This drop will be transferred through the 100u electrolytic so that when the positive lead of the electro drops a very small amount, the negative lead will fall the same amount.
The negative lead is connected to the base of the first transistor and it will work against the effect of the 10k resistor connected to the base. The 10k was having a slight effect on trying to turn the transistor ON but now the 100u is reducing this effect.
This means the first transistor will be starting to be turned OFF and the voltage on the collector of the transistor will start to rise.
The 470R resistor and the LED will pull the positive lead of the first 100u towards the positive rail and the negative lead will follow. But the negative lead cannot rise more than 0.6v and so, when the positive lead is pulled towards the positive rail, the effect is to charge the 100u.
This charging current flows through the base-emitter junction of transistor 2 to turn it ON more.
Transistor 2 turns ON more and the voltage on the base of transistor 1 becomes so small that transistor 1 is not turned ON at all and now the first 100u electro gets charged by the 470u and LED 1. This current is much more than the second transistor needs to illuminate LED2 but if we had put a high current device in place of LED2, it would also have operated. The transistor is being turned ON so hard that anything you put in the collector circuit will work. That's why we say the transistor is SUPERSATURATED.
To get to this super-saturated condition the two transistors "feed" each other with the "turning-ON" effect, with hundreds and hundreds of cycles we call REGENERATION and eventually the effect produces SUPERSATURATION.
Normally regeneration does not have this enormous effect but in this circuit it makes the circuit very reliable and almost any transistor will drive almost any load.
The circuit is not just one transistor turning on the other. The TWO transistors operate in a cyclic or feedback way with POSITIVE FEEDBACK, to create a very fast switching action that is a SQUARE WAVE with very fast rise and fall time.
One transistor feeds back to the other to turn it OFF more and more and now the components in the circuit take over to supply current to turn one transistor ON FULLY. It is now the components that turn the transistor ON fully and the other transistor does NOTHING. This is quite a surprise. Show me anywhere, where a text book or instructor has even hinted at this during part of the cycle!!!
We have the state where the first transistor is OFF and the second transistor is fully ON.
What makes the circuit change state?
The first transistor has no voltage on the base because the small voltage across the second 100u has made the negative lead put a negative voltage on the base of the first transistor. The circuit would stay in this state but two things are happening that make the circuit change states.
The 10k resistor on the base of the first transistor is beginning to charge the second 100u and the voltage on the base of the first transistor is starting to rise. When it gets to 0.55v, the transistor starts to turn ON.
When it turns ON a small amount, the voltage on the collector drops a very small amount. This means the voltage on the positive lead of the first 100u reduces slightly and this effect is passed through the 100u to make the negative lead drop by the same amount. Another hidden secret has also occurred in the circuit. The first 100u has charged considerably during this time and the current being passed to the base of the second transistor has been reduced considerably but the transistor is still fully turned ON. But not turned on "Extra Hard."
This means that when the current into the second transistor is reduced, it will start to turn OFF. And that is what happens, the first transistor starts to turn ON and the current through the first 100u has reduced considerably because the capacitor is in a charged state and when the voltage on the positive lead is reduced, this effect is passed to the base of the

second transistor to start and turn it off.
The voltage on the collector of the second transistor rises and the second 100u starts to charge via the base-emitter junction of the first transistor and the two transistor form a loop of POSITIVE FEEDBACK called REGENERATION and the end result is a change of state where the other transistor becomes FULLY SATURATED.
It is no wonder this complexity has never been described before but when you build the circuit and add car globes and find it does not work, you need the knowledge of SUPERSATURATION to use transistors that allow a high current to be delivered to the load AND the power supply must be able to deliver the high current. Car globes take 6 times more current when they are starting to illuminate and if the transistors and power supply cannot provide the current, the circuit FREEZES.
It is the hidden secrets of how a circuit works, that you need to know. But these have never been covered in any text book.
For instance, just before the circuit changes state, the transistor that has been turned ON "with great force," has now had this "force" reduced considerably because the capacitor creating the "great force" is in a charged state and the current flowing through it is considerably reduced, to a point were the second transistor is turned ON but not excessively. Any slight movement in the down direction of the first 100u will reduce the voltage on the base of the second transistor and remove the "turn ON" effect. If the first 100u was still turning on the second transistor "with great force," a slight reduction in its ability to deliver a reduced voltage would simply change the state of the second transistor to SUPERSATURATED to FULLY TURNED ON and the circuit would not start to change state.
One thing you have to understand is the interspersal of voltage and current. The transistor actually works on current but when you deliver a higher voltage via parts of the circuit, this translates to a higher current and the transistor reacts.
You have to forget what you have read, seen and been told as none of it related to understanding how the circuit actually works. It's a mystery that no-one has exposed. You only find out these things when you experiment and find that everything you have learnt has not solved the problem.

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