The Transistor Amplifier

A simple explanation of how a transistor works in a circuit, and how to connect two transistors to create a number of different circuits. No mathematics and no complex wording.
Just a completely different approach you can understand . . .

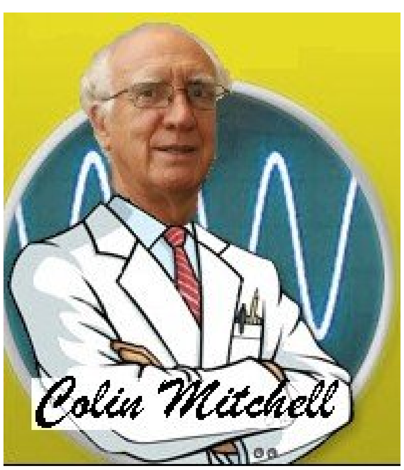
TOPICS:

Adjusting The Stage Gain
AF Detector
Analogue To Digital
A "Stage"
Blocking Oscillator
Bridge - the
Bootstrap Circuit
Colpitts Oscillator
Common Base Amplifier
Connecting 2 Stages
Constant Current Circuit - the
Coupling Capacitor - the
Current
Darlington - and the Sziklai Pair
Design Your Own Transistor Amplifier
Differential Amplifier
Digial Stage - the
Gates
Hartley Oscillator
Impedance Maching
Input and Output Impedance
Interfacing
Latch Circuit
Long Tailed Pair
NPN Transistor
NPN/PNP Amplifier
Oscillators Oscillators
Phase-Shift Oscillator
PNP Transistor
Push Pull

Regulator - transistor
Saturating a Transistor
Schmitt Trigger - the
Sinewave Oscillator
Sinking and Sourcing
Square Wave Oscillator
Stage Gain
Time Delay
Totem Pole Stage
1 watt LED - driving a high-power LED

This eBook starts by turning **ON** a single transistor with your finger (between two leads) and progresses to describing how a transistor can be connected to the supply rails in 3 different ways.
Then it connects two transistors together DIRECTLY or via a capacitor to produce amplifiers and oscillators.
As you work through the circuits, the arrangement of the parts are changed slightly to produce an entirely different circuit with new features.
This way you gradually progress through a whole range of circuits (with names you can remember) and they are described as if the parts are "moving up and down" or "turning on and off."
Even some of the most complex circuits are described in a way you can see them working and once you get an understanding, you can pick up a text book and slog though the mathematics.
But before you reach for a text book, you should build at least 50 circuits . . . otherwise you are wasting your time.

I understand how the circuits work, because I built them.
Not by reading a text book!



Let's Start:

THE NPN TRANSISTOR

There are thousands of transistors and hundreds of different makes, styles and sizes of this amazing device. But there are only two different types. NPN and PNP. The most common is NPN and we will cover it first. There are many different styles but we will use the smallest and cheapest. It is called a GENERAL PURPOSE TRANSISTOR. The type-numbers on the transistor will change according to the country where it was made or sold but the actual capabilities are the SAME.

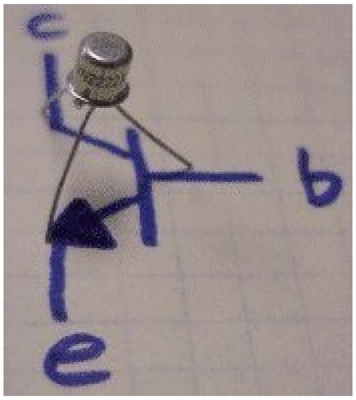


Fig 1 shows an NPN transistor with the legs covering the symbol showing the name for each lead.
The leads are BASE, COLLECTOR and EMITTER.

Fig 1. NPN Transistor

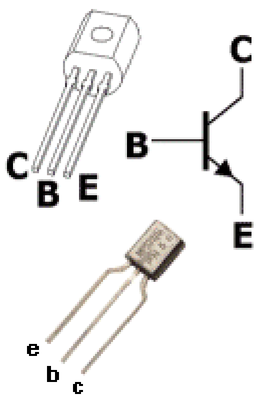


Fig 2 shows two "general purpose" transistors with different pinouts. You need to refer to data sheets or test the transistor to find the pinout for the device you are using.
The symbol for an NPN transistor has the arrow on the emitter pointing AWAY from the BASE.

Fig 2. NPN Transistor Symbol

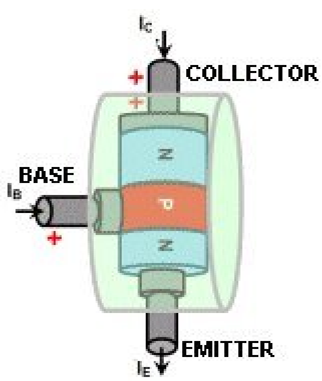


Fig 3 shows the equivalent of an NPN transistor as a water valve. As more current (water) enters the base, more water flows from the collector to the emitter. When no water enters the base, no water flows through the collector-emitter path.

Fig 3. NPN "Water Valve"

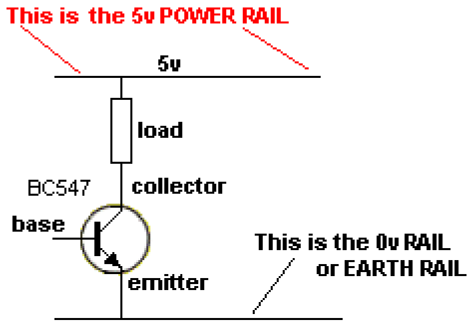


Fig 4 shows an NPN transistor connected to the power rails. The **collector** connects to a resistor called a LOAD RESISTOR and the **emitter** connects to the 0v rail or "earth" or "ground."
The **base** is the input lead and the collector is the output.
The transistor-type **BC547** means a general-purpose transistor.
Sometime a general-purpose transistor is called **TUN** - for **T**ransistor **U**niversal **NPN**.

Fig 4. NPN connected to the power rails

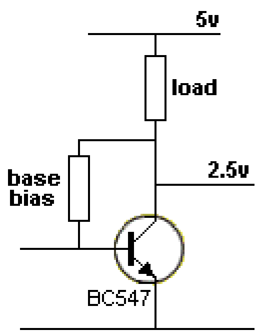


Fig 5. NPN Transistor biased with a "base bias" resistor and a LOAD resistor

Fig 5 shows an NPN transistor in SELF BIAS mode. This is called a COMMON EMITTER stage and the resistance of the BASE BIAS RESISTOR is selected so the voltage on the collector is half-rail voltage. In this case it is 2.5v.
To keep the theory simple, here's how you do it. Use 22k as the load resistor.
Select the base bias resistor until the measured voltage on the collector is 2.5v. The base bias resistor will be about 2M2.
This is how the transistor gets turned on by the base bias resistor:
The base bias resistor feeds a small current into the base and this makes the transistor turn ON and creates a current-flow though the collector-emitter leads.
This causes the same current to flow through the load resistor and a voltage-drop is created across this resistor. This lowers the voltage on the collector.
The lower voltage causes a lower current to flow into the base, via the base-bias resistor, and the transistor stops turning on a slight amount. The transistor very quickly settles to allowing a certain current to flow through the collector-emitter and produce a voltage at the collector that is just sufficient to allow the right amount of current to enter the base. That's why it is called SELF BIAS.

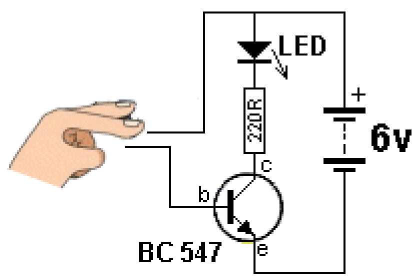


Fig 6. Turning ON an NPN transistor

Fig 6 shows the transistor being turned on via a finger. Press hard on the two wires and the LED will illuminate brighter. As you press harder, the resistance of your finger decreases. This allows more current to flow into the base and the transistor turns on harder.

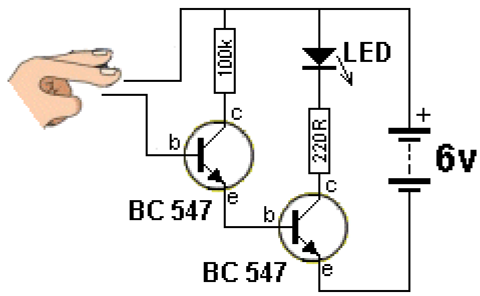


Fig 7. Two transistors turning ON

Fig 7 shows a second transistor to "amplify the effect of your finger" and the LED illuminates about 100 times brighter.

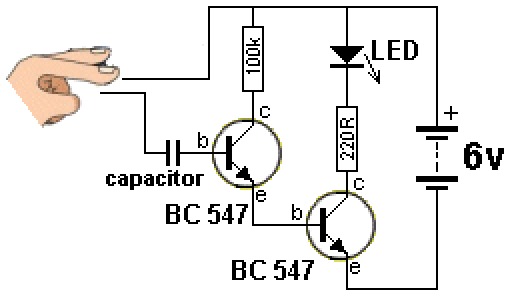


Fig 8. Adding a capacitor

Fig 8 shows the effect of putting a capacitor on the base lead. The capacitor must be uncharged and when you apply pressure, the LED will flash brightly then go off. This is because the capacitor gets charged when you touch the wires. As soon as it is charged, NO MORE CURRENT flows though it. The first transistor stops receiving current and the circuit does not keep the LED illuminated. To get the circuit to work again, the capacitor must be discharged. This is a simple concept of how a capacitor works. A large-value capacitor will keep the LED illuminated for a longer period of time as it will take longer to charge.

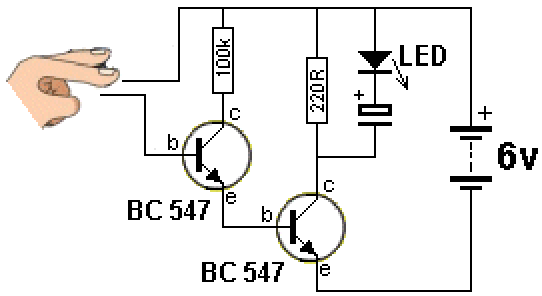
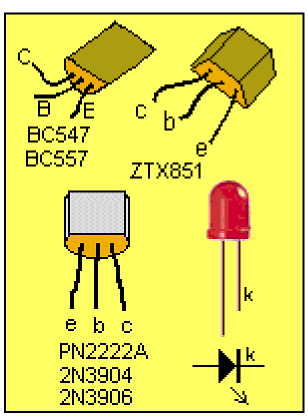


Fig 9. Adding a capacitor to the output

Fig 9 shows the effect of putting a capacitor on the output. It must be uncharged for this effect to work. We know from Fig 7 that the circuit will stay ON constantly when the wires are touched but when a capacitor is placed in the OUTPUT, it gets charged when the circuit turns ON and only allows the LED to flash.

1. This is a simple explanation of how a transistor works. It amplifies the current going into the base about 100 times and the higher current flowing through the collector-emitter leads will illuminate a LED or drive other devices.
2. A capacitor allows current to flow through it until it gets charged. It must be discharged to see the effect again.

TRANSISTOR PINOUTS:



Transistor Pinouts

Just some of the pinouts for a transistor. You need to refer to a data sheet or test the device to determine the pins as there are **NO** standard pin-outs.

A "STAGE"

A "Stage" is a set of components with a capacitor at the input and a capacitor on the output.
We have already seen the fact that the capacitor only has an effect on the circuit during the time when it gets charged. It also has an effect when it gets discharged. But when the voltage on either lead does not rise or fall, NO CURRENT flows through the capacitor.
When a capacitor is placed between two stages, it gradually charges. When it is

charged, the voltage on one stage does not affect the voltage on the next stage. That's why the capacitor is drawn as two lines with a gap. A capacitor is like putting a magnet on one side of a door and a metal sheet on the other. Moving the magnet up and down will move the metal up and down but the two items never touch. Only a rising and falling voltage is able to pass through the capacitor.

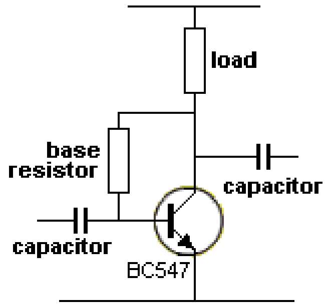


Fig 10. This is a STAGE. A transistor, with a capacitor on the input and output.

Fig 10 has a capacitor on the input and output. This means the stage is separated from anything before it and anything after it as far as the DC voltages are concerned and the transistor will produce its own operating point via the base resistor and LOAD resistor. We have already explained that the value of the two resistors should be chosen so the voltage on the collector should be half-rail voltage and this is called the "idle" or "standing" or "quiescent" conditions.
It is the condition when **no signal is being processed**.
When the voltage on the collector is mid-rail, the transistor can be turned off a small amount and turned on a small amount and the voltage on the collector will fall and rise. (note the FALL and RISE).

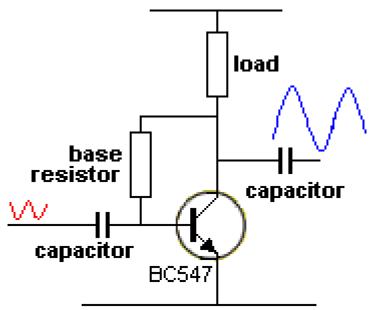


Fig 11. The Input and output waveforms

Fig 11 shows a small waveform on the input and a large waveform on the output. The increase in size is due to the **amplification** of the transistor. A stage like this will have an amplification of about 70.
This is called "**Stage Gain**" or "**Amplification factor**" and consists of two things. The output **voltage** will be higher than the input voltage and the output **current** will be higher than the input current. We will discuss the increase in current in a moment. We will firstly cover the voltage increase.

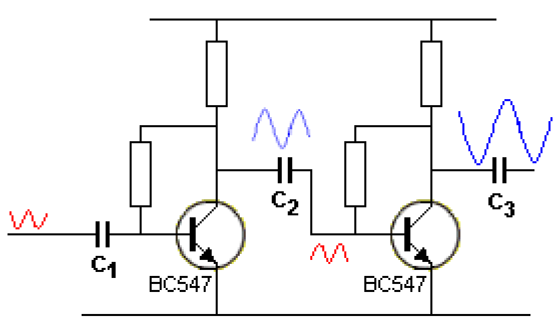


Fig 12.

Fig 12 shows the signal (the voltage waveform) as it passes through 2 stages. Note the loss in amplitude as the signal passes through capacitor C2.

CONNECTING 2 STAGES

There are 3 ways to connect two stages:
1. direct coupling - also called **DC coupling** (Direct Coupling) - it also happens that it is the only coupling that passes DC voltages. This type of coupling will pass both AC signals and DC voltages. When the DC voltage moves up and down (even at a slow rate) we call it an AC voltage or AC signal or a rising and falling voltage and when it rises and falls faster, we call it a "signal" or waveform.
2. via a capacitor - this is also called **RC coupling** (Resistor-Capacitor coupling) - only passes AC signals - fluctuating signals - rising and falling signals.
3. via a transformer - called **Transformer Coupling** or Impedance Coupling or Impedance

Matching - only passes AC signals.

Fig 12 shows two stages with a capacitor coupling the output of the first to the input of the second. This is called **Capacitor Coupling** or **Resistor-Capacitor Coupling** (**RC Coupling**).
The increase in the size of the waveform at three points in the circuit is also shown.
The waveform is inverted as it passes through each transistor and this simply means a rising voltage will appear as a falling voltage and after two inversions, the output is **in-phase** with the input.
We have already explained the fact that a capacitor only works **once** and has to be discharged before it works again. When the first transistor turns off a little, the voltage on the collector rises and the resistor pulls the left lead of C_2 UP. The right-hand lead can only rise to 0.7v as the base-emitter voltage does not rise above 0.7v. This means C_2 charges and during its charging, it delivers current to the second transistor.
When the first transistor turns ON, the collector voltage drops and C_2 passes this voltage-drop to the base of the second transistor. But the transistor does not provide a path to discharge the capacitor fully so that when the capacitor gets charged again, it is already partially charged and it cannot activate the base of the second transistor to the same extent as the first cycle.
This means a lot of the energy available at the collector of the first transistor is not delivered to the second stage. That's why capacitors produce losses between stages.
However enough is delivered to produce a gain in the second stage to get an overall gain in the two stages.
The value of C_2 will be from 10n to 10u, and the larger capacitance will allow low frequencies to be passed from one stage to the other.

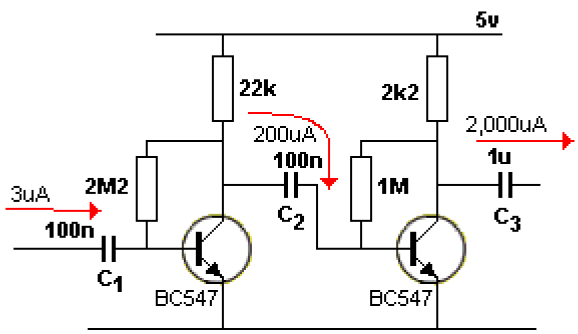


Fig 13.

Fig 13 provides a guide to the values of current that will be flowing at 3 important sections of the circuit.
The input current to operate the first transistor will be about 3uA. This is worked out on the basis of the current required to saturate the transistor with a 22k load. The collector-emitter current equals 5/22,000 = 200uA. If the gain of the transistor is 70, the input current is 3uA.
The only time when energy passes from the first stage to the second is when transistor turns OFF. The collector voltage rises and the 22k pull the 100n HIGH. The maximum current that can be delivered by the 22k is 5v/22,000= 200uA. This is the absolute maximum for a very small portion of the cycle. However it is important to realise it is not the transistor that passes the current to the next stage but the load resistor.
The gain of the second stage is not the deciding factor for the output current but the value of the 2k2 load resistor. This resistor will deliver a maximum of 2,000uA (2mA) and that is how a 3uA requirement at the input of the circuit will deliver 2mA at the output.

You can see it is not the gain of the transistors that produce the output current but the value of the load resistors. The transistors play a part but the limiting factor is the load resistors (and the transfer of energy via the capacitor). This is not always the case but applies in the above circuit.

We will now explain an emitter-follower stage and show how it works.
An EMITTER-FOLLOWER is an NPN transistor with the collector connected to the positive rail. (You can also get PNP EMITTER-FOLLOWER stages - see below). Both can be called a COMMON COLLECTOR stage.

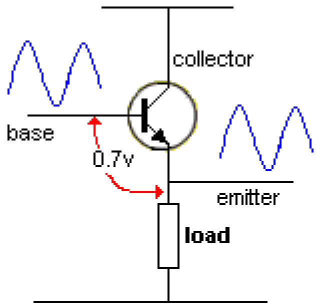


Fig 14. An Emitter-Follower or Common Collector. The names are the SAME

Fig 14 shows an Emitter-Follower.
The load is in the emitter and as the base is taken higher, the emitter follows. But the input and output voltage signals are the SAME amplitude! You would ask: "What is the advantage of this?" Answer: You only need a small amount of "lifting power" to raise the base and the emitter rises with 100 times more strength. The voltage waveform stays the same but the CURRENT waveform increases 100 times.
The voltage on the emitter is always 0.7v lower than the base and the base can be as low as 0.8v and as high as 0.5v less than the supply voltage. This gives the possibilities of producing an enormous "swing."
In the **common-emitter stage** the base rises from 0v to about 0.7v but in the **Emitter-Follower** stage it rises from 0.8v to nearly rail voltage.
This means the stage does not produce a higher output voltage but it does produce a higher output **CURRENT**.
We mentioned before the current amplification of a stage was not dependent on the transistor characteristics but the value of the load resistor.
In a common-emitter stage we may not be able to get a current gain of 100 but in an **Emitter-Follower** stage we can quite easily get a current gain of 100.
Why do we want "Current Gain?" We need **current** to drive a low resistance load such as a speaker.

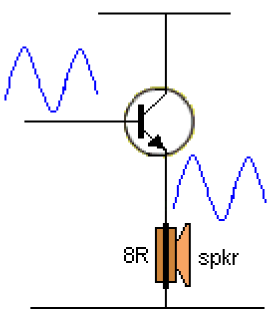


Fig 15. A transistor driving a speaker

Fig 15 shows an 8 ohm speaker as the load in the emitter. If the gain of the transistor is 100, the 8R speaker becomes 8x100 = 800 ohms on the base lead. In other words we see the circuit as "800 ohms."
1. For an emitter-follower circuit, we know the base can rise and fall by an amount equal to about rail voltage.
2. For a common-emitter stage the collector rises and falls by an amount equal to rail voltage.
3. So, why not connect the two stages together without a capacitor?
We know that a capacitor has considerable losses in transferring energy from one stage to another and removing it will improve the transfer of energy.

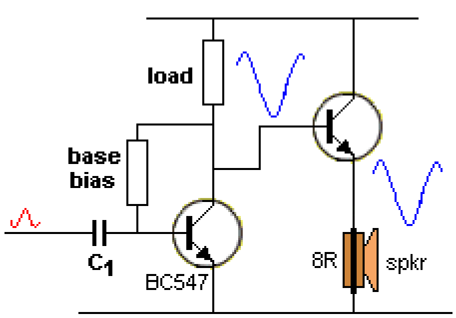


Fig 16. Two directly coupled stages

Fig 16. We now have two stages directly connected together.
The first transistor does not deliver energy to the second stage but the **LOAD RESISTOR** does.
The value of the load resistor pulls the base of the second transistor UP and this delivers current to the second transistor and the transistor amplifies this 100 times to drive the speaker.

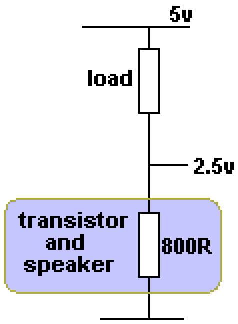


Fig 17. The load resistor and the effective load of the speaker

Fig 17. Using mathematics we can work out the effective load of the 8 ohm speaker as 8 x 100 = 800 ohms. To put at least half rail voltage into the speaker, (so the speaker can get the maximum higher voltage and the maximum lower voltage without distorting) the LOAD resistor has to be the same value as the "emitter follower."
This is a simple voltage-divider calculation where two equal value resistors produce a voltage of 50% at their mid-point.

This means the LOAD resistor for the first stage has to be 800 ohms.

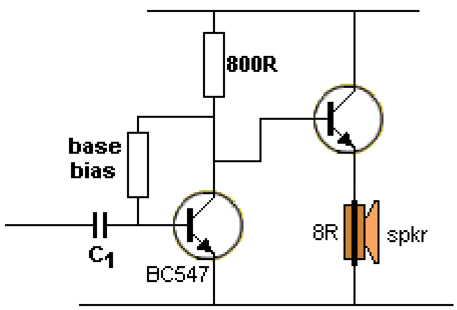


Fig 18. The load resistor is 800 ohms

Fig 18 shows the circuit with 800R load resistor in the collector of the first transistor.
The final requirement is to select a bas-bias resistor for the fist stage to produce approx mid-rail voltage on the collector.
This is generally done by experimentation.

We mentioned the capacitor separating two stages cannot be discharged fully and thus it does not provide very good transfer of energy from one stage to the other.
An improved concept is to directly couple two stages - and remove the coupling capacitor.
This is called DIRECT COUPLING or DC coupling and the circuit will process DC voltages (the press of your finger as shown above) and AC voltages (as shown by the sine-wave signal shown above). When a capacitor connects two stages they will only amplify AC signals.

There are many ways to directly connect two transistors and we will cover the simplest arrangement. It is an extension of Fig 18 above, because this arrangement has very good characteristics as the two stages transfer 100% of the energy due to the absence of a capacitor.

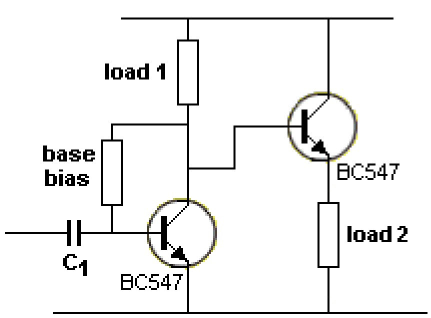


Fig 19.

Fig 19 shows the previous directly-coupled circuit with a load resistor replacing the speaker.
We have already learnt the common-emitter stage provides a voltage gain of about 70 but the emitter-follower stage has a voltage gain of only 1. We can improve on this by putting two resistors on the second transistor and changing the stage into a common emitter arrangement.

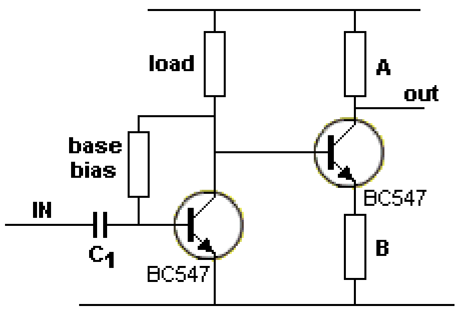


Fig 20.

Fig 20. This time we get the advantage of the base being able to move up and down so it matches the collector of the first transistor. It also provides a higher voltage gain by adding a collector resistor and taking the output from the collector. The voltage gain of the second transistor will not be as high as the first stage but we have added the advantage of direct coupling (called DC coupling).
The voltage gain of the second stage is the ratio of resistor A divided by resistor B. If resistor A is 10k and resistor B is 1k, the voltage gain is 10,000/1,000 = 10.

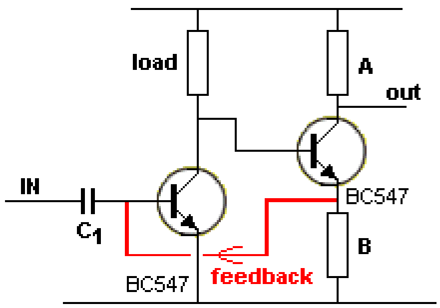


Fig 21.

Fig 21 shows biasing of the first transistor has been taken from the emitter of the second transistor. This does not save any components but introduces a new term: **FEEDBACK** (actually **NEGATIVE FEEDBACK**).
Negative feedback provides stability to a circuit. Transistors have a very wide range of values (called parameters) such as **gain** and when two transistors are placed in a circuit, the gain of each transistor can produce an enormous final result when the two values are multiplied together.
To **control this** we can directly couple two transistors and take the output of the second to the input of the first.

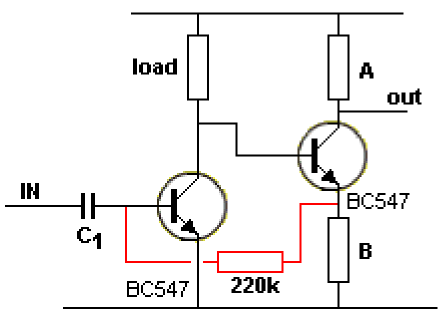


Fig 22.

Fig 22. When the voltage on the base of the first transistor rises, the voltage on the collector drops and this is transferred to the second transistor. The voltage on the emitter of the second transistor drops and this is fed back to the base of the first transistor to oppose the rise. Obviously this arrangement will not work as the voltage being fed back is HIGHER than the signal we are inputting, but if we add a 220k resistor we can force against the feedback signal and produce an output.

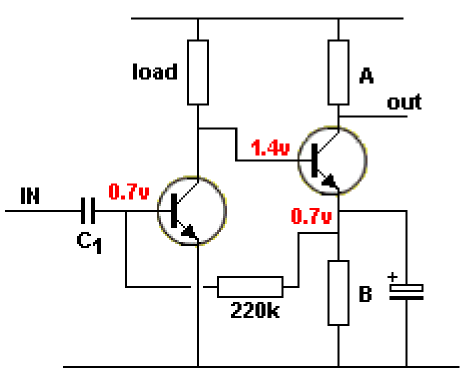


Fig 23.

Fig 23. We have added a capacitor (electrolytic) to the emitter of the second transistor.
Let's explain how this electrolytic works.
An electrolytic is like a miniature rechargeable battery.
It charges very slowly because it is a large value.
Initially it has 0v.
The circuit starts to turn ON by current flowing through the load resistor and this turns on the second transistor. (The first transistor is not turned on AT ALL at the moment). The base rises and pulls the emitter up too. And when the emitter is about 0.7v, this voltage is passed to the first transistor via the 220k and the first transistor starts to turn on.
This causes current to flow through the collector-emitter

leads and pulls the voltage on the base of the second transistor down to about 1.4v

This is how the two transistors settle, with the voltages shown in Fig 23.
The electrolytic has 0.7v on it and when a signal is delivered to the base of the first transistor, it is amplified and passed to the emitter of the second transistor. Normally the emitter would rise and fall as explained in the above circuits and the result would be heard in the speaker. But the electrolytic takes a long time to charge (and discharge) and it resists the rise and fall of the signal.
This means the signal cannot rise and fall at the emitter.
In other words we have placed the second transistor in a stage very similar to the first stage we described a **COMMON EMITTER**.
Since the emitter voltage does not rise and fall, it does not pass a signal through the 220k to the base of the first transistor. This means our input signal is not fighting against the feedback signal and it has a larger effect on controlling the first transistor. This gives the first transistor a bigger gain.
A common emitter stage has a voltage gain of about 70-100 and we now have one of the best designs. Two common-emitter stages, directly-coupled (DC) and with very HIGH GAIN. The feedback only controls the DC voltages on the two transistors and does not have an effect on the AC (signals).

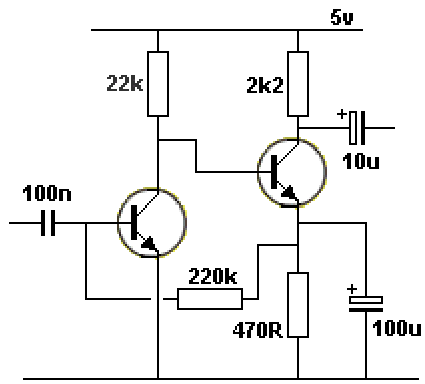


Fig 24.

Fig 24 shows typical values for biasing the two transistors.

From what you have learnt, you can see the mistakes and/or the voltages in the following circuit:

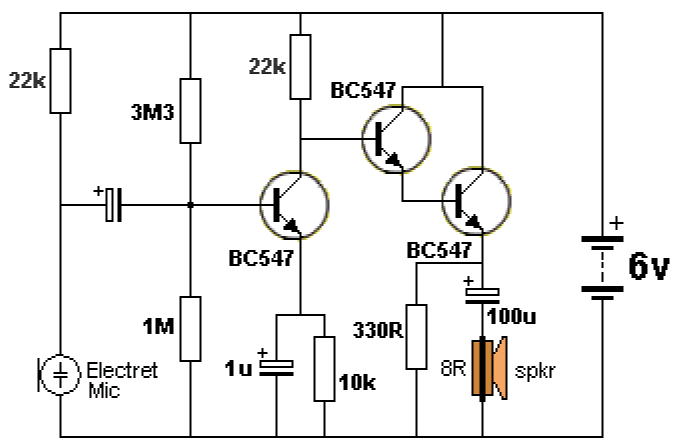


Fig 25.

Fig 25. The two joined transistors create a Darlington transistor and this is just a normal transistor with a large gain.
The 330R discharges the 100u and it will only discharge it a very small amount. This means the electro can only be charged a very small amount during the next cycle and the output will be very weak.
It is the 330R that determines how much (little) energy gets delivered to the speaker. The 330R has to be 15R to discharge the 100u to about its maximum.

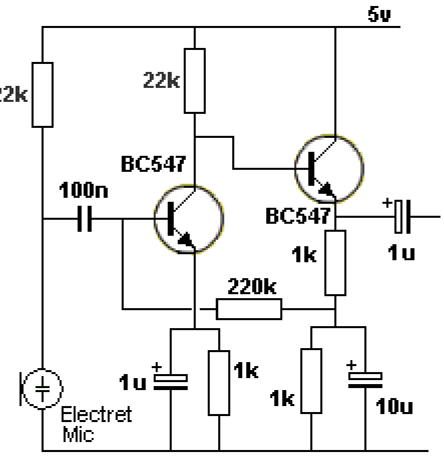


Fig 26.

Fig 26. You can work out the voltage on the various points in this circuit by referring to the examples we have already covered.

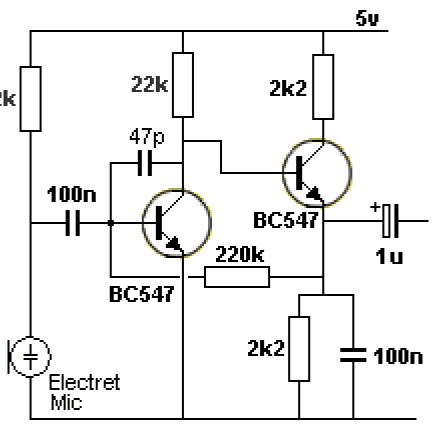


Fig 27.

Fig 27. This is a practical example of the circuit used as a microphone amplifier (called a pre-amplifier stage).

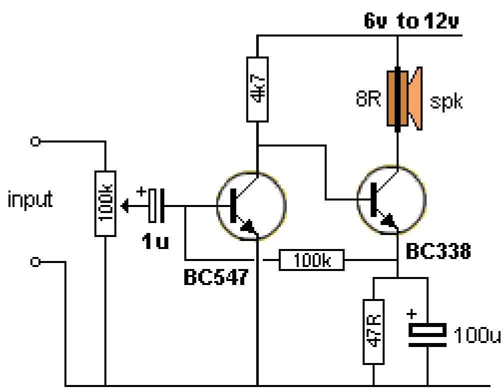


Fig 27a.

Fig 27a. Here is the same circuit used as a power amplifier.
Both transistors are common-emitter configurations and the circuit produces high gain due to the DC (direct) coupling.

USING PNP TRANSISTORS

A PNP transistor can be used in the 2-Transistor DC amplifier studied above. It does not produce a higher gain or change the output features of the circuit in any way but you may see an NPN and PNP used in this configuration and need to know how the combination works.
Firstly we will discus how a PNP transistor works. All those things you learnt in the first set of diagrams can be repeated with a PNP transistor. The circuits are just a mirror-image of each other and the transistor is simply "turned-over" and connected to the supply rail.
Study the following circuits to understand how a PNP transistor is TURNED ON.

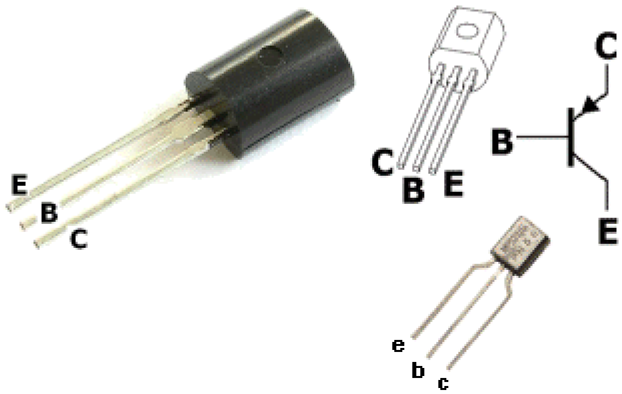


Fig 28. The symbol for a PNP transistor has the arrow pointing towards the BASE.

Fig 28. PNP Transistor Symbol

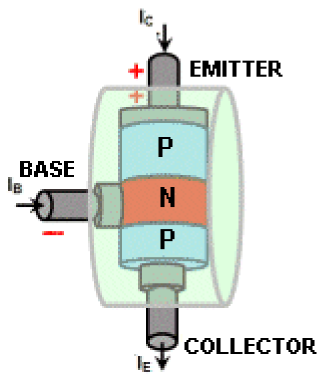


Fig 29 shows the equivalent of a PNP transistor as a water valve. As more current (water) is released from the base, more water flows from the emitter to the collector. When no water exits the base, no water flows through the emitter-collector.

Fig 29. PNP "Water Valve"

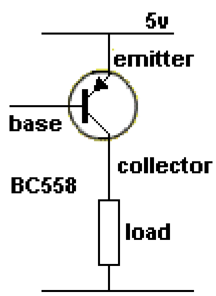


Fig 30 shows a PNP transistor with the emitter lead connected to the power rail. The collector connects to a resistor called a LOAD RESISTOR and the other end connects to the 0v rail or "earth" or "ground."
The input is the base.

Fig 30. PNP connected to the power rails

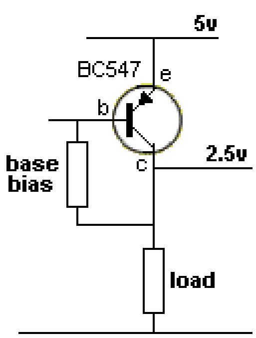


Fig 31. PNP Transistor biased with a "base bias" resistor and a LOAD resistor

Fig 31 shows a PNP transistor in SELF BIAS mode. This is called a COMMON EMITTER stage and the resistance of the BASE BIAS RESISTOR is selected so the voltage on the collector is half-rail voltage. In this case it is 2.5v.
Here's how you do it. Use 22k as the load resistance.
Select the base bias resistor until the measured voltage on the collector is 2.5v. The base bias resistor will be about 2M2.
This is how the transistor gets turned on by the base bias resistor:
The base bias resistor allows a small current to pass from the emitter to the base and this makes the transistor turn on and create a current-flow though the emitter-collector leads.
This causes the same current to flow through the load resistor and a voltage-drop is created across this resistor. This raises the voltage on the collector.
This causes a lower current to flow from the emitter to the base, via the base-bias resistor, and the transistor stops turning on a slight amount.
The transistor very quickly settles down to allowing a certain current to flow through the emitter-collector and produce a voltage at the collector that is just sufficient to allow the right amount of current to flow from the base. That's why it is called SELF BIAS.

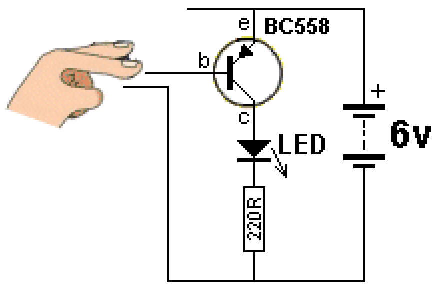


Fig 32 shows the transistor being turned on via a finger. Press hard on the two wires and the LED will illuminate brighter. As you press harder, the resistance of your finger decreases. This allows more current to flow from the emitter to the base and the transistor turns on harder.

Fig 32. Turning ON an PNP transistor

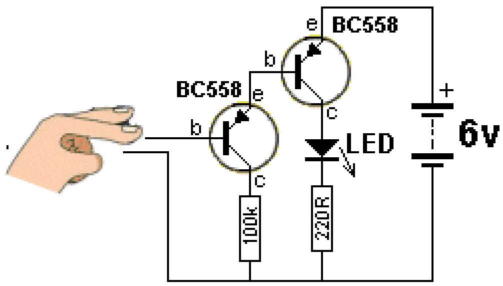


Fig 33 shows a second transistor to "amplify the effect of your finger" and the LED illuminates about 100 times brighter.

Fig 33. Two transistors turning ON

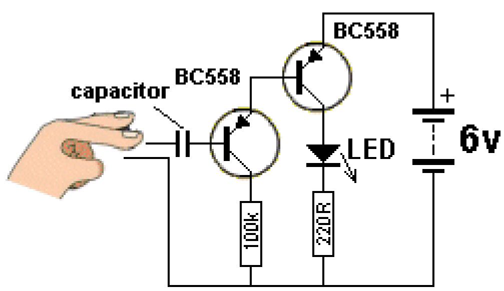


Fig 34. Adding a capacitor

Fig 34 shows the effect of putting a capacitor on the base lead. The capacitor must be uncharged and when you apply pressure, the LED will flash brightly then go off. This is because the capacitor gets charged when you touch the wires. As soon as it is charged, NO MORE CURRENT flows though it. The first transistor stops receiving current and the circuit does not keep the LED illuminated. To get the circuit to work again, the capacitor must be discharged. A large-value capacitor will keep the LED illuminated for a longer period of time as it will take longer to charge

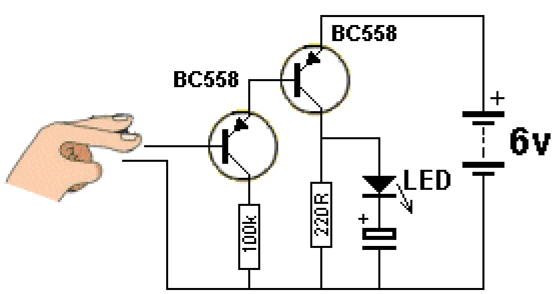


Fig 35 shows the effect of putting a capacitor on the output. It must be uncharged for this effect to work. We know from Fig 33 that the circuit will stay on constantly when the wires are touched but when a capacitor is placed in the OUTPUT, it gets charged when the circuit turns ON and only allows the LED to flash.

Fig 35. Adding a capacitor to the output

THE NPN/PNP AMPLIFIER

A 2-Transistor DC amplifier can be constructed using an NPN and PNP set of transistors.

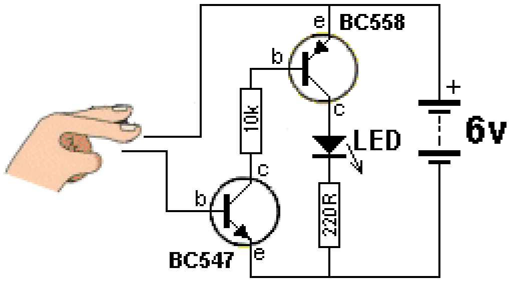


Fig 36.

Fig 36 shows how an NPN-PNP set of transistor is turned on.
You can think of the "turning ON" this way:
The base of the NPN get "Pulled UP" and the base of the PNP gets "Pulled DOWN."
It does not matter how you refer to the operation of the circuit, you must be able to "**SEE**" how the circuit works so you can **see** a more-complex circuit working too!

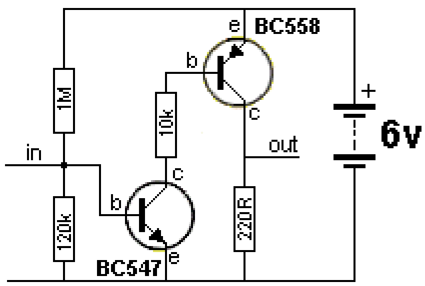


Fig 37.

Fig 37 shows biasing on the base of the first transistor and the "in" and "out" leads have been identified.
This circuit has a very high gain and if "general purpose" transistors are used with a very high spread of gain for each transistor, the result will be a very wide range of voltages on the output terminal. If each transistor has a gain of 100, a change of 1mV on the input will result is a voltage change of 0.001 x 100 x 100 = 10v. We don't have a 10v supply so, this type of circuit is very UNSTABLE!
We need to design a circuit that has FEEDBACK so the output voltage will remain within the voltage of the supply.
This feedback is called NEGATIVE FEEDBACK as it opposes an input signal to provide correction or stability.
Later we will talk about POSITIVE FEEDBACK and show what an amazing difference it creates - the circuit behaves totally differently.

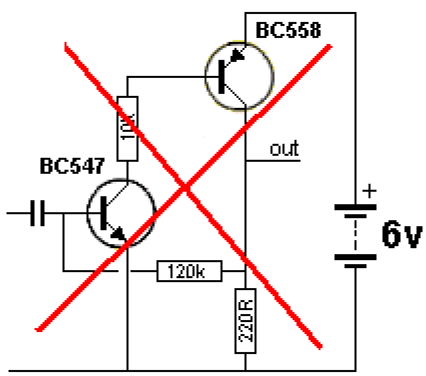


Fig 38 will not work because the base of the NPN transistor is not turned on when the circuit is switched on.
This is one of the things you have to look for when designing a circuit.

Fig 38. This circuit does not work

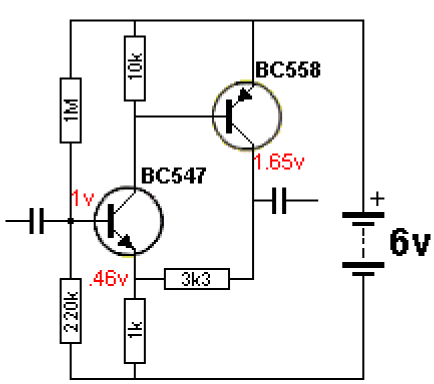


Fig 39. The voltages

Fig 39 has a voltage-divider network on the base of the NPN transistor. It turns the first transistor ON and this turns the PNP transistor on until the voltage at the join of the 3k3 and 1k puts a voltage on the emitter of the first transistor to start turning it OFF.
This is a point we have to explain.
There are two ways to turn on an NPN transistor.
1. Hold the emitter fixed and RAISE the base voltage.
2. Hold the base fixed and LOWER the emitter voltage.

In **Fig 39** the base is weakly fixed by the voltage divider made up of the 1M and 220k and even though the base can move up and down a little bit, we will assume the voltage is constant. If we raise the emitter voltage, the transistor will be turned off. This is what the FEEDBACK voltage via the 3k3 does. It raises the emitter voltage and turns the NPN transistor OFF slightly so an equilibrium point is reached where the two transistors are turned on a small amount and if one gets turned on a little more, the other sends signal to turn it OFF. This is not a practical circuit as an increase of 1mV on the input will produce a large change on the output and this will be reflected back to the emitter of the first transistor to cancel the input voltage.

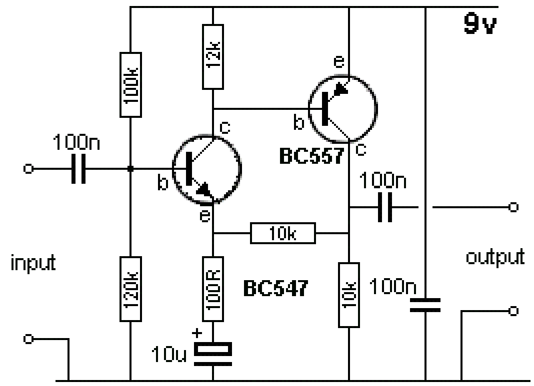


Fig 40. A practical example

Fig 40. By changing the value of the feedback resistors we get Fig 40. The values are now 10k and 100R.
This gives a ratio of 10,000:100 or 100:1 and it means the output can rise 100mV before the emitter gets 1mv to cancel the input voltage.
This means the amplifier will have a gain less than 100 but provides a very stable set of voltages.

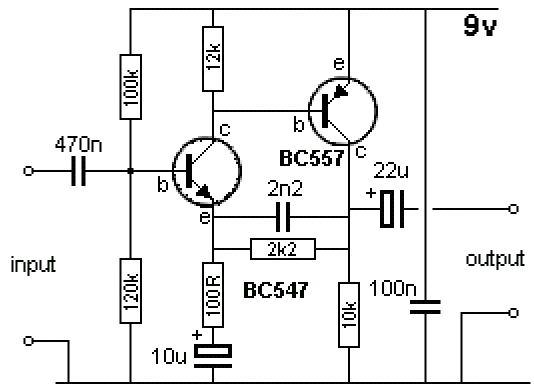


Fig 40a. Another practical example

Fig 40a. Here is an amplifier with the same DC biasing as Fig 40 but with a lower overall gain (2,200:100 or 22:1) and high-frequency feedback (attenuation) via the 2n2 capacitor.

OSCILLATORS

If we remove some of the components from Fig 39 and put a LED on the emitter of the PNP transistor we have a circuit that will illuminate the LED.
We have already talked about FEEDBACK in terns of NEGATIVE FEEDBACK to stabilize a circuit. We will now cover a new term called **POSITIVE FEEDBACK** - it changes the performance of circuit completely. It makes the circuit OSCILLATE. Negative feedback "kills" a circuits performance - positive feedback makes it oscillate. It increases the signal so much that the circuit becomes unstable. This is called oscillation.

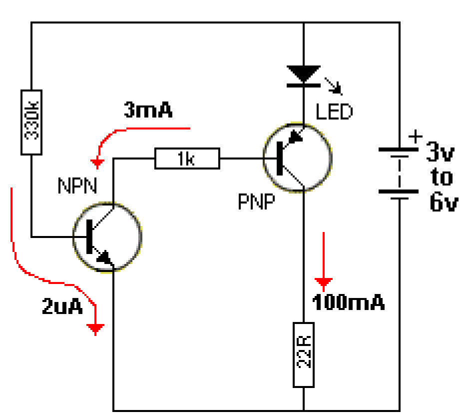


Fig 41.

Fig 41 shows a circuit using an NPN and PNP connected via a 1k resistor and turned on via a 330k base resistor.
The LED will illuminate.
There is nothing magic about this circuit. It is simply a HIGH-GAIN, DC-AMPLIFIER using two transistors.
The values of current are only approximate and show how each section allows an increasing amount of current to flow.

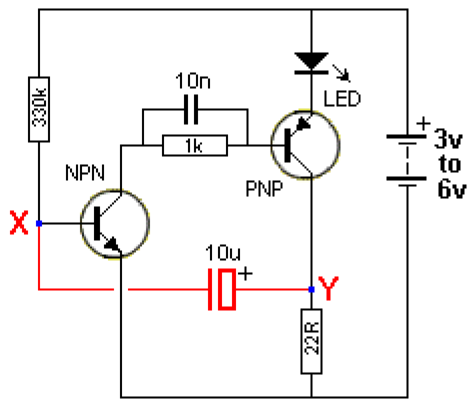


Fig 42.

Fig 42. But when we connect a capacitor, an amazing thing happens. The high-gain amplifier turns into an OSCILLATOR. When the voltage on point "X" is rising, the voltage on point "Y" is rising TOO. But point "Y" rises much higher than point "X." This means that if we join point X and Y, the voltage rise from point Y will push point X higher and turn the circuit ON more. This will continue until the circuit is fully turned ON. The two transistors are called SATURATED.

This effect is called POSITIVE FEEDBACK and the circuit will get turned ON until it cannot turn on any more.
But we haven't joined points "X" and "Y" so we have to start again and explain how the circuit works.
When the power is applied, the 10u gradually charges and allows a voltage to develop on the base of the NPN transistor. When the voltage reaches 0.6v, the transistor turns ON and this turns on the PNP transistor.
The voltage on the collector of the PNP transistor increases and this raises the right side of the 10u electrolytic and it firstly pushes its charge into the base of the NPN transistor then the 330k takes over then it continues to charge in the opposite direction via the base-emitter junction of the NPN transistor. This causes the two transistors to turn ON more. This keeps happening until both transistors cannot turn on any more and the 10u keeps charging. But as it continues to charge, the charging current eventually drops slightly and this turns off the first transistor slightly. This gets passed to the PNP transistor and it also turns off slightly. This instantly lowers both leads of the 10u and both transistors turn OFF.
The 10u is partially charged and it gets discharged over a long period of time by the 330k resistor and when it starts to charge in the opposite direction, the base of the first transistor sees 0.6v and the cycle starts again.
The end result is a very brief flash and a very long pause while the capacitor starts to charge again.
As you can see, there is very little difference between the high-gain DC amplifier we described above and the oscillator circuit just described.
That's why you have to be very careful when looking at a circuit, to make sure you are identifying it correctly.

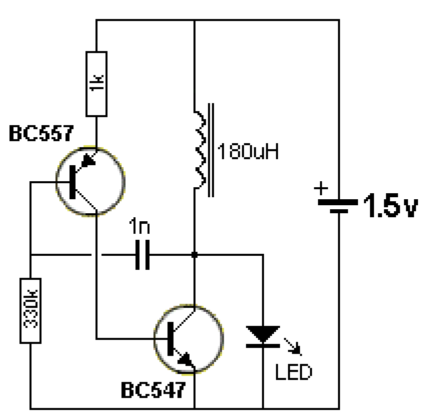


Fig 43.

Fig 43 is the same circuit with the components re-arranged. It is a high-frequency oscillator with an inductor as the load and when the circuit turns off, the inductor produces a high voltage in the opposite direction to the supply voltage and this is high enough to illuminate a LED. The LED will not illuminate on the 1.5v supply so when the LED illuminates, you know the circuit is working.

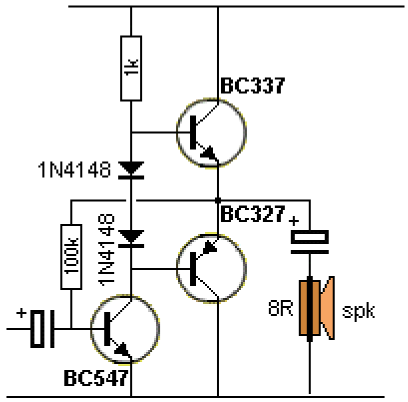


Fig 44.

Fig 44 is the same arrangement of the two transistors we have just studied, but with a third transistor above the two.
We have already seen the importance of charging a capacitor (and then it must be discharged so that the re-charge will produce a "current-flow.")
That's what the two transistors in the output are doing.
The top transistor charges the electrolytic and the bottom transistor discharges it.
In the process, the charging and discharging current flows through the speaker to produce audio.
We have already studied the two lower transistors. The BC327 turns ON and allows current to pass through the emitter-collector leads and this discharges the electrolytic.
The top transistor is an emitter-follower and it turns ON when the bottom two transistors are effectively "out of circuit."
The base is pulled to the supply rail by the 1k and the emitter follows. In other words the collector-emitter leads allow current to flow and this charges the electrolytic. The charging current flows through the speaker.

CURRENT GAIN OF AN EMITTER FOLLOWER STAGE

We have seen the need to provide current into and out of a speaker to move the cone. This is because current produces magnetic flux and many items work on magnetic flux, such as: motors, relays and speakers. And some items need a lot of current to be activated - especially globes.
Most transistors will provide a CURRENT GAIN of 100 when up to 25% of their rated current flows, but only a gain of 50 for the next 25% increase in current and a gain of 30 for the next 25% increase in current and a gain of only about 10 when the maximum allowable current flows.
There is a hidden factor with motors and globes. They take 6 TIMES more current for a globe to start glowing or to start a motor revolving. This is because the resistance of a cold globe is only one sixth of its glowing resistance and a motor has a very low resistance until the back emf (electro-motive force - another name for voltage) produced by the armature, reduces the current-flow.
This means you have to design a circuit that will deliver up to 6 times the operating current, so these items will turn on.
We explained the LOAD resistor provides the turn-on current for the speaker in the following circuit.
But we can design a circuit where this current is provided by a transistor.
This is important when we are providing high currents as a transistor can be turned on to deliver the current and turned off when the current is not required,. This saves energy and prevents over-heating.
We will look at the following 2-Transistor DC amplifier driving a speaker (taken from Fig 18) and modify the circuit.

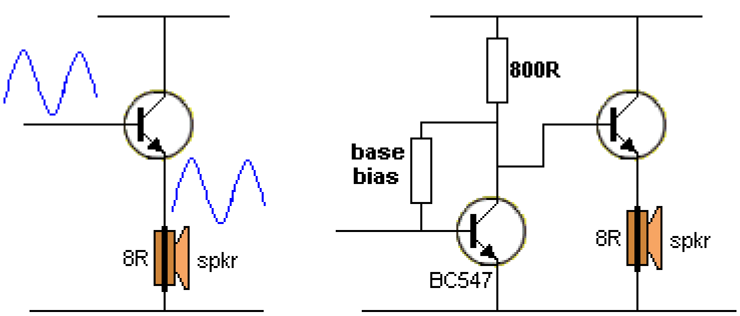


Fig 45. This circuit drives a speaker.

Fig 45. An emitter-follower driving a speaker

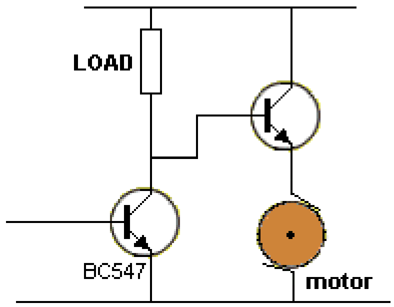


Fig 46.

Fig 46. We replace the speaker with a motor.

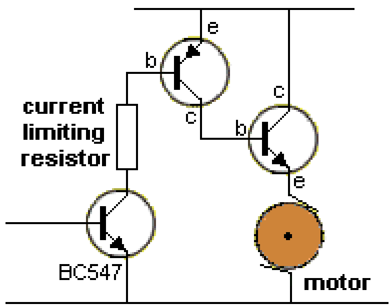


Fig 47.

Fig 47. We replace the LOAD resistor with a transistor and add a resistor called: **Current Limiting Resistor.**
It is designed to limit the current between the first and second transistors as these will turn on and allow a very high current to flow if the resistor is not included.

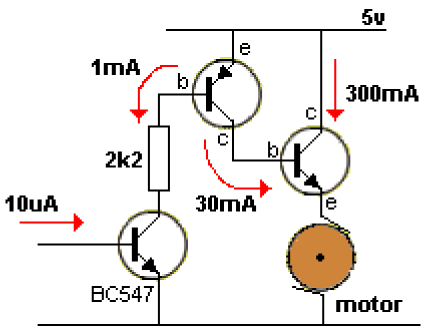


Fig 48.

Fig 48. The current required by the motor is 300mA. The emitter-follower will have a gain of 10 and the gain of the other two transistors produces the set of conditions shown on the diagram.
You can see that very little input current is required to activate the motor when 3 transistors are used.

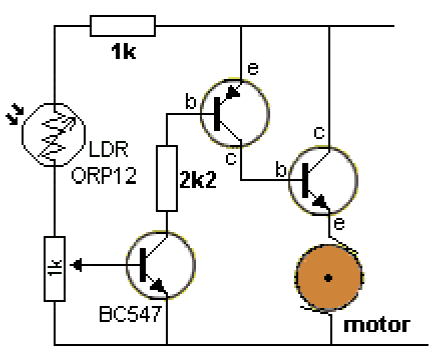


Fig 49.

Fig 49. The input current can be supplied from a voltage-divider using a pot (to adjust the setting) and a Light Dependent Resistor.
We cannot use only 2 transistors as the LDR cannot supply 1mA under low-level light conditions and that's why 3 transistors are needed.

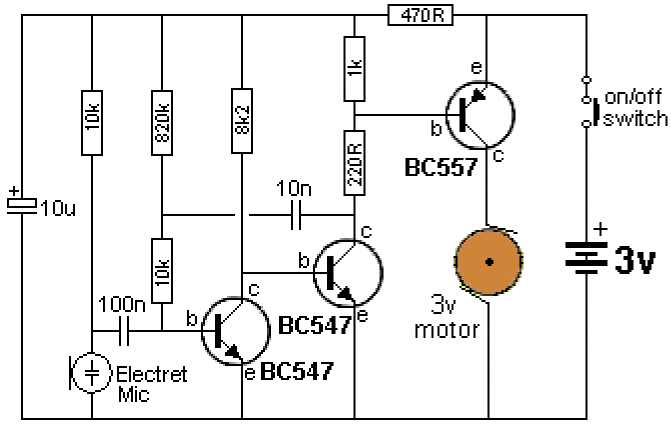


Fig 50. Here is a commercial version of a 3-transistor circuit.
This circuit was taken from a dancing flower. A motor at the base of the flower has a bent shaft up the stem and when the microphone detected music, the shaft makes the flower wiggle and move.
The circuit will respond to a whistle, music or noise.
The circuit uses a different arrangement to our 3-transistor design and we will discuss the differences.

Fig 50. Dancing Flower

It is very easy to get a voltage gain or "voltage amplification" from an input device such as an LDR or electret microphone to drive a motor using just 2 transistors, but to get CURRENT GAIN you need 3 transistors.
Both circuits (Figs 49 and 50) appear to perform the same but you need to look at the voltage drop across the leads of the output transistors to see how the two circuits compare.
There are two important values for a FULLY-TURNED-ON transistor:

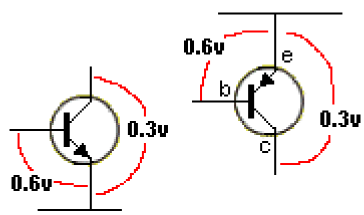


Fig 51. The characteristic voltage drops across a fully-turned-ON transistor

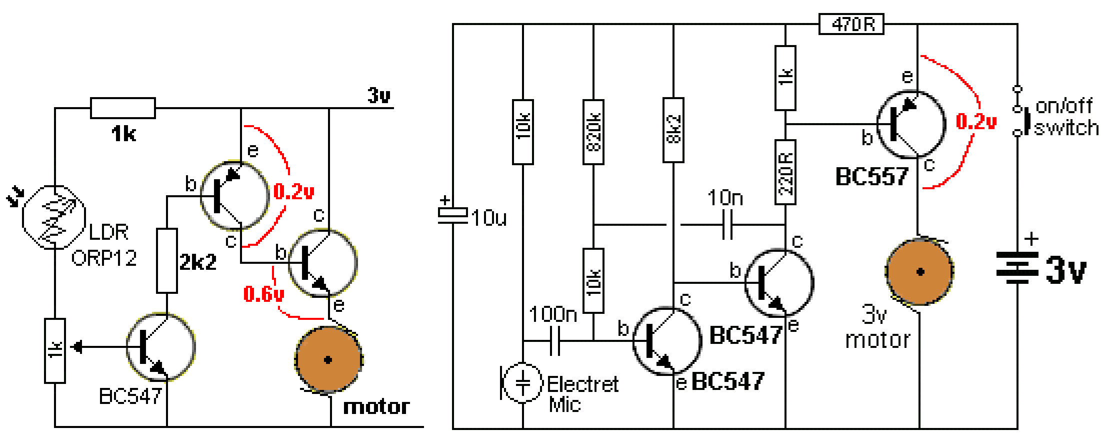


Fig 52. The voltage losses across the output transistor

The **emitter-follower** design (the first circuit) has a total voltage drop of 0.8v and the motor will see a maximum of 2.2v.   The motor in the **common-emitter** design will see a maximum of 2.8v.

SUMMARY

You can now see the advantages and disadvantage of each design. Because the emitter-follower has a 0.6v drop between base and emitter, it is generally used in a PUSH-PULL arrangement as we will see in Fig 53, to charge and discharge the electrolytic or in an H-Bridge to drive a motor forward and reverse as shown in Fig 54. .

THE PUSH-PULL STAGE   also called PUSH-PULL AMPLIFIER

We have studies the emitter-follower in Figs 45 to 49. We have also shown how to connect a PNP transistor to the power rails. It is basically a mirror-image of the NPN transistor. Combining these facts we can produce a circuit consisting of two emitter followers as shown in **Fig 52a**. The top emitter follower is an NPN transistor and the lower emitter-follower is a PNP transistor. The is called a **PUSH PULL** output stage or **PUSH PULL AMPLIFIER** or **Complementary-Symmetry output** stage.

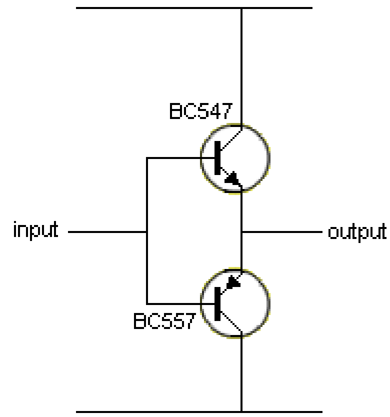


Fig 52a. Push-Pull Output

Lifting the Input line will raise the output line and it will have "100 times more strength." Lowering the input line will make the output line go down with "100 times more strength."
In other words this circuit turns a "weak line into a strong line."
This feature is also called **IMPEDANCE MATCHING**. The circuit is also called a **PUSH PULL OUTPUT** as one transistor "pushes energy" into a device connected to the output during one half of a cycle while the other transistor will "pull energy" out of a device. This is one of the ways to charge and discharge a capacitor on the output and any device connected to the other side of the capacitor will see the AC waveform and become active. This is shown in **Fig 53**:

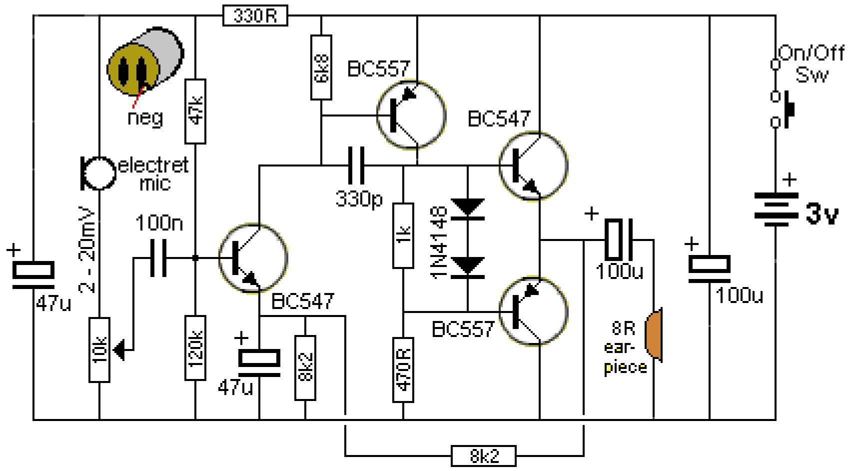


Fig 53 PUSH-PULL to charge/discharge the 100u electrolytic

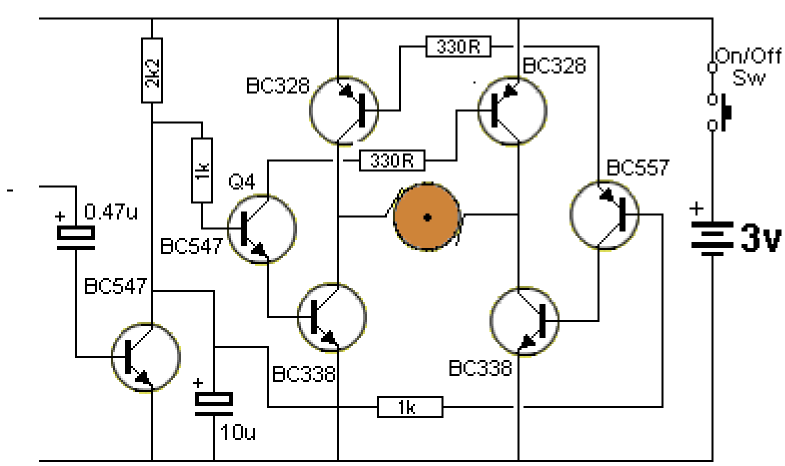


Fig 54 PUSH-PULL driving the motor forward/reverse

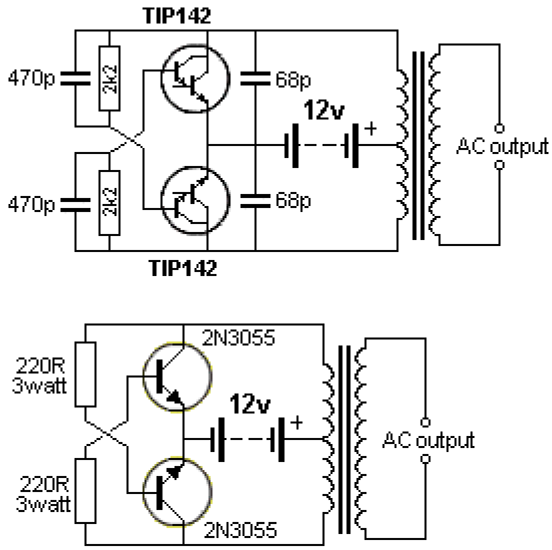


Fig 54a Two Push-Pull circuits driving the primary of a transformer

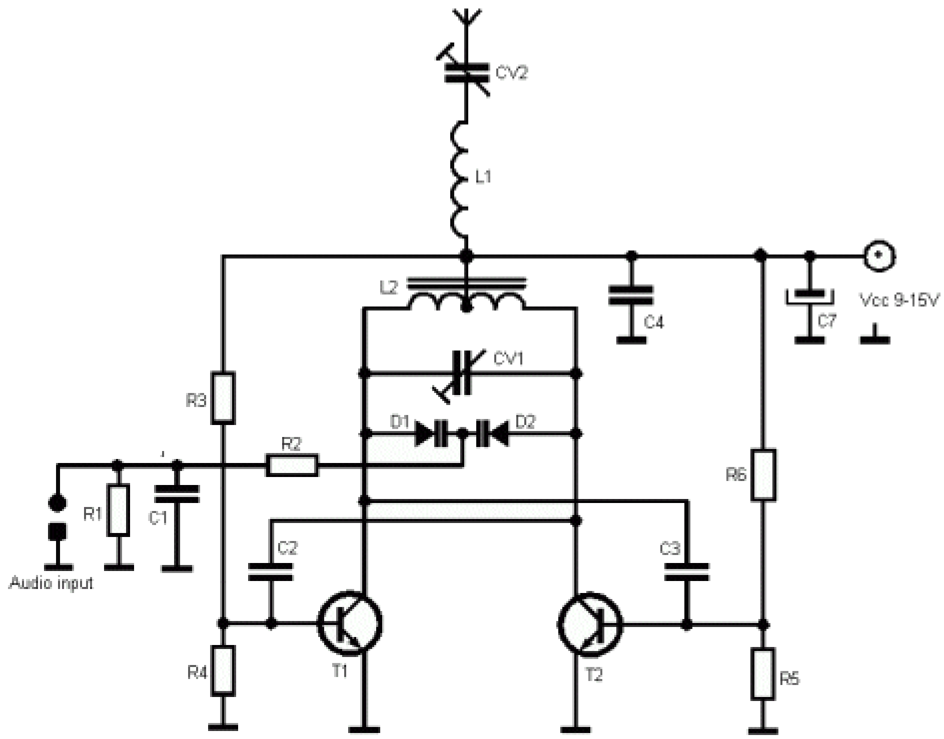


Fig 54b

Fig 54b shows a free-running multivibrator configured so the transistors drive a transformer in **Push-Pull**

THE TOTEM POLE OUTPUT STAGE

A slightly different push-pull output stage can be created with two NPN transistors. It is called a Totem Pole Output stage.

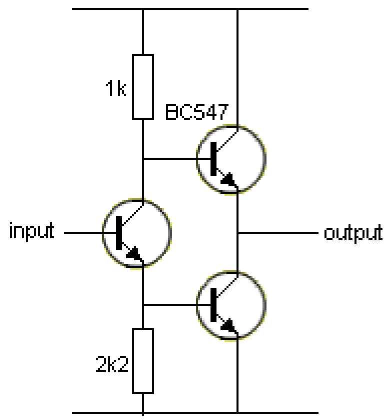


Fig 55a

Fig 55a. When the input is less than 1v, the output is pulled high via the 1k resistor and the "strength" of the "pull-up" will be 1,000/100 = approx 10 ohms.
When the input reaches 1.4v, the output is pulled low via the lower transistor and will about 0.2v from the 0v rail. The "strength" of the "pull-down will be about equivalent to a 10 ohm resistor.
This is about the same as the output driving capability of a normal Push-Pull arrangement, however there is a mid-point where both transistors are turned on at the same time and this produces a large current that can overheat the transistors or damage them.

THE BRIDGE

Another way to connect a transistor to produce a "stage" is called a BRIDGE.
It consists of 4 resistors:

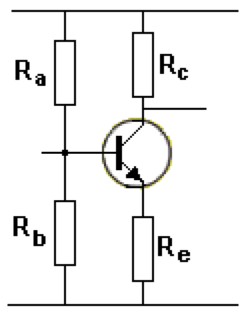


Fig 56. A BRIDGE arrangement consisting of 4 resistors

Fig 56. We have already studied the purpose of Ra and Rb to produce a voltage on the base of the transistor. If they are the same value, the base voltage will be half the supply. We also know the emitter voltage will be 0.7v lower than the base.
This will produce a current through Re and the same current will flow in Rc. We can now work out the voltages on the three leads of the transistor.

But that's not the point of our discussion at the moment.
We want to know how to work out the values of Ra, Rb, Rc and Re.
There are two types of "bridges."
1. A small-signal bridge and
2. A medium or high-power signal bridge.

A small-signal bridge deals with signals that do not have much input-current. We have already learnt the ability of a stage to pass a CURRENT from one stage to the next stage depends on the value of the LOAD resistor (for the common-emitter stages we have covered).
If this current is very small, we do not want to attenuates it (reduce it) by making the input of our bridge stage LOW IMPEDANCE (low resistance). If the values of Ra and Rb are low, any signal being applied to this stage will be partially lost (reduced - attenuated) by the value of the voltage-divider. That's why the resistors have to be as high as possible.
They are generally about 470k to 2M2.
Suppose we make Ra = 1M and Rb = 470k.

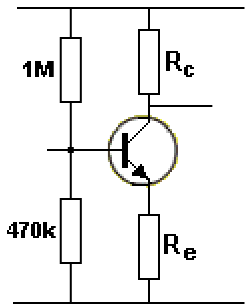


Fig 57. The base is biased at about 1/3 rail voltage.
The emitter will be about 0.7v below the base voltage so the collector can produce a swing of about 50% of rail voltage.
This is the normal way to bias this type of stage.

Fig 57. Biasing the BASE

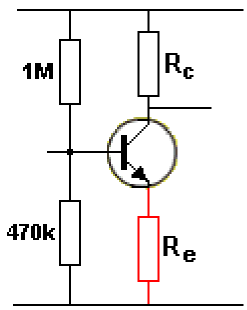


Fig 57a. The emitter resistor provides NEGATIVE FEEDBACK

Fig 57a. In the **Bridge Circuit**, 4 resistors bias the transistor and Re is the EMITTER RESISTOR.
It is also a NEGATIVE FEEDBACK resistor and works like this:
When the voltage on the base rises by 10mV, the transistor turns on more and the current through the collector LOAD resistor Rc increases and the same current flows through the emitter resistor Re. This causes a slightly higher voltage to appear across this resistor and the voltage on the emitter rises.
We have already discussed how to turn ON a transistor or turn OFF a transistor and when the voltage on the emitter increases, the transistor is turned OFF slightly. This means the 10mV rise on the base may be offset by a 2mV rise on the emitter and the transistor will not be turned on as much. This is the effect of **NEGATIVE FEEDBACK.**

STAGE GAIN

The gain of the stage is the ratio of Rc/Re If Rc=22k and Re=470R the gain is 46.
It does not matter if the transistor has a gain of 200 - the stage is limited to a gain of 46. The actual DC voltage on the leads of the transistor depends on the quality of the transistor (its gain) and we will not be concerned with these values as the stage will have a capacitor on the input and output and it will be biased by the 4 resistors.

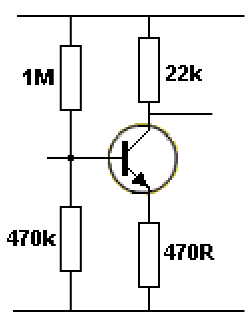


Fig 58. shows a stage with Rc=22k and Re=470R, producing a stage-gain of 46. The actual voltage on the collector will depend on the gain of the transistor.

Fig 58. A stage-gain of 46

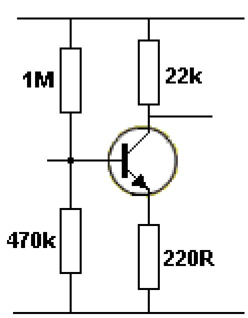


Fig 59. If we use the values: Rc=22k and Re=220R the gain will be 100.

Fig 59. A stage-gain of 100

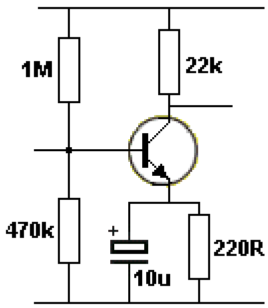


Fig 60. A stage-gain of 200 or more

Fig 60. If we add an electrolytic across the emitter resistor, the emitter will not move up and down when a signal is processed and this makes the transistor similar to a common-emitter stage. The transistor will now have a stage-gain similar to its specification. It may be 200.

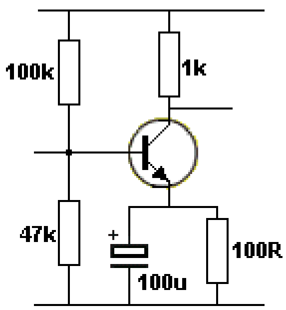


Fig 61. A medium-power bridge circuit

Fig 61. When we add the electrolytic, the gain of the stage is not dependent on the values of Rc and Re, and we can reduce the value Rc so the stage will pass a higher current to the following stage.
This stage is called a **medium-signal stage.**

ADJUSTING (SETTING) THE STAGE GAIN

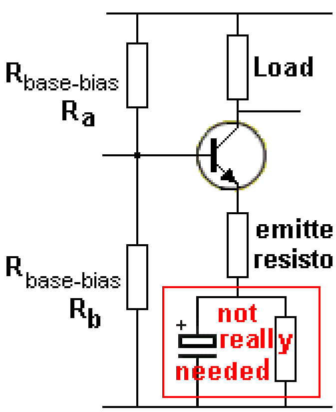


Fig 61a. "emitter resistor" adjusts the gain of the stage

Fig 61a. The gain of a stage can be adjusted (or SET) to a particular value by adding an emitter resistor. We have seen in Fig 58, the gain of a stage is determined by the ratio of:
the resistor in the collector/ the resistor in the emitter.
Increasing the value of the resistor in the emitter, decreases the gain of the stage.
In Fig 57a, we saw this as **NEGATIVE FEEDBACK**. This effect is also called **EMITTER DEGENERATION** as it reduces the gain of the stage.
On Page 2 you will find a program where you can design your own Transistor Amplifier:
Design Your Own Transistor Amplifier
It uses the circuit in Fig 61a to adjust the gain of the amplifier.
The components in the red rectangle are not really needed when the resistor called: **emitter resistor** is used. They only adjust the "sitting of the transistor" slightly up or down between the supply rails.

Connecting a small-signal stage to a medium-signal stage:

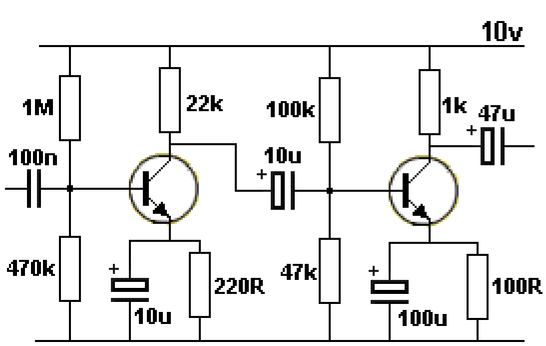


Fig 62. Connecting a small-signal

Fig 62. When describing small-signal and medium-signal stages we are referring to the size of the waveform (voltage waveform) and also the CURRENT they are capable of transferring. The two values normally go together.
In most cases the voltage AND current increase as it progresses though each stage.
Both stages in Fig 62 produce a high gain but the final gain will depend on the amount of energy each capacitor will transfer.
For instance, the 22k will pull the 10u high but the 47k discharges the 10u and so it will be partially charged for the next cycle. This means the energy

stage to a medium-signal stage transfer will only be equivalent to a load resistor of 47k.

COMMON BASE AMPLIFIER

We have discussed the importance of matching the output impedance of one stage to the input impedance of the next stage. When the two are equal, the maximum energy is transferred.
Suppose you want to match a very low resistance device (such as speaker or coil) to the input of an amplifier. The speaker may be 8 ohms and the input impedance of the common-emitter amplifiers we have described are about 500R to 2k. The two can be connected via a capacitor but we have already mentioned how a capacitor transfers only a small amount of energy when the two impedances are not equal. And when the two impedances are so mismatched as 8:2,000, the transfer will be very poor.
The answer is to use a stage that has a very low input impedance.

That's a COMMON BASE amplifier.

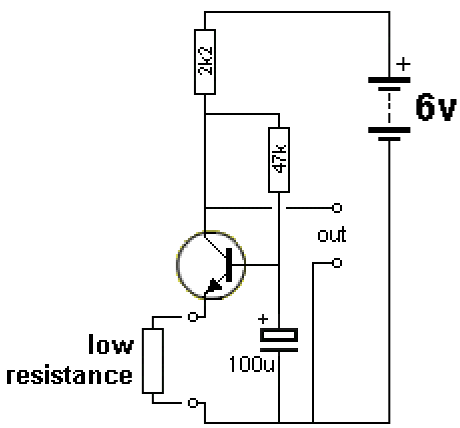


Fig 63.

Fig 63. The common-base amplifier (Common-Base stage) accepts a low value of resistance on the input and produces a high gain. Since the input is directly coupled to the transistor, there are no losses.
We have already mentioned two ways to turn on an NPN transistor.
1. Hold the emitter fixed and RAISE the base voltage.
2. Hold the base fixed and LOWER the emitter voltage.

We are using the second option. The base is held rigid (as far as signals are concerned) and any rise or fall in voltage on the emitter appears on the collector with a voltage increase of about 100.

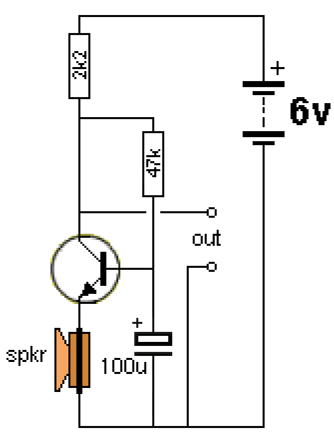


Fig 64. Dynamic Microphone

Fig 64. This circuit converts an ordinary speaker into a very sensitive microphone.
The fact that the load resistor is 2k2, means the stage has a good capability of driving energy to the next stage.
We have already discussed the fact that the "load" resistor determines the capability of the stage to pass energy to the next stage.

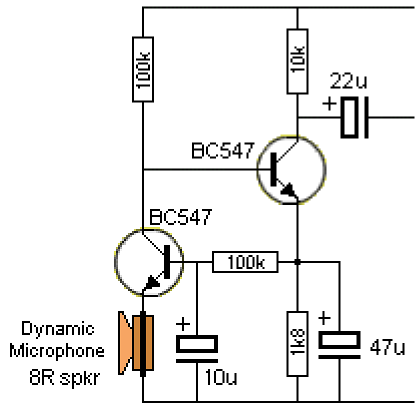


Fig 64a. Common Base and Common Emitter stages directly coupled together

Fig 64a. This circuit adds a Common Emitter stage to the Common Base shown in Fig 64 to produce a DC coupled (Directly Coupled) amplifier with very high gain.
The common-emitter transistor can be called a BUFFER stage as it provides a lower impedance output than the first stage.
In Fig 71ac, (below) the output of the second transistor has been taken back to the input to produce an improvement called a **BOOTSTRAP Circuit** to create a higher gain.

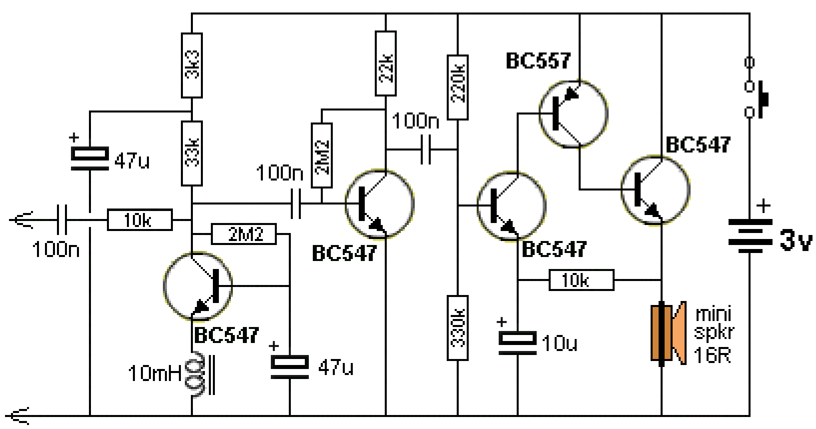


Fig 65. Hum Detector

Fig 65. This circuit picks up mains hum via a coil. The common-base first stage has very high gain. And we can see a common-emitter stage plus a 3 transistor DC amplifier driving a speaker.
All the things we have learnt, put into a single circuit.

PRACTICAL CIRCUITS

Here are a number of circuits using the stages we have covered:

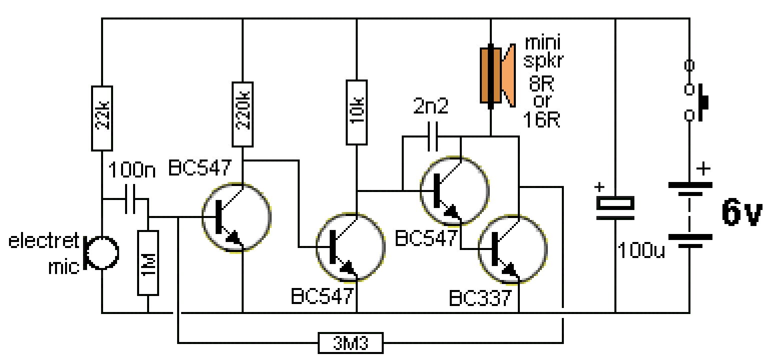


Fig 66. 4-Transistor Amplifier

Fig 66. This 4-transistor amplifier uses the minimum of components and has negative feedback via the 3M3 to set the voltages on all the transistors.
It is actually 3 stages and that is why the feedback can be taken from output to input.
Transistors 3&4 are equivalent to a single transistor called a Darlington transistor and this is covered in Fig 71.

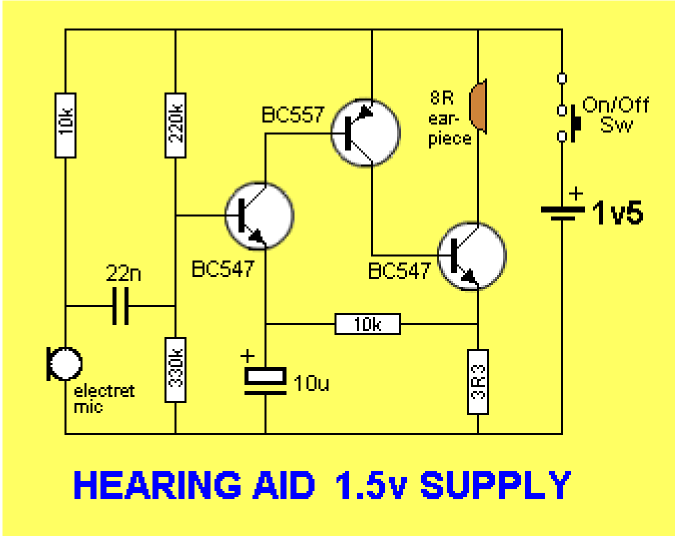


Fig 67.

Fig 67. This Hearing Aid uses the 3-transistor DC amplifier covered above, (with some variations).

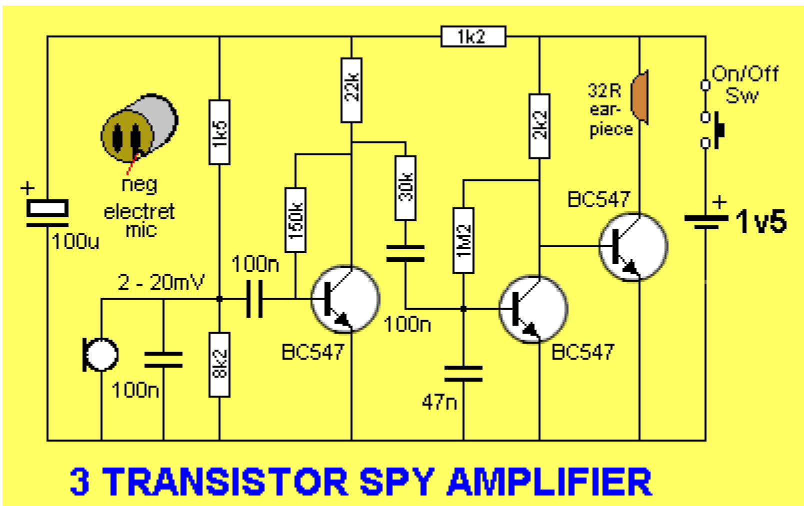


Fig 68.

Fig 68. A 3-transistor amplifier operating on 1.5v

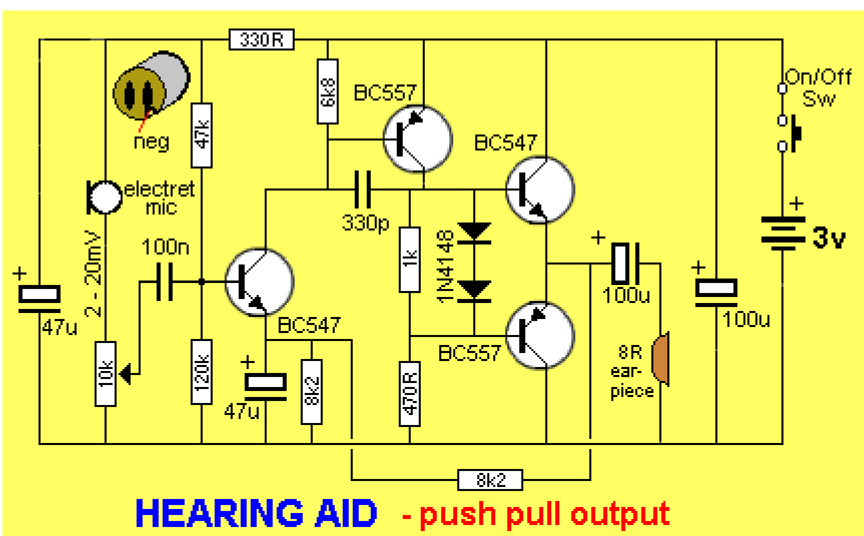


Fig 69.

Fig 69. This Hearing Aid circuit uses push-pull to reduce the quiescent current and also charge/discharge the electrolytic feeding the 8R earpiece.

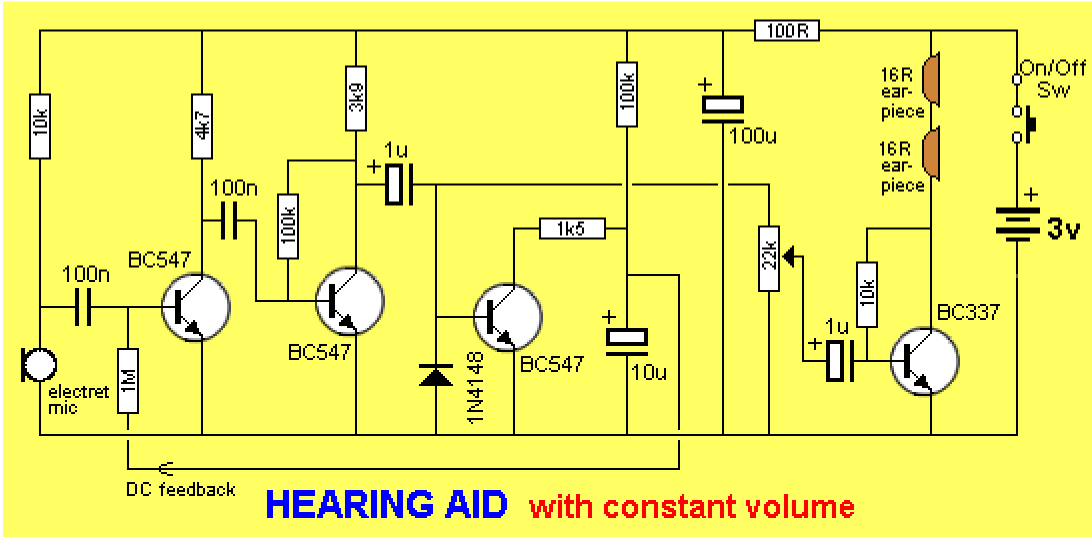


Fig 70.

Fig 70. This Hearing Aid circuit has the first transistor turned on via a 100k and 1M resistors. Connected to this supply is a transistor that discharges the biasing voltage when it sees a signal higher than 0.7v This reduces the amplitude of the signal being processed by the first transistor and produces a constant volume amplifier.

How does reducing the voltage on the base of the first transistor reduce the gain of the first stage?
When the voltage delivered by the 100k and 1M resistors on the base of the first transistor is REDUCED, the current (energy) being delivered to the base is reduced and thus more energy has to be delivered by the 100n capacitor. This causes a larger signal-drop across the 100n coupling capacitor (discussed in Fig 71c below) and thus the amplifier produces a reduced amplification. This is along the same lines as changing from a "Class-A" amplifier to a "Class-C" amplifier (as shown in Fig 107a) where a "Class-C" amplifier gets ALL its turn-on energy from the coupling capacitor.

THE DARLINGTON

There are two types of Darlington transistors. One type is made from two NPN or PNP transistors placed "on-top" of each other as shown in Fig 71 and Fig 71aa:

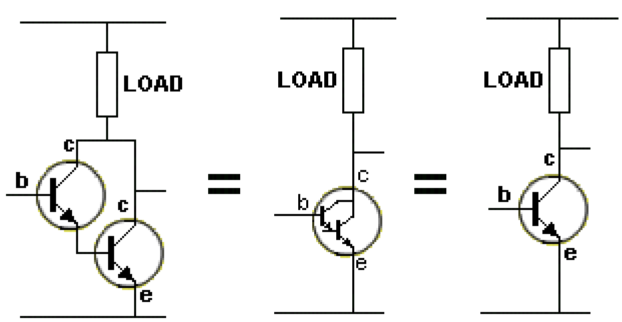


Fig 71.

Fig 71. Two NPN transistors connected as shown in the first diagram are equal to a single transistor with very high gain, called a DARLINGTON.
The second diagram shows the symbol for an NPN Darlington Transistor and the third diagram shows the Darlington as a single transistor (always show a Darlington as TWO transistors.) One difference between a Darlington and a normal transistor is the input voltage must rise to 0.65v + 0.6v5 = 1.3v before the NPN Darlington will turn ON fully.

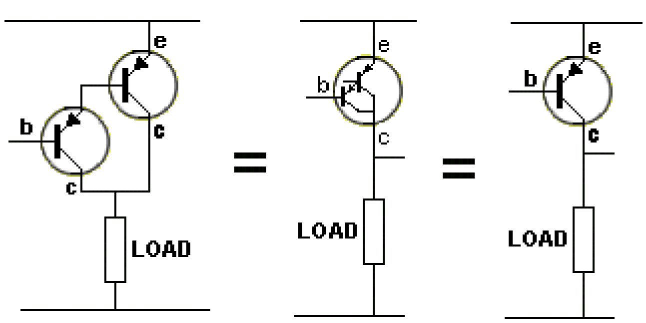


Fig 71aa. shows two PNP transistors connected to produce a single transistor with very high gain, called a PNP DARLINGTON.
The second diagram shows the symbol for a PNP Darlington Transistor and the third diagram shows the Darlington as a single transistor. The input voltage must fall 0.65v + 0.6v5 = 1.3v before the PNP Darlington will turn ON fully.

Fig 71aa.

The other type of Darlington transistor is called the Sziklai Pair. It has an advantage:

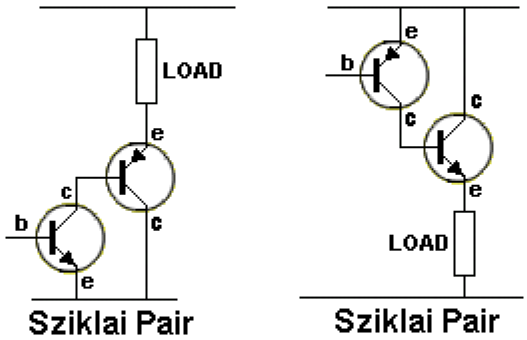


Fig 71ab.

Fig 71ab. shows a NPN and PNP transistor connected to produce a single transistor with very high gain, called a **Sziklai Pair**.
The second diagram shows a PNP and NPN transistor connected to produce a single transistor with very high gain, also called a **Sziklai Pair**. The advantage of this arrangement is the input voltage only needs to be 0.6v5 for the **Sziklai Pair** to turn ON fully.

THE BOOTSTRAP CIRCUIT

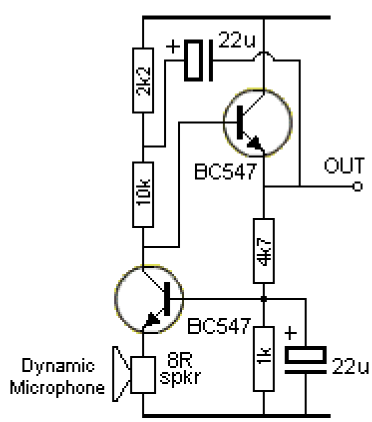


Fig 71ac

Another very interesting design is the **Bootstrap Circuit.** It uses positive feedback to achieve very high gain.
The two transistor circuit shown in **Fig 71ac** has a gain of approx 1,000 and converts the very low output of the speaker into a waveform that can be fed into an amplifier.
The circuit is simply a common-base stage and an emitter-follower stage.
But the output of the emitter-follower is taken back to the input of the same stage and this is the Bootstrap feature. It is like pulling yourself UP by pulling your shoe laces.
When the voltage from the speaker reduces by 1mV, the transistor turns ON a little more and pulls the collector voltage lower.
This action takes a lot of effort and to pull it lower, requires more energy from the speaker.
In the Bootstrap circuit, the first transistor pulls the 10k down and this pulls the emitter-follower transistor down. At the same time the 22u is pulled down and it pulls the 10k down to assist the first transistor. In other words the first transistor finds it much easier to pull the 10k resistor down.
When the first transistor turns off, the 2k2 pulls the 10k resistor UP and it is aided by the 22u. The end result is a very high output voltage swing.

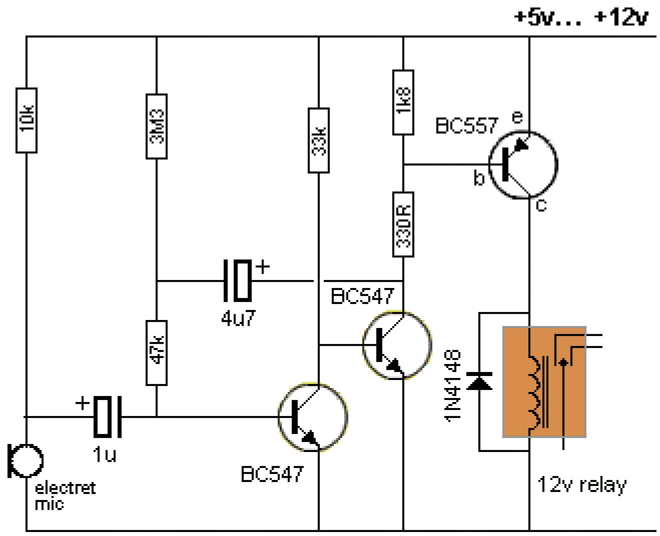


Fig 71acc

Fig71acc shows a Sound Activated Switch using a BOOTSTRAP arrangement for the first two transistors.
The first transistor is biased ON via the 3M3 and 47k. This means the
collector voltage will be very low and the second transistor will be biased OFF and the third transistor will also be OFF. The relay will not be activated.
When the electret microphone receives audio in the form of a CLAP, the peak will not have any effect on the first transistor as it is already saturated, but the falling part of the waveform will reduce the voltage on the base and allow the transistor to turn off a small amount.
This will turn ON the second transistor and the voltage on the collector will fall.
The 4u7 is connected to this point and it will fall too and reduce the voltage on the base of the first transistor considerably. This will turn the first transistor off more and the process will continue and turn on the relay.
But during this time the electrolytic is discharging then charging via the 3M3 and eventually it charges to a point where the base of the first transistor sees a voltage above 0.7v and it it turned on again.
The collector voltage of the second transistor rises and this turns on the first transistor fully and the two transistors swap states. The relay turns off.
If the microphone continues to produce negative (or falling waveforms), the relay will continue to remain active.

THE DIFFERENTIAL AMPLIFIER

or

LONG TAILED PAIR

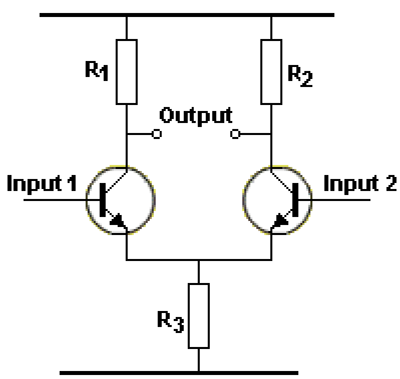


Fig 71ad

The **DIFFERENTIAL AMPLIFIER** is also called the "**Difference Amplifier"** or **long-tailed pair** (LTP)**,** or **emitter-coupled pair,** because it amplifies the **difference** between the voltages on **Input 1** and **Input 2.** It is called a Long Tailed Pair because the emitter resistor has a high value. The circuit has the advantage of ONLY amplifying the signals on the Inputs. Any noise on the power rail is not detected on the output as both transistors will see this fluctuation and both lines of the output will either rise or fall.
Since the **Long Tailed Pair** does not pick up noise from the supply, it is ideal as a pre-amplifier as shown in the 60 watt amplifier in **Fig 71ae**:

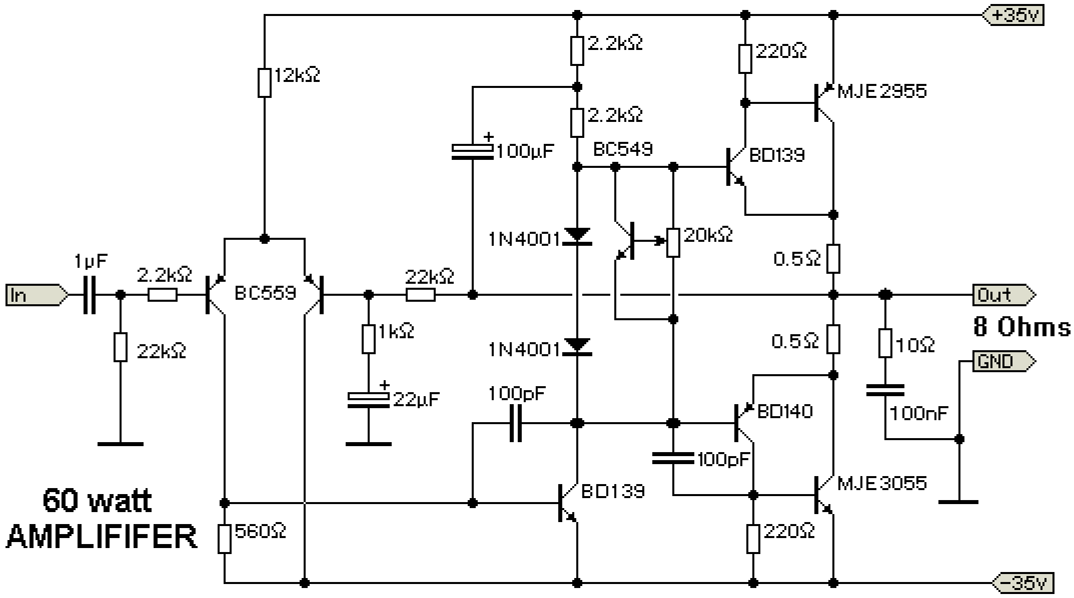


Fig 71ae

THE CONSTANT-CURRENT CIRCUIT

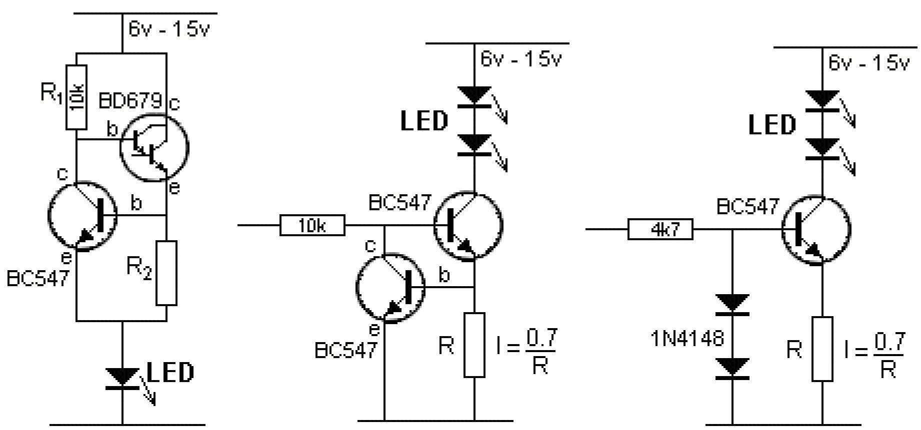


Fig 71a Constant-Current Circuit

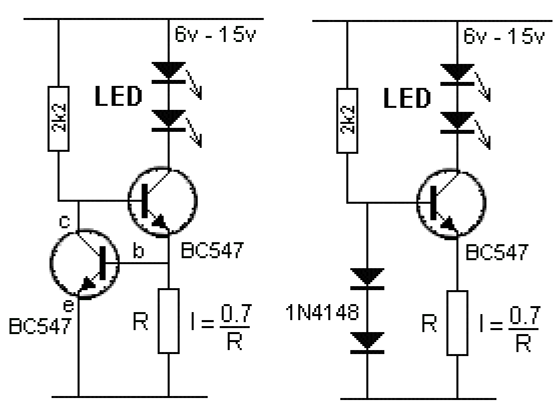


Fig 71b Constant-Current Circuit

Fig 71a. We have studied the Darlington transistor, the common-emitter stage and how to turn off a common-base configuration by raising the voltage on the emitter.

The first circuit in Fig 71b is a constant-current arrangement, providing a fixed current to the LEDs, no matter the supply voltage.

This is done by turning on the top transistor via the 2k2 resistor. It keeps turning on until the voltage-drop across resistor **R** is 0.65v. At this point the lower transistor starts to turn on and current flows through the collector-emitter terminals and it "robs" the top transistor of current from the 2k2 resistor. The top transistor cannot turn on any more and the current flowing though R is the same as the current flowing through the LEDs and does not increase.

The second diagram in **Fig 71b** is also a constant-current circuit with the base fixed at:
0.7v + 0.7v = 1.4v via the two diodes.

The transistor is turned on via the 2k2 resistor and a voltage is developed across resistor **R**. When this voltage is 0.7v, the emitter is 0.7v above the 0v rail and the base is 1.4v. If the transistor turns on more, the emitter will be 0.8v above the 0v rail and this will only give 0.6v between base and emitter.

The transistor would not be turned on with this voltage-drop, so the transistor cannot be turned on any more than 0.65v across the resistor **R**.

TWO TRANSISTOR REGULATOR

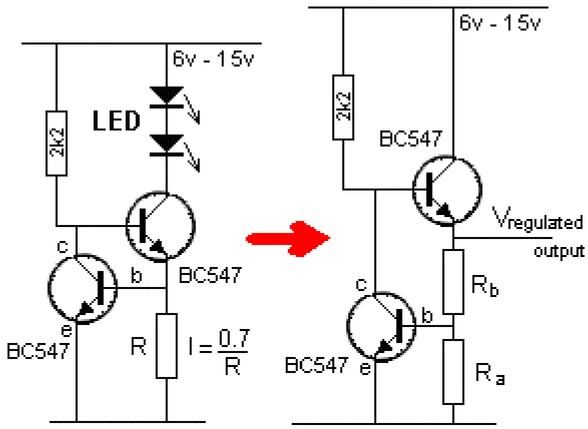


Fig 71bb

If we take the Constant-Current Circuit shown in **Fig 71b** above, and split resistor **R** into **R**a and **R**b, we produce an identical circuit with a completely different name. It is called a **TWO TRANSISTOR REGULATOR**.
The circuit will produce a smooth voltage on the output, even though the rail voltage fluctuates AND even if the current required by the output increases and decreases. That's why it is called a REGULATOR CIRCUIT.
The current through Ra and Rb is "wasted current" so it does not have to be more than 1mA - enough to turn on the lower NPN transistor.
Ra and Rb form a voltage divider and when the join of the two resistor reaches 0.7v, the lower transistor turns ON.

The lower transistor forms a voltage-divider with the 2k2 to pull the top BC547 transistor DOWN so the voltage on the output is kept at the "design voltage" (the top transistor is an emitter follower). If the device connected to the output requires more current, the top transistor will not be able to provide it and the output voltage will drop. This will reduce the voltage on the base of the lower transistor and it will turn OFF slightly.
The voltage on the base of the top transistor will rise and since this transistor is an emitter-follower, the emitter will rise too and increase the output voltage to the original "design value."
Regulation is also maintained if the supply decreases (or increases).
If the supply decreases, the voltage on the base of the top transistor will fall and the output voltage will also fall.
The voltage on the base of the lower transistor will also fall and it will turn off slightly.
This will increase the voltage on the base of the top transistor and the V regulated will rise to the design value. Both the supply and the load can change at the same time and the circuit will compensate.
All we have to do is re-draw the circuit as a standard 2-Transistor Regulator as shown in **Fig 71bc** and you have covered the principle of its operation.

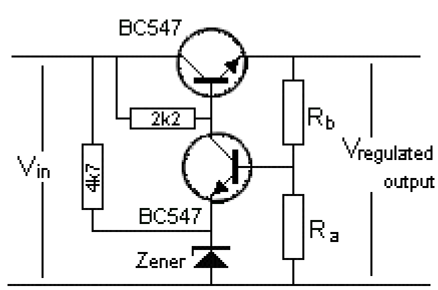


Fig 71bc
2-Transistor Voltage Regulator

THE TRANSISTOR AS AN AF AND RF DETECTOR

A transistor can be used as a "detector" in a radio circuit. The Detector stage in a radio (such as an AM receiver), is usually a crystal, but can be the base-emitter junction of a transistor.
It detects the slowly rising and falling audio component of an RF signal. This signal is further amplified and delivered to a speaker. A single transistor will perform both "detection" and amplification.
In **Fig 71bd**, the first transistor provides these two functions and the output is passed to the second transistor via direct-coupling.
The two transistors provide enormous gain and a very high input impedance for the tuned circuit made up of the 60t aerial coil and 415p tuning capacitor. The signal generated in the "tuned circuit" is prevented from "disappearing out the left end" by the presence of the 10n capacitor as it holds the left end rigid.

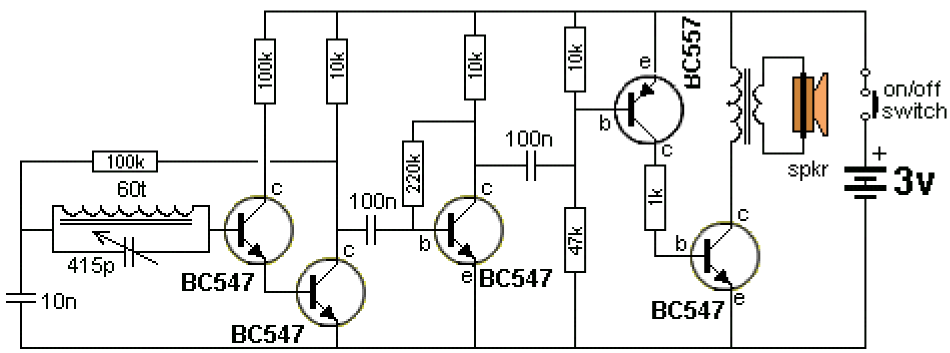


Fig 71bd   5-TRANSISTOR RADIO

THE COUPLING CAPACITOR

We have shown the coupling capacitor transfers very little energy when it does not get fully discharged during part of the cycle and this means it cannot receive a lot of energy to charge it during the "charging" part of the cycle.
This is a point that has never been discussed in any text books. It is the energy (actually the current - due to the difference in voltage between the two terminals of the capacitor) that flows into the capacitor that creates the flow of energy from one stage to the other. It is the "magnet on the door" analogy described above.
But the question is:
1. How much energy will a capacitor pass under ideal conditions?
2. How do you work out if a capacitor needs to be: 100n, 1u, 10u or 100u?

Without going into any mathematics, we will explain how to select a capacitor.
Many test books talk about the capacitive reactance of a capacitor. This is its "resistance" at a particular frequency.
But an audio circuit has a wide range of frequencies and the lowest frequency is generally selected as the capacitor will have the highest resistance at the lowest frequency.
We will select 200Hz as the lowest frequency for an amplifier.

A 100n will have a "resistance" of about 10k at 200Hz
A 1u will have a "resistance" of about 1k at 200Hz
A 10u will have a "resistance" of about 100R at 200Hz
A 100u will have a "resistance" of about 10R at 200Hz

A 100n capacitor at 200Hz is like putting a 10k resistor between one stage and the next.

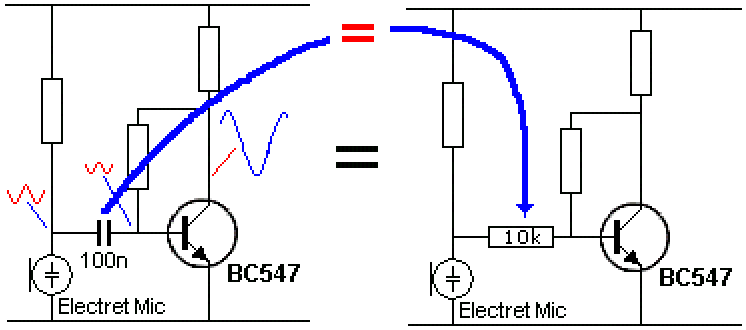


Fig 71c

A 1u capacitor at 200Hz is like putting a 1k resistor between one stage and the next.

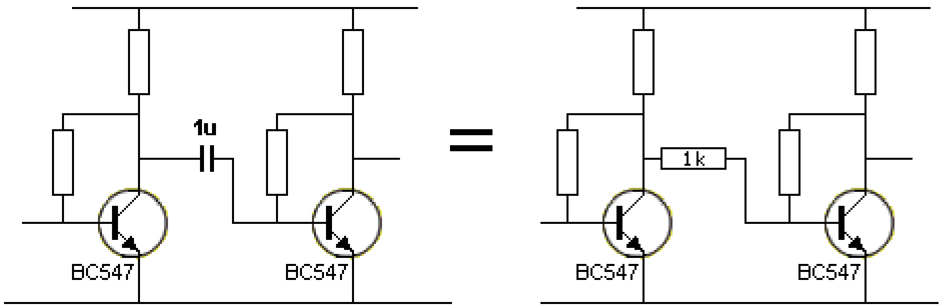


Fig 71d

A 10u capacitor at 200Hz is like putting a 100R resistor between one stage and the next and a 100u capacitor at 200Hz is like putting a 10R resistor between one stage and the next.

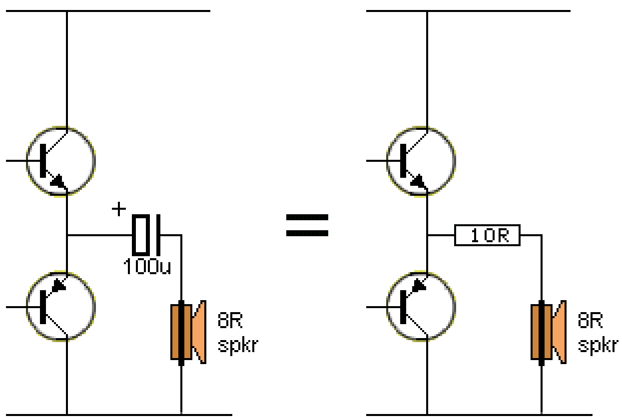


Fig 71e

The capacitive reactance of the 100u ranges from 10R to less than 1R (depending on the frequency being processed).

In **Fig 71d** you can see the "resistance" of a capacitor is very small compared to the LOAD resistance (the main component that determines the amount of energy that can be transferred from one stage to another and the impedance of the receiving stage - the component that determines the discharging of the capacitor). The "resistance" of a capacitor decreases as the frequency increases. Thus the "capacitive reactance" of a capacitor has very little effect on the transfer of energy from one stage to the next (when it is correctly selected). The major problem is not discharging the capacitor. It only transfers the maximum amount of energy when it is completely discharged.
When it is completely discharged, it acts like a "zero-ohm" resistor during its initial charging-cycle. This is called **INRUSH CURRENT** and can be ENORMOUS. This is the "plop" you hear from some amplifiers when they are turned ON. It is also the inrush current to a power supply. To reduce this

electrolytic(s) in the circuit (or power supply).

Let's go over this again:
The transfer of energy from one stage to another depends on 3 things:
1. The value of the LOAD resistor of the first stage. This resistor charges the capacitor. It's resistance should be as **low as possible** to transfer the maximum energy.
2. The value of the capacitor. It should be **as high as possible** to transfer the maximum energy.
3. The value of the input impedance of the receiving stage. It should be **as low as possible** to discharge the capacitor.

Let's take a 100n capacitor:
In the following circuit, a 100n capacitor separates an electret microphone from the input of a common-emitter stage.

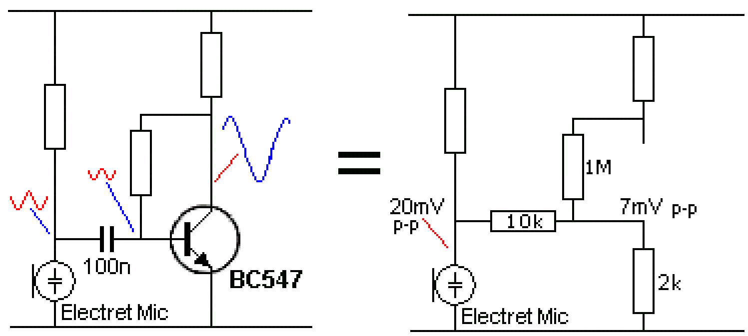


Fig 71f

The waveform on the output of the electret microphone is 20mV p-p (peak-to-peak). This amplitude passes through the 100n capacitor, which we have drawn as a 10k resistor, (to represent the capacitive reactance of the capacitor at 200Hz). The input impedance of the common-emitter amplifier is about 500 ohms to 2k. (500 ohms when the base current is a maximum and 2k when the base current is very small).
The capacitor and the input impedance form a simple voltage-divider, as shown in **Fig 71f.** When a 20mV signal appears on the input of the voltage divider, the voltage at the join of the two resistors will be about 3.3mV. This means about 16% of the waveform gets transferred to the base of the transistor. A common-emitter stage will have a gain of about 70, so 3.3mV input will create 230mV output. It's called a "swing" of 230mV or 230mV P-P (peak-to-Peak) or 230mV AC signal.
But most signals have a frequency of about 2kHz and the capacitive reactance of the capacitor will be about 1k. In this case the transfer will be 66% or 13mV and the output of the stage will be nearly 1v.
This is an ideal situation where the capacitor is being fully discharged.
The actual transfer of energy from one stage to another is much more complex than we have described, however you can see it involves the LOAD resistor, the size of the capacitor and the efficiency of discharging the capacitor.
The only way to see the actual result is to view the waveforms on a CRO (Cathode ray Oscilloscope).

INPUT AND OUTPUT IMPEDANCE

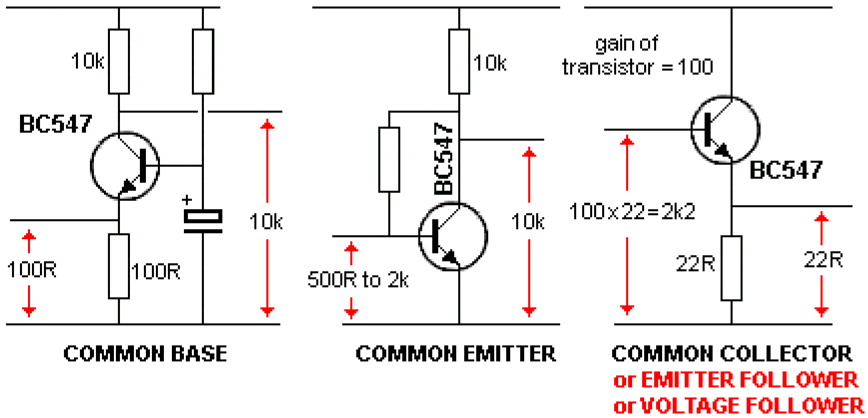


Fig 71g

Fig 71g shows each transistor stage has an input and output impedance. This really means an input and output resistance, but because we cannot measure the value with a multimeter, we have to find the value of resistance by measuring other things such as "waveform amplitudes" and then create a value of resistance, we call IMPEDANCE. The values shown are only approximate and apply to transistors called SMALL SIGNAL DEVICES. The values are really just a comparison to show how the different stages "appear" to input and output devices, such as when connecting stages together.
The input impedance of a common-emitter stage ranges from 500R to 2k. This variation depends on the type of transistor and how much the stage is being turned ON. In other words, the amount of current entering the base.
The value of 2k2 for the emitter-follower depends on the current entering the base and it can be increased by 500R to 2k to account for the base-emitter "impedance."
These values are all approximate and are just to give an idea of how to describe the various values of impedance.

THE TIME DELAY

Also called the TRANSISTOR TIME DELAY or **TIME CONSTANT** or **RC Delay Circuit** or **TIMING CIRCUIT.**
A Delay Circuit is made with a capacitor and resistor in series.
These are the two components that create the **TIME DELAY**. No other parts are needed. When the value of the capacitor and resistor are multiplied together the result is called the **TIME CONSTANT** and when the capacitor value is in FARADS and resistor in OHMs, the result is SECONDS
To detect when the capacitor has reached about 63% of its final voltage, we need some form of detecting device, such as a transistor.
But the detecting device cannot "steal" any of the current entering the capacitor, otherwise the voltage on the capacitor will never increase or take longer to increase.
We know a transistor requires current for it to operate but a Darlington Pair (or Darlington) requires very little current, so the detecting device must be something like a Darlington.
The transistor plays no part in the timing (or TIME DELAY) of the circuit. It is just a detector.

The main secret behind a good TIME DELAY circuit is to allow the capacitor to charge to a high voltage and use a large timing resistor. This reduces the size of the capacitor (electrolytic) and produces a long time delay.
There are lots of chips (Integrated Circuit) especially made for timing operations (time delays). Transistors (of the "normal" type - called Bipolar Junction) are not suited for long time delays.
Field Effect Transistors, Programmable Uni Junction transistors and some other types are more suited.
However a normal transistor can be used, as shown in **Fig 71h**.
The normal detection-point is 63% but you can make the circuit "trigger" at any voltage-level. The value "63%" has been chosen because the voltage on the capacitor is increasing very little (each second) when it is nearly fully charged and waiting for it to reach 65% may take many seconds. Trying to detect an extra 1% or 2% is very hard to do and since it takes a long time for the voltage to rise, the

circuit becomes very unreliable and very inaccurate. That's why 63% has been chosen.

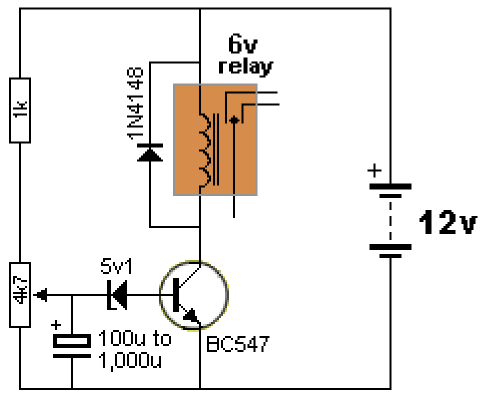


Fig 71h

Fig 71h shows a **TIME DELAY** circuit. This circuit does not wait for the capacitor to charge to 63% but it detects a voltage of 5v1 + 0.7v = 5v6.
The detecting circuit is made up of the 5v1 zener and base-emitter junction of the transistor.
These two components create a high impedance until a voltage of 5v6 because the zener takes no current until its "characteristic voltage" has been reached.

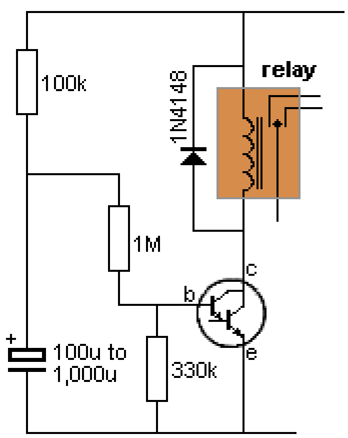


Fig 71j

Fig 71j shows a Time Delay Circuit. The 100k is the time delay resistor. The 1M is the "sense resistor" and the the 330k is the voltage divider resistor.
The base of the Darlington transistor detects 1.4v and the 1M/330k produces a voltage divider that requires 3 x 1.4v = 4.2v on the electrolytic. The 1M, 330k and transistor provide a fairly high impedance detecting circuit that does not inhibit the charging of the capacitor.
The circuit requires a supply of 12v.

HIGH FREQUENCY "NOISE"

Before we move on to the next phase of this discussion, there is one interesting point that needs covering.
When a circuit has a number of amplifying stages, there is always a possibility of noise being generated in one of the transistors in the "front-end" (the first or second stage in the amplifier) and this is amplified by the stages that follow. This is the case with the Hearing Aid Amplifier in **Fig 69**.

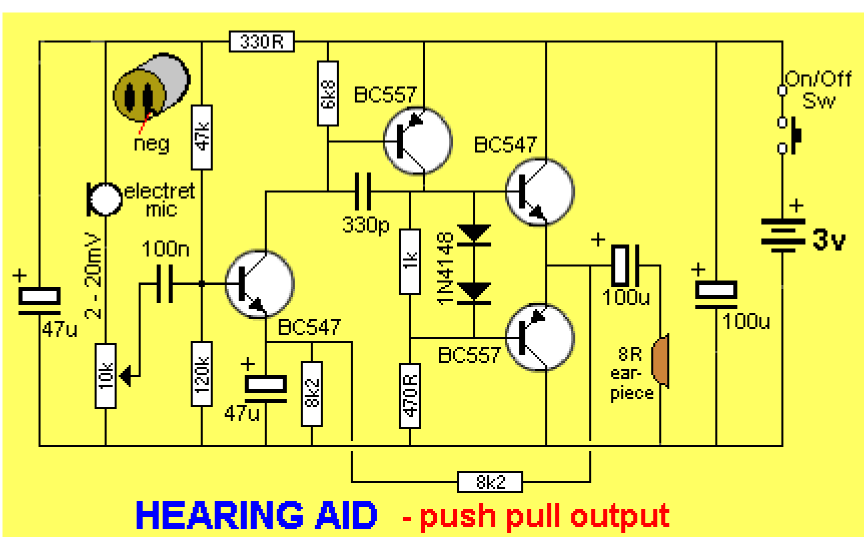


Fig 69.

The 330p between the base and collector of the BC557 removes high-frequency noise. If the 330p is removed a 1MHz waveform is generated in the front-end and amplified by the stages that follow. This noise cannot be heard but is visible on a CRO (Cathode Ray Oscilloscope) and causes the circuit to take extra current. The 330p capacitor provides **NEGATIVE FEEDBACK** to remove the waveform completely.

FILTERS

We have studied circuits that use components to produce NEGATIVE FEEDBACK. The first circuit we studied was the self-biased common-emitter stage. The base-bias resistor provided negative feedback to set the voltage on the collector.
Any component (resistor or capacitor) connected between the output and input of a stage produces NEGATIVE FEEDBACK.
A **resistor** connected between the output and input produces about the same amount of feedback no matter what frequency is being process by the amplifier.
But a **capacitor** provides more feedback as the frequency increases. That's because the effective "resistance" of the capacitor decreases as the frequency increases.
This feature can be used to "kill" the amplitude of high frequencies and thus only allow low frequencies to be amplified.
It can also be used to only allow high frequencies to be amplified. When it is used to couple two stages, a **low-value** capacitor will only allow high frequencies to pass from one stage to the next.
By using a resistor in series with a capacitor, the effect of the capacitor can be controlled.
Using these facts, we can design circuits that will amplify low frequencies or high frequencies. This type of circuit is called a FILTER.
A Filter can be given a number of names. Here are a few:
Active Filter contains a transistor or op-amp in the circuit
High Pass Filter suppresses or rejects the low frequencies Only the high frequencies appear on the output
Low Pass Filter suppresses or rejects the high frequencies Only the low frequencies appear on the output
Notch Filter: A Filter that rejects or suppresses a narrow band of frequencies.

To understand how a filter works, you need to know "HOW A CAPACITOR WORKS."

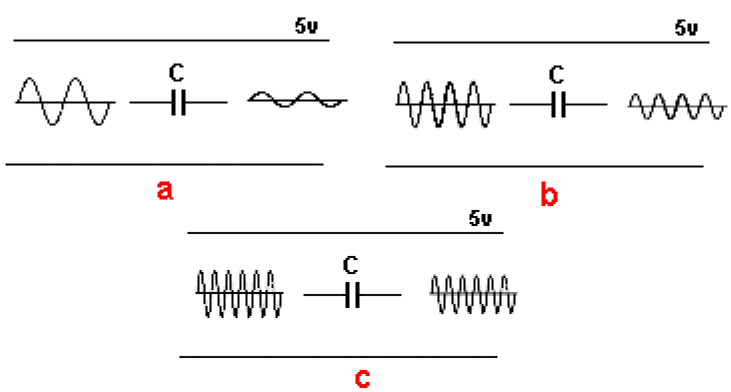


Fig 72a.

Fig 72a shows a capacitor with a low-frequency signal entering the left terminal. The output amplitude from the capacitor in diag **a** will be small because the capacitor is able to charge and discharge as the signal rises and falls.
As the frequency of the signal increases, the output increase in amplitude because the capacitor does not have enough time to charge and discharge and thus it does not "absorb" the amplitude of the signal.

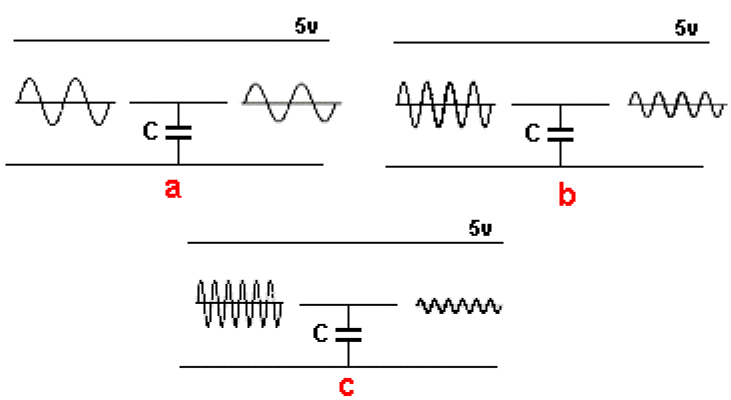


Fig 72b shows a capacitor connected between the "signal line" and 0v rail. When a low-frequency signal is on the "line," the capacitor has little effect on attenuating (reducing) the amplitude, as shown in diag **a** because the capacitor charges and discharges just like

Fig 72b.

pushing a "shock absorber" up and down **slowly**.
As the frequency of the signal increases, it is reduced in amplitude because the signal is trying to charge and discharge the capacitor very quickly and it takes **energy** to do this and the energy is coming from the signal.

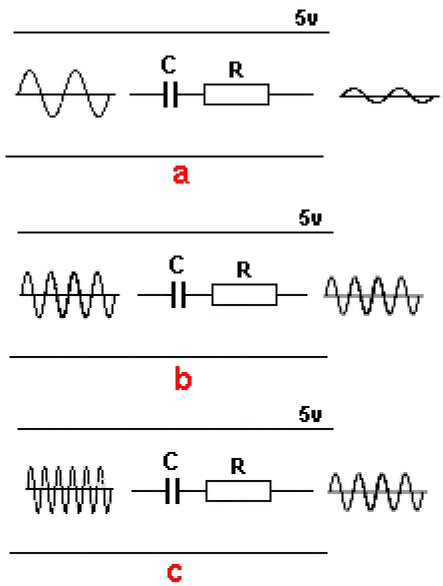


Fig 72c.

Fig 72c shows a capacitor and resistor connected in series on the "signal line." With a low-frequency signal, the capacitor reduces the amplitude because most of the signal is absorbed by the capacitor charging and discharging.
As the frequency increases, the output will be reduced by a smaller amount because the capacitor has less time to charge and discharge and less time to "absorb" the signal.
As the frequency is increased further, the resistor starts to have an effect on reducing the amplitude because these two components are connected to other components in a circuit and a higher frequency has a higher energy and more of this energy gets lost in the resistor - thus reducing the amplitude slightly.
In addition, the capacitor is already charging and discharging as quickly as possible and it is transferring as much of the signal as possible. It is only the resistor that is creating the attenuation at high frequencies.
It does not matter if the capacitor or resistor is placed first or last, the attenuation is the same.

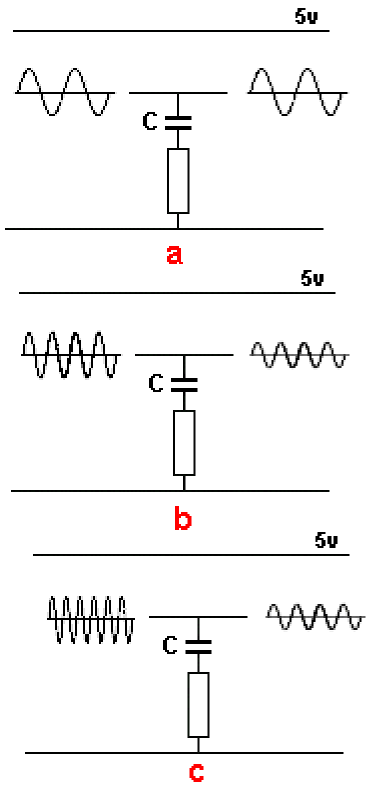


Fig 72d.

Fig 72d shows a capacitor and resistor connected in series between the "signal line" and 0v rail. With a low-frequency signal the capacitor can charge and discharge and the voltage across it will rise and fall so the effect on the amplitude of the signal is minimal.
The resistor has very little effect on reducing the amplitude.
The top plate of the capacitor rises and falls with the signal and the bottom plate rises and falls very little.

As the frequency increases, the capacitor cannot charge and discharge fast enough and more of the energy of the signal goes into charging and discharging it. The top plate of the capacitor is rising and falling very quickly and this is making the lower plate rise and fall a small amount. This puts a small current though the resistor and this has an effect on reducing the amplitude.
The amplitude of the output is reduced as shown in Fig **b**.

As the frequency is increased further as shown in diag **c**, the top plate of the capacitor is rising and falling as fast as it can and the lower plate is rising and falling too. This puts most of the amplitude-loss in the resistor but the signal is not killed as much as shown diag **c** in Fig 72b above.
It does not matter if the capacitor is above or below the resistor, the attenuation is the same.

Once you have a concept of the way a capacitor reacts to a high and low frequency, you can see how a circuit will pass or prevent (attenuate) a signal.

There are many different types of filters and they are all designed to improve the output of a poor signal, such as removing background "hiss" or "rumble" in audio recordings.
The following two circuits show the effect of adding capacitors and resistors between the output and input:

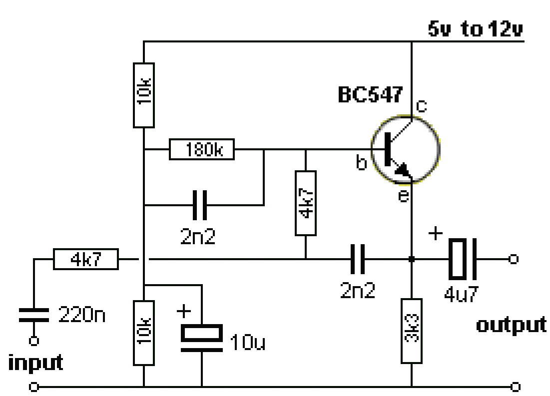


Fig 72e.

Fig 72e is a low-pass filter that provides unity voltage gain to all frequencies below 10KHz, but it rejects all frequencies above 10KHz at 12dB per octave. It is used to remove high frequency noise from audio recordings.

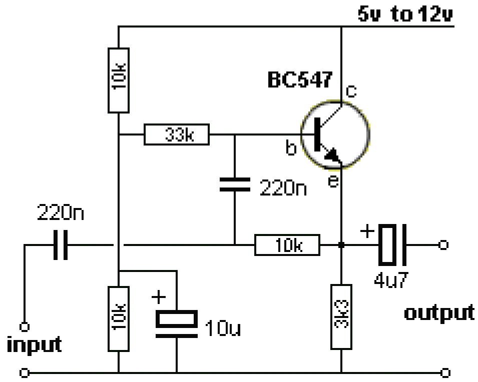


Fig 72f.

Fig 72f is a high-pass filter that provides unity voltage gain for all frequencies greater than 50Hz. However, it provides 12 dB per octave rejection to all frequencies below 50Hz. It is used to remove low frequency noise from audio recordings.
The transistor is configured as an emitter-follower biased at about half the supply value by the low-impedance junction formed by the top 10k resistor and the lower 10k in parallel with the 10u electrolytic.
Negative feedback applied through the filter network of the 33k and 220n and the 10k and 220n creates an *active* filter response.

THE "DIGITAL" STAGE - or Digital State
also called the DIGITAL CIRCUIT

All the circuits and stages we have discussed have been amplifiers for audio signals.
However there is another signal that can be processed via an amplifier. It is called a digital signal or "Computer" signal. It is a signal that turns a transistor ON fully or OFF fully.
The simplest example of a digital circuit is a torch. The globe is either ON or OFF. But a torch does not have any transistors. We can simply add a transistor and the circuit becomes **DIGITAL CIRCUIT.**
A **Digital Circuit** has **2 STATES: ON** and **OFF**. It is never half-ON or half-OFF.

The secret to turning a transistor ON fully is base current. If you supply enough base current the transistor will turn ON FULLY.
The Digital Circuit is the basis of all computers. It produces an outcome of "0" when not active or "1" when active. This is called **POSITIVE LOGIC**.

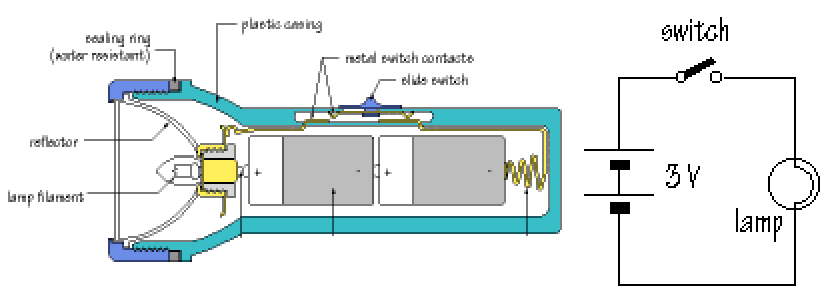


Fig 72. A TORCH is an ON-OFF circuit.
A Digital circuit is an ON-OFF circuit.

Fig 72.

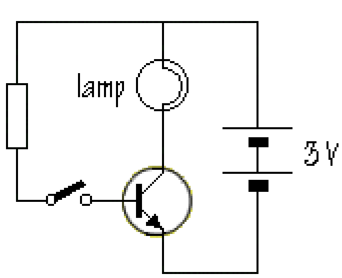


Fig 73. This is the simplest DIGITAL CIRCUIT. The globe illuminates when the switch is closed.

Fig 73.

Two reasons why a Digital Circuit was invented:

1. It produces either "0" or "1" (LOW or HIGH) and these are accurate values. By combining millions of "digital circuits" we can produce counting and this is the basis of a computer.
2. When a circuit is OFF, it consumes no power. When a circuit is fully ON the transistor also consumes the least power. This is because the globe is illuminated brightly and the transistor remains cool - as it has the lowest voltage across it.
The "ON" "OFF" states are called **LOGIC STATES** or **DIGITAL STATES** and when two transistors are put together in a circuit with "cross-coupling" they alternately flash one globe then the other.

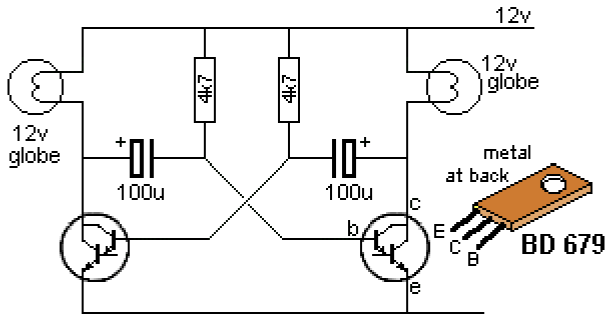


Fig 74.

Fig 74. This circuit is called a **FLIP FLOP** or **ASTABLE MULTIVIBRATOR**. (AY-STABLE - meaning not stable)

THE TRANSISTOR AS A SWITCH

Using a transistor as a switch is exactly the same as using it in **DIGITAL MODE** or in a **DIGITAL CIRCUIT** or in a **LATCH CIRCUIT** or any other circuit where the transistor changes from OFF state to ON state VERY QUICKLY.
A transistor in this type of circuit is called a **SWITCHING TRANSISTOR** and it may be an ordinary audio transistor but it is called a switching transistor when used in a switching circuit.
The two Darlington transistors in **Fig 74** are SWITCHING TRANSISTORS and the circuit is an **ASTABLE MULTIVIBRATOR.**
One of the most common circuits is used to activate a relay. A relay must be turned ON or OFF. It cannot be half-on or half-off. The transistor changes from OFF to ON very quickly. It is called a switching transistor.
All transistors used in a **DIGITAL CIRCUIT** are switching transistors. **DIGITAL CIRCUITS** or **DIGITAL LINES** are either **HIGH** or **LOW**.
When a digital transistor is turned **ON** (saturated) the output is LOW. When a digital transistor is **OFF** the output is HIGH. The output is taken from the collector of a common-emitter stage.
This is called two MODES of operation. **ON** and **OFF**.
Any circuit that operates in **TWO MODES** is called a **DIGITAL CIRCUIT**.

LATCH CIRCUIT

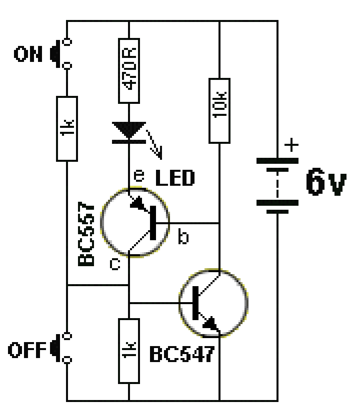


Fig 75. This circuit is a LATCH. The two transistors instantly change from the OFF state to the ON state.
This is also classified as a DIGITAL CIRCUIT.

Fig 75. Latch Circuit

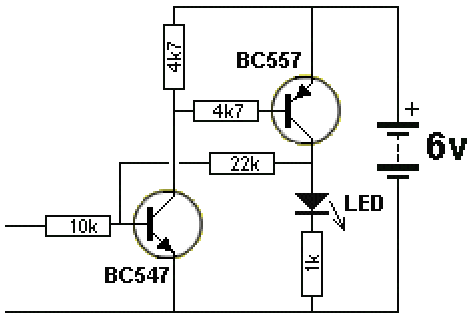


Fig 75a. Latch Circuit

Fig 75a. This circuit is a LATCH. The two transistors instantly change from the OFF state to the ON state when the input voltage rises above 0.6v
The 22k **POSITIVE FEEDBACK** resistor keeps the circuit **ON** when the input voltage is removed.

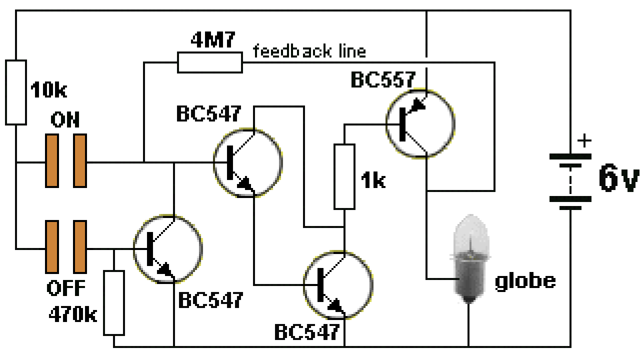


Fig 76. Touch Switch

Fig 76. This is a circuit of a TOUCH SWITCH. Touching the "ON" pads turns on the second and third transistors as they are a SUPER-ALPHA PAIR or DARLINGTON arrangement and have a very high input impedance and very high gain. The output of this pair goes to a PNP transistor that amplifies the 5mA current from the Darlington to deliver 250mA to the globe.
A feedback line from output to input via a 4M7 keeps the circuit ON when your finger is removed and provides a "Keep-ON" voltage (and current).
The first transistor removes this **"Keep-ON" voltage and current** when a finger is placed on the OFF pads. .

How can you tell a **DIGITAL CIRCUIT** from an **ANALOGUE CIRCUIT?**
1. Absence of capacitors. There are **NO** capacitors in a **DIGITAL CIRCUIT.**
2. A switch or push-button will be activating the circuit.
3. The circuit will be driving a **DIGITAL** or **ON - OFF** item such as a relay or globe.

The two states of a transistor in a **DIGITAL CIRCUIT** are: OFF - called "**CUT-OFF**" and ON - called "'**SATURATION**."
To saturate a transistor the base current is simply increased until the transistor cannot turn on any more. In this state the collector-emitter voltage is very small and the transistor can pass the highest current and the losses (in the transistor) are the lowest.

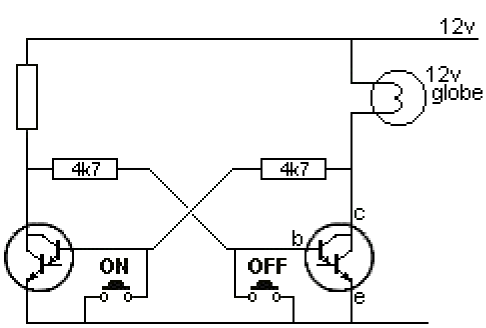


Fig 77.

Fig 77. This circuit has only two states. ON and OFF. The ON button turns off the first transistor so the second transistor turns the globe ON.
This is called a TOGGLE ACTION and the circuit is a BINARY CIRCUIT or BISTABLE CIRCUIT called a BISTABLE SWITCH or a bistable of the MULTIVIBRATOR family (**BISTABLE MULTIVIBRATOR**).
It can also be called a LATCH as it stores **one bit of information** and is the basis of a COMPUTER.

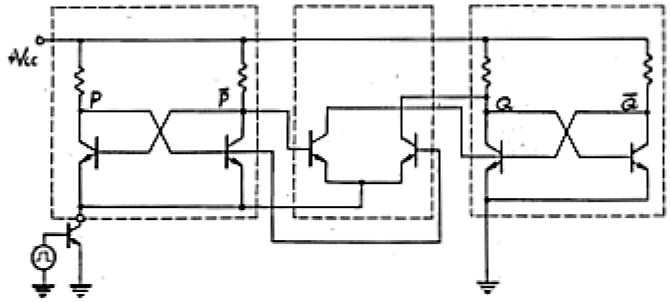


Fig 77a.

Fig 77a. This is part of a counting circuit and since it takes many transistors to create a circuit to count to "2" it is not practical to make it using discrete components. That's why INTEGRATED CIRCUITS were invented where dozens, then hundreds then thousands then millions of transistors are connected to produce counting chips and "bit-storing chips" and many other requirements.

Before we cover our next type of circuit, we will explain a 2-transistor directly-coupled arrangement from Figs 52 and 66. It is interesting as it can be used as a digital circuit or an analogue circuit.

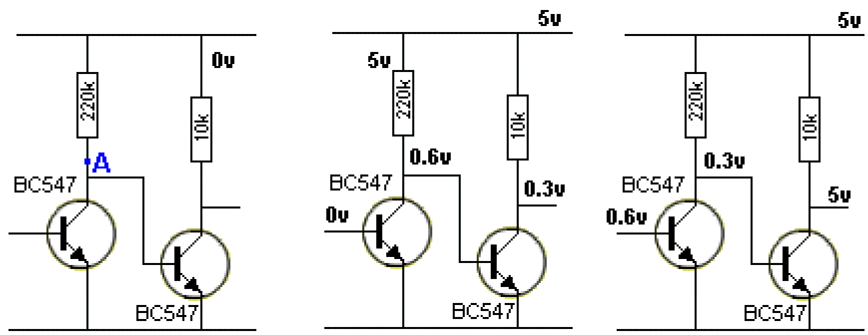


Fig 78.

Fig 78. Two facts to note:
1. Point "A" never rises above 0.6v as it is connected to the base of the second transistor.
2. When the first transistor is turned ON, the collector-emitter voltage is 0.3v and the second transistor is OFF - this is because the base of the second transistor needs 0.6v to turn ON.
In other words, when one transistor is **ON** the other is **OFF**. There is a very brief change-over point where the first transistor turns ON a little more and the second transistor turns OFF a very large amount. If you can find and maintain this change-over point, the two transistors will work in analogue mode with high gain but if you pass this point very quickly, the two transistors will operate as a switch in DIGITAL MODE.
We can turn this circuit into a DIGITAL CIRCUIT. The secret to doing this is FEEDBACK and the name of the circuit is a **SCHMITT TRIGGER:**.

THE SCHMITT TRIGGER

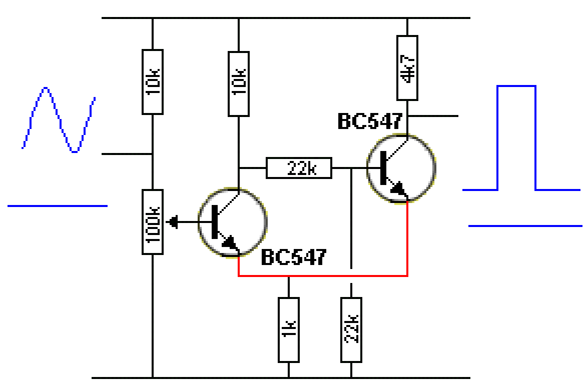


Fig 79a. Schmitt Trigger Circuit

Fig 79a. A **Schmitt Trigger** takes a slowly rising or falling voltage and turns it into a fast-acting ON-OFF signal. The secret is the feedback line shown in red.
The circuit can also be called a "sinewave-to-squarewave generator."
When the input is LOW the output i0 LOW.
It is a form of bi-stable multivibrator.
The distance between the lower voltage and the upper voltage (at which the circuit changes state) is called the HYSTERESIS. This can be widened or narrowed via the 1k resistor (the 100k pot needs to be re-adjusted when the 1k is changed).

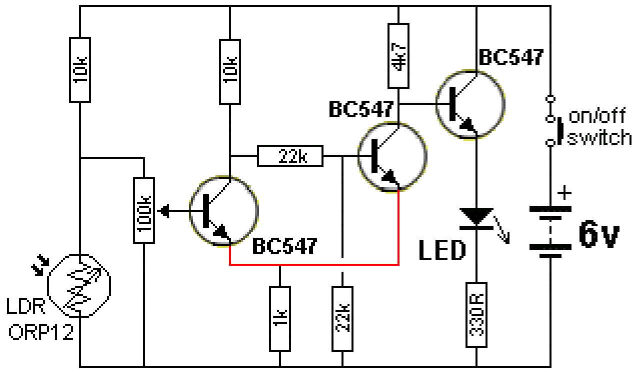


Fig 79. Schmitt Trigger Circuit

Fig 79. This circuit takes a slowly rising or falling voltage and turns it into a fast-acting ON-OFF signal to operate a LED or relay.
This is done via the positive feedback line shown in red. It is called positive feedback because it ADDS to the change to speed it up.
This circuit is fully explained in the: Talking Electronics website CD.

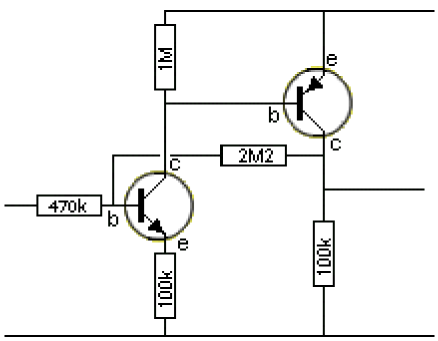


Fig 79aa. A Schmitt Trigger

Fig 79aa is a Schmitt Trigger made from NPN and PNP transistors.
As the voltage on the input rises, the first transistor is turned on slightly and a small voltage is developed across the 100k emitter resistor that reduces the "turn-on" effect slightly. This means the input voltage must rise more. As the input voltage rises more, the second transistor starts to turn on and the collector voltage rises. This voltage is passed to the base of the first transistor to assist the input voltage and because the collector voltage of the output transistor rises considerably, it has a large effect on turning ON the first transistor. They turn each other ON until they are both fully turned ON.
The 2M2 has taken over from the 470k and made the base of the input transistor slightly higher. The input voltage has to drop a small amount before the pair will start to turn off.
The circuit has created a small gap between the low and high input voltage (and between the HIGH and LOW input voltages) where the circuit does not change from one state to the other. This gap is called the **HYSTERESIS GAP**.
The output of the Schmitt Trigger in **Fig 79aa** is classified as "high impedance" (due to the value of the 100k on the output) and this must be connected to a stage with a high input impedance so the voltage on the output of the Schmitt Trigger is not affected.

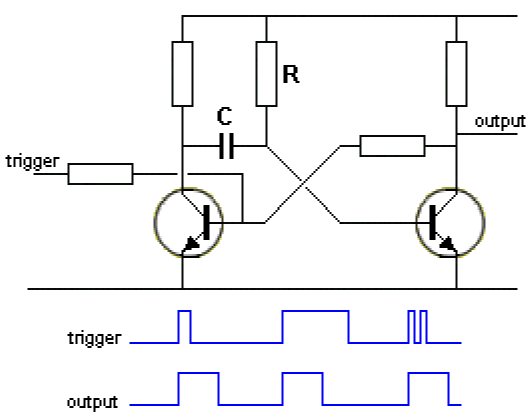


Fig 79ab. The Monostable or "Pulse Extender."

Fig 79ab. Before we leave the MULTIVIBRATOR family, the third type of Multivibrator is the **MONOSTABLE MULTIVIBRATOR**.
It is only stable in **ONE** state. This is called the "rest" state. The other state is "timed" via a capacitor.
The circuit is triggered and it changes to the other stage and a TIMING CAPACITOR **C** charges via a resistor **R** (called a TIMING CIRCUIT) and a multiplication of the two produces a value call the **time constant.** When it is charged, the circuit drops back to the rest state.
While the output is high, input pulses (trigger pulses) have no effect on the circuit. Also, if the input is triggered and kept high longer than the **time constant** of **C** and **R**, the output will NOT stay high for longer than the **time constant**.
This circuit is also called a **PULSE EXTENDER**.

GATES

We have described the transistor as an amplifier and the fact that **POSITIVE FEEDBACK** can turn a transistor **ON** more and more, so it changes from: "**not-turned-ON**" to **"fully-turned-ON"** in a very short period of time. When a transistor is operating in this mode, it is said to be in **DIGITAL MODE.** We saw the effects of **DIGITAL MODE** in Figs 74, 75, 76, 77 and 78. The advantage of **digital mode** is the transistor dissipates the least heat in either state.

The transistor can be put into a chip (IC - Integrated Circuit) and used in Digital Mode. When this is done, the transistor is put into a circuit called a **GATE. A Gate** is simply a **BUILDING BLOCK** in which the output changes from **LOW** to **HIGH** or **HIGH** to **LOW** very quickly. The simplest **GATES** are called AND, OR, NAND, NOR and NOT. In general a GATE operates on a 5v supply and the input has to change from **LOW** to **HIGH** or **HIGH** to **LOW** very quickly and the output will change from **LOW** to **HIGH** or **HIGH** to **LOW** very quickly. You may think the gate is not achieving anything, but most gates have 2 or more inputs and the output is "more powerful" than the input. The introduction of GATES revolutionised the development of the computer and was the beginning of the **DIGITAL AGE.**

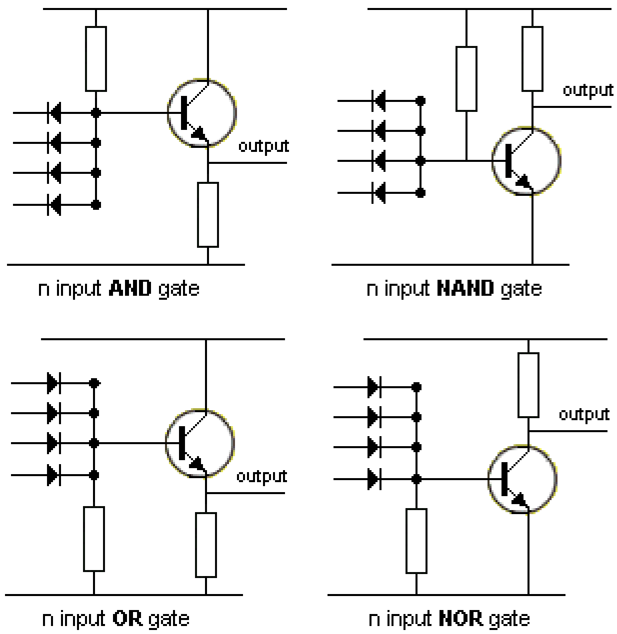
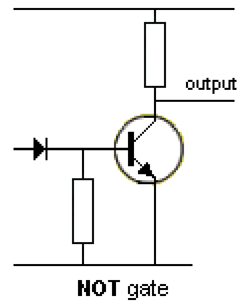


Fig 79ac shows AND, OR, NAND, NOR and NOT gates produced with transistors.



"n" indicates any number of inputs. ("n" is an unspecified number.)

Fig 79ac.

We have shown circuits with the load (such as a speaker or LED) above the transistor or below (it cannot be in both places at the same time). The position of the LOAD introduces two new terms:

SINKING AND SOURCING

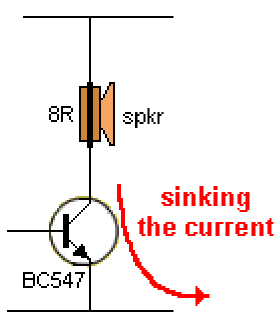


Fig 79b. When the speaker (LOAD) is placed above the transistor, the circuit is said to be **SINKING** the current.

Fig 79b.

There is no advantage in either placement. If the load is connected to "chassis" such as a globe in a car, the circuit will need to source the current.

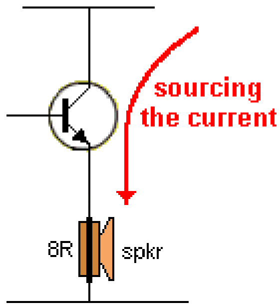


Fig 79c.

Fig 79c. When the speaker (LOAD) is below the transistor, the circuit is said to be **SOURCING** the current.

INTERFACING

Interfacing simply means: "Connecting." When a circuit connects a device (such as a microphone), to an amplifier, it is called **INTERFACING**. The characteristics of the microphone are matched to the input requirements of the amplifier. Or a relay may need to be connected to the output of an amplifier (that does not have enough current to turn the relay ON).
In most cases, the output of a circuit (or device - sometimes called a TRANSDUCER) does not have enough VOLTAGE or VOLTAGE-SWING or AMPLITUDE to drive the next circuit or device.
And sometimes the output of a circuit (or device) does not have enough CURRENT to drive the device (such as a relay or speaker).
That's why we have to add a circuit between.
The circuit we add has a number of names:
When it increases the CURRENT, we call it a **BUFFER**.
When it matches a high impedance to a low impedance or a low impedance to a high impedance, we call it **IMPEDANCE MATCHING**.
Or when we need an increase in voltage, it is called an **AMPLIFIER**.
In ALL "stages" (common-base, common-collector and common-emitter) the current is increased.
Interfacing can be as simple as adding a resistor or capacitor, but this is usually called "connecting."

We have learnt that all devices and circuits have an ability to deliver a "waveform" or "amplitude" or "voltage" and this can be weak or strong according to the amount of current it can deliver.
We have also learnt that this current may be delivered from the load resistor or from the device itself. It does not matter how the current is delivered; the **size** of the current (the amount of current) is important.

We have also covered the fact that the input to a circuit (or "stage") requires current and when these two are equal, the matching is ideal.
But this rarely happens.
If the input requires **more** current, the voltage (or voltage-swing) from the previous circuit or device will be reduced. If the input requires less current, the voltage-swing will be affected a very small amount. But in **ALL** cases the voltage-swing will be reduced - because you ARE supplying SOME energy to the stage that follows.

Interfacing is not easy.
You have to know the **output voltage** of the device and the **current** it can supply.
The current it can supply is related to its **OUTPUT IMPEDANCE**.
OUTPUT IMPEDANCE basically means its output resistance. A low resistance or LOW IMPEDANCE means it is capable of delivering a HIGH CURRENT. A high-impedance device cannot deliver very much current. A stage with a high output impedance cannot deliver very much current.
All these terms are relative. When we say: "cannot deliver much current" the value of current can be less than 1uA or 50mA. It depends on the circuit we are discussing and if you are working with low-current circuits or power circuits.
We have also learnt that the input impedance of a stage can be high or low and the voltage-swing it will accept can be small or large. (for instance, an emitter follower stage will accept a large input voltage).
This gives us a wide range of values (parameters) that may need to be joined

together - **INTERFACED**.
In some cases the output voltage of a device or circuit will be HIGH and by connecting a capacitor between the two stages, the output voltage will be "absorbed" in the capacitor and the energy from the output stage will be transferred. The "energy" is a combination of the voltage-swing and the current. But if the output voltage is very small, we may need to amplify it to deliver a high voltage to a device.

This is the case in the following requirement.
A piezo diaphragm or electret microphone is required to be interfaced to the input of a microcontroller.
The output of these devices is about 10mV and the input of a microcontroller requires about 3.5v (3,500mV).
This involves an amplification (gain, amplification factor) of 10:3500 = 350 and requires two stages of amplification.
The output of a piezo and microphone are classified as high impedance and the input of a microntroller is also high impedance.
This means the two amplifying stages can be low-current stages (also called high-impedance stages) and the load resistors can be high-value (about 22k - 100k).
The following two circuits have been designed for this application:

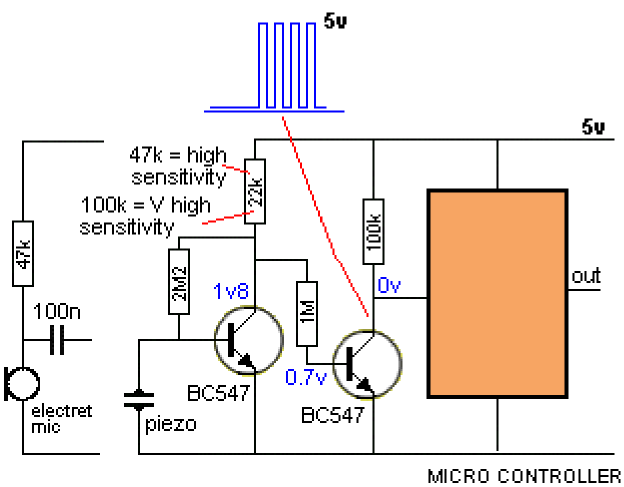


Fig 79d.

Fig 79d. In this circuit the first transistor is self-biased and the 2M2 base bias resistor turns the transistor ON and the voltage on the collector is only about 1.8v.
This means the collector has to drop by only 1.2v for the second transistor to turn off and the 100k will produce 5v on the input to the microcontroller.
If the transistor has a gain of 100, the electret mic or piezo has to produce a 12mV signal to activate the circuit.
When the load resistor is increased to 100k, the collector has about 850mV on it, and it only has to drop 300mV for the signal to enter the microcontroller. This makes the 100k load resistor produce a more-sensitive circuit. When no audio is being detected, the output of the second stage is 0v.

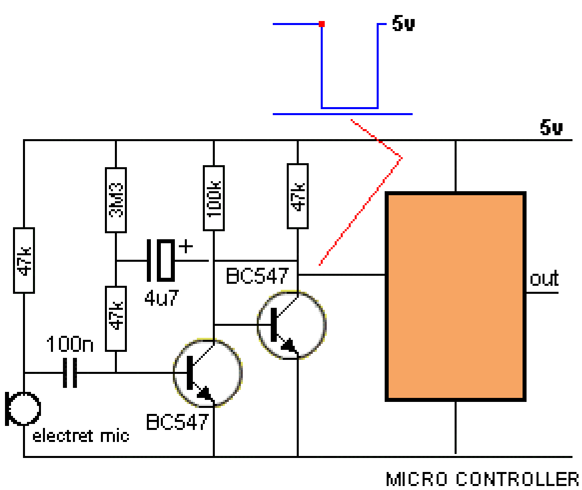


Fig 79e.

Fig 79e. This circuit has been taken from Fig 71acc. It is a bootstrap circuit and produces a very clever "switch."
The circuit sits with the first transistor turned ON and the second turned OFF as can be seen in the first line at the top of the output waveform - up to the red dot.
When a signal is picked up by the microphone (this is the red dot on the waveform),
a negative-going signal of about 100mV will turn the transistor off slightly and the second transistor will turn ON. The 4u7 will be "pulled down" and completely take over from the signal from the microphone. It will turn the first transistor off more and the second transistor will be turned ON more. This will continue until both have completely changed states.
They will stay like this until the 4u7 is charged in the opposite direction and the base of the first transistor sees 0.7v. This causes the second transistor to turn off and the 4u7 rises and turns the first transistor ON more. The 4u7 gets slowly discharged and the circuit remains in this state.
The circuit produces a very clean output every time it detects audio.
The duration of the low in the graph can be shortened by reducing the value of the electrolytic.

ANALOG TO DIGITAL

Many of the circuits we have described convert an **ANALOG** signal to a **DIGITAL** signal.
These are called **ANALOG TO DIGITAL CONVERTERS** but we have not given them this specific name because we have been concentrating on other features.
We will now cover the concept of **Analogue to Digital Conversion**.
An ANALOGUE signal rises and falls but doesn't have any defined amplitude or frequency.
This signal cannot be delivered reliably to a circuit that requires a DIGITAL SIGNAL as the amplitude of the waveform may not be large enough.
A **DIGITAL CIRCUIT** requires a **digital signal** and this type of signal is either a constant HIGH or LOW and the amplitude must be very close to rail voltage or almost 0v. And it must change from one state to the other **very quickly**.
Delivering a high amplitude analogue signal **may** be recognised by a digital circuit when it reaches a peak or goes to 0v, but this is not reliable.
In addition we may want the signal to be a CONSTANT HIGH when the audio is present.
This is what an **ANALOG TO DIGITAL** circuit will do. It will produce a constant HIGH when audio is present and ZERO (LOW) when the audio is not present.

Recapping:
To convert an analogue signal to a digital signal we need to deliver ZERO OUTPUT (called a LOW output) when the signal has a small amplitude and a HIGH output when the signal has a high amplitude.

To do this we use all the information we have studied. This includes:
1. A common-emitter stage - it has voltage-gain,
2. A smoothing circuit or storing circuit using a capacitor or electrolytic - to store the peaks, and smooth the waveform to produce a constant HIGH.

There are many ways to convert an Analogue signal to a Digital signal but the basic way is to amplify the signal by a large amplification-factor so the resulting waveform will rise as high as rail voltage.
This is normally called "over-driving" the signal and if this is done in an audio circuit, the result is distortion. But we are not going to listen to the output, so we take advantage of this feature to produce a DIGITAL OUTPUT.

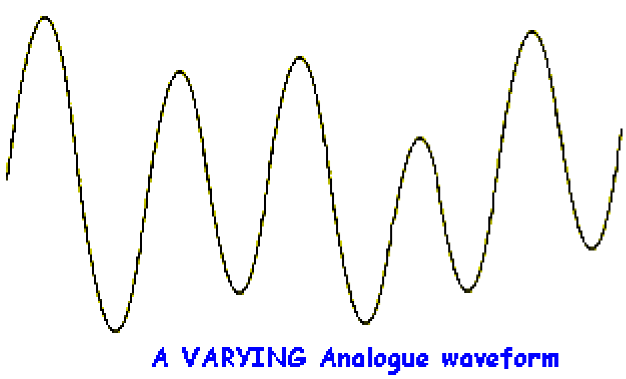


Fig 80a

Fig 80a shows an analogue signal. It is made up of lots of sine-waves and may be as small as a few millivolts. Low-level signals are generally expressed in mV, to make them instantly recognisable and easy to talk about. In general this type of signal will be too small to be detected by a Digital Circuit. A Digital Circuit needs a signal greater than about 3,500mV so the waveform appears on the input line as a HIGH, during the peak of its excursion. It should be nearly 5,000mV for reliable detection.

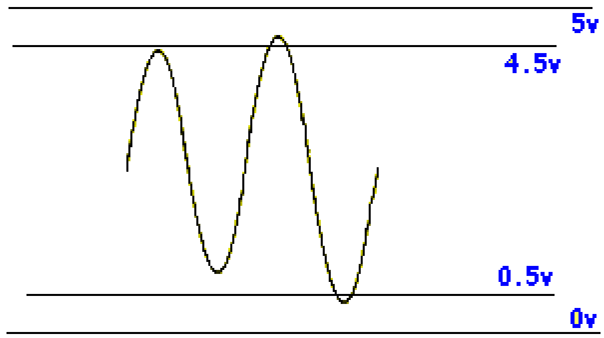
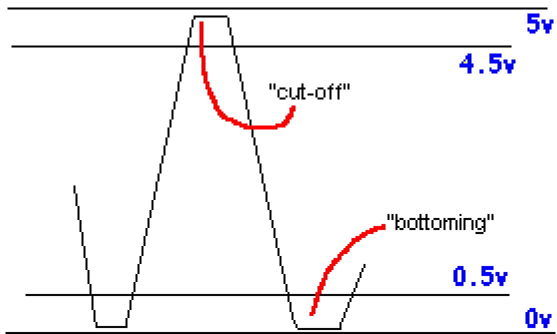


Fig 80b. A Digital Circuit will detect a waveform larger than 4.5v as a HIGH and less than 0.5v as a LOW

Fig 80b. Only the large excursion(s) will be detected by a Digital circuit as the other parts will not rise high enough to be detected. To increase the analogue signal to as much as 5,000mV, an amplifier is needed.



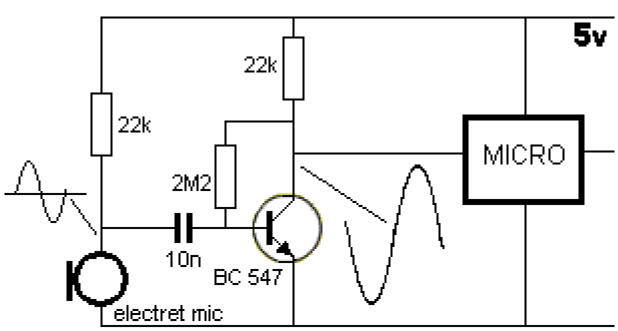
An "over-amplified" waveform will be cut-off at the top and bottom.

Fig 80c.

The amplifier maybe one or two stages, depending on the amplitude of the original signal. Each stage of an amplifier will increase the size of the signal about 70 times. If you are very lucky, you may get an amplification of 100x (100 times). Thus a 5mV signal with one stage of amplification will produce a 350mV signal. This is not sufficient to be detected by a Digital Stage. Another stage will easily produce a full 5,000mV signal. The second stage only needs to amplify the signal about 10 to 12 times to be sufficient and the added gain provided by the stage simply drives the waveform into "**bottoming**" and "**cut-off**" as shown in **fig 80c**.

This means the waveform will be "clipped" at the top and bottom and converted to a fairly "square-ish" shape.

Suppose you have a waveform that is higher than 5mV (say 30 - 50mV) and want to know if it will trigger the Digital Circuit after a single stage of amplification. Connect the components as shown in **Fig 80d** and write a program to illuminate a LED when the waveform is detected as a HIGH by the micro.



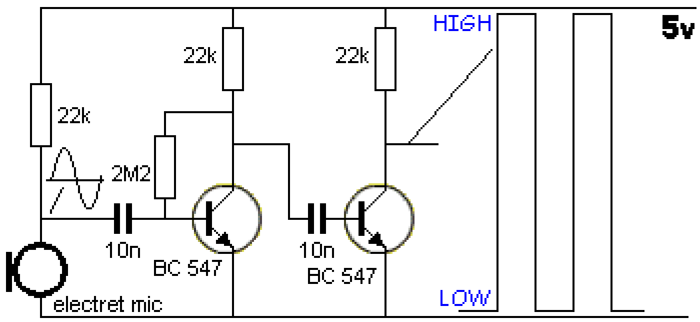
The waveform of a whistle.

Fig 80d.

There is only one problem with the circuit in Fig 80d.

At the end of a whistle or speech, the LED may be illuminated or extinguished. It all depends on the last cycle of the waveform. The circuit sits with the output approx mid-rail and the micro does not know if this is a high or low, and takes the reading

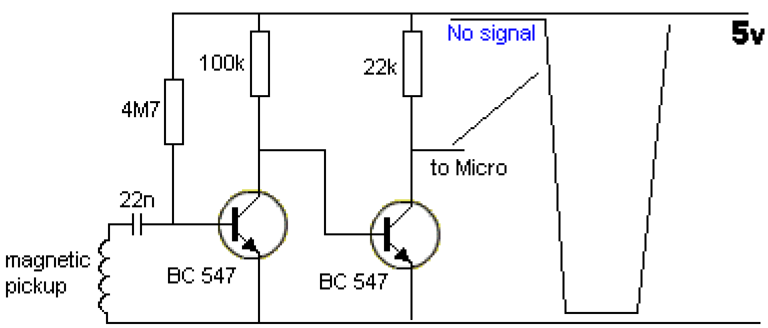
by the direction of the last cycle.
Some of the inputs of the micro are Schmitt Triggered. This means a HIGH has to be 85% to 100% of rail voltage for it to be seen as a HIGH and between 20% and 0% to be seen as a LOW.
The non-Schmitt Trigger inputs see a LOW as 20% to 0% and a HIGH as above 2v for 5.5v operation.
If the last cycle went from zero to mid-rail the micro will see the waveform as a low on Schmitt Trigger inputs and a HIGH on the other inputs. This problem can be overcome by adding a second stage that only produces a LOW when audio is detected. It also increases the amplitude of the audio to guarantee triggering of the Digital Circuit. This is shown in **Fig 80e**.



A two-stage amplifier with the second stage only responding to signals, greater than 650mV. The second stage converts analogue signals into digital.

Fig 80e.

The second transistor in **Fig 80e** is called a DIGITAL STAGE. This simply means the biasing resistor is left off the base of the second transistor so it turns on fully when a signal greater than 650mV is detected and is turned off at other times. This stage is ideal for a micro or other Digital Stage as only two voltage levels are delivered. Either 0v or rail voltage (5v).The other advantage is it does not take any quiescent (idle) current.
This stage is only suitable if you are sure you have plenty of "over-voltage" to drive the transistor into saturation. By this we mean you must have at least 1v (1,000mV) drive signal so you can be sure the transistor will turn on (saturate).
The fast rise and fall times means you have a "clean" period of time during a HIGH or LOW.



A two-stage amplifier interfacing a magnetic pick-up to the input of a micro.

Fig 80f.

Fig 80f couples a magnetic pick-up to the amplifying circuit so the biasing of the first transistor can be determined by the value of the base-bias resistor. The coil cannot be connected directly to the transistor as the low impedance (resistance) of the coil will upset the bias on the base.

With this arrangement, 100mV or less will turn off the transistor (a 100mV waveform will turn the transistor ON more during the "positive half" of the waveform and turn it off during the other half of the waveform).
Any coil of wire of any size will be suitable and to make it an effective collector of magnetic flux. It should have a magnetic core such as ferrite. No other impedance-matching is necessary.

OSCILLATORS

There are over 20 different types of oscillators and many more variations. We cannot cover them all - so we will concentrate on the most often-used and explain how they work.

Oscillators consist of one or two transistors. They start-up by one or more components in the circuit producing "noise" or a spike from the "mains" when the circuit is turned on. Some oscillators will not start-up if the supply is increased gradually. When a spike or noise is detected, the rest of the circuit amplifies it. In most cases the noise comes from the circuit being turned ON but it can also come from the noise generated within the junction of a transistor. This noise is random and of little use, but it is fed to components such as coils and capacitors as they have the ability to produce a waveform that rises and falls smoothly and this is amplified to produce the output.
When coils, crystals, capacitors and resistor are combined with transistors, many different effects and waveforms can be created and this all comes under the heading of OSCILLATORS. And the circuits are all amplifiers.
An amplifier can be turned into an oscillator by providing POSITIVE FEEDBACK.
The purpose of providing **NEGATIVE FEEDBACK** is to prevent oscillation.
The purpose of providing **POSITIVE FEEDBACK** is to create oscillation.
Positive feedback is when you take a point that is rising a **large amount** and pass it to a point that is also rising at the same time but only a **small amount**.
In other words, the feedback line must be able to **help** or **assist** the small-signal line. If it does not **assist** the small-signal line, NO oscillation will occur.
Some oscillators have a name - either after their inventor, by the way they are configured or by the shape of the wave. Some have 5 nam**es. Some have no particular name and are just called Feedback Oscillators (positive feedback).**

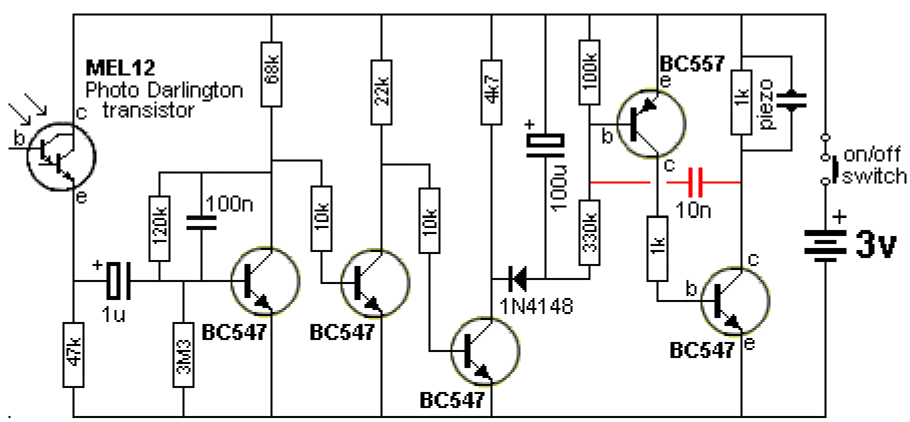


Fig 80. The 10n capacitor provides the positive feedback to keep the circuit oscillating.

Fig 80. A Feedback Oscillator

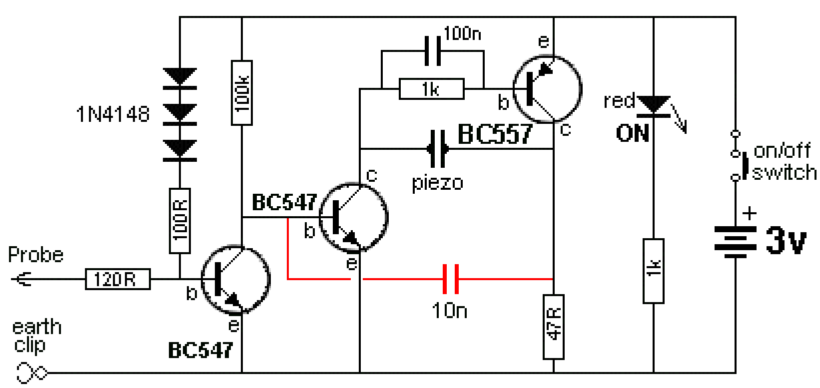


Fig 81. The 10n capacitor provides the positive feedback to keep the circuit oscillating.

Fig 81. A feedback oscillator

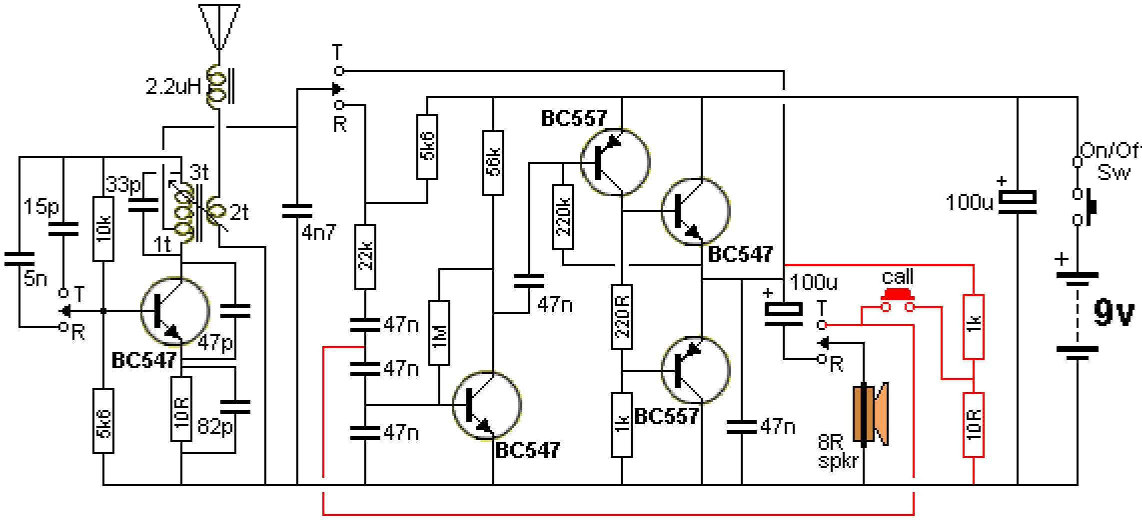


Fig 82. The positive feedback line creates the CALL tone

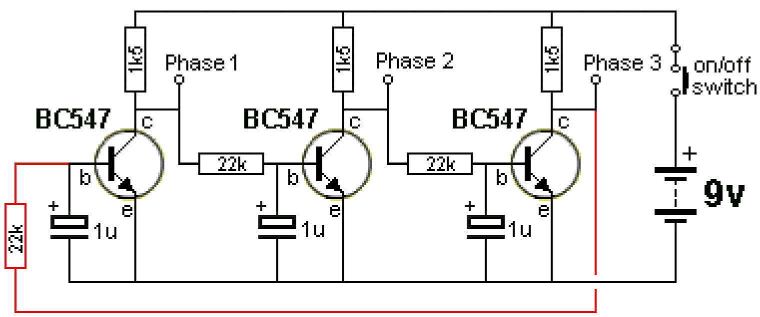


Fig 83. When the third transistor is turning OFF, the collector voltage is rising and this is passed to the base of the first transistor, to turn it ON. This is how the circuit keeps "cycling" or oscillating.

Fig 83.

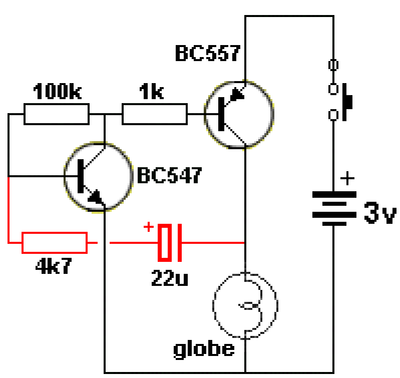


Fig 83a. Globe flashes at 1Hz

Fig 83a. The high-gain amplifier we studied in Fig 66, for example, has negative feedback to prevent oscillation.
By using positive feedback we can turn the high-gain amplifier into an oscillator.
This circuit is simply a high-gain amplifier with both transistors turning ON via the 1k and 100k resistors.
This makes the voltage on the collector of the BC557 rise and the 22u and 4k7 passes this rise to the base of the BC547 to turn both transistors ON more and more until they are fully turned ON.
The 22u charges a little more and this reduces the current into the base of the BC547 to turn it off a little.
This effect is passed to the collector of the BC557 and the two transistors start to turn OFF. When they are fully turned off, the cycle repeats by the transistors being turned on via the 1k and 100k.

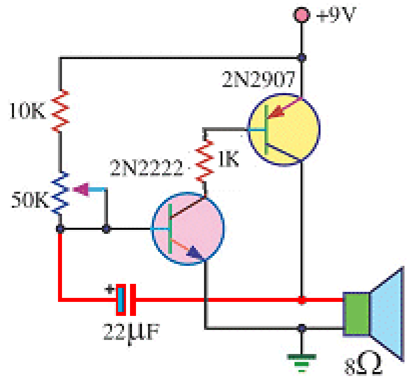


Fig 83aa. Simple Tone Oscillator

The 2-transistor amplifier we studied in Fig 42 can be changed slightly to drive peaker. The two common-emitter transistors turn on together and the 22u is "lifted" to turn on the NPN transistor harder.
Both transistors turn on until fully saturated and this puts current though the speaker.
The 22u charges a little more and this reduces the current into the base of the NPN transistors, turning it off a slight amount. The PNP is turned off a small amount and they both keep turning off until fully turned off.
The 10k and 50k start to charge the 22u to repeat the cycle. The 22u produces positive feedback. It can be replaced by values from 100n to 22u to change the frequency of the tone.

You can see the importance of FEEDBACK in a circuit. Some circuits will not work without feedback and some will distort. Sometimes the feedback is POSITIVE and sometimes NEGATIVE. The trick to understanding a circuit is to locate the feedback (component or "line") and work out what it is doing.

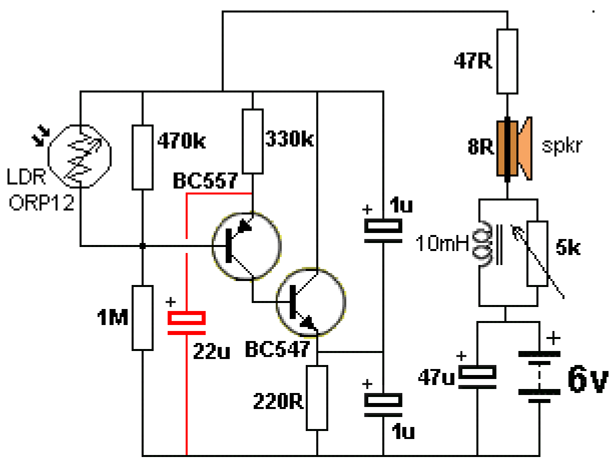
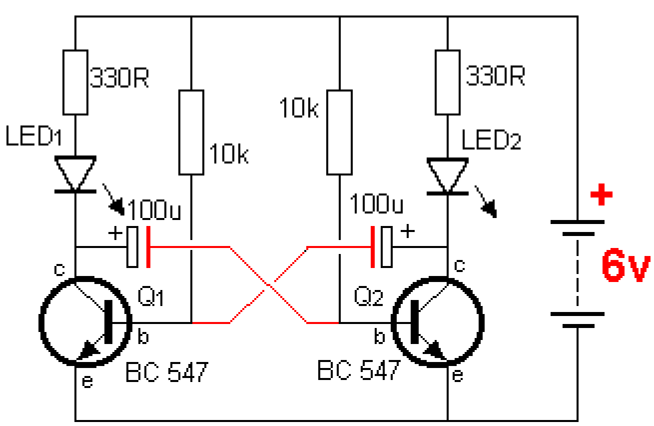


Fig 83b. Positive feedback comes from the 22u electrolytic.
This is a very unusual circuit.
Normally the feedback is obvious.

Fig 83b. Here's an oscillator circuit. We know it must have feedback to operate, but where is the feedback?
In this circuit the 4 electrolytics are equivalent to miniature rechargeable batteries.
When the circuit is turned on, they all get charged to a voltage according to the surrounding components but the 22u is the important component. The base of the BC557 sits at 4v and the emitter must rise to 4.6v for the PNP transistor to turn on. When it does, it turns on the BC547 and this transistor puts a load of 220R across the circuit. This reduces the voltage across the 470k/1M voltage divider and the base if the BC557 sees a lower voltage. During this time the 22u is acting as a miniature supply and maintaining the voltage of 4.6v on the emitter.
The BC547 turns ON more and more and even though the voltage on the 22u drops, the circuit turns ON and this takes more current from the 6v battery and produces a click in the speaker.

THE SQUARE-WAVE OSCILLATOR



When two transistors are cross-coupled as shown in **Fig 84**, you can safely assume the circuit will oscillate. The frequency of oscillation will depend on the value of the components but the oscillator is known as a **FREE-RUNNING OSCILLATOR** or **ASTABLE** (ay-stable) **MULTIVIBRATOR** and the output is a square wave. It will have an equal-mark-space ratio if the components are the same value.
This circuit is also called a **FLIP-FLOP**.

Fig 84.

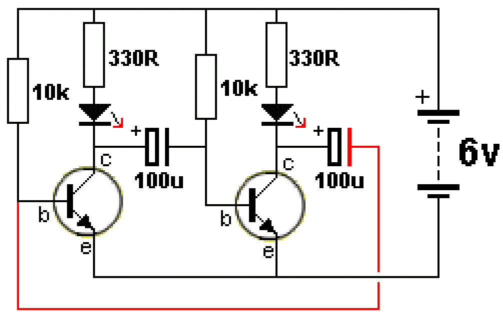


Fig 85.

Fig 85. By rearranging the components in Fig 84, we can draw the circuit as one common-emitter stage driving another common-emitter stage with a 100u providing positive feedback.
The circuit relies on the power being turned on quickly. Both transistors will turn ON but one will turn on faster than the other and prevent the other turning on.
The 100u connected to the turned-on transistor will start to charge in the opposite direction and the second transistor will start to turn ON. This will pull the 100u lower and the first transistor will start to turn OFF. This will continue until both transistors have changed states.

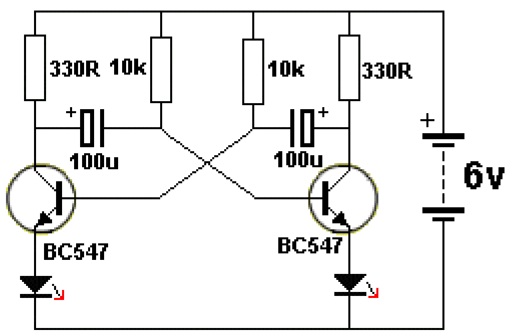


Fig 86.

Fig 86. Here is the **ASTABLE MULTIVIBRATOR** with the LEDs in the emitters instead of collectors (as is normal). The frequency of oscillation is approximately 1 second. The 330 ohm resistors set the LED current to 12mA for a 6v supply.

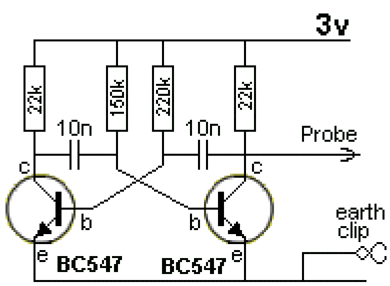


Fig 87.

Fig 87. The **ASTABLE** ("ay" - meaning not-stable) **MULTIVIBRATOR** circuit is rich in harmonics and is ideal for testing amplifier circuits. To find a fault in an amplifier, connect the earth clip to the 0v rail and move through each stage, starting at the speaker. An increase in volume should be heard at each preceding stage. This Injector will also go through the IF stages of radios and FM sound sections in TV's.

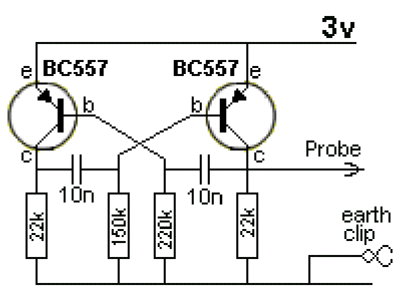


Fig 88.

Fig 88. The astable multivibrator can be made with PNP transistors.

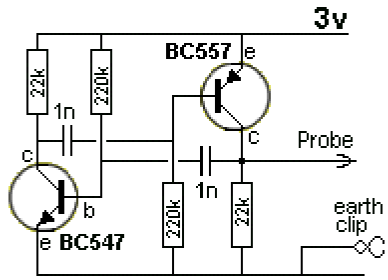


Fig 89.

Fig 89. A circuit can be made with one NPN and one PNP transistor. It ceases to be a FLIP FLOP or Multivibrator as both transistor turn on at the same time and the circuit becomes a **Relaxation Oscillator**.

THE SINE-WAVE OSCILLATOR - also called the PHASE-SHIFT OSCILLATOR

A Sine-wave Oscillator can be made with a single transistor.

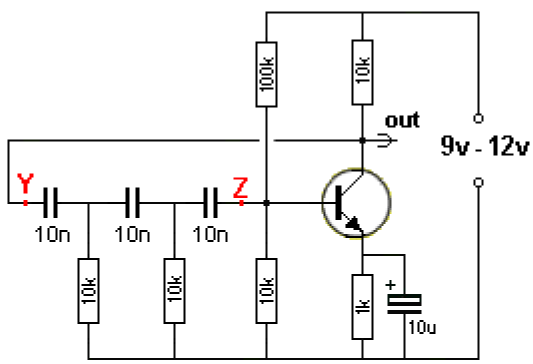


Fig 90. The Sinewave Oscillator

Fig 90. This circuit produces a sinewave very nearly equal to rail voltage.
The important feature is the need for the emitter resistor and 10u bypass electrolytic. It is a most-important feature of the circuit. It provides reliable start-up and guaranteed operation. For 6v operation, the 100k is reduced to 47k.
The three 10n capacitors and two 10k resistors (actually 3) determine the frequency of operation (700Hz).
The 100k and 10k base-bias resistors can be replaced with 2M2 between base and collector.
This type of circuit can be designed to operate from about 10Hz to about 200kHz.

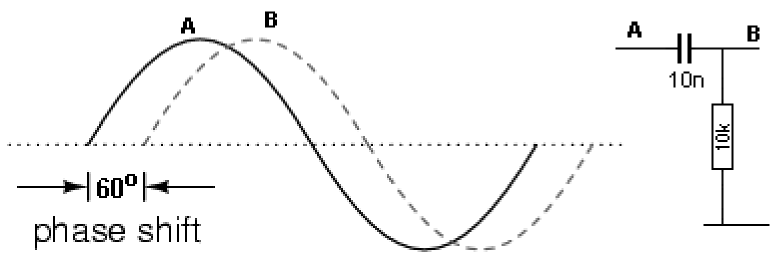


Fig 91.

Fig 91. The phase-shift oscillator has 3 "sections" made up of a 10n capacitor and 10k resistor. This "section" is shown above and each "section" produces a delay or "phase-shift" of about 60° but the total must be 180°. The base and collector of a common-emitter stage are 180° out-of-phase, so the signal entering the base is 360° (IN-PHASE with the output). This creates POSITIVE FEEDBACK.
This concept is very hard to understand so we need to explain it in simple terms.
Points Y and Z are the ends of a long piece of rope and the three resistors are weights tied to the rope.
You shake the rope up and down at Y and Z moves up and down at a later time in the cycle. You know this because you can make a wave travel down a rope. Exactly the same thing happens with a signal that enters at Y. It takes time for the peak to reach Z.
Now consider the circuit at switch-on. The caps are uncharged and the 10k collector resistor pulls the three capacitors high. Taking into account the voltage-dividing effect of the three lower 10k resistors, the collector is possibly at about 2v. The three 10k resistors start to charge the three 10n caps and the voltage on the base falls. This makes the collector voltage rise. This continues until the collector cannot rise any further and the capacitors continue to charge and the voltage on the base drops. The 100k base resistor takes over and starts to discharge the 3rd capacitor and turn the circuit on. The collector voltage drops and the energy in the three capacitors get passed into the base to fully turn the transistor ON.
This all happens in a "sliding motion" that produces a sweeping output called a SINEWAVE. It is a very "delicate" oscillator and any change to the LOAD (10k) may stop its oscillation.

How to read the Graph: Get a ruler and hold it "up and down" on the page (or on the screen) so you

view the right-hand edge of the ruler and can only see the word "phase" and "60° " Now slide the ruler to the right and you will see the graph "A" gradually rising. Keep moving the ruler to the right and you will see graph "B" gradually rising.
This is how you "interpret" the graph and see how graph "B" lags (is behind) graph "A." If you don't read the graph correctly, it looks like graph "B" is in front of graph "A" - but this is not the case.

THE BLOCKING OSCILLATOR

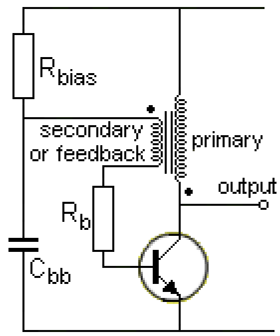


Fig 92.

Fig 92. The BLOCKING OSCILLATOR circuit uses a transformer to produce POSITIVE FEEDBACK to the base.
The circuit starts by Rbias charging Cbb to deliver voltage to the base of the transistor via Rb. The transistor turns on and produces expanding magnetic flux in the primary of the transformer. This flux cuts the turns of the secondary (or feedback) winding and increases the base voltage and CURRENT. The voltage out of the top of the secondary winding is prevented from "disappearing" by Cbb.
The transistor keeps turning ON until it cannot turn on any more. At this point, the current through the primary is a maximum but it is not expanding flux and its effect is not passed to the secondary winding. The base ceases to see its turn-on current and the transistor turns off abruptly. The heavy current through the primary is producing a very strong flux and it collapses, producing a voltage in both windings of opposite polarity and very high amplitude.

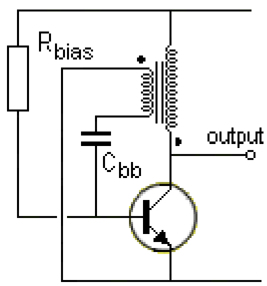


Fig 92a.

Fig 92a shows the base being "capacitor injected." This saves one capacitor and can produce a higher output. All the values and the transformer needs adjusting for the performance required. The start of each winding is shown with a dot. This assumes the windings are wound in the same direction.

Figs 92b,c shows alternative ways to produce a blocking oscillator. The difficulty with producing a Blocking Oscillator is getting a suitable transformer.

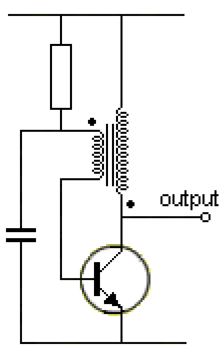


Fig 92b.

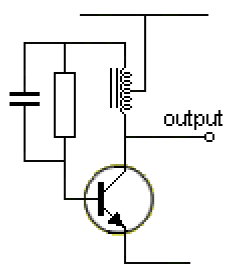


Fig 92c

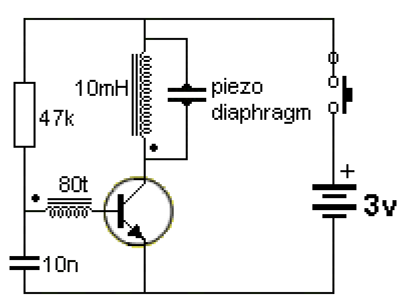
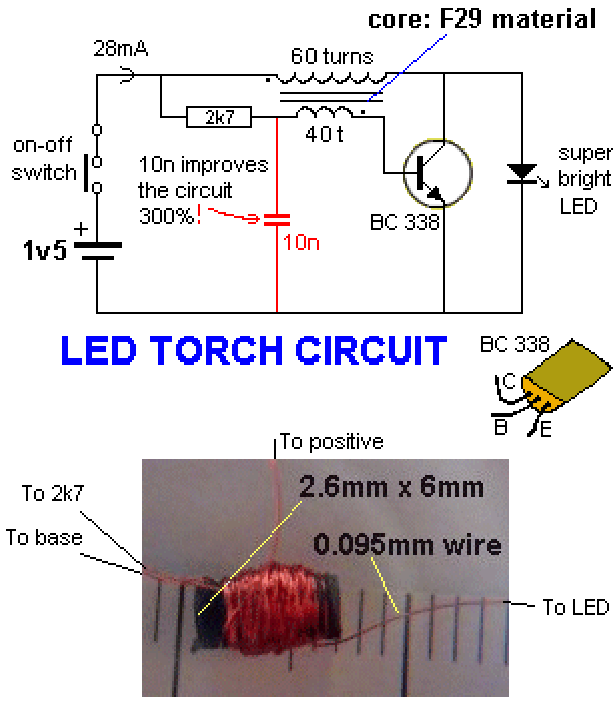


Fig 93.

Fig 93. A simple **BLOCKING OSCILLATOR** circuit can be made with a 10mH inductor and 80turns of very fine wire wound on top.
The piezo diaphragm reacts to the very high "FLYBACK VOLTAGE" produced by the primary when the transistor turns off. This type of circuit is often used to produce very high voltages.



Transformer Details

Fig 94.

Fig 94. This LED Torch circuit uses the "flyback" voltage of a BLOCKING OSCILLATOR to illuminate a 3.6v super-bright LED from a 1.5v supply.
Note: the 10n capacitor prevents the energy from the feedback winding being lost. All the energy from the feedback goes into the base of the transistor to turn it on hard.

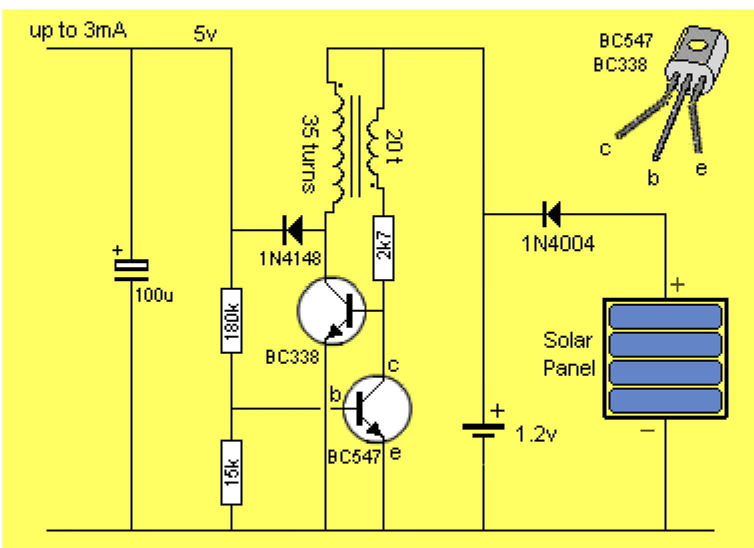


Fig 95.

Fig 95 shows a Blocking Oscillator producing a regulated 5v from a 1.2v supply.

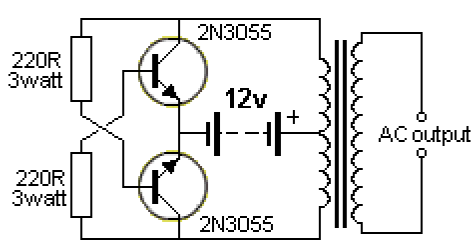


Fig 96. 2-transistors in PUSH-PULL - as a Blocking Oscillator circuit

Fig 96. A simple extension of the Blocking Oscillator in Fig 92c above, is shown in this diagram. It consists of two **BLOCKING OSCILLATOR** transistors that are turning each other off. The circuit starts by one transistor being slightly faster than the other. It turns ON and produces magnetic flux that cuts the turns of the other half of the primary winding to increase the voltage from the battery and at the same time it reduces the voltage to the base of the other transistor - because the transistor allows only a very small voltage to appear across the collector-emitter terminals when it is turning ON. It keeps turning on until it is fully ON.
At this point the flux is no longer expanding and the generated voltage in the winding that supplies the base voltage (and current) ceases. This turns it off a small amount and the magnetic flux starts to

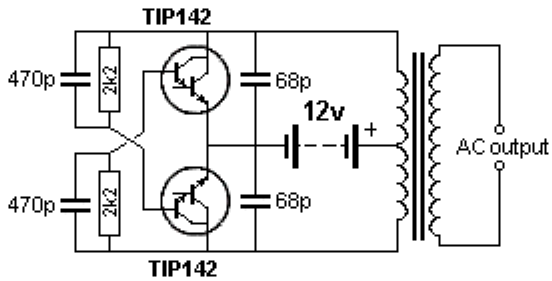


Fig 96a.

collapse and produce voltages in the opposite direction. The voltage (and current) to the base is less than before and this turns the transistor off more. The voltage to the base of the other transistor starts to rise and that transistor takes over. The two transistors operate in PUSH-PULL mode.

To reduce the wasted power in the 220R resistors, Fig 96a uses Darlington transistors and 2k2 0.5watt resistors. The circuit is used to drive a CFL lamp from a 12v battery.

The difficulty with producing a Blocking Oscillator is getting a suitable transformer. A similar "flyback voltage" can be obtained from an inductor. This will need an oscillator made up of two transistors to drive the inductor.

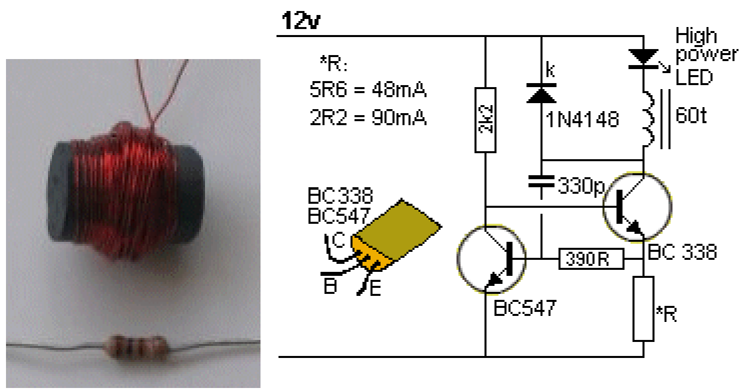


Fig 97.

Fig 97. This circuit is a "Buck Converter" meaning the supply is greater than the voltage of the LED. It will drive one high-power white LED from a 12v supply and is capable of delivering 48mA when R = 5R6 or 90mA when R = 2R2. The LED is much brighter when using this circuit, compared with a series resistor delivering the same current.
But changing R from 5R6 to 2R2 does not double the brightness. It only increases it a small amount.
The inductor consists of 60 turns of 0.25mm wire, on a 15mm length of ferrite rod, 10mm diameter. Frequency of operation: approx 1MHz. This circuit draws the maximum current for a BC 338.
When the circuit is turned on the 330p gets charged. This turns on the BC547 and keeps the BC338 off. When the 330p is charged the BC547 is not turned on as much and the 2k2 can start to turn on the BC338. It pushes the charge on the 330p into the base of the BC547 to keep it off. The 330p gets discharged by the 330R and the voltage across the *R resistor turns on the BC547 to turn off the BC338. The 1N4148 absorbs the high-voltage flyback pulse. The circuit is only active for a very short period of time and off for a longer period of time. This delivers a small amount of energy to the high powered LED and allows the LED to be connected to a 12v supply (via the circuitry).

MORE OSCILLATORS

The Armstrong, Clapp, Colpitts, Hartley, Wien Bridge and even unknown oscillators like the one below all use capacitors, resistors and coils to create a circuit called a **RESONANT CIRCUIT** and these two components produce a sinewave when they receive a pulse of energy.

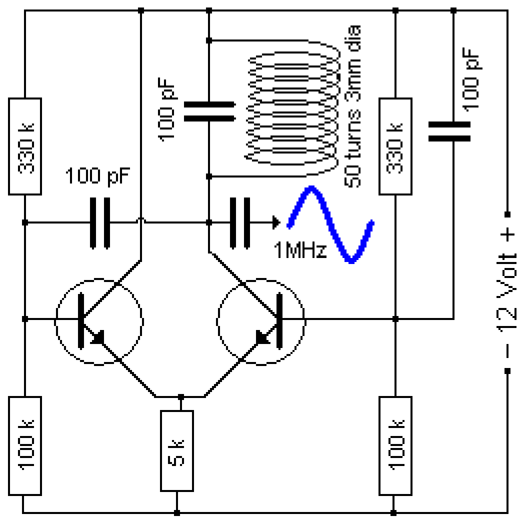


Fig 98.

We are going to lump all these oscillators together as they are variations on a similar design. There are two common oscillators that can be recognised by the layout of the circuit. The Colpitts oscillator has 2 capacitors across the coil with the signal taken from the join or it may have a tuned circuit with the signal taken from the active end. The Hartley Oscillator has a tapped coil. The Hartley Oscillator has a tapped coil and these are difficult to obtain.

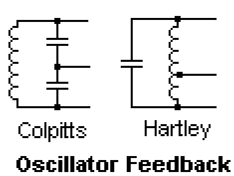


Fig 99.

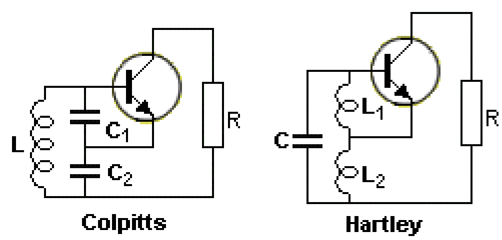


Fig 99a

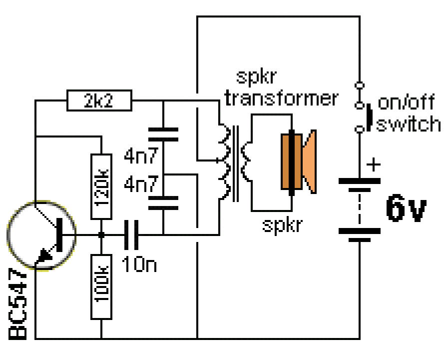


Fig 100. Colpitts Oscillator

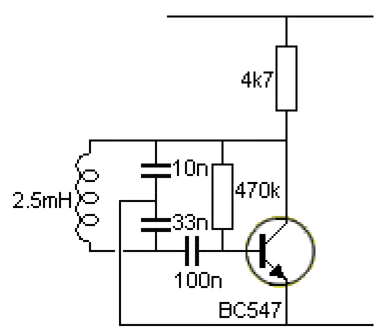


Fig 101. Colpitts Oscillator

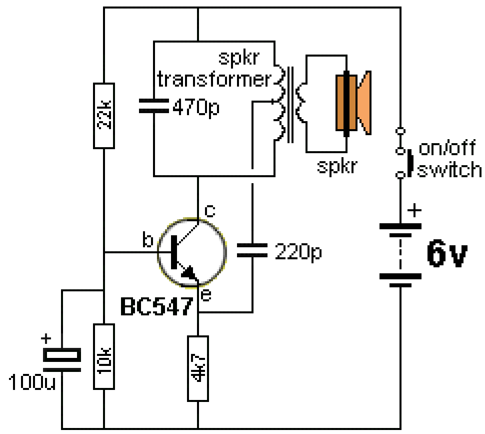


Fig 102. Hartley Oscillator

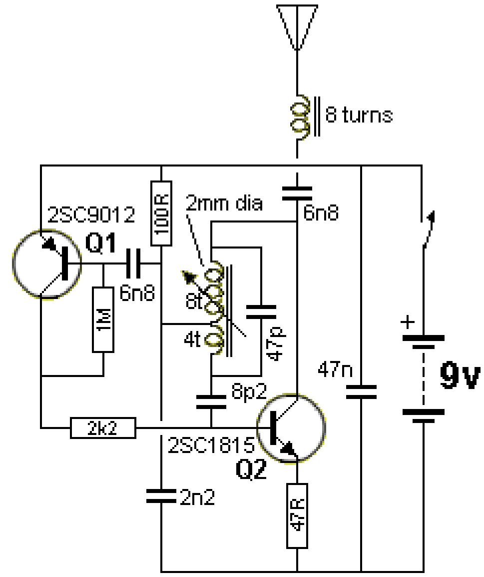


Fig 103. Hartley Oscillator

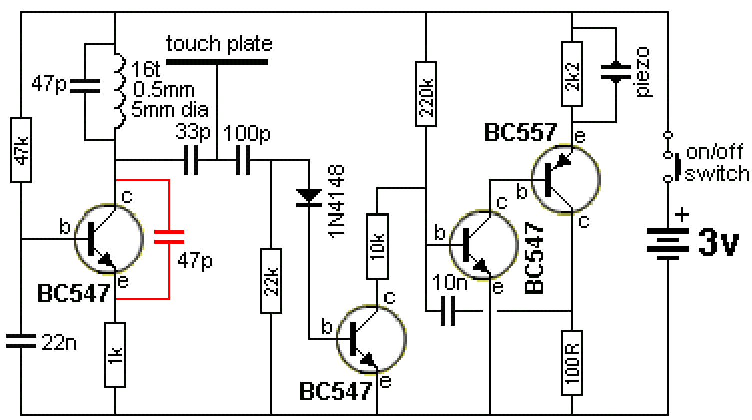


Fig 103a. Door Knob Alarm

DOOR-KNOB ALARM

This circuit can be used to detect when someone touches the handle of a door. A loop of bare wire is connected to the point "touch plate" and the project is hung on the door-knob. Anyone touching the metal door-knob will kill the pulses going to the second transistor and it will turn off. This will activate the "high-gain" amplifier/oscillator.

The circuit will also work as a "Touch Plate" as it does not rely on mains hum, as many other circuits do.

The first transistor is a **Colpitts Oscillator** and the feedback is via the 47p. Explaining the operation of this oscillator could take a page of discussion. We are only going to explain one amazing feature - how the oscillator creates the second half of its cycle. We know how the stage turns on (via the base-bias resistor) - but how does it turn OFF to create the other half of the waveform. Here's how:

We know that when a transistor turns ON, the collector voltage falls and the emitter voltage rises. Simply joining these two points with a resistor or capacitor will not produce feedback and one is falling and the other is rising. We need to join two points that are rising AT THE SAME TIME.

The secret comes from the inductor. The 16 turns of wire produces a voltage in the opposite direction when the transistor is turned off.

In the fist diagram of fig 103b we see the transistor turned ON and current flows through the coil. The voltage at the bottom of the coil will be slightly lower than the supply voltage. When the transistor is turned off, it is effectively out of the circuit and the current flowing through the coil produces magnetic flux that will collapse very quickly and produce a voltage across the ends of the coil that will be OPPOSITE to the applied voltage. This means the voltage at the bottom of the coil will be HIGHER than rail voltage and we can think of the coil rising above the power rail and producing a voltage 2, 5, 10 or even 100 times higher than the power-rail voltage.

This is the amazing fact about a coil (inductor) and is the secret behind the operation of this circuit.

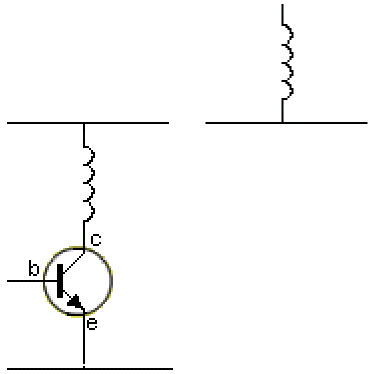


Fig 103b.

In circuit 103b, this high voltage is produced at some point in the cycle and it pulls the emitter UP a small amount via the 47p and this turns the transistor OFF. We are not going into what part of the cycle produces the high voltage via the inductor but it DOES. That's how the circuit produces the second part of its cycle. The inductor produces a high voltage that starts to turn off the transistor and this allows the inductor to produce a higher voltage and the transistor is turned off even more. During this time the 47p feedback capacitor is charging and RISING.

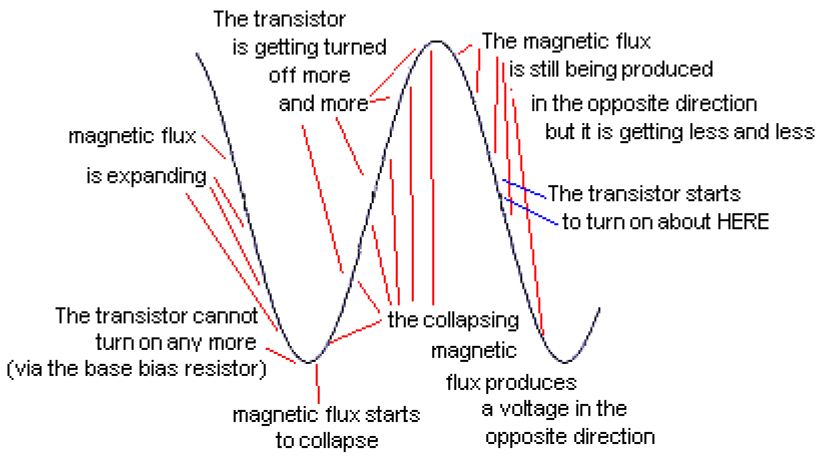


Fig 103c.

Most oscillators are described on the web and you can decide which type you need for your particular application.

OSCILLATOR SUMMARY

Look for a TUNED CIRCUIT and feedback line. It will be an oscillator.
Most have a high-impedance output and must be connected to a circuit that will not "load" them (and reduce the amplitude of the output) or prevent them oscillating.
But some oscillators have a very low output impedance and can drive a low-impedance device. You have to be aware of these features.

IMPEDANCE MATCHING

Every electronic component has a value of resistance. You can measure this value with a multimeter. But sometimes the value changes according to the light it receives, the frequency it is operating-at, or the voltage it is connected-to, or the sound it receives, or its temperature or many other influences.
Sometimes the output from a circuit might be 2v, but if you put a low-impedance device such as a speaker on the output, it "kills" the sound.
Or you may have a nearly flat 9v battery. It measures 5v with a multimeter but when you connect a 3v motor, it does not work.
These are both examples of poor IMPEDANCE MATCHING - yes, the battery has a HIGH Impedance and that's why it cannot deliver the current required by the motor.

What is **IMPEDANCE MATCHING**?

Impedance Matching is is connecting two items together so: "THEY WORK."

Some devices PRODUCE or DELIVER a signal or a voltage or a current.
Some devices ACCEPT a signal or voltage or current.
We need to connect these types of devices together.

Let's start with those that DELIVER:
An amplifier may be able to produce an output of 2v, but when a low-impedance device (low resistance device) such as a speaker is connected, it cannot deliver the CURRENT needed to drive the speaker. The same with a flat 9v battery. It cannot deliver the CURRENT needed to drive a 3v motor.
You cannot "test" or measure the output capability of a device. You must connect it to the input of the project you are designing and measure the waveform or voltage being delivered (or transferred).
If the voltage or waveform is considerably less than when it is not connected, you have decide if the attenuation (reduction) is acceptable. The ideal situation is NO attenuation - but in nearly all cases you will get some attenuation.

There are no "rules to follow" and every case is different. However when the output of a device is NOT reduced when it is connected to a circuit, the two items are said to be IMPEDANCE MATCHED.

There are three ways to "Match Impedances:"
1. via a resistor. This is generally a poor way to match impedances and is very inefficient. But it may be the only way to connect two devices.
2. via a capacitor. This can be a very good way to match impedances.
3. via a transformer. Generally the most efficient way to match impedances but requires a lot of calculation and expense in getting the transformer designed and manufactured.

Impedance Matching can also be referred to as "MATCHING" and the simplest example is connecting a 6v globe to a 12v battery. This is called "Resistance Matching" or "Current Matching" or "Voltage Matching" because the resistance, voltage and current are known quantities. But when when a device produces a signal; the voltage, resistance and current changes during the production of the signal and because these values are not constant, we use the term **IMPEDANCE MATCHING**. Impedance really means "resistance that changes during the production of the waveform."

Impedance matching can be worked out mathematically, but you need to know all the parameters of the device and the circuit you are connecting together. This is rarely possible to obtain.
Rather than calculate the result, it is much easier and more-accurate to connect the two items and view the result on a CRO (Cathode ray Oscilloscope). But if you cannot do this, simply connect them and listen or view the output from a speaker, relay or LED etc.

We have already studied "Impedance Matching" in the circuits above, but did not identify the concept. We will now go over some of the circuits and show where impedance matching took place:

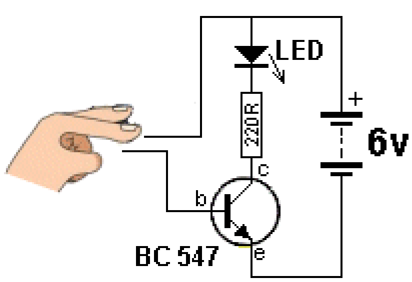


Fig 6

In **Fig 6**, the transistor matches the HIGH IMPEDANCE of your finger to the LOW IMPEDANCE needed to turn on the LED. The transistor converts the 50k resistance of your finger to less than 0.5k (due to the gain or amplification of the transistor of about 100 -200).
You can also say it matches the HIGH RESISTANCE of your finger to the LOW RESISTANCE needed to turn on the LED.

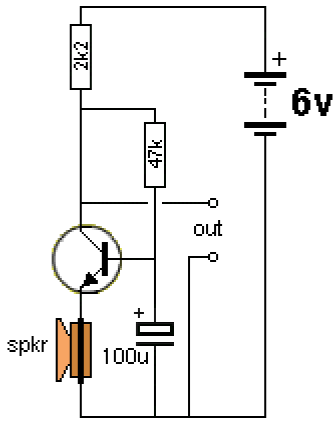


Fig 64

In **Fig 64**, the transistor matches the LOW IMPEDANCE of the speaker to produce a HIGH IMPEDANCE output on the "out" terminals, suitable for delivering to the input of an amplifier. The transistor converts the 8 ohms of the speaker to more than 800 ohms (possibly 1600 ohms) due to the gain or amplification of the transistor (about 100-200) and at the same time the 0.5mV produced by the speaker is amplified to about 400mV to 800mV.

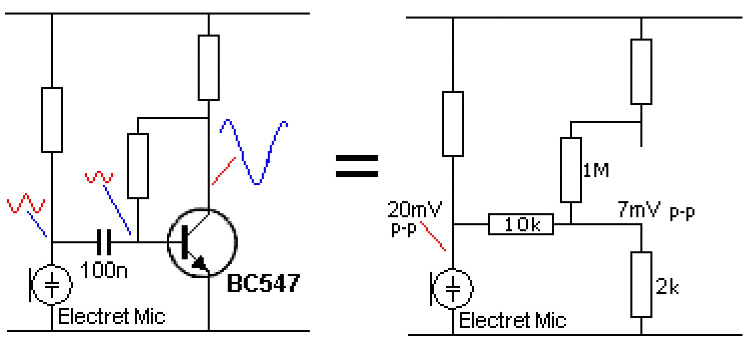


Fig 71f

The 100n capacitor in **Fig 71f** matches the impedance of the electret microphone to the input impedance of the transistor.
The impedance of the electret mic is about the same as the input impedance of the transistor but the mic needs about 0.5mA to operate and the voltage on the base of the transistor needs to be very accurately set for "self bias." A capacitor separates these slightly different DC values while passing the AC signal..

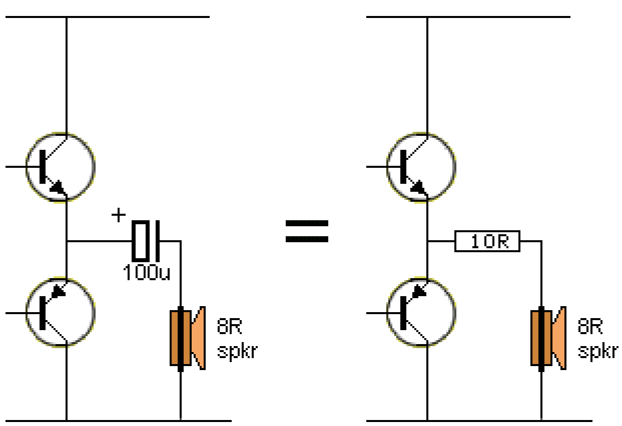


Fig 71e

Sometimes Impedance Matching is needed to separate or remove the DC component of a signal. In **Fig 71e**, the electrolytic matches the LOW IMPEDANCE output of the amplifier to the LOW IMPEDANCE of the speaker. The two impedances are almost identical and you could connect the speaker directly to the output of the amplifier, but the output has a voltage of approx mid-rail and this would enter the speaker and shift the cone when no audio is being reproduced. And the speaker would only be able to amplify the negative parts of the waveform.
To remove the DC component of the waveform, an electrolytic is included.

SATURATING A TRANSISTOR

This is the last topic for discussion because it is the last thing to attend to when designing a circuit.
We have explained the fact that a transistor turns ON when the base voltage is above 0.7v and the current though the collector-emitter leads is approximately 100 times the base current.
This means a transistor with a gain of 100 will deliver 100mA to a collector LOAD when 1mA enters the base.
This is theoretically true and will occur in nearly all cases, but some devices such as motors and globes need a lot more current to get them started or to get them to turn **ON** because the cold resistance of a globe is only about 1/5 its hot resistance.
This means a 100mA globe needs 500mA to get it to start to glow.
The same with a motor. The starting or "stalled current" is 5 times more than the

operating or "running current.
On top of this the transistor might not have a gain of 100 and the voltage may be slightly higher than expected. All these things means the transistor must be turned **ON** with more than 1mA into the base.
If you deliver 2mA, it does not mean the transistor will deliver 200mA to a LOAD. If the load requires 100mA, delivering 2mA to the base will simply turn the transistor **ON** harder and the collector-emitter voltage will be slightly lower, but the load will still draw (or take) 100mA.
But the devices we mentioned above require 500mA to get them started, so the base current needs to be 5mA.
Now, here's the unfortunate part, 5mA base-current will not deliver 500mA collector current. The transistor needs more than 5mA base-current to get it to deliver this HIGHER current. It needs about 7mA.

This process can be proven by experimentation.
Simply increase the base current until the device is turned **ON**, then measure the base current. Add 1mA to 3mA to guarantee reliability and the circuit is complete.
This process is called **SATURATING A TRANSISTOR** or **GUARANTEEING TURN-ON**, or **FULLY SATURATING the TRANSISTOR** or **FULLY TURNING the TRANSISTOR ON**.

CIRCUIT PROBLEMS:

CIRCUIT 1

The input to a microcontroller needs a HIGH when a microphone picks up audio. This is the requirement from a customer. The circuit in Fig 104 was designed to meet the customers requirements. The 10mV audio waveform from a microphone is converted to a 4v-5v CONSTANT HIGH. The following circuit is the result:

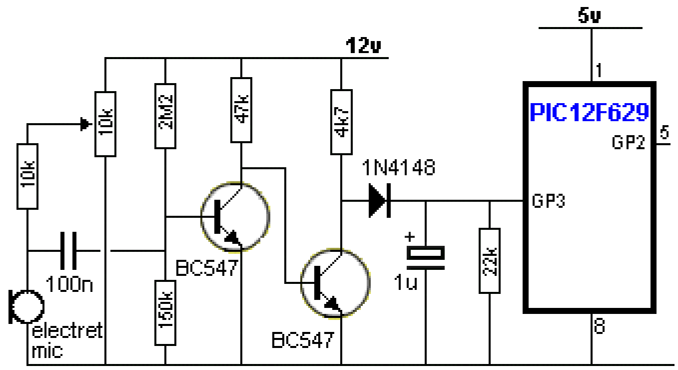


Fig 104.

The starting point is to bias the first transistor so the voltage on the base is just at the point of turning it ON.
This allows the 47k resistor to turn on the second transistor and the diode does not see any voltage.
This means the 1u does not get charged and the input to the microcontroller sees a LOW.
This is called the QUIESCENT (standing, stand-by or idle) condition.
The gain of the electret microphone is adjusted by the 10k pot and when it receives a loud audio signal it produces an output of about 20mV.
This signal is sufficient to turn ON the first transistor and turn OFF the second transistor so that signal diode sees a HIGH pulse via the 4k7.
This voltage is passed to the 1u and it gradually gets charged. When the voltage on the 1u reaches about 4-5v, the microcontroller sees a HIGH and the program in the micro produces an output.

CIRCUIT 2

How does this amplifier get biased?:

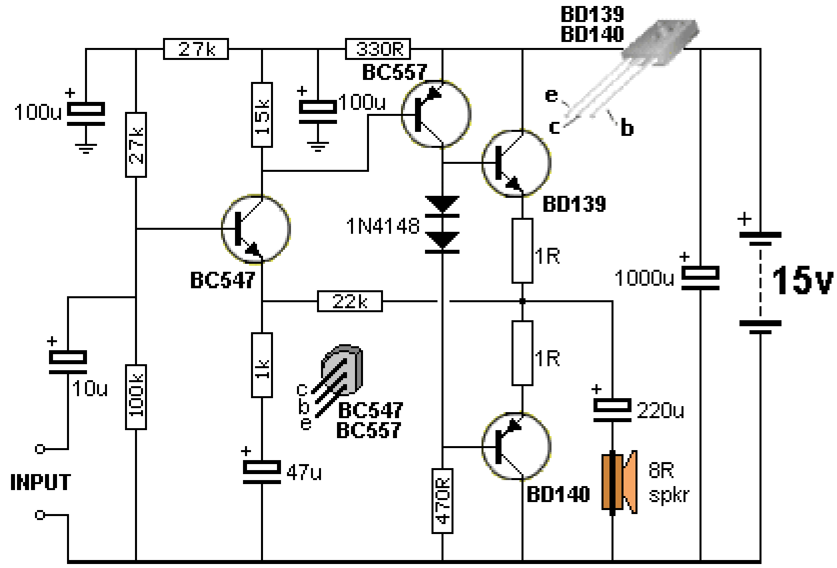


Fig 105.

One of the most difficult amplifiers to design and service is a DC (Directly-Coupled) amplifier. The voltage on the output is fed back to the input to create the idle (quiescent) state and the biasing of the input is created from the output. So, where do you start?
All the facts we have learnt in this discussion are needed to understand how this circuit works.
The circuit has high gain and without the 22k feedback, we would not be able to create an output "set-point." The first transistor has no DC voltage gain as but it does have an AC voltage gain of about 22. The BC557 provides a voltage gain of about 70-100 and the output transistors only provide a current gain. This gives the circuit a voltage gain of about 2,000. A 50mV input will produce an output of about 10v.
The aim is to get the output voltage near to mid-rail so it can swing both positive and negative and create a relatively distortion-less waveform.
The starting point is the voltage divider made up of the 27k + 27k and 100k. This puts 10v on the base.
Now we come to the 470R resistor on the base of the BD140 transistor. This resistor is a very low value and is keeping the BD140 turned on and the emitter will be very low.
Here's the interesting part: The collector of the BC557 can pull UP without any difficulty to about 1.4v due to the two 1N4148 diodes and also due to the base-emitter voltage-drops across the two output transistors. But this only raises the collector **about 1.4v**.
To be able to pull higher, the transistor must turn on harder and since the bottom transistor is being pulled down by 470R, the top transistor is also being pulled down via the two 1R resistors. The BC557 sees the base of the BD139 as a 470R resistor, plus the actual 470R resistor. This make it 220R.
To raise the voltage on the base of the BD140, requires current through the 470R and the BC557 needs to be turned on a certain amount to provide current through the 470R and into the base of the BD139 AT THE SAME TIME.
At the moment the join of the two one-ohm resistors has a very low voltage on it and the BC547 is also an emitter-follower and the emitter is about 10v minus 0.7v.
This puts a current through the 22k resistor of less than 1mA however this current also flows through the emitter-base junction of the BC557 and if the transistor has a gain of 100, the emitter-collector current can be as high as 100mA.
However the 220R (470R and 470R in parallel) resistor only needs a flow of 22mA to create a voltage of 5v across it, so we have plenty of gain to begin to turn on the circuit.
The BC557 creates a current-flow through the 470R and the BD140 starts to get pulled UP. This puts less current though the BC547 and less current through the base of the BC557, so the BC557 starts to turn off.
The actual settling-point has a lot to do with the 27k + 27k and 100k base-bias resistors as this puts 10v on the base and the emitter 9.3v. Suppose the output settles at 7.5v. This puts 1.8v across the 22k and creates a current-flow through this resistor. Approximately the same current flows through the emitter-base of the BC557 and about 100 times this current is available to be divided between the 470R and base of the BD139. This is how the output becomes biased at very nearly half-rail voltage.

CIRCUIT 3

Select the best circuit between Figs 106 and 107:

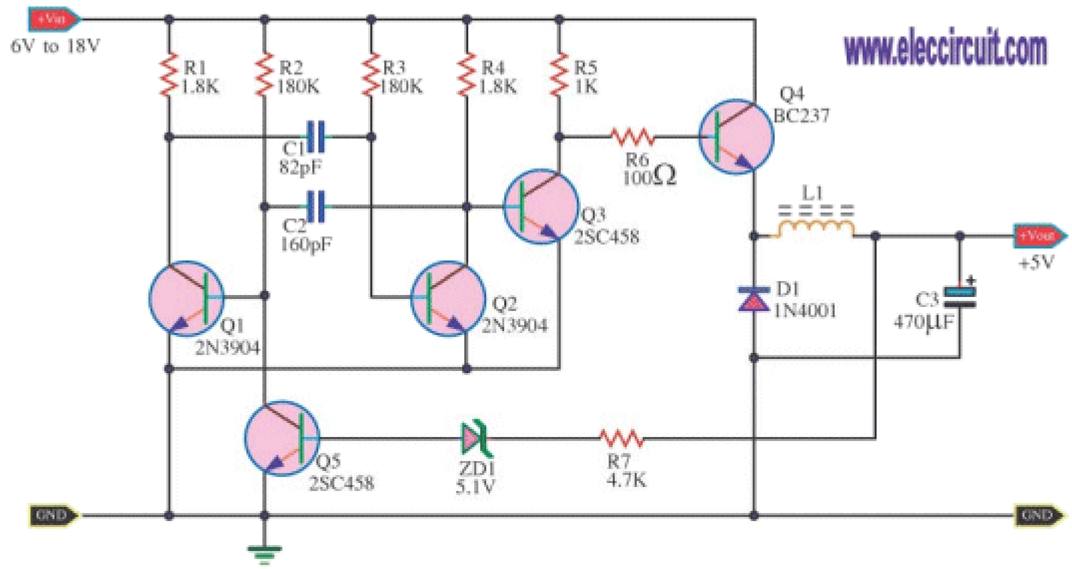


Fig 106.

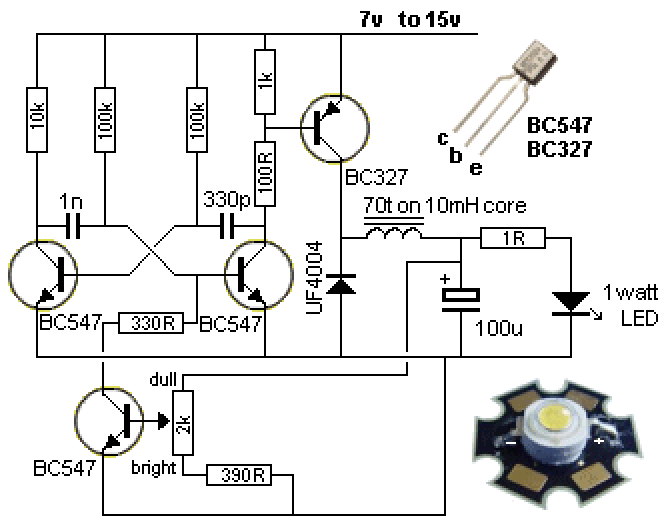


Fig 107.

From the theory discussed above, can you see the problem with driving the BC327 in **Fig106**.
It is being pulled HIGH via the 1k resistor. If the transistor has a gain of 100, Q4 will effectively be equal to a 10 ohm resistor. For 100mA current delivered to the output, 1v will be dropped across this transistor and it will start to get hot. This is wasted energy.
A BC237is only capable of delivering 100mA.

Fig 106 has been re-drawn as **Fig 107** with improvements and corrections.
The ouput transistor has been changed to a BC327. It will handle 800mA.
A 1N4001 is not a high-speed diode and using an Ultra Fast 4004 will deliver an extra 50mA to the output.
See: 200 Transistor Circuits for details.

CIRCUIT 4

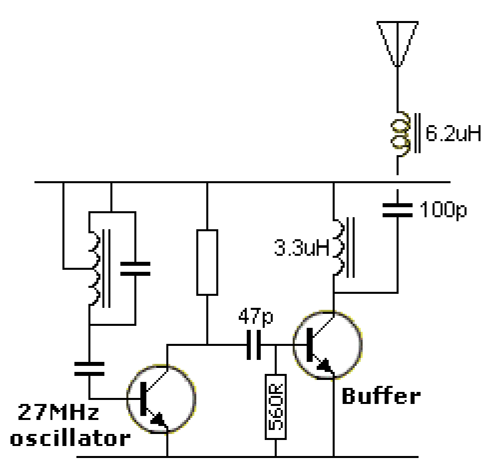


Fig107a shows a 560R resistor to discharge the 47p coupling-capacitor.
The circuit is a 27MHz transmitter with buffer. The buffer is an amplifying stage to increase the output.
You will notice two things: the buffer stage is not biased ON and a low value resistor is connected between base and 0v rail. This called a "Class-C" stage.
This resistor discharges the capacitor so it will transfer the maximum amount of energy (on each cycle), from the oscillator stage to the output stage.
The resistor is not needed when charging the capacitor but it is very important to discharge the capacitor.
Remove the resistor and the output will be nearly ZERO!

Fig 107a.

Another point to note with a **"Class-C" stage** is this: All the energy to turn-on the Buffer stage comes from the coupling capacitor.

LAB ELECTRONICS

Lab Electronics produces a "stand-alone" trainer that covers the **common-base**, **common-emitter** and **common-collector** stages:

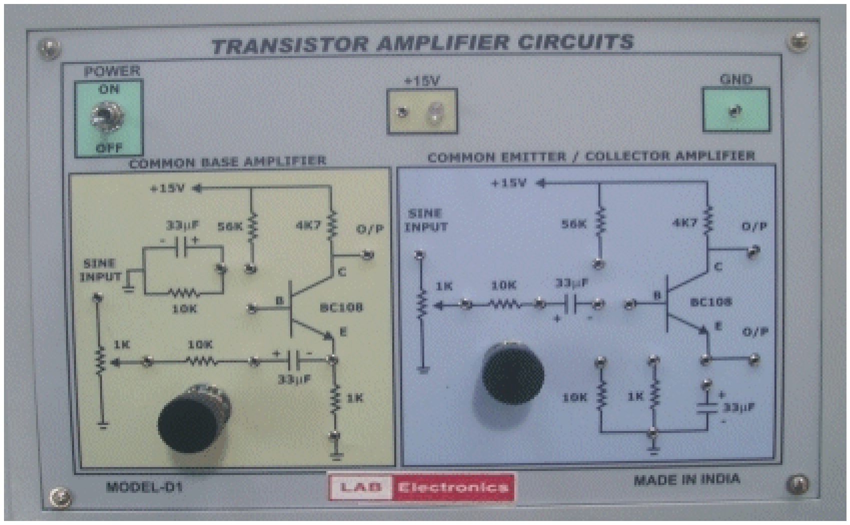


Fig 108.

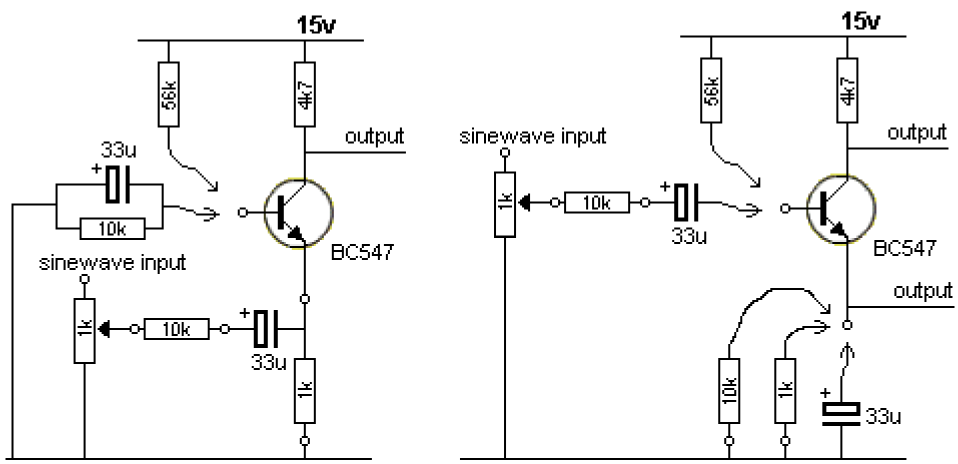


Fig 109.

Fig 109 shows the circuit for the trainer and how it can be wired to produce all the stages we have covered in this discussion. By feeding each stage with a sinewave at the input, you can view the output on a CRO and see how it works.

This is only part of the picture to understanding the operation of each stage as the input and output impedances are also important and the third important thing is the effect of the capacitor(s) and/or electrolytics that connect one stage to another and/or those connected to the emitter to provide EMITTER BY-PASS.

We have already explained the advantage of a common-base stage (to connect a very low impedance device to an amplifying circuit) and the advantage of a common-collector (emitter-follower) circuit to drive a low-impedance load.

A "trainer" only provides a fraction of the knowledge needed to understand "circuit-design" - but it helps. You must build "real-life" circuits to get a complete understanding.

The trainer above has lots of faults in its design. You cannot get a full understand of the common-base stage with 1k in the emitter. It should be 100R or less. The 10k feeding the 33u will attenuate the sinewave and is not needed.

The common-emitter stage does not provide any self-biasing option. The 56k base-bias is too low and the collector and emitters resistors are the wrong values to get any appreciable gain from the

stage. When the 33u is put across the emitter resistor, the gain will increase enormously.
It would be much better to work on the circuits we have presented above and view the output on a CRO.
This trainer does not give you a full understanding of the operation of the three stages. (33u and 15v is rarely used) I would give it a MISS.

Fig 110.

Fig 110 shows another trainer. It covers the common-emitter stage.
When a common-emitter stage drives a transformer or speaker as a load in the collector circuit, we want the sound to be free of distortion and to do this this we must bias the stage so the collector is at half-rail voltage when no audio is present.
This allows the transistor to turn ON and OFF to provide the maximum voltage-swing. If the transistor is not sitting at mid-rail, either the positive or the negative peaks of the signal will hit either the positive or negative rail and produce distortion - because the full excursion (height) will not be reproduced.
But biasing the transistor at mid-rail means the current though the speaker or transformer will be about half the peak current and this is wasted as it flows at all times, even when audio is not being processed.
That's why this type of stage is not efficient and it heats up the output transistor considerably, even with no audio.
This type of circuit is called "CLASS-A" and the trainer above has a "Bridge" circuit as a pre-amplifier and is capacitor-coupled to a common-emitter stage as an output stage - driving a transformer - as a class "A" amplifier. Since transformers are expensive, difficult to purchase and add weight to a project, they have generally been replaced by complementary-symmetry push-pull class-B output stages.
All the features in this trainer have been covered in the circuits above.

Which circuit is best?

Fig 111 shows four different circuits driving a speaker. Which circuit is best??

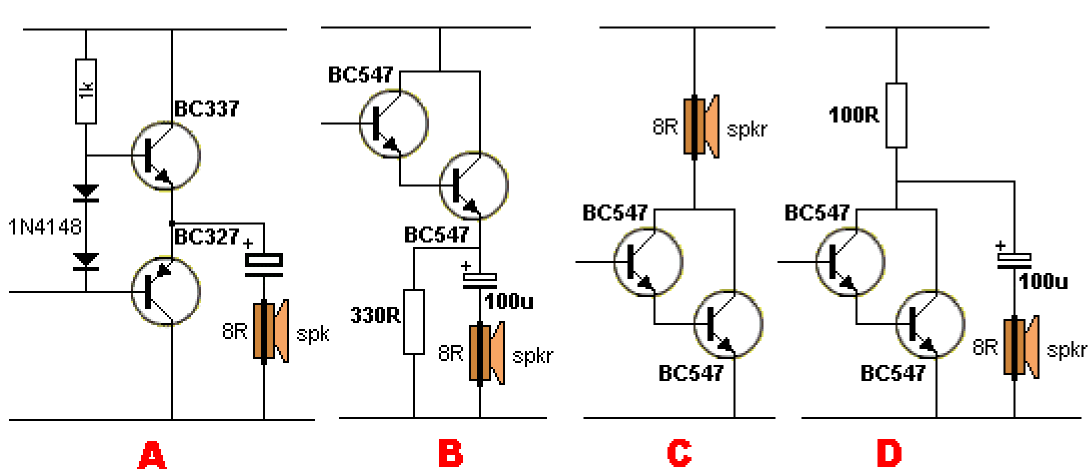


Fig 111.

The 4 circuits in **Fig 111** drive an 8 ohm speaker and are called **OUTPUT STAGES** or **DRIVER STAGES.** They are all different in performance and have different input voltage requirements.
Circuit A is really only a one transistor emitter-follower amplifier as the other transistor discharges the electrolytic.
However it is fully discharged and represents only a few ohms resistance (impedance) in series with the speaker. The input voltage-swing must be as large as possible (called rail-to-rail swing).
Circuit B is a two-transistor amplifier (called a **Darlington Pair**) and requires only a very small current but a rail-to-rail voltage-swing. The speaker is AC coupled and only the audio current enters the cone and it is not displaced via any DC current. However the 100u is discharged via a 330R and the electrolytic is equivalent to a 330R in series with the speaker. The output from this circuit will be very low.
Circuit C is a **Darlington Pair** directly connected to a speaker. The input is very sensitive and requires less than 1v swing for full output. However DC flows through the speaker and will heat up the coil as well as shift the cone and maybe reduce the output capabilities of the speaker.
Circuit D is a high gain **Darlington stage** and has a sensitive input and requires less than 1v for full output. However the electrolytic is discharged via a 100R and this means it is equivalent to a 100R in series with the speaker.
The best circuit is "**A**" but it needs a pre-driver transistor to achieve the gain (or amplification) of the other 3 circuits.

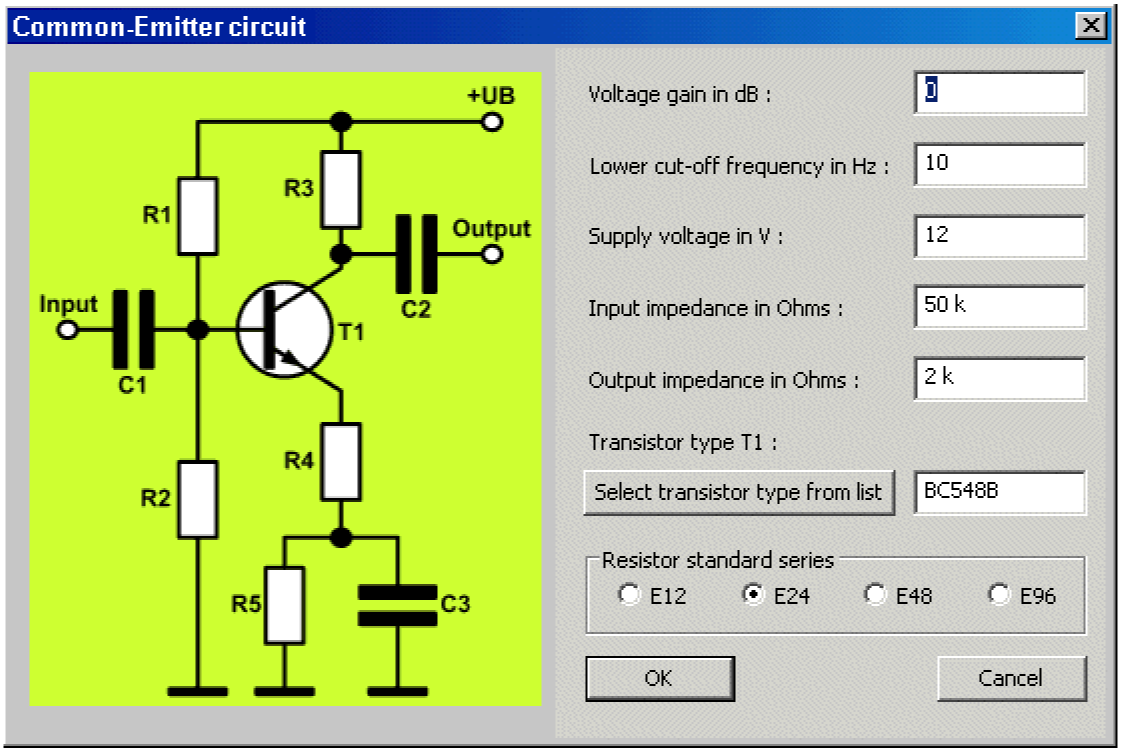
DESIGN YOUR OWN TRANSISTOR AMPLIFIER

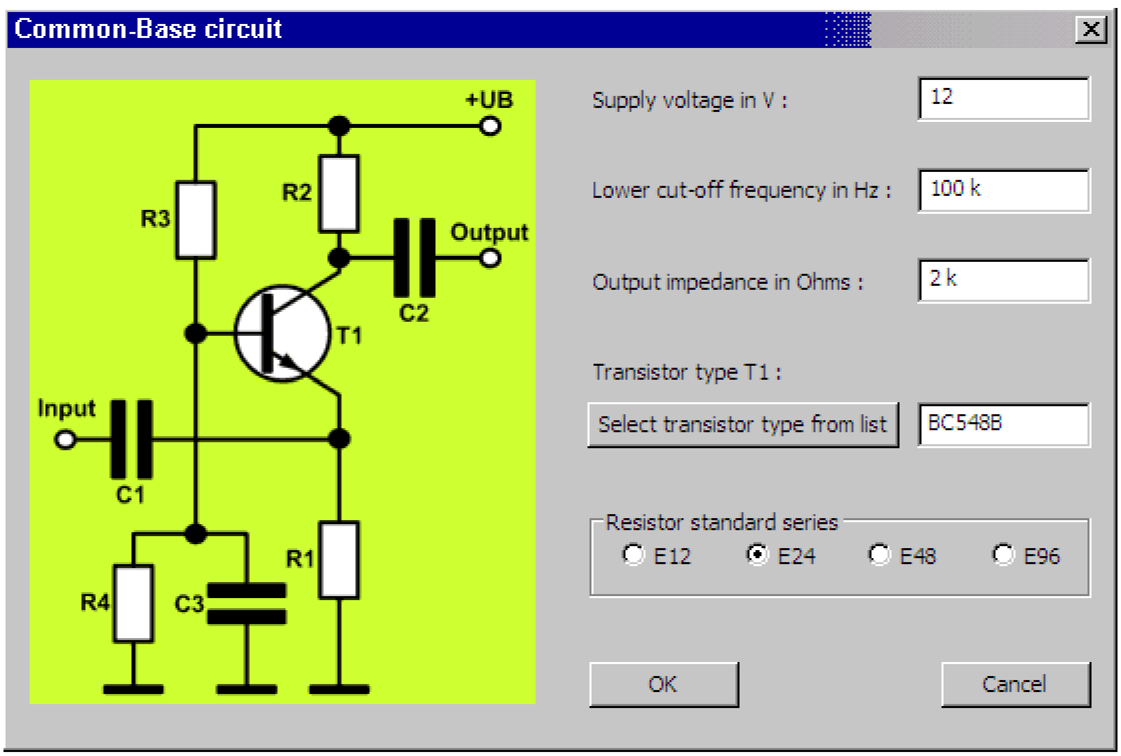
TransistorAmp software by Didaktik Software

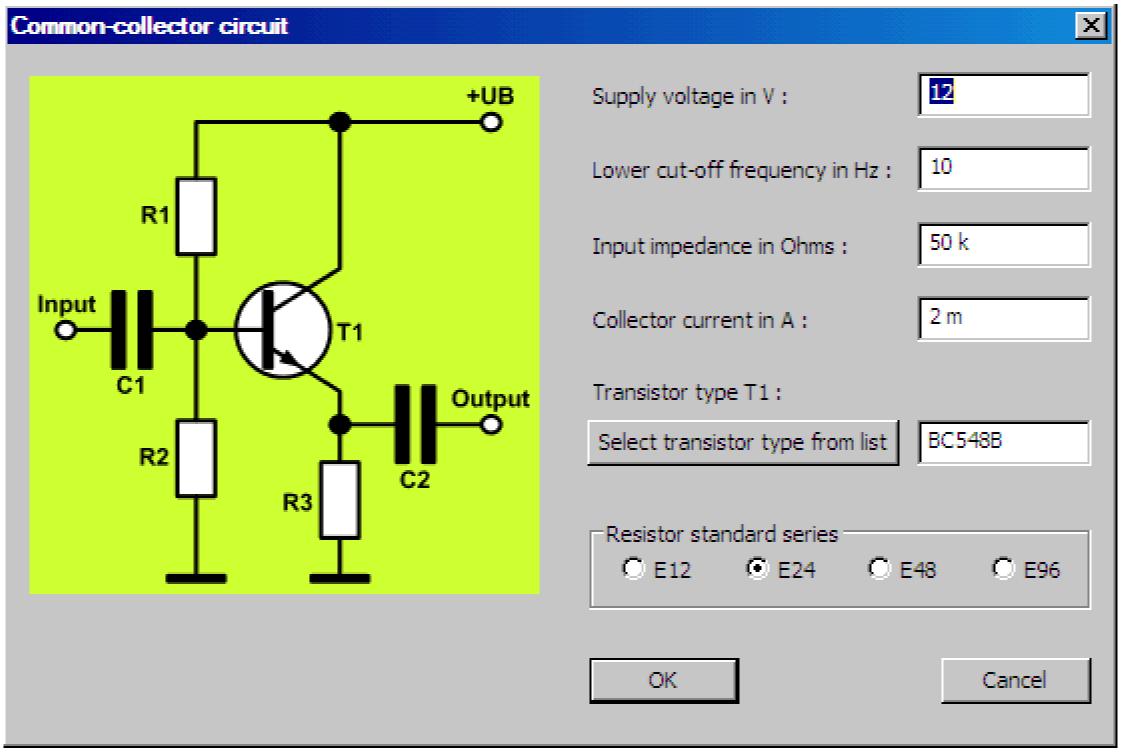
The following software allows you to design your own single-stage Common-Emitter, Common-Base or Common-Collector amplifier.
It has been created by **Didaktik Software**.
Download: **TransistorAmp** (.zip 520KB)
TransistorAmp unzips to TransistorAmp.msi (604KB) and will install on your computer with a desktop icon.
Or you can download: **TransistorAmp** **(.exe)** or **TransistorAmp** **(.rar)** Unzip .rar in a folder "TransistorAmp" and it will create TransistorAmp.exe Click on the file and the image above wil

How to use the software TransistorAmp

TransistorAmp is very easy to use. You start every design with the menu item: "**New Amplifier**". In the pull-down-menu you choose your desired circuit. You can choose between common-base-circuit, common-emitter-circuit and common-collector-circuit. After that you get a dialog, where you have to put in all parameters of your amplifier.
The following 3 images show the layout of the circuit you will produce:


Common-Emitter circuit
+UB
R1
R3
Output
Input
C2
T1
C1
R4
R2
R5
C3
Voltage gain in dB :
0
Lower cut-off frequency in Hz :
10
Supply voltage in V :
12
Input impedance in Ohms :
50 k
Output impedance in Ohms :
2 k
Transistor type T1 :
Select transistor type from list
BC548B
Resistor standard series
E12
E24
E48
E96
OK
Cancel


Common-Base circuit
+UB
R3
R2
Output
C2
T1
Input
C1
R1
R4
C3
Supply voltage in V :
12
Lower cut-off frequency in Hz :
100 k
Output impedance in Ohms :
2 k
Transistor type T1 :
Select transistor type from list
BC548B
Resistor standard series
E12
E24
E48
E96
OK
Cancel



For the selection of the transistor-type you can click on the button: "**Select transistor type from list**", and you will see a list of all supported transistor types. **TransistorAmp** supports some thousand transistor types - even some Germanium transistors. Select your desired transistor type and click OK. The selected transistor type will be displayed in the dialog. Both NPN and PNP transistors are supported.

When you have completed your input in the dialog, click OK and see the result. You see a window with your input data, the circuit, the component values and the most important parameters of the operation point. If you want to change your design, you only need to click again on "New Amplifier" and the circuit in the pull-down-menu. Your previous input data will be restored in the input dialog and you can change one or more parameters.

Note: for the Common-Collector amplifier: "**Collector current in A**" means: "Collector current in Amps." For 2mA, insert 0.002 etc.

Decibel (dB) Calculator

Decibels are defined as ten times the log of a power ratio. This calculator converts between decibels, voltage gain (or current), and power gain. Just fill in one field and the calculator will convert the other two fields.

dB= 20log(V1/V2)= 10log(P1/P2)

Decibels (dB)	Voltage Gain	Power Gain

When you are satisfied with the result, click on: "**Result - Save**". TransistorAmp saves all data in the result window to an HTML-file. You can open this file with a browser (e.g. Firefox or Internet Explorer), inspect it and print it.