Experimenting with Electronics

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Putting transistors to use

If you're looking to start designing your own circuits and building your own projects, then you won't come across a component more versatile than the transistor. Over the next couple of months, we'll look at some of the many ways you can use a transistor to great effect.

There is an attitude in society which seems to suggest that we make things simpler by making them more complicated. You only have to look at the number of microprocessor-controlled widgets and whizzbangs floating around — washing machines, videos — just about everything you can buy.

Now while they obviously allow more people to *use* the products, anyone who wants to service their own widget is in for one heck of a nightmare.

As far as active electronic components are concerned, the transistor would be the most useful and simplest to use. In essence, it's operation is fairly simple — a small current is applied to the base to control a much larger current flow between the emitter and collector. It's this *amplification* capability of the transistor that makes it so useful. However, there are many other things you can do with it besides making a simple amplifier, as we shall see over the next couple of months.

A simple amplifier

If you've never seen one before, then here it is in Fig.1 — the world's simplest audio amplifier. It's a 'common emitter' design, so called because the emitter is the common connection between the input and output signals. This circuit uses a current bias at its base, supplied by the 1MΩ resistor. It also provides the negative feedback for the circuit too. Let's see how this works.

When power is first applied, Q1 is suddenly turned on by the current flow through the 4.7kΩ collector resistor and the 1MΩ bias resistor. As the transistor turns on, the collector voltage decreases. This reduces the amount of bias current to the base, which forces the transistor to begin turning off. As it turns off, the collector voltage rises. More current flows to the base and Q1 turns on again.

This apparent swaying between one state and the other all happens quite rapidly and with the components and supply voltage specified, the collector voltage quickly reaches half the supply rail, the ideal spot for the output of an audio amplifier.

The two 0.1uF capacitors isolate the input and output from the DC voltages, to ensure that the DC bias points are not upset by outside loads.

The input impedance is only fairly low, due to the fact that there is no emitter resistor in this circuit. The AC input impedance of the circuit is roughly equal to the beta (current gain, or amplification factor) of the transistor, times the internal emitter resistance of the transistor.

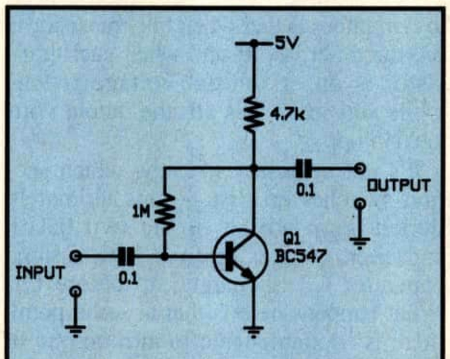

Fig.1

This last factor is often known as 'little r-e' and in our circuit, it is around 25 ohms. multiply that by 100 as a minimum figure for the gain of a BC547 transistor and you get an overall input impedance of around 2.5kΩ.

The output impedance is much easier to work out. As a rough guide, it is simply the value you have for the collector resistor — in this case, 4.7kΩ.

Now while you can't connect a loudspeaker to the output and expect to hear an awful lot, you can easily use it as a cheap microphone preamplifier. It will provide a gain of around 200, which is more than enough to drive your stereo system to a suitable level. Connect up a dynamic microphone to the input and the output to the line input of your stereo, and you've got a simple karaoke mic system.

Better control

The old saying is 'whatever can be done with one, can be often done better with two', and this is very true when it comes to transistor amplifiers. The circuit in Fig.2 is an equally common circuit and included for completeness; however it does have a number of advantages over the circuit in Fig.1.

Firstly, it has a much higher sound quality. In more technical terms, it has a lower amount of total harmonic distortion (THD). Simply, this is the amount of extra nasties the amplifier itself adds to the output signal. While you can't get rid of it completely, you can reduce it down to inaudible levels.

The new circuit has a much more stable method of applying negative feedback. In this case, the feedback is taken from the output (as before) via a 2.2kΩ resistor from the collector of transistor Q2, and fed to the emitter of Q1. Now while it may not be obvious, the emitter of Q1 is actually another input point. A signal applied to the emitter of a transistor will appear in the same phase at the collector.

The 100Ω resistor R1 and the 10uF capacitor, along with the 2.2kΩ feedback resistor R2 form a voltage divider for the feedback, which is extremely stable. By stable, I mean that it is not varied by the characteristics of the transistors used.

In Fig.1, the feedback, and hence the overall gain which we'll get to shortly, is controlled by the beta of the transistor. The problem here is that transistor betas can vary over a range of 4 to 1 and more. Some types of BC547's will have a beta of 100 and others as high as 400. This type of variation ensures that the gain of Fig.1's circuit will always vary.

By contrast, the gain of Fig.2's circuit is simply 1+(R2/R1), or 1+(2200/100)=23 as in the case of our circuit. To increase the gain, you reduce the negative feedback and vice versa. This is done by reducing or increasing, the 100Ω resistor. If you change the 2.2kΩ resistor, you will upset the DC bias points; so always stick with the same value of R2.

Strictly speaking the 33kΩ collector resistor on Q1 is not necessary, but it greatly reduces the amount of distortion — by a factor of five or more. It helps to linearise the current flow through the base of Q2.

The output voltage, at the collector of Q2, is set to 4.5V with a 9V supply rail and is set by the 100k and 150kΩ resistors biasing Q1. The base bias voltage of Q1 sits about 0.6V above half the supply rail, to allow for the 0.6V drop across the transistor's base-emitter junction. You can vary the supply voltage over a range of 6-18VDC and the output will be pretty close to half the supply rail. This ensures that the circuit can deliver the maximum voltage swing with little distortion.

Another factor which adds to THD is hum, or 50Hz leakage from your power supply into the audio path. If you're running from batteries, this is generally not a problem; but if you're running the circuit from a plug pack, you'll find quite a bit of hum getting through via the supply rails.

The 10kΩ resistor and 10uF capacitor on the left together act as a very low-pass filter, to remove the mains hum leakage and ensure that the input bias voltage for Q1 is as stable as possible.

The output impedance here is again determined largely by the collector resistor of Q2, and in this case, is approximately 1kΩ. The benefit of this circuit though is that the output impedance can be either reduced or increased without greatly affecting the overall gain of the circuit, since the collector resistor is not part of the feedback network.

This circuit has a distortion figure of around 0.1%, but with higher supply voltages (i.e., around 18V or so) the distortion can drop as low as 0.05%.

More noise

While transistors can be used to amplify other noises, they can also be used to generate their own. The simple circuit in Fig.3 is a square wave oscillator which starts as soon as you apply the supply voltage. It's official name is a 'cross-coupled astable multivibrator' — 'cross-coupled' because the RC components connect the output of each transistor to the input of the other, 'astable' because neither transistor has a stable operating state, and 'multivibrator' because it continues to oscillate indefinitely.

Both transistors are common BC547 types, which should cost you around 20c each or less. While this circuit may look fairly simple, it is more difficult than it looks to figure out how it works.

The difficulty with the circuit lies in the fact that there are really two parts to it, and it is impossible to figure out which part — that of Q1 or that of Q2 — will switch on first. In practice, all you need to remember is that when one transistor is on, the other is off; and when each transistor is on, its output voltage is *low*, while and when it is off, the output voltage is *high*.

It's not necessary to know which section switches on first — this ultimately depends on which of the two 0.1uF capacitors charges up first. Let's assume capacitor C2 is charged up before C1. What happens here is that at some point, there is enough charge to turn on one of the transistors; and because of the cross-coupled arrangement, one transistor turns on and the other is forced off.

C2 charging up first means that transistor Q1 switches on and Q2 is forced off. The reason for this is that when Q1 switches on, the Q2-base side of capacitor C1 is pulled below 0V! Now this may sound impossible, but it happens because capacitors cannot instantly get rid of or change the charge that is stored inside. So if one side of the capacitor drops from 5V down to 0V, the other side must go from 0 to -5V.

This well and truly forces Q2 off; but C1 now begins to charge up in the reverse direction until it reaches 0.7V, the limit forced upon it by the base-emitter junction voltage of Q2. Transistor Q2 now switches on, and its collector voltage drops from 5V down to 0V.

Capacitor C2 is now forced to go from 0.7V down to -4.3V (a 5V drop) which forces Q1 off. But C2 now also charges back up, until it reaches 0.7V when Q1 switches back on. The process then continues on, cycling back and forth until the power is removed.

The frequency of this circuit is dependent upon the two RC networks, and providing both the resistors (R1, R2) and both capacitors (C1, C2) have the same value, the frequency is determined roughly by the following equation:

$F = 1 / (R \times C)$

where F is the frequency in Hz, R is the resistance of R1 or R2 in ohms and C is the capacitance of C1 or C2 in Farads. The output is a square wave with both sets of components having equal values.

The output signal is taken from the collector of transistor Q2 via a 1uF DC isolating capacitor and a 10kΩ load resistor. The other interesting aspect of this circuit is that and opposite-polarity signal is available from the collector of transistor Q1, which can be very handy and something that we'll use in a future issue.

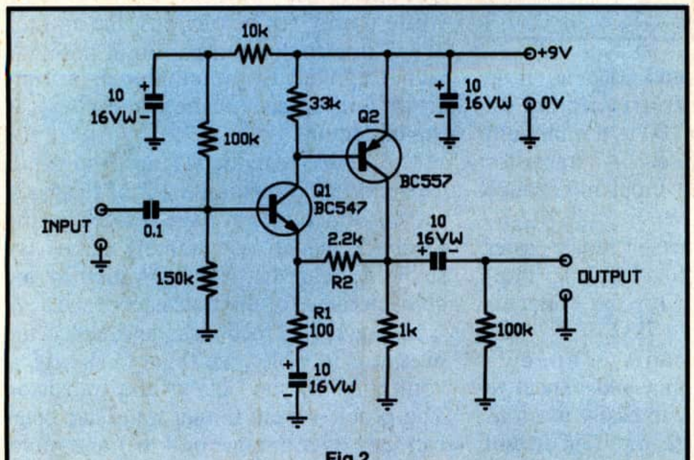

Fig.2

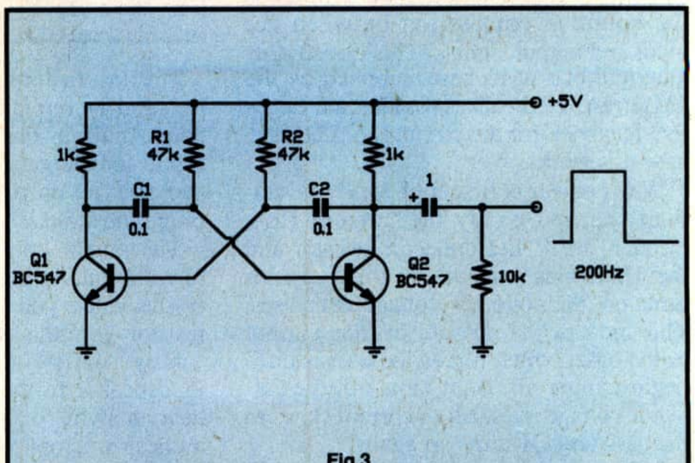

Fig.3

If you remember back to last month's column, we came up with a simple voltage-controlled volume control using a couple of series diodes. If we remove the DC volume pot and replace it with our newly created square wave oscillator, we can make a very crude 'Robot Voice' circuit as shown in Fig.4.

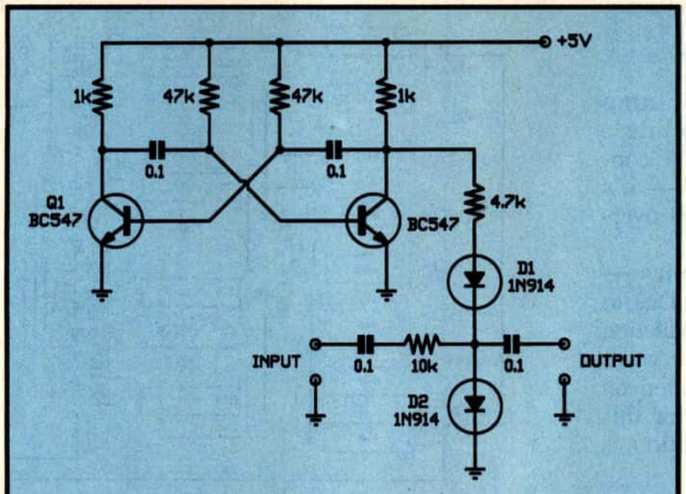

Fig.4

The audio signal, either from a tape source or from a microphone preamplifier, is fed into the circuit via a 0.1uF coupling capacitor. While the collector of Q2 is low, both diodes are off and the audio signal passes through the circuit as if nothing happened. But when the collector voltage rises to 5V, both diodes conduct and the audio signal is shunted to ground and the output goes silent.

By switching the audio off and on like this at 200 times a second, the effect is to chop the sound up, and this chopping action produces a beat frequency in the audio at 200Hz. It's this beat frequency which gives the audio that 'robotic' flavour. All you need to do is connect the audio output to a small power amplifier to hear the result.

There is plenty of room for experimenting with this circuit, particularly with the frequency of the oscillator. Try dropping the 0.1uF capacitors down to 0.047uF (47nF) and see what results you get. What you should find is that the beat frequency rises to around 400Hz.

This is a good example of how you can join these little 'building block' circuits together, to create something different. In fact, that's all electronics really is — working out new arrangements for common circuit elements.

Current source

Our last circuit for this month moves away from the audio domain and into the realms of voltage and current control. The circuit in Fig.5 is commonly called a *constant current source*, and that's because the current that flows through the collector of Q1 is 60mA, regardless of how small the load resistance is. Let's see how it works.

So far we've used the transistor as a switch and as an amplifier, but here we take advantage of the transistor's base-emitter junction voltage — which hovers around 0.6V. Another difference in this circuit is the use of a BC327 PNP transistor. It operates in essentially the same fashion as the NPN type, just 'upside down', as we'll see.

Diodes D1 and D2 are standard 1N914/1N4148 types wired in series, with a 330Ω current-limiting resistor connected to ground. Because silicon diodes develop a fixed 0.6V drop across them, we know that the voltage at the junction of D2 and the 330Ω resistor will be 7.8V (i.e., 9V minus twice 0.6V). This junction is also connected to the base of the PNP transistor Q1, and now the transistor's base-emitter junction comes into play.

Because we know that the B-E junction voltage is always 0.6V, the emitter of Q1 is 0.6V *higher* than its base. And as the base is at 7.8V, this makes the emitter voltage 8.4V. We therefore have 0.6V across the 10Ω emitter resistor.

With most small signal transistors, you can take it as a good rule of thumb that the collector current is equal to the emitter current.

Now while this depends on factors such as the base current flow and the gain of the transistor, these factors play on a tiny part in high gain transistors such as the BC5XX and BC3XX types.

Since we have a fixed resistance and voltage determining the transistor's emitter current, we therefore have a fixed current flow through the collector as well, regardless of how small the collector load is. In practice, there is a limit to how low you can go, with the load resistance between collector and ground. But this is more to do with the power dissipated by the transistor than the excessive current flow. With the transistor turned fully on, we can assume that there is no voltage drop between the emitter and collector and that we have a maximum voltage of 8.4V at the collector.

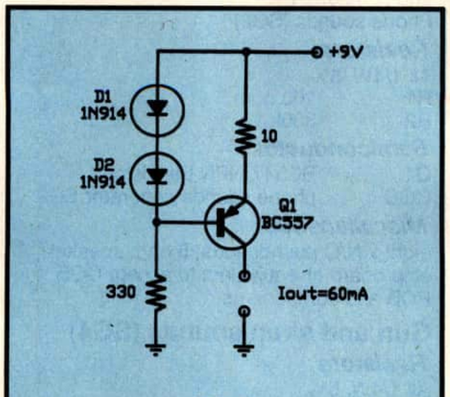

Fig.5

Now of course we can put a 1kΩ resistor between the collector and ground and the current flow will only be 8.4V/1000 or 8.4mA. But the circuit is designed to feed a constant current into a low impedance, which it does very well.

This is pretty much the only thing you need to consider when using constant current sources in basic circuits — don't load them up with too high an impedance or you'll drop too much voltage across the load, and the transistor won't be able to control the current.

An example of where this circuit can be used is as a simple NiCad battery charger. NiCad cells are best recharged using a constant current source. In fact, you could easily connect your 1.2V 'AA', 'C' or 'D' size cell between the collector and ground and it will eventually charge up. In fact, there have been quite a few projects in *Electronics Australia* that have used a circuit such as this, as the basis of a full blown multi-cell charger.

You can easily modify this circuit, particularly the amount of current the circuit can provide, by working out the following equation:

$I_{out} = 0.6V/R_x$

where Iout is the constant current in amps and Rx is the value of the emitter resistor. If we change Rx to 56 ohms, the current drops back to just over 10mA and we can now easily and safely charge up 7.2V transistor batteries. The only thing you need to worry about with a circuit as simple as this is that you don't overcharge the batteries.

A fair proportion of circuits using this approach also incorporate a timer, which automatically switches off the circuit after 15 or so hours. We will pick up this idea in a later issue.

Well, that's enough for this month. Next month, we'll continue with our look at transistor circuits with some common and some not so common designs.

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