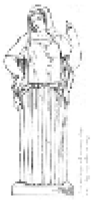
Sharron Field

- **Owner of** http://kkomp.com

-

Basic Electronic Design & Ohms' Law



This book is written with a view to teaching a few of the basics of electronic circuit design using a number of equations from or based upon Ohms' Law. It is aimed at the beginner-level student. Whilst knowledge of component function is assumed throughout, links to articles from other sources as well as kkomp.com have been included throughout in order that the reader can study and read up on the function of individual electronic components for the purpose of being able to better follow the basic tuition herein.

Electronics is such a huge subject that it is impossible to cover every aspect in the required detail in a single book. Maybe a 1.5 terabyte hard drive would be large enough to store the knowledge of the average engineer, if it were zipped and otherwise compressed.

My qualifications in electronics are fairly basic and maybe don't do my knowledge justice. However I have a City and Guilds 300 and 301 in basic electronics; analogue and digital. This qualifies me as an electronics technician; but unfortunately nowhere near the status of engineer.

The book begins by looking at the basics of Ohms' Law and goes on to design of a very basic DC inverting amplifier stage using three resistors and a transistor. I have attempted to keep the material as light as is possible, given such an intense learning curve packed into such a small space.

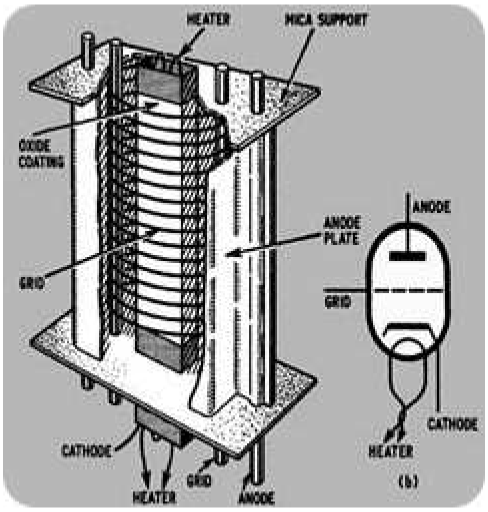
The main onus is left up to the reader, as near the end of the book I leave the reader with a conundrum to solve. The problem can be solved using only resistors, transistors, and a diode or maybe two. In solving the problem the reader will construct and solve many equations using Ohms' Law; therefore putting into practice all that they have learned herein whilst at the same time developing their skills further.

It's short and concise. There's a lot of study and knowledge packed into it, and I hope I've done the subject justice. This is my first proper e-book, and I know I've probably still got a lot to learn; but everyone has to start somewhere.

Foreword

Electronics is a vast and complicated field. There’s so much to learn, and that learning curve never stops. No matter how much you know; there’s always more to be known as new discoveries are constantly being made.

For instance; forty years ago, nobody would have thought that the recently-invented transistor would be at the centre of technological advancement. It would have been thought of a a crazy notion that over sixty million transistors could be compacted into a device with the volume of a standard matchbox that is the central processing unit of a powerful personal computer.



In those days the dominant technology was the thermionic valve or vacuum tube. The operation of these devices is, in a way, similar to that of a transistor; the problem being that high voltages are required in the associated circuitry before they will function. Also the cathode or negative electrode of every thermionic valve needs to be kept red hot, in order for the high voltage electricity to flow through the device. This required a separate low-voltage supply to power the heater, in addition to anything else.

Although it became possible eventually to incorporate up to three separate valves into a single vacuum tube; that was about the limit as far as that technology was concerned at the time.

In this book I’m not intending to describe in great detail the various functions of individual electronic components. Where this may be necessary I’ve linked to articles containing further information on this, should the reader require it.

This book is mainly about calculation used in simple circuit design, brought about by the use of basic calculus, in part using Ohms’ Law. The publication is intended to be the first in an ongoing series of books covering the basic principles of electronics and electronic circuit design. A basic knowledge of component identification and function is assumed in the reader. If this happens to not be the case then the information provided at the destination of the links incorporated within the text should be a sufficient source of knowledge.

The book that you’re now reading does not endeavour to go into digital electronics at this stage, and concentrates rather on basic analogue DC circuit principles, which should be learned as a forerunner to the discovery of digital circuitry.

Electronics is a very intense subject; and one could devote one’s entire lifetime to the furtherance of knowledge in this field. However with the rate of new discoveries now being made it is extremely unlikely that one could ever learn everything there is to know about the subject in even a very long lifetime.

This book is intended for the beginner class on levels 2 and 3. However, by utilising the links provided I feel even an absolute beginner on level 1 would be able to keep up, with much study, and maybe even progress a degree in doing so.

One thing that has been the very basis of all electronic advancement, from the days of valves up until the present day, is a set of equations known as Ohms' Law. In this book we'll be taking a look at Ohms' Law and showing how it is applicable to every aspect of electricity and electronics.

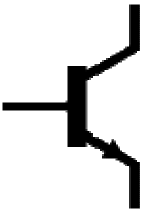
Georg Simon Ohm was born in Germany on 16th March 1789, and lived until 6 July 1854. He became a physicist, and during his career determined that there is a direct proportionality between the voltage applied across a conductor and the resultant electric current flowing in the circuit. Further experimentation meant that eventually Ohm was able to define the relationships of voltage, current, and electrical resistance.

–·–

In this book I'm going to be using circuit diagrams. For those not familiar with circuit diagrams I would suggest that you take a look at this link and/or here to familiarise yourself with some of the symbols used. You will notice that I don't always stick to the usual format in a number of cases when I'm drawing my own circuit diagrams freehand or other than on the computer itself: For instance; when I'm drawing a resistor I use a diagonal zigzag line rather than a rectangular box. Also when drawing a transistor symbol I usually omit the circle around the device.

This is for a number of purposes; the main ones being speed and neatness: If you've ever tried to draw a perfect circle without using a pair of compasses or a jar lid, you'll know just how difficult it is. The symbol inside the circle is the same and unique whichever way round one draws it. The reason for the circle is to indicate that the device is a discreet device, meaning a single device in a package; as opposed to part of a multi-transistor chip or an integrated circuit. For this article we'll just use the symbol without the circle where I've drawn the circuit diagrams myself: It's a transistor and that's it.

Standard Transistor Symbol



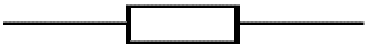
Transistor Symbol Used Herein

(The link shows only the symbols of a bipolar NPN and a PNP transistor, and also a phototransistor. There are many other types of transistor; such as the FET or Field Effect Transistor in its various different guises. (Which, incidentally, was not named after the author; Sharron Field. (Sadly.))

I commonly use a zigzag line as the symbol for a resistor; this was once the standard symbol for a resistor. It was abandoned for the sake of clarity because it looks too similar to the symbol for an inductor , the symbol of which has curves where the old resistor symbol has angles.

= This is how I draw a resistor

Whereas this is the modern standard symbol:



I personally use the old zigzag line symbol because it’s vastly easier to draw and takes less than 1/4 of the time. If I try to draw a rectangular box I end up wishing I hadn’t.

You’ll notice that a number of the circuit diagrams that I’ve included were drawn with a pen or pencil on paper and scanned in: That’s the way things are currently. I don’t at the moment have either the software to draw exclusively on the computer nor the time and patience to learn how to use it. The situation may be different in the future; but right now that’s the way things stand.

The Basic Triangle

So let’s look at the most basic bit of Ohm’s Law first; that being the relationship of Voltage to current to resistance in a DC (Direct Current) environment: -

The relationship can be expressed in an easy-to-remember format thus:

V

I R

Where V is Voltage in Volts,

I is electric current **in Amperes,**

and R is DC electrical resistance **in Ohms**

From this simple illustration we can draw the following equations: -

V / I = R

V / R = I

I x R = V

If we were to substitute the figure 1 for all of the variables we would notice that the equations are all true and equal in their most basic form: If a single Ampere flowed through a resistance of a single ohm at a voltage of a single volt it would be the point of correlation between the three measurements.

If, as happens in nearly all cases in a practical working environment, we were to increase or decrease the value to a number less than or greater than one for any or all of these variables, then that correlation vanishes; yet the equations still hold together.

Let’s look at an example on the next page: -

A current of 2 Amperes, or amps for short, is flowing through a resistance of 2 Ohms.

In this case Ohm’s law tells us that the voltage present at the point where the current exits the 2 Ohm resistor is 4 Volts; as 2 amps x 2 Ohms = 4 Volts.

Another example: –

An unspecified current is flowing through a resistance of 10 Ohms. The voltage at the point where the current exits the resistor is 5 Volts.

Ohms’ Law reveals that the unspecified current must be 5 Volts / 10 Ohms = 1/2 amp.

A third example: -

A current of 0.1 amps, or 100 milliamps, is outputting a resistor at a Voltage of 0.3 Volts, or 300 millivolts.

Ohms’ Law informs us that the resistor’s value in Ohms is 0.3 Volts / 0.1 amps = 3 Ohms.

Yes it really is that simple; at least at this stage in the proceedings.

Power

The next denomination we introduce into the mix is electrical power, represented by the letter P; and which is measured in Watts.

Here we introduce another law, that being Joule's Law, which is named after the British physicist James Joule.

Joules' Law has 2 main equations for giving the relation of power, or wattage, to the integers that we've already introduced in Ohms' Law: The following equations describe this relationship: -

$$\mathbf{P = I \times V}$$

$$\mathbf{P = V^{2}\ / I^{,}} \qquad \text{(P = V squared / square root of I)}$$

and

$$\mathbf{P = I^{2}\ R} \qquad \text{(P = I squared x R)}$$

Let's look at some examples of this: -

1) A lamp draws 1 amp of current at a voltage of 6 Volts. Joules' Law combined with Ohms' Law tells us that the lamp is burning 1 amp x 6 Volts = 6 Watts.

2) A DC circuit draws 2A of current, and has an overall resistance of 12 Ohms. Joules' Law tells us that (2 x 2) amps of current x 12 Ohms = 48 Watts.

In Circuit

So that’s the very simple bit out of the way and dealt with. let’s now take a look at connecting resistances in parallel and also in series, as well as working out the total resistance: -

There are different equations for calculating parallel and series resistances. Let’s first take a look at series resistances:

In the example above we have a circuit diagram of 2 resistances, R1 and R2, in series. To calculate the total resistance of the series pair we simply add up the sum of the values of the two resistors thus: -

Rt = R1 + R2

That was easy.

When calculating the resistance of 2 resistors in parallel, however, things are slightly more complicated. The equation for calculating the total resistance of 2 resistors in parallel is:

Rt = (R1 x R2) / (R1 + R2)

Let’s look at an example of this: -

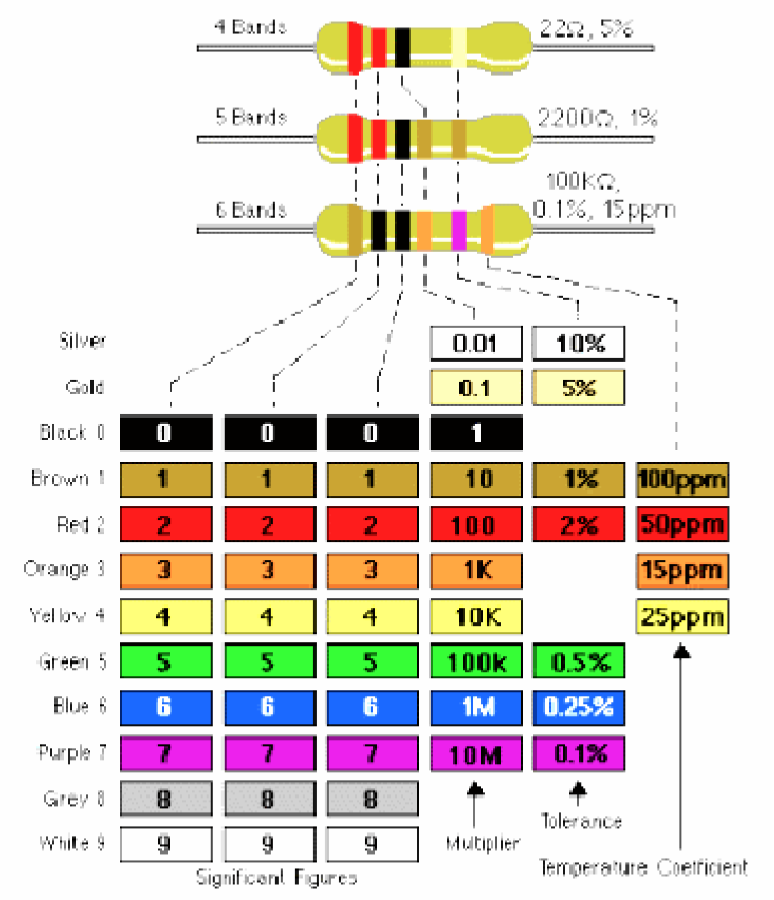
In the diagram above we have a 2,200 Ohm (2.2 kilohms) resistor connected in parallel with a 1,100 Ohm (1.1 kilohms) resistor. The total resistance is given by

Rt = (1,100 x 2,200) / (1,100 + 2,200)

Rt = 2,420,000 / 3300

Rt = 733.33 Ohms (0.73333 kilohms)

Here’s a reminder of the resistor colour code and how to read the resistance value of the component. (This code also applies to some capacitors too.) : -



Silver				0.01	10%	
Gold				0.1	5%	
Black 0	0	0	0	1		
Brown 1	1	1	1	10	1%	100ppm
Red 2	2	2	2	100	2%	50ppm
Orange 3	3	3	3	1K		15ppm
Yellow 4	4	4	4	10K		25ppm
Green 5	5	5	5	100k	0.5%	
Blue 6	6	6	6	1M	0.25%	
Purple 7	7	7	7	10M	0.1%	
Grey 8	8	8	8			
White 9	9	9	9			
	Significant Figures			Multiplier	Tolerance	Temperature Coefficient

Resistor Color Code System

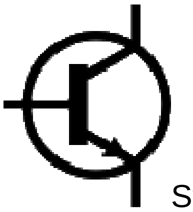
Introducing Semiconductors

In this book I’m not going to be covering any other “passive” components, such as capacitors and inductors. - I’ll save that for book 2. Right now I’d like to move on to what are termed “active components”, or semiconductors.

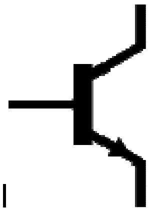
All the many types of transistor are classed as semiconductors, as are a range of components called diodes. There are also semiconductor components called thyristors which are used for DC power control, also triacs which are used in AC power control circuitry. High-current versions of these are probably utilised in the power supply of your computer, along with capacitors – large and small, resistors, diodes, power transistors, and inductors. Here we are starting to go beyond the scope of this book, however.

Herein I’d rather stick, for now, with just resistors, diodes, and a single basic type of transistor known as a bipolar transistor.

Very briefly; the diode in its raw form is a semiconductor device that only allows electricity to flow only one way through it. Click the hyperlink at the word “diode” above and discover more about it.



Standard Transistor Symbol

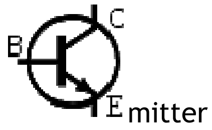


Transistor Symbol Used Herein

Yes you have seen these symbols before. They appear in the Foreword. I thought it prudent to place them here also to serve as a reminder of the point on circuit diagrammatic terminology touched upon therein, as well as to provide the circuit diagram symbol for a bipolar transistor. – No it’s not an electronic device with a mental condition. The name derives from its construction. See the link above for more information.

The bipolar transistor comes in 2 ‘flavours’; those being NPN and PNP:

NPN



PNP

The meaning of these terms is described in detail in the Wikipedia article linked to above. This book isn’t written with an intention of dealing with the construction and function of electronic components. Foreknowledge in this area is assumed. Links to locations which detail this are provided for those who need to know, however.

For the examples in this publication we’ll be using the NPN transistor.

Throughput

You will appreciate that every device has its limitations; therefore although there are expensive hi-current devices available that can handle several amps of power, most low-power, and small signal bipolar transistors can only deal with a fraction of an amp passing through them without burning out. With this fact in mind we have to ensure that the current supplied to the individual transistor will not overload it. This is accomplished by a resistor connected between the collector and the + supply rail (VS). This resistor is commonly referred to as the “collector load resistor”. the amount of current allowed by this resistor is calculated by means of Ohms’ Law:

$$I=V/R$$

The main amount of current flowing through the device passes from collector to emitter. A smaller current is also required to be applied to the base connection, usually about 0.1 times or 10% (maximum) of the larger current.

More Terminology

In electronics terminology we refer to the current flowing between collector and emitter as **Ice0**, and the current flowing between the diode junction of the emitter and base as **Ieb0**.

Similarly with respect to voltage, the terms **Vce0** and **Veb0** are used respectively.

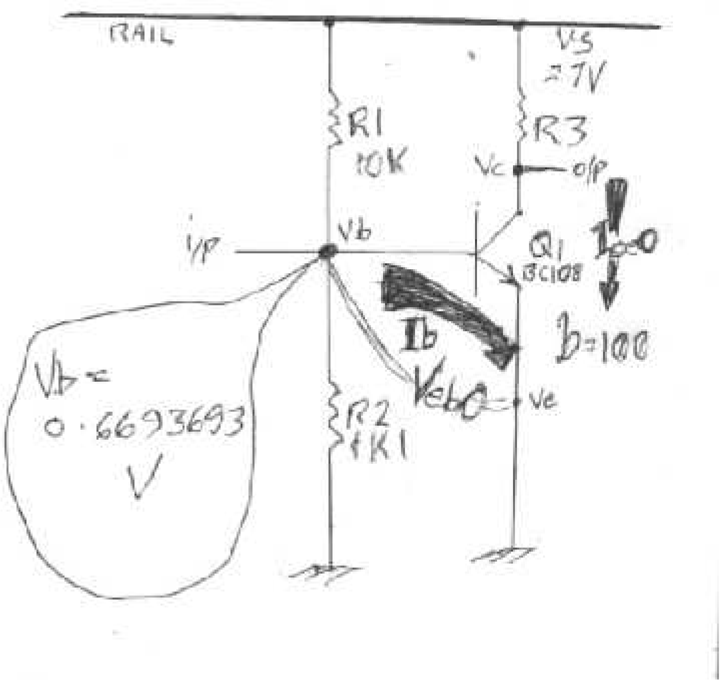
The terms **Vb**, **Vc**, and **Ve**, refer to the voltage present at the transistor's base, collector , and emitter respectively. Similarly the terms **Ib**, **Ic**, and **Ie**, refer to the current present likewise.

V+ usually refers to the supply voltage, otherwise referred to as **VS** or **Vss**.

Biasing the Base

A bipolar transistor requires a voltage of 0.7 volts present at its base before it will allow any current to pass between collector and emitter. This is known as the "***transconductance threshold***" It is for this reason, particularly where the device is used under small signal conditions such as audio amplification that the base needs to be biased with a tiny current in proportion to the input signal, to a voltage of just under 0.7 volts.

To achieve this, a pair of resistors connected in series across the supply rails is normally used as a potential divider. The resistances of each resistor are selected such that the voltage at the centre-tap to which the base is connected is just below 0.7 volts. In addition to this the resistances of the resistors are kept as high as is reasonably possible to ensure as little current as possible, and consequently as little wattage as possible, is wasted; as a potential divider will continue to burn the same amount of wattage whether or not an output is drawn from its centre point, due to it effectively being a resistance connected across the supply rails.



In the example above we use a 10 kilohm resistor as R1 and a 1.1 kilohm resistor as R2. The supply voltage, VS, is 7 volts.

To calculate the voltage at the centre tap between the two resistors, to which the transistor's base is connected, therefore the base voltage (**Vb**), we use the following equation:

Vb = VS X (R2 / R1 + R2)

Therefore in this example: -

Vb = 7 X (1100 / (10000 + 1100))

Vb = 7 X (1100 / 11100)

Vb = 7 X (11 / 111)

Vb = 7 X 0.099099

Vb = 0.6693693V

- Which puts the transistor right at the edge of the threshold of transconductance. A voltage of over 31 millivolts will flip the device over into transconductance and a proportionally equivalent current will flow between collector and emitter.

Beta

No this doesn't refer to a test-version of a new computer program: The beta of a transistor is the quantity giving the amplification factor of that transistor. There are two ways of looking at this; in-circuit and out-of-circuit.

Out-of-circuit, as a standalone unused component, a given type of transistor has a maximum beta rating that it can be run at in-circuit. This can vary from around 20 or less for some power-transistors, to up to 1500 or more for some hi-gain amplifier transistors.

Setting the beta of a transistor in-circuit is another part of circuit design.

The in-circuit beta of a given transistor can be calculated by the proportion of Ib when Vb is above the transconductance threshold to the amount of current represented as Ice0. (Unless the transistor is connected in-circuit as a voltage amplifier rather than a current amplifier; in which case the beta is calculated by replacing the term Ib with Vb and Ice0 with Vce0. That is beyond the scope of this book, so we'll stick to the current amplifier model for now.)

For example; let's assume that we have a transistor connected in circuit with a base voltage of 0.75 volts (Vb = 0V75), therefore biasing it into transconductance. The base current is set at 1 milliamp (1mA). The supply voltage (VS) is 10 volts, and the collector load resistor is 100 ohms:

Ic (collector current) = V / R

Ic = 10 / 100

Ic = 0.1A (100mA)

The in-circuit beta of that transistor can then be given as:

b = Ic / Ib

b = 100 / 1

b = 100

Provided that this doesn’t exceed the transistor’s out-of-circuit beta rating it’s perfectly safe to run the transistor at this beta and expect its amplification factor to be 100 X.

(In most cases, though, such a large amplification factor in a single-transistor amplifier stage would give rise to signal distortion; especially in high-frequency

AC amplifiers. For DC amplifiers such as we’re dealing with here, though, this beta rating is OK and won’t cause any distortion as there’s effectively nothing to distort in this example.)

Let’s sum up and take a look at an example of what we’re trying to achieve here:

In the circuit above we’re using the potential divider we mentioned earlier:

R1 = 10K and R2 = 1K1

That’s great with a supply voltage of 7V as it biases the base just below the transconductance threshold as we saw earlier.

- But we haven’t yet worked out Ib in this case. How do we do that? well the total current flowing in the potential divider will be:

VS / (R1 + R2)

7 / 11100 in other words; which equates to 0.00063A, or 63 microamps. That’s pretty low but it’s OK. If we want to run the transistor at a beta of 100 then we’ll need to make the collector load resistor allow 63 X 100 microamps to flow as Ice0.

So we want to arrive at a scenario where Ice0 = 6.3 mA.

We know just how to do that using Ohms’ Law: -

If Ice0 = 6.3 mA and V=7 volts, then V / I = R:

7 / 0.0063 = 1111.1111 ohms

- Is the value of resistor that we’re looking for. We look in the spares box and find that the nearest value of resistor that we have is 1100 ohms (1K1). only 11.1111 ohms out; which will make very little difference except that the beta will be a fraction over 100. That’s good enough. – So we choose 1K1 as the value for the collector load resistor.

Another Stage?

That's it then: We've designed a DC inverting amplifier with a beta of 100 (+/-1%) using a single transistor and 3 resistors.

For clarity here's a parts list: -

Transistor:

Q1: BC108C (I chose this one as its quite ideal for the purpose.)

Resistors:

R1: 1K1 1/8Watt

R2: 10K 1/8 watt

R3: 1K1 1/8 watt

If we were to apply a current of 1mV to the base, then the collector current (Ic) would drop by 100 mV. That's a very basic medium-high gain inverting amplification stage we've just designed. Give yourself a pat on the back – That's quite an achievement if you started this book without much, if any, idea of circuit design.

What's meant by an **inverting** amplification stage? Well basically the input is the opposite of the output: When the input voltage is zero the output voltage is equal to the supply rail voltage, and whatever voltage is applied to the input, the output drops by a factor proportional to the amplifier's beta.

For instance; if a DC voltage of 41mV was applied to the base of the transistor in this circuit, then the output would drop by 1.0 volts; from 7v to 6v. That means that if 101mV (0.101V) was applied to the input at the transistor's base, the output at the transistor's collector would drop from 7v to zero. – that's a pretty sensitive circuit we've designed there. - But we want to design a non-inverting amplifier; one where if we apply 101mV to the input then the output rises from zero volts to 7 volts.

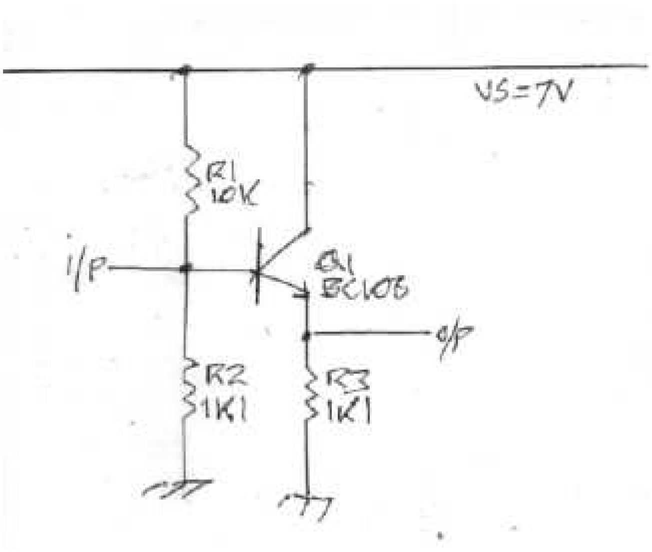
Why does it behave like this?

When there is no input, the transistor if switched off and current flows unopposed through R3 to the output. (Remember; a resistor gives resistance to current, not voltage; so although the collector *current* is regulated by R3, the voltage remains unchanged.) – Therefore the output is at 7v. As the input voltage rises and the transistor begins to switch on and allow current to flow through it to ground, the voltage at its collector falls proportionally.

We could take resistor R3 out of the collector circuit and connect it between the transistor's emitter and ground, taking the output from the emitter. That would work fine. - Then as the transistor begins to switch on the voltage at its emitter would rise from zero volts proportionally; but R3 as an emitter-load resistor would never allow the output voltage to rise as far as the 7 volts we require. Remember the transistor's 0v7 transconductance threshold? That would affect the output so that it would never be able to rise above 6v3. What we need is some more circuitry added to what we've designed so far. Let's get designing:

We can modify our existing circuit by adding an output stage to it: -

We have a condition at the output of our device we just designed where the output is at 7v with no input. The output drops by 0.1v with every millivolt above 31 mV applied to the input. Let’s ignore the 31mV for the time being, for the sake of simplicity. – But that idea of taking the output from the emitter can be used. First we’ll redesign the circuit: -



We’re now taking the output from the emitter. This type of circuit is called an “**emitter-follower**” for seemingly obvious reasons. We now design a second stage for this circuit to correct the error; or should I say **YOU** now design it.

“But I’m no circuit designer!”

You know enough now to solve the problem.

‘Your Turn

It’s tricky, but it can be done using only what you’ve already learned herein and by clicking on the links provided. You can use as many resistors and transistors as you wish, but remember, in the interests of cost efficiency you need to keep the number of components used as low as you can. If you manage to solve the problem using 64 transistors and 184 resistors then well done for solving it; but that’s far too many components. Keep the component-count low but keep trying.

I ask two further things: The first is that you don’t modify the original emitter-follower circuit in any way. You can connect *to* it at any point you choose; however you **must** take the output from the emitter and you cannot change either the existing circuit configuration or the component values. You also cannot change the supply voltage.

Good luck. You can refer to any electronics teaching media that you wish to use. However – here’s the second thing I ask of you – you cannot ask an electronics engineer or technician to solve the problem for you. This is your project. A qualified engineer will have no problem with it; but a qualified engineer doesn’t need to learn how to do it. Hopefully by the time you’ve solved it you’ll have learned how to do everything I’ve shown you off by heart and with ease.

All the information you need is written above; but you can use whatever other media you wish. If you want to learn then this is a worthy project. if not then I hope you’ve found what you’ve learned edifying.

If you happen to be a bit unsure of component function then click the links provided again and study the material. Several months’ basic electronics tuition has been crammed into this book to this point. It would be unrealistic to expect anyone to grasp it all in one reading; even if they did click every link and study the information there in full.

After – word

So you've decided you want to be an electronics engineer? Good choice. I'm not the one to teach you though: I'm only qualified as a technician. I am qualified to teach you the basics, though; and that's a start if nothing else.

I'm trying to limit what I teach herein to what I'm qualified to teach. What I *know* is more than I'm trained to know. Whilst I'm not up to engineer's status in knowledge, I do have perhaps a bit more know-how than the average technician. Had I qualified at a higher level I could teach more and feel comfortable in doing so.

The engineer's course is 4 years long. I studied the equivalent of 2 years ('Just over a years' *intensive* training.) for my technician's qualification. (City & Guilds 300, 301.)

I've deliberately not tried to make this book "pretty" or to give it extra appeal. What you see is what you get. Electronics is a cold hard emotionless science: There's a lot of maths involved; on a much higher level than this book has delved. (Bode plots and Nyquist diagrams included.) What you see is the beginnings of elementary calculus and an opportunity to dip your toe into using Ohms' Law for real. If this book's whetted your appetite for more then you're probably a natural to at least a certain extent. I suggest you glean as much of the elementary basics as you can from this book; following which you continue your studies both online and offline.

Keep your eye on http://kkomp.com for any electronics titbits that I throw out to my readers. Take a home study course, night school, even go for it and take an electronics engineer's degree if you like. This book only covers a few of the basics: I've barely touched on capacitors and inductors, mentioned diodes and some other components, and I've only once or twice mentioned digital electronics. - With its logic gates, pulse-triggered flip-flops, Schmitt triggers...

The material herein has barely scratched the surface of analogue electronics. There’s so much to learn; and you’ve hardly begun.

If you’re intent on learning more, or even becoming qualified in electronics, then I wish you the very best of luck. If you found this heavy going and decided that the subject’s not for you then thank you for reading and for purchasing this book. At least you now have some idea of a subject that you don’t want to pursue any further. I hope you gained some enlightenment from your reading.

Whatever you choose to do; I hope you get the very best from it. My thanks go to everyone who has helped me to gain my knowledge in whatever way; no matter how small or large. My thanks also go out to my online tutors in the fields of blogging and online marketing. – Particularly Yaro Starak, Gideon Shalwick, and David Risley; without whose help and encouragement I’d probably be running an unknown blog with little or no readership, and would never have gained the incentive to produce this book to share this with you. – This book might have in turn prompted you to take up another career path, or maybe just another hobby. Maybe you found it all too much and jumped to the end rather than tearing your hair out. Whatever the case I can’t take all the credit. That also means that I have to share any discredit too, which lightens the burden a bit. :-)

Thanks once again for reading. May success and enlightenment be yours, and may you learn much as you attempt to solve the problem posed.

Sharron Field is the owner and main author of http://kkomp.com :

-Taking **YOU** *Beyond* the comfort zone.-

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