Choosing Components: Part 1

INTRODUCTION

Electronic components are specified by their parameters. A parameter is some property of the component that has a numerical value, and describes one feature of the component's performance. The values of a given component's parameters are found in the manufacturer's data sheet and are usually called the "specs" (specifications).

For instance, the following is a partial list of specs for a resistor:

- tolerance: 5%, 1%, 0.1%, etc.
- wattage: 1/4 W, 1/2 W, 1 W, etc.
- material: carbon film, metal film, wire-wound, etc.
- temperature range: commercial (0 to 70 degrees C), military (-55 to 125 degrees C) , etc.
- temperature coefficient (tempco): given as percent/degree or ppm/degree
- physical dimensions: length, diameter, etc.
- form-factor: axial leads, radial leads, etc.
- MTBF (mean-time-before-failure): hours
- price: always a consideration

If something as simple as a resistor has that many specs, you can imagine how many a transistor or integrated circuit must have. The obvious question is: How do you choose a part? The answer is two-fold. First, know what specs a component has. Second, know which specs are important for your application.

The first part, knowing what specs a component has, is the easy one. For something as common as a resistor, you can find the information in an introductory text book. For any component, the best source of information is the manufacturer's data sheet. It used to be that you had to get the data sheets as hard-copy, often in the form of a data book. Now you can almost always go to a manufacturer's WEB site and download the data sheets.

It's the second part, knowing which specs are important for your application, that takes some analysis. A good source for this purpose are the application notes (ap-notes) that most component manufacturers supply, and which also can be found at the WEB site.

WHAT IS IMPORTANT

How do you know what's important? The answer is to understand what it is you're trying to do. If you understand what role a component plays in your design, you can identify most of the key parameters immediately. A few may not be obvious, but can usually be recognized when you test your breadboard.

For example, suppose you are building a "quick and dirty" 5-Volt power supply to use on your bench, and it uses an LED to indicate when it is on. You need to choose a resistor to limit the current in the LED. So what specs are important for that resistor? Well, certainly the value and wattage are important. But since you just want to see whether the LED is on or off, the tolerance of the resistor is not going to be critical. The worst tolerance you can find on a resistor is 20%, and that would be adequate. So a common 5% resistor will work fine.

Let's look at some of the other resistor specs:

- **Material:** since this is not a demanding application for a resistor, choose the most common, and lowest cost, device. That would be carbon film.
- **Temperature Range:** the supply is going to be on your bench, not in a tank. So you don't need a military temperature range, the commercial range is sufficient.
- **Tempco:** since the tolerance wasn't important in this application, then the drift in value due to temperature won't be an issue since it will have less impact than the tolerance.
- **Physical Dimensions:** once you have chosen the material, the size is mostly determined by the power rating.
- **Form-factor:** again, choose the most common, lowest cost, version: axial leads.
- **MTBF:** not a concern in this application. If the proper wattage is used, even common resistors are very reliable.

Some parameters, such as size and wattage, are interrelated. Higher wattage resistors are going to be physically bigger than lower wattage resistors of the same type. But a 2 Watt wire-wound resistor may be smaller than a 1 Watt carbon film resistor. Also, the dimensions of a 100 Ohm, 1/2 Watt carbon resistor will depend on whether it has radial leads or axial leads, or is a surface mounted device with no leads.

Some parameters depend on production considerations. We said to use a resistor with axial leads for that LED. The assumption was that your design was for a "one-off" project you're building by hand. If you were designing a commercial product for high-speed, high-volume production, then you would use a surface mount device. Why? Because high-speed, high-volume production is done by machines which can use surface-mount components more efficiently.

IDENTIFYING KEY PARAMETERS

The first step in choosing a device is to decide which parameters are crucial and which parameters are not. For the resistor example above, wattage was crucial but tolerance was not. We decided that by knowing what role that resistor had to play in the design. Now let's look at something more complicated than a resistor for an LED. Let's look at a bipolar junction transistor (BJT). If you have an Adobe reader, you can see a typical transistor data sheet at:

To be able to view this document, your free copy of Acrobat Reader software from the Adobe site.

Of all the parameters on a transistor data sheet, how do you identify the key parameters for your application? You do it by analyzing two things: first, what does this transistor do in the design, and second, what parameters relate to that job. While you know the role you want the transistor to play, components sometimes interact in ways that we didn't anticipate. So it is necessary to analyze just what the transistor is actually doing.

As for knowing how the specs relate to performance, look for those parameters that are expressed in the same terms, or units of measure, as the key role of the transistor. Start with the obvious things: the maximums for voltage, current, and power. Then move on to other parameters that are crucial to the application.

For example, suppose you want to use a transistor as a switch: either on or off ***(see Figure 1)***. When it is on, the transistor will conduct the most current through its collector. So you need to look at the spec for maximum collector current (MAX IC) which will be in Amps or milliAmps. When it is off, the transistor will have the maximum voltage at the collector. So you need to look at the spec for maximum collector voltage, sometimes called 'breakdown' voltage. You will find two maximum voltage specs on the data sheet: one for collector-to-emitter (VCE or VCEO) and one for collector-to-base (VCB or VCBO). Use the lesser of the two values.

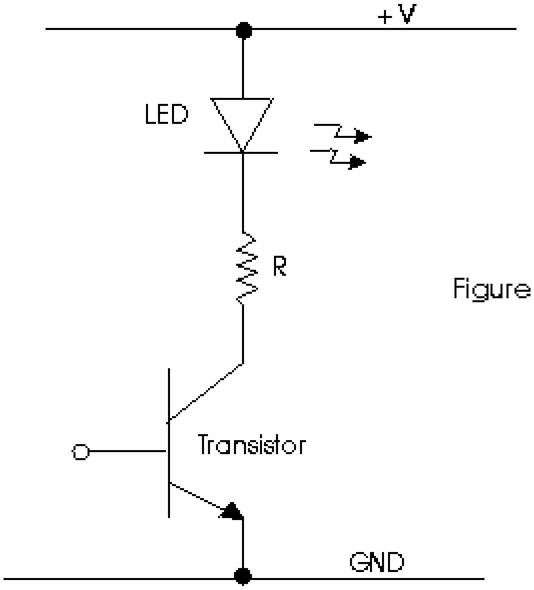


Figure 1

Consider speed. If you are using the transistor to switch an indicator LED on and off, then speed is not important. But if you are using the transistor to switch an LED in a fiber-optic data transmission circuit, then speed is important and you need to look for parameters measured in units of time (microseconds or nanoseconds). Remember that frequency is the inverse of time, so parameters measured in Hertz may also be important.

Suppose you are interested in speed. So you look on a transistor data sheet and find the following four parameters: delay time td , rise time tr , storage time ts , and fall time tf all specified in nanoseconds. You also find something called fT given in megaHertz. If you know what they mean then you can determine if they are suitable for the application. If you don't know what they mean then you've got some homework to do, but at least you what to look for. You can then refer to a textbook, the manufacturer's application notes (ap-notes), or use a search engine on the Internet to find what you need.

WHAT'S NOT SO IMPORTANT

For some parameters, the exact value is not important as long as it satisfies some minimum requirement. One such parameter is the current gain of a BJT, called hFE or beta. Transistors with the same part number can have values of beta that span a range of 3-to-1 or more. What's more, the value of beta can change with temperature and even can change with collector current.

The way to deal with beta is to design the circuit both to work with the lowest expected value, and also to be insensitive to changes in value. For example, just about any BJT will have a beta greater than 20, so you could always take that as your minimum value. If the circuit is designed properly, then it will work with beta equal to 20, 50, 100, or higher.

DERATING

The term 'derating' is often used to refer to the practice of using a component with a higher rating than is actually required. This is commonly done with the maximum ratings for voltage, current, and power dissipation. Voltage, current, and power are 'stressors' that have a strong influence on failure rate (MTBF). The more stress, the sooner the failure.

A derating factor of 2 is commonly used. For example, suppose you determine that a transistor in your design must withstand 50 Volts maximum collector to emitter voltage, 100 mA maximum of collector current, and dissipate 500 milliWatts of power. If possible, you should choose a device with a MAX VCE of at least 100 Volts, a MAX IC of at least 200 mA and a maximum power dissipation of at least 1 Watt.

KNOWLEDGE AND EXPERIENCE

If all your projects come straight out of a 'cookbook', then all you need to pick the right components is a catalog. But if you are modifying a circuit, of designing your own circuit 'from scratch', then you will need to be familiar with the parameters of common components. One way to do that is by reading textbooks, application notes, and data sheets. But it is also necessary to build your designs and test them out.

Don't feel that you need to have analyzed every possible aspect of your design before you can build a breadboard or prototype. And don't feel that if a breadboard circuit doesn't work perfectly the first time that you've 'failed'. We usually learn more from our mistakes then we do from our successes. The purpose of a breadboard is to help you identify the key areas in your design by allowing you to make measurements on the actual components. You'll find that with experience you will get your designs up and running more quickly.

WHAT'S NEXT

In later parts of this series of Tech Tips we will look at some specific circuits and identify the key parameters of each component. We will look at tracking symptoms back to the problem part. And along the way, you should be able to see common themes in design, and to become more familiar with device parameters.

Choosing Components Part 2:

Audio Amplifier Basics

AUDIO AMPLIFIERS

Once upon a time, if you were designing an electronic system and you needed an audio amplifier, you had to design it yourself. Today you would most likely choose an "off-the-shelf" integrated circuit "gain block". It's usually easier to select an amplifier than to design it from scratch. But to select an IC amplifier, you need to know which specifications are important to your application. Otherwise, you must pick a part at random and hope it does the job; the "plug-and-chug" approach.

SO, WHAT'S TO KNOW?

As you would expect from reading Part 1 of this series, an audio amplifier has many parameters which characterize its performance. The question is which specifications are critical to your application and which ones are not. To answer that question you need to know three things: 1) how you want the amplifier to perform in your design, 2) which parameters determine that performance, and 3) what the values need to be for those parameters.

There is more to say about audio amplifiers than will fit in one article, so we there will be several Tech Tips on this subject. In the following paragraphs we will discuss some key concepts needed to understand amplifier specifications and relate them to performance.

GAIN

The gain of an amplifier is the ratio of the output signal to the input signal. There are three categories of gain: voltage gain (Av), current gain (Ai) and power gain (Ap). Any amplifier has a value for all three gains, but typically you must specify just one of them. Depending on the application, Av and Ai may be expressed as a simple ratio or as the log (base 10) of the ratio:

EQ-1: $Av = \frac{Vout}{Vin}$ or EQ-2: $Av = 20 \text{ Log } \frac{Vout}{Vin}$

When using the log of the ratio, the result is referred to as dB. Strictly speaking, dB actually refers to the log of the power gain:

$$\text{EQ-3: dB} = 10\ \mathrm{Log}\ \frac{Pout}{Pin} = 10\ \mathrm{Log}\ \frac{(Vout)(Vout)/Rout}{(Vin)(Vin)\ /\ Rin} = 10\ \mathrm{Log}\ \frac{Rin}{Rout} + 20\ \mathrm{Log}\ \frac{Vout}{Vin}$$

But having Av expressed as a logarithm is very useful, and referring to it as dB is part of the culture.

BANDWIDTH AND FREQUENCY

The bandwidth (BW) of an amplifier is the range of frequencies, from lowest to highest, over which the amplifier delivers sufficient gain. The meaning of "sufficient" depends on your application, but one common meaning is when the gain (20 Log Av) has dropped by 3dB. IC amplifiers of the "op-amp" variety (operational amplifiers) will work from DC up to some frequency, the "break-point", where gain has dropped by 3dB. Amplifiers which amplify DC as well as AC are said to be "direct-coupled".

How much bandwidth does an audio amplifier need? It depends on what you mean by "audio". In a telephone circuit, 300 Hz to 3300 Hz is adequate bandwidth. In high-fidelity audio, 20 Hz to 20 kHz would be required. In some applications, 100 kHz is considered to be an "audio" frequency. Amplifiers are called audio amplifiers to distinguish them from either DC amplifiers used in instrumentation applications and from high-frequency (1 MHz and up) amplifiers used in radio frequency (RF) applications.

GBW

Amplifiers have a property referred to as the "gain-bandwidth product" or GBW. The GBW of a given amplifier is a constant. If you set the amplifier to a gain of Av (ratio, not dB), then the bandwidth is given by:

$$\text{EQ-4:}\quad BW = GBW\ /\ Av$$

For example, suppose the GBW is 100,000. At a gain of 10, the amplifier will have a bandwidth of 10,000 Hertz. At a gain of 100, the amplifier will have a bandwidth of only 1000 Hertz.

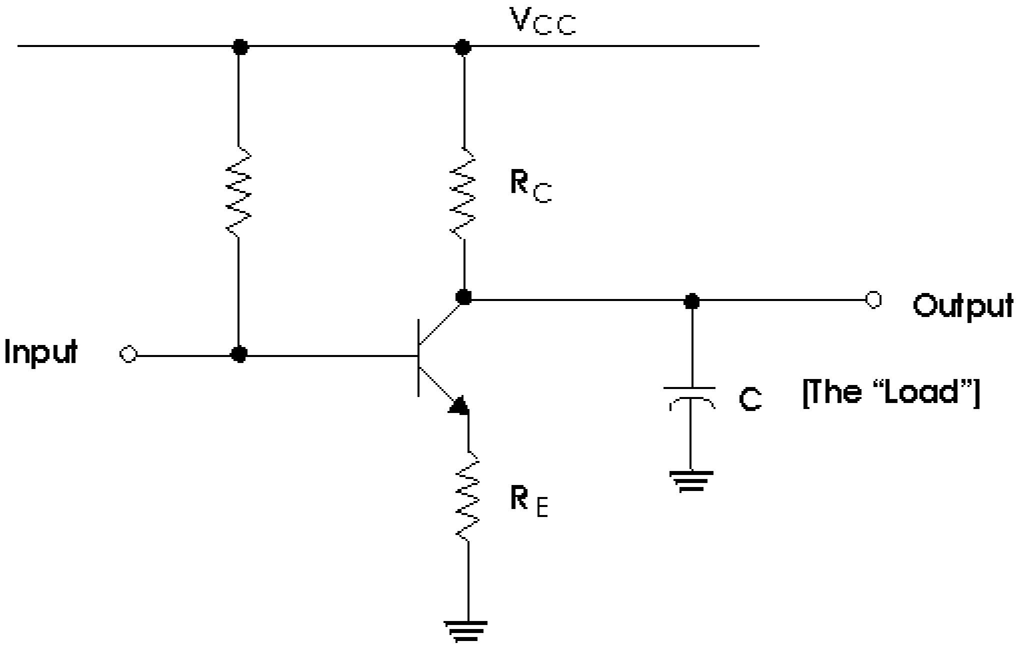


Figure 1

Look at the simple one-transistor amplifier in *Figure 1*. The gain of the circuit is given by equation EQ-5 while the bandwidth is given by equation EQ-6.

EQ-5: $$Av = \frac{Rc}{Re}$$

EQ-6: $$BW = \frac{1}{2 * PI * Rc * C}$$

EQ-7: $$GBW = \frac{1}{2 * PI * Re}$$

The GBW is found by multiplying Av by BW to get equation EQ-7. Note that EQ-7 says that GBW is independent of Rc. So if we raise the gain by increasing Rc, we also lower the bandwidth. Why don't we just lower C? Because C is the capacitance of what ever the amplifier is "driving", we are stuck with it. Then why don't we just lower Re to increase GBW? The answer is in the next section.

TRADE-OFFS: SPEED and POWER

GBW is an example of a "trade-off". A trade-off occurs when making one thing "better" makes another thing "worse". In designing electronic circuits there are always various trade-offs to be made. GBW is a trade-off between gain and bandwidth. Speed and power-dissipation is another trade-off. When designing an amplifier, it may be possible to increase the GBW (the "speed") if you are willing to have it "run hotter" by dissipating more power.

Let's look again at the circuit in ***Figure 1***. Suppose we lower Re to increase the GBW, but we want to keep the same gain. Then we must also lower Rc. In amplifiers such as figure 1, the average (DC) voltage across Rc is approximately half the supply voltage. So the power (P) dissipated in Rc is

EQ-8: $$P = \frac{V * V}{R} = \frac{(Vcc / 2) * (Vcc / 2)}{Rc} = \frac{Vcc * Vcc}{4 * Rc}$$

Note that the smaller Rc is, the more power is dissipated in it. So if Re and Rc are both lowered proportionately, we will get an increased GBW but at the cost of more power being dissipated by the circuit. The same analysis would apply to a digital circuit as well.

BODE PLOTS

A Bode Plot is a graph showing how gain and bandwidth are related in an amplifier. It is very useful, and is very commonly found in books and magazine articles on electronics. A typical Bode Plot is shown in ***Figure 2***.

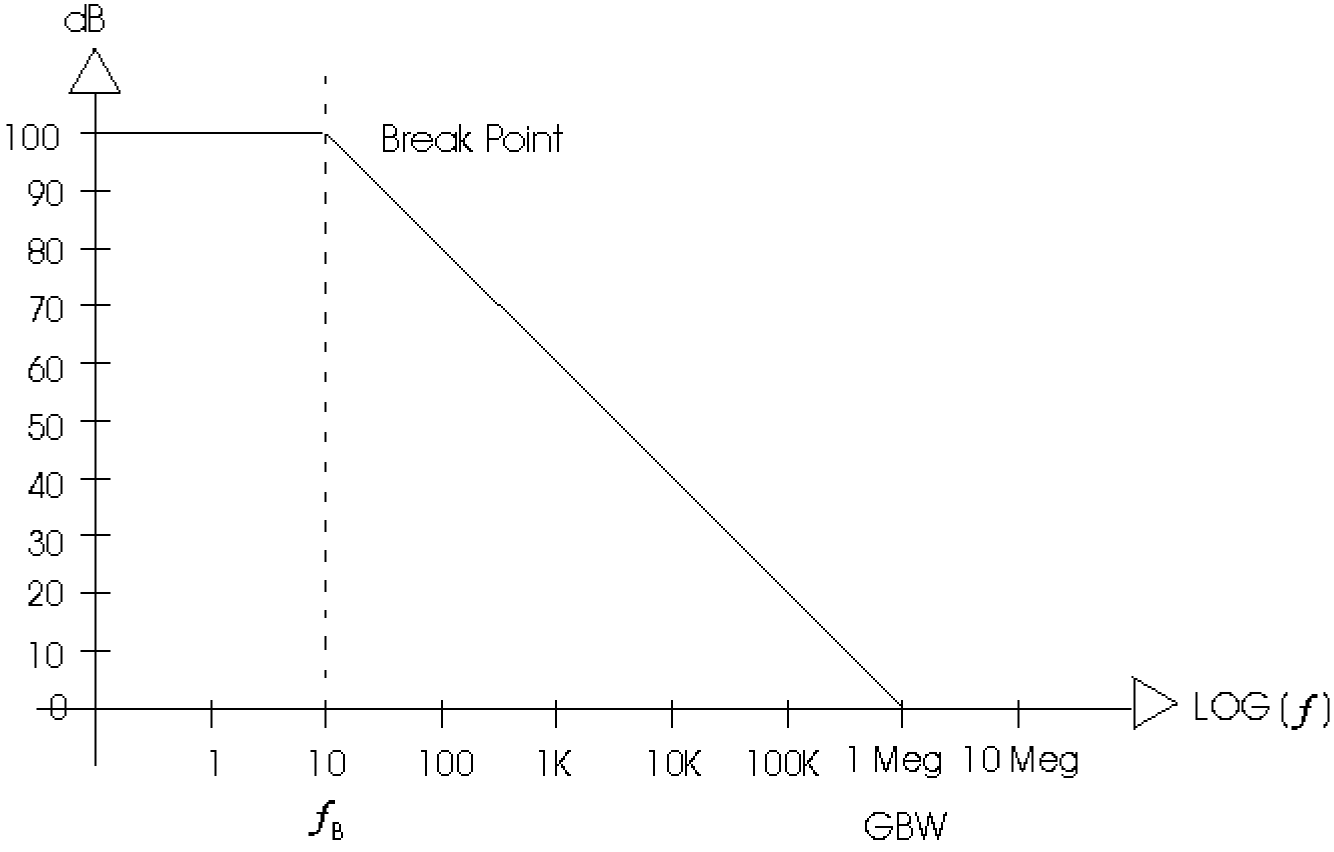


Figure 2

The vertical axis (Y-axis) is in dB. Remember that when dealing with amplifiers, dB is defined by equation EQ-2 given above. The horizontal axis (X-axis) is the Log of the frequency, so each mark on the horizontal axis represents a frequency 10 times higher than the previous mark. The distance from one mark to another, from f to 10f, is called a "decade". The distance from f to 2f is called an "octave".

BREAK-POINT, ROLL-OFF, AND FEEDBACK

Figure 2 shows the maximum voltage gain (Av) of an amplifier as a function of frequency. There are two important things to see on the graph. First is the "break-point" which occurs at the "break-frequency" fB. Av is constant until the break-point. The second thing is that after fB, Av starts to "roll off" at a constant rate of 20 dB per decade. The point where the graph crosses through the horizontal axis is the GBW. A roll-off of 20dB / dec is typical of many amplifiers.

Figure 2 shows that the amplifier starts out with a gain of 100 dB, which is a gain of 100,000. That's more gain than you need for most applications. So high-gain amplifiers in general, and op-amps in particular, use "negative feedback" to reduce the gain to a usable level. A total discussion of negative feedback is beyond the scope of this article. We will just say that negative feedback takes some of the output signal and connects it back to the input in such a way that the signal fed back subtracts from the input. The effect is to cause the amplifier to operate at a lower value of gain while the GBW stays the same. With no feedback, the amplifier is said to be "open-loop". With negative feedback, it is said to be "closed-loop".

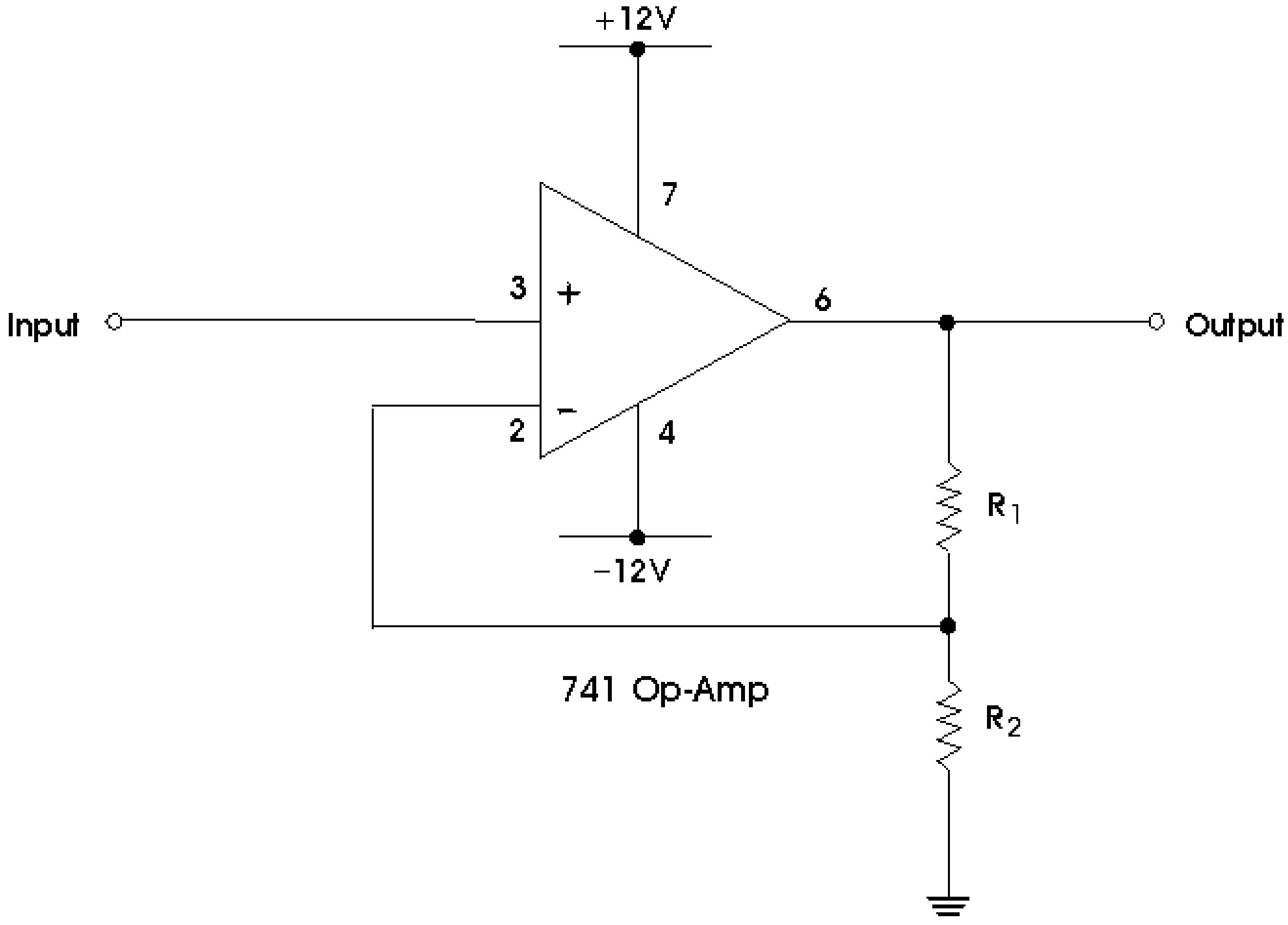


Figure 3

Figure 3 shows a 741 op-amp (an oldie but a goodie) in a closed-loop circuit. The gain is given by the equation:

EQ-9: $Av = 1 + R1 / R2$

Figure 4 shows how the Bode plot for the 741 has been changed by configuring it for a closed-loop gain of 10. Note that the usable bandwidth is much greater than the original fB.

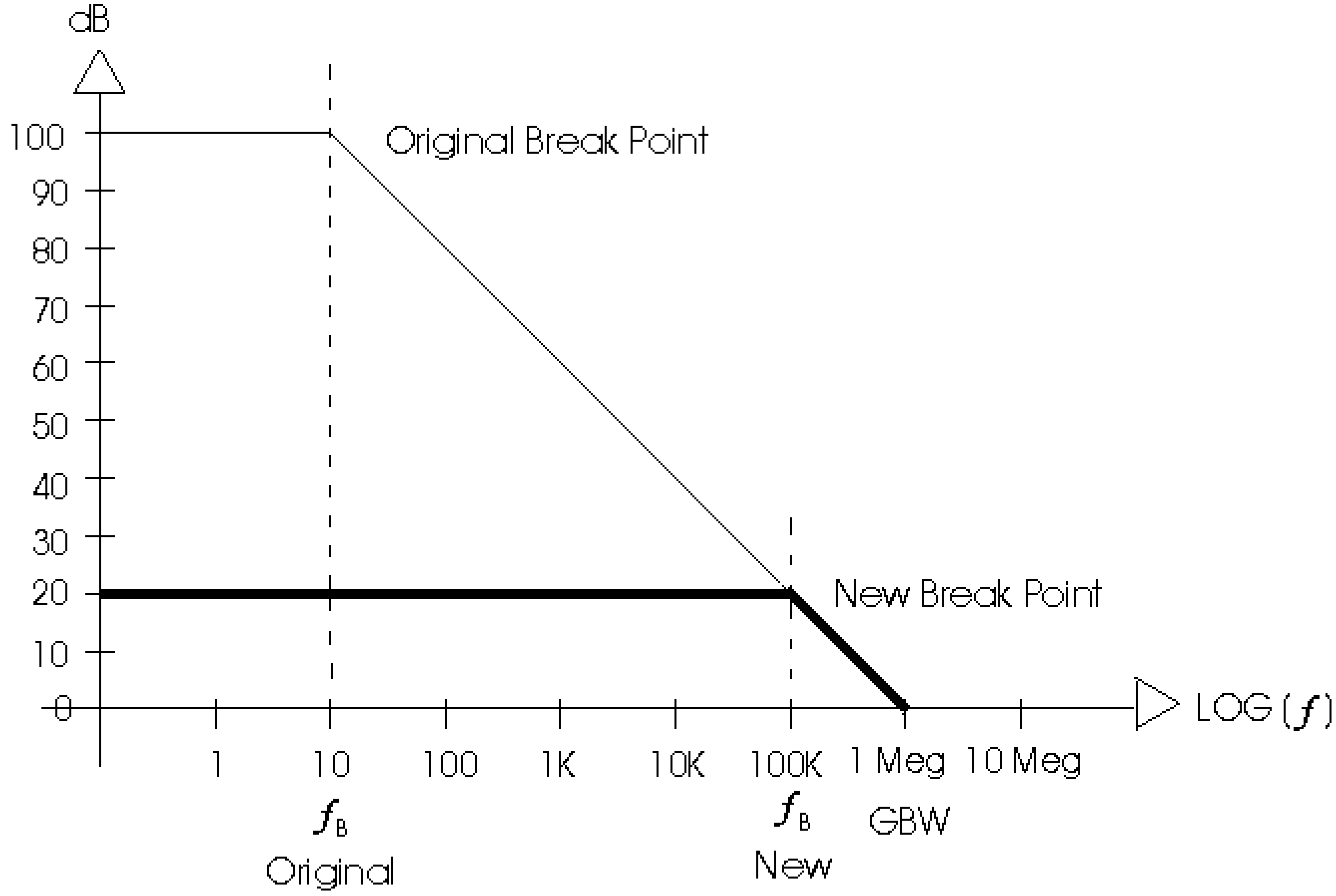


Figure 4

WRAP-UP

Connectors

INTRODUCTION

In electronics, connectors are one of those things we tend to take for granted. They're just something hanging off the end of a cable so we can plug and unplug power or signals on some circuit. So what's there to think about connectors? The answer is "plenty"!

Besides the obvious, such as having the right number of pins, there are several things to consider when choosing a connector:

- **Cost**: Nobody wants to spend more than they have to. But using the cheapest connector you can find may not, in the end, be cost effective if it fails to do its job.

- **Ruggedness**: Is it going to be plugged and unplugged once a year, or ten times a day?
- **Environment**: Will it be exposed to the weather, such as on an outdoors antenna? How about salt water, such as on a boat? Will it be subject to vibration, such as on a machine? Is someone likely to step on it?
- **Signals Type**: Is it for power and ground? For analog or digital signals? If analog, what frequency? Is it audio or RF? If digital, what clock speed or bit rate?
- **Power Level**: If it's for power, is it for 24 Volts? Or 240 Volts? Or 2,400 Volts? Will it carry 0.25 Amps? Or 2.5 Amps? Or 25 Amps? Higher currents require larger, thicker pins. Higher voltages require more insulation.
- **Signal Level**: Is it for 2 Volt signals or 2 microVolt signals? Will the current be 5 milliAmps or 5 microAmps? Connectors used for very low signal levels (so-called "dry circuits") often have gold plated pins.
- **Second Sources**: Is it a standard type of connector available from many manufacturers, or is it available only from one company?

TYPES OF CONNECTORS

If you've been around electronic equipment for any length of time, then you know there are many types of connectors. Here, in no particular order, are some of the common ones:

Power Connectors

Figure 1 shows a common type of 115 VAC receptacle used to connect the power cord to things such as personal computers and test equipment.

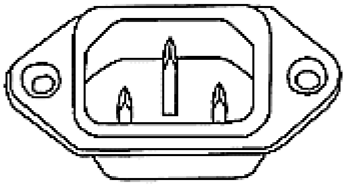
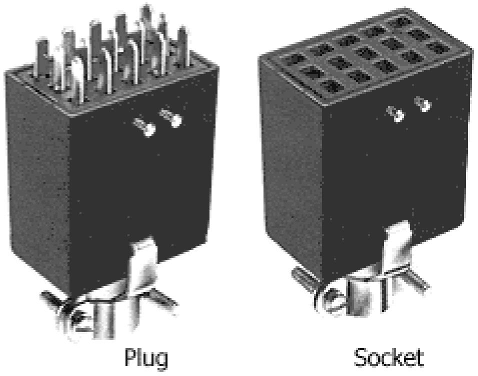


Figure 1

Figure 2 shows a "Jones" or "Cinch-Jones" connector. These have been around for decades, and are used in applications such as supplying power to a DC motor.



Plug

Socket

Figure 2

Audio Connectors

Like the Jones connectors, most of these have been around for decades. *Figure 3* shows what is commonly called an "RCA" plug and jack. They are two-conductor connectors typically used with shielded cable. They are used in applications such as connecting microphones and small speakers to audio amplifiers.

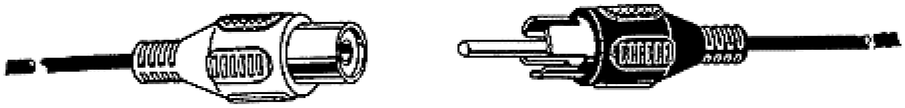


Figure 3

Figure 4 shows a "phone" (old telephone type) or "phono" plug and jack. They can be two or three conductor connectors used for one (mono) or two (stereo) audio signals carried on a shielded cable. There are several other types of connectors used for audio signals.

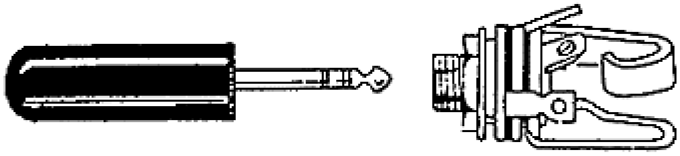


Figure 4

Modular (Telephone) Connectors These are used with UTP (unshielded twisted pair) cables. ***Figure 5*** shows an RJ11 connector commonly used with 4-wire telephone cables. An RJ12 connector is the same size but used with 6-wire cable. ***Figure 6*** shows an RJ45 connector used with 8-wire local area network (LAN) cables.

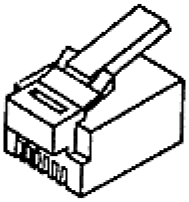


Figure 5

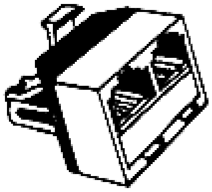


Figure 6

BNC and UHF Connectors

Figure 7 shows a BNC cable commonly used with shielded cable, such as RG58, carrying RF signals. Exactly what BNC stands for is unclear, but most people think the B is for bayonet because of the way the connector locks on to the receptacle. BNC connectors are common on electronics test equipment such as oscilloscopes.

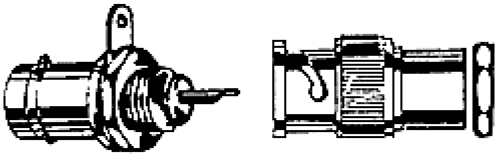


Figure 7

Figure 8 shows a UHF connector (UHF stands for Ultra High Frequency). Like the BNC connector, it is used on coaxial cables carrying RF signals. It can be used on thicker cable such as RG8. A UHF connector is threaded to screw onto the receptacle.

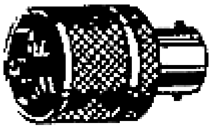


Figure 8

D-Shell Connectors

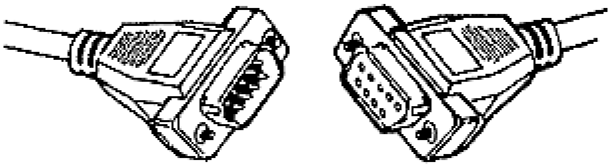


Figure 9A

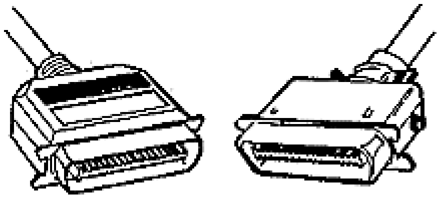


Figure 9B

Figure 9A shows a DB9 connector. *Figure 9B* shows a so-called Centronics connector commonly used for the printer port of a PC.

Edge Connector

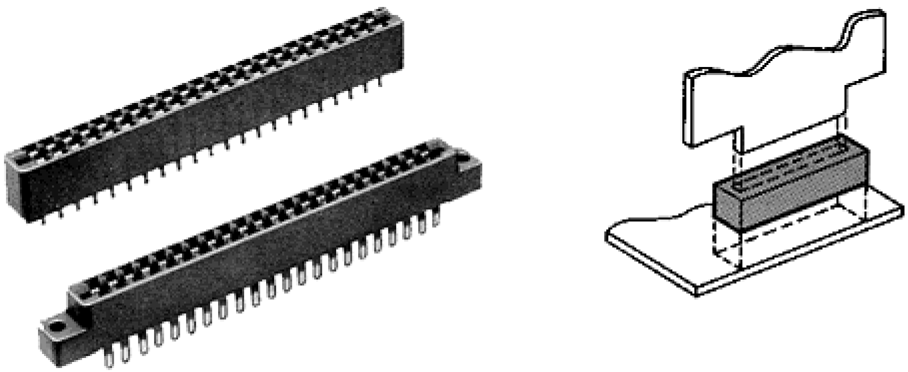


Figure 10

Figure 10 show a typical connector used to connect to copper traces on the edge of a removable circuit board.

Insulation Displacement Connectors (IDCs)

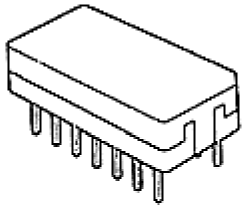


Figure 11A


Figure 11B

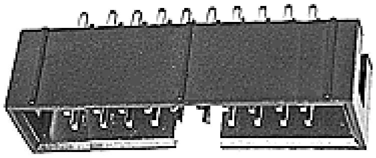


Figure 11C

Figure 11 shows the types of connectors used with ribbon cables. *Figure 11A* is a "DIP" connector, which can plug into a standard IC DIP socket. The connector of *Figure 11B* mates a "header", which has pins on 0.1" centers and is common on circuit boards. The connector of *Figure 11C* is a "shrouded" header.

Contact Bounce and De-Bouncing

The Definition

Push-button switches, toggle switches, and electro-mechanical relays all have one thing in common: contacts.

It's the metal contacts that make and break the circuit and carry the current in switches and relays. Because they are metal, contacts have mass. And since at least one of the contacts is on a movable strip of metal, it has springiness. Since contacts are designed to open and close quickly, there is little resistance (damping) to their movement.

Because the moving contacts have mass and springiness with low damping they will be "bouncy" as they make and break. That is, when a normally open (N.O.) pair of contacts is closed, the contacts will come together and bounce off each other several times before finally coming to rest in a closed position. The effect is called "contact bounce" or, in a switch, "switch bounce" ***See Figure 1.*** Note that contacts can bounce on opening as well as on closing.

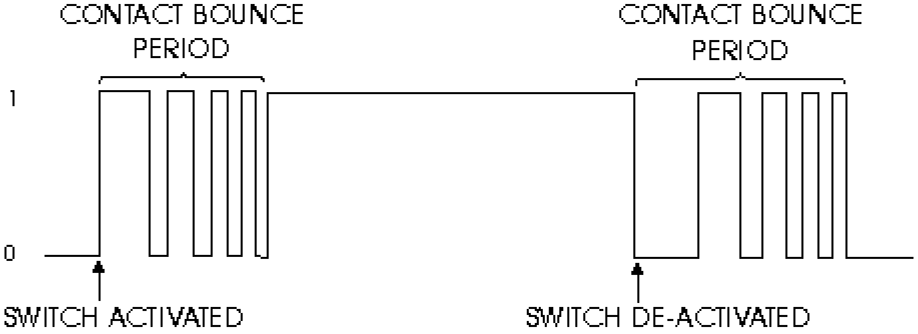


Figure 1

The Problem

If all you want your switch or relay to do is turn on a lamp or start a fan motor, then contact bounce is not a problem. But if you are using a switch or relay as input to a digital counter, a personal computer, or a micro-processor based piece of equipment, then you must consider contact bounce. The reason for concern is that the time it takes for contacts to stop bouncing is measured in milliseconds. Digital circuits can respond in microseconds.

As an example, suppose you want to count widgets as they go by on a conveyor belt. You could set up a sensitive switch and a digital counter so that as the widgets go by they activate the switch and increment the counter. But what you might see is that the first widget produces a count of 47, the second widget causes a count of 113, and so forth. What's going on? The answer is you're not counting widgets, you're counting how many times the contacts bounced each time the switch is activated!

The Solution

There are several ways to solve the problem of contact bounce (that is, to "de-bounce" the input signal). Often the easiest way is to simply get a piece of equipment that is designed to accept "bouncy" input. In the widget example above, you can buy special digital counters that are designed to accept switch input signals. They do the de-bouncing internally. If that is not an option, then you will have to do the debouncing yourself using either hardware or software.

Using Hardware

A simple hardware debounce circuit for a momentary N.O. push-button switch is show in ***Figure 2***. As you can see, it uses an RC time constant to swamp out the bounce. If you multiply the resistance value by the capacitance value you get the RC time constant. You pick R and C so that RC is longer than the expected bounce time. An RC value of about 0.1 seconds is typical. Note the use of a buffer after the switch to produce a sharp high-to-low transition. And remember that the time delay also means that you have to wait before you push the switch again. If you press it again too soon it will not generate another signal

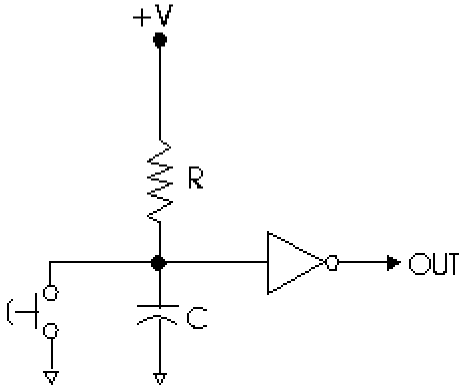


Figure 2

Another hardware approach is shown in *Figure 3.* It uses a cross-coupled latch made from a pair of nand gates. You can also use an SR (sometimes called an SC) flip flop. The advantage of using a latch is that you get a clean debounce without a delay limitation. it will respond as fast as the contacts can open and close. Note that the circuit requires both normally open and normally closed contacts. In a switch, that arrangement is called "double throw". In a relay, that arrangement is called "Form C".

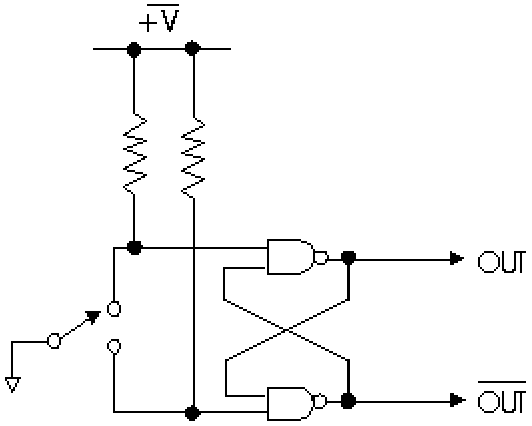


Figure 3

Using Software

If you're the one developing the digital "box", then you can debounce in software. Usually, the switch or relay connected to the computer will generate an interrupt when the contacts are activated. The interrupt will cause a subroutine (interrupt service routine) to be called. A typical debounce routine is given below in a sort of generic assembly language.

```
DR:     PUSH    PSW    ;  SAVE PROGRAM STATUS WORD
LOOP:    CALL    DELAY   ;  WAIT A FIXED TIME PERIOD
       IN      SWITCH  ;  READ SWITCH
       CMP     ACTIVE  ;  IS IT STILL ACTIVATED?
```

```
JT      LOOP    ;  IF TRUE, JUMP BACK

CALL     DELAY   ;
POP      PSW     ;  RESTORE PROGRAM STATUS
EI               ;  RE-ENABLE INTERRUPTS
RETI             ;  RETURN BACK TO MAIN PROGRAM
```

The idea is that as soon as the switch is activated the Debounce Routine (DR) is called. The DR calls another subroutine called DELAY which just kills time long enough to allow the contacts to stop bouncing. At that point the DR checks to see if the contacts are still activated (maybe the user kept a finger on the switch). If so, the DR waits for the contacts to clear. If the contacts are clear, DR calls DELAY one more time to allow for bounce on contact-release before finishing.

A debounce routine must be tuned to your application; the one above may not work for everything. Also, the programmer should be aware that switches and relays can lose some of their springiness as they age. That can cause the time it takes for contacts to stop bouncing to increase with time. So the debounce code that worked fine when the keyboard was new might not work a year or two later. Consult the switch manufacturer for data on worst-case bounce times.

Making Electrical Measurements Part 1

The Fundamentals

In electronics, the fundamental physical property is charge. Charged particles, such as electrons and protons, interact with each other over time and distance by exchanging discrete bundles of energy called photons. It is the ebb and flow of photons that gives rise to electro-magnetic phenomenon such as light and radio waves. It is our ability to control and use electro-magnetism that lets us build all our wonderful gadgets.

Physicists have worked out elegant mathematical structures to describe electro-magnetic fields in time and space. For the most part, we do not deal directly with such fields in the equipment and circuits we work on every day. Instead, we deal with them one step removed by working with voltages and currents. Roughly speaking, you can think of voltage as corresponding to the electric field and current as corresponding to the magnetic field.

Making Measurements

To measure a quantity such as voltage or current, we must make that quantity interact with an instrument in such a way that the instrument changes in a way that we can sense.

For example, ***Figure 1*** shows an old-fashioned meter-movement for measuring current. The current flows through the coil of the meter and creates a magnetic field proportional to the current.

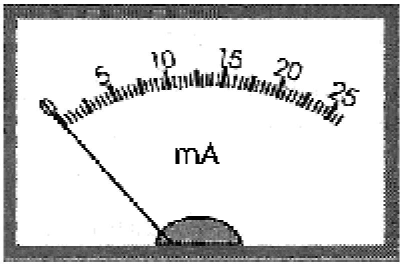


Figure 1

The magnetic field attracts an iron pointer which is held back by a spring. The more current, the more magnetic "pull", and the more the pointer moves.

Modern digital meters work on a completely different principle, but they still involve using the voltage or current you are measuring to do something to the meter which causes a change.

The Limitation of Measurements

The fact that the quantity being measured must interact with the instrument making the measurement implies that we change the value of the thing we are measuring by the very act of measuring it. In other words, there is always a limitation on how accurately we can measure voltage or current. There will always be some error, or uncertainty, in the numbers we get from our instruments and meters.

For most of the measurements we make every day, a small error is not important. For example, if the 5-volt power supply is actually 5.001 volts, it will not make a difference to our computer. However, it is good to keep in mind that there are limits to accuracy. Think of it as "noise".

Accuracy as a Percentage

The accuracy of an instrument is often stated as a percentage. For example, a voltmeter may be specified as 1% accurate. An important question is: 1% of what? Is it 1% of the reading or 1% of the "full-scale"?

Suppose you have a meter which reads voltages in the range of 0 to 100 volts. Then the full-scale value is 100 volts. Now suppose you use that meter to measure an unknown voltage, Vx, and it reads 50 volts.

If the accuracy of your meter is ±2% of the reading, then the actual voltage is somewhere between 49 volts and 51 volts since 2% of 50 volts is 1 volt.

On the other hand, if the accuracy is ±2% of full-scale (or f.s.) then the actual voltage is somewhere between 48 volts and 52 volts since 2% of 100 volts is 2 volts.

Accuracy is often given as percentage of full-scale, which means you should use the lowest scale you can to make the measurement. Suppose a 5% voltmeter has two ranges, 0-10 volts and 0 to 20 volts. If you want to measure a 9-volt battery then you should use the 10-volt scale since 5% of 10 volts is 0.5 volts while 5% of 20 volts is 1.0 volts.

Digital Meters: That Last Digit

Digital meters are often compared by the number of digits they can display. For example, a 2-digit meter can display values from 00 to 99 while a 3-digit meter can display values from 000 to 999. Suppose you have a 2-digit voltmeter that reads 0 to 99 volts. Effectively it has a full-scale capability of 100 volts. Suppose you use it to measure a voltage with a value of 50.5 volts. What will the meter read? The only choices are 50 or 51, so either way there will be an error. That fact about digital meters is expressed by saying that all readings are plus or minus a count of one.

Digital Meters: Accuracy vs. Resolution

The fact that the reading on a digital meter is always uncertain by a count of 1, either up or down, defines the resolution of the meter. Resolution is the smallest change an instrument can measure (or "resolve"), so in a digital instrument it is the last bit: +/- a count of 1.

Like accuracy, resolution can be expressed as a percentage. A 2-digit meter has 1% resolution (1 count out of 99) while a 3-digit meter has 0.1% resolution (1 count out of 999). However, resolution is not accuracy. A 3-digit meter has 0.1% resolution buy may only have 0.5% f.s. accuracy. Read the specifications of the meter carefully: it is usually the case that the resolution is better than the accuracy.

Extra Resolution

In a digital meter, it is relatively easy to increase resolution by adding another digit. It is more difficult to make that extra digit accurate. Even if the last digit on a meter is not accurate, there are times when that extra resolution is useful.

For example, in radio circuits, you sometimes have to "tune-for-a-dip", meaning you adjust the frequency until you hit resonance as indicated by the amplifier current going to minimum (not zero) value. The exact value is not as important as the fact that it is minimum. Look at the table below which shows actual values compared to measured values.

Freq.	Actual Current (mA)	Measured Current (mA)
f1	16.99	16.88
f2	16.96	16.85
f3	16.93	16.82
f4	16.91	16.80
f5	16.94	16.83
f6	16.97	16.86

A 3-digit meter, even if it was accurate, would not let you see the minimum at f4 since it would read 16.8 for f3, f4 and f5.

For the extra resolution to be useful, as in the above example, it is necessary that it "do the right thing". That is, as the actual value increases, the measured value increases and as the actual value decreases, the measured value decreases. Such "doing the right thing" is referred to as being monotonic. If you do not have monotonicity, the extra resolution is useless.

Making Electrical Measurements Part 2: Loading

Meter Loading

When making a measurement with a volt-meter, an oscilloscope, or any type of electronic measurement equipment, it is important to understand the concept of *loading* if you want to be sure your readings are accurate.

For example, suppose I use a volt-meter to measure the DC voltage at the output of a voltage-divider as shown in ***Figure 1,*** and I get a reading of 4 Volts. Assuming my meter is working properly, am I sure it's a good reading? Well, that depends on two things: the values of the resistors in the circuit, and the input impedance of the meter. In order to see what's going on, I need to look at the Thevenin's Equivalent Circuit for the voltage divider

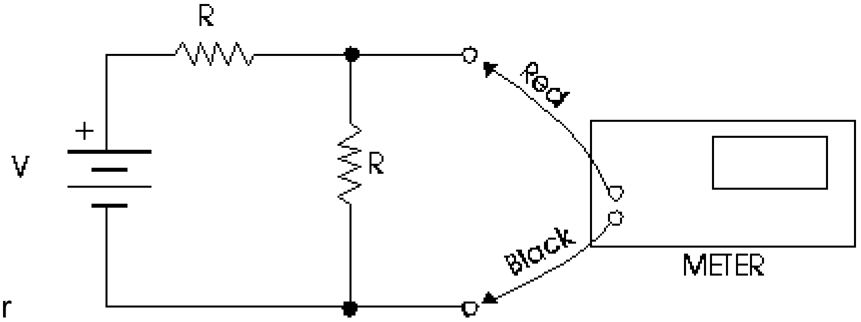


Figure 1

If you're not familiar with a Thevenin's Equivalent, it can be found in any book on circuit analysis. Basically, it's a single voltage (Vth) in series with a single resistor (Rth) as shown in ***Figure 2.*** The voltage (Thevenin's Voltage) is what you would measure with a perfect volt-meter. The resistance (Thevenin's Resistance) is found from R = E/I where E is the Thevenin's Voltage and I is the current you would get if you were to short-circuit the output to ground

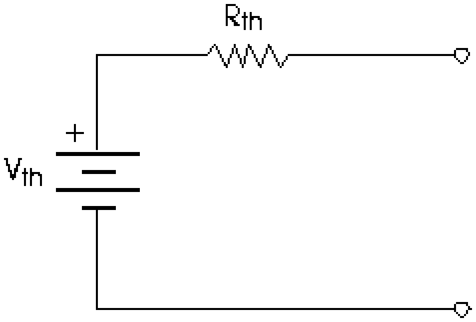


Figure 2

For the voltage divider I'm trying to measure, since both resistors are equal, Vth would be V/2 and Rth would be R/2. ***Figure 3*** shows my meter as a resistor connected to the Thevenin's Equivalent of the voltage divider. Note that the input impedance of the meter looks like a resistor forming another divider. So the voltage across the leads of my meter is *not* Vth as you might expect, but is a value I can calculate as:

$$Vm = \frac{Rin}{Rin + Rth} \times Vth$$

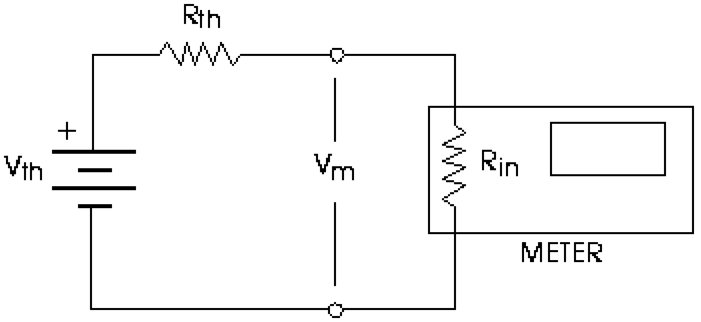


Figure 3

Now suppose that V is 12 Volts and R is 2k Ohms. Then Vth will be 6 Volts and Rth will be 1k Ohm. Suppose that Rin of the meter is 10 Meg-Ohms. Using the above equation I get:

$$Vm = \frac{10{,}000k}{10{,}000k + 1k} \times 6 \text{ Volts} = 5.9994 \text{ Volts}$$

Which, on a typical 3-digit meter, will read 6.00 volts. No problem since that's the right reading.

But what if R in the divider is 2 Meg-Ohms. Then Rth is 1 Meg-Ohm and the equation will give:

$$Vm = \frac{10{,}000k}{11{,}000k} \times 6 \text{ Volts} = 5.4545 \text{ Volts}$$

Which, on a typical 3-digit meter, will read 5.45 Volts. Now I have a problem. The reading is wrong because the meter *loaded-down* the circuit I was trying to measure. If R was 20 Meg-Ohms it would be even worse!

What can I do to solve the problem? A few things. First, I can see if I can get a meter with a higher input impedance. Second, I can use a X10 probe if there is one for my meter (see Tech Tip on X10 probes). If all else fails, I can use a little math. If I know the input impedance of my meter and the Rth of the circuit I'm trying to measure, then I can correct my readings as follows:

$$\text{True Voltage} = \text{Measured Voltage} \times \frac{Rin + Rth}{Rin}$$

If you are using a digital multimeter to measure voltage, then the input impedance is typically high (say, 10 Meg), and the same value for all input ranges. But if you are using an old-fashioned VOM, then the input impedance depends on the range the meter is set to. For instance, if the VOM is rated at 10k Ohms per volt and is on the 0 - 50 Volt range, then Rin is 10k x 50 or 500k Ohms. But on the 0

- 5 Volt range Rin will only be 10k x 5 or 50k Ohms. Typical ratings for VOMs are 1 k Ohm per Volt at the low end to 20k Ohms per Volt at the high end.

But what if I don't know the input impedance of my meter, or if there is no way to calculate Rth. Can I find out if I have a loading problem? Yes, by running a little test. Measure the voltage with your meter. Then put a 100 K resistor in series with the red lead of the meter and measure the voltage again. If the readings change significantly, then you may have a problem.

So know the input impedances of all your measurement equipment. You'll find it on the specifications page in your user's manual. And have some idea of the internal resistances in the circuits you are measuring. Then you won't be fooled by loading. In later technical tips we will look at other factors that affect the accuracy of your measurements.

Making Electrical Measurements Part 3: Testing Diodes and Transistors

BACKGROUND

One of the nice things about solid-state devices is that, under normal conditions, they rarely go bad. However, "rarely" is not the same as "never". And if conditions are not "normal", if an excessive voltage gets to a semiconductor, it can be damaged. In this article we will discuss how to test for a damaged transistor or diode.

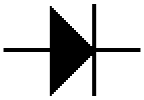
Device testing can be done at two levels: functional and parametric. A functional test determines whether or not the device works well enough for the intended use. A parametric test measures all device parameters to see if they meet the specified values. In the production of semiconductor devices, it is often the case that functional testing is done on all units while parametric testing is done on a small percentage of the units as test samples.

For the most part, the performance of semiconductor devices does not deteriorate gradually over a period of time. Typically, transistors and diodes work well up to the point where they stop working completely, so all we will need to do is make a few simple functional tests.

TESTING SILICON DIODES (NOT LED OR ZENER)

To test a silicon diode such as a 1N914 or a 1N4001 all you need is an ohm-meter. If you are using an analog VOM type meter, set the meter to one of the lower ohms scales, say 0-2K, and measure the resistance of the diode both ways. If you get zero both ways, the diode is shorted. If you get INFINITY both ways, the diode is open. If you get INFINITY one way but some reading the other way (the value is not important) then the diode is good.

If you use a digital multi-meter (DMM), then there should be a special setting on the Ohms range for testing diodes. Often the setting is marked with a diode symbol



Measure the diode resistance both ways. One way the meter should indicate an open circuit. The other way you should get a reading (often a reading around 600). That indicates the diode is good. If you measure an open circuit both ways, the diode is open. If you measure low resistance both ways, the diode is shorted.

TESTING DIODES IN CIRCUIT

The procedures described above assume the diode under test is not part of any circuit. If you are trying to test a diode that is on a circuit board or otherwise connected to other components, then you should disconnect one end of the diode. On a circuit board you can unsolder one end of the diode and lift it off the board. Make sure that you first disconnect all power going to the circuit before you disconnect the diode. After disconnecting one end, proceed as described above.

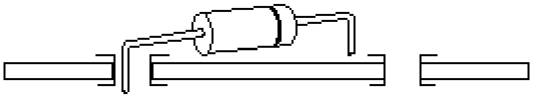


Figure 1

KNOW POLARITY OF YOUR METER

When set to measure resistance, both VOMs and DMMs apply voltage to the test leads. You should know which lead is positive. Don't assume the red lead is positive, it may not be. Use another meter set to measure DC volts on, say, the 20V scale and determine which lead of your Ohm-meter is positive.

Another way is to take a diode you know is good and find which way you need to put the leads to get an Ohms reading. At that point, the positive lead is on the anode and negative lead is on the cathode (cathode is the banded end.)

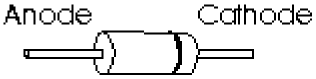


Figure 2

One reason to know the polarity of your meter is so you can determine which end of a diode is the cathode if the band has been removed. Also, as we will see below, you can use your Ohm-meter to tell an NPN transistor from a PNP if you know which meter lead is positive.

TESTING ZENERS

If you just want to know if a Zener diode has opened-up or shorted-out, then just test it as described above for standard diodes. if you want to measure its Zener voltage level, you will have to build a circuit as shown in *Figure 3.*

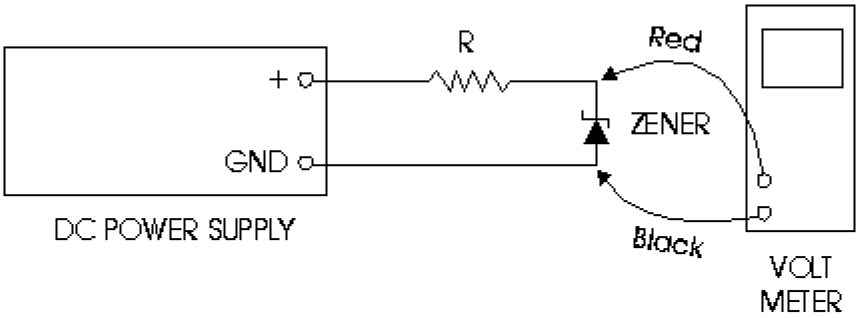


Figure 3

The power supply voltage should be set to a value slightly higher than the Zener value. For example, for a 12 volt diode, the supply voltage should be about 15 volts. The value of the resistor R should limit the current to about a milliAmp. For example, using 15 volts with a 12 volt Zener, use a 3.3K resistor. The exact value is not critical.

Once the circuit is built, just read the Zener voltage off the meter (if you read 0.6 volts, reverse the diode). **NOTE:** Any diode will become a Zener diode if you apply enough voltage to it.

TESTING LEDS

LEDs have a larger voltage-drop across them than regular diodes. Depending on the LED, the drop can be between 1.5 to 2.5 volts. If you have a DMM with a diode setting on the Ohms scale (see above), then you may be able to test an LED as you test a standard diode. The difference will be that the meter will read 1600 or 50 when the diode conducts instead of the 600 you read on a silicon diode.

If you can't use your multi-meter, then build the circuit shown in ***Figure 4*** and see if the LED light up.

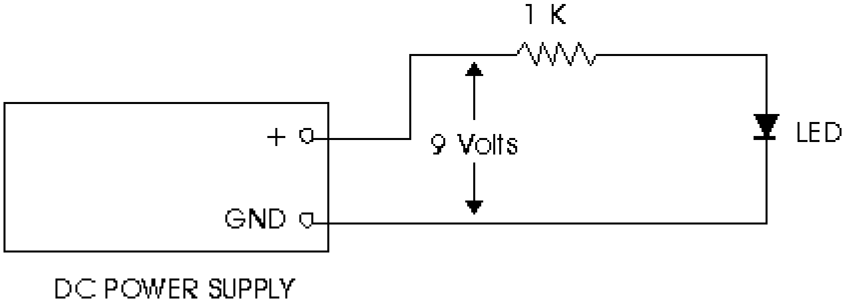


Figure 4

If the LED doesn't light, reverse polarity on the diode. If it still doesn't light, it's bad. (See ***Figure 4).***

TESTING ZENERS AND LEDS IN CIRCUIT

To test a Zener or an LED while it is in a circuit, you just need a volt-meter.

For a Zener, just measure the voltage across it. Using a VOM or a battery-operated DMM, put the black lead on the anode and the red lead on the cathode. You should read the Zener voltage. If you read zero volts, the Zener is shorted or the resistor feeding the Zener is open or not getting voltage. if you read a value higher than the Zener voltage, the Zener is open.

For an LED that is supposed to be lit but isn't, use a VOM or battery-operated DMM to measure the voltage across it. If you measure more than 3 volts or so, the LED is open.

TRANSISTORS

As with diodes, it is usually the case that a transistor either works or it doesn't. So again we will be able to make a few simple tests with a meter to see if a transistor is good or bad.

You can think of a transistor as two back-to-back diodes in one package as shown in ***Figure 5.***

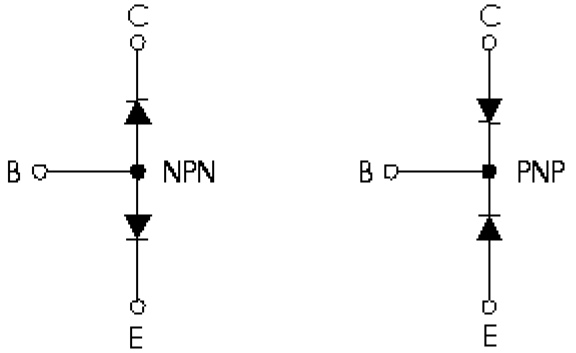


Figure 5

Note that transistors come in two basic types: NPN and PNP. The letters C, B, E stand for COLLECTOR, BASE, EMITTER which are the names of the three leads which come out of a transistor.

Transistors come in many different case styles, three of which are shown in ***Figure 6.*** It is important to know where C, B, E are for any given case.

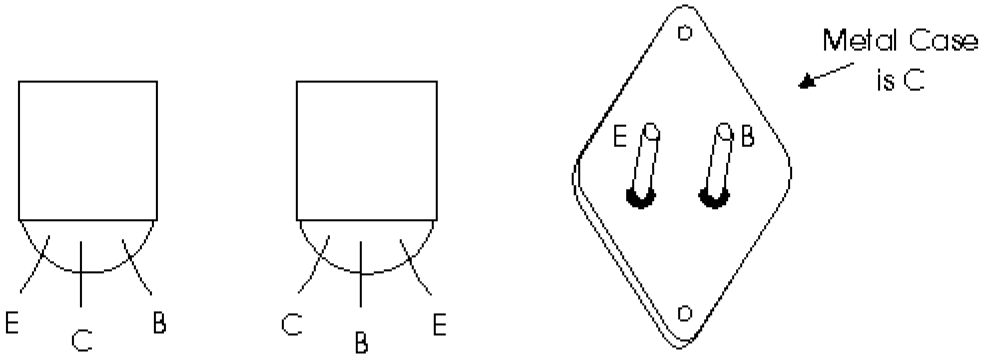


Figure 6

TESTING TRANSISTORS

Assuming you know if the transistor is NPN or PNP, and assuming you know where B, C, and E are, then just test the B-C junction and the B-E junction as if they were standard diodes. if one of those junctions is a "bad diode", then the transistor is bad.

Also, check the resistance from C to E using a higher Ohms scale (say, the 2 Meg scale). Be sure your fingers don't touch the metal test points or you will just measure your skin resistance.

If the transistor is good, you should get an open-circuit reading from collector to emitter. NOTE: the above assumes silicon. With germanium transistors you may measure a high resistance from C to E.

USING METER TO SEPARATE NPN FROM PNP

If you have a transistor but you don't know if it is NPN or PNP, then you can find out which it is using your Ohm-meter if you know which lead of your meter is positive.

Assuming you know where C, B, and E are on the transistor, do the following. Connect the positive lead of your Ohm-meter to the base. Touch the other lead of your meter to the collector. If you get a reading, the transistor is NPN. To verify, move the lead from the collector to the emitter and you should still get a reading.

If your meter reads open-circuit, then connect the negative lead to the base and touch the positive lead to the collector. If you get a reading, then the transistor is PNP. Verify by measuring from base to emitter.

THINGS TO WATCH FOR

Some transistors have diodes from collector to emitter built into them. They will not read open-circuit when measuring resistance between C and E.

Some transistors have resistors from base to emitter built into them. They will read that resistance when measuring Ohms B to E.

Some transistors are Darlingtons. They have a higher reading base to emitter which may appear as an open on a VOM.

CHECKING TRANSISTORS IN CIRCUIT

With power disconnected from the circuit, you can try some of the above measurements on transistors that are in the circuit. However, your readings can be deceptive due to resistors and other components in the circuit. You can try disconnecting the base lead from the circuit before making measurements. Be sure to reconnect it after testing.

Keypads

HOW THEY ARE BUILT

A keypad, with 12 or 16 keys, is one of the most commonly used input devices in microprocessor applications. The telephone keypad shown below in ***Figure 1*** is a typical example. Like most such keypads, it is wired as an X-Y switch matrix as shown in ***Figure 2***. The normally-open switches connect a row to a column when pressed. Note that the resistors are not part of the keypad. Because this keypad has 12 keys, it is wired as 3 columns by 4 rows. A 16 key pad would have 4 columns by 4 rows.

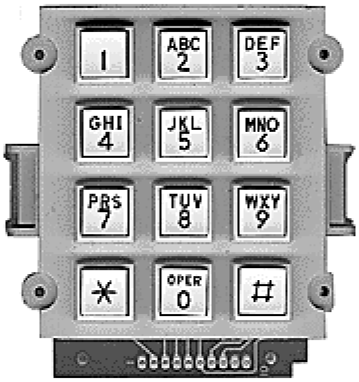


Figure 1

HOW THEY ARE READ

As shown in ***Figure 2***, the columns are connected to +5 Volts (logic level 1) by pull-up resistors. The other ends of the columns are connected to an input port so that the logic level on each column can be read. The rows are connected to an output port where the software pulls one row at a time low in a repeating cycle. First row 0 is low while rows 1,2, and 3 are kept high. Then row 0 is pulled high, row 1 is pulled low, and rows 2 and 3 are kept high. And so on until each row has been pulled low, at which point the cycle repeats.

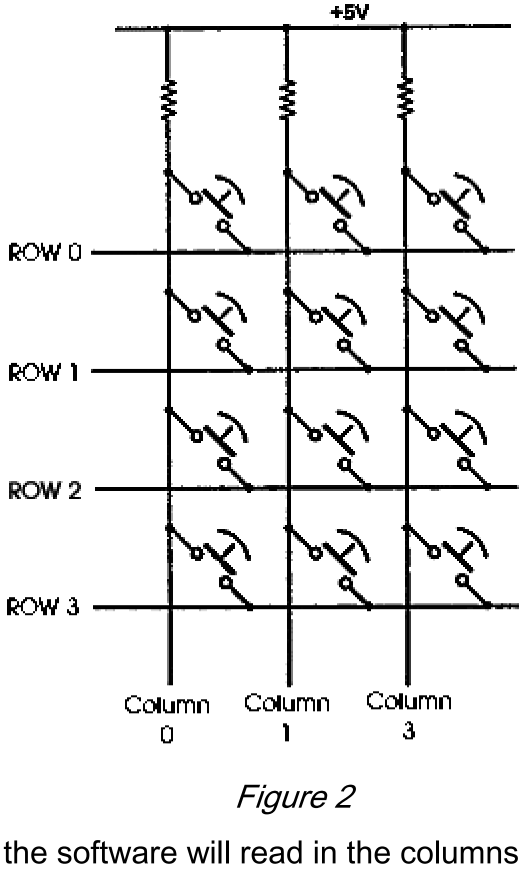


Figure 2

Each time a row is pulled low, the software will read in the columns. If no key is pressed, all the columns will be high. If a key is pressed, one column will be connected to one row. When that row is pulled low, that column will also go low. By knowing the row number and column number that are low, the software knows which key was pressed. The software runs through the scan cycle in a matter of microseconds, so no matter how fast you press the keys the software will catch it.

Table 1 shows the pin assignments for the Electronix Express keypad (part number 1704627).

WIRING DIAGRAM FOR TELEPHONE-TYPE
3-BY-4 X - Y MATRIX KEYPAD

		COL 0	COL 1	COL 2
		PIN 4	PIN 2	PIN 6
ROW 0	PIN 3	1	2	3
ROW 1	PIN 8	4	5	6
ROW 2	PIN 7	7	8	9
ROW 3	PIN 5	*	0	#

Table 1

THE OSCILLATING AMPLIFIER

You say you built a simple little battery-powered audio amplifier, and instead of amplifying the darn thing just sits there and oscillates? You say you put a capacitor from +V to ground and it still oscillates? You say you don't know what to do next? Cheer up, you can fix it!

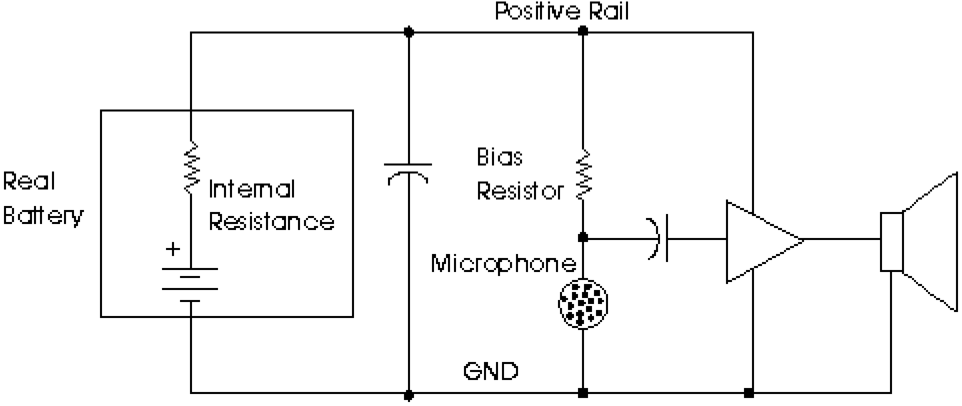


Figure 1

The problem is feedback from the amplifier's output back to it's input through the positive voltage rail. You say you knew that, and that's why you put a 10 uF cap across the 9 Volt battery? Well, let's look at it carefully. Suppose you're using one of those popular capacitor microphones. They need to be biased to +V to operate. Look at the circuit in *Figure 1*. You see that the DC bias voltage on the microphone comes directly from +V via a resistor. So if there is any AC "ripple" on +V, it will show up at the input to the amplifier. Where would ripple come from you ask? Well I'll tell you.

Real batteries have some internal resistance, and as you use them that resistance gets bigger. Also, the wires used to build the circuit (or the copper traces on a circuit board) have a small amount of resistance. Amplifiers such as the LM386 can easily put out 500 mW of signal, which from a 9-volt battery means an AC current of over 50 mA due to the audio signal.

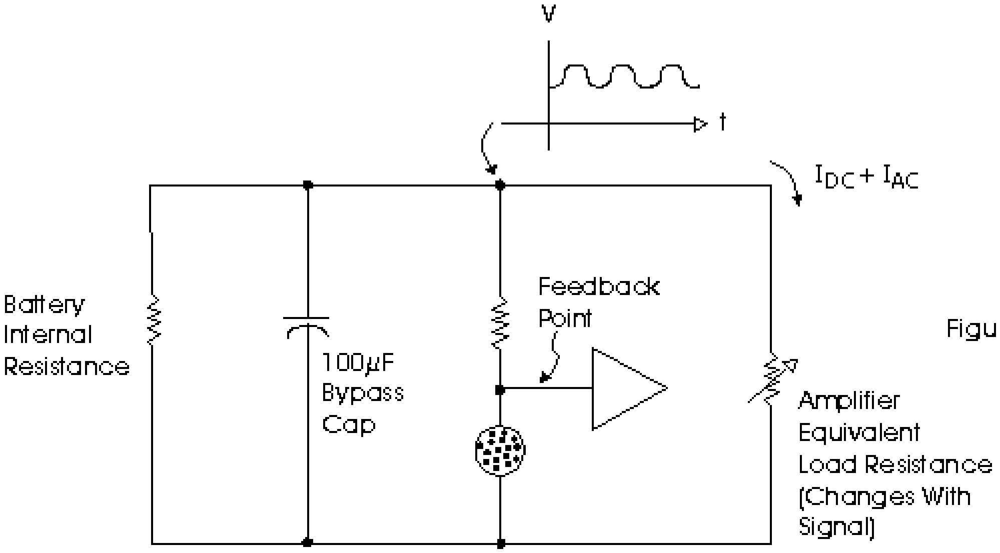


Figure 2

Look at *Figure 2*. Suppose the internal resistance of the battery is 1 Ohm. Then 50 mA of AC current will cause 50 mV of AC ripple on the +9 rail. Likewise, suppose you have .05 Ohms of resistance in the wiring. Then you'll get 2.5 mV of ripple. While 2.5 mV may not sound like much, note that through the biasing it ends up at the input to the amplifier, where it causes more output on the load leading to more current being drawn and more ripple voltage getting back to the amplifier input. In other words, you've got feedback!

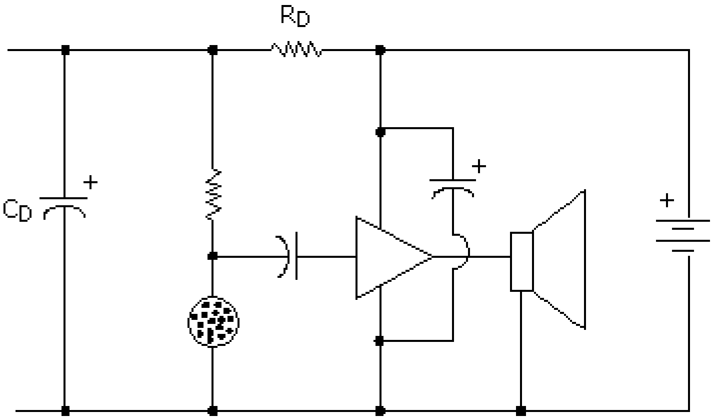


Figure 3

What about the cap across the battery you ask? At 60 Hertz, the impedance of a 100 uF cap is about 27 Ohms, which is considerably bigger than the resistances we've been talking about. A capacitor alone may not be enough. What you need is decoupling. *Figure 3* shows a typical decoupling circuit. First off, you want to connect the battery (or other voltage source) directly to the amplifier with a capacitor right across the amplifier's power pins. Then you want to build an RC low-pass filter into the +V rail for the rest of the circuitry (RD and CD). You want to make the break-frequency (1 / 2piRC) at least 10 times lower than the feedback frequency that is occurring. Be careful that you don't make RD too big, or the DC drop across it will be too much.

For example, if the problem is 60 Hz, then with RD = 1000 Ohms C should be at least 27 uF, with values like 47 uF or 100 uF being better. Use the formula:

$$C = \frac{1}{2p \times (10f) \times R}$$

where f is the troublesome frequency.

Another approach is to use a zener diode. Zener diodes of 5.1 V or higher are actually avalanche diodes, which have a very low resistance when they are conducting at their break-down voltage. Look at *Figure 4*. Basically, we power the amplifier from the battery, but power the rest of the circuit from a separate power rail. See *Figure 4*.

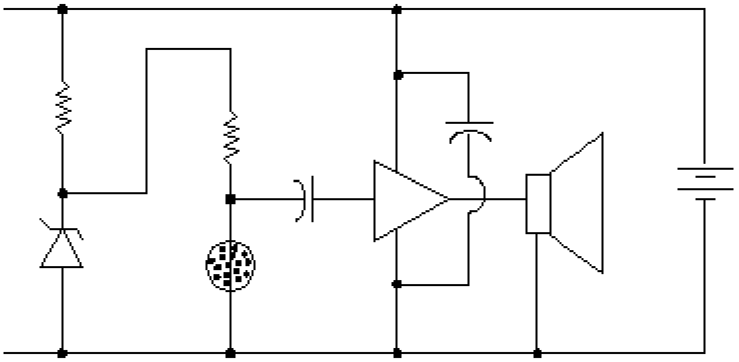


Figure 4

In summary, accidental feedback through the power supply is one of those things designers must be aware of, otherwise it sneaks up and bites you.

Notes On Gain-Error In Op-Amp Amplifiers

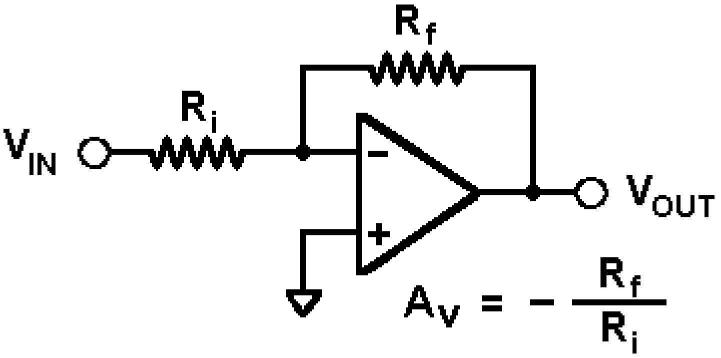
This article is about the errors you can make in calculating the gain of an op-amp amplifier circuit. I'm assuming here that you are familiar with op-amp amplifier circuits. But let's do a quick review anyway.

As you know, the key idea in op-amp circuits is that you start with a very high gain, and then trade off that gain in exchange for increased bandwidth and improved characteristics. What characteristics? You remember; things like input impedance (it gets bigger), output impedance (it gets smaller), distortion (it becomes less), and so forth.

Op-amps have enormous open-loop gain (A_{OL}). Open-loop gain is the gain of the op-amp chip itself with no feedback. That gain is too big to be used, so you lower it with negative feedback. The gain with feedback is the closed-loop gain (A_{CL}).

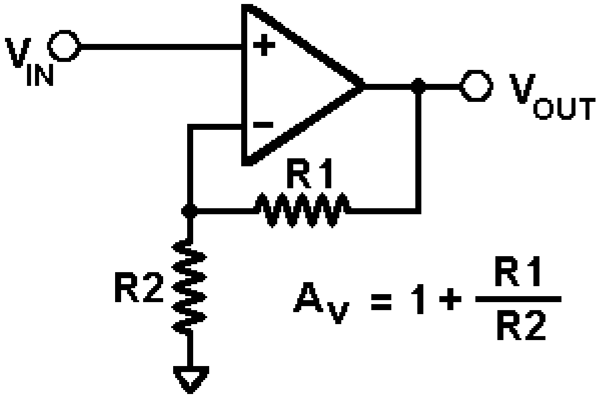
Below are schematics for the two basic feedback circuits: the inverting amplifier and the non-inverting amplifier. The gain equation for each circuit is included. Notice that the gain equations do not include frequency as a variable.

Inverting Amplifier



$$A_V = -\frac{R_f}{R_i}$$

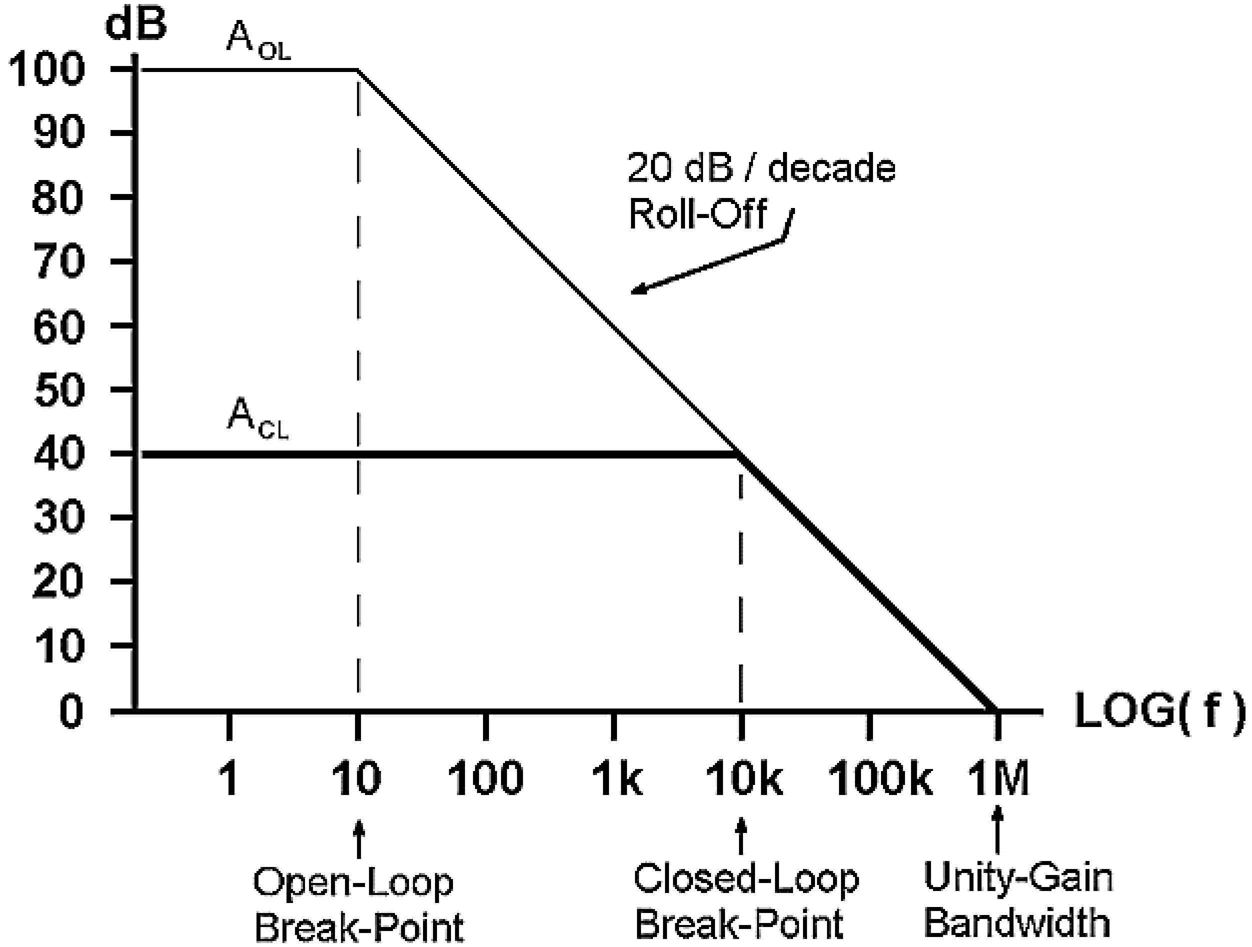
Non-Inverting Amplifier



$$A_V = 1 + \frac{R1}{R2}$$

Before we get to the punch-line of this article, there's a short story to tell. So, please be patient. Many books either say or imply that the closed-loop gain doesn't change with frequency until the line for ACL meets the line for AOL on the amplifier's Bode plot. What's a Bode plot? C'mon, you remember! It's a graph that shows how the gain of an amplifier "rolls off" as signal frequency increases. Many op-amps, like the lovable old 741, roll off at 20 dB per decade. (A decade is when the frequency changes by a factor of 10, but you knew that.) The open-loop gain of an op-amp starts rolling off at a relatively low frequency, maybe 10 Hertz. But they have so much AOL that it doesn't get to 1 (0 dB) until you get up to mega-Hertz.

Hey! Someone left a Bode plot right here for us to look at! It could be for a 741.



OK, you've been patient. Here's the punch-line: ACL does NOT stay constant until it hits the roll-off. A decade before the roll-off, when AOL is still 20 dB higher than ACL, you've already lost about 10% of your closed-loop gain!

What? You're shocked? You don't believe me? I can understand. But remember, it's not the things you don't know that get you into trouble. Instead, it's the things you do know, but which turn out to be wrong. But it's always good to be skeptical, so the math is below. Better yet, build a circuit and measure the closed loop gain as you get close to the roll-off and see if the gain stays constant or not.

Ideal closed-loop gain value is $A_{CL} = \frac{1}{\beta}$ where β is the feedback ratio

Actual closed-loop gain value is $A_{CL} = \frac{A_{OL}}{1 + \beta A_{OL}}$

Let's call the ideal closed loop gain value A_V

We can express the difference between the ideal value and the actual value as

$\Delta = A_V - A_{CL}$

The difference as a fraction of the ideal closed-loop gain is

$$\delta = \frac{\Delta}{A_v}$$

which we can calculate as

$$\delta = \frac{A_v - A_{CL}}{A_v} = 1 - \frac{A_{CL}}{A_v} = 1 - \frac{\frac{A_{OL}}{1 + \beta A_{OL}}}{A_v}$$

Let $A_{OL} = N \, x \, A_{CL}$ meaning that the open-loop gain is N times bigger than A_v now we have

$$\delta = 1 - \frac{\frac{N A_v}{1 + \beta N A_v}}{A_v} = 1 - \frac{N}{1 + \beta A_v N}$$

But, with an "ideal" op-amp, the closed-loop gain is $A_v = \frac{1}{\beta}$

so

$$\delta = 1 - \frac{N}{1 + N} = \frac{1}{1 + N}$$

If the open-loop gain is 20 dB more than the closed-loop gain then N = 10 which gives

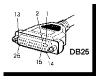
$$\delta = \frac{1}{1 + 10} = \frac{1}{11} = 0.091$$

or an error of 9.1%

An error of 9.1% is not negligible.

RS-232 Interface

DB25 Plug



SIGNALS FROM TERMINAL	SIGNALS FROM MODEM
---------------------	------------------
PIN 2	PIN 3
Transmitted Data (TD)	Received Data (RD)
Data from terminal.	Data from modem

PIN 4 Request to Send (RTS) Tells modem that terminal wants to send data.	PIN 5 Clear to Send (CTS) Tells terminal that it may now place data on the transmit data line (PIN 2).
PIN 20 Data Terminal Ready (DTR) Tells modem that terminal is connected, powered up and. ready	PIN 6 Data Set Ready (DSR) Tells terminal modem is connected, powered up and ready.
PIN 7 Signal Ground Common ground reference for all signal lines.	PIN 7 Signal Ground Common ground reference for all signal lines.
PIN 1 Protective Ground Safety or power line ground for equipment.	PIN 1 Protective Ground Safety or power line ground for equipment.
PIN 24 Transmit Signal Element Timing Clock signal from terminal.	PIN 8 Received Line Signal Detector or Carrier Detect (CD) Tells terminal that carrier is being received from computer modem.
PIN 14 Secondary Transmitted Data Identical in function to PIN 2 except it applies only to systems with full secondary channel implemented.	PIN 15 Transmission Signal Element Timing Clock signal from modem (used only with synchronous modems.
	PIN 22 Ring Indicator Signal telling terminal that phone line is "ringing". i.e. there is an incoming call.

PIN 19

Secondary Request to Send

Tells modem to turn on the secondary channel carrier used for HD supervisor operation.

PIN 23

Data Rate Signal Selector

Used by Modem/Terminals with programmable data rate selection.

PIN 17

Received Signal Element Timing

Clock signal from modem (used only with synchronous modems).

PIN 16

Secondary Received Data

Identical in function to PINs 3 and 5 except as they apply only to systems with full secondary channels implemented.

PIN 13

Secondary Clear to Send

Identical in function to Pins 3 and 5 except as they apply only to systems with full secondary channels implemented.

PIN 12

Secondary Received Line Dignal Detect

Tells terminal that carrier is present on secondary channel. used for HD supervisor operation.

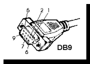
PIN 21

Signal Quality Detector

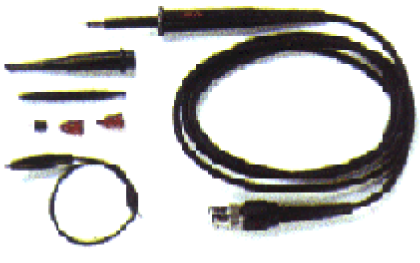
Used by some modems which incorporate signal evaluating circuitry to advise terminal that present signal is poor and a high error rate is probable.

Pins receiving signal from modem:	Pins receiving signals from terminal
3, 5, 6, 8, 12, 13, 15, 16, 17, 21.	2, 4, 14, 19, 30, 23, 24.

DB9



DB9 PIN	DB25 PIN	NAME	DESCRIPTION



1	8	CD	RLSD Carrier Detect
2	3	RD	Receive Data
3	2	TD, SD	Transmit Data
4	20	DTR	Data Terminal Ready
5	7	GND	Signal Ground
6	6	DSR	Data Set Ready
7	4	RTS	Request to Send
8	5	CTS	Clear to Send
9	22	RI	Ring Indicator

Keep in mind that on many computers, COM1 and COM2 are wired differently, COM1 being DTE, COM2 being DCE. If COM2 is configured as a DCE, a null modem cable with TX and RX reversed will be needed to use it. Some 9 pin to 25 pin adapters, but not all of them, also reverse TX and RX.

Importance of X10 Probes

Here is something you may have experienced: You build a simple digital circuit using flip-flops, like a ripple-counter, and it seems to be working OK. But as soon as you try to look at one of the Q outputs with your scope, things get funny. You don't see what you expect to see; maybe the counter even stops working. What's going on?

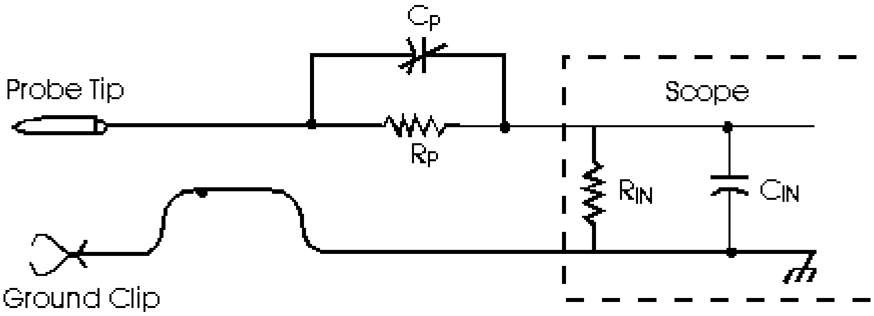
The answer may be your scope probe. Instead of using an actual scope probe, you may have a length of coaxial cable ("co-ax") with a BNC connector at one end and a couple of alligator clips at the other. It may work fine for looking at lower frequency sine-waves, but it's the wrong thing for digital circuits.

Here's the problem: that piece of coax has a certain amount of capacitance (50 pF/foot is typical) and a certain amount of inductance. But it has very little resistance. So what you have is a resonant circuit with very little damping. Trying to put a fast rise-time digital signal through it is like hitting a bell with a hammer. That cable is going to "ring".

When a cable rings, a signal applied at the input end will travel up the cable, echo off the other end, and travel back down to the input where it arrives, out of phase, on top of the signal you're trying to measure. The result is that at the point you attach the cable, you cause transients: very narrow voltage "spikes" that go both positive and negative.

Getting back to your digital circuit, by causing a voltage spike in the middle of your counter you cause the flip-flops to change state. Obviously a spike on an input can "flip" your flip-flop. But so can a spike on an output. The solution is to use a real scope probe instead of a piece of co-ax. Usually you want a properly adjusted "X10" probe. Probes can be X1 ("times-one") or X10 ("times-ten"). Often a probe has a switch on it so you can use it in either X1 mode or in X10 mode.

A scope probe is built to minimize ringing by adding resistance. A X1 is better than a piece of co-ax, but a X10 probe is more effective than a X1. A X10 probe has the effect of reducing capacitance by a factor of ten. The trade-off is that is also attenuates the signal by a factor of ten. That is, 1/10 the signal applied to the tip of the probe actually reaches the input of the oscilloscope.



X10 Probe Schematic

Above is the schematic of the circuit inside a X10 probe. You can see that it is basically a voltage divider. Rp and Cp are selected to form a 10 to 1 divider with the input of the scope. Assume that the scope has 1 Meg-Ohm input resistance and 100 pF of input capacitance. Then Rp is 9 Meg-Ohms and Cp is 9 pF (remember: small C gives big X). Note that Cp is adjustable. That's to allow for adjusting the response of the cable to fast rise times. Often Cp can be adjusted with a small screwdriver. It may be located at the probe end of the cable, or at the end that attaches to the scope. Most scopes have a "calibrator output" somewhere on the front panel. It supplies a square-wave to look at with your probe. Adjust Cp until the rising edge of the square-wave looks like *Figure 2* below.

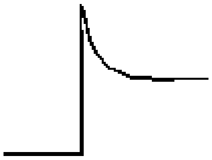


Figure 1
Under-Compensated

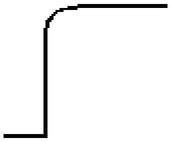


Figure 2
Properly Compensated

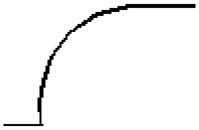


Figure 3
Over-Compensated

Now you should be able to look at signals in your digital circuits without flipping your flops. Also, if you are using a frequency counter to measure the frequency of a digital signal, then ringing in the coax will give you a false reading. Again, the solution is a X10 probe.

SHUNT REGULATOR

The lab manuals for many DC circuits courses, including the ones that come with popular text books, have experiments with circuits like the one shown in figure 1.

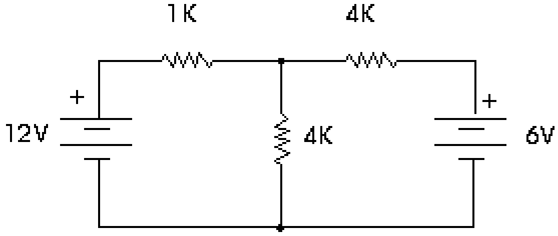


Figure 1

The problem with them is that sometimes the measured values of voltage and current don't agree with the calculated values. It seems like a mystery: does circuit analysis not always work? Of course it does!

The problem is likely to be in the power supply you're using. Circuits like the one in *Figure 1* assume that you are using batteries to supply the voltage. An ideal battery will sink current as well as source current. That means that current can flow "backwards" into the battery.

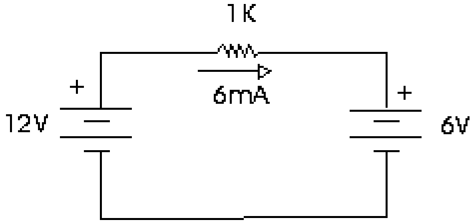


Figure 2

Look at *Figure 2* (we are using conventional current here). Using Ohm's Law, we can calculate the current as:

$$I = \frac{E}{R} = \frac{V1 - V2}{R} = \frac{12 - 6}{1000} = 6 \text{ mA.}$$

But if you are using a typical power supply instead of batteries, you will measure 0 mA. What's more, you will measure 0 Volts across the resistor. What's going on?

The answer is that the typical power supply uses a series regulator. A simplified schematic of a series regulator is shown in *Figure 3*.

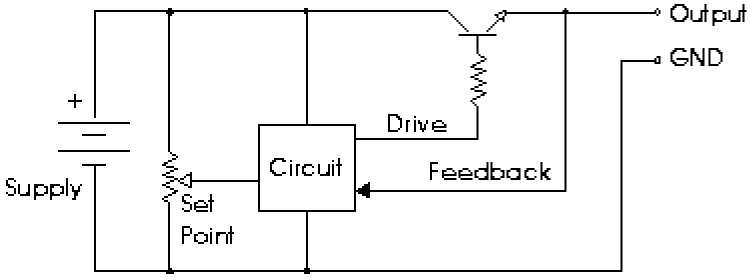


Figure 3

If you apply a voltage to the emitter that is greater than what the supply is set to put out, then you reverse bias the transistor. That means that current can flow out the emitter of the transistor, but current can not flow into the emitter. In fact, if too much reverse bias is applied to the transistor it will be damaged. So often a diode is put in series with the output as protection.

Is there some way to get a power supply to sink current? Yes there is! You can use a circuit called a shunt regulator.

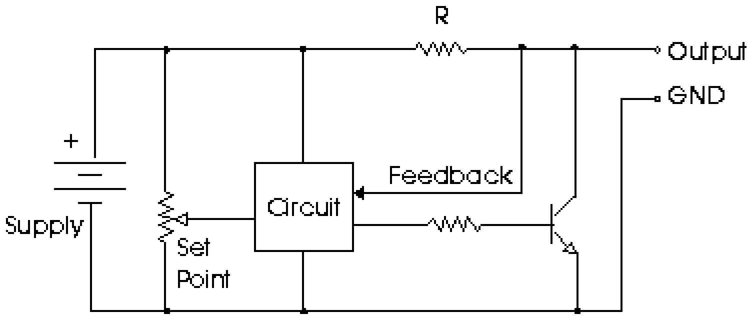


Figure 4

Figure 4 shows a simplified shunt regulator. Note that instead of current going through a transistor to get to the output, the current flows through a resistor to the output. By Ohm's Law, there is going to be a voltage drop across the resistor. The job of the transistor is to conduct just the right amount of current to ground so that the output voltage is at the set value.

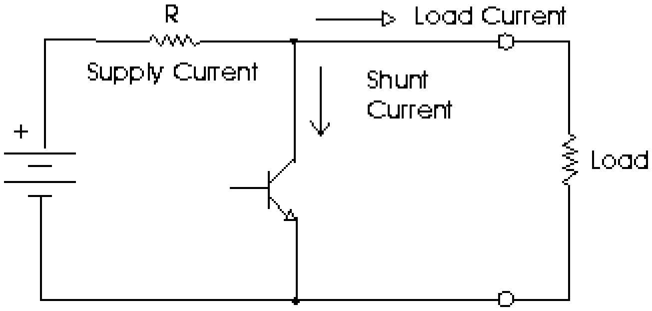


Figure 5

If there is no load on the supply, all the current goes through the transistor. If there is a resistive load, some current goes through the load and the rest goes through the transistor. But here's the important part: if something tries to drive current back into the supply, the transistor will shunt that current to ground as well. Look at *Figure 5*.

Figure 6 shows a practical circuit. The diodes are there because the output of a standard 741 op-amp can not go from "rail-to-rail". So when the 741 output tries to go to zero, it can only go as low as about 2 Volts. That would mean the transistor would always be on, and you wouldn't be able to get maximum output voltage from the regulator. If you use a CMOS op-amp, you won't need the diodes.

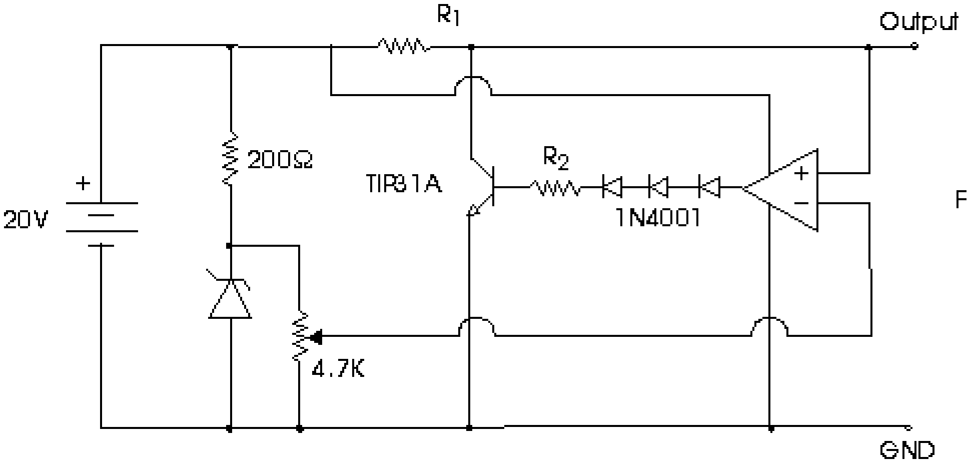


Figure 6

You calculate the resistor values as follows:

SUPPLY VOLTAGE - MAX OUTPUT VOLTAGE
R1 = -------------------------------------

MAXIMUM OUTPUT CURRENT

$$\text{WATTAGE of R1} = (\text{SUPPLY VOLTAGE})^2 / \text{R1}$$

$$\text{BASE CURRENT} = \frac{\text{MAXIMUM SINK CURRENT}}{\text{MINIMUM BETA of TRANSISTOR}}$$

$$\text{R2} = \frac{\text{SUPPLY VOLTAGE} - \text{DIODE DROP}}{\text{BASE CURRENT}}$$

$$\text{WATTAGE of R2} = (\text{MAX CURRENT})^2 \times \text{R2}$$

EXAMPLE:

SUPPLY VOLTAGE = 20 V

MAX OUTPUT VOLTAGE = 10 V

MAX OUTPUT CURRENT = 100 mA

MIN BETA = 50

DIODE DROP (3 + 1 for BASE-EMITTER JUNCTION) = 4 x 0.625 V = 2.5 Volts

$$\text{R1} = \frac{20\text{ V} - 10\text{ V}}{100\text{ mA}} = \frac{10\text{ V}}{0.1\text{ A}} = 100\text{ Ohms}$$

WATTS = (20) x (20) / 100 = 4 W (use a 5 Watt resistor)

$$\text{BASE CURRENT} = \frac{200\text{ mA}}{50} = 4\text{ mA}$$

$$\text{R2} = \frac{18\text{ V}}{\quad} = 4.5\text{ K Ohms (Use 4.7 K Ohms)}$$

4 mA

WATTS = (.004) x (.004) x (4700) = 75 mW (use 1/4 Watt)

You can use a value as low as 1 K for R2 to provide some over-drive capability since a 741 can supply up to 20 mA. If you use a CMOS op-amp, check it's maximum current output.

To develop a voltage for the adjustable set-point, we used a 15 V, 1 W zener diode and a 4.7 K trim-pot. To calculate the series resistor for the zener, we just used:

VOLTAGE DROP (20 - 15) V
R = ------------ = ------------- = 250 Ohms. We used 200 Ohms.
ZENER CURRENT 20 mA

WATTS = (5V) x (5V) / 200 = 125 mW (Use 1/4 Watt)

Note that you don't have to build a whole new power supply to use this circuit. It can be connected to the output of a standard supply.

Better Soldering

(A COOPERTools Reprint)

Purpose

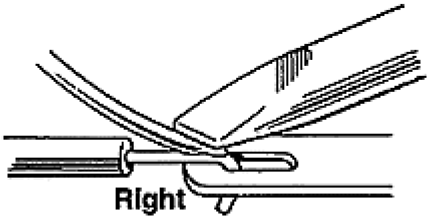
We hope this short manual will help explain the basics of Soldering. The emphasis will be on the care and use of equipment.

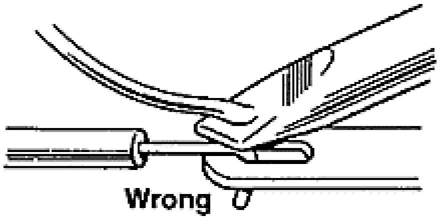
Overview

Soldering is accomplished by quickly heating the metal parts to be joined, and then applying a flux and a solder to the mating surfaces. The finished solder joint metallurgically bonds the parts - forming an excellent electrical connection between wires and a strong mechanical joint between the metal parts. Heat is supplied with a soldering iron or other means. The flux is a chemical cleaner which prepares the hot surfaces for the molten solder. The solder is a low melting point alloy of non ferrous metals.

Solder and Flux

Solder is a metal or metallic alloy used, when melted, to join metallic surfaces together. The most common alloy is some combination of tin and lead. Certain tin-lead alloys have a lower melting point than the parent metals by themselves. The most common alloys used for electronics work are 60/40 and 63/37. The chart below shows the differences in melting points of some common solder alloys.





Tin/Lead	Melting Point
40/60	460 degrees F (230 degrees C)
50/50 418 degrees F	(214 degrees C)
60/40 374 degrees F	(190 degrees C)
63/37 364 degrees F	(183 degrees C)
95/5 434 degrees F	(224 degrees C)

Most soldering jobs can be done with fluxcored solder (solder wire with the flux in a "core") when the surfaces to be joined are already clean or can be cleaned of rust, dirt and grease. Flux can also be applied by other means. Flux only cleans oxides off the surfaces to be soldered. It does not remove dirt, soot, oils, silicone, etc.

Base Material

The base material in a solder connection consists of the component lead and the plated circuit traces on the printed circuit board. The mass, composition, and cleanliness of the base material all determine the ability of the solder to flow and adhere properly (wet) and provide a reliable connection. If the base material has surface contamination, this action prevents the solder from wetting along the surface of the lead or board material. Component leads are usually protected by a surface finish. The surface finishes can vary from plated tin to a solder - dipped coating. Plating does not provide the same protection that solder coating does because of the porosity of the plated finish.

The Correct Way to Solder

Some Reasons for Unwettability

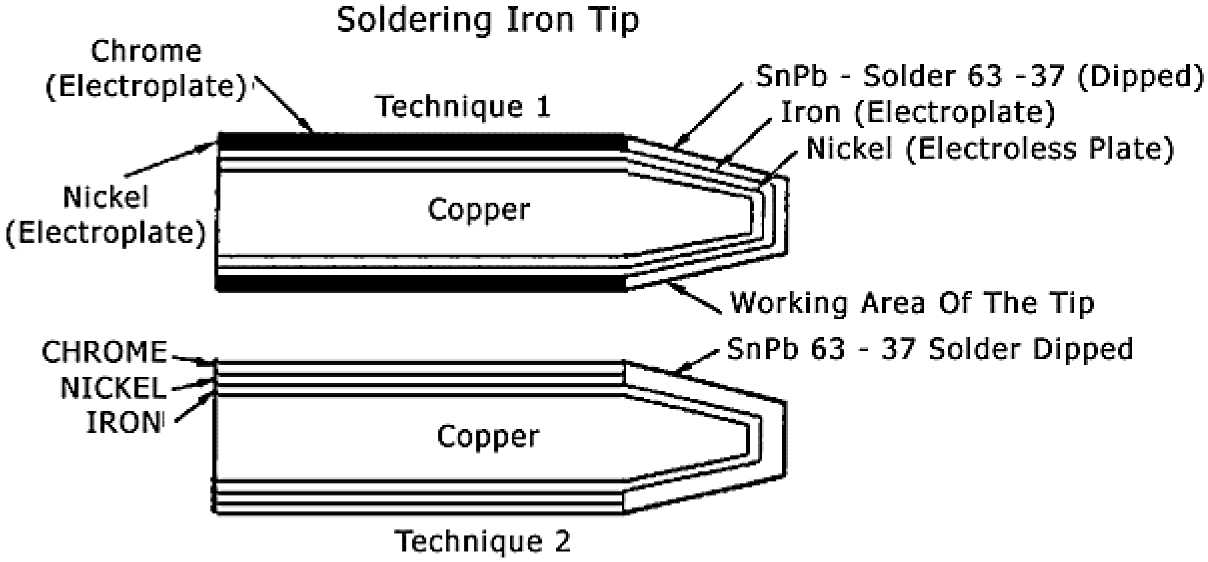
1. The selected temperature is too high. The tin coating is burnt off rapidly and oxidation occurs.
2. Oxidation may occur because of wrong or imperfect cleaning of the tip. E.G.: when other material is used for tip cleaning instead of the original damp Weller sponge.
3. Use of impure solder or solder with flux interruptions in the flux core.
4. Insufficient tinning when working with high temperatures over 665 degrees F (350 degrees C) and after work interruptions of more than one hour.
5. A "dry" tip, i.e. If the tip is allowed to sit without a thin coating of solder oxidation occurs rapidly.
6. Use of fluxed that are highly corrosive and cause rapid oxidation of the tip (e.g. water soluble flux).
7. Use of mild flux that does not remove normal oxides off the tip (e.g. no-clean flux).

The Soldering Iron Tip

The soldering iron tip transfers thermal energy from the heater to the solder connection. In most soldering iron tips, the base metal is copper or some copper alloy because of its excellent thermal conductivity. A tip's conductivity determines how fast thermal energy can be sent from the heater to the connection.

Both geometric shape and size (mass) of the soldering iron tip affect the tip's performance. The tip's characteristics and the heating capability of the heater determines the efficiency of the soldering system. The length and size of the tip determines heat flow capability while the actual shape establishes how well heat is transferred from the tip to the connection.

There are various plating processes used in making soldering iron tips. These plating operations increase the life of the tip. The figure below illustrates the two types of plating techniques used for soldering iron tips. One technique uses a nickel plate over the copper. Then an iron electroplate goes over the nickel. The iron and the nickel create a barrier between the copper base material and tin used in the solder alloy. The barrier material prevents the copper and tin from mixing together. Nickel-chrome plating on the rear of the tip prevents solder from adhering to the back portion of the tip (which could cause difficulty in tip removal) and provides a controlled wetted area on the iron tip. Another plating technique is similar but omits the nickel electroless plating, leaving the iron to act as the barrier metal.



What is a Weller*(r)* Tip - How Does It Work?

A Weller tip is made of a copper corewhich is electro-plated with iron to extend the life of the tip. The non-working end of the tip is plated with nickel for protection against corrosion and then chrome plated to prevent the solder from adhering except where desired. The wettable part is tin covered. The task of the tip is to store the heat which is produced by the heating element and to conduct a maximum amount of this heat to the working surface of the tip.

For fast and optimal heat transfer to the solder joint the tip mass should be as large as possible. When choosing a soldering tip always select the largest possible diameter and shortest reach. Use fine-point long reach tips only where access to the work piece is difficult.

How to Care For Your Tip

Because of the electro-plating Weller tips should never be filed or ground. Weller offers a large range of tips and there should be no need for individual shaping by the operator. If there is a need for a specific tip shape which is not in our standard range we can usually provide this on a special order basis.

Although Weller tips have a standard pretinnng (solder coating) and are ready for use, we recommend you pretin the tip with fresh solder when heating it up the first time. Any oxide covering will then disappear. Tip life is prolonged when mildly activated rosin fluxes are selected rather than water soluble or no-clean chemistries.

When soldering with temperatures over 665 degrees F (350 degrees C) and after long work pauses (more than 1 hour) the tip should be cleaned and tinned often, otherwise the solder on the tip could oxidize causing Unwettability of the tip. To clean the tip use the original synthetic wet sponges from Weller (no rags or cloths).

When doing rework, special care should be taken for good pretinnng. Usually there are only small amounts of solder used and the tip has to be cleaned often. The tin coating on the tip could disappear rapidly and the tip may become unwettable. To avoid this the tip should be retinned frequently.

Additional Tip and Tiplet Care Techniques

Listed below are suggestions and preventative maintenance techniques to extend life and wettability of tips and desoldering tiplets.

1. Keep working surfaces tinned, wipe only before using, and retin immediately. Care should be taken when using small diameter solder to assure that there is enough tin coverage on the tip working surface.
2. If using highly activated rosin fluxes or acid type fluxes, tip life will be reduced. Using iron plated tips will increase service life.
3. If tips become unwettable, alternate applying flux and wiping to clean the surface. Smaller diameter solders may not contain enough flux to adequately clean the tips. In this case, larger diameter solder or liquid fluxes may be needed for cleaning. Periodically remove the tip from your tool and clean with a suitable cleaner for the flux being used. The frequency of cleaning will depend on the frequency and type of usage.
4. Filing tips will remove the protective plating and reduce tip life. If heavy cleaning is required, use a Weller WPB1 Polishing Bar available from your distributor.
5. Do not remove excess solder from a heated tip before turning off the iron. The excess solder will prevent oxidation of the wettable surface when the tip is reheated.
6. Anti-seize compounds should be avoided (except when using threaded tips) since they may affect the function of the iron. If seizing occurs, try removing the tip while the tool is heated. If this fails, it may be necessary to return the tool to Weller for service. Removing the tip from the tool on a regular basis will also help in preventing the tip from seizing.

7. We recommend using distilled water when wetting the cleaning sponge. The mineral content in most tap water may contaminate your soldering tips.
8. Storing tips after production use:
    -- Clean hot tip thoroughly with damp sponge.
    -- Apply coating of solder to tip.
    -- Turn unit off to allow tip to cool.
    -- Put tip away in proper storage or in iron holder

How to "Renew" Your Tip

Emery cloth may be carefully used to wipe away oxidation when the tip is hot. The tip should then be immediately retinned to prevent further oxidation. In extreme cases of tip oxidation or "tip burnout" they may be cleaned using a soft steel brush along with an active flux. Once again, retinning the tip immediately is important.

Soldering Iron Temperature Settings

In order to raise the temperature of solder above it's melting point, soldering tip temperatures are usually set between 700 degrees F and 800 degrees F. Why such a high temperature when the most commonly used solders have a melting point under 400 degrees F? Using a higher temperature stores heat in the tip which speeds up the melting process. The operator can then complete the solder connection without applying too much pressure on the joint. This practice also allows a proper formation of an intermetallic layer of the parts and solder. This is critical for reliable electrical and mechanical solder joints.

How Precise is the Indicated Tip Temperature?

Very fine long soldering tips have less heat conductivity than large short tips and therefore will run slightly cooler. Electronic control soldering stations have a tip temperature control accuracy of at least plus or minus 10 degrees F (6 degrees C) which is the current Mil Spec. Weller tips for electronic soldering tools are carefully designed to give accurate temperatures measured at the center of the solder wetted area. The specifications of the individual soldering stations are assured only if Weller tips are used. The sensor hole in these tips is very critical to their proper operation. Use of other than Weller tips may cause damage by overheating or tip freezing on the sensor or in the tool barrel.

Tip Temperature Measuring

Weller offers two methods for measuring tip temperature. One is a contact method which may yield low readings but is useful in verifying tip temperature stability and showing that the tip is within the desired range for soldering. The second method employs a welded thermocouple tip. This approach is based on using a standard calibration tip and results in much more accurate tip temperature measurements. Both methods require the use of the WA2000 Soldering Iron Analyzer. Please consult with your Cooper Tools representative or your local distributor for more information.

The Operator's Effect on The Process

The operator has a definite effect on the manual soldering process. The operator controls the factors during soldering that determine how much of the soldering iron's heat finally goes to the connection. Besides the soldering iron configuration and the shape of the iron's tip, the operator also affects the flow of heat from the tip to the connection. The operator can vary the iron's position and the time on the connection, and pressure of the tool against the pad and lead of the connection.

When the tip of the iron contacts the solder connection, the tip temperature decreases as thermal energy transfers from the tip to the connection. The ability of the soldering iron to maintain a consistent soldering temperature from connection to connection depends on the iron's overall ability to transfer heat as well as the operator's ability to repeat proper technique.

The Reliable Solder Connection

Two connection elements must properly function for a solder joint to be reliable. The solder within the connection must mechanically bond the component to the PCB. The connection must also provide electrical continuity between the device and board. The proper intermetallic layer assures both.

Mechanical

In surface mount and nonclinched through-hole technology, the solder provides the mechanical strength within the connection. Important factors for mechanical strength include the wetting action of the solder with the component and board materials, physical shape and composition of the connection, and the materials' temperature within the connection during the process. The connection temperature should not be too high, causing embrittlement, or too low, resulting in poor wetting action.

Electrical

If a solder connection is mechanically intact, it is considered to be electrically continuous. Electrical continuity is easily measured and quantified.

Recognizing the Reliable Solder Connection

Two easily measured indicators in the soldering process that can determine the reliability of the solder connection are the soldering iron's tip temperature and the solder's wetting characteristics. The tip's temperature during the soldering process is an indicator of the amount of heat being transferred from the tip to the connection. The optimum rate of heat transfer occurs if the soldering iron tip temperature remains constant during the soldering process.

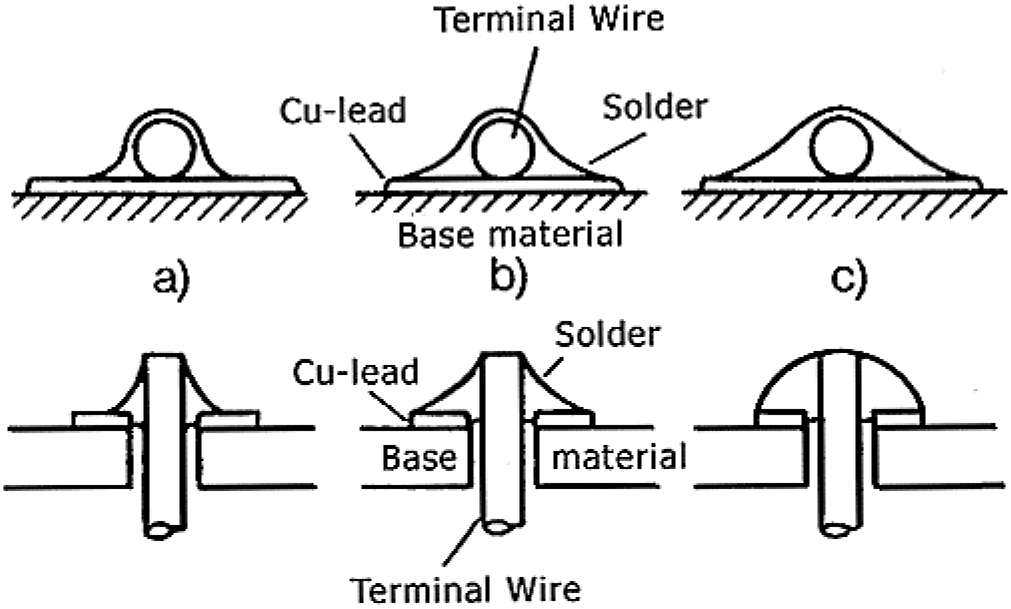
Another indicator for determining reliability is the solder's wetting action with the lead and board materials. As operators transfer heat to the connection, this wetting characteristic can be seen visually. If the molten solder quickly wicks up the sides of the component on contact, the wetting characteristic is considered good. If the operator sees the solder is flowing or spreading quickly through or along the surface of the printed circuit assembly, the wetting is also characterized as good.

Right Amount of Solder

a) Minimum amount of solder

b) Optimal

c) Excessive solder

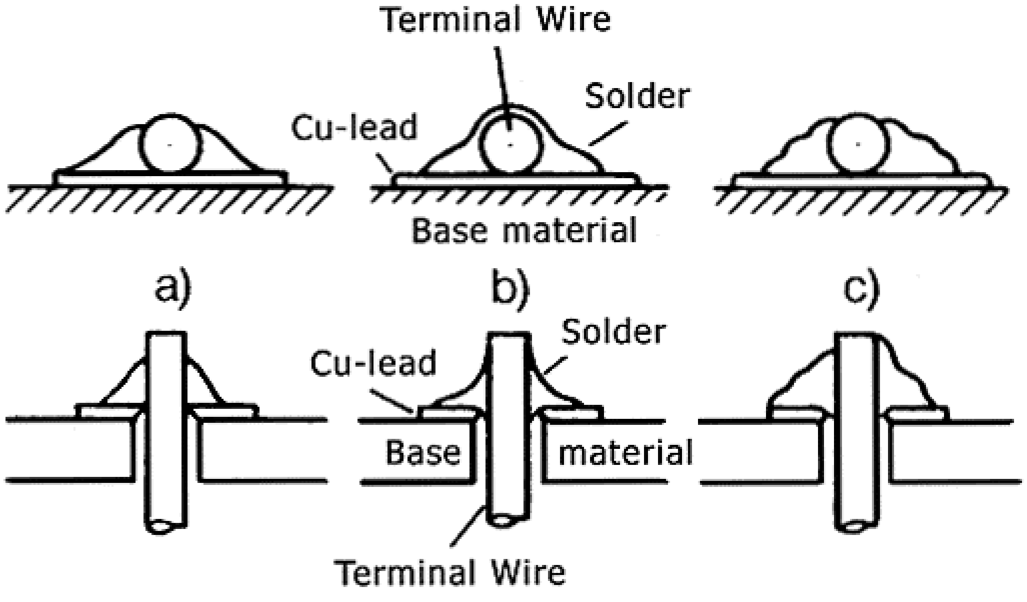


Solderability

a) Bad solderability of terminal wire

b) Bad soldering of PCB

c) Bad soldering of terminal wire and PCB



Key Points to Remember

1. Always keep the tip coated with a thin layer of solder.
2. Use fluxes that are as mild as possible but still provide a strong solder joint.
3. Keep temperature as low as possible while maintaining enough temperature to quickly solder a joint (2 to 3 seconds maximum for electronic soldering).
4. Match the tips size to the work.
5. Use a tip with the shortest reach possible for maximum efficiency.

Summary

Operator training and experience will, over time, provide the consistency needed for excellent hand soldering results. Part of the training includes a proper understanding of solder characteristics, how a soldering iron works, how to maintain tips, correct techniques, recognizing good solder joints, and potential problems.

Reading Transistor Markings

Most transistor markings follow one of these codes: JEDEC, JIS or Pro-Electron. For ICs, look for known numbers (e.g. 741, 4001, 7400) between the prefix and the suffix. Don't confuse it with the date code. ICs typically have two numbers: The part number and the date code.

1. Joint Electron Device Engineering Council (JEDEC)

These part numbers take the form: digit, letter, sequential number, [suffix]

The letter is always 'N', and the first digit is 1 for diodes, 2 for transistors, 3 for four-leaded devices, and so forth. But 4N and 5N are reserved for opto-couplers. The sequential numbers run from 100 to 9999 and indicate the approximate time the device was first made.

If present, a suffix could indicate various things. For example, a 2N2222A is an enhanced version of a 2N2222. It has higher gain, frequency, and voltage ratings. Always check the data sheet.

Examples: 1N914 (diode), 2N2222, 2N2222A, 2N904 (transistors).

NOTE: When a metal-can version of a JEDEC transistor is remade in a plastic package, it is often given a number such as PN2222A which is a 2N2222A in a plastic case.

2. Japanese Industrial Standard (JIS)

These part numbers take the form: digit, two letters, sequential number, [optional suffix]

Digits are 1 for diodes, 2 for transistors, and so forth. The letters indicate the type and intended application of the device according to the following code:

SA:	PNP HF transistor	SB:	PNP AF transistor
SC:	NPN HF transistor	SD:	NPN AF transistor

SE: Diodes

SF: Thyristors

SG: Gunn devices

SH: UJT

SJ: P-channel FET

SK: N-channel FET

SM: Triac

SQ: LED

SR: Rectifier

SS: Signal diodes

ST: Avalanche diodes

SV: Varicaps

SZ: Zener diodes

The sequential numbers run from 10-9999. The optional suffix indicates that the type is approved for use by various Japanese organizations. Since the code for transistors always begins with 2S, it is sometimes omitted; for example, a 2SC733 could be marked C733.

Examples: 2SA1187, 2SB646, 2SC733.

3. Pro-Electron (European)

These part numbers take the form: two letters, [letter], sequential number, [suffix]

The first letter indicates the material:

A = Ge
B = Si
C = GaAs
R = compound materials.

The second letter indicates the device type and intended application:

A: diode, RF
B: diode,varactor
C: transistor, AF, small signal
D: transistor, AF, power
E: Tunnel diode
F: transistor, HF, small signal
K: Hall effect device
L: Transistor, HF, power
N: Opto-coupler
P: Radiation sensitive device
Q: Radiation producing device

R: Thyristor, Low power

T: Thyristor, Power

U: Transistor, power, switching

Y: Rectifier

Z: Zener, or voltage regulator diode

The third letter indicates if the device is intended for industrial or commercial applications. It's usually a W, X, Y, or Z. The sequential numbers run from 100-9999.

Examples: BC108A, BAW68, BF239, BFY51.

Instead of 2N and so forth, some manufacturers use their own system of designations. Some common prefixes are:

MJ: Motorola power, metal case

MJE: Motorola power, plastic case

MPS: Motorola low power, plastic case

MRF: Motorola HF, VHF and microwave transistor

RCA: RCA device

TIP: Texas Instruments (TI) power transistor, plastic case

TIPL: TI planar power transistor

TIS: TI small signal transistor (plastic case)

ZT: Ferranti

ZTX: Ferranti

Examples: ZTX302, TIP31A, MJE3055.

Trouble-Shooting

What Is It

Simply put, trouble-shooting is the art and science of getting something to work. If you work in electronics then, at some level, you will be involved in trouble-shooting. If you are a repair-tech, trouble-shooting is the name of the game. If you are a designer, then you will have to "debug" your designs which means trouble-shooting of another sort. Trouble-shooting can be divided into two kinds of situations: repair and development.

In repair, you know that the equipment you are trouble-shooting did, at one time, work. Then something happened that made it stop working. Maybe a component failed. Your job is to find out what went wrong and then to fix it.

In development you are working on prototypes. Either new designs or modifications of existing designs. In such a case, when it doesn't work properly there are three possibilities. First, as in repair, there may be a faulty component. Second, the breadboard or prototype wasn't built according to design. Third, there may be a fault in the design. Usually, there is a combination of all three in an early prototype.

We'll discuss some basic ideas of trouble-shooting that will apply to all situations. One principle should be stated right here: SAFETY FIRST. Don't do anything that may harm you, others, or the equipment you are working on. Remember that high voltage can cause burns, and a shock across your chest can stop your heart.

What You Will Need

Before starting to trouble-shoot, there are a few things you should have:

- A good set of tools (see our catalog).
- Appropriate test equipment (see our catalog).
- Schematics, source-code, and other documentation.
- A knowledge of what the equipment is supposed to do.
- If possible, a working unit for comparison.
- A knowledge of basic electronics theory and devices.
- A clean, well-lit place to work.

Check The Obvious

Some things that can go wrong are so obvious that sometimes people forget to look for them. Here is a partial list of things to check before you start ripping the equipment apart:

- Is it plugged in?
- Is it turned on?
- If the "ON" light is not lit, is the light burned out?
- Is the fuse blown? NOTE: If the fuse is blown, replace it once and try again. If it blows again, then there is a major problem somewhere; do not keep replacing the fuse.
- Are all the cables connected? To the right places?

Think Logically

In their frustration, novice trouble-shooters have been heard to say: "There's nothing wrong with this thing, it just refuses to work!". Equipment is inanimate. If it doesn't work, then there is something wrong with it. It's not being stubborn. So just keep cool and use some basic logic on it. It has to follow the laws of science.

One basic thing you should know about logic is the idea of Logical Induction. It says that if "A" causes "X" and "A" is true, then "X" must be true. But be careful! If "A" causes "X" and "X" is true it does not necessarily follow that "A" is true. Look at the circuit in ***Figure 1***. If switch "A" is closed (true) then light bulb "X" must be on (true). But if light bulb "X" is on, it is not necessary that switch "A" is closed since switch "B" might be closed instead. In other words, use common sense but don't leap to conclusions.

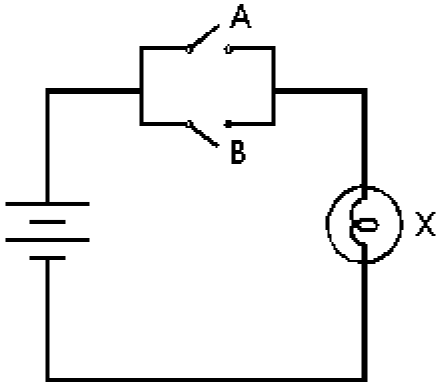


Figure 1

Here is an example of the above. In trouble-shooting, you often trace a signal from stage to stage to find out where it goes wrong. *Figure 2* shows a block diagram of a two-stage amplifier. Suppose the signal going into stage_1 is good but the signal coming out of stage_1 is bad. Does that mean that stage_1 must be defective? Not necessarily. Stage_2 could be defective in such a way that any signal on its input is shorted to ground. That will make the output of stage_1 look bad. If you disconnect the stages then the output of stage_1 might look good. But before separating stages, be careful! Does stage_1 need a certain load on its output to work? Find out first.

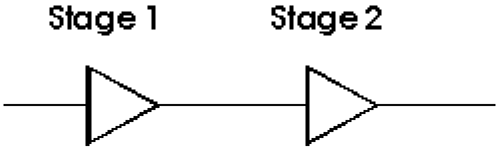


Figure 2

Where to Start

You check the obvious and decide that the equipment is actually broken. Where do you start? The answer is: where there is the most stress on the components. Stress kills. In electronic equipment stress takes the form of heat, vibration, moisture, corrosion, high voltages across components, and high current through components.

Places where you are likely to find high stress are:

- Power supplies.
- Power amplifiers.
- Output stages.
- Cable connectors, especially if subject to vibration or frequent coupling/uncoupling.
- Sockets.

If you are a field-service technician, then remember that to the customer in front of you with the broken equipment you are your company. You may have to "fix the customer" before you fix the equipment. People skills are important, especially if you're not going to be able to fix it that day.

What To Do Next

If you've looked at the usual suspects and they're not to blame, then the fun begins. Two useful things to do are "differential diagnosis" together with "what if". Differential diagnosis means you look at the problem and try to figure out all the things that could cause the observed symptoms. Then you try to figure out ways of telling one cause from another. For example, you see 5 Volts at a point where you should see 8 Volts. Possible causes may be:

1. problem in power supply
2. heavy load on 8 Volt bus
3. bad solder joint in 8 Volt bus

Then you go to those areas one by one looking for problems.

The what if technique is similar. You say to yourself something like: "OK, the 8 Volt bus is low. What if I disconnect the circuit from the bus and use an external 8 Volt supply? Can I damage something doing that? If that cures the symptom, then what have I learned? If it doesn't, then what have I learned?"

Time Is Money, Maybe Yours

Depending on how complicated the equipment is that you are trouble-shooting, you can divide it up into various levels as shown in *Figure 3*:

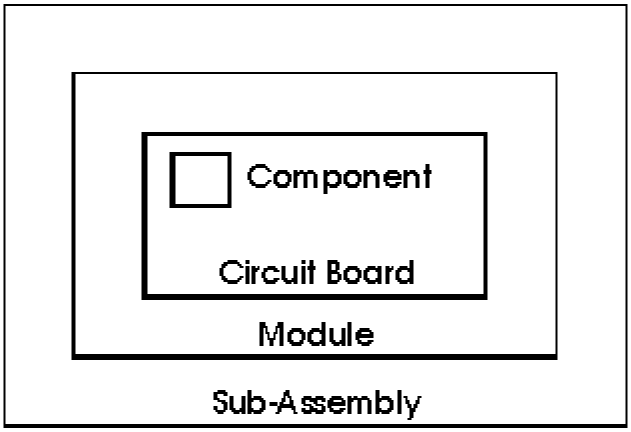


Figure 3

- sub-assembly
- module
- circuit-board
- component

How far down you go in finding the fault depends on the economics of the situation. If you are being paid $50 per hour and a module costs $20, then once you identify the faulty module it is cheaper to replace it than to repair it. On the other hand, if the module costs $500 but the circuit boards are $25, then it is cost-effective to continue trouble-shooting until you identify the bad board. But at that point it would be cheaper to replace the board than to trouble-shoot down to the bad component.

Buttoning Up

In summary, to be an effective electronics trouble-shooter you need to know how the circuits works, you need documentation, you need the right tools, and you need to be able to think logically. It also helps to have self-confidence, which will only increase with experience. So roll up your sleeves, turn on your test-equipment, get the schematic and a cup of coffee, and make that thing work!

Commonly Used Acronyms

A

A	Amperes
AC	Alternating Current
A/D	Analog to Digital
ADC	Analog to Digital Converter
AE	Applications Engineer
AI	Artificial Intelligence
ALU	Arithmetic-Logic Unit
AM	Amplitude Modulation
AMD	Advanced Micro Devices, Inc.
ANSI	American National Standards Institute
ARQ	Automatic Retransmission reQuest
ASCII	American Standard Code for Information Interchange
ASEE	American Society for Engineering Education
ASIC	Application Specific Integrated Circuit
ASPI	Advanced SCSI Programming Interface
ATDM	Asynchronous Time Division Multiplexing
ATM	Asynchronous Transfer Mode
AUI	Attached Unit Interface

B

B	Magnetic Flux
BBS	Bulletin Board System
BCC	Block Check Character
BCD	Binary Coded Decimal
BiCMOS	Bipolar Complementary Metal-Oxide Semiconductor
BIOS	Basic Input / Output System
BNC	Bayonet Nut(?) Connector
BPS/bps	Bytes/bits Per Second
BSC	Binary Synchronous Communications
BSD	Berkeley Standard Distribution

C

C	Capacitance
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CAM	Content Addressable Memory
CAS	Column Address Strobe
CBX	Common Branch eXtender
CCD	Charge Coupled Device
CCITT	Consultative Committee of International Telephony and Telegraphy
CD	Carrier Detect
CDDI	Copper Distributed Data Interface
CDROM	Compact Disk Read Only Memory
CDMA	Code Division Multiple Access
CGA	Color Graphics Adapter

CISC	Complex Instruction-Set Computer
CLA	Carry Look-ahead Adder
CMOS	Complementary Metal-Oxide Semiconductor
CP/M	Control Program / Monitor
CPI	Clocks Per Instruction
CPLD	Complex Programmable Logic Device
CPU	Central Processing Unit
CR	Carriage Return
CRC	Cyclic Redundancy Code
CRQ	Command Response Queue
CRT	Cathode Ray Tube
CS	Chip Select / Check-Sum
CSMA	Carrier Sense Multiple-Access
CSMA/CD	Carrier Sense Multiple-Access with Collision Detect
CSR	Command Status Register
CTS	Clear To Send

D

D	Dissipation Factor
D/A	Digital to Analog
DAC	Digital to Analog Converter
DAT	Digital Audio Tape
dB	(DB) deciBels
dBm	dB referenced to 1 milliWatt
DC	Direct Current
DCD	Data Carrier Detect
DCE	Data Circuit (Channel) Equipment

DD	Double Density
DDD	Direct Distance Dialing
DEC	Digital Equipment Corporation
DES	Data Encryption Standard
DID	Direct Inward Dial
DIN	Deutsche Industrie Norm
DIP	Dual-In-line Package
DMA	Direct Memory Access
DOS	Disk Operating System
DPDT	Double-Pole Double-Throw (switch)
DPE	Data Parity Error
DPSK	Differential Phase Shift Keying
DRAM	Dynamic Random Access Memory
DS	Double Sided
DSP	Digital Signal Processor
DSR	Data Set Ready
DTC	Data Terminal Controller
DTE	Data Terminal (Terminating) Equipment
DTMF	Dual-Tone Multi-Frequency
DTR	Data Terminal Ready
DVD	Digital Video Disk

E

E	EMF
EBCDIC	Extended Binary Coded Decimal Interchange Code
ECC	Error Correction Code
ECL	Emitter-Coupled Logic

ECN	Engineering Change Notice
ECO	Engineering Change Order
ECR	Engineering Change Request
EEPROM	Electrically Erasable Programmable Read-Only Memory
EGA	Enhanced Graphics Adapter
EIA	Electronic Industries Association
EISA	Enhanced Industry Standard Architecture
EMI	Electro-Magnetic Interference
EMF	Electro-Motive Force
EMS	Expanded Memory Specification
EOF	End Of File
EOL	End Of Line
EPROM	Erasable Programmable Read-Only Memory
ESD	Electro-Static Discharge
ESDI	Enhanced Small Devices Interface

F

F	Farads
FAT	File Allocation Table
FCC	Federal Communications Commission
FDD	Floppy Disk Drive
FDDI	Fiber Distributed Data Interface
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FDX	Full-Duplex Transmission
FE	Front End
FEP	Front End Processor

FF	Form Feed
FF	Flip-Flop
FFT	Fast Fourier Transform
FIFO	First-In First-Out
FILO	First-In Last-Out
FLOPS	Floating-point Operations Per Second
FM	Frequency Modulation
FPGA	Field Programmable Gate Array
FPU	Floating Point Unit
FRU	Field-Replaceable Unit
FSK	Frequency Shifty Keying
FTP	File Transfer Program

G - H - I

G	Giga
GAs	Gallium Arsenide
GFLOPS	Billions (10^9) of FLOating Point Operations Per Second ("Giga-Flops")
GHz	Giga Hertz
GNU	Gnu's Not Unix
GPIB	General Purpose Interface Bus
GUI	Graphical User Interface
H	Henries
H	Magnetic Force
HD	High Density
HDD	Hard Disk Drive
HDX	Half-Duplex Transmission
HFS	Hierarchical File System

HP	Hewlett-Packard
I	Current
HPIB	Hewlett-Packard Interface Bus
I/O	Input / Output
IBM	International Business Machines Corp.
IC	Integrated Circuit
IDC	Insulation Displacement Connector
IDE	Integrated Device Electronics
IEEE	Institute of Electrical and Electronic Engineers
IMP	Interface Message Processor
IP	Internet Protocol
IPC	InterProcess Communication
IRQ	Interrupt ReQuest
ISA	Industry Standard Architecture
ISDN	Integrated Services Digital Network
ISO	International Standards Organization
ISP	ISP Internet Service Provider

J - K - L

J	Joules of energy
K	Kilo
KVA	Kilo Volt-Amps
LAN	Local Area Network
LAP	Link Access Protocol
LAPB	Link Access Protocol Balanced
LCD	Liquid Crystal Display
LED	Light Emitting Diode

LF	Line Feed
LIFO	Last In First Out
LSB	Least Significant Bit (or Byte)
LSI	Large Scale Integration
LUN	Logical Unit Number

M

M	Mega
m	milli
MAN	Metropolitan Area Network
MB	Mega Bytes
MBR	Master Boot Record
MCA	Micro Channel Architecture
MCGA	Multi-Color Graphics Array
MCM	Multi-Chip Module
mfd	micro Farads
MFLOPS	Millions of FLOating Point Operations per Second ("MegaFlops")
MFM	Modified Frequency Modulated
MHz	MegaHertz
MIDI	Musical Instrument Digital Interface
MIPS	Millions of Instructions per Second
MMU	Memory Management Unit
MNP	Microcom Network Protocol
MODEM	MOdulator / DEModulator
MOPS	Millions of Operations Per Second
MOS	Metal-Oxide Semiconductor

MSB	Most Significant Bit (or Byte)
MSDOS	Microsoft Disk Operating System
MSI	Medium Scale Integration
MTBF	Mean Time Between Failures

N - O

n	nano
NAND	Not And
N/C	No-Connect
NBS	National Bureau of Standards
NEMA	National Electrical Manufacturers Association
NFS	Network File System
NIC	Network Interface Card
NIST	National Institute of Standards and Technology
NMI	Non-Maskable Interrupt
NMOS	Negatively doped Metal-Oxide Semiconductor
NOP	No OPeration
NSF	National Science Foundation
NVRAM	NonVolatile Random Access Memory
OCR	Optical Character Recognition
ODI	Open Datalink Interface
OEM	Original Equipment Manufacturer
OS	Operating System
OSF	Open Software Foundation
OSI	Open Systems Interconnect

P

p	pico
PAL	Programmable Array Logic
PLA	Programmable Logic Array
PB	Push Button
PBX	Private Branch eXchange
PC	Personal Computer, Program Counter
PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect
PCM	Pulse Code Modulation
PCMCIA	Personal Computer Memory Card International Association
PE	Professional Engineer
PGA	Pin Grid Array
PIA	Peripheral Interface Adapter
PIC	Programmable Interrupt Controller
PIO	Programmed Input/Output
PLCC	Plastic Leaded Chip Carrier
PLD	Programmable Logic Device
PLL	Phase Locked Loop
PMOS	Positively doped Metal-Oxide Semiconductor
POP	Post Office Protocol (email)
POST	Power On Self Test
POTS	Plain Old Telephone Service
PPP	Point-to-Point Protocol
PQFP	Plastic Quad-FlatPack
PROM	Programmable Read-Only Memory

PSTN	Public Switched Telephone Network

Q - R

Q	Charge
QAM	Quadrature Amplitude Modulation
QFP	Quad-FlatPack
R	Resistance
RAM	Random Access Memory
RAS	Row Address Strobe
RCA	Radio Corporation of America
R/C	Radio Control
RC	Resistor - Capacitor
RF	Radio Frequency
RFC	Radio Frequency Choke
RFI	Radio Frequency Interference
RFP	Request For Proposal
RFQ	Request For Quotation
RI	Ring Indicator
RISC	Reduced Instruction-Set Computer
RLL	Run Length Limited
RMS	Root Mean Square
ROM	Read-Only Memory
RPM	Revolutions Per Minute
RS	Recommended Specification
RTC	Real Time Clock
RTS	Request To Send

S

S	Siemens
SASI	Shugart Associates Standard Interface
SCSI	Small Computer Systems Interface
SD	Single Density
SDLC	Synchronous Data Link Control
SIMM	Single Inline Memory Module
SIP	Single Inline Package
SLIP	Serial Line Internet Protocol
SMD	Surface Mount Device
SMT	Surface Mount Technology
SNA	System Network Architecture
SNR	Signal to Noise Ratio
SOT	Small Outline Transistor
SOIC	Small Outline Integrated Circuit
SPOOL	Simultaneous Peripheral Operation On Line
SPST	Single-Pole Single-Throw (switch)
SPT	Sectors Per Track
SQE	Signal Quality Error
SRAM	Static Random Access Memory
SS	Single Sided
STDM	Synchronous Time Division Multiplexing
STN	Super Twisted Nematic
STP	Shielded Twisted Pair
STU	Streaming Tape Unit
SVGA	Super Video Graphics Array

T

TCM	Trellis Code Modulation
TCP/IP	Transmission Control Protocol / Internet Protocol
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TI	Texas Instruments
TIA	Telecomm. Industry Assocation
TPI	Tracks Per Inch
TSR	Terminate and Stay Resident
TTL	Transistor-Transistor Logic
TUV	Technischer Ueberwachuags Verein

U - V

UV	Ultra Violet
UART	Universal Asynchronous Receiver/Transmitter
UDP	User Datagram Protocol
UMB	Upper Memory Block
UPS	Uninterruptible Power Supply
UTP	Unshielded Twisted Pair
UUCP	Unix to Unix Copy Program
VCR	Video Cassette Recorder
VESA	Video Enhanced Standards Association
VGA	Video Graphics Array
VLB	VESA Local Bus
VLSI	Very Large Scale Integration
VM	Virtual Memory

VME	Versa Module Eurocard
VRAM	Video Random Access Memory
VTR	Video Tape Recorder

W - X - Y - Z

W	Watts
WAN	Wide Area Network
WATS	Wide Area Telephone Service
WORM	Write-Once Read-Many
WWW	World Wide Web
XGA	eXtended Graphics Array
XMS	Extended Memory Specification
XOR	Exclusive-Or
Y	Admittance
Z	Impedance
ZIF	Zero Insertion Force

Capacitor Code Guide

VALUE	TYPE	CODE	VALUE	TYPE	CODE
1.5pF	Ceramic		1,000pF / .001uF	Ceramic / Mylar	102
3.3pF	Ceramic		1,500pF / .0015uF	Ceramic / Mylar	152
10pF	Ceramic		2,000pF / .002uF	Ceramic / Mylar	202
15pF	Ceramic		2,200pF / .0022uF	Ceramic / Mylar	222
20pF	Ceramic		4,700pF / .0047uF	Ceramic / Mylar	472
30pF	Ceramic		5,000pF / .005uF	Ceramic / Mylar	502
33pF	Ceramic		5,600pF / .0056uF	Ceramic / Mylar	562
47pF	Ceramic		6,800pF / .0068uF	Ceramic / Mylar	682
56pF	Ceramic		.01	Ceramic / Mylar	103
68pF	Ceramic		.015	Mylar	

75pF	Ceramic		.02	Mylar	203
82pF	Ceramic		.022	Mylar	223
91pF	Ceramic		.033	Mylar	333
100pF	Ceramic	101	.047	Mylar	473
120pF	Ceramic	121	.05	Mylar	503
130pF	Ceramic	131	.056	Mylar	563
150pF	Ceramic	151	.068	Mylar	683
180pF	Ceramic	181	.1	Mylar	104
220pF	Ceramic	221	.2	Mylar	204
330pF	Ceramic	331	.22	Mylar	224
470pF	Ceramic	471	.33	Mylar	334
560pF	Ceramic	561	.47	Mylar	474
680pF	Ceramic	681	.56	Mylar	564
750pF	Ceramic	751	1	Mylar	105
820pF	Ceramic	821	2	Mylar	205

Usually the first two digits of the code represent part of the value; the third digit corresponds to the number of zeros to be added to the first two digits. This is the value in pf.

For Example: CODE: 4 7 3

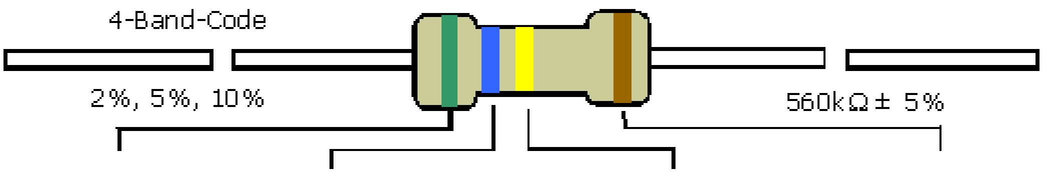
VALUE: 4 7 $\overbrace{0\,0\,0}$ or .047uF

Diode Data

Device	Type	Material	PIV (Volts)	Forward (Reverse) Io (Ir)	Max Surge Max Current Ifsm 1sec.@25C Amps	Max Drop Vf Volts
1N34	Signal	Germanium	60	8.5 mA(15.0 uA		1.0
1N34A	Signal	Germanium	60	5.0 mA(30.0 uA)		1.0
1N67A	Signal	Germanium	100	4.0 mA(5.0 uA)		1.0
1N191	Signal	Germanium	90	5.0 mA		1.0
1N270	Signal	Germanium	80	200 mA(100 uA)		1.0
1N914	Switch	Silicon	75	10.0 mA(25.0 nA)	0.5	1.0
1N2071	Rect.	Silicon	600	0.75 mA(10.0 uA)		0.6
1N4001	Rect.	Silicon	50	1.0 A (0.03 mA		1.1
1N4002	Rect.	Silicon	100	1.0 A (0.03 mA)		1.1
1N4003	Rect.	Silicon	200	1.0 A (0.03 mA)		1.1
1N4004	Rect.	Silicon	400	1.0 A (0.03 mA)		1.1

1N4005	Rect.	Silicon	600	1.0 A (0.03 mA)			1.1
1N4006	Rect.	Silicon	800	1.0 (0.03m)			1.1
1N4007	Rect.	Silicon	1000	1.0 (0.03m)			1.1
1N4148	Signal	Silicon	75	10.0 mA (25.0 nA)			1.0
1N4149	Signal	Silicon	75	10.0 mA (25.0 nA)			1.0
1N914	Switch	Silicon	40	20.0 mA (0.05 uA)			0.8
1N4445	Signal	Silicon	100	0.1 A (50.0 nA)			1.0
1N5400	Rect.	Silicon	50	3.0	200	-	
1N5401	Rect.	Silicon	100	3.0	200	-	
1N5402	Rect.	Silicon	200	3.0	200	-	
1N5403	Rect.	Silicon	300	3.0	200	-	
1N5404	Rect.	Silicon	400	3.0	200	-	
1N5405	Rect.	Silicon	500	3.0	200	-	
1N5406	Rect.	Silicon	600	3.0	200	-	
1N5767	Signal	Silicon		0.1(1.0uA)			1.0

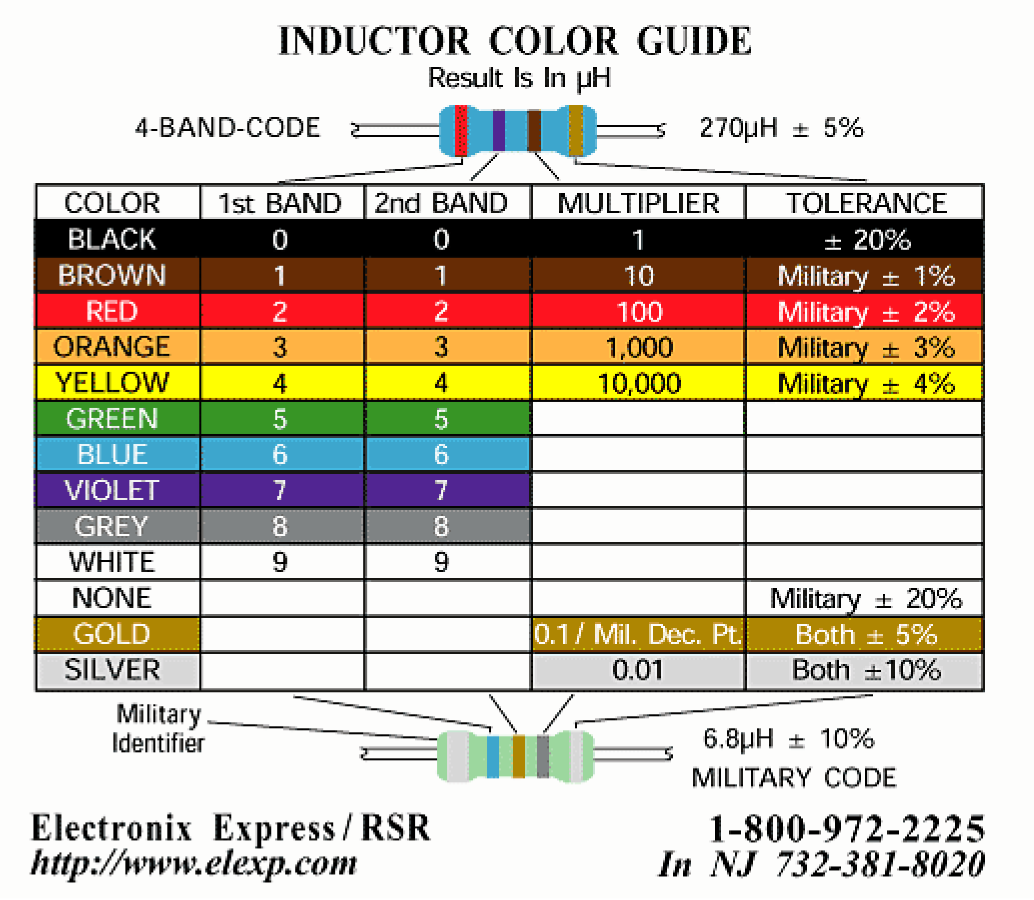
Resistor Color Code Guide



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

Electronix Express / RSR
http://www.elexp.com

1-800-972-2225
In NJ 732-381-8020



INDUCTOR COLOR GUIDE

Result Is In µH

COLOR	1st BAND	2nd BAND	MULTIPLIER	TOLERANCE
BLACK	0	0	1	± 20%
BROWN	1	1	10	Military ± 1%
RED	2	2	100	Military ± 2%
ORANGE	3	3	1,000	Military ± 3%
YELLOW	4	4	10,000	Military ± 4%
GREEN	5	5		
BLUE	6	6		
VIOLET	7	7		
GREY	8	8		
WHITE	9	9		
NONE				Military ± 20%
GOLD			0.1 / Mil. Dec. Pt.	Both ± 5%
SILVER			0.01	Both ±10%

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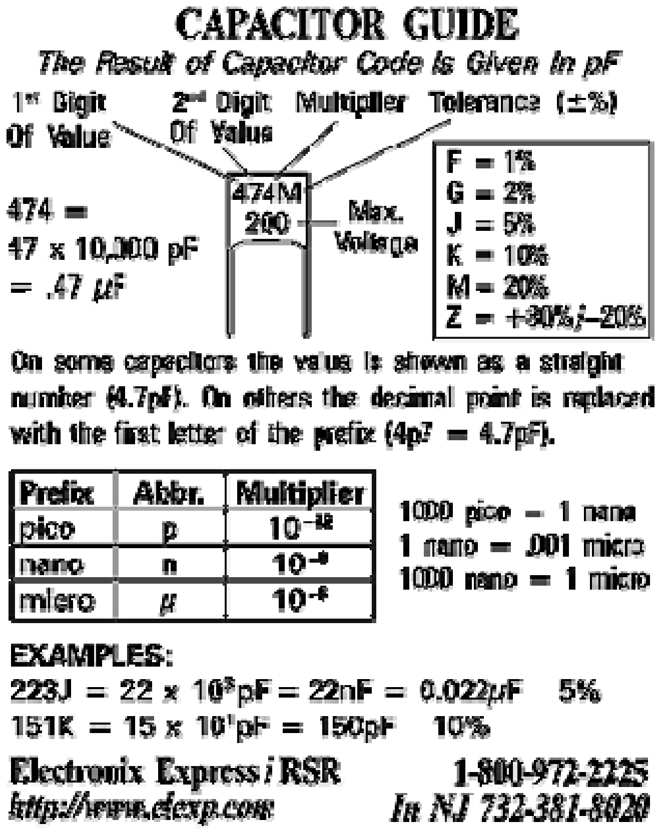

CAPACITOR GUIDE

The Result of Capacitor Code Is Given In pF

474 =
47 x 10,000 pF
= .47 µF

F = 1%
G = 2%
J = 5%
K = 10%
M = 20%
Z = +80%/–20%

On some capacitors the value is shown as a straight number (4.7pF). On others the decimal point is replaced with the first letter of the prefix (4p7 = 4.7pF).

Prefix	Abbr.	Multiplier
pico	p	10^{-12}
nano	n	10^{-9}
micro	µ	10^{-6}

1000 pico = 1 nano
1 nano = .001 micro
1000 nano = 1 micro

EXAMPLES:

223J = 22 x 10^3pF = 22nF = 0.022µF 5%
151K = 15 x 10^1pF = 150pF 10%

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EIA STANDARD RESISTOR VALUES

These values under 100 Ohms are meant to show the significant digits. All resistors would have these values multiplied by the appropriate power of 10. For example, a 1% resistor could be 10.2 Ohms, 102 Ohms, 1020 Ohms, 10200 Ohms, and so forth.

0.1%, 0.25%, & 0.5%	**1%**	**2% & 5%**	**10%**
10.0	10.0	10.0	10.0
10.1	10.2	11.0	12.0
10.2	10.5	12.0	15.0
10.4	10.7	13.0	18.0
10.5	11.0	15.0	22.0
10.6	11.3	16.0	27.0
10.7	11.5	18.0	33.0
10.9	11.8	20.0	39.0
11.0	12.1	22.0	47.0
11.1	12.4	24.0	56.0
11.3	12.7	27.0	68.0
11.4	13.0	30.0	82.0
11.5	13.3	33.0	
11.7	13.7	36.0	
11.8	14.0	39.0	
12.0	14.3	43.0	
12.1	14.7	47.0	
12.3	15.0	51.0	
12.4	15.4	56.0	
12.6	15.8	62.0	

12.7	16.2	68.0	
12.9	16.5	75.0	
13.0	16.9	82.0	
13.2	17.4	91.0	
13.3	17.8		
13.5	18.2		
13.7	18.7		
13.8	19.1		
14.0	19.6		
14.2	20.0		
14.3	20.5		
14.5	21.0		
14.7	21.5		
14.9	22.1		
15.0	22.6		
15.2	23.2		
15.4	23.7		
15.6	24.3		
15.8	24.9		
16.0	25.5		
16.2	26.1		
16.4	26.7		

16.5	27.4		
16.7	28.0		
16.9	28.7		
17.2	29.4		
17.4	30.1		
17.6	30.9		
17.8	31.6		
18.0	32.4		
18.2	33.2		
18.4	34.0		
18.7	34.8		
18.9	35.7		
19.1	36.5		
19.3	37.4		
19.6	38.3		
19.8	39.2		
20.0	40.2		
20.3	41.2		
20.5	42.2		
20.8	43.2		
21.0	44.2		
21.3	45.3		

21.5	46.4		
21.8	47.5		
22.1	48.7		
22.3	49.9		
22.6	51.1		
22.9	52.3		
23.2	53.6		
24.4	54.9		
23.7	56.2		
24.0	57.6		
24.3	59.0		
24.6	60.4		
24.9	61.9		
25.2	63.4		
25.5	64.9		
25.8	65.5		
26.1	68.1		
26.4	69.8		
26.7	71.5		
27.1	73.2		
27.4	75.0		
27.7	76.8		

28.0	78.7		
28.4	80.6		
28.7	82.5		
29.1	84.5		
29.4	86.6		
29.8	88.7		
30.1	90.9		
30.5	93.1		
30.9	95.3		
31.2	97.6		
31.6			
32.0			
32.4			
32.8			
33.2			
33.6			
34.0			
34.4			
34.8			
35.2			
35.7			
36.1			

36.5			
37.0			
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45.9			
46.4			
47.0			

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59.7			
60.4			
61.2			

61.9			
62.9			
63.4			
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65.5			
67.3			
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69.0			
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74.1			
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80.6			
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84.5			
85.6			
86.6			
87.6			
88.7			
89.8			
90.9			
92.0			
93.1			
94.2			
95.3			
96.5			
97.6			
98.8			

5% Carbon Film and 1% Metal Film Resistor Charts

5% Carbon Film Resistors

Table of Values in Ohms

1.0	5.6	33	160	820	3.9K	20K	100K	510K	2.7M
1.1	6.2	36	180	910	4.3K	22K	110K	560K	3M
1.2	6.8	39	200	1K	4.7K	24K	120K	620K	3.3M
1.3	7.5	43	220	1.1K	5.1K	27K	130K	680K	3.6M
1.5	8.2	47	240	1.2K	5.6K	30K	150K	750K	3.9M
1.6	9.1	51	270	1.3K	6.2K	33K	160K	820K	4.3M
1.8	10	56	300	1.5K	6.6K	36K	180K	910K	4.7M
2.0	11	62	330	1.6K	7.5K	39K	200K	1M	5.1M
2.2	12	68	360	1.8K	8.2K	43K	220K	1.1M	5.6M
2.4	13	75	390	2K	9.1K	47K	240K	1.2M	6.2M
2.7	15	82	430	2.2K	10K	51K	270K	1.3M	6.8M
3.0	16	91	470	2.4K	11K	56K	300K	1.5M	7.5M
3.3	18	100	510	2.7K	12K	62K	330K	1.6M	8.2M
3.6	20	110	560	3K	13K	68K	360K	1.8M	9.1M
3.9	22	120	620	3.2K	15K	75K	390K	2M	10M
4.3	24	130	680	3.3K	16K	82K	430K	2.2M	15M
4.7	27	150	750	3.6K	18K	91K	470K	2.4M	22M
5.1	30								

To Top Of Page

1% Metal Film Resistors

Table of Values in Ohms

10	33	100	332	1K	3.32K	10.5K	34K	107K	357K
10.2	33.2	102	340	1.02K	3.4K	10.7K	34.8K	110K	360K
10.5	34	105	348	1.05K	3.48K	11K	35.7K	113K	365K
10.7	34.8	107	350	1.07K	3.57K	11.3K	36K	115K	374K
11	35.7	110	357	1.1K	3.6K	11.5K	36.5K	118K	383K
11.3	36	113	360	1.13K	3.65K	11.8K	37.4K	120K	390K
11.5	36.5	115	365	1.15K	3.74K	12K	38.3K	121K	392K
11.8	37.4	118	374	1.18K	3.83K	12.1K	39K	124K	402K
12	38.3	120	383	1.2K	3.9K	12.4K	39.2K	127K	412K
12.1	39	121	390	1.21K	3.92K	12.7K	40.2K	130K	422K
12.4	39.2	124	392	1.24K	4.02K	13K	41.2K	133K	430K
12.7	40.2	127	402	1.27K	4.12K	13.3K	42.2K	137K	432K

13	41.2	130	412	1.3K	4.22K	13.7K	43K	140K	442K
13.3	42.2	133	422	1.33K	4.32K	14K	43.2K	143K	453K
13.7	43	137	430	1.37K	4.42K	14.3K	44.2K	147K	464K
14	43.2	140	432	1.4K	4.53K	14.7K	45.3K	150K	470K
14.3	44.2	143	442	1.43K	4.64K	15K	46.4K	154K	475K
14.7	45.3	147	453	1.47K	4.7K	15.4K	47K	158K	487K
15	46.4	150	464	1.5K	4.75K	15.8K	47.5K	160K	499K
15.4	47	154	470	1.54K	4.87K	16K	48.7K	162K	511K
15.8	47.5	158	475	1.58K	4.99K	16.2K	49.9K	165K	523K
16	48.7	160	487	1.6K	5.1K	16.5K	51K	169K	536K
16.2	49.9	162	499	1.62K	5.11K	16.9K	51.1K	174K	549K
16.5	51	165	510	1.65K	5.23K	17.4K	52.3K	178K	560K
16.9	51.1	169	511	1.69K	5.36K	17.8K	53.6K	180K	562K
17.4	52.3	174	523	1.74K	5.49K	18K	54.9K	182K	576K
17.8	53.6	178	536	1.78K	5.6K	18.2K	56K	187K	590K
18	54.9	180	549	1.8K	5.62K	18.7K	56.2K	191K	604K
18.2	56	182	560	1.82K	5.76K	19.1K	57.6K	196K	619K
18.7	56.2	187	562	1.87K	5.9K	19.6K	59K	200K	620K
19.1	57.6	191	565	1.91K	6.04K	20K	60.4K	205K	634K
19.6	59	196	578	1.96K	6.19K	20.5K	61.9K	210K	649K
20	60.4	200	590	2K	6.2K	21K	62K	215K	665K
20.5	61.9	205	604	2.05K	6.34K	21.5K	63.4K	220K	680K
21	62	210	619	2.1K	6.49K	22K	64.9K	221K	681K
21.5	63.4	215	620	2.15K	6.65K	22.1K	66.5K	226K	698K
22	64.9	220	634	2.2K	6.8K	22.6K	68K	232K	715K
22.1	66.5	221	649	2.21K	6.81K	23.2K	68.1K	237K	732K
22.6	68	226	665	2.26K	6.98K	23.7K	69.8K	240K	750K
23.2	68.1	232	680	2.32K	7.15K	24K	71.5K	243K	768K
23.7	69.8	237	681	2.37	7.32K	24.3K	73.2K	249K	787K
24	71.5	240	698	2.4K	7.5K	24.9K	75K	255K	806K
24.3	73.2	243	715	2.43K	7.68K	25.5K	76.8K	261K	820K
24.7	75	249	732	2.49K	7.87K	26.1K	78.7K	267K	825K
24.9	75.5	255	750	2.55K	8.06K	26.7K	80.6K	270K	845K
25.5	76.8	261	768	2.61K	8.2K	27K	82K	274K	866K
26.1	78.7	267	787	2.67K	8.25K	27.4K	82.5K	280K	887K
26.7	80.6	270	806	2.7K	8.45K	28K	84.5K	287K	909K
27	82	274	820	2.74K	8.66K	28.7K	86.6K	294K	910K
27.4	82.5	280	825	2.8K	8.8K	29.4K	88.7K	300K	931K
28	84.5	287	845	2.87K	8.87K	30K	90.9K	301K	953K
28.7	86.6	294	866	2.94K	9.09K	30.1K	91K	309K	976K
29.4	88.7	300	887	3.0K	9.1K	30.9K	93.1K	316K	1.0M

30	90.9	301	909	3.01K	9.31K	31.6K	95.3K	324K	1.5M
30.1	91	309	910	3.09K	9.53K	32.4K	97.6K	330K	2.2M
30.9	93.1	316	931	3.16K	9.76K	33K	100K	332K	
31.6	95.3	324	953	3.24K	10K	33.2K	102K	340K	
32.4	97.6	330	976	3.3K	10.2K	33.6K	105K	348K	

Telephony Dialing and Signaling Tones

North American Call Progress Tones (CPTs)

FUNCTION	FREQUENCIES	TIMING
Dial Tone	350 Hz + 440 Hz	Continuous
Ring Back	440 Hz + 480 Hz	ON 2.0, OFF 4.0 seconds
Busy	480 Hz + 620 Hz	On 0.5, OFF 0.5 seconds

RING SIGNAL TO PHONE:

Voltage: 40 Volts RMS (or more) at 20 Hertz (sinusoidal)

Timing: ON 2.0, OFF 4.0 Seconds

THE DIALER: PULSE and TONE

In the early days, to call someone you picked up the telephone and told the operator the number of the person to whom you wanted to be connected. Then the operator connected you. But soon telephones were built so that you entered the number yourself. Originally, you entered the numbers by means of a rotary "dial" as shown in *Figure 1 (A)*. As you "dialed" the digits of the number, a switch connected to the rotary would pulse the DC loop-current. *Figure 1 (B)* shows that when the digit 3 was dialed, the loop-current was interrupted three times. The central office equipment would detect the pulses and decode the number.

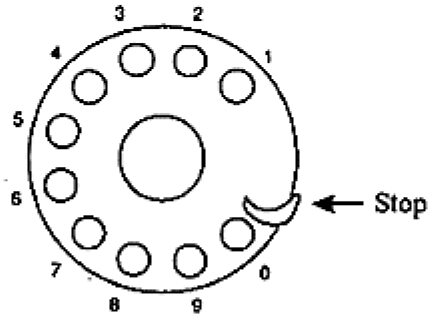

Figure 1 (A)

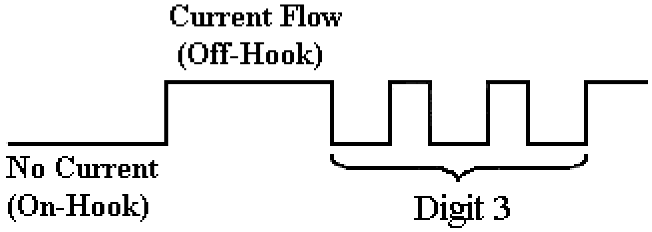

Figure 1 (B)

Newer phones use a system called "Dual-Tone Multi-Frequency" or DTMF. Touch-Tone(r) is the name used by AT&T for the system. DTMF uses push-buttons as shown in *Figure 2*. When you push the button corresponding to a digit, circuitry inside the telephone generates a pair of tones. For example, pushing the button for digit 3 will produce a 697 Hertz tone along with a 1477 Hertz tone. Equipment at the central office detects the tones and decodes the number.

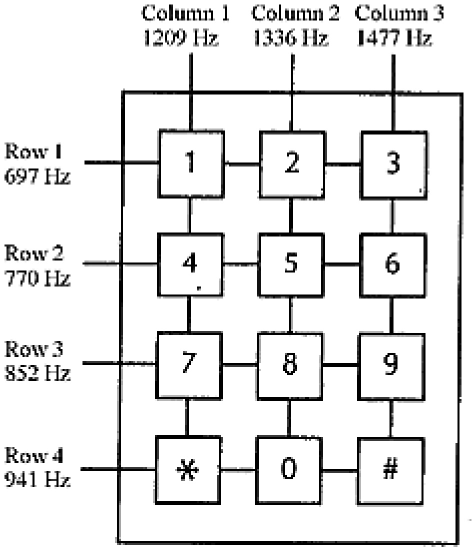

Figure 2

General Purpose Transistors

Vceo - Collector-Emitter Voltage
Vcbo - Collector-Base Voltage
Vebo - Emitter-Base Voltage
Ic - Collector Current
Pd - Device Dissipation

Device	Type	Vceo Max. V	Vcbo Max. V	Vebo Max. V	Ic Max. mA	Pd Max. W	Beta (hfe) @ Ic = Low, High	BW (fT) MHz	Noise Figure dB

2N918	NPN	15	30	3.0	50	.0200	20, -	600	6.0
2N2102	NPN	65	120	7.0	1000	1.0	20, 40	60	6.0
2N2218	NPN	30	60	5.0	800	0.8	20, 40	250	
2N2218A	NPN	40	75	6.0	800	0.8	20, 40	250	
2N2219	NPN	30	60	5.0	800	3.0	35,100	250	
2N2219A	NPN	40	75	6.0	800	3.0	35,100	300	4.0
2N2222	NPN	30	60	5.0	800	1.2	35,100	250	
2N2222A	NPN	40	75	6.0	800	1.2	35,100	300	4.0
2N2905	PNP	40	60	5.0	600	0.6	35	200	
2N2905A	PNP	60	60	5.0	600	0.6	75,100	200	
2N2907	PNP	40	60	5.0	600	0.400	35	200	
2N2907A	PNP	60	60	5.0	600	0.400	75,100	200	
2N3053	NPN	40	60	5.0	700	5.0	- , 50	100	
2N3053A	NPN	60	80	5.0	700	5.0	- , 50	100	

Device	Type	Vceo Max. V	Vcbo Max. V	Vebo Max. V	Ic Max. mA	Pd Max. W	Beta (hfe) @ Ic = Low, High	BW (fT) MHz	Noise Figure dB
2N3904	NPN	40	60	6.0	200	0.625	40, -	300	5.0
2N3906	PNP	40	40	5.0	200	1.5	60, -	250	4.0
2N4037	PNP	40	60	7.0	1000	5.0	- , 50		
2N4123	NPN	30	40	5.0	200	0.350	- , 25	250	6.0
2N4124	NPN	25	30	5.0	200	0.350	120, 60	300	5.0
2N4125	PNP	30	30	4.0	200	0.625	50, 25	200	5.0
2N4126	PNP	25	25	4.0	200	0.625	120, 60	250	4.0
2N4401	NPN	40	60	6.0	600	0.625	20,100	250	
2N4403	PNP	40	40	5.0	600	0.625	30,100	200	
2N5320	NPN	75	100	7.0	2000	10.0	- ,30		
2N5415	PNP	200	200	4.0	1000	10.0	- ,30	15	
MM4003	PNP	250	200	4.0	500	1.0	20, -		
MPS6547	NPN	25	35	3.0	50	0.625	20, -	600	

Wire Chart

AWG SIZE	D.C. OHMS PER 1000 FT	WIRE DIA INCHES	APPROX. TURNS PER INCH, SOLID ENAMEL COVERED	FEET PER POUND

1	.1264	.2893	X	3.947
2	.1593	.2576	X	4.977
3	.2009	.2294	X	6.276
4	.2533	.2043	X	7.914
5	.3195	.1819	X	9.980
6	.4028	.1620	X	12.58
7	.5080	.1443	X	15.87
8	.6405	.1286	7.6	20.01
9	.8077	.1144	8.6	25.23
10	1.018	.1019	9.6	31.82
11	1.284	.0907	10.7	40.12
12	1.619	.0808	12.0	50.59
13	2.042	.0720	13.5	63.80
14	2.524	.0641	15.0	80.44
15	3.181	.0571	16.8	101.40
16	4.018	.0508	18.9	127.90
17	5.054	.0453	21.2	161.3
18	6.386	.0403	23.6	203.4
19	8.046	.0359	26.4	256.5
20	10.13	.0320	29.4	323.4
21	12.77	.0285	33.1	407.8
22	16.20	.0253	37.0	514.2
23	20.30	.0226	41.3	648.4
24	25.67	.0201	46.3	817.7
25	32.37	.0179	51.7	1031
26	41.02	.0159	58.0	1300
27	51.44	.0142	64.9	1639
28	65.31	.0126	72.7	2067
29	81.21	.0113	81.6	2607
30	103.7	.0100	90.5	3287
31	130.9	.0089	101	4145
32	162.0	.0080	113	5227
33	205.7	.0071	127	6591
34	261.3	.0063	143	8310
35	330.7	.0056	158	10480
36	414.8	.0050	175	13210
37	512.1	.0045	198	16660
38	648.2	.0040	224	21010
39	846.6	.0036	248	26500
40	1079	.0031	282	33410
41	1323	.0028		

42	1659	.0025
43	2143	.0022
44	2593	.0020
45	3348	.00176
46	4207	.00157
47	5291	.00140

Magnet wire coatings from Phelps-Dodge:

All data pertain to 18 AWG magnet wire. Build = thickness of coating

COATING	MATERIAL	BUILD	DC BREAKDOWN
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Thermaleze-T (TZT)	polyester-imide	2.8mils	11kV
Armored (APTZ)	Polythemaleze modified polyester and modified polyamide-imide	3.05mils	11kV
Imideze (ML)	Aromatic polyimide	2.9mils	12kV
Formvar	modified polyviynyl formal	3.0mils	10kV
Sodereze	modified polyurethane	2.9mils	8.5kV
Nyleze	Polyurethane and polyamide	2.9mils	8.5kV

Dielectric constant/DF numbers for these materials:

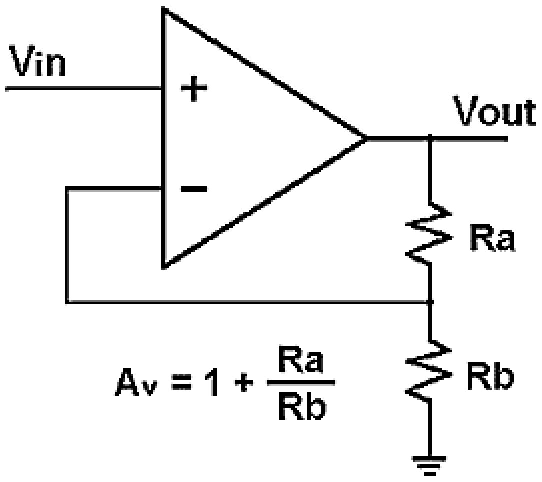
Material	Dielectric Const. / DF x 10^-3			
	1kHz	100kHz	1Mhz	Rating
TZT	3.7/5.6	3.56/16.4	3.58/21.5	3rd
APTZ	3.86/6.9	3.69/22.1	3.67/26.6	5th
ML	3.34/0.9	3.3/5.7	3.36/9.8	2nd to teflon
Formvar*	3.6/11.2	3.41/25.2	3.37/28.4	5th
Soldereze	3.85/11.3	3.66/20.7	3.66/23.1	4th

Nyleze	4.07/19.7	3.78/27.1	3.75/27.2	6th

Using The Find_R Utility Program

There are applications of Op-Amps, such as in active filter circuits, that require a precise gain. Such circuits often use the non-inverting configuration as shown in *Figure 1* below. The gain of the amplifier is given by the equation below. Note that the gain must be greater than unity (i.e. Av greater than 1).

$$Av = 1 + \frac{Ra}{Rb}$$



There are two ways to achieve a precise gain:

1. **Use a potentiometer**
   For example, a 10k Ohm, 20-turn trimmer type potentiometer could be used to set almost any value of gain. But such potentiometers are expensive relative to the cost of other components. And they need to be adjusted by a technician while measuring the gain. For a circuit being made in large quantities, that's a very expensive thing to do.
2. **Use two precision resistors for Ra and Rb**
   If an accuracy of 1% is sufficient, then using two 1% precision resistors is very cost effective. But for arbitrary values of gain (e.g. 1.414) it can be tedious to find the pair of resistor values that will come closest to achieving the desired value. Of course, you would need to try every likely combination of values and see which pair comes closest. There are so many values of 1% resistors, where do you start? But hey, that's why they make computers!

The **FIND_R** program is small and quick. It runs in a DOS box under Windows. When run, FIND_R prompts you for the gain you want to achieve. It then finds the best combination of values to give you that gain. It also calculates the actual gain you achieve using those values, as well as the percent error between the desired gain and the actual gain. The percent error is typically in the range of 0.00 % to 0.03 %, which is well within the tolerance of 1% resistors.

If you find this program to be useful, please let us know. If you have any suggestions for other utility programs, please pass them along. Someone on our engineering team just might write a program to do it.

"Quick and Dirty" Audio Amplifiers

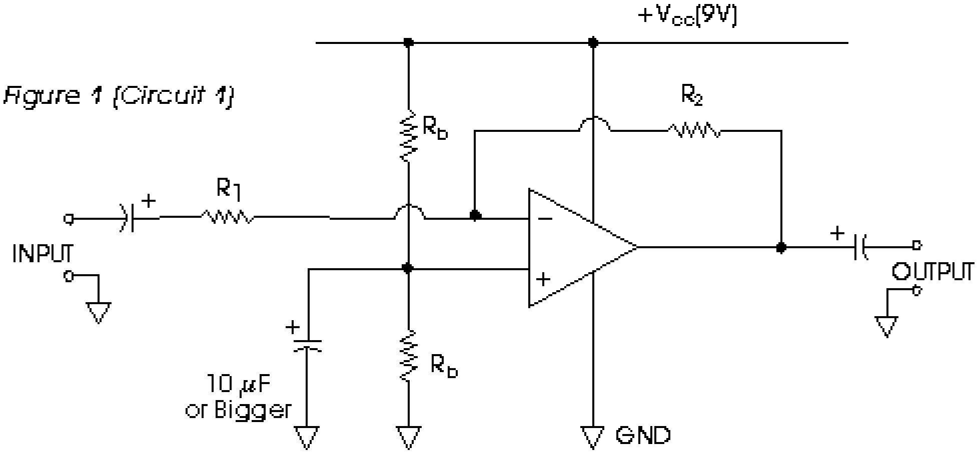


Figure 1 (Circuit 1)

For those of you who like to experiment with audio circuits and would like a "quick and dirty" amplifier that frees you from having to figure out the biasing resistors, we have two for you (and they run off 9 Volts too!). One uses an Op-Amp *(Figure 1)* and the other uses a transistor *(Figure 2)*.

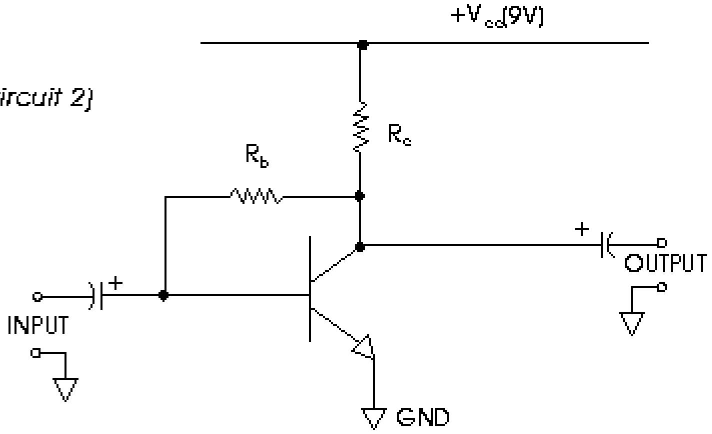
Both circuits need capacitors on the input and output to block DC while passing AC. The capacitor values depend on which circuit you use and what signal frequency you are amplifying. Start with a 1uF and go from there. Low frequencies may require a bigger value. *(See Figure 1)*

While Op-Amps normally run off of a dual voltage supply (+V and -V), it is possible to run them from a single voltage by using two equal value resistors (Rb) to create a separate DC grounding point midway between Vcc and actual ground, just for biasing the Op-Amp. The DC ground is connected to actual ground through a by-pass capacitor. The value of Rb is not critical; 10K should work just fine. To minimize DC offset in the output, Rb should have a 1% tolerance.

The gain of the amplifier is set by R1 and R2 {Av = R2/R1}. R2 should be 2K or bigger so as not to load the Op-Amp too much. If you use a bipolar device such as the venerable 741, the output can't go lower than 2 volts above ground or higher than 2 volts below Vcc. So with a 9-volt battery, the maximum output swing will be 5 volts: from 2V to 7V. If you want to go "rail-to-rail" from Vcc to

Ground, then use a CMOS device like the CA3130; Vcc can then be as high as the Op-Amp allows. The CA3130 requires a 100 pF compensation capacitor.

Figure 2 (Circuit 2)



If you really want "quick and dirty", this one transistor circuit is an 'oldie but goodie'. ***(See Figure 2)***. Note that by connecting the base-bias resistor Rb to the collector you get two benefits: 1) the biasing can not cause saturation or cut-off and 2) you introduce some negative feedback into the signal path which reduces distortion. It's not as good as the Op-Amp circuit but it does work. As for gain, you'll just have to measure it and see. Play around with different values of Rc, and make Rb = 100Rc. The input signal should not exceed 30mVp-p.

Parts List (Based on an AF signal of 1khz):

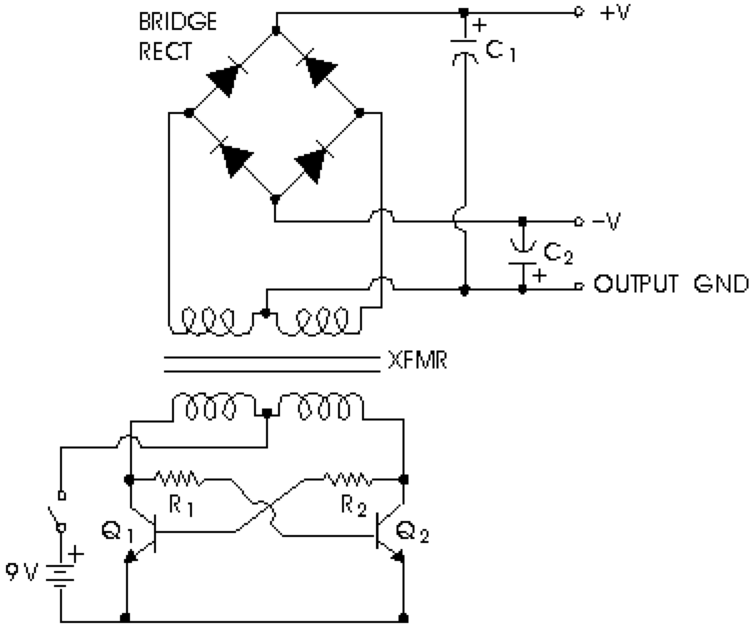
For Circuit #1	Circuit #1 w/CA3130:	For Circuit #2:
1 LM741 Op Amp	1 CA3130 Op Amp	1 2N3904 Transistor
2 1 uF Capacitor	2 1uF Capacitor	2 1 uF Capacitor
1 10 uF Capacitor	1 10 uF Capacitor	1 1K .5W Resistor
4 10K .5W 1% Res	1 100pF Capacitor	1 10K .5W Resistor
1 100K .5W Res	4 10K .5W 1% Res	1 100K .5W Resistor
1 9V Battery	1 100K .5W Res	1 9V Battery

Simple DC-DC Converter

Allows Use of Single Battery

Have you ever wanted to build a circuit to run off a single 9 Volt battery only to find you needed levels like +12 and -12 Volts? The thought of multiple batteries might have put you off. Why not use a simple DC to DC converter?

Just to prove a point, here's a DC to DC circuit put together just from parts found on the test-bench. All it took was two transistors, two resistors, an audio transformer, a bridge and two caps. It may not be the ultimate in performance, but it does work.



DC-TO-DC CONVERTER

The key to how it works is the transformer. As you can see, two transistors drive the transformer primary with the base drive for each coming from the collector of the other. When power is applied, suppose Q1 turns on a few nanoseconds faster than Q2.

As Q1 turns on two things happen: The Q1 collector voltage drops shutting off Q2, and Q2 collector voltage rises turning Q1 on more. Q1 collector voltage drops due to the inductive reactance of the primary coil.

As current flows through the transformer primary, a voltage is induced in the secondary by the expanding magnetic field in the transformer core. But at some point the magnetic field stops expanding, because either the transistor reached the maximum collector current it could pass or because the transformer core reached the maximum magnetic field it could hold. Either way, the inductive reactance of the primary drops causing the voltage on the collector of Q1 to rise.

Since the collector of Q1 drives the base of Q2, Q2 turns on which in turn shuts off Q1. Now current is flowing the opposite way through the primary causing the magnetic field in the core to reverse itself, which induces an opposite voltage in the secondary which continues until the field stops expanding and the process switches again. Basically, the circuit is a square-wave oscillator.

This circuit is perfect for enabling students to become familiar with the basics of DC to DC conversion. Use the parts listed, or use what you have. Use a scope to look at the voltage wave-shapes on the primary and secondary. Measure DC output with and without load.

See if you can improve it. Have some fun with it! And check our web site at www.elexp.com for more information on such circuits. NOTE: Use an Ohm-meter to measure both sides of the transformer. The side with the lower resistance, should be used as the primary. Both sides need a center tap.

DC to DC Converter Parts List

RECTIFIER	11W01
Q1, Q2 NPN power	11D40D4
R1, R2 10k, 1/4 W	
C1, C2 10 uF, 50 V	14ER05010U
XFMR audio	16A10K-2K

Adjustable Duty-Cycle Oscillator

In the study of electronics, the concept of duty-cycle pops up in various places such as digital circuits, one-shots, switching regulators, and D/A converters to mention a few. Lab experiments to examine duty-cycle usually require two parts: a square-wave oscillator driving a monostable multivibrator (one shot). A common circuit involves two 555 chips and a bunch of resistors and capacitors for each chip. Also, the RC time constant associated with the capacitor coupling the two 555s is critical.

In contrast, the circuit shown in ***Figure 1*** can be built with a single IC, two capacitors, three resistors, two trim-pots, and a diode. The component values and time-constants are not critical. And with this simple circuit, here is what you can demonstrate:

- What is hysteresis
- What is a Schmitt-trigger input
- How can hysteresis be used to build a square-wave oscillator
- What is duty cycle
- How do you adjust duty-cycle to different values
- How does duty-cycle relate to DC value
- What is a low-pass filter
- How does filter cut-off relate to square-wave frequency
- How does filter time-constant relate to speed of response to changing duty-cycle

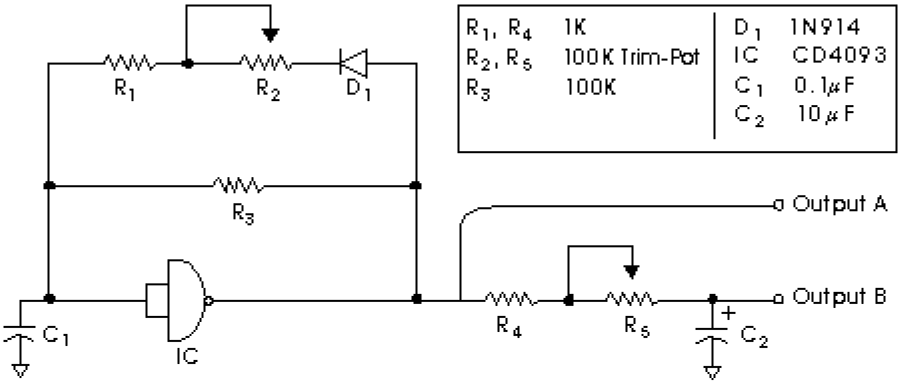


Figure 1

Of course, with such a simple circuit you would expect that there was some kind of trade-off. And you're right: this circuit changes frequency as you change duty-cycle. But even with that limitation, you can still demonstrate all the items listed above. And you can use this circuit as a lead-in to a follow-up experiment with a circuit that maintains constant frequency as you vary duty-cycle.

The key to the circuit is the CD4093 CMOS digital IC. It's a quad two-input NAND gate chip with Schmitt-trigger inputs. In an inverting configuration, driving the inputs high will force the output low, while driving the inputs low will force the output high. The value of the input voltage that causes the output to change is the switching-threshold. The switching-threshold on a Schmitt-trigger input is not fixed; it has one of two different values depending on whether the output is high or low. In the 4093, the input voltage to force the output low is higher than the input voltage that forces the output high (see *Figure 2*). The result is a hysteresis effect.

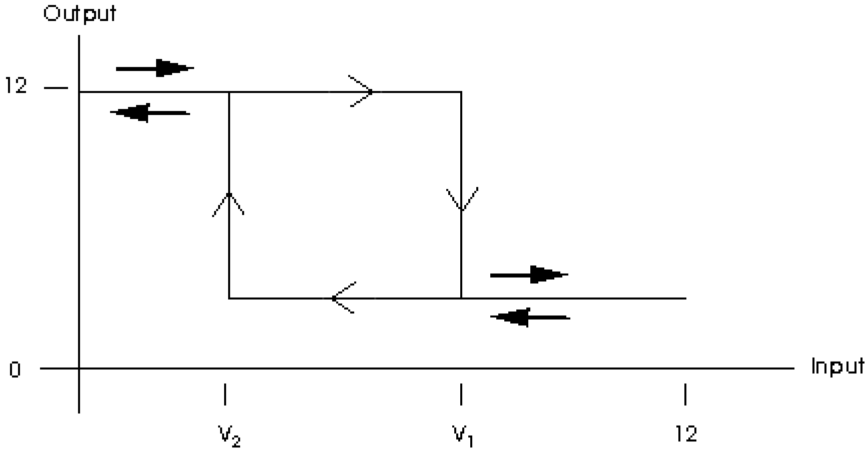


Figure 2

We all have experience with the property of hysteresis. It can be seen in an old-fashion oil-can, the kind with a long flexible spout on a semi-spherical can with a wide, flat bottom. You pick the can up with one hand: the spout between your fingers and your thumb on the bottom. As you press on the bottom of the can, nothing happens until there is enough pressure to "pop" the bottom in and a squirt of oil comes out. As you release the pressure, the bottom will "pop" back out at less pressure than it took to "pop" it in.

The way hysteresis leads to oscillation can be seen in an automobile with a loose "front end". As you turn the steering wheel, nothing happens at first. Then, at a certain point, the car will turn. As you turn the wheel back to "straighten out", again nothing happens until you get to a point where the car suddenly swerves the other way. The result is that, as you travel down the road, the car is swerving left and right. You can't get it to go in a straight line. In effect, you're oscillating.

In this circuit, let's assume that C1 is discharged, making the input of the IC low and causing its output to go high. The voltage on the high output is fed back to the input through R1, R2, D1 and R3. The resistors limit the current, so C1 charges up with a certain time-constant. When the Voltage on C1 reaches a certain point, call it V1, it will be high enough to force the output low. At that point C1 will start to discharge through R3 only, since D1 will be reverse-biased. When the Voltage on C1 drops to a certain point, call it V2, it will be low enough to force the output high again. The cycle then repeats, and we have made a square-wave oscillator. Note that it is necessary that V1 be a higher value than V2 so that there is a fixed amount of Voltage that C1 must charge and discharge to produce a cycle. Then by changing the resistance, the time needed to charge and discharge (and thereby the frequency) can be changed.

The square-wave output can be seen by placing the probe of a oscilloscope at output 'A'. We will define the "on-time" of the cycle to be when the output is high, and the "off-time" when the output is low. Duty-cycle is defined to be:

$$\text{Duty-Cycle} = \frac{\text{On-Time}}{\text{On-Time = Off-Time}}$$

Since C1 discharges through R3 only, the "off-time" of the cycle is fixed. But C1 charges partly through the R1-R2 path, so adjusting the R2 trim-pot will vary the "on-time" and thereby vary the duty-cycle. Since the square-wave output goes from 0 to +12 Volts and back to 0, it can be thought of as an AC signal riding on top of a DC voltage. The value of the DC can determined from the duty-cycle by the relationship:

DC Voltage = (Duty-Cycle) x (High-Output Voltage)

where, in this case, the high-output voltage is 12 Volts. The square-wave output is fed through an R-C low-pass filter made up of R4, R5, and C2. The purpose of the filter is to "smooth-out" (or "integrate") the square-wave. In effect, it removes the AC signal and leaves only the DC Voltage on C2. the filtered voltage can be seen on output 'B'. Just how "smooth" the DC will appear (i.e. how much AC "ripple" will be seen) depends on the RC time-constant of the filter. The "cut-off" frequency (f0) of the filter is given by:

$$f0 = \frac{1}{2pRC}$$

Define N to be the ratio of the oscillator frequency (f) to f0 as follows: N=f/f0. Then the bigger N is, the smoother the DC will be, as will be seen by adjusting the R5 trim-pot. One note about using CMOS gates: don't leave any inputs "floating". Be sure to ground all unused inputs on the CD4093 chip.

So have some fun with this circuit. Play around with it and try different values for the resistors and capacitors. Try reversing the direction of D1 and see what happens. And see if you can think of some interesting applications for it. Maybe you can get it published in this newsletter.

Duty Cycle Demonstration Circuit Parts List

C1	0.1 uF Capacitor
C2	10 uF Capacitor
D1	1N914 Diode
IC	CD4093
R1, R4	1K Ohm 1/4 Watt Resistor
R2, R5	100K Ohm Potentiometer (STC)
R3	100K Ohm 1/4 Watt Resistor