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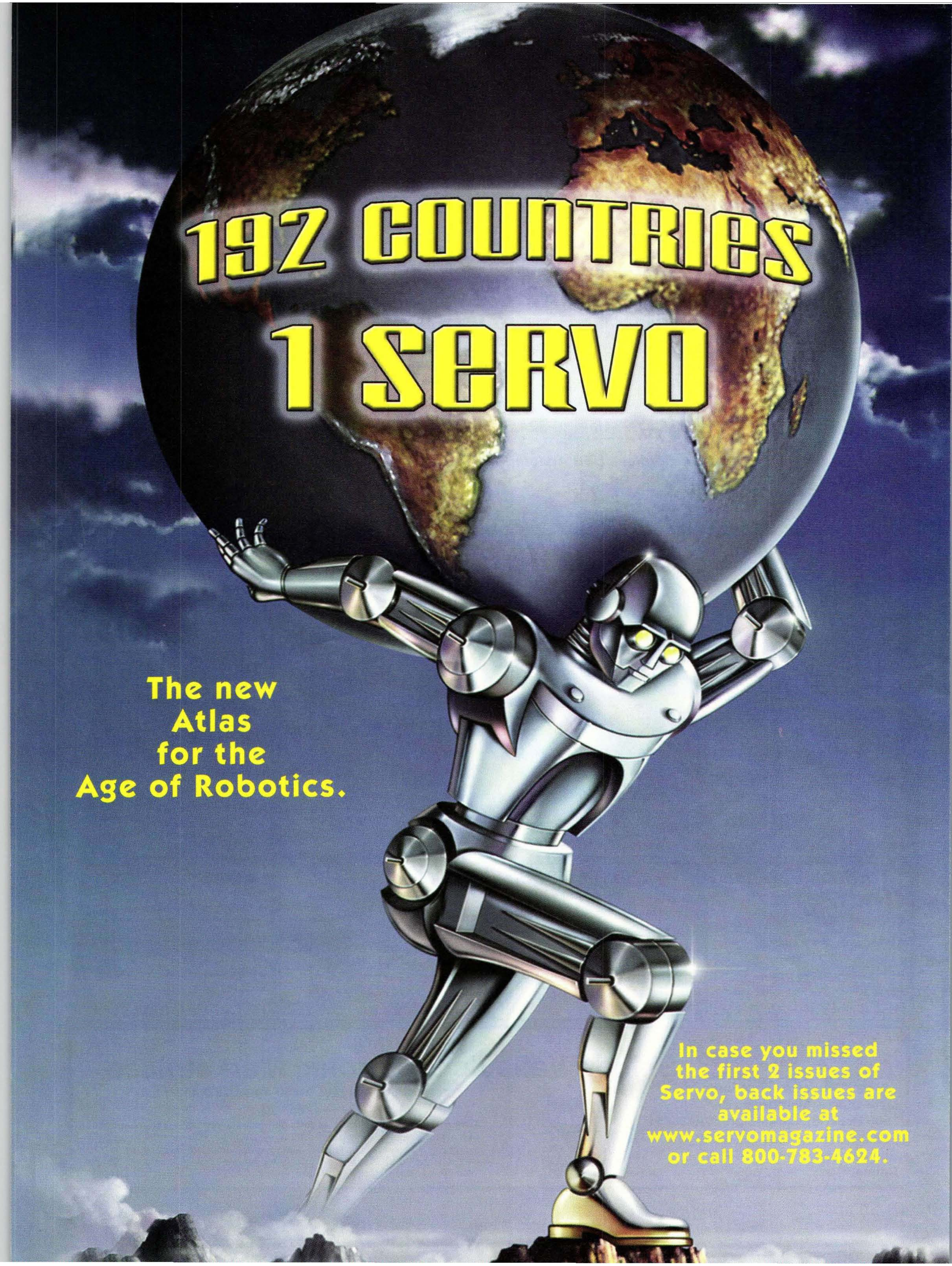

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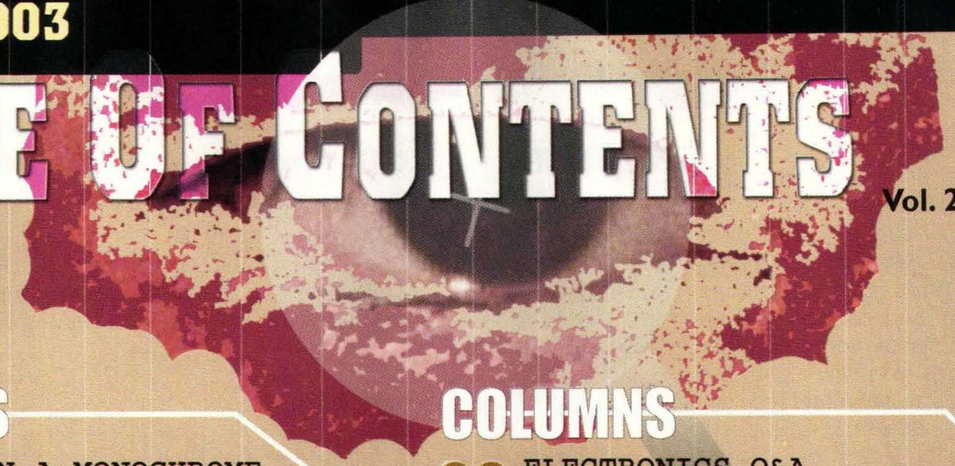

Vol. 24 No. 12

PROJECTS

FEATURED ARTICLES

COLUMNS

DEPARTMENTS

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Dear Nuts & Volts:

There is an astonishing 3-D effect in the picture on Page 22 of the Oct. 2003 issue. If you hold up the page at a reading distance (with its longer right corner, inches slightly down), and cross your eyes until the two dishes come together in three images, you will see, in the center one, a concave effect with the triangle of antenna supports appearing to be stuck out toward you. The 3-D image will appear to be about 12 inches down from your face, and you can put the point of a pencil right at the edge of it.

Hilary Ryan
Sorrento, FL

Dear Nuts & Volts:

I wanted to let you know that *Nuts & Volts* has been a valuable source of examples for the electronics course that I'm teaching. For example, we were covering timers when I received the Nov. 2003 issue, so I had my students analyze the two examples involving the 555 timer in the "Electronics Q & A" column. The students enjoy seeing applications that go beyond the usual textbook examples.

I also used the Question #09034 from the Sept. 2003 "Tech Forum" column. This regarded using two "wall-warts" (DC power supplies) with the outputs connected together to power a 120 VAC underwater pump. Both of the replies published in the Nov. 2003 issue made the good suggestion of plugging the pump into a GFI socket. However, neither answer stated clearly why a wall-wart will not work in reverse. The three main components in a DC power supply are a transformer, a rectifier, and a voltage regulator. Inputting a DC voltage into the output of any of these components will not produce the desired AC voltage at its input.

Alan J. DeWeerd
Department of Physics
University of Redlands, CA

Dear Nuts & Volts:

I just wanted to thank you and author John Carter for a super and really neat project that was printed in your August and September 2003 issues, and to let you know how dedicated the author has been to the project.

Continued on Page 41

ERRATA — LCD Fluid Level Monitor

A kind reader pointed out that there were errors (Figures 3 and 5) in my Fluid Level Monitor article that appeared in the Oct. 2003 issue. I sincerely apologize to anyone who may have had difficulty understanding or constructing the project due to these errors. The mistakes were entirely my own, not those of the editorial staff at *Nuts & Volts*. Included here are the corrected figures which will assist readers duplicating the project.

Probe Construction

The copper tube of the probe is to be grounded. It forms the outside of the probe capacitor. The inside part of the capacitor is the loop of wire. The bottom of the loop is at the bottom of the tube, and the top of the loop extends out of the top of the tube, where the wires are stripped, soldered together, and connected to the "probe" input of the circuit.

The quality of the wire insulation is important, as none of the uninsulated wire can contact the fluid. Use the best insulation you can find — Teflon insulated wire (Mouser and other sources) would probably be good. I have also used Tefzel aircraft wire. I'd recommend finding out about those and also Kapton, and wires designated THW or XHHW. As I am not an expert on insulation, I cannot make a firm recommendation.

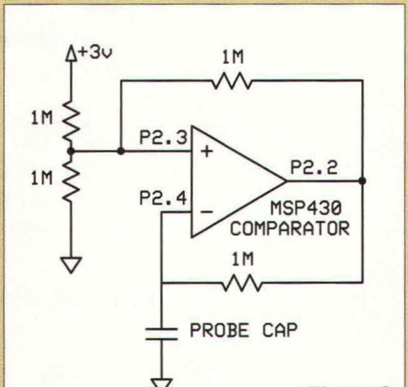


Figure 3

Probe Protection Resistor

The 470 ohm resistor shown in the original article is not really necessary, as during idle periods, all the comparator pins are configured as outputs with zero volts out, so a probe short to ground will do no damage. The resistor was a feature of an alternate design in which the probe capacitor was charged to the battery voltage, and then allowed to discharge through a resistor. For space reasons, the alternate design was not presented.

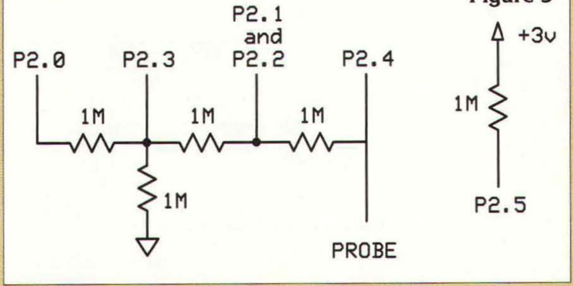
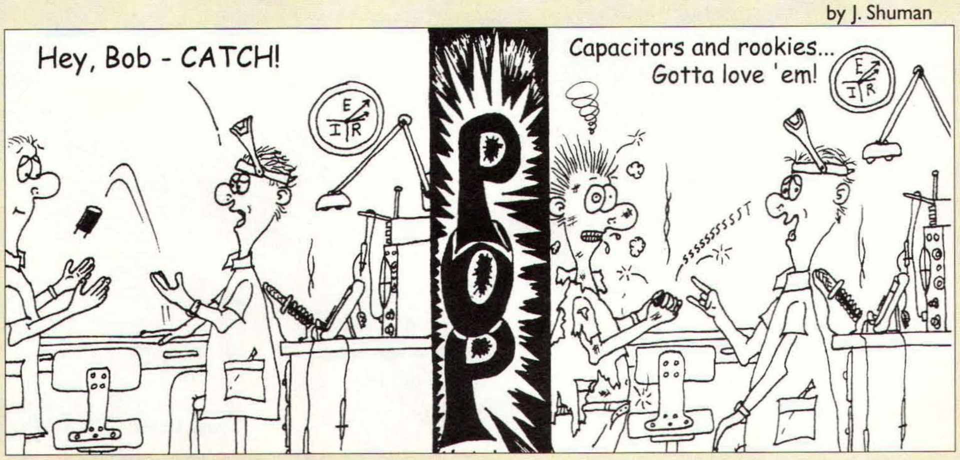


Figure 5

— Glen Worstell

by J. Shuman



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Understanding, Designing, and Constructing Robots and Robotic Systems

Personal Robotics

A Slight Twist on Line Following

Line Following is one of the "holy grails" of robotics — a staple at many Amateur Robotics competitions. While line following is a task often found difficult for beginners, even some of the more complex designs miss some of the simplest points. I hope to help you see line following with a slight twist. I hope you'll see it from the robot's point of view.

It is that view that lead the two robots I worked on for the last Dallas Personal Robotics Group (DPRG **www.dprg.org**) Table Top contest to take 1st and 3rd place (Mike-3 and Grindel) and for the last Roborama 1st and 2nd place, as well (Shnoz and Mike-3).

At those contests, you see many amazing and varied types of line following devices of every imaginable construction — some incredibly complicated. However, line following really doesn't have to be that hard. In fact, some very simple line followers are possible.

Locally, 2-Tran, made by Clay Timmons, was famous as an example of simplicity. The entire brains of this robot consisted of two transistors, explaining its name. 2-Tran not only worked, it even took a prize at the Spring DPRG Roborama in April 2001, coming in 3rd. Clay also went on to make a 1-Tran just to prove it was possible. Ed Okerson also made an award-winning robot called 123, named for having 1 transistor, 2 motors and 3 batteries.

Photo Courtesy of Dale Wheat

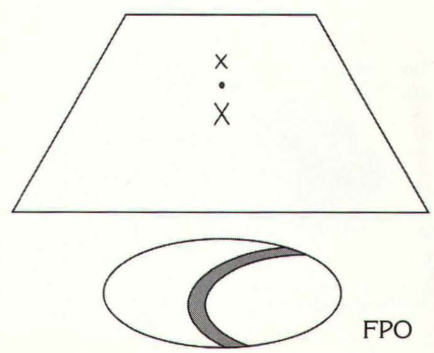
The limit of simplicity — discussed on the DPRG mailing list — is probably a "no transistor, no relay, no switching device at all" line follower, that might use a large CdS cell applied directly to a motor.

On the opposite end of the scale, you see systems with literally millions more transistors than 1-Tran and 2-Tran doing the same task, and sometimes not as well. Everything from multiple sensors to phototransistor arrays, to cameras with microprocessors and PCs are used to look for the line and to decide what to do about turning to follow it.

Often, it seems the more complex the design, the more unrealistic our expectations. In our rush to anthropomorphize robots in our own image, we hope to make the robot act human. We expect it to look at the line and plan to follow it the way we do when driving a car — slowing to an appropriate speed for the perceived, upcoming curve, and initiating a smooth, matching, curved path, using PID-like course corrections to tighten or loosen the curve as needed.

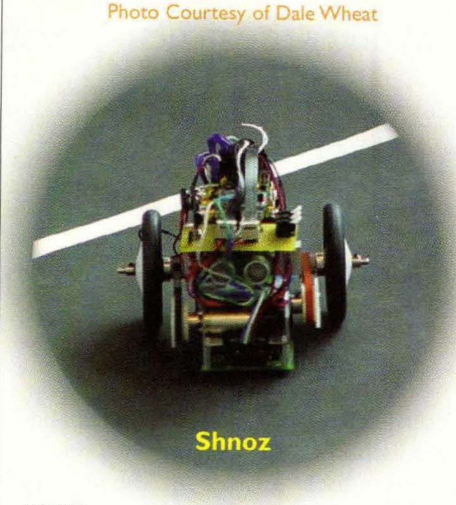
A task this complex is well above almost all amateurs, and frankly, most professionals, as well. We get caught up in our own world view, and can't see the problem any other way. The cure for the illusion is to bring our advanced senses down to the level of what the robot sees.

To get a feeling of just how limited our robot's connections are to the real world, I suggest making a simulator. Take a small piece of construction paper. Make a small (e.g., 8") circle. Draw a slowly curved 1" line on one side, and a much tighter curved line to the opposite direction on the other. The lines should be solid and consistent with solid color, so no local features can be seen. Take a large piece of construction paper and put a pinhole in the center that is just large enough to be a dot, so you can see the color of the object below, but not so large as to make out any detail, such as direction of a line edge. Mark two Xs a few inches to either side of the pinhole.



Have a friend place the lined card down on a table or desk in a random orientation. Use a little tape to hold it to the underlying surface. Then have them place the larger sheet over the smaller. The pinhole represents a single line sensor. The Xs represent differential driving wheels. Now, put

Photo Courtesy of Dale Wheat



Shnoz

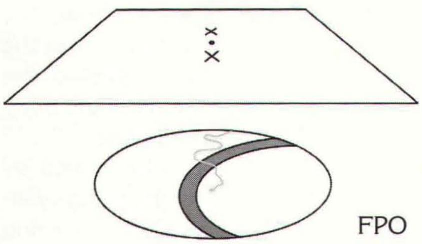
your fingers on the Xs and "drive" the top sheet around, following the line by what you see through the pinhole. Try to keep your movements consistent with those differential wheels would make. Keep them simple. Move only straight ahead with both wheels, or pin one down with extra pressure and pivot the other around it as a radius turn. Try not to make any sliding, sideways movements.

You will very likely find this much more difficult to do than you would have imagined. Why? Because we are accustomed to integrating a great deal of information about the line from a glance. We can normally see a large section in comparison with the robot's body size. The robot has no such luxury. The robot usually only sees a small section, even smaller than the size of its own body. Most designs have a very limited array of sensors. The typical sensors used for line following only give a digital response. The line is either (1) there or (2) it isn't.

You will find that if you do pick up the line in the pinhole, you have no more information than just what you have for that moment. While you might imagine (from your persistent vision of seeing the line in overview), by finding the line once, you know where it is going. However, if you make a movement, you may lose the line.

The least likely strategy to keep the line would be to wander around. You are much more likely to just go straight when you're on the line. When you lose the line, you do not know if it was because you were crossing it at an angle, or if it curved away from you. Both produce exactly the same visual effect in the pinhole.

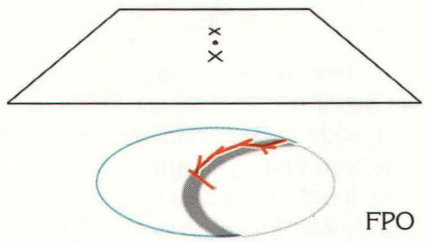
So, after losing the line, how can you recover it with realistic vehicle movements? With a differentially driven robot with only one sensor placed between the two wheels, you have very few sure options. For instance, a gradual turning in the direction the line was lost in to recover it is not an option. Why? Well, first ask yourself, which direction is that? To the left? Or the right? You don't have that information. All you know is you saw the line in the pinhole at one instance, and it was gone in the next.



FPO

You might imagine, you'll just turn 90 degrees, move ahead, and be sure to find the line again. This is an inadequate strategy. If the line makes a turn, and you came off just before the turn, you may never recover the line. Furthermore, you don't know which side of the line you came off — to the left or to the right. Choose wrong and you may wind up turning back on the line, and reversing direction, going back the way you came.

So the only reliable strategy with this configuration is to back up well into the section where you had the line, modify your direction slightly to one side or the other, and go forward. If you do not lose the line after going the same distance, your turn was correct. If you do lose the line in a shorter distance, you should again back up to the same spot and repeat a comparable turn in the opposite direction, and start again.



FPO

Since line following is a timed competition, the strategy of trying directions, and taking the time to back up and restart if they fail, would be rather poor. A colorfully appropriate colloquialism of the south for this situation is, "That dog don't hunt!" So how can our line follower "hunt?"

Perhaps a first step would be to add another sensor. Just as a hunting

Author Bio

Randy M. Dumse is the Founder/Owner of New Micros, Inc. NMI has specialized in rapid microprosessor system development for over 20 years. NMI offers selected CPUs on carefully designed computer boards. Email: rmd@newmicros.com

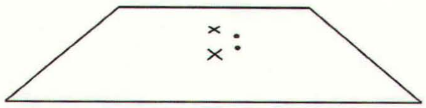
dog has two nostrils — a right and a left — a line follower will be more efficient if it has two light sensors — one set right and one set left. By comparing the two signals, considerably more steering information can be attained.

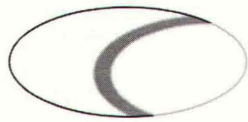
Braitenberg's classic book, *Vehicles* lends support to this idea. He postulated some very simple robotic designs. He was able to show his hypothetical robots could demonstrate some very complex animalistic behaviors. His simplest design had one sensor and one motor, and wasn't very interesting. Many of his other simple robots had two sensors and two motors, and were surprisingly interesting.

In one example, light sensors at the front corners of his robots crossed so they would energize opposite motors. These acted as phototropic creatures, turning toward light sources. By rewiring them to energize same-side wheels instead, he made photophobic creatures. These "light avoiders" would turn away from light, and run into darkness. (You can't see one of these later designs working and not think cockroach!)

Depending on whether we wish to follow a dark line on a light background, or a light line on a dark background and how closely the two sensors are set, we can choose between designs and have a new starting point for an improved line follower.

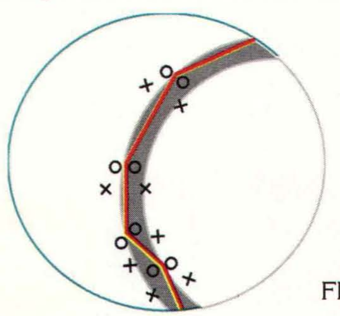
The analogy to a hunting dog continues to be a very good one. Have you ever wondered why nature didn't put the dog's nose right in the center of his belly, down close to the trail? Instead, the sensor array is out in front of his mechanical driving system. Apparently the left/right orientation allows tracking as Braitenberg illustrated. Also, mounting this sensor in front of the drive system has design merit. So remake the top sheet with the design inspirations of (1) two pinholes for sensors and (2) placing them an arbitrary distance ahead of the differential drive.





FPO

Now notice how the system works. If the sensors are less than a line width apart, and both see the line, you know you are on top of the line. If only one sensor sees the line, you know the line is in the direction of that sensor. The first sensor to come off indicates the opposite direction of turn is required. For instance, if the left sensor comes off, then the correction to steering should be toward the right. If the right sensor comes off, then the correction to steering should be toward the left.



FPO

Notice that the algorithm for following the line has become very simple. If one sensor comes off the line, twist back toward the line. There is no need to back up. The twist moves the sensors toward the line. The sensor still on the line shows the direction the twist must be applied. Once both sensors are again on the line, drive straight ahead at full speed.

Think about what this means. If a robot is running a timed course, it should try to go as fast as it can. A twist on a differential drive system means a differential in speed from one side to the other. If the outside drive is going as fast as it can, it can't go faster to help with the turn. If the outside has to be faster than the inside to get a turn, then the inside drive has to be slowed.

This simple twisting by slowing the inside drive is the key to successful line following. This method means the outside tire is always going as fast as it can. Since the sensors are ahead of the drive, one sensor will go off the line at a time. The twist swings the sensor back over the line. The body follows behind the sensors. The twist reorients the body to align with the tracked line.

Top speed has to be limited by the inertia of the system being operated. Going from straight to twisting requires acceleration, and the body of the robot itself will resist this conversion from linear to circular motion. Likewise, the deceleration of this rotational body energy will have to be taken back to again go straight.

Also, the rotational inertia stored in the drive train in its many spinning gears may be too great to be slowed quickly. If the twist comes too late, both sensors may come off the line. Both kinds of inertia will put an upper limit on the top speed allowed in the straight-aways. Interestingly, nature's left-right, two-sensor arrangement is hard to improve upon.

One additional sensor adds no additional steering information. For instance, a middle sensor added would make whichever sensor was still on the line with it redundant, telling us nothing more about how to steer. While our steering would be tighter, just moving the sensors of the two-sensor version closer together would give essentially the same results.

Can the core of efficient line following really be this simple? Basically, yes. Unless additional information is taken in about the line far ahead of the body (as would be possible with vision), this is about as good as you can do. Without an early warning system that a turn or correction is eminent, sensed well ahead of time to allow a slowing for the corner, you can go no faster. NV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Basics For Beginners

Just For Starters

What is a PCB?

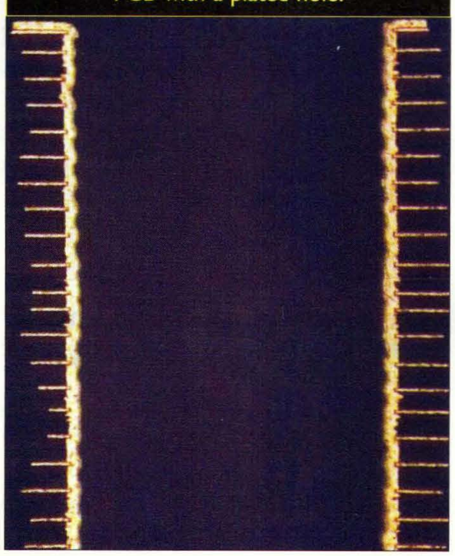
Circuit boards are familiar items to electronics enthusiasts and lay people alike. Clear cellphone bezels reveal small circuit boards jammed with tiny components. When you open a PC, the motherboard is visible — populated with a variety of integrated circuits and other components.

With the exception of certain prototype circuitry, the great majority of electronic circuits are constructed using printed circuit boards, or PCBs. If you plan on working with a PCB, it helps to understand some basic terminology, as well as what a PCB actually is. PCB design and construction is a vast area of concentration that fills volumes of text. This article provides a brief overview of PCB basics.

Fiberglass and Copper

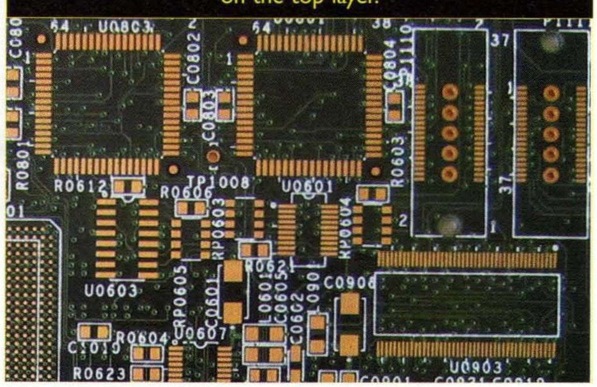
A PCB is constructed from multiple layers of thin fiberglass. Some layers are coated with copper foil and others are bare fiberglass. The thickness of each layer ranges from several mils (a mil is 1/1000 of an inch) to tens of mils. Layer thickness is determined by the desired electrical properties and dimensions of the finished PCB. The PCB is built up by stacking layers of fiberglass and copper until the specifications are met. Figure 1 shows a cross-section of a multi-layer PCB. Note the thin copper foil layers sandwiched between thicker fiberglass layers. Electrical connections are formed by etching patterns into the copper layers. This is where the term "printed" comes from. A photographic mask is created and each layer of copper foil is treated with a photo-resistive chemical. Much like a normal photograph, wiring patterns are "printed" onto the copper by exposing it to light through the mask. The exposed copper is chemically etched and individual wires remain behind.

Figure 1. Cross-section of a multi-layer PCB with a plated hole.



Copper foil is manufactured in three common thicknesses, or weights per square foot. A PCB fabricator, or "fab-house," will specify the copper weights that it stocks. The most common weight is half ounce, but one and two ounce copper is common, as well. Half-ounce copper is approximately 0.006" thick. Thicker copper can carry more current, but poses etching problems as the patterns get smaller.

Figure 2. Surface view of vias with wires on the top layer.



Vias

Wires from multiple layers are connected after the stacking process. A small hole — called a via — is precisely drilled through the fiberglass stack and the surface of the hole is metal plated. The plating makes electrical connections to copper that is penetrated in each layer. The vertical metal surfaces in Figure 1 illustrate this concept. Each via appears as a small hole from the surfaces of a PCB. Figure 2 shows a finished PCB with vias clearly visible. Some vias have etched copper connections visible on the top layer.

Printed wires on each copper layer are very narrow. Mature construction technologies allow copper "traces" as thin as 8 mils. More advanced manufacturing techniques routinely produce traces down to 3 mils. Below 3 mils is possible, but expensive.

Each fab-house has its own manufacturing capability. Some offer finer pitch PCBs than others. A fab-house should tell you how small they can reliably manufacture traces and the spaces between them. For example, a quote of "8-mil trace and 7-mil space" means that the fab-house can etch copper traces

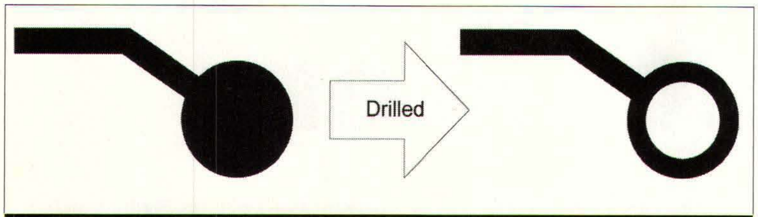


Figure 3. Wire with circular via pad.

down to 8 mils wide with 7 mils between each trace. With such small copper features, properly aligning each layer and drilling vias is not trivial. Vias are not simply drilled to hit wires because a wire's cross-section does not contain enough copper to make a reliable electrical connection with the via plating. Instead, Figure 3 illustrates how via connections are designed with circular pads at the end of each wire. When drilled, the pad forms a ring that surrounds the via. The via's plating has much more area to form a connection.

Blind and Buried Vias

Blind and buried vias are special types of vias used in leading-edge systems. Conventional vias are drilled through the entire PCB after all layers have been stacked. Blind and buried vias are drilled only through a few layers during the stacking process. As seen in Figure 4, the result is that vias do not take up the entire layer stack and two or more such vias can be located in the same place on different layers. High density PCBs may require blind and buried vias. This technology is more expensive than conventional vias because additional manufacturing steps are required and layer stacking becomes a more difficult process.

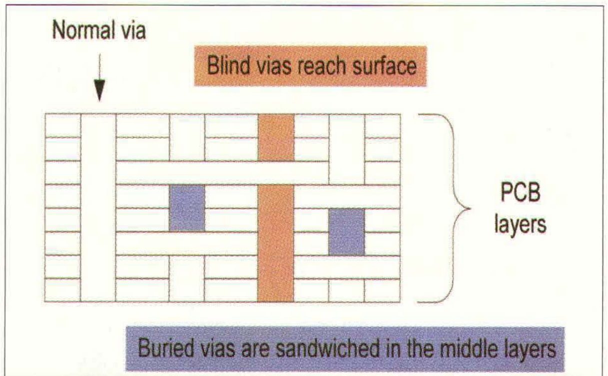


Figure 4. Blind and buried vias connect only a few layers of the PCB.

Planes

Not all PCB layers are used for conventional wiring. Most PCBs reserve some layers for use as power planes. As their name implies, planes are nearly continuous sheets of copper. A plane is used to carry power to many or all components on the PCB with low inductance and resistance. These electrical properties become critical in fast and sensitive circuitry.

Planes are continuous except for via clearance holes. Clearance holes are necessary to prevent vias shorting their signals to the power planes. This would normally happen because vias are drilled through all PCB layers (or some layers with blind and buried vias). The solution is to etch away a circle of copper in each plane where each via hole is drilled. There can be no electrical connection between the via and the plane if there is no copper between the via hole and plane. Most PCBs have several planes and assign each plane to carry a specific power rail. For example, a microprocessor board may have 5-volt and 3.3-volt power supplies plus ground return. The PCB may have four planes: 5, 3.3, and two grounds. In some cases, a product cannot accept the added cost of one plane for each power rail. It may be possible to split a plane into multiple areas for multiple power rails. Whether or not this split is possible depends upon the circuit's electrical constraints. A split plane is constructed by etching a copper void into an otherwise continuous plane.

Moats

Sometimes a plane is partially split for electrical reasons. Noisy circuits may cause problems in a sensitive system. Some engineers attempt to minimize noise transmission by etching a void into part of a plane, but leaving a small electrical connection for power and signal routing purposes. This type of void is called a moat. Figure 5 shows several moats on a single PCB as the board is held up to a light. The fiberglass is translucent, while the copper planes are opaque. Moats can cause as much trouble as they solve, so it is best to fully understand their dynamics before proceeding.

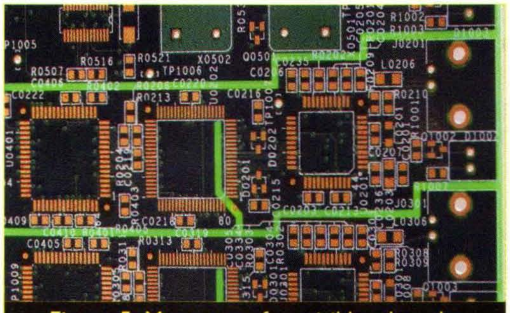


Figure 5. Moats are often visible when the PCB is held up to the light. The moats allow light to pass through the fiberglass.

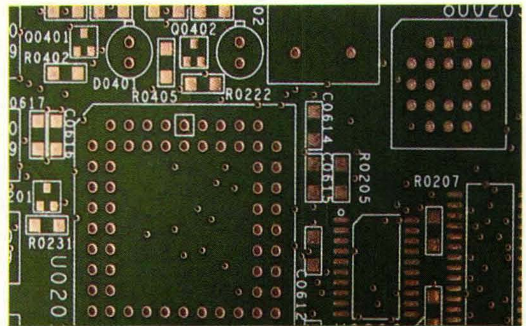


Figure 6. Through-hole PLCC and LED land patterns with solder finish.

Land Patterns

We've discussed wiring up till now, but PCBs exist to connect components. Most components are soldered to PCBs. In order for soldering to be effective, the leads or pins on a component must be capable of reliable mechanical and electrical connections to the etched copper wiring.

Each component is provided with a matching land pattern — a set of etched copper features that directly correspond to the leads or pins of the component. The features are usually made larger than the leads or pins so that a sufficient quantity of solder can adhere. Land patterns may be combinations of plated holes and surface pads, depending on the type of component being mounted. Figures 2, 5, 6, and 7 show a variety of land patterns. There are patterns for through-hole connectors, quad-flat packs (QFP), small-outline integrated circuits (SOIC), discrete surface-mount resistors, and more. Land patterns sometimes include special visual markers called fiducials. The figures also show several examples of fiducials. Fiducials are typically round patterns located in the corner of surface-mount land patterns that robotic assembly machines key off of to accurately place components onto the PCB. These machines are often called "pick-and-place" machines. The fab-house finishes exposed copper land patterns different-

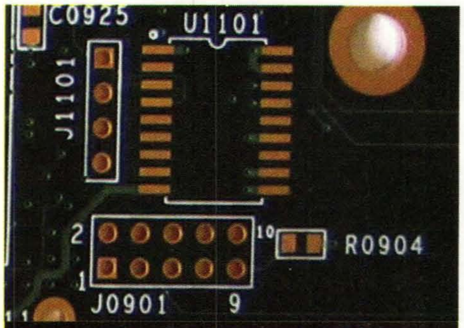


Figure 7. Through-hole headers, SOIC, and plated mounting hole with gold finish.

ly according to your assembly requirements. The basic finish is a solder wash (shown in Figure 6) that takes on a silvery solder appearance. Another finish is gold, which is shown in the other figures. There are other finishes, as well.

Solder-mask and Silkscreen

Did you ever wonder why PCBs tend to be green? Green is simply the default color for solder-mask that most fab-houses use. Solder-mask is applied over the entire surface of a PCB, except for land patterns and other copper areas that must make electrical connections. The solder-mask eases assembly by preventing solder from adhering. Solder-mask is available in a rainbow of colors including blue, red, and clear. Silkscreen patterns and lettering are applied to most PCBs to ease human inspection and debugging. Assembly machines usually don't care about the silkscreen. However, if you need to find resistor 125 out of 600, then silkscreen is your friend! Silkscreen seems to most often be white, but it, too, is available in a variety of colors.

There's a lot more to say about PCBs. Understanding their electrical characteristics is very important. The dimensional properties already mentioned have significant electrical consequences. This is where transmission line theory takes over. There are many books, magazines, and websites out there that cover these topics, so happy reading! **NV**

About the Author

Mark Balch is the author of *Complete Digital Design* (see **www.completedigitaldesign.com**) He is an electrical engineer in Silicon Valley, CA, who designs high-performance computer-networking hardware. His responsibilities have included PCB, FPGA, and ASIC design. Prior to working in telecommunications, Mark designed products in the fields of HDTV, consumer electronics, and industrial computers. In addition to his work in product design, Mark has actively participated in industry standards committees and has presented work at technical conferences. Mark holds a bachelor's degree in electrical engineering from The Cooper Union in New York City. He can be reached via email at **mark_balch@hotmail.com**.

Electronics Q&A

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist.

Feel free to participate with your questions, as well as comments and suggestions.

You can reach me at: **TJBYERS@aol.com**.

What's Up:

Working with balanced microphone cables, auto dome light chime, and an RR crossbuck sound circuit. A primer on capacitors and a speed controller for fractional horsepower DC motors.

High-Power PM Speed Controller

Q. I have a Magnetek 90-volt, 15-amp permanent magnet (PM) DC motor. I would like a schematic for a variable DC power supply so that I can vary the speed of the motor.

Paul
via Internet

A. For this application, I suggest plugging into the AC line for the power source because of the high voltage and currents involved. First the AC has to be rectified to get the DC voltage needed. This is done using a full-wave bridge rectifier (Figure 1). The DC voltage is purposely not filtered because we will use the pulsing waveform to provide speed control using an SCR (silicon controlled rectifier). In fact, this is a sophisticated lamp dimmer in disguise. The secret to this "power supply" is delayed-angle firing of the SCR (Figure 2).

The timing starts when the waveform touches the zero voltage base line. If the SCR fires now, the full power of the waveform is sent to the load. However, if the firing is delayed by 90 degrees, only half the power contained in the waveform is seen by the motor, thereby reducing its speed.

Using this technique, you should have full control of the motor's speed from dead stop to top gun. Concerned that the motor is rated 90 volts and the peak rectified DC voltage is 161 volts? No need to worry. Motors are current — not voltage — operated devices, and in the robotics world it's common to hit a 5-volt stepper motor with 12-volt pulses to increase its torque. The limiting factor is heat, which builds up faster with increased voltage. A word of caution: the controller is connected directly to the AC line and does present a possible shock hazard — so be careful!

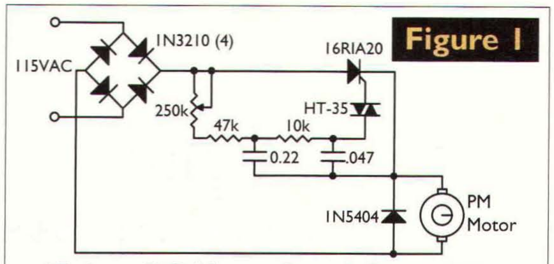


Figure 1
15-Amp DC Motor Speed Controller

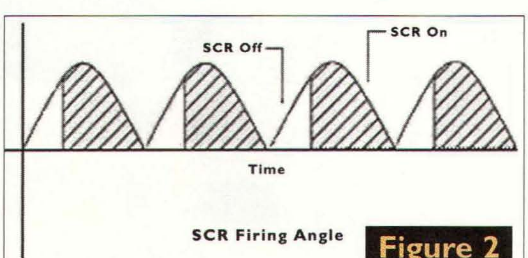


Figure 2

Crossbuck Sound

Q. In the Sept. 2003 issue you provided a simple 555 LED flasher to simulate lights flashing at a railroad crossing. You also wrote "Want the ding-dong, too?" I've been hunting for a circuit that will produce that ding-ding sound heard at a railroad crossbuck without any success. Do you have any circuits that can do this?

Frank Renck
via Internet

A. I was half joking when I said that, but serious enough to keep my promise and design the circuit in Figure 3. The secret to the clang sound you hear is what's called "damped' oscillation. When a bell is struck, it sounds loudly at first. As time passes, though, the volume of the sound slowly decreases to zero. To create this effect in an oscillator, I placed a large capacitor across the Vcc of an astable 555 oscillator. When power to the oscillator is removed, the voltage across the capacitor slowly decays creating a proportional decrease in volume. The 555 is an ideal chip for this application because the frequency remains the same even as the Vcc voltage changes. The bell is "struck" using another 555 astable multivibrator (oscillator). The 100K resistor sets the rate at which the bell is hammered; by adjusting its value you can speed up or slow down the tempo. The bell can also be synchronized with the blinking crossbuck lights, but I'll leave that for another column.

Capacitor Primer

Q. In your August 2003 column you made the statement: "... the circuit operates at 1.25 MHz, so be sure to use ... good quality capacitors — ceramics are preferred." Could you say a few words about how to tell good quality from bad in a capacitor, and give a little instruction about how to select from the various types, such as ceramic, polyester, silver mica, polypropylene, and tantalum?

Judy May
via Internet

A. I wish I could say a few words that would define capacitors, but it can't be done in the limited space I have. So I'll just have to do the best I can. Basically, a capacitor consists of two metal plates separated by an insulator. It is the insulator (dielectric) that determines the type of capacitor and its properties.

An aluminum electrolytic capacitor is constructed by using two strips of aluminum foil (anode and cathode) with paper interleaved. This foil and paper are then wound into an element and impregnated with electrolyte. The electrolyte (which can be either liquid or solid) forms a very thin layer that puts the plates in close proximity, resulting in very high capacitance in a small package. In newer electrolytic designs, the electrolyte serves as the second electrode. Since the oxide layer used to form the plates has rectifying properties, an electrolytic capacitor has polarity much like a leaky diode. Electrolytics also have rather high leakage currents (which increases with temperature) and poor high-frequency response, which usually limits their applications to off-line power supply filters.

Tantalum capacitors are a special version of the electrolytic. Its dielectric is sintered tantalum powder that is formed under high pressure and temperature. This produces a fairly stable electrolytic with a solid dielectric and leakage currents that are lower than aluminum electrolytics. Because of a shortage of raw tantalum ore, niobium is increasingly replacing the element as a dielectric. For power signal wire and power plane decoupling in digital electronics, tantalum, and ceramic capacitors are considered the best solutions.

The term ceramic capacitors covers a large group of capacitors. Ceramic generally refers to an inorganic polycrystalline material that's formed by sintering the compound at high temperatures. Their properties may vary widely, but they all have the oxide ceramic dielectric in common. By means of special production methods, extremely thin layers of ceramic materials can be obtained, leading to high capacitance. Ceramics can compete with electrolytic capacitors in high-frequency applications like switch-mode power supplies because of their lower ESR, and are commonly found in RF applications. However, ceramics are not suitable for all applications due to their "strange" effects, like changing capacitance with bias voltage and temperature. In fact, ceramic capacitors are often tailored for specific temperature curves (both positive and negative temperature coefficients) for use in RF circuits.

RR Crossbuck Sound Effect

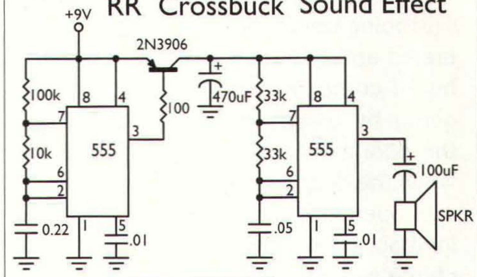
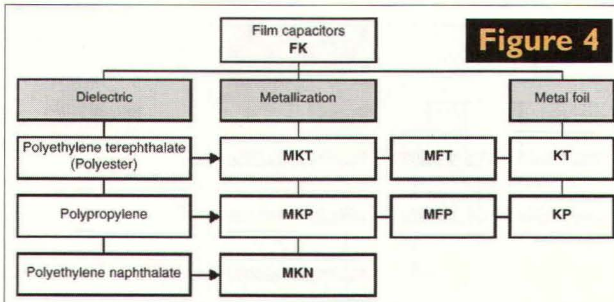


Figure 3

In high-end audio applications, ceramic, electrolytic, and tantalum are all considered inferior to plastic-film capacitors (especially polystyrene). The plastic dielectric runs a wide range of materials that includes Polyester, polyethylene napthalate, and polypropylene to name a few. Film capacitors come in two broad categories: film-foil and metallized film (Figure 4). Film-foil capacitors are made of alternating layers of plastic film and metal foil, while metallized film capacitors have the metal vacuum deposited directly on the film. In general, film-foil is better at handling high current, whereas metallized film caps are much better at self-healing. The plastic film's main virtues are low leakage, good breakdown voltage, and low dissipation factor.

Figure 4



Classification of film capacitors according to DIN 41 379

Car Door Chime

Q. I'd like a circuit that would produce a pleasant boing-boing chime tone that was used to alert the driver when a car door was ajar. I believe this chime was triggered from the dome light.

Vonn Hockenberger
via Internet

A. Actually, the dome light and the boing-boing tones were both generated and controlled by the car's onboard computer. And both were triggered by a normally-open switch in the doorjamb that became grounded when the door was opened. If the door was open and the key was not in the ignition, the light was enabled and the chime was disabled; a key in the ignition and an open door enabled both the light and the chime. Because of this arrangement, I can't fully recreate this circuit short of using a microcontroller like a BASIC Stamp or PIC. However, I can create a reasonable facsimile using a 555 square wave oscillator and a bandpass filter (Figure 5).

As you probably already know, a square wave is made up of a sum of odd-frequency sine waves (i.e., 1st tone, 3rd tone, 5th tone, 7th tone, etc.). By running the square wave through a bandpass filter (Figure 6), the odd frequencies are stripped off, leaving a clean sine wave equal to the fundamental frequency (1st tone). To get the boing effect, the waveform is damped by reducing the volume with time (Figure 7). This is done by allowing the 100 µF capacitor to discharge slowly through the astable oscillator, slowly reducing the voltage to the chip as it does and lowering the volume proportionally. The signal is then amplified by the LM386 IC. R1 adjusts the sound for loudness and clarity of the tone; the pitch of the tone can be adjusted by changing the value of the .015 µF capacitor. The automobile is a very harsh environment, so make sure that the decoupling capacitors are placed as close as possible to the ICs indicated on the schematic.

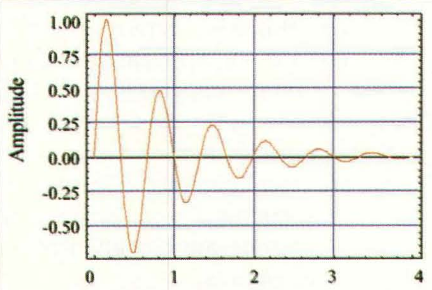


Figure 7 Damped Sine Wave

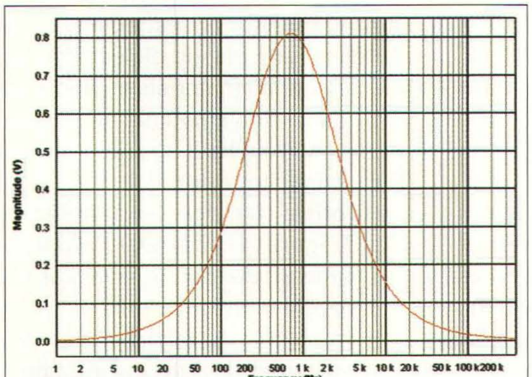


Figure 6 Bandbass Filter Response

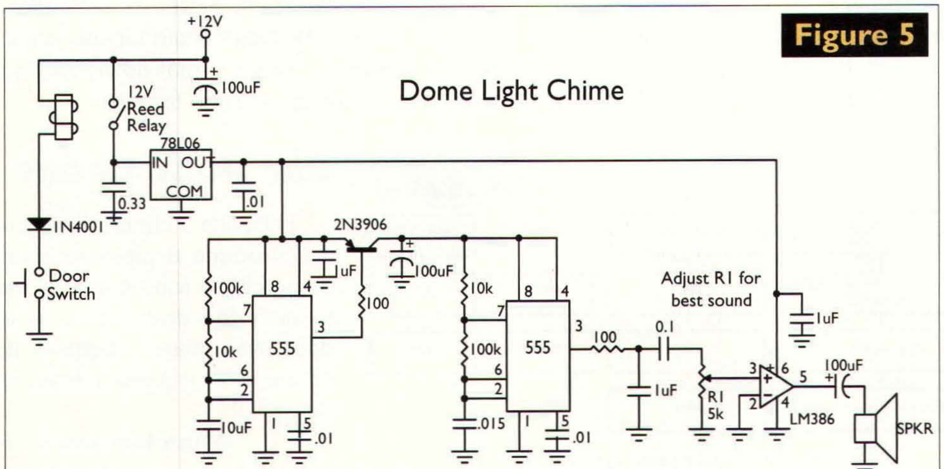


Figure 5 Dome Light Chime

Phantom Power

Q. Do you have a phantom power supply schematic? I have a 15K to 600 ohm transformer with a center tap on both sides.

Bill Bushing
via Internet

A. The underlying concept of phantom power only works if you have a balanced transmission line – like those used with XLR connectors in professional audio equipment, such as mixer panels. In this application, there are two wires that carry a differential audio signal. By using differential — or balanced — transmission lines, the noise that the signal may encounter on its way from the source to the destination is easily removed.

This technique is very popular in the digital world. The professional audio world goes it one better by wrapping the two wires (typically a twisted pair) in a metal braid or shield to further prevent unwanted interference from stage lights and other production related equipment. This adds an extra wire to the power supply formula. If we were to apply an identical voltage to both of the signal wires, no DC current will flow across them. Hence, it leaves the AC signal across the lines unbiased and unaffected. Now remember that we have a metal shield surrounding these wires — a metal conductor that's capable of passing current. Ah, phantom power! If we connect the positive leg of a power source to the balanced pair and the negative leg to the shield, we have current flow without disturbing the current balance in the signal pair.

The phantom power is injected into the signal cable as shown in Figure 8. The resistors typically limit the short-circuit current to about 8 mA. This protects the power supply and hopefully the mic from an incorrect connection — which can easily happen. There is no set standard on the phantom voltage or wiring. It ranges from 9 to 48 volts (plus a T-power configuration), and unless you know for sure what you're plugging into, there is a risk of equipment damage. The circuit in Figure 8 (a) represents typical values for a 48 volt line; (b) shows a battery-operated, 18 volt phantom power source. Figure 8 shows how the signal and power sources are separated at the microphone end.

Microphone Preamp

Q. I bought a Sony Lavaleer microphone without its preamp. This mic has a balanced output with a level that's very much less than a normal dynamic microphone. I'm not sure if it's a ribbon mic or not, but when I connected it to a phantom 48 volt power supply I still couldn't get a signal level that I could use. Do you have a preamp for a very low level mic that I could use?

Anthony Stammers
via Internet

A. Try the circuit in Figure 9. The circuit is designed around a pair of precision, low-noise op-amps. Notice that a +5 volt and a -5 volt power supply is required to maintain the balance. A simple -5 volt supply can be made using an ICL7660 voltage converter chip (Figure 10).

Simulated Lighthouse Lamp

Q. I am trying to build a circuit for a small lighthouse lawn ornament. The "lighthouse" has an existing fixture for a 60 watt light bulb. I would like to vary the bulb brightness to simulate the rotating light of a real lighthouse. The light should start at full brightness, slowly dim until it is completely off, and then slowly brighten to full brightness. This cycle should repeat continuously. My plan is to use a triac and vary the voltage to the light bulb, but I am having trouble determining how to cycle the gate voltage to keep in step. Any help would be greatly appreciated.

Ted
via Internet

A. The solution is an X-10 12 A dimmer switch (a.k.a., Levitron 2208) that normally mounts in the wall in place of the toggle switch (don't mistake this for the ultra-cheap WS467). If you hold it down, the light dims to nada, then brightens to full, then dims back down, up again, down again ... forever. The time period is about seven seconds per cycle. If you buy one of these Decorator switches brand new, it will cost you a lot more than if you were to find one on eBay.

Ferroresonance Transformer

Q. I have a SOLA constant voltage transformer that I would like to use on the input power to my computers. It will power four Macs, two printers, a scanner, and a 12-inch cooling fan (intermittent usage). However, I'm a little chicken to try it because I've been told that they put out lousy wave shapes that could destroy computer power supplies. I really don't know that much about how these things work, so I am looking for some good advice.

Maurice
via Internet

A. SOLA transformers work on the principle of ferroresonance. Basically, it provides a constant output voltage using a saturated core transformer. Unfortunately, this arrangement "flattens" the top of the sine wave so it more closely resembles a square wave; some models use a loosely-coupled third winding with a capacitor across it that reduces some of the higher-frequency harmonics to smooth out the waveform.

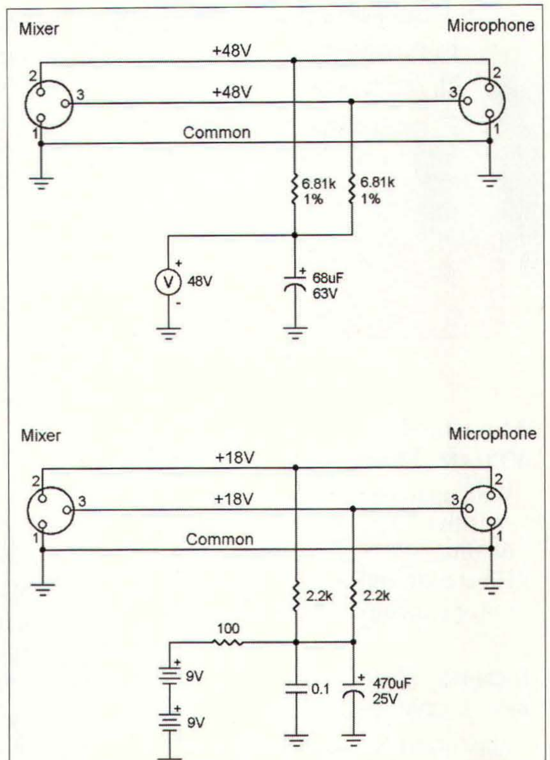


Figure 8

Ferroresonant transformers are mostly used with resistive devices, like photoflood lamps, and aren't recommended for use with capacitor-input power supplies because of voltage spikes on the waveform. They also have to be heavily loaded (typically 50% or more of rated power) to work, which makes them run hot.

MAILBAG

Dear TJ,

Computer Geeks (**www.comp**

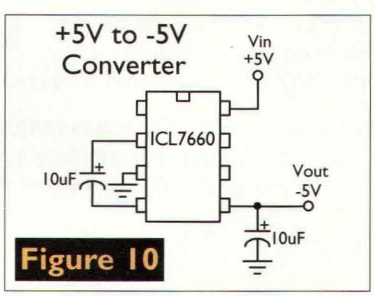


Figure 10

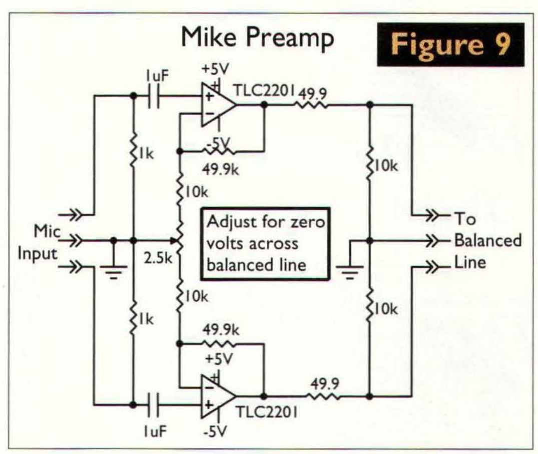


Figure 9

geeks.com) has a two-port KVM switch with attached cables for $27.95. It's a small unit and works fine. The product number is MPC2000. Jameco also has one (Jameco 216063) available for $69.95, but you have to buy cables. Be careful of the cables (Jameco 204062 according to Jameco; $16.95) because the ones I got didn't match the monitor connections. You might want to pass this info along in response to the item in your August 2003 column.

James Tadlock
via Internet

Dear TJ,

My September 2003 issue arrived today, and I noted the question in your column about TVI from a nearby taxi dispatch point. I spent 37 years with the Kansas Turnpike in communications, 20 of them as head of the department. I have also been a licensed radio amateur since 1947. I have become fairly well acquainted with TVI, and offer the following additional suggestions.

Many newer TV sets do not have a good single channel selection front end, and such a close transmitter (typically 100-250 watts or more) will itself cause some problems. A very common problem up close is common mode signal injection. A simple choke filter made from a RadioShack ferrite core in the shape of a square, which will come apart upon pressure relief from the plastic binder, should do the trick. Winding four to eight turns of the coaxial cable on the core near the point it enters the TV will often rid the offending black bar interference. My personal transmitter on 10 meters was getting into my wife's TV each time I talked until I did that. It completely got rid of the interference.

Other information on finding and eliminating TVI can be found in the *Amateur Radio Handbook* from ARRL. Many local libraries have one (even one several years old) which can be borrowed for a few days to help out. Finally, if all else fails, check with the local amateur radio club — there is likely somebody there who has the knowledge and equipment necessary to help out a neighbor.

Carl Fisher W0HIK
via Internet

Cool Web Sites!

MIT has launched an open class format dubbed OpenCourseWare that allows anyone to access their courses for free over the web.
http://ocw.mit.edu

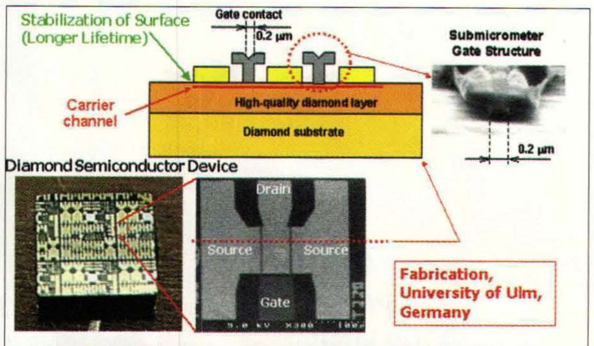
by Jeff Eckert

TechKnowledgey 2003

Events, Advances, and News From the Electronics World

Advanced Technologies

Diamond Semiconductors Reach 81 GHz



Fabrication technology of diamond semiconductor devices. Courtesy of NTT.

Nippon Telegraph and Telephone Corp. (**www.ntt.co.jp/index_e.html**) has developed a diamond semiconductor device whose operating frequency and power are said to be the highest in the world. NTT Basic Research Laboratory (BRL), in collaboration with the University of Ulm, Germany, fabricated the device using high-purity diamond crystals. Its highest operating frequency is 81 GHz, so it operates as an amplifier in the millimeter wave region (which ranges from 30 to 300 GHz). Because of the properties of diamond semiconductors, the device dissipates heat very rapidly, can withstand operation at very high voltages, and will operate very stably, even in space.

In recent years, communication capacity has drastically increased, so there is a demand for high-frequency, high-power electronic devices. A portable telephone needs only about 1 W at 1.5 GHz, but communication satellites and television broadcasting stations require 1 kW at 10 GHz. In the 10 GHz frequency region, vacuum tubes are still used. However, vacuum tubes exhibit low energy efficiency, and thus a high energy loss. From the environment viewpoint, these vacuum tubes should be replaced by semiconductors.

According to NTT, "Once we establish device peripheral technologies, we will reach the power of 30 W/mm, the level needed for practical use." The research lab is working to further improve the quality of diamond crystal by decreasing impurities. The target is a frequency of 200 GHz with an output power of 30 W/mm.

May I Borrow a Cup of Electricity?

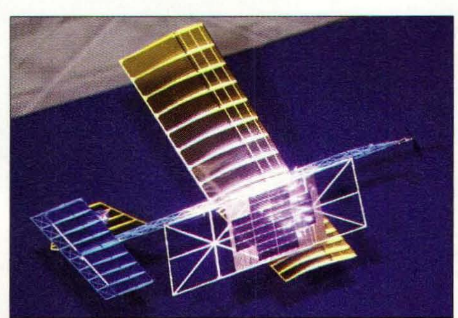
At the University of Massachusetts, Amherst (**www.umass.edu**), Prof. Derek Lovley and researcher Swades Chaudhuri have discovered a microorganism that is capable of stable, long-term production of electricity by oxidizing carbohydrates. The organism —Rhodoferax ferrireducens — transfers electrons directly onto an electrode as it metabolizes sugar into electricity, producing carbon dioxide as a by-product. Because sugars are a substantial component of many types of waste and carbohydrate-rich crops — which can be classified as renewable energy sources — carbohydrates could become economical alternatives to fossil fuels in the production of electricity, according to Lovley.

"There's been a lot of interest in microbial fuel cells trying to covert sugar into electricity," Lovley said. "But in the past, they've converted 10 percent or less of the available electrons, and we're up over 80 percent. And previous attempts to convert carbohydrates to electricity have required an electron shuttle, or mediator, which is typically toxic to humans."

Theoretically, the improved method would allow a cup of sugar to drive a 60 W light bulb for 17 hours, but commercial adaptation is still a few steps away. Lovley added, "Although the process is highly efficient, it is slow. And as the process is right now, we're not talking about a lot of power. It's barely enough to run a calculator, but we did it using unpolished graphite as a receptor. There are almost certainly better electroactive materials.

"The other thing that limits this is that the microorganisms have to attach to the surface of the receptor, so we're working with polymer scientists ... to find a receptor with a maximally uneven surface, so more microbes can attach to it."

Airplane Powered by Ground-Based Laser



NASA's laser-powered, radio-controlled airplane carries no on-board fuel. Photo courtesy of NASA Marshall Space Flight Center.

A team of researchers from NASA's Marshall Space Flight Center in Huntsville, AL (**www.msfc.nasa.gov**), NASA's Dryden Flight Research Center at Edwards, CA (**www.dfrc.nasa.gov**), and the University of Alabama in Huntsville (**www.uah.edu**) recently demonstrated what is believed to be the first aircraft that flies solely by means of propulsive power delivered by an invisible, ground-based laser. The laser tracks the aircraft in flight, directing its energy beam at specially designed photovoltaic cells that drive the plane's propeller.

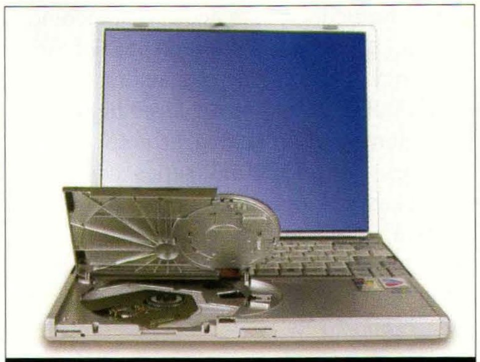
The machine is constructed of balsa wood, carbon fiber tubing, and a Mylar film skin, has a five-foot wingspan, and weighs only 11 oz. According to NASA, improved versions of the plane could be used to carry scientific or communication equipment, staying in flight indefinitely without the need for onboard fuel or batteries. Potential commercial value is envisioned for remote sensing and telecommunications applications.

Granted, this is not the most amazingly high-tech device you have ever seen — and it looks like you could probably build one yourself from RadioShack parts — but it does tend to prove that laser power beaming has potential for practical applications. It also proves that, if these guys are actually being paid to play around with model airplanes, most of us have made some bad career choices.

Computers and Networking

Notebook Computer for Tough Environments

Maybe your work or pleasure takes you into rough physical environments. Or perhaps the suspension in your car is worn out, or you are just in the habit of dropping things. In any of these cases, it might be worthwhile to take a look at the Toughbook CF-W2 ruggedized notebook computer from Panasonic (**www.panasonic.com/toughbook**). The unit is built for rough handling, employing features that include a full magnesium alloy case, shock absorbers built into the hard drive and liquid-crystal display, reinforced screen case edges, stainless steel hinges, and a scratch-resistant outer coating. Even so, it weighs only 2.8 lbs. (1.04 kg), including the battery.



Panasonic's Toughbook® CF-W2 is designed to withstand abuse yet weighs less than three pounds. Courtesy of Panasonic.

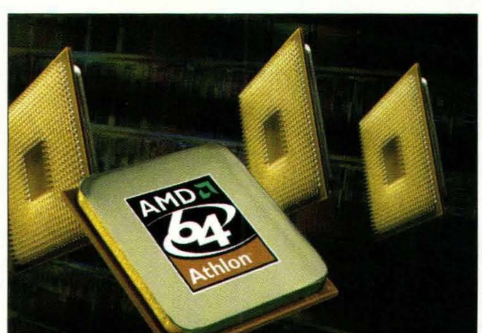
The W2 Toughbook is powered by a 900 MHz ultra-low-voltage Intel® Pentium® M CPU, with 1 MB on-die L2 cache, 256 MB PC2100 DDR RAM (expandable to 512 MB), and a 40 GB UDMA hard drive. It employs thin-glass display technology in the form of a 12.1-inch XGA TFT active-matrix LCD that is said to be almost 25 percent lighter than conventional panels of the same size. Maximum resolution is 1024 x 768 pixels with 16 M colors on the internal LCD and 1600 x 1200 pixels with 16 M colors on an external monitor. The integrated multispeed, multi-format ComboDrive features an 8x DVD-ROM, 6x CD-R, 4x CD-RW, and 24x CD read performance. Expect to pay about $2,250.00 for the machine.

Another 64-Bit Processor Introduced

If Apple Computer hoped to own the market for 64-bit PCs for an extended period of time, disappointment should be setting in about now. At the end of September, Advanced Micro Devices (**www.amd.com**) introduced the Athlon™ 64 FX device, which it calls "the world's first and only Windows® compatible, 64-bit PC processor."

In their introduction, AMD representatives focused on the enhanced performance for gaming applications. "Extreme PC enthusiasts and gamers have long been the drivers of the industry, shaping and influencing what new technology ultimately reaches mainstream computer users," said Dirk Meyer, senior vice president of AMD's Computation Products Group. "We custom-made the AMD Athlon 64 FX processor for these power users. Now, they can spend more time playing, imagining, and creating." Microsoft is backing it up with its Windows XP 64-Bit Edition, which was in beta release as of this writing. The street version is expected to be released during the first quarter of 2004. The chip is based on the x86 architecture, allowing it to be compatible with existing 32-bit software. The AMD press release neglected to mention clock rates, but eight hours of benchmarking and stress tests were conducted by the online magazine *Hardware Analysis* (**www.hardwareanalysis.com**) on a system running at 2.2 GHz, and the reported result was 40 to 50 percent better performance than a similarly configured 3.06 GHz Pentium 4-based machine.

Several versions are available for both desktop and mobile computers, and the wholesale prices run from $417.00 to $733.00 in 1,000-unit quantities. According to AMD, you will soon be seeing Athlon 64-based machines from Hewlett-Packard, Fujitsu, Packard Bell, and many others.



AMD's Athlon 64 FX brings 64-bit computing to the Windows world. Photo courtesy of Advanced Micro Devices.

Circuits and Devices

Ultrasonic Sensors for Robots and Other Applications

Murata Manufacturing Co. (**www.murata.com**) has begun mass production of the MA200D1 series high-frequency ultrasonic sensors, designed to enable distance measurement for robots, household electrical appliances, and other devices at short distances. The major advantages of this over previous products include quick response and short ringing time. Through a review of materials, and optimization of the structural design, the MA200D1 series is designed to provide improved traceability of the drive signals. This results in higher measuring accuracy, particularly at shorter distances. In the frequency band of 220 kHz ± 20 kHz, the series has achieved sensitivity attenuation improvement from approximately -20 dB (for previous products) to approximately -3 dB. As a result, the devices provide stable sensitivity over a wide frequency band. Directivity is increased from approximately 7 to 20 degrees, enabling the sensor to be easily installed in users' equipment.
Furthermore, through improvement of the production of the acoustic matching layer (*3), which is required for high frequency ultrasonic sensors, the MA200D1 series has achieved high production yields resulting in competitive prices. The MA200D1 series can also be used for applications other than distance measurement, such as to detect double-fed paper in scanners and copying machines, and double-fed bills in cash and ATMs.

Brushless DC Motor Boosts Performance

A new line of brushless DC motors from EADmotors (**www.eadmotors.com**) claims a 15 percent increase in performance and lower cost, as compared to traditional brushless DC motors. For example, the recently introduced NEMA-size 23 BLDC motor runs at up to 10,000 RPM with continuous torque rated up to 53 oz-in and power output up to 150 W. Winding options include rated voltages from 12 to 160 VDC. Available in three stack lengths, it's designed for integration into tight system spaces and is compatible with all three-phase brushless DC amplifiers.

Built with permanently lubricated ball bearings and a totally enclosed motor housing, it's rated for 10,000 hours of continuous operation in most high-speed applications. Dynamically balanced rotors reduce audible noise and vibration. Specially engineered options are available to suit customer application requirements including windings, stack lengths, shaft modifications, shielded cables and connectors, optical encoders, and turnkey assemblies. Motors are also offered as rotor/stator sets. Suggested uses include medical instruments, semiconductor equipment, robotics, antenna position, X-Y and rotary positioning equipment, and control devices.

Industry and the Profession

Motorola to Spin Off Semiconductor Business

In October, Motorola, Inc. (**www.motorola.com**), Chairman and CEO Christopher Galvin announced that the company intends to slice off its semiconductor operations into a publicly traded company. This is said to reflect Motorola's desire to increase its focus on communications and integrated electronic systems while creating an opportunity for the company's Semiconductor Products Sector (SPS) to exist as an independent semiconductor company with its own strategy. Motorola is considering an initial public offering (IPO) of a portion of SPS, followed by a distribution of the remaining shares to existing shareholders.
Motorola will retain its other divisions, including the Personal Communications Sector (cellular handsets and related products), Global Telecom Sector (cellular network products), Commercial, Government, and Industrial Solutions Sector (integrated radio and information services for public safety, government, and so on), Integrated Electronic Systems Sector (automotive electronics, embedded computing systems, and portable energy systems), and BroadBand Communications Sector (cable and broadband devices and technology). NV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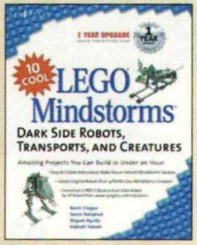
Selected Titles for the Electronics Hobbyist and Technician—

The Nuts & Volts Hobbyist Bookstore

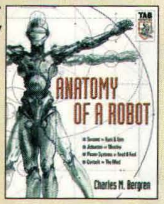
Robotics

10 Cool LEGO Mindstorms: Dark Side Robots, Transports, and Creatures
by Kevin Clague / Søren Rolighed / Miguel Agullo / Hideaki Yabuki



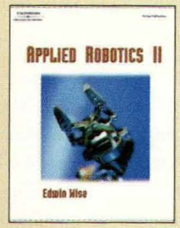
Okay, you bought the kit for yourself or one of your kids. You used the instructions in the box to build a robot or two. Now what? You may not be ready to design and build your own robots, but you don't want to build the same robot over again. This book is the perfect way to build additional projects from the same kit, and then improvise and design your own. Ten cool projects — one hour each ... perfect! **$24.95**

Anatomy of a Robot
by Charles Bergren



Discover how robots articulate movements, how they see and hear, what gives them their power, and, at times, their gentleness. Delve into the robot's "brains," and learn how experienced robot designers use control systems to make their machines think. Much more than an enumeration of parts, *Anatomy of a Robot* exposes the life and human creativity behind today's robot. Always entertaining, this exceptional book takes you deep inside the theory and craft, philosophy, and science of robotics. **$29.95**

Applied Robotics II
by Edwin Wise



Instructive illustrations, schematics, part numbers, and sources are also provided, making this book a "must" for advanced builders with a keen interest in moving from simple reflexes to autonomous, AI-based robots. Create larger and more useful mobile robots! Ideal for serious hobbyists, *Applied Robotics II* begins by discussing PMDC motor operation and criteria for selecting drive, arm, hand and neck motors **$41.95**

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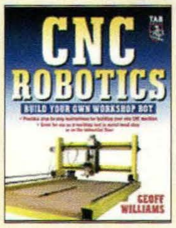
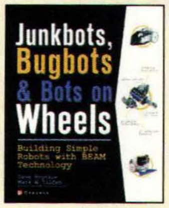
CNC Robotics
by Geoff Williams



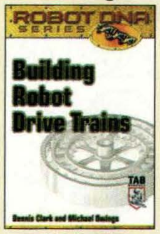
CNC Robotics gives you step-by-step illustrated directions for designing, constructing, and testing a fully functional CNC robot that saves you 80 percent of the price of an off-the-shelf bot — and that can be customized to suit your purposes exactly, because you designed it. Written by an accomplished workshop bot designer/builder. **$34.95**

JunkBots, Bugbots, and Bots on Wheels: Building Simple Robots With BEAM Technology
by David Hrynkiw / Mark Tilden



Ever wonder what to do with those discarded items in your junk drawer? Now you can use electronic parts from old Walkmans, spare remote controls, even paper clips to build your very own autonomous robots and gizmos. Get step-by-step instructions from the Junkbot masters for creating simple and fun self-guiding robots safely and easily using common and not-so-common objects from around the house. Using BEAM technology, ordinary tools, salvaged electronic bits, and the occasional dead toy, construct a solar-powered obstacle-avoiding device, a mini-sumo-wrestling robot, a motorized walking robot bug, and more. Grab your screwdriver and join the robot-building revolution! **$24.99**

Building Robot Drive Trains
by Dennis Clark / Michael Owings

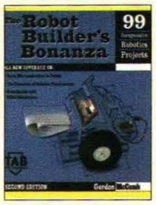


This essential title is just what robotics hobbyists need to build an effective drive train using inexpensive, off-the-shelf parts. Leaving heavy-duty "tech speak" behind, the authors focus on the actual concepts and applications necessary to build — and understand — these critical force-conveying systems. **$24.95**

Everything you need to build your own robot drive train:

* The Basics of Robot Locomotion
* Motor Types: An Overview
* Using DC Motors
* Using RC Servo Motors
* Using Stepper Motors
* Motor Mounting
* Motor Control
* Electronics Interfacing
* Wheels and Treads
* Locomotion for Multipods
* Glossary of Terms/Tables, Formulas

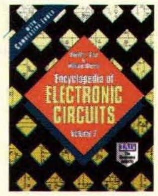
The Robot Builder's Bonanza
by Gordon McComb



A major revision of the bestselling "bible" of amateur robotics building — packed with the latest in servo motor technology, microcontrolled robots, remote control, Lego Mindstorms Kits, and other commercial kits. **$24.95**

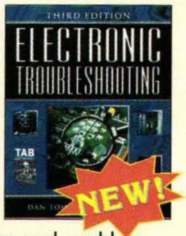
Electronics

Encyclopedia of Electronic Circuits Vol. 7
by Rudy Graf



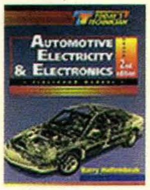
Designed for quick reference and on-the-job use, the *Encyclopedia of Electronic Circuits, Volume 7*, puts over 1,000 state-of-the-art electronic and integrated circuit designs at your fingertips. This collection includes the latest designs from industry giants such as Advanced Micro Devices, Motorola, Teledyne, GE, and others, as well as your favorite publications, including *Nuts & Volts*! **$39.95**

Electronic Troubleshooting
by Daniel Tomal / Neal Widmer



If you work with electronics — either through your profession or your pastime — here's one resource you need handy at all times: the updated, Third Edition of McGraw-Hill's *Electronic Troubleshooting*. Revamped to include the latest electrical and electronic devices and problem-solving methods, this information-packed volume provides a fundamental understanding of electronic troubleshooting theory. **$49.95**

Today's Technician: Automotive Electricity & Electronics
by Barry Hollembeak / Jack Erjavec



The best-selling book/shop manual package in our landmark Today's Technician series, the third edition of *Automotive Electricity and Electronics* continues to equip its readers with the most in-depth discussion of basic theory, safety, tools, and major automotive electrical/electronic systems available anywhere! And, perhaps most importantly, we've added many all-new examples to guide readers, step-by-step, to complete mastery of all of the electrical/electronic knowledge plus hands-on diagnostic and troubleshooting skills they need to become highly skilled automotive technicians. **$75.95**

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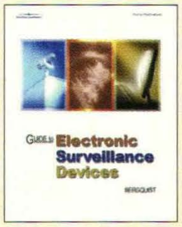
Guide to Electronic Surveillance Devices

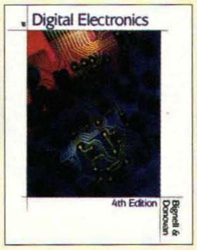
by Carl Bergquist



Enjoy the peace of mind that comes from knowing how to set up and maintain an effective surveillance system! Perfect for do-it-yourselfers, *Electronic Surveillance Devices* contains all of the information needed to enhance the safety and security of a home or office, from safeguarding against theft to monitoring employee performance and preventing illegal activities from occurring on site. **$35.95**

Digital Electronics

by James Bignell / Robert Donovan



This basic text for *Digital Electronics* offers complete, practical coverage of the latest digital principles, techniques, and hardware. Written in a concise, easy-to-read style, it includes everything from basic digital concepts to an introduction to microprocessors/microcontrollers.
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Electronic Gadgets for the Evil Genius

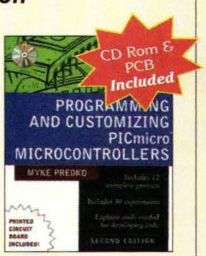
by Robert Iannini

The do-it-yourself hobbyist market, particularly in the area of electronics, is hotter than ever. This books gives the "evil genius" loads of projects to delve into, from an ultrasonic microphone, to a body heat detector, and all the way to a *Star Wars* Light Saber. This book makes creating these devices fun, inexpensive, and easy. **$24.95**

Microcontrollers

Programming & Customizing PICmicro Microcontrollers *2nd Edition*

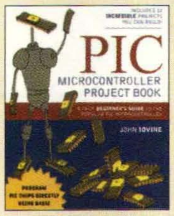
by Myke Predko



This book is a fully updated and revised compendium of PIC programming information. Comprehensive coverage of the PICMicro's hardware architecture and software schemes complement the host of experiments and projects making this a true, "learn as you go" tutorial. **$49.95**

PIC Microcontroller Project Book

by John Iovine



This project-oriented guide gives you 12 complete projects, including: using transistors to control DC and AC motors, DTMF phone number logger and distinct ring detector and router ... home automation using X-10 communications ... digital oscilloscope ... simulations of fuzzy logic and neural networks ... and many other applications.
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by Dennis Clark

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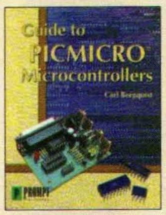
Guide to PICMICRO Microcontrollers

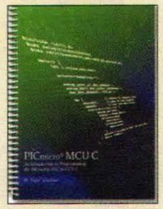
by Carl Bergquist



Aimed at both students and seasoned users, this book will take the reader through the peripheral interface controller (PIC) like no other text. Hardware and software are also discussed in detail. Topics include: physical appearance, electrical structure, software requirements, hardware requirements, prototype layout boards, simple PIC programmers, PIC instruction set, use of the Microchip tools including MPLAB and Technical Library, software applications, software codes, and 8-10 PIC projects. **$45.95**

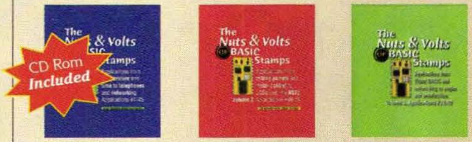
PICmicro MCU C

by Nigel Gardner



This 2nd edition book is a complete introduction to programming Microchip PICmicros in C with the use of the CCS C compiler. The book overviews the ease of using C and the CCS compiler for optimization of your programming. There are many examples to get you started on while using the compiler. **$29.95**

The Nuts & Volts of BASIC Stamps Volumes 1-3



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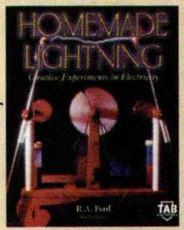
In 1995, Scott Edwards began authoring a column on BASIC Stamp projects in *Nuts & Volts Magazine*. The column quickly became a favorite of *Nuts & Volts* readers and continues today with Jon Williams at the helm. *The Nuts & Volts of BASIC Stamps* is a three-volume collection of over 90 of these columns.

Volume 3 is new and contains columns 76-92!

High Voltage

Homemade Lightning: Creative Experiments in Electricity

by R.A. Ford



Enter the wide-open frontier of high-voltage electrostatics with this fascinating, experiment-filled guide. You'll discover how to make your own equipment, how electricity is used in healing, and the workings of many experiments in high potential physics! **$24.95**

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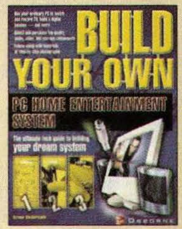

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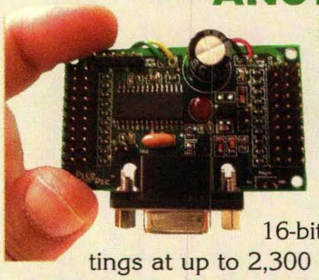

PicoPic™ is a dedicated serial R/C servo controller slave that is capable of controlling 20 R/C servos with 16-bit resolution and 256 speed settings at up to 2,300 commands/sec.

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If you can send serial data through a computer or microcontroller, you can command a PicoPic.

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TEXT-TO-SPEECH PLATFORM — SPEECH-ENABLE ANY PRODUCT

Grand Idea Studio introduces the Emic Text-to-Speech Platform — a simple way to speech-enable any product. The Emic Platform provides high-quality speech synthesis on a single module. The module is an off-the-shelf solution aimed at engineers, hobbyists, and product designers seeking a simple, low-cost method for integrating text-to-speech into their mobile and consumer designs.

The core of the Emic Platform is provided by Winbond's WTS701 text-to-speech single chip solution. The WTS701 creates a more natural human sounding speech by converting text to speech using recorded human speech samples. This ensures that the output is a recognizable human voice — unlike computer-generated synthesis solutions.

The Emic Platform can easily be interfaced to the PC, BASIC Stamp®, Microchip PIC®, or other processor.

Highlights of the module include:

- Serial TTL interface (two-wire, 2400 baud)
- 1.6" L x 1.0" W x 0.256" max. H
- Requires single +5VDC supply
- Internal 8 ohm, 23.5 mW speaker driver
- Analog audio output pin for external amplification
- Easy-to-use ASCII or hex command sequences
- Bi-color LED for visual indication of activity
- 0.100-inch pin spacing for easy prototyping

The Emic Platform can provide text-to-speech for an unlimited number of applications. Potential uses include industrial and scientific (reading laboratory measurements and results, industrial equipment warning and status systems), educational and special needs (aids for reading or language learning, personal communication systems), telecom and mobile devices (SMS-to-voice, instant messaging, Email and fax reading, information services, webpage reading, traffic reports, news, weather forecasts), multimedia (proof reader, translation tools, personal assistant, talking/interactive characters), and automotive (driving directions, navigational aids, on-board alert system, on-board diagnostics, adaptive cruise control technology).

Emic Platform modules are available at an introductory price of $79.00 USD each. Discount pricing is offered for volume, OEM, and educational purchases. Data sheets, application notes, and audio samples are available on the Grand Idea Studio website.

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Circle #54 on the Reader Service Card.

ETHERNET WEB SERVER CAPABILITY FOR EMBEDDED CONTROLLERS

Vesta Technology introduces an affordable expansion capability for its family of compact, cost-effective embedded controllers. NetMedia's SitePlayer (**www.sitepla yer.com**) — billed as the world's smallest Ethernet Web Server – is now supported as a web-based graphical user interface for Vesta controllers. Vesta controllers communicate with the SitePlayer via the serial port, reading and writing to variables for display on the web pages served by the SitePlayer.

The SitePlayer uses a standard 10 Mbit Ethernet connection to provide simple web access using a standard browser, giving users a convenient method of communicating with their Vesta-based embedded systems to remotely set system parameters, and monitor sensors or system conditions. Ranging in price from $19.00 to $259.00, Vesta's embedded controllers can be expanded with the SitePlayer module for under $30.00, providing versatile, inexpensive embedded solutions for OEM applications. Visit Vesta's website for information and pricing, and Vesta Basic programs that demonstrate the ease of integrating SitePlayer with Vesta controllers.

For more information, contact:

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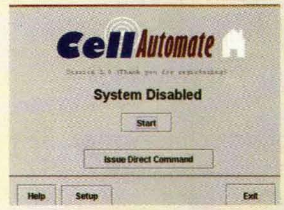
11465 W. I-70 Frontage Rd. N.
Wheat Ridge, CO 80033
303-422-8088 Fax: **303-422-9800**
Web: **www.VestaTech.com**

Circle #70 on the Reader Service Card.

CONTROL YOUR PC, IT SERVER, OR HOME AUTOMATION UNIT WITH ANY CELL PHONE OR PDA



Cellautomate is an application that allows users to control their PC or server and thus a home automation network with email. This means that you can interact with your PC or server with email from your cell phone, PDA, Blackberry, office email, etc. Users email a command from their phone to their home PC email account and the command is received and executed by CellAutomate. The results of the command are then captured and emailed back to the user's mobile device. For people that have a PDA with a web browser, our software generates a "Remote Control File" that allows them to issue commands through a point and click user friendly interface.

For more information, contact:

CELL AUTOMATE
Web: **www.cellautomate.com**

Circle #114 on the Reader Service Card.

by Dave Sweeney

Color In A Monochrome World

Investigate the Psychological Perception of Color in Your Living Room!

This Month's Projects

The Fuzzball Rating System

To find out the level of difficulty for each of these projects, turn to Fuzzball for the answers.

The scale is from 1-4, with four Fuzzballs being the more difficult or advanced projects. Just look for the Fuzzballs in the opening header.

You'll also find information included in each article on any special tools or skills you'll need to complete the project.

Let the soldering begin!

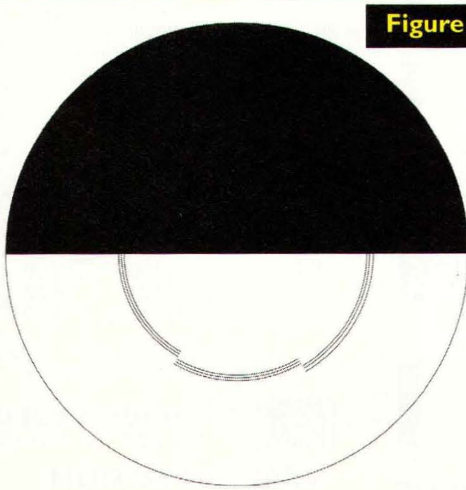
Color, like beauty, is in the eye of the beholder. The color phenomenon enhances life, from roses and yellow striped bumblebees, to colorful sunsets, gourmet food, and even the tone of someone's skin. Colors often stimulate human emotion. Color has the longest definition in the dictionary, yet, color doesn't even exist. Our eyes decode electromagnetic radiation, and our brains imagine color.

You can prove that the brain only imagines colors by fooling the brain into thinking it's seeing color with an image that contains none. You can generate the effect by spinning a peculiar, monochrome image on a rotating disc. The image is called a Fechner pattern, and is shown in Figure 1.

The circular image is half-black and half-white, with black arc segments within the white portion. When it spins at the right speed, the arc segments appear as color-hued circles.

For best results, a computer prints the black and white pattern, and a well-developed demonstrator is used to spin the pattern. The demonstrator includes a unique, low power motor which spins at 240 RPM. (You may download a PDF of the Fechner pattern from the *Nuts & Volts* website at **www.nutsvolts.com**).

Figure 1



As it spins, color rings will appear. Watch the colors for a while, and then suddenly stop the spinning. The colors are gone. Consider the larger, philosophic aspects of this experience. You may look around the room and realized that the objects that you see have no color, unless you are looking at them! Otherwise, they merely reflect electromagnetic radiation.

The Eye and Color Perception

The Fechner disc in Figure 1 is simply a piece of paper containing a circular black and white pattern. The pattern reflects room light as it spins, and at four rotations per second, it exhibits the colors.

Our eyes use a number of elements to provide an image for our brains. Focused by the lens with brightness limited by the pupil, light stimulates the retina, which contains photoreceptor cells called rods and cones, and its the cones that specialize in color vision ... the brain defines the visual image.

The retina sends visual information along the optic nerve. When receiving signals from our specially designed, rotating black and white pattern, the brain introduces color into the processed image.

However, it's not clear if the cones are involved. Signals sent along the optic nerve from the rotating pattern may contain the same frequency components as signals from objects viewed as having color. The complete mechanism is not totally understood, since color is the human mind's interpretation of electromagnetic radiation of a particular frequency.

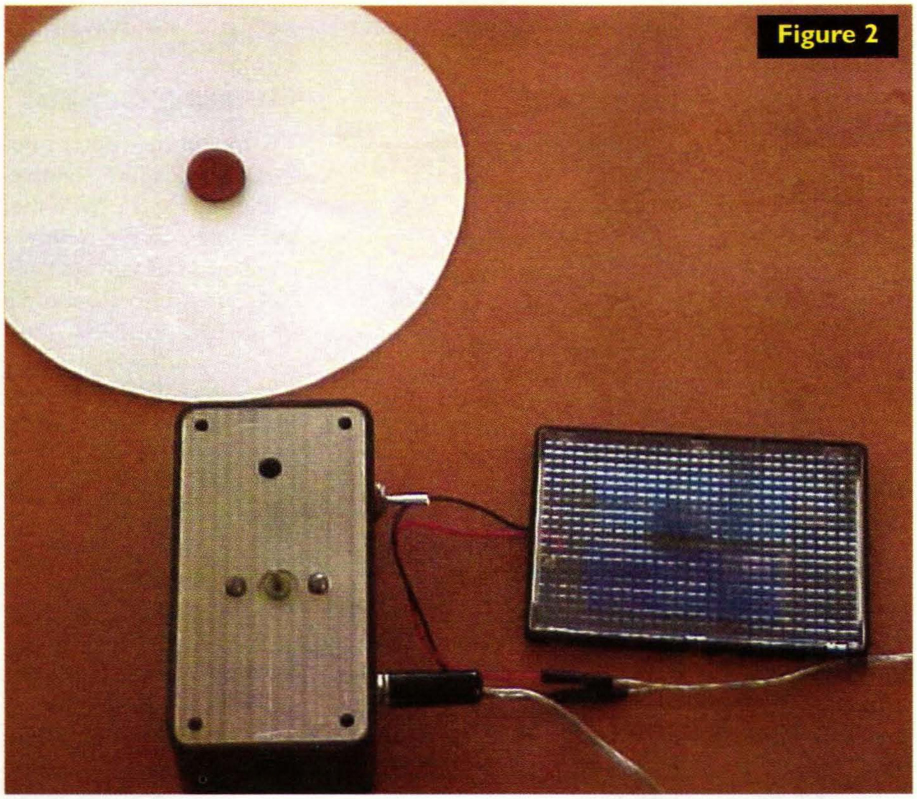


Figure 2

Color perception can vary among individuals and image perception can depend greatly on the surrounding background.

It is interesting that a monochrome videotape of a Fechner image played back on monochrome television — which uses a raster scan — generates the same color effect as viewing the disc "live." The result produces color on a black and white television.

The rotating black imprint on a piece of paper generates red, green, and blue lines when it is viewed. This phenomenon is named after Gustav Fechner (1801-1887) who studied mental perception and developed early theories of psychophysics.

Born in Gross-Sächen, Prussia, Fechner received a medical degree at the University of Leipzig, then pursued physics and mathematics. In 1834, he was appointed Professor of Physics at Leipzig.

Although he was essentially a physicist, he turned to the problems of philosophy, and concentrated on the entire spectrum of perception. Considering the interaction of the mind with matter, he developed his theories of psychophysics, which other scientists have examined and written about.

More information about Fechner can be found on the Internet as well as your local library.

Desktop Demonstration

Figure 2 shows the desktop Fechner demonstrator. The lamp energizes the solar cell, which connects to the motor mounted under the disk. Move the lamp to vary the RPM and optimize the color effect.

A half inch, rubber disc from a plumbing supply store is glued to the Fechner disc and provides a base to attach to the motor shaft. Note also the toggle switch on the case and a mini jack and plug.

As you will see in the schematic, the switch reverses the polarity of the power applied to the motor, thus reversing the spin direction and reversing the order of the color rings. The jack and plug connect power from the solar cell.

Fechner Demonstrator: Schematic

Figure 3

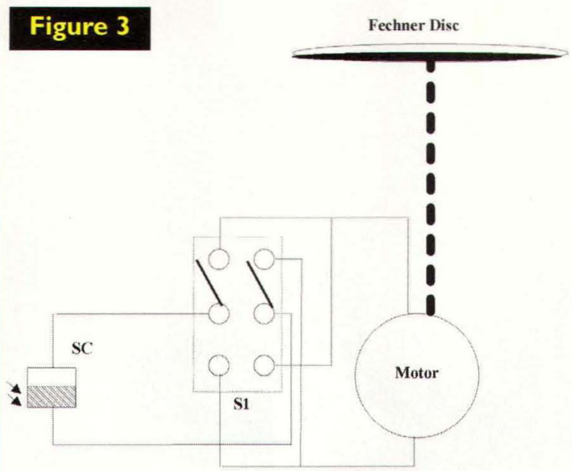


Figure 3 shows the schematic of the apparatus used to control the disc, as well as the parts list for the necessary materials. The motor, specially designed to run at 200-300 RPM under solar cell power, turns with 3 VDC applied.

A power supply or batteries with some kind of speed control could supply the 3 VDC, but the solar cell and lamp are simpler and add to the mirth when demonstrating the phenomenon. (The audience suspects there's something sneaky about the lamp. Its fun watching them look for the "trick.")

Throw the switch and the motor changes direction. In one direction, the colors are ordered red-green-blue, with the outside rings being red. Spin the motor the other way and the order of colors reverses to blue-green-red.

Assembling the Demonstrator

Mount the motor and DPDT switch in a suitable equipment case. Wire the solar cell and the motor as shown in Figure 2.

Due to the pattern's need for precisely positioned, perfectly circular arcs as well as the pattern's lack of symmetry, please download the PDF pattern from the website as mentioned earlier.

By changing the PDF image size, you can create a disc of any practical size as well as explore the relationship between image segments and color effects. You may want to explore the way that perceived colors vary with line segment length and width, and with changes to the black field.

Assemble the demonstrator by cutting out the disc pattern. Use a pin to punch a small hole through the pattern's center, and then glue the faucet disc with a hole in its center matched to the hole in the paper. Next, press the disc on the shaft of the electric motor.

When you see the colors, invite friends and family for a demonstration of something important. Ask them to observe the colors. Mention the rings and point out the locations of the red, green and blue.

When they agree that they see the colors, have them focus on the disc as you move the lamp away and the disc stops rotating. Presto – there's no more color! Your audience might be heard to mutter, "cool."

Then you can ask them a question: If a light bulb glows and no one is there to see it, is there light? **NV**

PARTS LIST

SC - Solar Cell	Edmund Scientific, #T37,334
Motor	Edmund Scientific, #37590
S1	DPDT toggle switch
Fechner Disc	Shown in Figure 1, mounted on motor shaft
Enclosure	RadioShack, #270-231
Misc.	Rubber mount for disc, mini phone jack and plug

Reader Feedback

Continued from Page 6

Without getting long-winded, "The Ben Clock" has been one of the most fun projects I have ever built and is mostly due to John's sincerity and support of the project. I had a little goof in my project and John was able to help me work it out. His response time has been staggering, getting replies to my Emails — in most cases — the same day. I have been a long time reader since the old days of *Popular Electronics* and this has been one of the most enjoyable and educational projects I have ever done. It's a pleasure to see top quality articles and work with the people who write them.

Willie Jones
Indianapolis, IN

Dear Nuts & Volts:

I received a complimentary September issue, but what prompted me to request it, was a strange large size issue that I received back in August 2002, but frankly didn't pay much attention to. It seemed to be just one more of the many such commercial advertisement magazines I receive at work. However, after reading the very interesting article by Ray Green and other authors of that issue, I said to myself ... finally, a magazine that's not all about the latest and fastest PC to come out, or what's wrong with Windows.

Moreover, your magazine still believes that there is a need to teach basic electronics, with articles such as those by Ray Marston and others. Way back when I started in electronics, I got more practical information and product ideas from magazines like *Radio Electronics* than the stack of college textbooks I had gone through. Keep up the good work.

Frank S. Giannone
via Internet

Dear Nuts & Volts:

I just read your Nov. 2003 "Micro Memories" and did not see the company that I think did a lot for the micros of the 70 and 80s mentioned. This was OSI (Ohio Scientific Instruments). They had a small system that used a 6502 that was a very good system for its time. They also had a small business system that had two eight-inch drives and three microcontrollers. These were a 6502, 6800, and an 8080 so you could run CPM software. The computer came with very good software and you could run any of the micros to start with (6502), and change at some point in the program to the 6800 or the 8080. We don't have that today. This system had paged memory and you could run 16 of the 6502 systems into it. If you had a lot of money, you could get a 76 meg hard drive. The first system that I had was a Trash 80, and when I bought the OSI, I was sure that this was the best thing since sliced bread. The company got a big head though, and people dropped them so fast that, in less than a year, they were gone.

R.W. Eisnaugle
via Internet

Dear Nuts & Volts:

Thanks very much for your entertaining and informative series, the "Bipolar Transistor Cookbook." I especially appreciated November's offering on oscillators. Please keep this series alive.

Jim Wood
Brea, CA

by Josh Bensadon

Digital Combination Lock (With a Twist)

Here is a digital twist to an old idea. Locks have been around since at least the twelfth century B.C., and have been mentioned frequently in the Old Testament. A good history lesson about locks can be found at **www.nokey.com/ankeymus.html**

Digital combination locks have also been in existence for a long time. They are a popular circuit for beginners. One of my first projects back in 1977 used discrete push button switches and a staged flip-flop circuit.

The combination buttons were hard wired to clock the next flip-flop from the previous flip-flop (if set), while other dummy buttons reset the flip-flops and canceled the sequence. The construction took many hours and the button wiring was messy. Microcontrollers simplified the circuit and enhanced the operation. Matrix keyboards reduced the wiring. Easy to change combinations made them more secure. This type of circuit has been so successful that many security manufacturers build them as commercial units known as "stand alone keypads." The stand alone keypad looks professional and impressive when mounted at the entrance to a building. But, they look out of place when mounted on smaller lockable objects such as a filing cabinet. I bet the keys to my second hand filing cabinet were probably lost within months by the original owner. As a true do-it- yourself kind of person, I decided to make my own type of combination lock.

Matrix keypads are difficult to mount, look awkward, and require seven wires. A different kind of input device was needed. Potentiometers are easier to mount (only one hole to drill), look better, and only require three wires. By assigning numbers to various potentiometer positions, a unique combination can be entered or "dialed" in. The different positions will produce a corresponding voltage when the potentiometer is connected as a voltage divider (Table 1). These voltages can be decoded using an Analog to Digital Converter (ADC). The ADC has become a popular feature embedded in many microcontrollers. Thanks to this, the digital twist combination lock requires very few components.

Another bonus is the reduction of microcontroller I/O pins required. It could boil down to two I/O pins: one for the potentiometer input and the other one for the unlock output.

The PIC12CE674 has six I/O lines, and to not waste any, four additional functions were added — two inputs for setup programming and manual unlocking, and two outputs for re-locking and an audible sounder. The sounder output is needed for programming to provide an audible feedback. It is also convenient when dialing in the combination, but can be disconnected via jumper JP2.

Features

Up to twelve definable positions exist for the dial digits. The software supports a three to six digit combination. Separate unlock and re-lock outputs provided to allow a motor type lock device with up to 500 mA of current drive. The programmable unlock times as shown in Table 2. Re-lock on change allows the system to remain unlocked until the dial is moved. A manual unlock input available. Finally, the combination is stored in non-volatile memory (EEPROM).

Operation

On power up, jumper JP1 determines if programming mode is entered (pins 1-2 shorted) or normal operation (pins 2-3 shorted).

TABLE 1
Values Measured for Nine Defined Positions

Position	Voltage	ADC Input
1	0.00 V	0
2	0.16 V	8
3	0.91 V	46
4	1.70 V	87
5	2.45 V	125
6	3.23 V	165
7	4.00 V	204
8	4.69 V	239
9	5.00 V	255

Programming Mode

Phase 1 — Calibrating the dial

Install jumper JP1 on pins 1-2. Set the dial to first digit and apply power. Listen for a long steady tone heard followed by a chirp. This indicates the position was recorded.

Now, set dial to next digit. A steady tone will be heard while the dial is moving. Wait for the chirp, and then continue to set all digit inputs (up to 12 maximum). If less than 12 digits are to be entered, wait six seconds after the last digit.

Phase 2 - Setting the combination

A double beep will sound to mark the entry of the combination. Turn the dial to first digit of the combination and wait for a chirp. Then, set dial to next combination digit. Beeps will be heard as you pass "through" the digits. Wait for the chirp, and then continue to enter all combination digits (up to six maximum). If less than six digits are to be entered, wait six seconds after the last digit.

Phase 3 - Setting the unlock time

Use the dial digits (the first digit is zero, second digit is one, etc.) to enter the unlock time. Set the dial to the first digit of the unlock time and wait for a chirp. After a short delay, the next unlock digit will be entered. Note, if less than 10 dial digits were defined then you will not be able to enter all unlock times (e.g., 009). Once all three phases are completed, the configuration data is written to the EEPROM. Normal operation will begin when JP1 is moved back to pins 2-3.

Normal Operation

The dial positions, combination, and unlock time are all read from the EEPROM. A long chirp will sound, and a re-lock will occur. Short beeps will sound as you move the dial to any digit. To unlock, set the dial to any digit other than the first combination digit and wait one second. This will reset the combination sequence.

Next, set the dial to the first digit and wait one second. Continue to dial each digit of the combination, waiting one second after each combination digit. Do not stop the dial on an incorrect digit for more than one half of a second, or else the sequence will need to be restarted.

When the combination has been entered correctly, the unlock output will activate as programmed in Table 2. The re-lock output is fixed as a four second pulse (preceded by a two second delay).

Construction

Since the circuit is small, it can easily be made in about an hour using an unclad PC board and some small hook- up wire. See Figure 2 for a suggested layout of the parts. The leads of some of the parts can be used to make the connections — just bend them in the direction needed. A small drop of crazy glue will hold the pin headers securely. The emphasis here is on making the unit simpler by using fewer parts.

Before inserting U1/U2, apply power and ensure you have +5 VDC between U1 pin 1 (+) and U1 pin 8 (-). Disconnect the power and insert U2 and the programmed PIC (U1). R3 is mounted vertically to save space. The use of R3/J2 is optional — you may simply short U1 pin 6 to +5 V to omit

TABLE 2
Unlock Time Operation

000	Unlock indefinitely, re-lock on change only
001-003	Unlock 2 to 6 seconds, re-lock on change
004-255	Unlock 8 to 510 seconds, auto re-lock

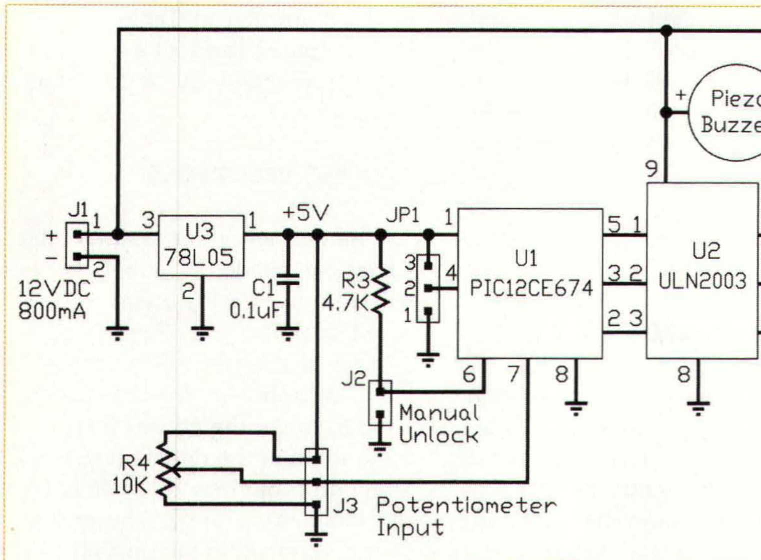


Figure 1. **Combination lock schematic**

a logarithmic taper (audio taper). Since it is used as a voltage divider, the value is not critical, anything from 500 ohms to 25K will work. Most pots will have an effective rotation of 300 degrees like the part I listed, but there are some with only 180 degrees (though rare). The first few degrees do not count. Notice in Table 1, the voltage difference between positions 1-2 and 8-9 is much less than the other adjacent positions.

these parts. The use of R1/R2 is based on the output configuration you require — I list some options at the end of this article. In my installation, I omitted J3 by soldering the leads of the potentiometer directly onto the board to support/mount the board (Photo 2).

The parts listed are just to make this project complete. I suggest a visit to your local surplus store, they will most likely have potentiometers, knobs, transformers and some type of geared motors. Almost all of the parts I used came out of my junk box and are not exactly the parts listed. The two most critical parts are the motor and the potentiometer knob, especially when combing through surplus shops.

The potentiometer must have a linear taper, and not

The geared motor to unlock and re-lock is mostly dependent on what you are unlocking. I used a surplus motor from a camera lens. A small linkage using a coat hanger wire was added by drilling a hole into the gear (Photo 3). The geared motor listed provides a starting force of 60 oz-in. (0.42 NM) at 1 RPM. If your surplus shop doesn't have something useful, try visiting your local automotive junkyard — door lock motors have a lot of kick! My guess is these motors will demand three to nine amps of inrush current so you will need to replace R1/R2 with relays to handle the high current. Finally, choose your power supply accordingly.

Alternative Endings

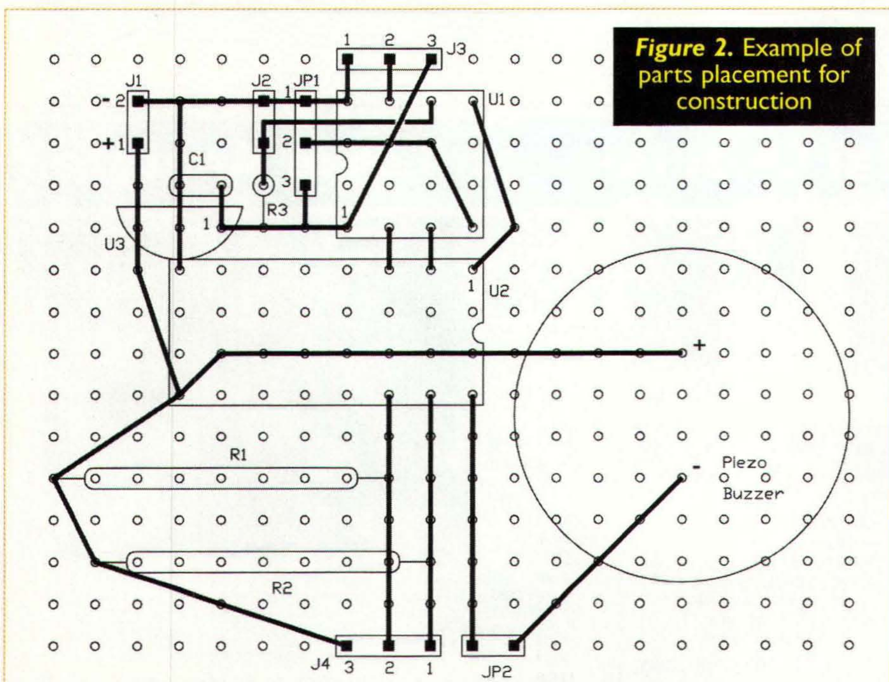


Figure 2. **Example of parts placement for construction**

Some movies have them, so why not this project? Figure 3 shows some alternative outputs. U2 can directly drive most small commercial electric door strikes (omit R1/R2 and don't forget to add the diode.) The output as shown in Figure 1 uses two resistors (R1/R2) which allows a low current motor to be used. When the open collector drives one output low, the motor will use the other resistor to source the current. R1/R2 are slightly under rated at 2 W. The voltage across the driven output is 12 V (ignoring the voltage drop by U2). The power generated will be 12 X 12 / 56 = 2.6 Watts. If the unlock time is kept short, the resistor will not burn out. You can use 3 W resistors but the 2 W make the board smaller. With the motor I have used, the source resistor will drop about 2 V. A full H bridge circuit can be used to maximize the motor voltage. If higher current or voltage is needed, two relays can be used as shown.

Alternative Inputs

Figure 4 shows how a standard common bus and matrix keyboard can be used instead of the dial pot. Connect the resistors directly to the keyboard to reduce keyboard wiring to only two wires. Different resistor values for Rk will produce unique voltages when in a series with resistor Rs. The first key doesn't need a resistor since 0 V is a definable value for a digit. When using a matrix keyboard, select Rc2 and Rc3 to be much larger than Rr4. They should act like a multiplier. For example, try 1K and 2K for the column resistors with 100, 200 and 300 for the row resistors. The matrix will add these resistances together to produce unique voltages with the series resistor. I will leave it up to you to calculate or experiment with different values. Keep the total resistance under 40K to comply with the recommended PIC 10K input impedance. The software for the PIC was written to ignore voltages that are not close to a defined digit, so the open circuit voltage (5 V) will not count as an input digit when you release a key.

Software Operation

Phase 1 of the programming creates a table of numbers (ADC values) as selected for each digit on the dial. During normal operation, the ADC input is compared to its previous sample to determine if the dial has been turned. When turned, the new input is then compared to every number in the table of digits. If it's within the "DigitRange" to the closest number in the list, then that becomes the new dial digit and a short beep sounds. If it remains on this digit for more than one half of a second, then it is considered to be the digit that the user intended to register. This registered digit is then compared to the combination sequence. If incorrect, then the sequence resets. If correct, the sequence advances until the full combination has been registered. When that happens, the unlock mechanism allows you access to that well guarded treasure!

The complete source code and compiled HEX program files are available at the *Nuts & Volts* website at **www.nutsvolts.com** The PIC configuration fuses are documented in the readme.TXT file.

PARTS LIST

Part	Description
U1	PIC12CE674 microcontroller, OTP or EPROM version
U2	ULN2003AN 500 mA open collector driver
U3	LM78L05 5 V 100 mA voltage regulator
J1-J4, JP1-2	40 pin header, break away
R1, R2	56 Ω 2 W
R3	4.7K Ω 1/8 W
R4	10K Ω linear taper pot
C1	0.1 µF

Misc.
Unclad PC board
8 pin socket
16 pin socket
Geared motor, about one RPM

Knob with numbers

Mini jumpers
Piezo buzzer (quiet, 70 db)
Piezo buzzer (loud, 85 db)
12 VDC 800 mA wall transformer

Software Construction

The program is written in assembly code. Special thanks to MicroChip for their assembler (MPASM), template code and EEPROM routines (which were simplified

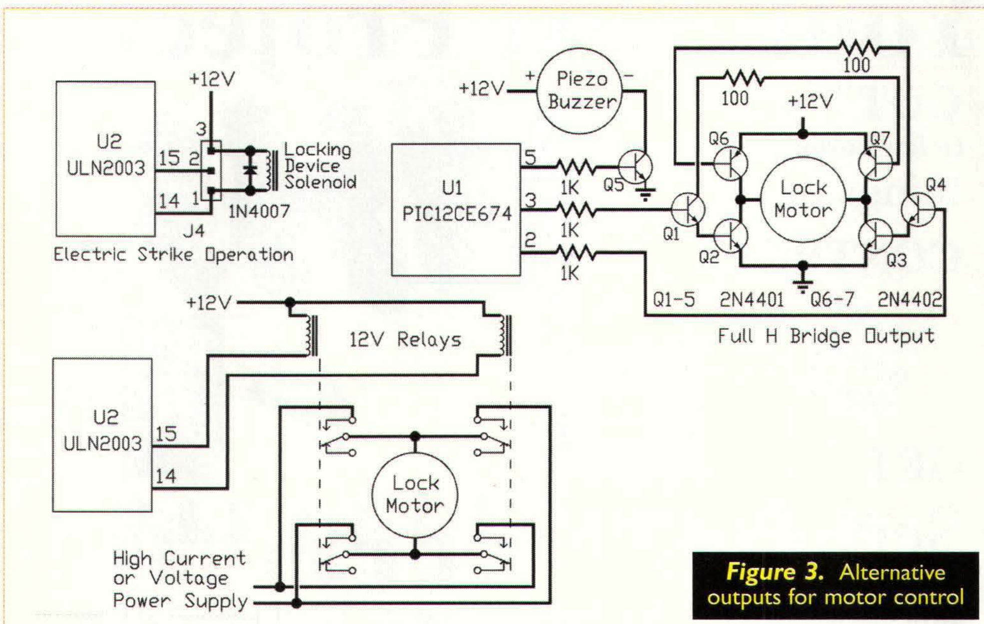


Figure 3. Alternative outputs for motor control

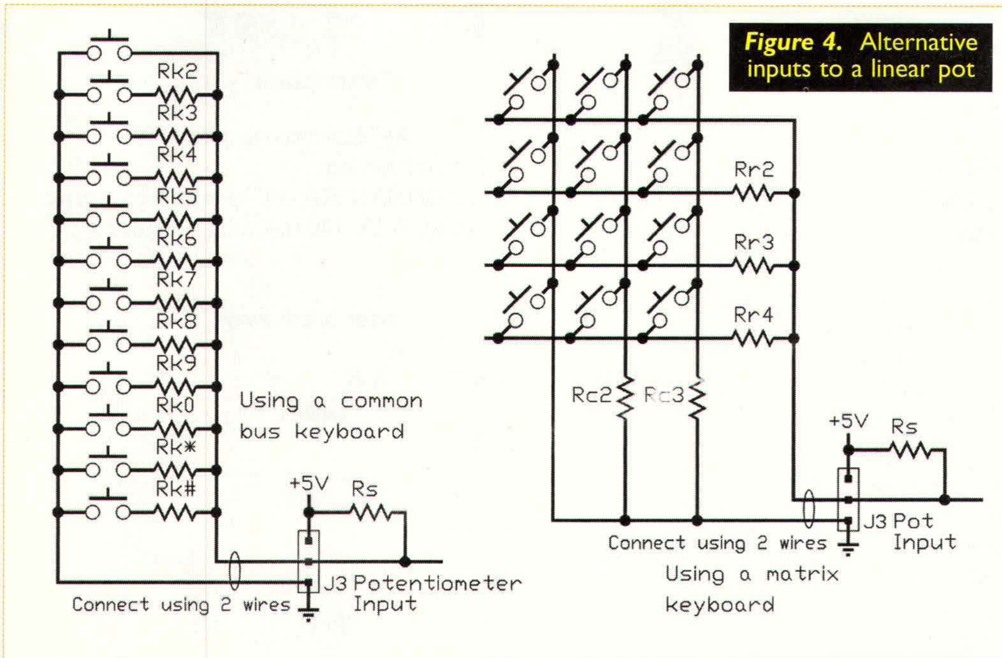


Figure 4. Alternative inputs to a linear pot

for the 4 MHz operation and then appended to the template file.) The rest of the code was first planned using BASIC to create the logic, then implemented in assembler. Some instructions were redefined as simple words.

For example, "BTFSS Status, Z" was redefined as "SkipIfZero" to make the code more readable. Instructions that refer to the I/O pins are also defined so that different I/O pins can be easily assigned. The use of the piezo buzzer made debugging easier by using beeps at various milestones.

Chip Selection

MicroChip makes many microcontrollers. Atmel also makes a very nice eight pin device (TinyAVR). Because I had the PIC12CE674 in my inventory, I chose this microcontroller with 2 K of program memory. The program will also fit the PIC12CE673 device, which has only 1 K of space. According to Digi-Key pricing, these two PICs are the same when bought in unit quantities, so I use the 2 K device for the same cost.

A "One Time Programmable" (OTP) PIC can save you even more money. Another very attractive PIC device is the new PIC12F675. Using Flash technology, the device can be reprogrammed without erasing via UV light. At a glance, the program provided would need minor alterations to registers ADCON1 and ADCON2 (ANSEL in PIC12F675) and patching in new EEPROM routines for this device.

Final Word

By using extended temperature parts, this lock can be used outside. A small O-ring can make the potentiometer water-resistant. Another idea is to put the potentiometer and a battery in a hand held unit. Use a short cable with a three pin connector to connect it to the lock circuit mounted on the secure side.

This system can provide high security for anything your imagination can think of! **NV**

ABOUT THE AUTHOR

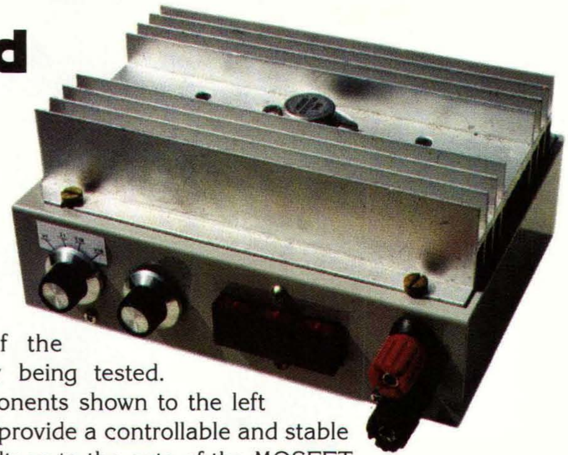
Josh Bensadon has been an electronics technologist since 1987 and an active electronic hobbyist ever since he could use a soldering iron. He used to assist his father in repairing old black and white TVs when he was nine years old.

Currently, Josh works for ADT Security Systems, in the field of CCTV and Card Access. He can be reached for questions or comments at JBensadon@hotmail.com

by David Ponting

Variable Resistive Load

Reduce the Number of Power Resistors in Your Toolbox with this Project!



I was going to have a need for extensive use of a variable load to check power supplies of up to 50 volts and up to 10 amps, so I decided to investigate magazine advertisements and the Internet for second-user units and found, to my dismay, that even one with inferior parameters was $300.00. This was more than enough pressure to explore the possibilities of designing my own. Surely, it need be little more than the electronic equivalent of a very large, very high wattage rheostat?

Put like that, what immediately came to mind was an N-channel, enhancement-type MOSFET. This type of transistor can control large currents by varying small voltages to the gate pin. In other words, it can be made to perform as a variable resistance. And power MOSFETS are widely available in high wattage packages. Figure 1 shows a practical reality of this simple idea. The load consists of the MOSFET Q1, with R7 as a current limiting resistor. The supply being tested is connected between the MOSFET's drain and the ground line. With zero volts on Q1's gate, the transistor exhibits virtually infinite resistance between drain and source, and consequently no current passes. However, as the voltage on the gate is gradually increased, the effective resistance of the MOSFET reduces and current flows out of the supply being tested.

Components shown to the left of Q1 provide a controllable and stable low voltage to the gate of the MOSFET. D1 is a constant voltage diode with R1 as its current limiting resistor. The ZXRE125 component recommended produces a pretty constant 1.223 volts, but the exact value does not matter and there are many different kinds of similar diodes which may be used. S1A is the first pole of a four-way switch. Switched as shown, the 1.223 volts appears across the series combination of R2 (560K) and VR1 (50K). Therefore, the voltage at the pole is given by 50/(560+50) x 1.223, or about 0.1 volts. The same voltage appears with the switch in its second position. But in its third and fourth positions, the series combination of R3 (11K) with VR1 (50K) results in about 1 volt at the pole. Hence, switch S1A allows the selection of either 0.1 volt or 1.0 volt at the "A" end of VR1. Via R4, the wiper of VR1 provides a proportion of one of these as a reference voltage at the non-inverting input of IC1. The potential at the "north" end of R7 due to whatever current is flowing, is fed back via R6 to the inverting input of IC1. In this configuration, the

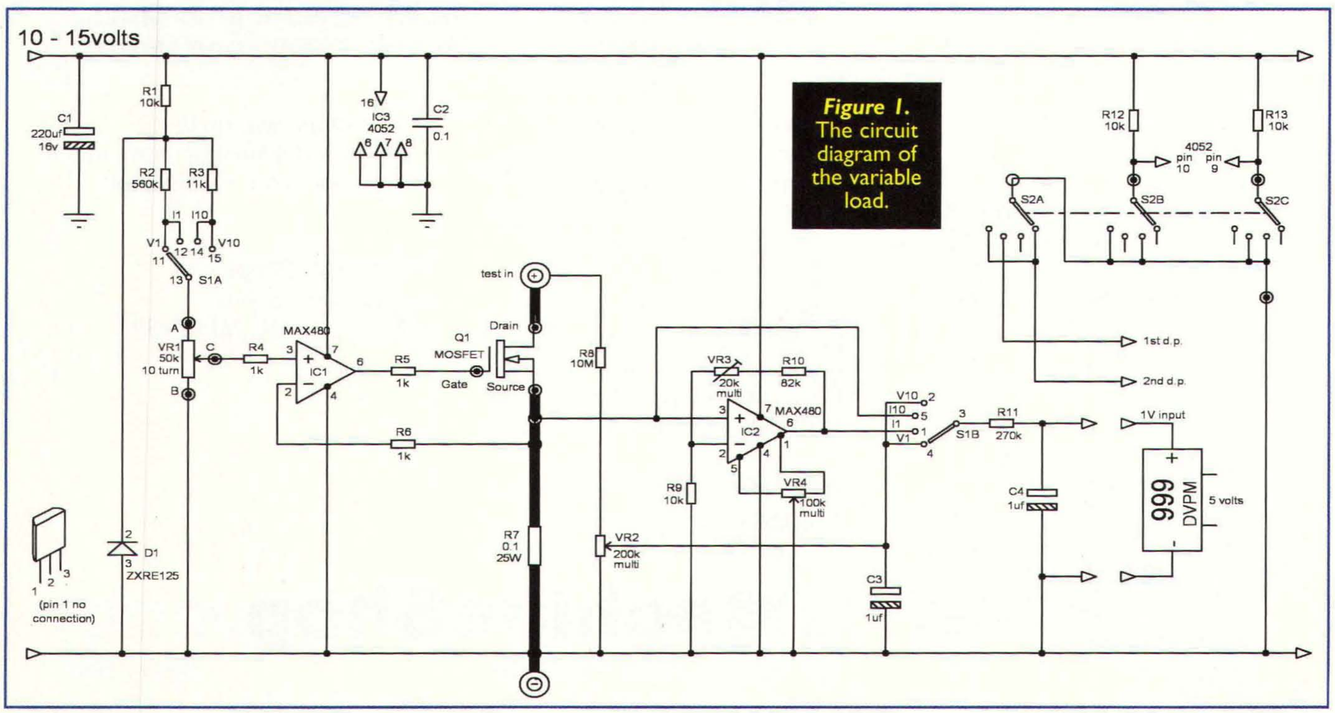


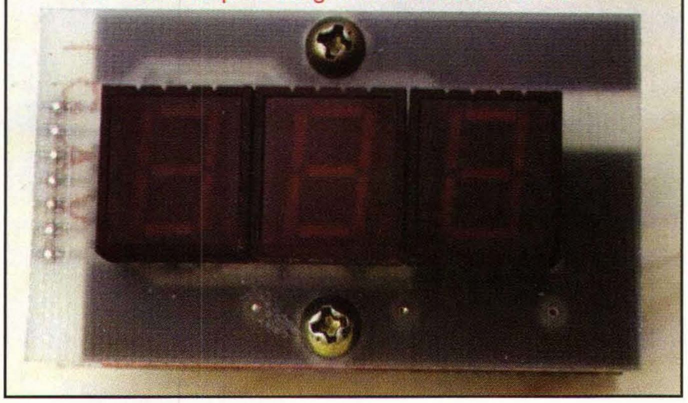
Figure 1. The circuit diagram of the variable load.

primary aim of the op-amp will be to try and maintain the same voltage level at both its inputs. Consequently, IC1 will drive the MOSFET just hard enough for the current flow through the transistor and R7 to be no more than just sufficient for stability. Hence, the switch S1A in positions 1 and 2, together with the 10-turn potentiometer VR1, allows the selection of the voltage at IC1 pin 3 to be in the range of 0 to 0.1 volts, resulting in a current flow through the MOSFET and R7 of 0 to 1 amp; alternatively, with the switch in its third and fourth positions, the voltage at IC1 pin 3 can be varied from 0 to 1 volt when the current flow will be adjustable from 0 to10 amps. The MAX480 is particularly suitable for use in this circuit. It is a precision op-amp which can be powered asymmetrically while still allowing its inputs and output to include ground. That is all there is to the variable load. However, in use, it is much more convenient if the same unit can also display both load current and input voltage. By designing the variable load circuit with a 0.1 ohm value for resistor R7, a simple and non-invasive way of "measuring" the current flow is possible.

Every millivolt dropped across R7 represents a current flow of 10 milliamps. So a digital multimeter used on either its 200 mV or 2 volt range can determine the current flow. However, it can be confusing to interpret a meter reading of 010.0 on the 200 mV range as a current of 100 mA, or 0.456 on the 2 V scale as 4.56 A. A bespoke digital voltmeter hav-


The almost complete, piggy-backed DVM.

ing a fundamental range from 0 to 1 volt full scale would provide more meaningful readings. Using such a DVM to display current flow in the 10 amp range is easy, since the voltage at the "north" end of R7 goes from 0 to 1 volt as the current flow varies from 0.00 to 9.99 amps. So with S1B switched to pin 5, the "north" end of R7 is connected via R11 to the DVM. Measuring current flow in the 0 to 1 amp range is not quite so simple, although just using the same direct connection would provide useful, but more limited readings, since voltages on R7 going from 0 to 0.099 would display as



Close-up of the top surface of the display PCB. The ends of all protruding wires have been filed flat.

0.00 to 0.99. This, of course, fails to take advantage of the full potential of a three-digit DVM. Consequently, a DC amplifier, built around IC2, is included. The gain of this sub-circuit is given by:

$$\frac{(VR3 + R10)}{R9} + 1$$

By suitable adjustment of the potentiometer, (VR3 + R10) can be set precisely at 90K ohms when the gain will be exactly 10. So, with S1B switched to pin 1, the DVM is connected to the output of the x10 DC amplifier and a voltage of, say, 567 mV across R7 can be read as 567 mA on the DVM. VR4 in this sub-circuit allows correction for off-set nulling, ensuring that the op-amp outputs zero for zero input. Finally, we need to be able to measure the full value of the test voltage being applied. This is an important parameter, particularly when testing batteries under discharge. Having set the discharge current, the DVM can be switched to the voltage range where the battery's potential can be monitored under load. Scaling resistors R8 and VR2 provide this facility. Suppose that the input is 50 volts — the maximum planned for. Then as before, the voltage at the R8/VR2 junction will be given by 200K/(10M+200K) x 50, or about 0.98 volts. Hence, by adjusting VR2 to more or less its center position, the voltage on the wiper can be set at 0.5 volts, which can be displayed on the DVM as 50.0.

This voltage scale needs to be the same for both current ranges and this is achieved when S1B is switched to either pin 2 or pin 4. In summary, when S1 is in its first position, as shown in Figure 1, the maximum current through the load can be adjusted up to 1 amp with the DVM displaying the input voltage. In position 2, the current scale is the same, but the DVM now shows the load current in milliamps. In position 3, the current through the load can be set to a maximum of 10 amps, and this will be displayed on the DVM as 9.99. Finally, in the fourth position, the load current remains adjustable up to 10 amps, but the DVM will again display the test voltage.

S1A and S1B could be separate switches, but a third pole is certainly necessary in order to control the position of the decimal point on the DVM's display. Consequently, a better solution is to use the analog switches incorporated in the CMOS 4052 integrated circuit. This IC contains two 1P4W switches which now take the place of S1A and S1B and whose actions are both controlled by the binary code on pins 9 and 10. To operate the 4052 used in this circuit, a mechanical 3P4W switch is still required, but as can be seen for the three poles shown in the top right hand corner of Figure 1, the only signal switched is ground. In the position of S2 shown in the diagram, S2A connects the second decimal point to ground (displaying as 00.0) while S2B and S2C are open, leaving IC3 with the code on both pins 9 and 10 as high via pull-up resistors R12 and R13. With that code, pins 3 and 4, and 13 and 11 are joined within the 4052. This means that on the DVM we are reading the test voltage, while VR1 is controlling the load current in the scale 0 to 1 amp. That connection I am calling V1.

Operating S2 one position clockwise results in no decimal point being connected (we are reading the current flow in milliamps within the low current range) while the code on pins 9 and 10 is low/low. In IC3, this joins the pairs of pins 3,1 and 13,12. That connection I shall call I1. In the third position of S2, the first decimal point is lit (0.00), pin 9 is low, pin10 is high, thus joining pin pairs 3,5 and 13,14 in the IC; we are reading the current flow in the 10-amp range (I10). Finally, in the fourth position of S2, the second decimal point is again lit (00.0), pin 9 is high, pin 10 is low resulting in the joining of pin pairs 3,2 and 13,15 — we are again reading the test voltage (V10). For proper operation of IC3, power pin 16 must be connected to +V and pins 6, 7, and 8 must be grounded. In Figure 1, the only components not mentioned so far are the de-coupling capacitors C1, C2, and C3, and the components R11 and C4. This last pair is rather important. Op-amp IC2 provides the potential for high gain coupled with very high input impedance. This is a sure-fire combination for picking up stray noise. To avoid this, and since we are

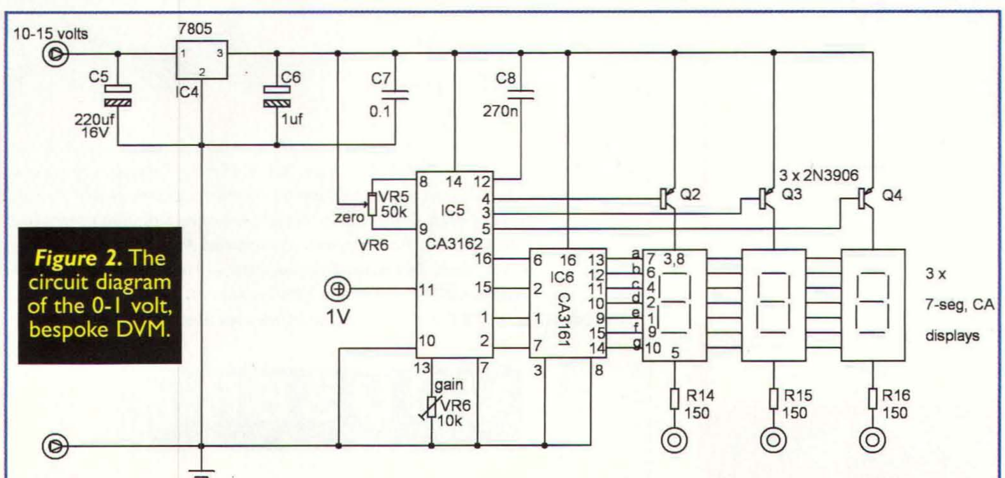


Figure 2. The circuit diagram of the 0-1 volt, bespoke DVM.

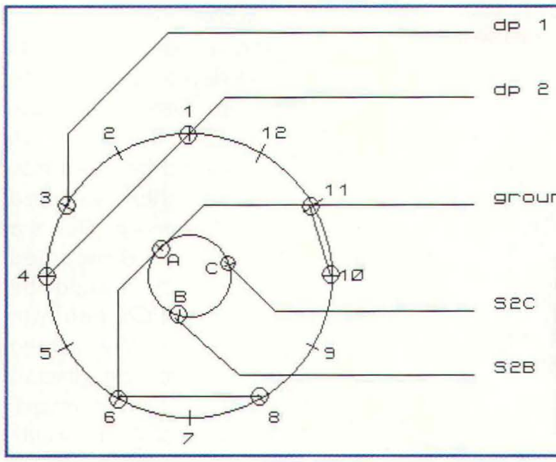


Figure 7. Wiring diagram for 3P4W switch.

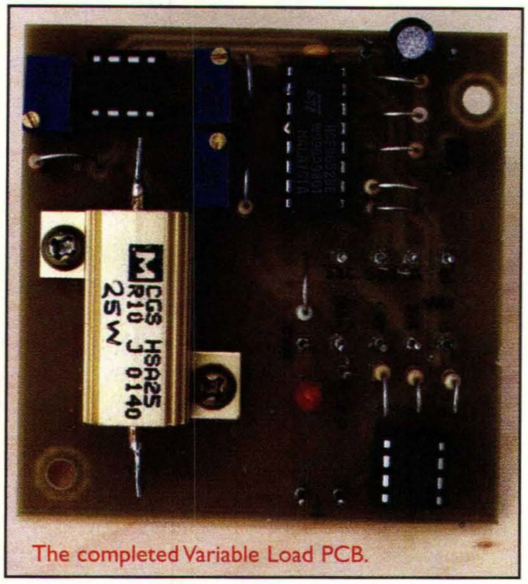
only interested in using IC2 as a DC amplifier, R11 with C4 form a very low frequency, low-pass filter which carries changes in the DC component of the op-amp's output while by-passing any spurious noise signals. The circuit of Figure 1 can be operated from any voltage from about 10 to 15.

Figure 2 is the circuit diagram of the bespoke DVM used in this project. There are many off-the-shelf DVM modules which could be used, but those which are easily and cheaply available invariably have a 199 mV full scale reading (which is no real disadvantage), but all require a completely independent power supply (which is). The DVM circuit proposed here will not only operate from the same power source as that used for the Variable Load PCB, but will do so using common ground. In addition, it displays 999 (1 volt) at full scale so it is particularly appropriate for use in this design. However, the 10-15 volt supply must be reduced to a well regulated five volts, and that is the reason for IC4 and its decoupling components C5, C6, and C7.

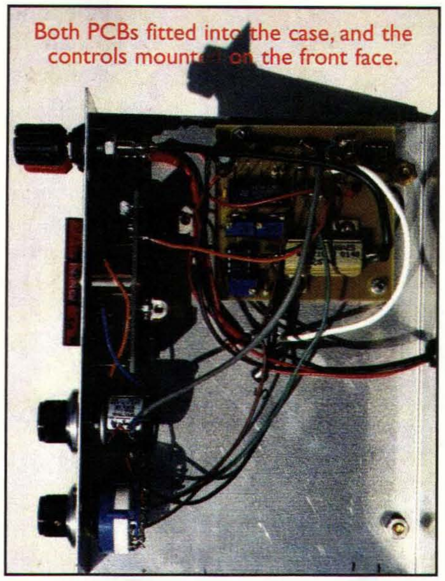
Little extra needs to be said about this DVM circuit design, which is well documented in Intersil data sheet FN1080.3. VR5 is adjusted to provide a 000 display for zero input, and VR6 controls the gain. In general R14, R15, and R16 can be connected to ground to light whichever decimal points are needed. In this design, only R14 and R15 are used.

Building the Variable Load Board

There should be few problems in building this project. All the components are readily obtainable from the usual suppliers. Consider the MOSFET first. This transistor will get warm even carrying relatively small currents (1/2 A). Consequently, it is not included on the PCB, but must be attached to as large a heatsink, as is reasonable. When the project is completed, the thermal efficiency of this coupling must be carefully checked under heavy load conditions. Even then, if you are planning to run this circuit at 10 amps



The completed Variable Load PCB.



Both PCBs fitted into the case, and the controls mounted on the front face.

for hours at a time, the MOSFET and heatsink will almost certainly need forced air cooling from a substantial fan. A wide variety of N-channel, enhancement power MOSFETs will function in this circuit, including those with rather modest "on" resistances. However, the recommended types (in order of preference) are the somewhat expensive BUZ900D, which is a 250 watt, TO3 type, and the more modest TO220-packaged IRL540N. The latter is cheaper, but limited to a maximum of 94 watts. Whichever type you use, it will need to be insulated from the heatsink to which it is attached. Note that in general, MOSFETs are very sensitive to static electricity and should be handled as little as possible.

The PCB design for this project is single-sided, but no part of its copper surface should be used for load-carrying. All high-current connections from ground to the earthy side of R7, from the other side of R7 to the source pin on the MOSFET, and between the FET's drain pin and the positive binding post, must be made with heavy-duty single wire such as that in high-current, house-wiring mains cable. They should all be as short as possible. The connection between the gate of the MOSFET and the main PCB can be standard hook-up wire.

All the integrated circuits used in this design are prone to damage from static discharge and should be handled with care. They should be fitted into sockets rather than soldered directly onto the board. VR1 is a 10-turn, front panel-mounted component which should be connected to the PCB with twin screened cable — the screen being soldered to the ground plane at point B on the board. VR2, VR3, and VR4 are multi-turn, trim potentiometers.

Before these are fitted, they should be adjusted to their mid-positions so that at set-up you can be sure where their wipers are. Most of the board space allowed for resistors will require them to be fitted "standing up" rather than across the board. Power for this project can be via the usual transformer and 7812 voltage regulator or a regulated 13.5 volts from a wall-wart. The maximum current requirement is no more than 300 mA.

Fabricating the DVM Board

For convenience, the DVM PCB starts life as one, single-sided board with only the left-hand section carrying a fill ground plane (download Figures 5 and 6 from the *Nuts & Volts* website at **www.nutsvolts.com**) IC5 and IC6 are both static sensitive and should be handled with care before being fitted into sockets on the board. The multi-turn trimpots VR5 and VR6 should also be set to their center positions before being soldered in. Take care that the three displays are the correct way round (decimal point in the bottom right corner) before they are soldered. Then, on the copper side of the board, solder R14 and R15 from pins 5 of both Displays 1 and 2 to their un-drilled pads. R16 does not need to be fitted.

PARTS LIST

Resistors

R1,R9,R12,R13	10K
R2	560K
R3	11K
R4,R5,R	1K
R7	0.1Ω, 25W
R8	10M
R10	82K
R11	270K
R14, R15	150Ω

Variable Resistors

VR1	50K, 10 turn, panel
mountVR2	200K, multiturn, trim
VR3	20K, multiturn, trim
VR4	100K, multiturn, trim
VR5	50K, multiturn, trim
VR6	10K, multiturn, trim

Capacitors

C1,C5	220 µF, 16 V
C2,C7	0.1 µF
C3,C4,C6	1 µF, tantalum
C8	70 nF, polyester film

Diodes

D1	ZXRE125, constant voltage

Transistors

Q1 MOSFET	BUZ900D, IRL540N, etc.
Q2-Q4	2N3906 (or equivalent)

Integrated Circuits

IC1, IC2	MAX480
IC3	4052, CMOS
IC4	7805 voltage regulator
IC5	CA3162
IC6	CA3161

Displays

Displays1-3	7-segment LED, common anode

Switch

S2	3P4W

Miscellaneous

Dual in line, IC sockets
- 8 pin 2
- 16 pin 3

13.5 volt (regulated) wall transformer
13 amp connecting wire
PCB connecting pins
Two, 14mm, M3 spacers, and four bolts
Heatsink
Case

Setting Up

It is probably easier to set up the DVM board first. To check that this circuit is functioning correctly, solder temporary wire links from the collector pads of Q2, Q3, and Q4 to their respective anode pads on the three displays (Q2 to MSD — most significant digit, Q3 to the middle digit and Q4 to LSD — least significant digit). Power-up this PCB with a suitable supply. If all is well, the three displays will light with some small, random number. Link the one volt input pad to the ground plane so that the DVM has a zero input. Adjust VR5 until the display reads 000. For the moment, leave VR6 at its center setting. Remove the three temporary transistor-collector/display-anode links and carefully cut the board in half along the central line. Use 5/8-inch spacers and bolts to piggyback the two boards together with their copper tracks facing each other. Now the PCBs must be connected across with links joining corresponding pads together. Take time and care over this, as shorts between tracks from solder splashes may be difficult to correct after this stage. When all 10 links have been completed, cut off and file flat the surplus wires protruding from the top face of the display PCB. If the completed DVM is to be fitted into a metal case, pieces of insulation tape should be used to cover the filed down wires so that they cannot be shorted by direct contact with the metal case. Note that the photographs show the prototype of my DVM, while the unit described in the text is an updated version. The DVM and Variable Load PCBs can now be wired together. Connect the DVM pin on the Variable Load board to the one volt input pin on the DVM PCB. Use Figure 7 to as a guide to wire the pins on the 3P4W switch to S2B, S2C, and ground on the main PCB and to the free-end pads of R14 and R15 on the DVM board.

Now the final adjustments can be made. You will need a multimeter and a bench DC power supply to be your "source-under-test." Turn the 50K panel potentiometer right back to zero, switch S2 to its second position, power up, and set the bench supply to about 30 volts. Connect it to the binding posts. The piggybacked DVM should display a small reading with no decimal point. If it reads "EEE" (over-range) or a high value, then you have probably got the A and B connections to the 50K potentiometer round the wrong way. Assuming all is well, adjust VR4 until the on-board DVM displays 000. Now set the multimeter to its 2 V range and connect it across R7. It should read 0.000. Switch S2 to its third position — the DVM should show 0.00. Slowly advance the 50K pot when both meters should start to display low readings. Continue to wind up the 50K pot until the bench supply is providing close to its highest current output, assuming this to be no greater than 10 amps. The current flow can be read from the multimeter where, for example, 0.234 will indicate 2.34 amps. Now adjust VR6 until the DVM reads 2.34. That sets up the high current scale.

Now wind the 50K potentiometer back to zero, return switch S2 to the second position, and the multimeter to its 200.0 mV scale. This should read 000.0. If the DVM does not now read 000, VR4 should be tweaked until it does. Advance the 50K potentiometer until the multimeter reads 099.0 and adjust VR3 until the DVM reads 990. This sets the low current scale. Finally, wind the 50K potentiometer back to zero and set S2 to its first position. Use the multimeter to measure the voltage across the binding posts. Adjust VR2 until the same reading is displayed on the DVM. Check that when S2 is switched to its fourth position, the same voltage is shown. That completes the setting up process. If any readjustments have to be made, they should be carried out from the top and in the same order. The final set-up is best made when the unit is thoroughly warmed up after, say, 10 minutes or so of a one or two amp flow. When switching S2 through its positions during this process, wait a few seconds after each switching action to allow capacitors to reach their new charge levels. Some other checks of the system can now be tried. Experiment with a number of settings of the 50K pot to test the current limits of your bench DC supply. If this has the facility of current-limiting, you can check the accuracy of the point at which this operates. If it is not current-limited, be careful not to adjust the 50K potentiometer past the point where it exceeds the supply's maximum current output. Special care must be exercised in using switch S2. When in positions 3 and 4, the current demands of the Variable Load are multiplied by a factor of 10 over positions 1 and 2. Consequently, before making any connections to the binding posts, it is always good practice to turn the 50K potentiometer right back to zero and check that S2 is on the one amp range (i.e., positions 1 or 2).

Finally, a warning about power dissipation. Although this Variable Load will test supplies up to 50 volts and at 10 amps, it will not do both at the same time. Power in watts is the product of volts and amps. If you have elected to use the BUZ900D MOSFET, it has a maximum power rating of 250 watts. This means that if you are testing a 50-volt supply, the current limit is five amps maximum, and even at those values the heatsink will quickly get too hot to handle.

Similarly, if you want to test 10 amp supplies, then you are limited to voltages below 25. The situation is even tighter if you use the IRL540N which has a maximum power rating of 94 watts — 50 volt supplies will be limited to less than two amps, and 10 amp tests will be restricted to an applied voltage of less than 10. These "rule-of-thumb" calculations are somewhat conservative as they ignore the power dissipated in R7. **NV**

Circle #52 on the Reader Service Card.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News Bytes

Extreme Solar Activity Pounds Earth, Space

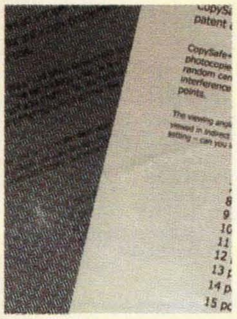
What started out as an isolated occurrence on October 28th —

the eruption of a powerful X17-category solar flare — has turned into a repeating pattern of coronal mass ejections from the Sun in recent days. CMEs routinely explode from the surface of our nearest star at speeds over 5 million MPH, and produce strong solar radiation storms when they impact the ionosphere of our planet. Although physically and electrically violent, they produce beautiful auroras in the northern latitudes.

Most CMEs cause very little effect on the Earth, the huge power grids can couple to the energies in flux, causing voltage spikes and disruptions. "It's like the Earth is looking right down the barrel of a giant gun pointed at us by the Sun ... and it's taken two big shots at us," said John Kohl of the Harvard-Smithsonian Center for Astrophysics in Massachusetts.

Communication satellites are also vulnerable to these huge "charge storms" — the G5 level geomagnetic storm caused by X17 incapacitated the Japanese satellite, Kodoma, an experimental communications relay satellite owned by the Japanese Aerospace Exploration Agency (JAXA). Tsuguhiko Katagi, JAXA's associate executive director, expressed optimism that the satellite ultimately can resume operations. But Japanese officials also raised the possibility that Kodama has suffered permanent damage.

Attack of the Clones Unclonable



Content copy protection is popping up all around us; DVDs employ CSS and digital music is turning to multiple digital right management schemes — some are even natively implemented in computer operating systems. So it's no wonder that uncopyable paper now exists, as well.

Enter Verify First (**www.verifyfirst.com**) with their offerings of anti-copy paper. Cleverly designed and not entirely disclosed for reasons of security, they have leveraged physics to contain information after it leaves the digital domain. Currently, they offer two products of interest, as explained by anti-fraud consultant Noal Philips:

"The first is what we call a "copy evident" stock that shows a message such as "VOID" or "Unofficial Copy" once copied in color copiers. The background includes microtext and an algorithm that is visible through a magnifying glass. The stock is also layered with a heat sensitive ink that disappears when you apply warmth to it, usually by rubbing or breathing on it, and in most cases, the warmth emitted from the copier."

"The second is what we consider a "non-copyable" stock, which has a highly reflective surface and is camouflaged with a white titanium oxide ink over it. The benefit of this stock is that you can't scan or copy it. It makes any image or text that is printed on it completely illegible on the copy."

So where aren't the clones? LucasFilm's *Star Wars: Episode II* used Verify First's product to maintain a fixed inventory of scripts during production.

BIPOLAR TRANSISTOR COOKBOOK — PART 6

Ray Marston describes a variety of practical transistor multivibrator waveform generator circuits in this month's edition of an eight-part series.

by Ray Marston

The two most widely used types of transistor waveform generator circuits are the oscillator types that produce sine waves and use transistors as linear amplifying elements, and the multivibrator types that generate square or rectangular waveforms and use transistors as digital switching elements. Last month's installment described practical circuits of the oscillator type. This month, we describe ways of using bipolars to make practical multivibrator types of waveform generator circuits.

MULTIVIBRATOR CIRCUIT TYPES

Multivibrators are two-state (output high or output low) circuits that can be switched between one state and the other via a suitable trigger signal, which may be generated either internally or externally. There are four basic types of multivibrator (multi) circuits, and they are all useful in waveform generating applications. Of these four, the astable has two quasi-stable states and is useful as a free-running square wave generator. The monostable has one stable and one quasi-stable state and is useful as a triggered pulse generator. The bistable has two stable states and is useful as a triggered stop/go or high/low waveform generator. Lastly, the Schmitt has two stable input-voltage-sensitive states and is useful as a sine-to-square waveform converter or threshold switch.

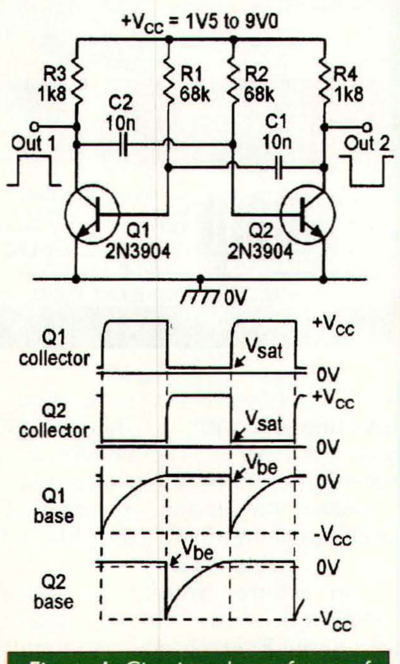


Figure 1. Circuit and waveforms of a basic 1 kHz astable multivibrator.

ASTABLE MULTIVIBRATOR BASICS

Figure 1 shows the circuit and generated waveforms of a simple 1 kHz astable multivibrator, in which the two transistors are cross-coupled (from collector to base) via timer networks C1-R1 and C2-R2. The basic circuit action is such that, at the moment that power is initially switched to the circuit, inevitable differences in the precise characteristics of Q1 and Q2 make one transistor turn on slightly faster than the other, and the cross-coupling then causes a regenerative switching action to take place in which one transistor switches abruptly on and the other switches abruptly off.

After a delay determined by the C1-R1 or C2-R2 time constant, the off transistor starts to turn on again, and the cross-coupling then causes another regenerative action in which the two transistors abruptly change state again. The whole process then repeats add infinitum. Thus, the basic Figure 1 circuit acts as a self-oscillating regenerative switch in which the on and off periods are controlled by the C1-R1 and C2-R2 time constants. If these time constants are equal (C1=C2=C, and R1=R2=R), the circuit acts as a square wave generator and operates at a frequency of about 1/(1.4CR). The frequency can be decreased by raising the C or R values, or increased by reducing the C or R values, or can be made vari-

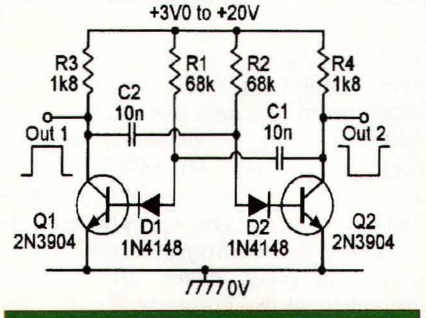


Figure 2. Wide-supply-voltage example of a 1 kHz astable multivibrator.

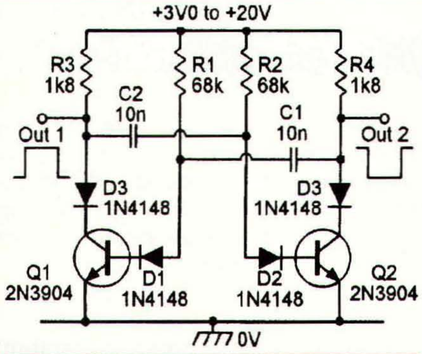


Figure 3. High-stability version of the basic Figure 2 1 kHz astable multivibrator circuit.

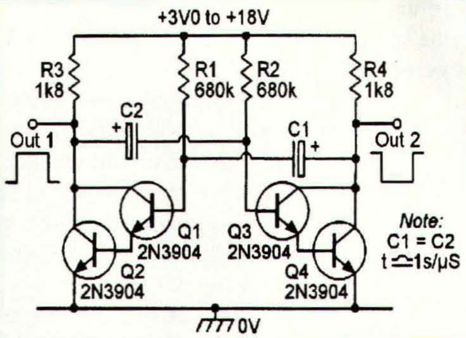


Figure 4. Long-period astable multivibrator.

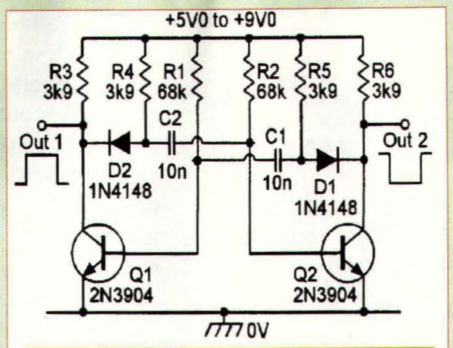


Figure 5. 1 kHz astable with waveform correction via steering diodes D1 and D2.

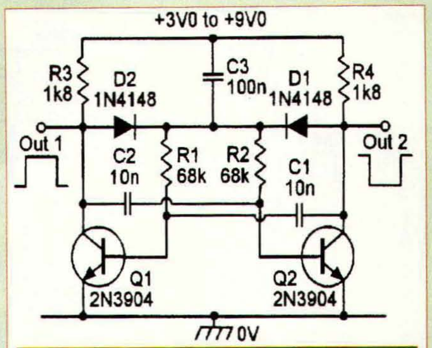


Figure 6. 1 kHz astable with sure-start facility.

able by using twin-gang variable resistors (in series with 10K limiting resistors) in place of R1 and R2.

Outputs can be taken from either collector, and the two outputs are in anti-phase. The Figure 1 circuit's operating frequency is almost independent of supply-rail values in the range 1.5 V to 9.0 V; the upper voltage limit is set by the fact that, as the transistors change state at the end of each half-cycle, the base-emitter junction of the off one is reverse biased by an amount almost equal to the supply voltage and will zener (and upset the timing action) if this voltage exceeds the junction's reverse breakdown voltage value (which is typically about 10 V).

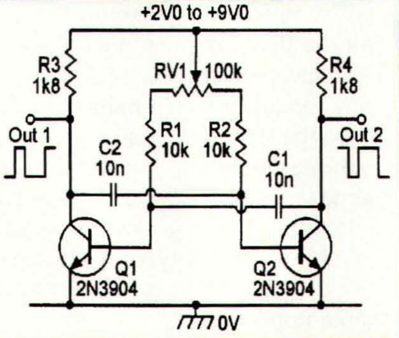


Figure 7. Basic 1,100 Hz variable mark/space ratio generator.

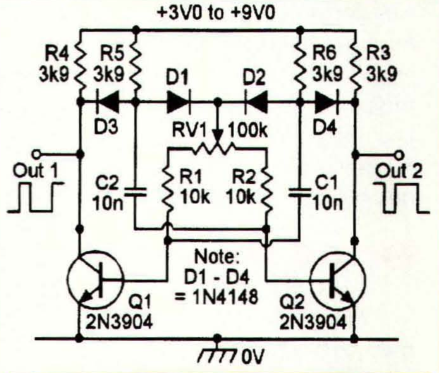


Figure 8. 1,100 Hz variable mark/space ratio generator with waveform correction and sure-start facility.

This problem can be overcome by wiring a silicon diode in series with the input of each transistor, to raise its effective zener value to that of the diode, as shown in Figure 2. This protected circuit can be used with any supply in the range 3 V to 20 V, and gives a frequency variation of only 2% when the supply is varied from 6 V to 18 V. This variation can be reduced to a mere 0.5% by wiring an additional compensation diode in series with the collector of each transistor, as shown in the circuit of Figure 3.

ASTABLE CIRCUIT VARIATIONS

The basic Figure 1 astable circuit can be usefully modified in several ways, either to improve its performance or to alter the type of output waveform that it generates. Some of the most popular of these variations are shown in Figures 4 through 9.

One weakness of the basic Figure 1 circuit is that the leading edges of its output waveforms are slightly rounded — the larger the values of timing resistors R1-R2 relative to collector load resistors R3-R4, the squarer the edges become. The maximum usable R1-R2 values are, in fact, limited to h_{fe} x R3 (or R4), and one obvious way of improving the waveforms is to replace Q1 and Q2 with Darlington connected pairs of transistors and then use very large R1 and R2 values, as in the Figure 4 circuit, in which R1 and R2 can have values up to 12M, and the circuit can use any supply from 3 V to 18 V.

With the R1-R2 values shown, the circuit gives a total period or cycling time of about one second per µF when C1 and C2 have equal values, and gives an excellent square wave output. The leading-edge rounding of the Figure 1 circuit can be eliminated by using the modifications of Figure 5, in which steering or waveform-correction diodes D1 and D2 automatically disconnect their respective timing capacitors from the transistor collectors at the moment of transistor switching. The circuit's main time constants are set by C1-R1 and C2-R2, but the effective collector loads of Q1 and Q2 are equal to the parallel resistances of R3-R4 or R5-R6.

A minor weakness of the basic Figure 1 circuit is that if its supply is slowly raised from zero to its normal value, both transistors may turn on simultaneously, and the oscillator will not start. This snag can be overcome by using the sure-start circuit of Figure 6, in which the timing resistors are connected to the transistor collectors in such a way that only one transistor can be on at a time.

All astable circuits shown so far give symmetrical output waveforms, with a 1:1 mark/space ratio. A non-symmetrical waveform can be obtained by making one set of astable time constants larger than the other. Figure 7 shows a fixed-frequency (1,100 Hz) generator in which the mark/space ratio is variable from 1:10 to 10:1 via RV1. The leading edges of the output waveforms of the above circuit may be objectionably rounded when the mark-space control is set to its extreme positions. Also, the circuit may not start if its supply is applied too slowly. Both of these snags are overcome in the circuit of Figure 8, which is fitted with both sure-start and waveform-correction diodes.

Finally, Figure 9 shows a basic astable circuit modified so that its frequency is variable over a 2:1 range (from 20 kHz

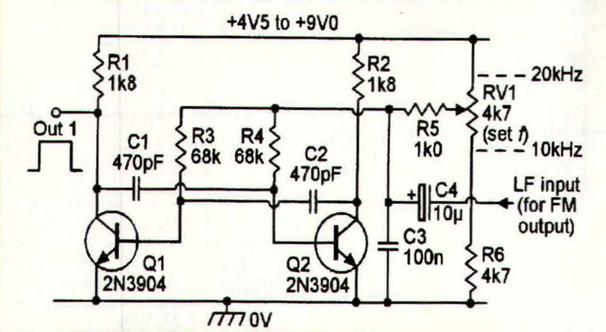


Figure 9. Astable with variable-frequency and FM facility.

down to 10 kHz) via a single pot, and so that its generated waveform can be frequency modulated via an external low-frequency signal. Timing resistors R3 and R4 have their top ends taken to RV1 pot and the frequency is greatest when the pot is at the positive supply line. Frequency modulation is obtained by feeding the low-frequency signal to the tops of R3-R4 via C4; C3 presents a low impedance to the carrier signal, but a high impedance to the modulating one.

MONOSTABLE BASICS

Monostable multivibrators are pulse generators, and may be triggered either electronically or manually. Figure 10 shows a circuit of the latter type, which is triggered by feeding a positive pulse to Q2 base via S1 and R6. This circuit operates as follows. Normally, Q1 is driven to saturation via R5, so the output (Q1 collector) is low. Q2 (which derives its base-bias from Q1 collector via R3) is cut off under this condition, so C1 is fully charged. When a start signal is applied to Q2 base via S1, Q2 is driven on and its collector goes low, reverse biasing Q1 base via C1 and thus initiating a regenerative switching action in which Q1 is turned off (and its output switches high) via C1's negative charge, and Q2 is driven on via R1-R3 after S1 is released. As soon as the switching is complete, C1 starts to discharge via R5, until its charge falls to such a low value that Q1 starts to turn on again, thus initiating another regenerative action in which the transistors revert to their original states and the output pulse terminates, completing the action.

Thus, a positive pulse is developed at the Q1 output each time an input trigger signal is applied via S1. The pulse period (P) is determined by the R5-C1 values, and approximates 0.7 x R5 x C1, where P is in mS, C is in µF, and R is in kilohms, and equals about 50mS/µF in the example shown. In practice, the Figure 10 circuit can be triggered either by applying a negative pulse to Q1 base or a positive one to Q2 base (as shown). Note that the base-emitter junction of Q1 is reverse biased by a peak amount equal to V_{SUPPLY} during the operating cycle, thus limiting the maximum usable supply voltage to about 9 V. Greater supply voltages can be used by wiring a silicon diode in series with Q1 base, as shown by D1 in the diagram, to give the same frequency correction action as described earlier for the astable circuit.

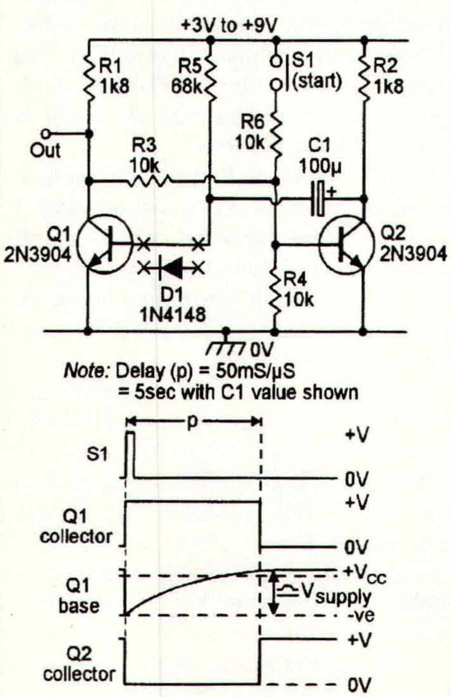


Figure 10. Basic manually-triggered monostable pulse generator.

LONG DELAYS

The value of timing resistor R5 must be large relative to R2, but must be less than the product of R1 and Q1's h_{fe} value. Very long timing periods can be obtained by using a Darlington or Super-Alpha pair of transistors in place of Q1, thus enabling large R5 values to be used, as shown in the Figure 11 circuit, which gives a pulse period of about 100 seconds with the component values shown.

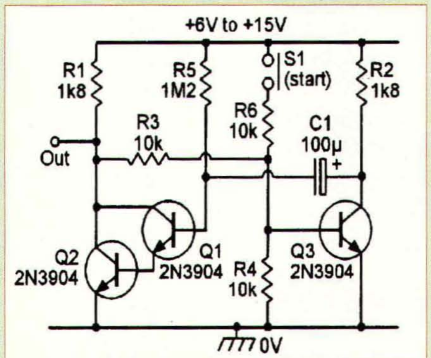


Figure 11. Long-period (100 second) monostable circuit.

An important point to note is that the basic Figure 10 circuit actually triggers at the moment of application (via S1 and R6) of a positive-going pulse to the base of Q2. If this pulse is removed before the monostable completes its natural timing period, the pulse will end regeneratively in the way already described, but if the trigger pulse is not removed (via S1) at this time, the monostable period will end non-regeneratively and will have a longer period and fall-time than normal. This problem can be eliminated by using electronic (rather than manual) triggering, as described in the next section.

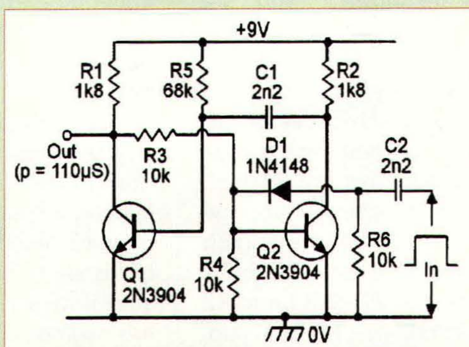


Figure 12. Electronically triggered monostable.

ELECTRONIC TRIGGERING

Figures 12 and 13 show

alternative ways of applying electronic triggering to the monostable pulse generator. In each case, the circuit is triggered by a square wave input with a short rise time. This waveform is differentiated by C2-R6, to produce a brief trigger pulse. In the Figure 12 circuit, the differentiated input signal is discriminated by D1, to provide a positive trigger pulse on Q2 base each time an external trigger signal is applied. In the Figure 13 circuit, the differentiated signal is fed to Q3, which enables the trigger signal to be quite independent of Q2. Note in the latter circuit that speed up capacitor C3 is wired across feedback resistor R3 to help improve the shape of the circuit's output pulse.

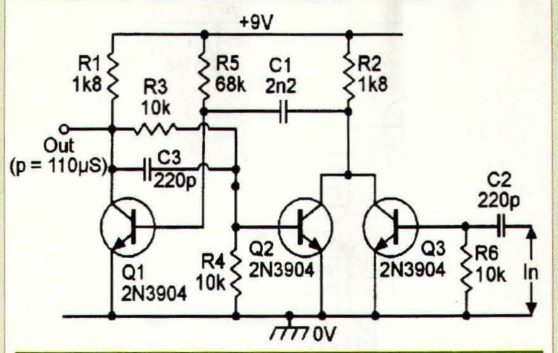


Figure 13. Monostable with gate-input triggering.

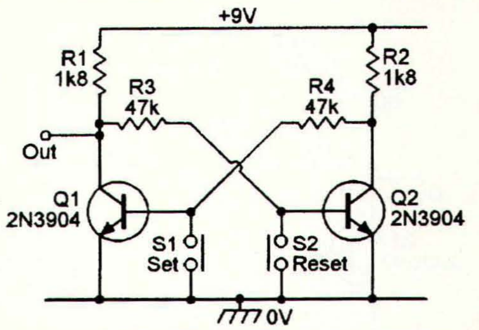


Figure 14. Basic manually-triggered R-S bistable multivibrator.

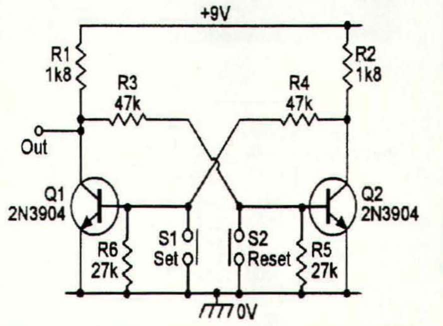


Figure 15. Improved manually-triggered R-S bistable multivibrator with switch-low triggering.

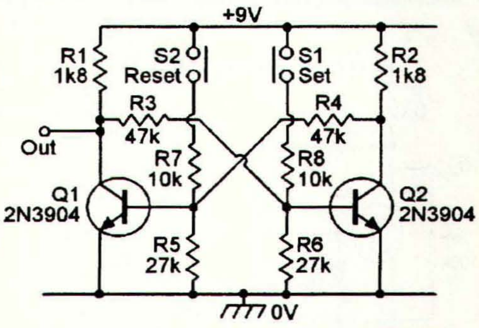


Figure 16. Manually-triggered R-S bistable with switch-high triggering.

The Figure 12 and 13 circuits each give an output pulse period of about 110 mS with the component values shown. The period can be varied from a fraction of a millisecond to many seconds by choice of the C1-R5 values. The circuits can be triggered by sine or other non-rectangular waveforms by feeding them to the monostable input via a Schmitt trigger or similar sine/square converter circuit (see Figure 20).

BISTABLE CIRCUITS

Bistable multivibrators make good stop/go waveform generators, and Figure 14 shows a basic manually-triggered version of such a circuit, which is also known as an R-S (Reset-Set) flip-flop. Its output can be set to the high state by briefly closing S1 (or by applying a negative pulse to Q1 base via a current-limiting resistor), thus turning Q1 off (and simultaneously turning Q2 on via the R3 cross-coupling), and the circuit then latches into this state until it is reset to the low state by briefly closing S2 (or by applying a negative current-limited pulse to Q2 base), thus turning Q2 off and therefore turning Q1 on via the R4 cross coupling. The circuit then latches into this new state until it is set again via S1, and so on.

The latching action of the basic Figure 14 circuit relies on the fact that the saturation voltage (typically 200 mV) of the ON transistor is significantly lower than the base-biasing voltage (typically 600 mV) of the opposing device. In practice, these ideal conditions may not be met if the transistor is not a good-quality silicon type, or if it operates at an excessive temperature or with a low-value collector load. In cases of doubt, the circuit's reliability can be greatly enhanced by using the modifications shown in the improved circuit of Figure 15, in which resistors R5 and R6 act as simple potential dividers with R3 and R4, respectively, thus reducing the undesirable effects of high saturation voltages, etc.

The circuits of Figures 14 and 15 both give a switch-low triggering action, in which the circuit changes state when an ON transistor is turned OFF by pulling its base low via a switch or by applying a negative pulse to its base.

Figure 16 shows an alternative version of the basic manually-triggered bistable, in which the circuit gives a switch-high action in which the circuit changes state when an OFF transistor is turned ON by pulling its base high via a switch or by applying a positive current-limited pulse to its base.

Note that when power is initially applied to the basic Figure 14 to 16 circuits, the output initially settles into a randomly-determined state that depends on the relative characteristics of the two transistors and their associated passive components.

If desired, the basic circuit can be made to automatically switch into a desired initial power up state by automatically feeding a suitable switch-on trigger pulse to the base of one or the other of the two transistors, as shown in Figure 17, which shows the basic Figure 15 circuit modified (via R7-C1 and current-limiting resistor R8) so that the circuit automatically switches into the set (Q1 output high) state at power-up.

One of the most useful applications of the basic bistable multivibrator is as a push-button-controlled timer circuit, in which the output automatically goes high at power-up or on the closure of a push-button start switch, but goes low again automatically after a pre-set delay. Figure 18 shows the basic Figure 17 circuit modified to give such

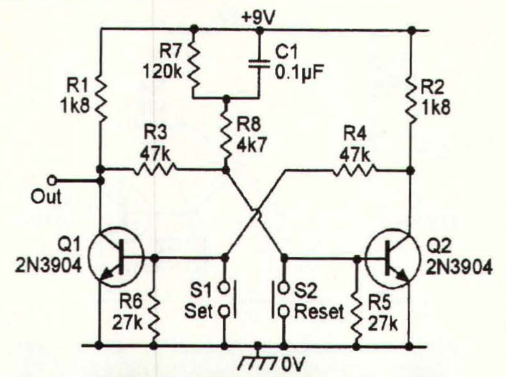


Figure 17. Basic Figure 15 circuit modified to give SET action at initial power-up.

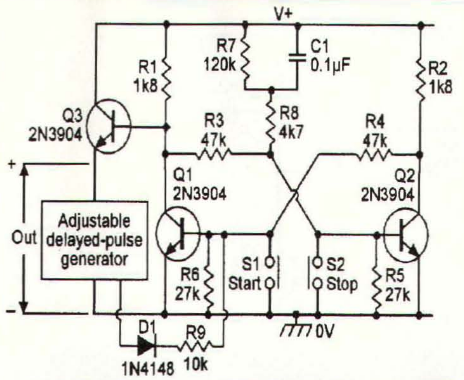


Figure 18. Basic circuit of a manually-triggered bistable multivibrator with timed auto-reset action.

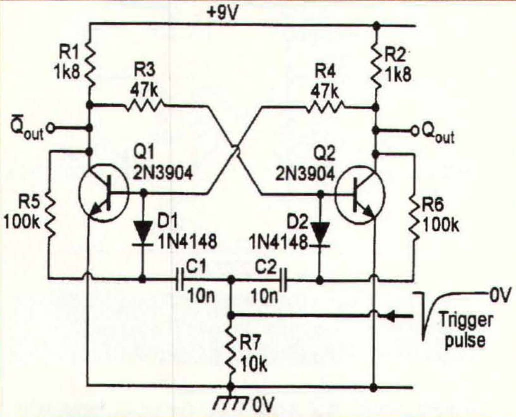


Figure 19. Divide-by-two bistable circuit.

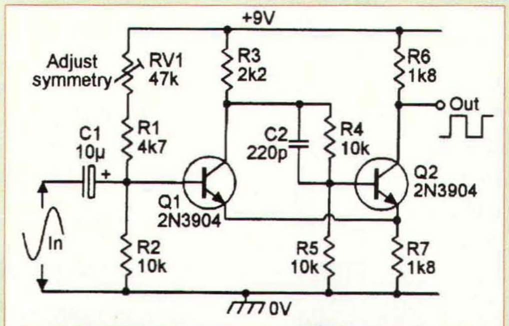


Figure 20. Schmitt sine/square converter.

action. Here, the Q1 output automatically goes high (via R7-C1 and R8) at the moment of initial power-up, thereby activating (via emitter follower Q3) an adjustable delayed-pulse generator, which automatically feeds a reset pulse to Q1 base via D1-R9 at the end of the desired delay period, thereby completing the circuit's operating cycle.

Finally, before leaving the basic bistable multivibrator circuit, note that it can, by connecting two steering diodes and associated components as shown in Figure 19, be modified to give a divide-by-two or counting action in which it changes state each time a negative-going trigger pulse is applied. The circuit generates a pair of anti-phase outputs, known as Q and not-Q (denoted by a bar over the Q sign in the diagram). In practice, greatly improved versions of this counting type of circuit are readily available in CMOS or TTL digital IC form.

THE SCHMITT TRIGGER

The final member of the multivibrator family is the Schmitt trigger. This is a voltage-sensitive bistable switching circuit that changes its output state when the input goes above or below pre-set upper and lower threshold levels; to complete this month's discussion, Figure 20 shows a simple Schmitt trigger circuit used as a sine-to-square waveform converter that gives a good performance up to a few hundred kHz and needs a sine wave input signal amplitude of at least 0.5V RMS. The output signal symmetry varies with input signal amplitude; RV1 should be adjusted to give best results. Next month, we'll describe a variety of audio power amplifier circuits and associated gadgets. **NV**

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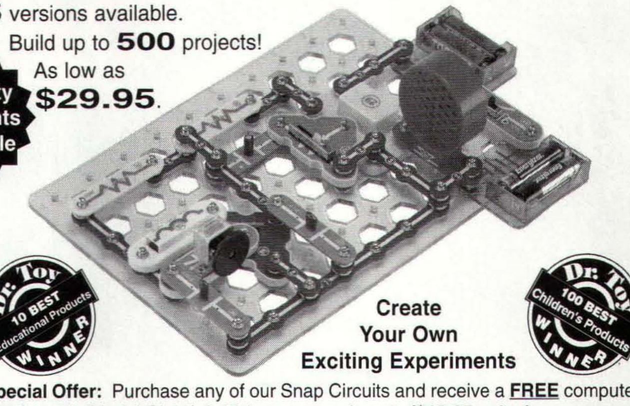

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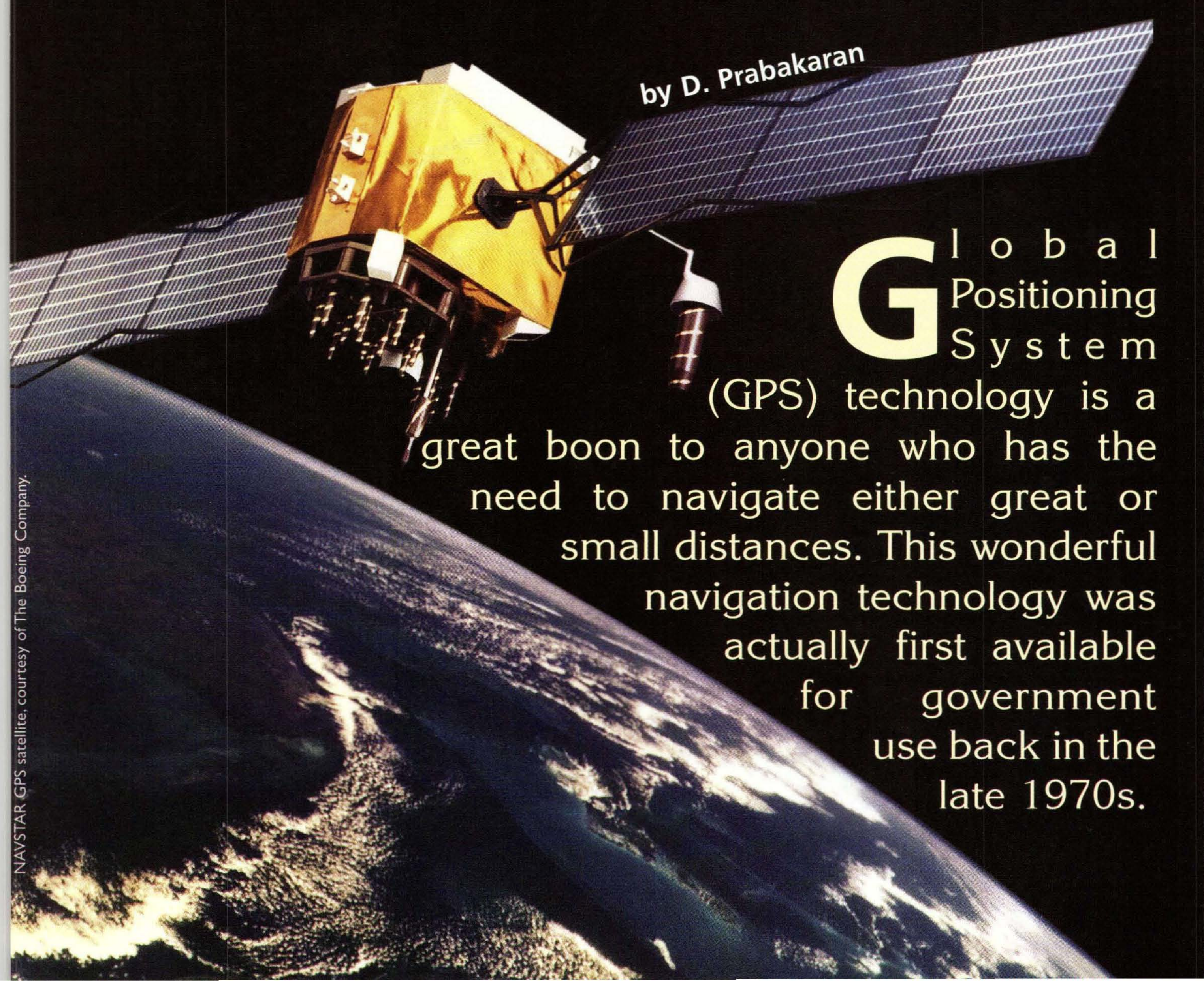
All About GPS
PART 1

by D. Prabakaran



NAVSTAR GPS satellite, courtesy of The Boeing Company.

Global Positioning System (GPS) technology is a great boon to anyone who has the need to navigate either great or small distances. This wonderful navigation technology was actually first available for government use back in the late 1970s.

In the past 10 or so years, GPS has been made available to the general public in the form of handheld receivers that use this satellite technology provided by the US government. Through the use of these handheld receivers, one can navigate back to a starting point or other predetermined locations without the use of maps or any other equipment.

GPS is a satellite based navigation system developed and operated by the US Department of Defense. The idea behind GPS is to transmit spread spectrum radio signals that allow a range measurement from an unknown satellite location. With knowledge of the transmitter location and the distance to the satellite, the receiver can locate itself on a sphere whose radius is of the distance measured. After receiving signals and making range measurements on other satellites, the receiver can calculate its position based on the intersection of several spheres.

It is a worldwide radio-navigation system, formed from a constellation of 24 satellites and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. The US Military launched the first GPS satellite in February 1978, and civilian use began in the early 1990s. Since then receivers have decreased rapidly in price and are now as little as $145.00. They are increasingly found in domestic vehicles for navigation, and used by geographers and others to record spatial information. With advanced forms of GPS, you can make measurements to better than a centimeter! In a sense, it's like giving every square meter on the planet a unique address.

GPS receivers have been miniaturized to just a few integrated circuits and are becoming very economical. And that makes the technology accessible to virtually everyone. These days, GPS is finding its way into cars, boats, planes, construction equipment, movie-making gear, farm machinery, and even laptop computers. Soon GPS will become almost as basic as the telephone. GPS permits users to determine their 3-D position, velocity, and time. This service is available for military and commercial users around the clock, in all weather, anywhere in the world.

GPS uses NAVSTAR (NAVigation Satellite Timing And Ranging) satellites. The constellation consists of 21 operational satellites and three active spares. This provides a GPS receiver with 4 to 12 usable satellites 'in view' at any time. A minimum of four satellites allows the GPS card to compute latitude, longitude, altitude and GPS system time. The NAVSTAR satellites orbit the Earth at an altitude of 10,898 nautical miles in six 55-degree orbital planes — with four satellites in each plane. The orbital period of each satellite is approximately 12 hours.

How GPS Works

In order to understand how the GPS system works, we're going to jump into a bit of simple algebra. Remember echolocation from high school physics? If we send out a pulse of sound or radio waves and wait for them to bounce off something and come back, we can determine the distance to the object by dividing the time it took for the reply by the speed of sound or light:

Distance = Speed * Time
Time = Distance / Speed

GPS works on much the same principle, except that unlike RADAR/SONAR where the transmitter is also the receiver of the signal, GPS satellites only transmit the timing data pulses; GPS receiver units only receive.

Imagine you and a friend have precision-synchronized watches and were standing in a cricket stadium. If he shouted, "I'm at the far right corner end and it's now 5:00 and 0.0000 seconds!" and you heard this message at 5:00 and 0.333 seconds, you could determine how far away he was by the timing delay of 0.333 seconds. Estimating the speed of sound at around 300 meters per second, you can guess he's about 100 meters away from you (or that you're 100 meters away from the far right corner end).

Figure 1. Constellation of NAVSTAR satellites.

Suppose you had another friend at the far left corner end and he shouted the same message at the same time and you calculated him to be 150 meters away. Could you tell where you were? Pretty much. You know that you're 100 meters away from your first friend, so you could take a diagram of the field and draw a circle with a 100-meter radius around his known position. Then you could draw a circle with a 150-meter radius around your second friend's known position. The two circles should intersect at two points — one of which should be your real position The Global Positioning System works on this principle, although it uses much more precise clocks and the speed of light.

The total GPS configuration is comprised of three distinct segments:

- The Space Segment — Satellites orbiting the earth
- The Control Segment — Stations positioned on the earth's equator to control the satellites
- The User Segment — Anybody that receives and uses the GPS signal

The Space Segment of the system consists of the GPS satellites. These space vehicles (SVs) send radio signals from space. The nominal GPS Operational Constellation consists of 24 satellites that orbit the Earth in 12 hours. There are often more than 24 operational satellites as new ones are launched to replace older satellites. The satellite orbits repeat almost the same ground track (as the earth turns beneath them) once each day. The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (four minutes earlier each day).

There are six orbital planes (with nominally four SVs in each), equally spaced (60 degrees apart), and inclined at about 55 degrees with respect to the equatorial plane. This constellation provides the user with between five and eight SVs visible from any point on the Earth.

The GPS satellite signal contains information to identify the satellite, as well as provide positioning, timing, ranging data and satellite status. Space vehicle number or the pseudo random code number identifies the satellites. The satellites transmit on two L-band frequencies: 1.57542 GHz (L1) and 1.22760 GHz (L2). The L1 signal has a sequence encoded on the carrier frequency by a modulation technique, which contains two codes: a precision (P) code and a course/acquisition (C/A) code. The L2 code contains only P code, which is encrypted for military and authorized commercial users.

The control segment of the system consists of the worldwide system of tracking and monitoring stations. The monitor stations measure signals from the GPS satellites and relay the information they collect to the Master Control Station located at Colorado Springs, CO. The station uses this data to compute precise orbital models for the entire GPS constellation. This information is then formatted into updated navigational messages for each satellite.

The user segment consists of the GPS receivers, processors and antennas utilized for the positioning and timing by the military and community. Users figure their position on Earth by measuring their distance to a group of satellites. Each GPS satellite transmits an accurate position and time signal. The user's receiver measures the time delay for the signal to reach the receiver. By knowing the distance to four points in space, the receiver is able to triangulate a three-dimensional position.

The GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert SV signals into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of X, Y, Z (position) and time. GPS receivers are used for navigation, positioning, time dissemination, and other research.

Navigation in three dimensions is the primary function of GPS. Navigation receivers are made for aircraft, ships, ground vehicles, and for hand carrying by individuals. Precise positioning is possible using GPS receivers at reference locations, providing corrections and relative positioning data for remote receivers. Surveying, geodetic control, and plate tectonic studies are examples.

Time and frequency dissemination — based on the precise clocks on board the SVs and controlled by the monitor stations — is another use for GPS. Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precise time signals or controlled to accurate frequencies by special purpose GPS receivers. GPS works in five logical steps:

#1. The basis of GPS is "triangulation" from satellites.
#2. To triangulate, a GPS receiver measures distance using the travel time of radio signals.
#3. To measure travel time, GPS needs very accurate timing, which it achieves with some tricks.
#4. Along with distance, you need to

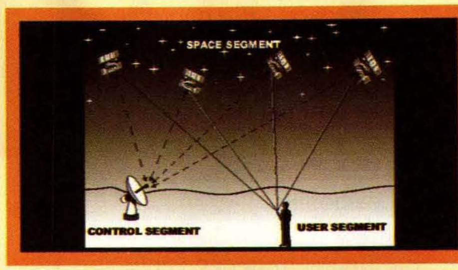


Figure 2. The components of GPS.

know exactly where the satellites are in space. High orbits and careful monitoring are the secret.
#5. Finally you must correct for any delays the signal experiences as it travels through the atmosphere.

GPS Satellite System

The 24 satellites that make up the GPS space segment are orbiting the Earth about 12,000 miles above us. They are constantly moving, making two complete orbits in less than 24 hours. These satellites are traveling at speeds of roughly 7,000 miles an hour. GPS satellites are powered by solar energy. They have backup batteries onboard to keep them running in the event of a solar eclipse, when there's no solar power. Small rocket boosters on each satellite keep them flying in the correct path. Here are some other interesting facts about the GPS satellites:

- The first GPS satellite was launched in 1978.
- A full constellation of 24 satellites was achieved in 1994.
- Each satellite is built to last about 10 years. Replacements are constantly being built and launched into orbit.
- A GPS satellite weighs approximately 2,000 pounds and is about 17 feet across with the solar panels extended.
- Transmitter power is only 50 watts or less.

Pseudorandom Code

The PseudoRandom Code (PRC) is a fundamental part of GPS. Physically, it's just a very complicated digital code, or in other words, a complicated sequence of "on" and "off" pulses. The signal is so complicated that it almost looks like random electrical noise. Hence the name "pseudorandom." The complex patterns help make sure that the receiver doesn't accidentally sync up to some other signal. The patterns are so complex that it's highly unlike-

L1 Carrier	L2 Carrier	L3 Carrier
19 cm wavelength	24 cm wavelength	
1575.42 MHz	1227.6 MHz	N/A
C/A Code	P Code	
Navigation	Navigation Message	

TABLE 1. GPS carrier waves.

ly that a stray signal will have exactly the same shape.

Since each satellite has its own unique pseudorandom code, this complexity also guarantees that the receiver won't accidentally pick up another satellite's signal. So all the satellites can use the same frequency without jamming each other. And it makes it more difficult for a hostile force to jam the system. In fact, the PRC gives the DoD a way to control access to the system.

But there's another reason for the complexity of the PRC, a reason that's crucial to making GPS economical. The codes make it possible to use "information theory" to "amplify" the GPS signal. And that's why GPS receivers don't need big satellite dishes to receive the GPS signals.

GPS satellites broadcast on three different frequencies, and each frequency (or carrier wave) has some information or codes on it. You can think of it as three different radio stations broadcasting several different programs. Table 1 lists the signals and the contents.

- **P Code:** Reserved for direct use only by the military.

- C/A Code: Used for rougher positioning.

- For Single frquency, only the L1 carrier is used.

- For Double frequency, the L1/L2/L3 carriers are used.

- The navigation message (usually referred to as the ephemeris) tells us where the satellites are located, in a special coordinate system called WGS-84. If you know where the satellites are at any given time, then you can compute your location here on earth.

DGPS - Differential GPS

Satellites send a continuous stream of signals to the Earth, enabling a GPS unit to determine their position, using various calculations. Such systems give an accuracy of about 100 meters. This uncertainty is due to several types of errors, which are inherent in the system. For some uses, like mining and high accuracy navigation (for example, a car through city streets) required higher accuracy than this. DGPS is a system, which provides up to sub-meter accuracy.

Differential GPS carries the triangulation principles one step further, with a second receiver at a known reference point. To further facilitate determination of a point's position — relative to the known Earth surface point — this configuration demands collection of an error-correcting message from the reference receiver.

Differential-mode positioning relies upon an established control point. The reference station is placed on the control point, which is a triangulated position, the control point coordinate. This allows for a correction factor to be calculated and applied to other roving GPS units used in the same area and in the same time series. Inaccuracies in the control point's coordinate are directly additive to errors inherent in the satellite positioning process.

Error corrections derived by the reference station vary rapidly, as the factors propagating position errors are not static over time. This error correction allows for a considerable amount of error to be negated — potentially as much as 90 percent. There are two methods of DGPS:

- **Post Processing** requires differential information to be stored in the unit and used to calculate the position. This information has to be updated from time to time, and the accuracy is lost as soon as you leave the area for which the differential information was calculated, or if the differential information is old.

- **Real Time DGPS** gets past this by transmitting differential information continually from a known location. It is this system that is suited for RDS (Radio Data Systems). Real Time DGPS works by placing a DGPS station at a location which is known to a high level of accuracy, and then comparing this known location with the location computed using the GPS system. The difference is then calculated, and this difference is then transmitted to special DGPS systems in the field, which can then use this to calculate a highly accurate position.

Errors in GPS Systems

Factors that can degrade the GPS signal and thus affect accuracy include the following:

Ionosphere Error — The ionosphere is a band of charged particles in the atmosphere over 80 miles up. Because the radio waves travel at the speed of light, and most of the distance is in a vacuum, the speed of light in a vacuum is assumed to calculate the range to the satellite. When the radio waves pass through the ionosphere, the charged particles slow down the waves. Because the signals actually travel slower than the receiver assumes in a short distance, the calculation is slightly inaccurate.

HDOP — Horizontal Dilution of Precision, or HDOP, is caused by satellite geometry. If the GPS receiver is using satellites which are close together, as opposed to spread across the sky, the area of where you are probably located gets long and thin, instead of being circular. Even though both have the same area, a long thin area gives you a higher uncertainty.

Receiver Error — Sometimes the receiver will round numbers or perform incorrect calculations due to electromagnetic interference. These small inconsistencies can change the results by a few feet.

Ephemeris Error — GPS satellites are inserted into very precise orbits when launched. The Department of Defense monitors these orbits closely, and informs the satellite if there is any variation. GPS receivers can then pick up this data, so that they use the correct position of the satellite to triangulate the receiver's co-ordinates.

Selective Availability (SA) — Because location information is of major strategic importance (which is why the system was created in the first place), the Department of Defense limits the accuracy of the signals available to civilian receivers. This is intended to stop enemies from making use of the system for targeting or navigation Even when standing still, your location reading can vary from your true position. Introducing a random distortion, Selective Availability (SA), of the signals sent by each satellite, purposely creates this error. Because the intent is to limit the accuracy of GPS signals, not destroy their utility, certain rules are followed:

- Signals have a stated accuracy of ±100 meters 95% of the time.

- Over a period of 24 hours, the effect of the randomly introduced errors cancel out so a 'true' location will be available as long as the receiver is stationary for the full period. This 'true' location will be subject to variations in physical factors, as listed in Table 2.

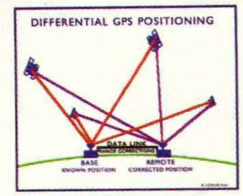


Figure 3. DGPS system.

Satellite and Receiver Clock Errors — Even though the clocks in the satellite are very accurate (to about 3 nanoseconds), they do sometimes drift slightly and cause small errors, affecting the accuracy of the position.

Multipath Errors — Multipath occurs when the receiver antenna is positioned close to a large reflecting surface such as a lake or building. The satellite signal does not travel directly

Error source	Potential error	Typical error
Ionosphere	5.0 meters	0.4 meters
Troposphere	0.5 meters	0.2 meters
Ephemeris data	2.5 meters	0 meters
Satellite clock drift	1.5 meters	0 meters
Multipath	0.6 meters	0.6 meters
Measurement noise	0.3 meters	0.3 meters
Total	~ 15 meters	~ 10 meters

TABLE 2. Error sources and magnitudes.

to the antenna but hits the nearby object first and is reflected into the antenna creating a false measurement. Multipath can be reduced by use of special GPS antennas that incorporate a ground plane (a circular, metallic disk about 50cm (2 feet) in diameter) that prevent low elevation signals reaching the antenna.

Accuracy of GPS Reviewed

There are four basic levels of accuracy — or types of solutions — you can obtain with your real-time GPS system as shown in Table 3.

The accuracy that can be achieved using GPS depends on the type of equipment used, the time of observation, and the positions of the satellites being used to compute positions. In general, recreational and mapping grade receivers using C/A code without differential correction are accurate to between 10 and 15 meters.

In purchasing a GPS system the user should define what their GPS needs will be for the next few years. (When considering the accuracies of GPS receivers a user should realize that in almost all cases, more than one receiver is needed.) When one receiver is tracking satellites and obtaining position data, the information received has traveled over 12,000 miles and has been distorted by numerous atmospheric factors. This results in accuracy of about 25 meters. With SA turned on, and one receiver is used, the greatest accuracy a user can expect is ±100 meters.

Autonomous	Accuracy of 15 - 100 meters
Differential GPS (DGPS)	Accuracy of 0.5 - 5 meters
Real-Time Kinematic Float (RTK Float)	Accuracy of 0 cm -1 meter
Real-Time Kinematic Fixed (RTK Fixed)	Accuracy of 1 - 5cm

TABLE 3. GPS solutions and their accuracy.

To improve the accuracy of GPS, differential or Relative Positioning can be employed. If two or more receivers are used to track the same satellites, and one is in a known position, many of the errors of SA can be reduced, and in some cases, eliminated.

Differential data can be accomplished using common code or carrier data (L1 or L2). The most accurate systems use differential data from a GPS base station that continually tracks 12 satellites and transmits the differential data to remote units, or "rovers" using a radio link. With these systems centimeter accuracy and real-time navigation is possible.

In Part 2 of this article, I'll explain more about methods of error correction, applications of GPS in industry and recreation, and finally some practical considerations to weigh before purchasing a GPS receiver. **NV**

About the Author

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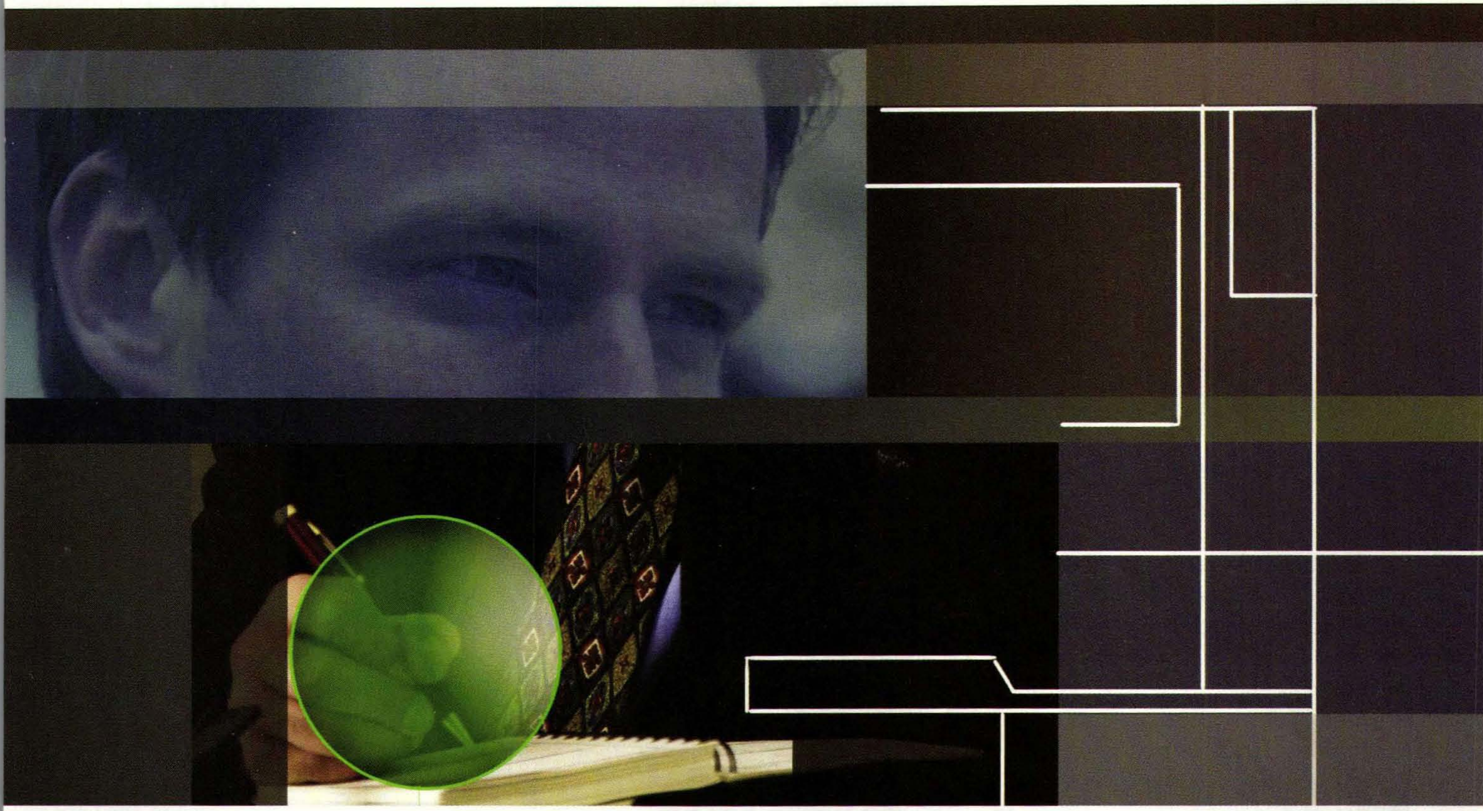
Defeating Bugs And Other Electronic Pests

by David Vine



The field of Technical Surveillance Countermeasures (TSCM) is both an art and a science. There is an art to understanding and second-guessing the work of the eavesdropper. Actor Gene Hackman seems to lead the field in "artistic" portrayal of this type of technician. Many years ago in *"The Conversation,"* he played the part of a troubled surveillance specialist whose conscience got the best of him. More recently, in the movie *"Enemy of the State,"* his ultra-low-profile curmudgeon-hero character saved the life of an unwitting lawyer who had stumbled into a lethal intra-government conspiracy.

TSCM Defined

TSCM can be defined as a service provided by qualified personnel to detect the presence of technical surveillance devices and hazards, and to identify technical security weaknesses that could aid in the conduct of a technical penetration of a facility. A TSCM survey will provide a professional evaluation of the facility's technical security posture, and normally will consist of a thorough

REI's ORION device, an NLJE

DJ-X2000

visual, electronic, and physical examination in and about the surveyed facility.

Electronic surveillance is generally illegal. Most states have some form of law covering electronic eavesdropping but in many states "one party" recording of telephone conversations is lawful. For information about laws in specific states, try a keyword search at **www.firstgov.gov** and restrict the search to the state in which you are interested.

The Federal Crimes and Criminal Procedure, USC Title 18, includes Chapter 119 — where Wire and Electronic Communications Interception and Interception of Oral Communications are outlined. There is, in effect, legal electronic surveillance. Department of Justice policy on the use of electronic surveillance is codified at 18 U.S.C. § 2510, et seq.

Chapter 7 of the United States Attorney's Manual contains the specific mechanisms, including applicable approval requirements, for the use of wiretaps, "bugs" (oral interception devices), roving taps, video surveillance, and the consensual monitoring of wire or oral communications, as well as emergency interception procedures and restrictions on the disclosure and evidentiary use of information obtained through electronic surveillance.

Legal electronic surveillance is performed by a variety of government and military organizations, while illegal electronic surveillance is performed by various individuals ranging from jealous spouses to corporate espionage specialists and others.

Bugs and Extermination

Bugs transmit information (not necessarily intelligence) back to a monitoring post via wired or wireless means. TSCM operators start with a physical assessment of the premises and then check for video cameras, wired microphones, and radio transmitters. Innocent devices such as wireless intercom systems that plug into electrical outlets are sometimes misused. Continuity testers and current detectors are used to find these types of bugs.

While it was easy to spot cameras 20 years ago due to their large size, this has become increasingly difficult during the last decade. Cameras have become much smaller and consume a fraction of the power they did 10 years ago.

Due to this, covert installation in nearly any imaginable place is possible. Methods frequently used for hiding cameras, as well as methods to detect and locate covertly installed cameras, are presented in a paper by Marc Roessler available on the Internet.

One expert has reported that incandescent and fluorescent lights can be modulated inside a room and then the visible light demodulated from outside via a window. Infrared (IR) light also has been reported in similar systems. Night vision viewers or video cameras sensitive to IR (such as Sony Handycam and most black and white surveillance video cameras) can detect IR hotspots. Many *Nuts & Volts* advertisers sell suitable equipment for IR detection. Faintly flickering lights (when loud music is playing in the room) can be a giveaway in detecting visual systems.

The *Amazing Products* catalog contains information about a "Remarkable Concept" allowing you to listen to sounds picked up from a reflecting surface illuminated by a laser. This is accomplished by listening to these light reflections or scatter with a sensitive optical receiver. "Assembled laser and receiver modules may be placed on video tripods and temporarily aligned for limited performance demonstration systems.

They may also be enclosed as shown in the instructions for use as a field-worthy device with a potential range of up to 500 feet." Eavesdroppers using such devices can be countered by the acoustic countermeasures given above. In some cases, night vision devices can detect the infrared beam that may be emitted by the laser.

Wired microphones (as well as video cameras) can be installed in a variety of ways using existing but unused telephone or computer network wiring, hair-thin wires or even a single wire and earth ground. Telephone set microphones or earpieces can be used, as well as radio or stereo speakers wired to a monitoring post. Physical inspections and connection of suspect wiring to voltmeters (first), ohmmeters (second) and audio amplifiers (third) can be used to detect these devices.

According to Research Electronics International, LLC (REI), "Most people that are not familiar with spying technology think of bugging devices as mainly transmitters. However, 'spies' will use many electronic devices that do not utilize radio frequency transmissions. This is the forte of the non-linear junction detector, which will detect and locate any electronic device regardless of whether or not the device is powered.

REI markets the ORION Non-Linear Junction Evaluator. It can be used to locate electronic devices whether in furniture, walls, ceiling fixtures or elsewhere. Since the ORION is detecting semiconductor junctions — not receiving transmitted signals from a surveillance device — it works even when the bug is turned off.

According to REI, "When doing a countersurveillance investigation, it is important to analyze all of the wiring in the environment to ensure that building wiring is not being utilized to transport audio or video information. This wiring may include, but is not limited to, telephone wiring, LAN wiring, security system or access control wiring, intercom speaker wiring, heating and cooling wiring, etc. The main reason for analyzing suspect wiring is that a microphone that is well shielded is very difficult to detect with an ORION.

REI's CMA-100 is a high gain audio amplifier that is used to detect and identify certain types of surveillance devices connected to building wiring including telephone wiring, LAN, server systems, de-energized AC power, left-over wiring that is no longer being used, etc. This multi-functional amplifier has a built in AC/DC digital voltmeter, selectable audio filters, and an extremely wide dynamic range. The CMA-100 is an ideal tool to analyze miscellaneous wiring for audio content. Some problem scenarios that can be discovered with a CMA are:

1. An unused pair of telephone or LAN wires are used to connect directly to a shielded microphone in the suspect environment.

2. A phone set with a hot microphone or hot earpiece is used as a microphone.

3. Microphones can easily be installed in miscellaneous wiring such as motion detectors, intercom speakers, etc.

4. Many digital phone systems have audio leakage that occurs on the lines due to cross talk within the phone set. A CMA can be used to expose this type of vulnerability.

5. Conference call mics are sometimes kept active without the user knowing it. The CMA-100 can be connected to wiring (assuming that the AC voltage does not exceed 40 VAC or 250 VDC) and the audio content can be accessed. Furthermore, if there is video content on the wiring, the video synchronization pulses can be heard and identified through the CMA.

The ORION extends for sweeping

Telephone Bugs

One of the pioneers in the TSCM field is semi-retired Martin L. Kaiser — portrayed by Gene Hackman in the movie *"Enemy of the State."* According to Kaiser, "The telephone

Amazing Products' laser emitter and modulation detector

represents a genuine threat simply because it contains too many microphones to leave unattended in a room. The mouthpiece, earpiece and speaker portion of the speaker-phone all are effective microphones. Anyone who even leaves a telephone in a secure area should be questioned as to their intent! Do not take this instrument too lightly."

"Thanks to the breakup of AT&T there is now a proliferation of telephones and telephone systems — far too many to describe in individual detail.

A common thread usually runs throughout any telephone system. The first is that all the telephones in the system are like peas in a pod. The insides of one telephone will look just like another. For this reason it is best to have on hand a spare telephone that can be placed besides the one being inspected for comparison.

Look carefully for add-on circuits or evidence of tampering with the circuit boards i.e. jumpers, external components, etc. Make a log which contains as much detail as possible about each telephone and keep it for future reference. Once a thorough physical inspection is made, proceed with the electronic testing."

A source of high-quality telephone tap detection equipment is Information Security Associates (ISA). ISA's products to detect telephone taps include: the ETA-1, the ETA-2, the ETA-3A and the LIT-1. The ETA series of telephone analyzers are designed to detect major types of electronic surveillance devices used on phone lines or in telephone instruments. The analyzers are engineered to be used on regular telephone lines as found in residential installations, and also on business telephone systems and instruments.

Digital telephone systems and fiber optic cabling are other mediums for eavesdroppers. Physical inspection of telephone sets, wiring and outgoing lines (right up to the pole) is critical.

Various types of wire and cable anomalies can be detected with a Time Domain Reflectometer (TDR). According to test equipment maker Riser Bond Instruments, "There are two ways a TDR can display the information it receives. The first and more traditional method is to display the actual waveform or 'signature' of the cable." The display, which is either a CRT or an LCD, will display the outgoing (transmitted) pulse generated by the TDR and any reflections which are caused by impedance changes along the length of the cable.

"The second type of display is simply a numeric readout which indicates the distance in feet or meters to the first major reflection caused by a fault along the cable." Some instruments also indicate if the fault is an open or a short, indicating a high impedance change or a low impedance change respectively, or if power is detected on the cable. A bridged tap is a component within a telephone system that can be one of the easiest things to locate and "see" with a TDR.

Indoor wireless and cell phones have proliferated and questions often arise about information security when using them. First generation cellular phones used frequencies under 1,000 MHz with analog transmission that could be easily monitored with simple receivers. Today, most people use digital phones that are nearly impossible to decipher without specialized equipment and "inside" knowledge of digital formats and decoding procedures.

Bug Hunts and Barriers

Pursuant to the provisions of Section 102 of the National Security Act of 1947 and Executive Order 12333, physical security standards for sensitive compartmented information facilities (SCIFs) were established. Aggressors have historically used a wide range of offensive strategies reflecting their capabilities and objectives. These offensive strategies are categorized into tactics that allow facility planners and physical-security personnel to define threats in standardized terms usable as a basis for facility and security-system design.

Among 15 aggressor tactics are some that are often of concern to the TSCM professional. They are:

Covert entry — The aggressor attempts to enter a facility or a portion of a facility by using false credentials or stealth.

Insider compromise — A person authorized access to a facility (an insider) attempts to compromise assets by taking advantage of that accessibility.

Visual surveillance — The aggressor uses ocular and photographic devices (such as binoculars and cameras with telephoto lenses) to monitor facility or installation operations or to see assets.

Acoustic eavesdropping — The aggressor uses listening devices to monitor voice communications or other audibly transmitted information.

Electronic-emanations eavesdropping — The aggressor uses electronic-emanation surveillance equipment from outside a facility.

There are many other considerations in physical security, including "sound insulation." Sound Transmission Class (STC) is a system for the measurement of sound insulation properties of partitions between rooms or buildings, particularly in the case of speech or office noise interference. Various partitions can be rank ordered on the basis of this measurement, which uses the transmission loss of sound in the frequency range of 125 to 4,000 Hz.

Sound vibrates surfaces such as walls, glass, and doors. A contact microphone can pick up these vibrations and transmit the information along wires or modulate it onto radio waves to be received by an unwanted listener residing outside the room. Laser and microwave beams reflected off these surfaces are modulated with the information and pose the same threat. Vibrations caused from talking in a room can be transferred along air ducts, plumbing, walls and ceilings.

Various low-tech devices can be used to mask conversations. Such sound-generating relaxation devices that emit sounds of rain, surf, waterfalls and generic sound masking audio frequencies can be employed with varying degrees of success. Also effective is the transducer speaker system that attaches to surfaces like windows to create a loudspeaker using the surface as the diaphragm.

Radio Frequency Devices

Martin L. Kaiser, Inc., manufactures a number of products of various types and purposes. This includes radio frequency (RF) surveillance transmitter detectors/demodulators, several varieties of electronic stethoscopes and bomb detection equipment, telephone line analyzers and accessories. In addition to these highly specialized devices, consumer equipment has evolved to the point of being very useful in the RF realm.

During the 1990s, a variety of wide range compact frequency-scanning receivers were developed with such brand names as Alinco, AOR, ICOM, and several others. Some of these could be connected to a second device (most of which were portable units manufactured by Optoelectronics in Florida) to "flash tune" a radio to nearby ambient signals. Alinco has combined the two functions into a single scanner radio.

DJ-X2000 can receive signals from 0.1 to 2,149.99995 MHz. Their DJ-X3 (a smaller and lower cost model) can receive signals from 0.1 to 1,299.995 MHz. Both models are blocked from receiving cellular telephone frequencies. Unblocked models are available for authorized purchasers. A Transweeper™ function is used to detect a wireless microphone or similar device using analog voice modulation. Transweeper will assist you in locating the place where it is installed. Frequency scanning can be performed three ways. VFO mode starts scanning from a certain frequency up or down. MR mode scans a specified set of programmed frequencies. PMS mode performs scanning within a programmed scanning range. If the existence of a transmitter is detected the DJ-X2000 LCD display is activated and displays frequency, as well as an approximate, relative direction and distance. The effective range is approximately one to five meters.

In addition to the Transweeper function, the DJ-X2000 automatically tunes to a detected radio frequency without any outboard devices. The radio itself has circuitry that allows it to instantaneously tune and receive transmissions on frequencies from 50 to 1,300 MHz. In addition to flash

Web Resources

The Association of CounterIntelligence Professionals
www.acipnet.org/main.html

Audiotel International is a manufacturer of electronic countermeasures equipment and other secure communications products. They offer a complete range of electronic sweep equipment.
www.audiotel-int.com

California POST certified Wiretap Investigation course
www.post.ca.gov/catalog/3316.htm

Enemy of the State pictures and other details
http://movieweb.com/movie/enemystate

Federation of American Scientists maintains an extensive website and information archive on security and intelligence related matters.
www.fas.org/index.html

National Counterintelligence Executive (NCIX), formerly the National Counterintelligence Center (NACIC), has created an Internet presence to alert and inform readers about new and updated information.
www.ncix.gov

Office of Law Enforcement Technology Commercialization (OLETC), a program of the National Institute of Justice's Office of Science and Technology
www.oletc.org

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www.dami.army.pentagon.mil/offices/dami-ch

Ramsey Electronics sells RF, microwave communications, and test equipment.
www.ramseyelectronics.com/te/default.asp

Signal Intelligence offers a family of software tools that allow radio receivers to be operated by a personal computer running Windows. Individual tools are provided for maintaining frequency databases, automated statistics gathering, data logging, interactive monitoring and spectrum analysis.
www.scanstar.com

SWS Security manufactures audio, video, and RF electronic surveillance, intelligence gathering, and radio communications systems and has an interesting section on its website devoted to sale of used, overstock, or obsolete equipment.
www.swssec.com

Technical Security Branch, a Canadian company, provides good basic details and information.
www.ipg-protect.com/doc068.htm

The Conversation movie review and more
www.filmsite.org/conv.html

ISA sells high-quality telephone tap detection equipment

tune, the radio itself can serve as a frequency counter to display a frequency it senses. Receiver sensitivity varies slightly (from 0.1 to 4 µV) depending upon the type of signal being transmitted.

One expert provides good suggestions for the efficient use of frequency counters (sold by several *Nuts & Volts* advertisers). Among his points were the following:

First, it helps considerably if you know a bit about the signal you're trying to measure. A quarter-wave antenna for a two-meter and 70 centimeter ham radio is approximately 19 inches and six inches, respectively. A quarter-wave cell phone antenna is a scant three inches in length.

"If you don't want to carry around several antennas with you, it might be wise to invest in a collapsible antenna with a BNC connector (which is the style of connector found on most counters). To calculate how far to extend the antenna, divide the target transmitter's frequency (in MHz) into 2,808 and the result is the approximate best antenna length in inches. For example, if you were trying to capture a business radio in the 460 MHz range, 2,808/460 would yield 6.1, or approximately six inches. Now, with your antenna adjusted to that length, you stand a much better chance of success!

Another trick of the trade is to employ a filter, which is inserted between the counter and the antenna, to help isolate the target frequency. A filter basically attenuates unwanted signals while allowing those in the target range to pass through to the counter. Subsequently, the counter does not have to contend with as many conflicting signals as it attempts to lock onto the target.

Advanced Bug Detection

OSCOR (Omni Spectral Correlator) from REI is said to be the most technologically advanced countersurveillance detection system on the market today. OSCOR provides an automatic, reliable, and cost effective means of protecting a business environment 24 hours a day. OSCOR is designed to detect all major types of audio and video RF transmitters including carrier current and infrared.

Portable and programmable, it is a complete package of test equipment that continuously scans all bands and silently detects eavesdropping equipment. Its high sensitivity digital synthesized receiver scans the RF spectrum from 10 kHz to 3 GHz. The unit also detects devices in the portion of the electromagnetic spectrum (infrared 850-1,070 nm), or below the frequency of visible light.

Its Audio Analyze Mode demodulates a received signal to audio and provides an RF signal lock to support correlation. The Acoustic Correlator utilizes passive sound pattern matching to automatically detect a listening device. OSCOR's strip chart plotter provides a "hard copy" of spectrum profiles for future comparisons.

The OSCOR PC Interface software can store signal database information from the OSCOR for later retrieval. Using the PC as a permanent storage device for OSCOR information, records of previous sweeps from various locations can be created, manipulated, and compared. After an accurate signal database is established for a specific environment, it may be used as a reference database and will save significant time in performing future sweeps.

Conclusion

Illegal eavesdropping is undertaken by a variety of people ranging from paranoid spouses to international terrorists. This article presents various aspects of countermeasures that can be employed to thwart the threat. Raising awareness and providing basic techniques, as well as providing sources for advanced expertise can contribute to personal privacy and, perhaps most importantly, may be used to defeat eavesdropping by those who would harm others in the name of their "cause." NV

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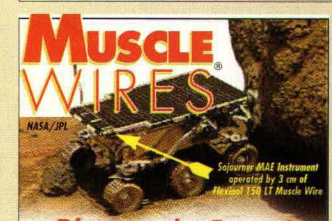

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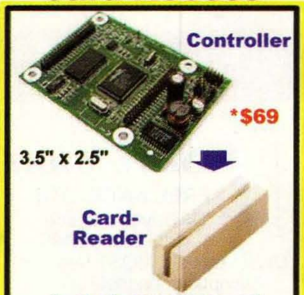

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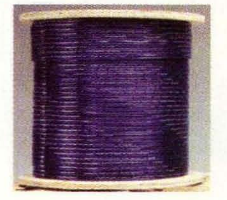

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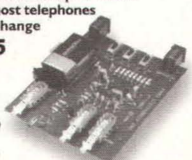

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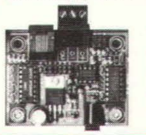

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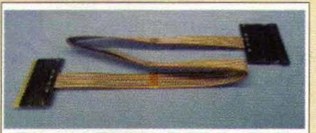

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The Business of Electronics Through Practical Design and Lessons Learned

In The Trenches

Tips and Techniques

Many times, the engineer runs into practical problems with prototyping and development tasks. This article will provide an assortment of practical approaches to some of these common problems.

"White Board" Prototyping

The general term most often used for those white plastic prototyping boards with all the holes is "white board." Many engineers find these very useful for prototyping circuits. These white boards are excellent for quick testing and circuit examination. But, they have limitations. White boards generally have thin plastic walls between the strips of springy bus contacts. This thin plastic can be damaged by using thick wires or excessive force. This causes two problems. The first is that broken pieces of plastic can interfere with making good contacts. This is a relatively minor problem. However, the second problem is of much greater concern. There is a distinct probability of a short circuit between adjacent bus strips. Obviously, shorting out the power supply is a bad thing.

A more subtle point is that there is measurable capacitance between adjacent bus strips. Typically, this is about 2 to 3 pF. This may not seem like much. And, for low frequency work, it can usually be ignored. But, for high frequency and/or high impedance work, this capacitance can be a problem. For example, a high gain op-amp circuit may use a 1 megohm feedback resistor. Putting a 2 pF capacitor in parallel with this can have effects down to 500 Hz! Capacitance affects loading and decreases slew rate.

Digital circuits may lose those few critical nanoseconds needed to operate properly. In particular, I've had problems getting a 32,768 Hz watch crystal to oscillate. This factor does not mean that white boards are not good things. White boards are tremendously useful. It's just that many engineers don't stop and think about the effects of randomly hanging 2 pF capacitors throughout their design. There is a way to improve matters. The way to do this is to ground every other bus strip. In this way, the strips couple to ground rather than to each other. This is like a ground plane. Admittedly, most ground planes have much less coupling to ground. Nevertheless, significant improvements in performance are possible. (I designed a 50 MHz amplifier this way.)

The easiest method of doing this is to use a strip of 0.1" header pins after removing every other pin. (Header strips with 0.2" spacing are available from some sources.) Then simply solder a wire across the top of the remaining pins and run it to ground. Obviously, this means that standard DIP (Dual InLine) parts cannot be used (since every other bus strip is grounded). White boards also have a problem with SMT (Surface Mount Technology) parts. They simply don't fit. The solution to this is to use a converter socket. Unfortunately, commercial converter sockets are fairly expensive and not always readily available. So, here's how to make your own.

Use a DIP "component carrier". This is a piece of flat plastic with 0.1" pins in it that you can solder wires to. It fits into a standard DIP socket.

For SMT parts, get a carrier with the appropriate number of pins and solder bare wires to each contact (I use #30 wire-wrap wire). Then, using a very fine tipped soldering iron, carefully solder the other end of the bare wire to the appropriate SMT pin. Keep the leads short and neat. You'll find that after the first wire or two things will go fairly quickly. There are a couple of points to note. Always solder to the carrier first and use a fair amount of solder to act as a heatsink. Otherwise, when you solder the other end of the wire, the heat will conduct through the wire and it will become un-soldered. Secondly, the plastic used for the component carrier is usually a thermoplastic. This means that it melts very easily. So, be quick with the iron. Of course, there is a tip for this, as well. Press the component carrier into the white board before soldering. This holds it in place, keeps the pins aligned, and acts as a heatsink. (Use a screw driver to gently remove it, if necessary.)

If the white board circuit is going to be more than just a quick circuit test, do a neat job. This means trimming the wires to the proper length and dressing them so that they lie flat. Don't forget to label the inputs, outputs, and power, and document the circuit. If this is done properly, the white board circuit can be used for a long time. I've actually seen white boards embedded in prototype products.

Prototyping Labeling and Documentation

If you're a regular reader of this column, you already know I'm a stickler for labels and documentation. With today's automated test gear and computerized design tools, it's easier than ever. With the complexity of today's circuits, it's more important than ever, as well. First, label important points on the prototype circuit board itself. I use "correction tape" or "whiteout tape."

This is narrow (1/6") white adhesive tape that is easy to write on. You can find it at most any office supply store. It's great to identify connections to power, ground, outputs, chip identifications, software revisions, and anything else. Once you start using this, you'll like it. Don't forget that you can label the bottom of the board with information like chip number, pin number, etc. (Note, similarly, adding comments and notes to the silkscreen layer of production Printed Circuit Boards [PCB] is a good idea. It doesn't cost extra and can be extremely helpful during assembly, test, and repair.) With the advent of inexpensive digital cameras, every oscilloscope is a storage 'scope. Even the cheap and low resolution "web cams" can be used for this. They're great for documenting assembly procedures, too. Pictures add so much to understanding how something works ... or doesn't. There's really no excuse not to have photographic documentation nowadays. Just remember to label them with the instrument settings or other pertinent information.

Prototype Front Panel Fabrication

There are generally two problems with in-house fabrication of front panels. The first is the proper positioning of all the holes. It's not always easy to be sure everything is properly registered to the PCB that attaches to it. The second problem is making it look nice. Both problems are solved with a good printer and some tape. Laying out hole and cut-out positions on the front panel can be greatly simplified by printing the layout at actual size on plain paper. Then, use doublesided adhesive tape to attach the printout to the front panel.

Now, you only have to align one piece of paper rather than dozens of individual holes. Drill and cut right through the paper. When you're done, just peel off. The template remains. There are a couple of things to watch out for, though. First, you can try to use ordinary, singlesided adhesive tape around the edges, instead of doublesided tape. However, it tends to allow a fair amount of movement. Doublesided tape is clearly better. The second thing is that some printers do not print exactly at a 1:1 scale. Be sure to check that the holes that are the farthest apart are accurate. Otherwise, your PCB mounting holes may be misaligned. You can use a similar method to create a near production quality front panel artwork. Use the computer to print out your front panel artwork at actual size. Again use doublesided tape to attach it to the front panel.

Now, use wide, transparent cellophane tape to cover and protect the paper. If you are careful, the tape and seams are virtually invisible. (I use the 2" wide packaging tape available at office supply stores.) Trim with a razor knife. Voila! You now have a "custom" plastic laminated front panel. No money is spent on tooling and no time is spent waiting for your vendor.

Soldering Aluminum and Stainless Steel

Making any reliable electrical connection to aluminum is always difficult. This is because aluminum forms an oxide film nearly instantly when exposed to air. This oxide is a good insulator and ruins electrical conduction. (This is why aluminum is generally banned for all house electrical wiring. It causes fires.)

The only really reliable and practical method of making good electrical connections to aluminum is welding (that I know of). But, welding is not usually available for quick prototype work. Soldering is possible. But, it is difficult and takes time. It is not practical for production on a large number of connections. Here's how you do it. Use rosinless solder.

You can get this at places that sell welding supplies. (Common solder for plumbing no longer contains lead. I haven't tried this approach with that type of solder.) Prepare the aluminum by vigorously cleaning with steel wool. The surface must be shiny and absolutely clean. Use plenty of heat. (I use my old 100/140 watt soldering gun.) Remember that aluminum is a good conductor of heat and will be difficult to keep hot. This means that it may be impossible to solder to a heatsink. The area to be soldered must be kept above the melting point of the solder. Get a blob of solder onto the area.

Then, use the point of the iron to scrape at the aluminum under the solder. This breaks up the oxide layer and the solder above it keeps the oxygen away. Keep it up. It will take a few minutes to scrape enough oxide away to allow the solder to wet the aluminum. When you get an area large enough to suit your needs, tap the aluminum to remove excess solder that, by now, is too oxidized to use. You should have a tinned aluminum spot. It should solder easily. Stainless steel is also difficult and also takes patience. Use a paste acid flux that's available at the plumbing department. Clean and roughen the metal with sandpaper or a file. Steel wool doesn't touch stainless steel.

Again, use a lot of heat. You may have to apply additional flux. Once you get the solder to wet the stainless steel, remove the excess. Like aluminum, the first objective is only to tin the object.

Once that is done, it's easy to make a good solder connection. Be careful of flux fumes. Check the label for warnings. You may need to have ventilation for this.

Working with Plastic

There are generally three basic types of plastics in common use for electronics. The first is polyvinyl which is a colored, opaque thermoplastic used for project boxes and the like. It's easy to work with and I won't discuss it further. The second is polystyrene and it is used for pill bottles and inexpensive hinge-type boxes.

This type is a clear or clear-colored thermoplastic and is very brittle. It's difficult to work with because it cracks easily. The only way I've found to work with this type of plastic is to melt it. If you do this, get lots of ventilation. The decomposition products are dangerous and have been linked to cancer. Generally, I don't consider this suitable for anything unless I can use it in the exact form it's already in.

The last plastic is the polyacrylic type and it's also clear or clear-colored. It's more commonly called "Plexiglas" or "Lucite." Note that I include "Lexan" in this class. It is basically the same except it is quite a bit harder and much more scratch resistant. These plastics usually come in flat sheets, with thicknesses from 1/16" to 1/4" being most common. This plastic is common for front panels and other electronic packaging uses. Here's how to work with it.

Generally, the ideal approach for cutting polyacrylic is the score and snap method. That is, you use a sharp tool to score the plastic along the line you want, and then bend it until it breaks along that line. It's a little more complicated than that, though. (This plastic usually comes with a protective covering of paper or plastic film. Usually, you work the material with the covering in place. You remove it only when the work is completed.) You can sand the edges when you're done, if desired. The scoring should be done on both sides. The depth of the scoring should be a fair amount of the thickness, say 10% on each side. (There are inexpensive scoring tools for this.) The scoring is being done correctly when you hear a squeal and a thin ribbon of material is formed.

A razor does not work well for this, although a razor knife can work reasonably well if the back of the blade is used. An awl, scribe, or a narrow edged screw driver can sometimes work.

Snapping the work should be done quickly and sharply. This means that the work has to be held properly. Boards and clamps work. I have found that a drawer works well, too. Slide the plastic into the area above the drawer and close it until just snug. Position the score mark at the edge of the drawer and then snap down. This works well for fairly large pieces. (Be careful. The plastic can easily scratch the finish on the furniture.) A vise works well for small pieces. Use paper or wood to protect the plastic from the vise jaws. For curves or very large pieces, you will have to cut it with a saw. However, there is a big problem.

If the saw blade heats up too much, the plastic melts and sticks to the side of the blade. This causes binding. Oiling the blade helps by cooling it and reducing the amount of material build-up. Obviously, it's messy. A saber saw with a fine tooth blade will work for small cuts. With long cuts, the plastic can melt and re-form behind the blade resulting in no cut at all! A band saw (with fine teeth) works quite well because the band is so big it doesn't usually get too hot. I have actually used a circular saw to cut very large sheets (1/4" thick, 5' by 8').

The work must be well supported at all points. Use a large blade, with a shallow cut and very fine teeth. Go slowly and oil the blade. In theory, a table saw could be used, but I haven't tried that. Drilling this type of plastic is also a challenge. A drill press is the best tool. A hand drill is just too difficult to control with enough precision.

Always use a wood backing to support the work and always hold the work down. As the drill penetrates the plastic, it will try to climb up the drill bit. This is what causes the most problems. Drill a small hole first, and then enlarge it. If the back of the plastic splinters with the small hole, the larger hole will usually remove the cracks. Drill slowly and use a shallow angle bit. (Bits for wood have a sharp angle. Bits for metal have a more shallow angle. There are special plastic bits that have a proper angle.)

Dull bits actually work better than sharp ones. If possible, after drilling the small hole, drill halfway through with the larger bit, and then turn the work over and finish the hole from the other side. Again, holding the work firmly down is very important.

Oscilloscope Tips

One of the most useful and least used accessories for an analog oscilloscope is the "hood." (Digital oscilloscopes don't need one.)

This is a simple opaque fixture that attaches to the front of the scope to shield it from ambient light. (Football referees use a hood to view "coach's challenges" on a TV monitor on the field.) You can buy one. I think mine cost $25.00. Most 'scopes have a metal bar with a channel above the CRT for the hood. If yours doesn't, or you are too frugal, you can easily make one. It's basically a square tube that connects your face to the 'scope without letting in outside light. Why is a hood useful? It allows you to see things that are otherwise washed out by the outside light. It's basically the same reason why you can't see the stars during the day. Additionally, the outside light slightly activates the phosphor on the screen. This reduces the available contrast and further reduces the ability to see dim signals. Your eyes are more sensitive at low light levels, too. The hood greatly extends your oscilloscope's ability to communicate to you. You can also see nanosecond events that occur only once a second or so. You can identify missing pulses or see triggering signals that were previously invisible. It's truly amazing what a hood can allow you to see. It really is like the difference between night and day.

I use my oscilloscope for both hardware and software. But, I work on hardware at one spot on the bench and software at another spot. So, I put my 'scope on a Lazy Susan. A gentle tug on the test probes and the 'scope faces me wherever I am. I'd hate to say how many years I've used this trick. Let's just say that the first 'scope had a round CRT. Obviously, be sure the Lazy Susan is big enough and strong enough. You don't want your 'scope to take a dive off the bench.

Also, never yank on the probes. It can ruin expensive leads or cause the oscilloscope to fall. Just be careful and use common sense. I also have lots of leads that look the same but go to different places. Typically, there are three or four 'scope leads and just as many clip leads to test equipment. I color code these. I use a ring of different colored paint at each end or connector. This makes it easy to know what goes where. There's nothing more annoying than triggering on Channel 1 while using Channel 2's probe — unless it's wondering why my DMM isn't reading properly because I'm actually connected to my distortion analyzer.

Conclusion

That's all I've got room for in this installment. I'll do another on this topic in a while. Hopefully, you've found a tip

Exploring and Experimenting With Lasers and Their Properties

Laser Insight

Now That You Have It ... Cool Ways to Use It!

The past few columns have been devoted to the building of a Cr:Ruby laser. Last month, we looked at the capacitor charging and trigger circuits, and wrapped up the construction of the system. This month, we'll look at ways of quantifying the laser we built, and see if we can come up with a way to measure the energy output.

WARNING! WARNING! WARNING!
The laser described in this issue contains a power supply that could be lethal if not built and tested properly. Follow all instructions in this article, and use common sense when testing and operating it. The capacitors contained within the supply can retain a high voltage for a long time, and must be discharged completely before working on, or adjusting anything inside the power supply cabinet. In keeping with this caution, anyone using the laser should be wearing eye protection suitable for the wavelength involved.

Cavity Length and Gain

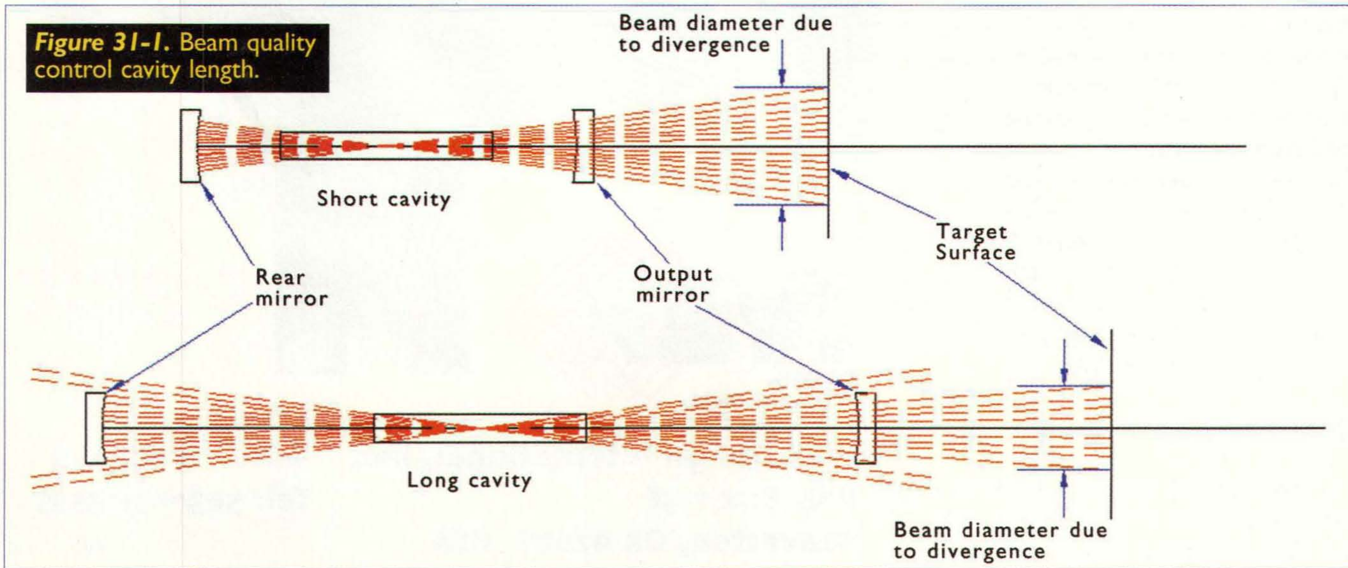
If you are a regular reader of this column, you'll remember that some time ago, we covered beam quality and how it is defined. We also discussed how important good beam quality is when holograms are considered. When used for drilling or welding, beam quality is not such a great concern, as the primary goal is to concentrate as much energy into the workpiece as possible in a single pulse. In applications such as these, close coupling is required between the rod and mirrors in order to get the highest gain, and therefore the greatest yield of energy in each pulse. Mirror spacing is reduced as far as possible to get the highest energy pulse.

With short mirror spacing and high gain, there are drawbacks, of course. After all, what would life be like if there were no challenges? As I mentioned in a previous column, the mirror spacing relative to the laser rod has great influence on the divergence of the output beam. The closer the mirror spacing, the greater the divergence.

Consider the simplified laser resonators in Figure 31-1. In the short cavity example, the possible internal beam paths are shown in red, while the ideal beam path is shown in black. All of the internal rays are reflected back into the rod by the end mirrors. Note the difference in the long cavity. The possible beam paths conform more closely to the ideal path, and the beam divergence is considerably less. The peripheral rays are not reflected back by the mirrors, and therefore do not contribute to the cavity gain.

From this simple illustration, it is clear that the high gain/high energy situation means greater divergence and poor beam quality, while low

Figure 31-1. Beam quality control cavity length.



gain/low energy means a less divergent and better beam quality output. The black lines representing the target surfaces are equidistant from the output mirror, and the difference in divergence (beam spread) can be seen.

While the number of possible beam paths through the laser rod in Figure 31-1 is infinite, only the rays that pass through the center of the rod are considered. Regardless of the length or configuration of the laser cavity, it is convenient to think that the infinity of beam paths in the short cavity is greater than the infinity of beam paths in the long cavity. Figure 31-2 illustrates the premise behind this statement. (I haven't discussed the cavity configuration up to this point, but it determines if the resonator is stable or unstable, depending on the mirror surfaces, but I'll save this discussion for another article.)

If you consider a very short rod and closely-spaced mirrors, it is easy to visualize more possible beam paths between the extremes in the short cavity, simply because of the greater acceptance angle of the rays through the rod. In the longer cavity, the rays illustrated in red do not get returned to the rod because they don't even hit the mirror. Only the blue rays are returned, contributing to the gain of the cavity.

You will notice in Figure 31-1 that the paths in the longer cavity are more nearly parallel than those in the short cavity. The paths in both cases are bound by the constraints of the rod, but since the mirrors in the short cavity are closer to the ends of the rod, more of the boundary rays are able to get back into the rod, increasing the pump volume (the name given to the volume of the rod where stimulated emission can take place, i.e., where reflected rays pass through the medium), and therefore increasing the gain.

So, the reason the gain is lower and the output energy is lower in the longer cavity is easy to see. The rays close to the edges of the rod do not get returned within the periphery of the rod and are lost, therefore they cannot contribute to the gain. The outside rays of light just graze the edges of the rod, rather than going cleanly down it.

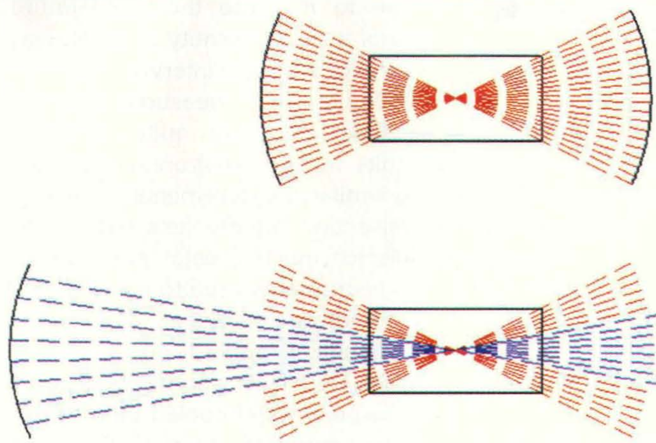


Figure 31-2. Comparing infinities

In addition, because of the greater path length, the pulse width tends to stretch out in proportion to the cavity length. (Remember, light has a finite speed of about 11-3/8 inches per nanosecond in a vacuum. In a laser rod, the speed is reduced according to the refractive index of the rod material.) On the millisecond scale, a few nanoseconds (more or less) won't be noticeable, but it does make a difference to the number of transits of the beam through the laser rod. Fewer transits equals lower gain.

On the plus side, a longer cavity does ensure that more energy is packed into the center of the beam, dropping off quickly away from the center. (In a pure single mode operation, the beam energy profile falls off as a Gaussian distribution.)

Energy Distribution and Divergence

To look at the energy distribution in the laser beam, you need some way of capturing the energy burst and retaining it for analysis. There are commercial instruments available for doing just this, but they are very expensive, and are typically bought by laboratories that have absolute need of the energy profile for their experiments.

For a cheaper alternative, we turn again to our friends at Kentek (**www.kentek-laser.com**). They have a paper product ("Zap-it") that is used as a quick means of recording the beam profile from a pulsed laser. The laser beam is simply fired onto the paper at a short distance, and an accurate beam profile can be recorded. The paper burns quickly and can respond to pulses down in the picosecond regime.

With care, it can also be used for CW laser systems. You can then see at a glance if the beam is round, how the energy is distributed within the beam, and the diameter of the beam. Also, if the beam is multimode, you see approximately where the hot spots are. If the pulse is short enough, you can actually see the instantaneous spatial modes, too, but the pulse needs to be in the nanoseconds to see them.

This paper can also be used to measure the divergence of the laser beam. We covered divergence and how it is measured some time ago, but in case you don't have that information, I'll go over it again.

Figure 31-3 shows the basic setup for measuring beam divergence. The laser is fired at a piece of Zap-it paper in the far field, and then the paper is moved a given distance closer to the laser. The laser is then fired again. You now have two spots from the laser at the same energy level and same pulse width. The only variable is the distance between the shots. Given this information, you can calculate how much the beam is diverging (in radians) by using the following simple equation:

$$df = \frac{\text{far-field diameter - near-field diameter}}{D}$$

where df is the full angle divergence, and D is the distance between the two laser firings.

For example, if you have a far field diameter spot, let's say 5 mm in diameter, and a near field spot 3 mm in diameter, and the distance between them was two meters (all the units should be the same), then the full angle divergence is:

$$\frac{5-3}{2000} = 0.001 \text{ radian or 1 milliradian}$$

(one milliradian is typical for this type and size of laser)

When you take shots like this, try to keep the nearfield burn at least 12 inches from the front mirror. When the paper is hit, the surface layers will explode, throwing pieces of film outward toward the mirror. The pieces may be ejected fast enough to become stuck to the mirror surface, degrading the output. Keeping a safe distance away will prevent this.

Measuring the Energy Output

The output from this laser is pulsed. The pulse amplitude is high (several KWatts), while the duration is fairly short (about 1-2 mS or less, depending on your PFN). Measuring such a short, high intensity pulse calls for some rather specialized equipment. For instance, you cannot hope to measure the temperature rise of a small quantity of water, say, over a one minute interval.

While such measurements are feasible and give quite accurate results in slow environments, making similar measurements in the sub millisecond regime gets tricky and calls for much greater precision in the instruments used to measure the temperature difference.

When I worked on the high-power CO_2 lasers some years ago, we used a water-cooled calorimeter to continuously measure the laser output power. This device consisted of a machined copper cone with a spiral path running down the outside. The cone was placed inside a Plexiglas block that had a cone-shaped hole cut into it, such that the high points of the copper spiral formed a water path around the outside of the cone.

A number of thermocouples were then distributed in an additive/subtractive fashion, to get an average temperature rise as the water flowed through the assembly. The laser beam was then shot into the inside of the cone, and the thermocouples measured the temperature rise, giving the output as a voltage proportional to the rise.

For our application, this method would give insufficient output voltage because of the pulsed nature of the beam, and the fast-flowing water would remove the heat so quickly that there would be no discernible output from the device. However, we can adapt the idea to develop a device that does give a reasonable output voltage, even though we're only looking at pulses. The idea is shown in Figure 31-4.

Here, the laser beam is directed at a cone that is coated on the inside for maximum absorption. The energy in the beam is absorbed by the cone and is sufficient to cause a small change in output voltage from the sensor attached to the back side of the cone.

Silicon diodes are used to provide both the reference voltage and the voltage produced by the change in temperature in the cone. The two voltages are then compared and the result read out on a moving coil type meter. I don't have space in this issue to give any circuit details, so I'll save that for next time.

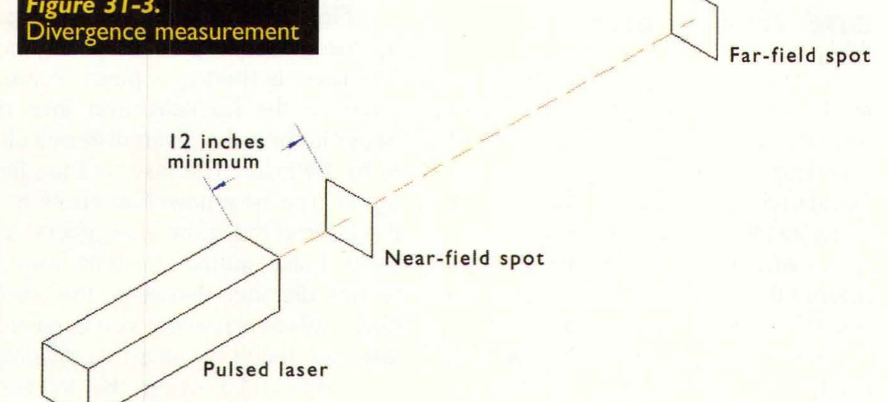
I mentioned last month that I would also discuss the requirements for a double-pulsed holographic setup. To convert this laser to a double-pulse system, you will need to spend some serious cash, unfortunately, so it's not something you're likely to rush into until you have a good feel for what you will be doing with the laser. Not to dampen your spirits though, I will say that you can sometimes pick up some of these items at places like Laser Resale (**www.laserresale.com**), Laser Surplus (**www.lasersurplus.com**), and MWK lasers (**www.mwkindustries.com**).

Since the devices are quite sensitive, it is possible that they may require some attention before they are useable. I found a good link to many laser surplus dealers while researching this column. The URL is: **http://home.earthlink.net/~skywise711/LasersOptics/UsedSurplus/lasersurplus.html**

You'll find links to the three mentioned above, plus a whole slew of other dealers.

You will need a polarizer (at least one) for this wavelength (694.3 nM), that will be able to take a couple of megawatts peak power, a double pulse generator (the item just referred to above), and a Pockels

Figure 31-3. Divergence measurement



cell, also coated for this wavelength. As you may remember, we discussed the Pockels cell briefly. It is the electro-optical device that can be made to switch polarization under the influence of an electric field. The double-pulse generator is the control box that generates the high voltage, double-pulse signal that causes the Pockels cell to switch, and the laser to emit a double Q-switched pulse.

In the next issue, I'll present the schematic and construction details for the laser energy meter in Figure 31-4, and discuss in more detail how double-pulsing works.

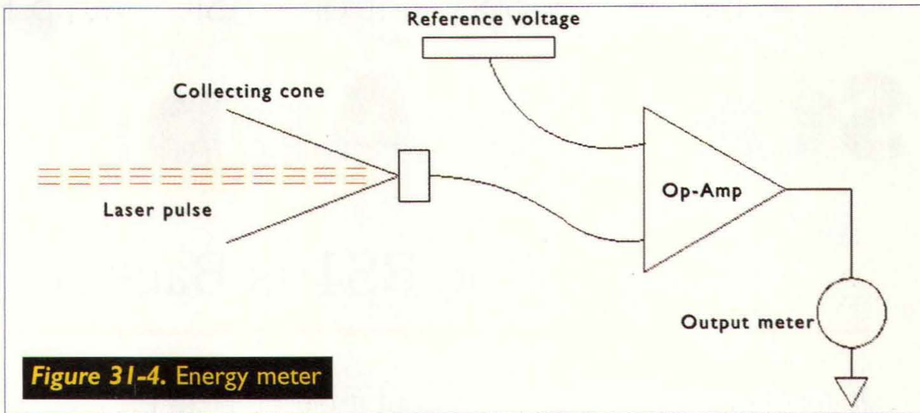


Figure 31-4. Energy meter

Judging from the amount of email I receive, it seems that a lot of readers like the way I present my writing. I'd like to thank everyone who writes to me for their input and encouraging comments. It gives me great pleasure to present these articles to you each month, and I welcome any suggestions or comments you have regarding current columns or ideas for future columns. I like to present articles that the usual run of magazines skip over, or don't try to explain. I try not to be too technical, as you see, and putting my own spin on some of the theories and accepted ideas presents an easily visualized view (I hope) of what is happening inside the laser.

Don't be discouraged if you don't understand some of my babbling. Each month I get Emails from people that don't quite grasp an idea I presented. Some of you even take the trouble to actually write a letter, which is a refreshing change in itself, these days. Just drop me a line and I'll write back as soon as I can.

Contact me as always, at **stanley_york@peoplepc.com**, or through this magazine. **NV**

Putting the Spotlight on BASIC Stamp Projects, Hints, and Tips

Stamp Applications

The BS1 Is Back, Baby!

It couldn't get you to the moon, but it did open a universe of ideas among hobbyists.

Did I ever tell you about my first BASIC Stamp? No? Okay, then, the story goes like this: I was scheduled for surgery on my skull (not my brain as many have claimed would have been a better use of the doctors' time ...) and decided to take a couple weeks off work while I recovered. The thing is, I'm a fidgety guy and don't like sitting still for very long, so I decided to find something to occupy myself with during the recovery.

I had been seeing the advertisements for the BASIC Stamp on the back of *Nuts & Volts* for a few months, but kept thinking to myself, "It's too good to be true ..." In the end, though, I decided that I could spend $100.00 on the BS1 Starter Kit — if it wasn't any good then, oh well, I tossed away $100.00.

A few days later, the box arrived from Parallax. I opened it up, checked it out, hooked it up, and started playing. It was about 6:00 or 7:00 in the evening when I started. I didn't get to bed until 5:00 AM the next day (I called in sick). That was almost 10 years ago, and I think it is safe to say that I've worked with or played with BASIC Stamps every day since.

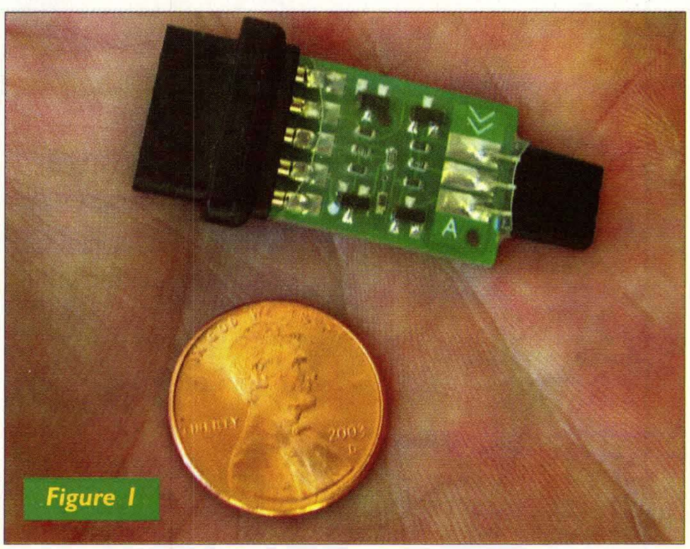


Figure 1

On my trip out to the California office in October, I was handed a gift — a small gift — but one with big promise: the BS1 serial port adapter. I connected it to my shiny new laptop computer (running XP Pro), started up the new editor, and downloaded a program to an old BS1 Rev. D module — the very same module that I had purchased and worked with all those years ago. Dare I say the same goofy smile I had way back when crossed my face that day in the office.

Parallel? Serial? Huh?

Okay, I know what a few of you Stamp old-timers are thinking ... "Wait a minute there, buddy, the BS1 programs through the parallel port — so what's the story with a SERIAL adapter?" The truth is the BS1 actually programs serially at 4800 baud. What happens is that the DOS BS1 editor bit-bangs serial data through a couple of lines on the parallel port. Why? Because the parallel port works at TTL (5V) levels so that simplifies the design of the module. If you look at the BS1 schematic, you'll find there is a direct connection between the programming port and the PIC interpreter.

The serial adapter takes care of the RS-232 to TTL level conversion required by the BS1. But here's the trick: Laptop computers usually don't come anywhere near the RS-232 limits, in fact, they frequently fall very short (though within the specification). The engineering staff at Parallax came up with a very simple circuit that will handle swings through the entire RS-232 range, making the adapter work with virtually any PC serial port. Yeah baby, the BS1 is back!

The photo in Figure 1 shows the adapter — literally putting BS1 programming through Windows in the palm of your hand. If you're adventurous and want to build your own, feel free to download the schematic from the Parallax website (**www.parallax.com**).

What Can You Do with Eight Pins?

Way back in the early days — when I was really getting into the BS1 — I can remember one of my technical buddies asking me what I could do with an eight-pin microcontroller (technically, the BS1 has more than eight pins, just eight I/O). In his mind, it just wasn't enough. Interesting how things change, isn't it? It seems like every major microcontroller manufacturer in the world offers an eight-pin micro — and two of those pins get used for the power supply! And to answer the question at the head of this section, we can do quite a lot with just eight pins. Also, remember that with a bit of code and some standard I/O chips — like the 74HC595 and 74HC165 — we can create as much I/O as we need.

What we're going to do this month is create a little serial slave device using a BS1. Now to be perfectly honest, this isn't an especially practical project. I've never claimed that everything I present in my column is practical — my purpose is teaching and inspiring.

Because of the BS1's limited I/O structure, serial devices became very popular. I believe it's fair to say that Scott Edwards started the serial device (for micros) movement with his "Stamp Stretcher." In my book, he started a whole cottage industry (and is still a leader in it). So, as a tribute to Scott, we'll create a serial display — albeit a very simple one. Our project will be a serial seven-segment digit. Okay, okay, after you pick yourself up and stop laughing, give it a read through. I told you this wasn't going to be terribly practical; the goal is to show you how to make your own serial accessory device.

Device on a Wire

One of the first things I noticed about those big ads that ran on the back of *Nuts & Volts* was that the BS1 could do serial input or output on any pin. This is a very cool feature for talking to other Stamps, or even a PC. Better yet, the BS1 could do different serial baud rates and modes. It's the latter part we're interested in here — the various modes.

Of particular interest are the "open" baud modes. When using one of these modes, the Stamp only drives the serial line in one direction — either to ground in True mode or to Vdd in Inverted mode. The other state of the serial line is controlled by a pull-up or pull-down resistor; the Stamp "opens" the pin [makes it an input] to let the resistor set the state of the serial line.

This comes into play when we want to drop more than one slave device on the serial line and expect that they can talk back to the master. Since the master and slaves can only drive the serial line in one direction (the same direction for all), there is no possibility of an electrical conflict. Of course, this is not new or strange to most of you. This strategy is used on the Dallas/Maxim 1-Wire® bus (a specialized serial bus) and the Philips I2C™bus (a synchronous serial bus).

So that our project is compatible with Parallax AppMod accessory modules, we will use an open-drain setup: the serial bus will be pulled high through a 4.7K resistor. The master and slaves will pull the bus line low for a "1" bit. Figure 2 shows the schematic for our BS1 slave.

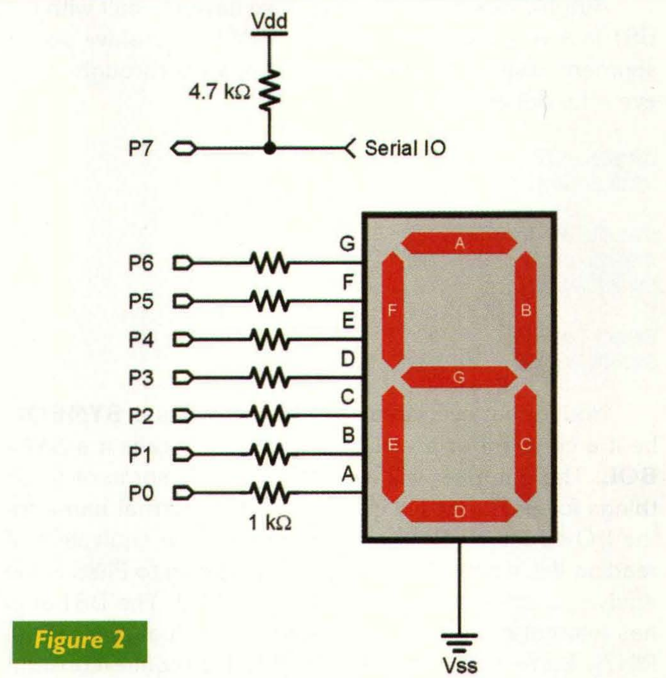


Figure 2

BS1 in Review

Before we smash through the code, let's look back at the BS1 since it differs quite a lot from the Stamp 2, especially lately with the release of PBASIC 2.5.

- The BS1 has only 14 total bytes of variable space
- The BS1 uses three variable types: Bit, Byte, and Word
- Bit-level access is only allowed on variables B0 and B1 (W0)
- The programmer assigns variable location by aliasing internal variables
- PBASIC 1.0 is very terse — not as flexible or feature-rich as PBASIC 2.5

Now, don't let that last point throw you — the BS1 is a very capable little beast (it started a microcontroller revolution after all), and with a bit of practice and planning, you will be surprised at what you can pull off. The key is to let go of any smug suppositions of what BASIC should be. Remember that there aren't a lot of resources within the BS1, so the language is deliberately lean, and in many cases, the high-level part of the language is very close to the machine code.

The biggest bit of grief that people have is the lack of **IF-THEN-ELSE**. I have news for you: **IF-THEN-ELSE** doesn't exist in assembly language [without macros] either. Most microcontrollers have compare-and-branch type instructions. The PBASIC 1.0 **IF-THEN** uses this structure, so the code after **THEN** is an implied **GOTO** followed by a program label [address]. If you're new to Stamps, it will take just a bit of time to get used to the idea, but trust me, the lack of **IF-THEN-ELSE** hasn't stopped tens of thousands of hobbyists and engineers from succeeding with the BS1.

Alright, let's get into it. Since we haven't dealt with the BS1 in a very long time and the code for our slave seven-segment display is very simple, we'll go through it all, even the declarations.

```
SYMBOL Sio        = 7
SYMBOL Segs       = PINS

SYMBOL Baud       = OT2400
SYMBOL Off        = %00000000
SYMBOL MaxDig     = $F

SYMBOL cmd        = B2
SYMBOL value      = B3
```

Notice that everything in PBASIC 1.0 is a **SYMBOL**; be it a constant or a variable, PBASIC 1.0 calls it a **SYMBOL**. The compiler will actually reconcile some of these things for us. PINS, for example, is the internal name for the I/O structure. Reading from PINS is the equivalent of reading INL on the BS2. Conversely, writing to PINS is the equivalent of writing to OUTL on the BS2. The BS1 also has internal names for each of the individual pins (PIN0-PIN7). Some commands in PBASIC 1.0 require constant values for pin numbers and the compiler doesn't reconcile them. We're going to use **SERIN** which requires a constant value, so the **SYMBOL** for Sio is 7; P7 is where our serial connection will be.

Since the BS1 has a fixed number of possible baud settings, they have internal names. For this program, we're going to use OT2400, for Open-True-2400 baud. Strictly speaking, we don't have to define an open mode for a receiver (because **SERIN** makes the pin an input), but we're going to have a command that causes our slave module to send data back to the master. Remember that when using an open baud mode, the serial line needs to be pulled up (for True) or pulled down (for Inverted).

Okay, let's talk about variables. If you've only ever used a BS2, you're accustomed to the compiler automatically assigning variables in the Stamp's RAM by type. The BS1 compiler doesn't do this. The way that we give variables useful names (aliasing) is to assign a name to a given internal variable. For bytes, we can have B0 through B13. Before I go on, look at the listing and note how the first variable assigned is B2. The reason for this is habit, mostly, but a good one. You see, the only variables that allow bit-level access are B0 and B1 (bits can be addressed as Bit0-Bit15), so reserving these bytes for bits that we might want to add later is a good idea.

Finally, don't get lazy and use the internal variable names. Now read that last sentence again. You'll get away with this for a little while, but ultimately the programming demons will catch up to you and you will end up with a misbehaving program because of an assignment error. Take a few minutes to give your variables meaningful names. Trust me, it's worth it. Let's move on.

To create our own EEPROM-base tables, we'll use the **EEPROM** statement (similar to the **DATA** statement in PBASIC 2.x). Here's a short table that holds the segment maps for decimal digits:

```
Digits:  ' .gfedcba
  EEPROM (%00111111)
  EEPROM (%00000110)
  EEPROM (%01011011)
  EEPROM (%01001111)
  EEPROM (%01100110)
  EEPROM (%01101101)
  EEPROM (%01111101)
  EEPROM (%00000111)
  EEPROM (%01111111)
  EEPROM (%01100111)
```

As you can see, it's about the same as using a **DATA** statement on the BS2. Just be aware that we need to track the starting addresses of multiple **EEPROM** tables manually — we can't use a program label as an address constant. This is usually not a problem since we're dealing with such a small micro and multiple tables are a rarity.

Okay, the definitions are done, it's time to initialize and start the program. We generally start with the I/O pins. In this case, we need to make the segment-driving pins outputs. Simple: A "1" in the associated bit of the DIRS register makes the pin an output.

```
Setup:
  Segs = Off
  DIRS = %01111111
```

No sweat there, right? Now we can get into the main program loop. The first thing we're going to do is wait for a serial command. For our slave, we want to wait on a specific header so that we know that the master is talking to us. When that header arrives, we'll save the next two bytes that follow. The first byte will be our command, the second will be a value for that command.

```
Main:
  SERIN Sio, Baud, ("!SS0"), cmd, value
```

In the BS1, the header string to wait on is placed in parenthesis ahead of the input data variables. For this module, the header is "!SS0." If we want to add more than one of these slaves to the same serial connect, we simply change the unit digit in the header.

Another strategy would be to accept the ID byte as a variable after the header. By doing this, we could check to see if a command was specified for us, or was a global command that all slave units act on. In that case, the serial input might look something like this:

```
  SERIN Sio, Baud, ("!SS"), id, cmd, value
```

If you decide to adopt the latter method, just be sure that slaves don't send anything out the serial line as a result of a global command. If they do, the master won't understand anyone as they'll all try to talk at once. For the time being, let's keep things simple and keep the ID byte in the header.

Once we get a valid header and the command and value bytes, we can act on them. Now you'll see the BS1 **IF-THEN** construct in action and the cleanest way to deal with it. The first valid command that we'll check for is "I" (identification).

```
Check_ID:
  IF cmd <> "I" THEN Check_Bits
  PAUSE 1
  SEROUT Sio, Baud, ("1.0")
  GOTO Main
```

The purpose of this routine is to allow the master to see that the slave is connected and working. Notice that if the command byte is not "I," we will skip to the next check, otherwise, we will run the code for identification. Yes, this seems inverted but it works, and once you get used to it, you won't have to think twice. In this case, we will **PAUSE** briefly so the master can set up to receive our data, then we'll send the identification string. This can be used by the master to see that we're available and even check what capabilities we have by looking at the ID data.

The next valid command is "B" (for bits). This command lets the master decide which bits (segments) to control on the display. The bit pattern is sent in the value parameter. As you'll see when we hook up a BS2 master, this can be useful for simple animated indicators.

```
Check_Bits:
  IF cmd <> "B" THEN Check_Numeric
  Segs = value & %01111111
  GOTO Main
```

The final valid command is "N" for numeric. This command will cause the slave to place the digit passed in the value byte on the display, and works for all hexadecimal digits (0-F). This section of code makes use of the EEPROM table that we defined earlier.

```
Check_Numeric:
  IF cmd <> "N" THEN Main
  IF value > MaxDig THEN Main
  READ value, Segs
  GOTO Main
```

As you can see, it also checks the range (defined by the MaxDig constant) so that we don't read invalid EEPROM locations and put garbage on the display.

Before we wrap up our slave and move on to the master demo, I'm sure a few of you advanced Stamp programmers are wondering why we did all the **IF-THEN** jumping around instead of using a **LOOKDOWN** table for the command. In fact, both work, but it turns out that with small command sets, the **IF-THEN** route actually uses less EEPROM space for the compiled program. If we were building a slave that was processing a lot of commands, I think the opposite would be true, and certainly more convenient. In case you're curious, here's what that would look like:

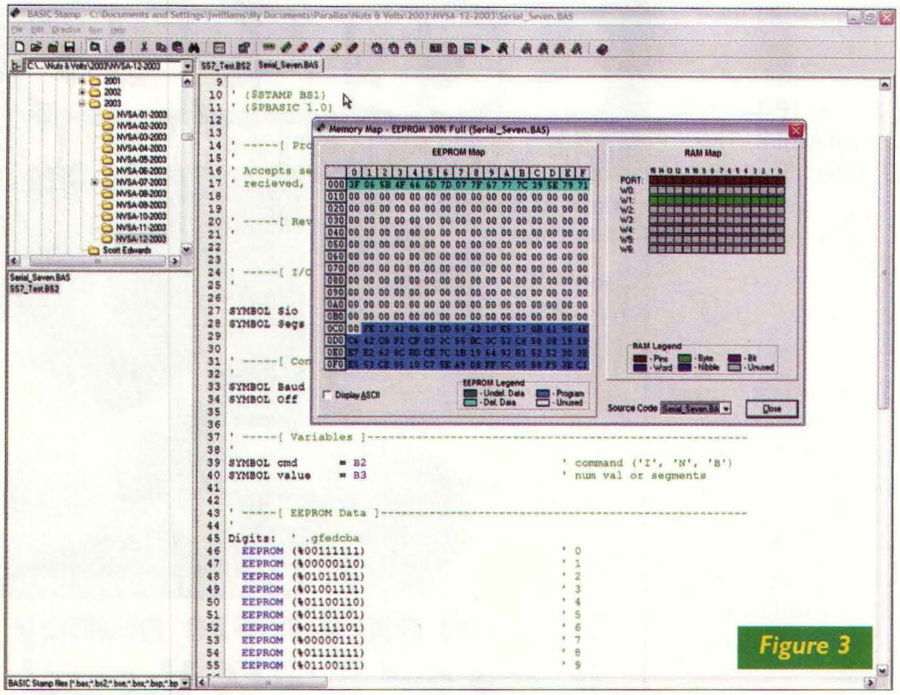


Figure 3

As soon as the command is sent, we will wait on the input. If it doesn't arrive within a second, the program will jump to No_Slave. In the demo, this just tells us there was no response and loops back to try again. In other systems, we may need to take some corrective action or modify the program behavior if we don't have the slave device.

Let's say it's connected. The slave sends three ASCII characters as its ID so we can use the STR modifier to collect them in an array. And since they are ASCII, we can again use the STR modifier to spit them right back out onto the **DEBUG** window. When you create slave modules that have variable capabilities, you'll want to check the ID data and deal with it accordingly.

The next test is the "bits" mode where the master defines which LEDs on the seven-segment display are lit.

```
Check_Cmd:
  LOOKDOWN cmd, ("IBN"), cmd
  IF cmd > 2 THEN Main
  BRANCH cmd, (Show_ID, Show_Bits, Show_Dig)
```

If the command is valid the **LOOKDOWN** table will convert cmd to a value from zero to two which can be used by **BRANCH**. If not in the table, cmd will fall through unchanged and **IF-THEN** will send the program back to Main. Again, if we were processing a lot of possible commands, this would probably be a better way to go.

The reason I know it takes more memory is that with the BS1 integration in the Windows Stamp compiler, we finally have a memory map (yippee!!!). Figure 3 shows a screen shot from my system with the memory map of our slave program. Okay, let's test this dude. To test the slave seven-segment display, we're going to connect a BS2 (any in the series) and run a simple program.

The first thing to do is check the ID as this lets us know that the slave is connected (remember, this is now BS2 code so the syntax is slightly different).

```
DEBUG CLS, "Serial Seven ID = "
SEROUT Sio, Baud, ["!SS0", "I", value]
SERIN Sio, Baud, 1000, No_Slave, [STR id\3]
DEBUG STR id\3
```

The code sends a message to the **DEBUG** window then sends the "I" command to the slave. Notice that a value is also being sent. To keep the slave simple, it has a fixed-format command structure so even when we don't need it, we will send the value parameter. In this case, it will just get ignored so it doesn't matter what we send in value.

```
DEBUG CLS, "Bits Mode"
FOR idx1 = 1 TO 10
  FOR idx2 = 0 TO 5
    READ (Bug + idx2), value
    SEROUT Sio, Baud, ["!SS0", "B", value]
    PAUSE 50
  NEXT
NEXT
SEROUT Sio, Baud, ["!SS0", "B", 0]
```

This code uses two loops. The outer loop runs the inner loop 10 times. The purpose of the inner loop is to animate the segments on the display. In this case, the segments value is read from a **DATA** table and will be the outer LEDs on the display. When the demo runs, the LEDs will "chase" in a clockwise manner 10 times. This is a great indication for waiting, or to show that a program is busy. Note that at the end of the loops we are sure to clear the display by using the bits command again with a segments value of zero. The final test is the numeric mode where we pass a single-digit value to display:

```
DEBUG CLS, "Numeric Mode"
FOR value = $0 TO $F
  SEROUT Sio, Baud, ["!SS0", "N", value]
  PAUSE 500
NEXT
SEROUT Sio, Baud, ["!SS0", "B", 0]
PAUSE 10
GOTO Main
```

There's no mystery here — this is easy stuff. I just want to make one note. Since the BS1 doesn't have a timeout facility on its **SERIN** function, you have to make sure it's ready before you start sending information to it. Putting a small **PAUSE** after each command sent to the

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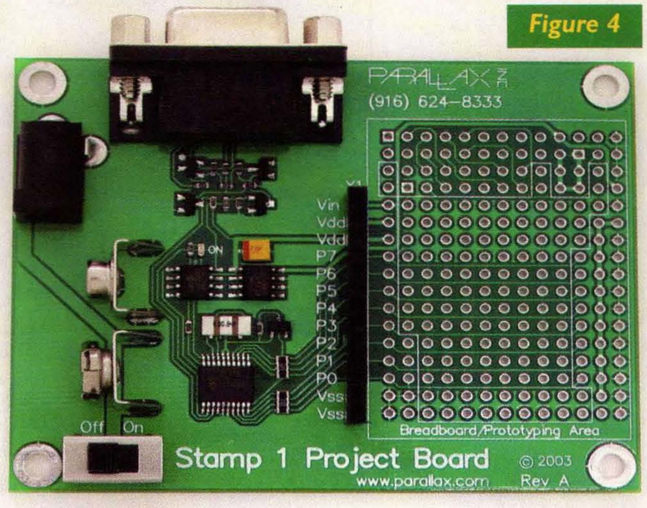
www.parallax.com

BS1 slave gives the slave plenty of time to receive, decode, and act on the command before getting ready for the next.

That's a Wrap

Well, I'd say that's about enough for this month and look at that, we've made it through another year! I hope those of you that have BS1 modules will get them out and rediscover how much fun they are, and those of you that took advantage of the Parallax special pricing on the older model Rev. D modules really have reason to celebrate. The BS1 is a great training tool for kids of all ages. With the popularity of the BS2 HomeWork board, Parallax has created a similar product using the BS1. Figure 4 shows the new BS1 Project Board that has the built-in serial adapter and a power switch. You can add a solderless breadboard if you like, or take advantage of the trace layout and add connectors for servos, LCDs, and other accessories. And yes, it will mount on a BOE-Bot chassis so you can get into robotics very inexpensively. In closing, I'd like to say thanks again for all your kind notes and the exchanges that we've had this past year. Please keep them coming — I do my best to write this column for your needs so I love hearing from you. And I do hope that this holiday season brings joy and peace to you and yours. God bless you and peace be with you. Happy Stamping and have a very Happy New Year! **NV**

Figure 4



The Latest in Networking and Wireless Technologies

Open Communication

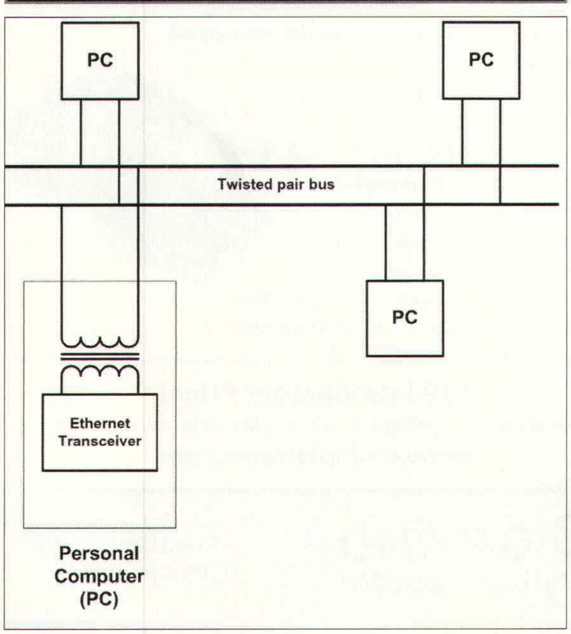
ETHERNET — PART 1: Wired Local Area Networks

Before the year is over, I want to say congratulations and thanks to Robert M. Metcalfe. Who is Bob Metcalfe and why am I saying this? Metcalfe is the inventor of the planet's more widely used local area networking (LAN) technology called Ethernet. And as of May 22, 2003 Ethernet was 30 years old. No kidding. It is pretty amazing for any technology to last that long, much less become the dominant technology with over 80% ... some say over 90% ... of all LANs in the world using it. That's a pretty big deal.

Bob Metcalfe invented Ethernet while he was working at Xerox's Palo Alto Research Center back in 1973. His first version used large (RG-8/U) coax cable and interconnected up to 100 computers together to communicate with one another and to share various resources. The system transmitted data in packets at a rate of 2.94 Mb/s. That is pretty slow by today's standards, but an amazing feat back then.

Anyway, Ethernet was patented in 1977. In the early 1980s, Metcalfe went on to be the founder of 3Com Corporation —one of the first companies producing Ethernet interface products for personal computers. In 1983, the Institute of Electrical and Electronic Engineers (IEEE) made Ethernet a standard designated 802.3. Over the years, Ethernet has not only grown in usage with over a billion ports worldwide, but it has also evolved from its coax roots into a high-speed data communications system using either unshielded twisted pair (UTP) cable or fiber optic cable with data rates to 10 Gb/s.

FIGURE 1. Tranceivers are connected to a common two wire bus, so they must take turns transmitting and receiving. Transformers in each interface provide DC isolation and impedance matching.



Since Ethernet is so ubiquitous, it is worth knowing about. If you work in an organization with PCs connected by a LAN, you are most likely using Ethernet. If you use any kind of high-speed broadband internet access at home on your PC, you are using Ethernet. With its usage continuing to grow, Ethernet will eventually have its affect on everyone. You just may want to find out a bit more about it. In this column, I will give a quick tutorial overview on wired Ethernet. In the next column, I will cover wireless Ethernet, which is continuing to expand the influence of this amazingly flexible technology.

Versions of Ethernet

The first standard versions of Ethernet transmitted at a 10 Mb/s and many Ethernet LANs still operate at that speed. The first transmission medium was coax cable — the large RG-8 type initially, and designated 10BASE-5 where 10 means 10 Mb/s data rate, BASE means baseband data transmission with the data pulses applied directly to the cable, and the 5 meaning a 500 meter maximum length. The 10BASE-2 version used the smaller RG-58 coax cable and had a maximum range of 200 meters. The cable was configured as a bus that multiple computers tapped into and shared. Coax is expensive and difficult to work with but soon a newer version of Ethernet was developed using UTP cable.

This type of cable is standardized by the American National Standards Institute (ANSI), the Electronic Industries Association (EIA), and the Telecommunications Industry Association (TIA), and is designated under the 568A/568B specifications. There are several versions used, but the most common for LANs is category 5 (CAT5) that contains four pairs and can handle a data rate of up to 100 Mb/s. New LANs are wired with CAT5E (155 Mb/s) or CAT6 (200-250 Mb/s). A modular connector called an RJ-45 is used to terminate the cable. It is similar to the smaller RJ-11 modular connectors used on most telephones, only larger. Twisted pair is much less expensive and easier to work with than coax, making it cheaper and easier to build a LAN anywhere. It is hard to find a building or office complex that is *not* wired for Ethernet today. Even new homes are routinely wired with CAT5 or better, making home networking easy to implement.

As computers got faster, so did the need for a faster LAN. IBM, who developed a competing LAN technology called Token Ring, upgraded their original 4 Mb/s ring topology LAN to 16 Mb/s. That set off a speed race that Ethernet won with their 100 Mb/s 100BASE-TX standard. Known as Fast Ethernet, it achieves 100 Mb/s on CAT5 UTP at a range of up to 100 meters. Most LANs quickly upgraded their systems to the faster version right about the time the Internet was growing like crazy in the mid to late 1990s.

But that's not all. One of the main reasons that Ethernet has not only survived, but also grown, is that it scales well. That means that speed improvements are relatively fast and easy to make. Just add in the necessary interfaces and ... voila' ... the same wiring produces 10 times the speed. What's not to like?

In the late 1990s, the IEEE ratified the final version of the standard that took Ethernet to the next decade speed bump of 1,000 Mb/s or 1 Gb/s. Known as Gigabit Ethernet (1 GE) or 1000BASE-T, or by its IEEE standard designation 802.3z, this version defines both twisted pair and fiber optical cable transmission media. How do you transmit one billion bits per second on a twisted pair? Well, it isn't easy. What this standard does is to break the 1 Gb/s data stream into four 250 Mb/s streams. It then uses a line coding scheme that transmits two bits per coding symbol where each symbol is a different voltage level. This puts the data rate on each of the four twisted pairs at 125 Mbaud — well within the UTP's capability. (Remember that the baud rate is the symbol rate, not the bit rate.)

With this arrangement, a rate of 1,000 Mb/s is achieved at a range of up to 100 meters. Again, no change in wiring was needed to jump to another factor of ten speed increase. No wonder it was an instant success with many LANs already converted to handle it and most new PCs incorporating the 1 Gb/s interfaces.

The fiber optic versions of 1 GE are primarily for transmitting over longer distances. They make a good backbone for larger corporate or campus LANs. And it is also being incorporated into the new storage area network (SAN) systems that connect corporate network and Internet servers to large disk arrays for mass storage. It is also finding use in some metropolitan area networks (MANs). These so-called metro networks are used in cities to interconnect LANs to wide area networks (WANs), which carry data to the Internet backbones.

The 1000BASE-LX version of 1 GE uses single mode fiber (SMF) only 9 µm in diameter. (A µm is a micron or one millionth of a meter.) The laser driver creating the digital pulses operates at an infrared light wavelength of 1,310 nanometers (nm). It has a reach of 10 kilometers (km). If the larger, less expensive multimode fiber (MMF) is used, the range decreases to 500 meters. The 1000BASE-SX version is even less expensive. It uses MMF and a 780 nm laser for a range of about 500 meters.

And believe it or not, it does not end there. The IEEE recently blessed the 10 gigabit version of Ethernet (10 E). Also called by its standard designation 802.3ae, this truly is a fiber optic version since it is even more difficult to transmit 10 Gb/s over UTP. One version of the 10 Gb/s standard does specify a method that achieves 10 Gb/s on a pair of coax cables up to 15 feet long. A twisted pair version is also under development.

There are five different optical fiber versions of 10 GE. Three of them use purely serial transmission. One uses a 850 nm laser over 50 µm MMF to get a range of up to 65 meters. Using 9 µm SMF and a 1310 nm laser nets a maximum range of 10 km. Going to a longer wavelength, a 1,550 nm laser on the 9 µm SMF

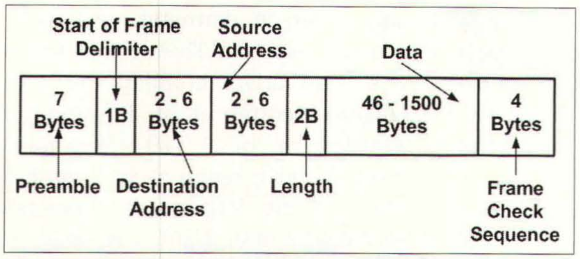


FIGURE 2. The Ethernet frame. Data is transmitted in packets where the data is bracketed by other bytes that assist in the transmission. Note: One byte is eight bits.

achieves a reach of 40 km at 10 Gb/s.

The two versions of 10 GE use what is called wavelength division multiplexing (WDM). This a technique like frequency division multiplexing used in cable TV systems. Each TV signal is modulated onto a different carrier frequency, and all of them are simply added together and put on the cable at the same time. The cable box sorts them out. In WDM, different serial bit streams pulse modulate lasers on different infrared light wavelengths (λ). These methods are also referred to as wide wavelength division multiplexing (WWDM) or coarse wavelength division multiplexing (CDWM). Both versions split the 10 Gb/s bit stream into four slower streams and put each on a different wavelength laser. All of the signals are transmitted down the fiber at the same time and filters at the receiving end separate them. The bit streams are recombined at the receiving end into a single 10 Gb/s stream. One version of WWDM uses 62.5 µm MMF with lasers in the 1,310 nm range to achieve a distance to 300 meters. The other uses 9 µm SMF with 1,310 nm range lasers to get a distance to 10 km.

10 GE Ethernet is just now emerging and has yet to be widely adopted. But it will no doubt be adopted in the larger LANs as the demand for more speed and capacity grows. 10 GE will also find its way into SANs and metro networks. Most metro networks use a well established technology known as Sonet, for synchronous optical network. This is primarily a fast fiber optic digital telecommunications system developed for telephones. It easily achieves speeds of 2.5 Gb/s and 10 Gb/s, but it is expensive and complex. Some say that 10 GE will give Sonet a run for the money because it is cheaper and because the emphasis has shifted from voice to data as far as telecom traffic is concerned. We shall see.

What's next for Ethernet? Is a jump to 100 Gb/s inevitable? That's not too likely in the near future since that speed is well beyond the capabilities of most transistors, integrated circuits, or other semiconductor devices. However, one possibility is a jump to 40 Gb/s. Sonet defines a 40 Gb/s version called OC-768. Some circuits are available already.

These are not made with plain old silicon like most other ICs, but with more exotic semiconductor materials like silicon-germanium (SiGe), gallium arsenide (GaAs), or indium phosphide (InP). The economic downturn slowed development in this area, but as the economy returns, we can expect to see development grow. It wouldn't surprise me to see 40 Gb/s Ethernet in a few more years.

FIGURE 3. A typical Ethernet transceiver. This IC is the heart of all Ethernet interfaces. This MY1001 by Mysticom is designed to handle 10/100/1,000 Mb/s versions of Ethernet and can achieve a maximum range of 140 meters on UTP. Courtesy of Mysticom. **www.Mysticom.com**

Ethernet Operation

Ethernet is a baseband signaling method that connects the binary pulses directly to the transmission line. This works fine, but can cause problems depending upon the pulse format. Ethernet uses a form of line coding called Manchester coding that converts the binary 1 and 0 voltage levels into double frequency pulses where the high-to-low or low-to-high transitions mark the center of the binary value. The value of this method is that the clock signal can be easily derived from the transmitted data. The clock signal is regenerated at the receiver from the data and it is used to manipulate the received data in the interface.

A key feature of Ethernet is the access method it uses. Access method explains how multiple users can share and access a single communications bus. Figure 1 shows an Ethernet bus shared by four personal computers (PCs). Any PC can talk to any other PC. Obviously, they have to take turns transmitting and receiving. And there has to be a way for them to know when it is safe to transmit and not interfere with a transmission already in progress. Ethernet uses a method known as carrier sense multiple access/collision detection, or CSMA/CD.

All PCs on the bus continuously monitor the bus signal which is called the carrier. If some PC is transmitting, all other PCs know it by this carrier presence. Once the carrier disappears, any PC can transmit. It effectively broadcasts the signal to all connected PCs. If two or more PCs try to send at the same time, a "collision" occurs. This collision is detected by all of the interfaces so all transmissions are stopped. The transmitting PCs then wait a random amount of time — different for each PC — then they try again to transmit. Statistically, one PC will capture the bus first, transmit its data and then stop.

The data is put on the

bus for all to see. Each computer decodes the message to see if the message is for it. The receiving PCs capture the data while all the other PCs ignore the data.

This access method works pretty well, but you can imagine that the greater the number of users on a bus and the greater their need to communicate, the slower things become. All that contention for the bus takes time away from the actual data transmission.

The data to be transmitted is assembled into frames or packets in the format shown in Figure 2. What you see here is a long stream of binary bits making up all of the information to be transmitted. The preamble and the start frame delimiter are eight bytes that are alternating 1s and 0s transmitted first so that the receiving interface can get ready for the data and synchronize its clock. The next two or six bytes are the destination address. A unique address code is assigned to each PC on the network. The next two or six bytes are the source address — the address of the sending PC. Next is a byte that tells how many bytes of data are being transmitted. Finally, the data is transmitted. The length of the data field is 46 to 1,500 bytes. The frame ends with the frame check sequence which is a four byte error detection code. Ethernet uses what is called the cyclical redundancy check (CRC). The CRC process is essentially that of binary division. The entire data block is considered to be one big binary word. It is mathematically divided by a special code. The result is a quotient and the remainder. The quotient is discarded and the remainder becomes the CRC. This 32-bit code is transmitted last.

At the receiving end, the PC recognizes its address and takes in the data. The CRC is regenerated and the received and generated CRCs are compared to see if any errors occurred. The interface chip looks at all the data fields and sorts everything out putting the data itself into memory.

The Hardware of Ethernet

The only thing a PC needs to connect to an Ethernet LAN is an interface. On older PCs, you had to buy a network interface card (NIC) that plugged into the PC bus. That card connected via CAT5 cable to the LAN bus. That's basically all there was to it. If you have an older PC, this is still the way it is. However, because Ethernet is so widely used, almost every new PC or laptop has an Ethernet port built in. Just look on the back for the RJ-45 connector. The Ethernet interface today is simply one large IC and a handful of discrete components. A typical Ethernet transceiver chip is

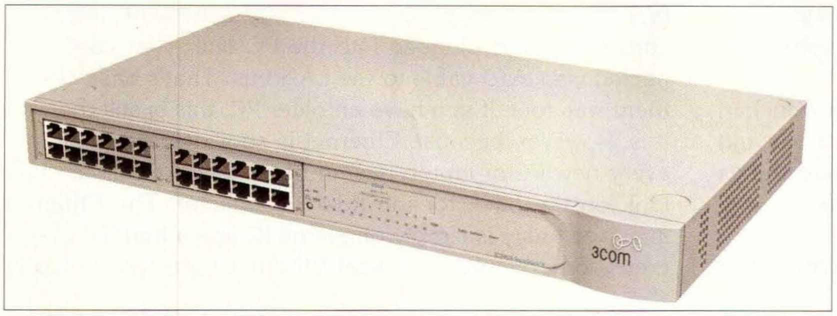


FIGURE 4. A typical Ethernet hub. This 24-port SuperStacker 3 Baseline hub by 3Com can be stacked and daisychained with others to build even larger LANs. Courtesy 3Com Corp. **www.3com.com**

shown in Figure 3. This one implements a 10/100/1,000 port which, of course, defines the speeds in Mb/s at which the interface will operate. In a business environment, the PC hooks to the LAN with UTP cable. At home, the PC connects to any high speed Internet device like a cable TV modem, a DSL modem, or some other broadband router or gateway via the Ethernet port.

At the other end of the LAN is usually one or more servers — larger, faster versions of PCs that handle the network software, the data bases that users may access or control to access the Internet. The servers also have Ethernet ports. Between the PCs and the servers are a variety of other devices that help connect and consolidate everything. The main devices are hubs and switches.

A hub is simply a central connecting point for two or more PCs. You can recognize a hub by its low, flat enclosure and multiple RJ-45 connectors on the front into which plugs the CAT5 from the various PCs. A typical hub is shown in Figure 4. The hub, more or less, creates what we call a physical star connection where the hub is the center and all the PCs and their wiring are the points of the star. However, the logical topology of the LAN is still basically a bus.

The bus is just collapsed so that it is all contained within the hub. Referring back to Figure 1, picture all of the connections on the bus to be in one box. Note that a transformer is used in the interface to connect the Ethernet transceiver chip to the bus. The hub also contains signal amplifiers and regenerative circuits to reshape weak signals from PCs at the ends of long cables. You can get hubs with 4, 8, 12, 16, 24, 32, and 48 ports. If more ports are needed, you just daisy chain one hub to another and so on. The hub connects to the server.

Another hub-like device is the Ethernet switch. It basically looks like a hub and serves the same purpose, but it also does something else. It can switch selected portions of the network off and on as needed. What this does is minimize interference between sending PCs and results in an overall faster transmission of data. As more PCs are added to a bus, the cables get longer and slow the data down. The greater the number of PCs, the greater the competition for using the bus so all the negotiation with the access method really slows things down.

What a switch does to solve this problem is divide the LAN into smaller sections. If a section is not being used, it is switched off so as not to load the network. The switch looks at the destination address of a transmitting packet and then switches on the segment containing the destination PC. Most Ethernet LANs use switches as they produce a remarkable increase in performance.

Ethernet is everywhere and its use continues to grow. It is now becoming the network of choice for industrial applications in factories and plants to interconnect control computers, sensors, and other devices. And a modified version of Ethernet could end up being the protocol of choice for the fiber optic cable replacements for the current twisted pair telephone lines generally known as the plain old telephone service (POTS) local loop.

An IEEE committee is on the verge of approving 802.3ah — a standard for passive optical networks (PONs) that will eventually connect your home to telephones, Internet access, and cable TV via fiber. And then, of course, there is wireless. I will cover wireless Ethernet in my next column. **NV**

Tech Forum

QUESTIONS

Can someone tell me what the difference is between an S-video input and the plain old video input on a television set?
#12031 **Ron Rosien**
Los Angeles, CA

Does anyone have plans for a portable ultrasonic leak detector that operates in the 20-100 kHz range?
#12032 **James Dinsdale**
Alomogordo, NM

My 13-year-old son is heavily into electronics and was given a Lewis Lektronix scrolling LED sign, model 1000/RS232, for his birthday. Unfortunately, it is without the manual, keyboard, and software for programming. I've called the phone number on the sign and scoured the Internet, only to learn that the company has apparently gone out of business.

Does anyone know where we can find hardware and/or software to make this sign work?
#12033 **Matt Loiselle**
via Internet

I am considering building a CNC milling machine for PCB prototyping. I have most of the necessary mechanical and electrical components accumulated, and now I need the software to drive the X,Y, and Z axes. Where can I find a shareware or low-cost Windows based program that will accept HPGL or Gerber files as input, and output motion control code?
#12034 **Stan Grupinski K2OTN**
Wimberley, TX

Is it possible to set up a remote video monitoring system using my home PC (with a cable modem ISP) as my base, to monitor my cabin 80 miles away? The PC at the cabin only has plain telephone service (as well as the two cameras).

Are there other options that I should consider?
#12035 **Anonymous**
via Internet

I'm a student and I'm building a three axis robot arm using stepper motors, controlled through the parallel port of a PC. I'm having difficulty building the stepper motor controller board, and writing the software to run it.

Can anyone point me to any good information regarding basic control of stepper motors?
#12036 **Le Quoc Huy**
Vietnam

Does anyone know of a reference book on electronic component footprints?
#12037 **Stephen Ory**
via Internet

This is a READER-TO-READER Column. All questions AND answers will be provided by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. All questions submitted are subject to editing and will be published on a space available basis if deemed suitable to the publisher. All answers are submitted by readers and NO GUARANTEES WHATSOEVER are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

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- Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

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All questions should relate to one or more of the following:
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2) Electronic Theory
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- Be brief but include all pertinent information. If no one knows what you're asking, you won't get any response (and we probably won't print it either).
- Write legibly (or type). If we can't read it, we'll throw it away.
- Include your Name, Address, Phone Number, and Email. Only your name, city, and state will be published with the question, but we may need to contact you.

ANSWERS

[08033 - August 2003]

The PLL system of my Kenwood R-5000 SW receiver went out and I discovered that Kenwood OEM PLL boards are dreadfully expensive.

I have a factory manual and have access to an oscilloscope, VOM, etc., but have no idea how to begin debugging the circular system. It does not look like the Kenwood website will help.

Here are some suggestions:

1. A possible answer may be available at **www.qth.net** Once there, from the 'select list,' choose Kenwood and search through the archives. Possibly, you may find the answer. If not, sign on to the Kenwood list and post the question. Many times, someone within the group will have the information. The Kenwood TS 440 had a generic VCO problem. With time, the 'goop' that held some components together became conductive. The solution was to remove the goop and replace some components.

2. Kenwood may have a service bulletin on this subject. Go to **www.kenwood.net**, jump to service bulletins and search.

3. If both of the above fail, look at the PLL board for 'cream color' hard goop (hard synthetic rubber) covering several components. Determine the circuit associated with this area and check in the service manual if it is a VCO. If indeed there is such a situation, this is probably the number one suspect.

The cream colored goop must be removed, and associated parts replaced. Kenwood Service Bulletin SB 973 and 974 describe the procedure for the TS 440. Use the details in Bulletin 973 on how to clean the goop.

Parts may be hard to find. A good source is: East Coast Transistor Parts, Inc., **www.eastcoasttransistor.com**; (516) 483-5742.

I hope this helps.

Mort Arditti
Los Angeles, CA

[09033 - September 2003]

I would like to control a process that requires a time and temperature sequence. I need a temperature span from 90° F to 170° F and time periods from 15 to 120 minutes in duration. What would be the easiest and least expensive way to accomplish this task?

This appears to be an ideal application for control by an inexpensive MCU. Since minimal I/O ports are required, an eight pin PIC12F675 would serve very well, taking analog temperature input from a Dallas 18B20 sensor. The nature of the heater is not specified, but in almost any case it can be controlled by a suitable relay activated by a PIC output, probably through a transistor since the coil will likely draw more than 20 mA.

Because of the long time periods involved, the 12F675 might conveniently run on a slow (e.g., 32 kHz) external oscillator, although for minimum cost the internal 4 MHz oscillator can be used, with a lot of delay counting. Since the MCU is doing nothing most of the time anyway, lots of counting is probably appropriate. The cost of parts, less power supply (5 V) and heater relay, is far less than $10.00. The programming is trivial, and can be altered (the 12F675 is flash programmable) to meet modified heating requirements.

Ed Grens
via Internet

[10031 - October 2003]

After the big blackout, my Panasonic VCR, model PV-8662, no longer works at all. I know that the internal fuse blew and one power supply transistor, as well. However, I don't have the know-how to go much further without a schematic.

#1 The transistor you found with the problem is probably Q1001, a 2SC4533. It should exhibit a short between the emitter and collector. At the shop I work at part time, we have had a few of the Panasonic PV line of VCRs with the same problem after a lightning storm or a power interruption. Besides replacing the transistor and the 1.6 amp fuse, you should also look at all the capacitors in the output of the SMPS. Pay particular close attention to C15, C16, C17, and C19. Even if they check good, replace them. You can replace them with a higher DC voltage than what they are. They should currently be 6.3 VDCs and 16 VDCs. Replace them with higher working voltages (whatever will fit in their confined spaces, go with it). Really, replacing ALL of the caps in the output of the supply isn't a bad idea while you have the supply out of the VCR; it will save you time and effort when another one of them should let go. For the sake of a few extra pennies, it will save you headaches down the road. Most of the power-supply-caused problems in the PV line of VCRs can be traced down to these few capacitors, so get them all at one time and avoid the Christmas rush. The transistor, if it is a 2SC4533, crosses to a NTE2339 and it is an NPN. You should be able to pick it up through an NTE distributor. If you can't locate one, then try an online source such as Electronix (**www.electronix.com**), they carry it in stock at a reasonable price.

Ralph J. Kurtz
Old Forge, PA

#2 I have never had any problem

getting service manuals for Panasonic equipment. At **www.panasonic.com**, they give you the toll-free number for the national parts warehouse, where service manuals can be ordered. I generally order through a distributor, which is the only way you can get parts or service manuals from many manufacturers. At **www.fox-international.com** they can order your manual for $19.30 plus $4.00 for shipping.

Considering your luck finding a manual, maybe you should take it in for repair.

Dave DeLeersnyder
Kansas City, MO

[10033 - October 2003]

I am 13,000 feet from the phone company office and can only get 768K download and 128K upload on the Internet. Yet, if I was 11,000 feet away, I could get 1500K/256K.

It seems to me that all I need is a bi-directional amplifier with low noise to increase my speeds. Is this true?

#1 If it were so easy to increase DSL range and bit rate, the phone companies would already have done it. They would like nothing better than to make their product more competitive with cable modems, which are usually faster than DSL.

Unfortunately, the problem you're having is not due to receiver noise and signal levels; it's primarily due to interference between twisted-pair lines (originally intended for audio frequencies), which increases with their length. If you amplified the received signal, you would also amplify the interference, and if you amplify the transmitted signal, you would interfere with the signals on your neighbors' lines.

Therefore, a simple amplification will not help. What will help eventually are more sophisticated modulation methods as the technology improves and the chips get cheaper. There are some higher speed versions of DSL available today to businesses (e.g., SDSL), but these are expensive and not generally available to consumers.

Larry Russell
Atlantic Highlands, NJ

#2 Yes, a bi-directional amplifier and data re-former would help, but only if you placed it in the middle of the run, which the phone company is unlikely to do. The problem with distance in a DSL connection is not signal strength or noise, but the length of the wire run itself, so any devices at the ends won't help. The long wires have enough capacitance to cause data bits to spread out a little bit. If they spread out too much, they start to overlap, and the data is corrupted. At higher data speeds, the bits are smaller, and so can tolerate less spreading. Unfortunately, there is little you can do to get a higher DSL data rate, short of moving closer to the phone office. A 768 Kb download rate isn't all that bad.

Don Rotolo N2IRZ
River Vale, NJ

[10034 - October 2003]

I am looking for a speed sensor that would work with a microcontroller such as the Motorola 68HC11. I also need an ultrasonic distance sensor that is reliable up to 60 feet.

Since you are looking for a sensor to be used in harsh environments, I recommend a magnetic type with a Hall Effect sensor. These types work well in dirty or moist environments. Allegro and Melexis offer semiconductor sensors and have extensive information on their websites with unique sensors. Melexis also offers a designer kit, which includes several sensors, design samples, and a linear type to measure magnetic flux for a low price, which will be useful for your design. These sensors can be incorporated into your design and produce pulse signals which can be easily measured with a microcontroller. It is also easy to add quadrature for direction and an index signal, if required.

Senix makes excellent ultrasonic distance sensors, however they are limited to 37 feet.

Walter Heissenberger
Hancock, NH

[10035 - October 2003]

I need a simple frequency allocation chart for terrestrial American digital radio (DAB-T) and television (DVB-T).

The following file on the Internet **www.ntia.doc.gov/osmhome/allochrt.pdf** provides a complete United States frequency allocation chart from 3 kHz to 300 GHz.

Additionally, this page **www.jneuhaus.com/fccindex/index.html#Freq_chart** provides links to a large number of less comprehensive, but more detailed frequency allocation tables and charts, including at least one to an FCC table of TV channels and an FCC table of FM radio broadcast channels.

As I recall, terrestrial digital broadcasts will have to be provided within these same allocations. In any event, this site **www.100000watts.com** claims to list, among other things, 1,643 digital TV stations.

Tom Tillander
Bay Village, OH

[10036 - October 2003]

I am looking for a circuit that is a laser light activated switch. It should be activated by a standard red laser pointer and also be immune to ambient light. The output from the switch would give a pulse to activate a timer.

I wrote an article in the July 1999 issue of *CQ-VHF*, discussing an experimental laser data transmitter and receiver. In this case, you would use only the receiver portion, shown in Figure 1. Q1 can be a phototransistor as shown, but in this case, you might be better off using a regular red LED, one with a red lens. The LED has plenty of sensitivity to red light and some immunity to other colors. If possible, mount it in a tube (like a paper towel tube) to reduce ambient light, put a red filter over the tube to further decrease sensitivity to other light, and use a simple lens to make the aiming of the pointer easier. Locate the 'chip' of the LED right at the focus of the lens, and hitting anywhere on the lens will illuminate the LED. Use VR1 to adjust the sensitivity, so the output (labeled 'Data to TNC') only goes high when there is laser light shining on the LED or phototransistor. This output can easily trigger a 555 or small relay directly, or you can use a 2N3904 transistor to trigger a large relay, or something else.

For the power supply, use a 12 volt DC wall wart and a 78L05 voltage regulator to drop it down to 5 volts. Review the 78L05 spec sheet (widely available on the Internet) for details on that simple circuit. All the parts are available at RadioShack and other electronic supply shops.

Don Rotolo,N2IRZ
River Vale, NJ

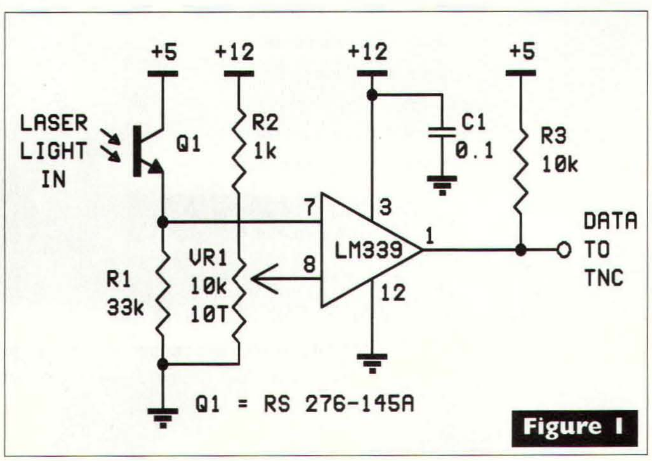

Figure 1

[10037 - October 2003]

I am building a down counter using the ICM7216 four-digit up/down counter and cascade them to create an eight digit counter. The only way I've found to load the counters with numbers is using expensive BCD switches. I need a way to use a keypad instead, possibly the 74C922. If this is possible, how do I do it since the 7216 strobes each of the BCD switches to get its input?

You want to load one counter at a time. First digit needs a holding register (four bit latch), then the second holding register loads with the first into the first counter. Reuse that holding register for the next two digits, into the next counter. A four-bit "ring counter" can provide the sequencing, using two bits to provide the latch strobe. (A and not B type gates, or similar?) The counter should be stopped while loading.

The more expensive route would be to set up a chain of eight, four-bit latches, each loaded from the previous, on each digit. Then you can parallel load the counters from that chain. (This is logically how it would likely be done in software.)

J DD Arbaugh
Pearblossom, CA

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