Experimenting With Shape-Memory Alloy Wire

By Forrest M. Mims III

Shape-memory alloys are metals that possess a crystalline structure that rapidly and dramatically change shape in response to a temperature change. The length of a shape-memory alloy (SMA) that has been drawn into a wire will contract as much as 10 percent when the wire has been heated beyond its transition point. Such a wire can be easily heated simply by passing a current of a few hundred milliamperes through it. After the current is removed, the wire rapidly resumes its normal length as it cools.

It's interesting to recall that metal generally expands when heated and contracts when cooled. This explains the incorporation of expansion joints in metal bridges and structures and the intentional slack of power lines. Over its transition temperature range, an SMA alloy behaves in exactly the opposite fashion.

SMA wire can be used to make various kinds of circuit breakers. Its most interesting application, however, is in the production of many different kinds of simple but effective electromechanical actuators. These actuators are well suited for many kinds of robotic applications. They can also be used to make electrically operated latches, indicators, heat engines, louver and valve controls and pumps.

Later in this column, a new kind of SMA wire, BioMetal™, will be described in detail. Also presented are some simple circuits for use with the wire. First, let's examine some of the basics of shape-memory alloys.

Shape-Memory Alloy Basics

In 1961, William Beuhler and his team of researchers at the Naval Surface Weapons Center, then known as the U.S. Naval Ordinance Laboratory, discovered that a titanium-nickel alloy exhibited the shape-memory effect. This effect had first been discovered in a gold-cadmium alloy a decade earlier by Chang and Read in Europe. Later, the effect was found in an alloy of indium and titanium.

The discovery by Beuhler's team was important since their Ti-Ni alloy was less expensive and lacked the possible health risks of earlier shape-memory alloys. They named the material "nitinol" (after *ni*ckel *ti*tanium *N*aval *O*rdinance *L*aboratory).

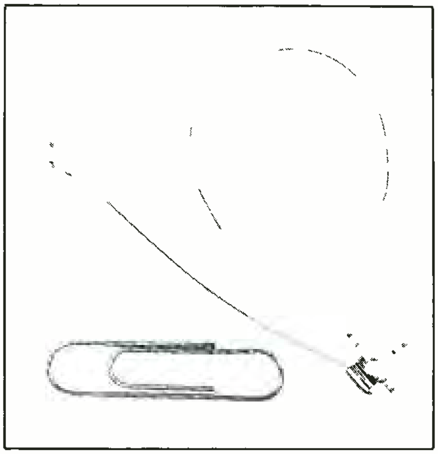


Fig. 1. Terminated and unterminated BioMetal Wire.

In 1985, Japan's Toki Corp. announced that Dr. Dai Homma had discovered an improved version of nitinol. Dr. Homma had accidentally discovered the improved alloy some years earlier, and several years were required before he was able to recreate his original discovery. Toki now manufactures the improved nitinol alloy as a wire under the trade name "BioMetal."

BioMetal wire can be purchased from TokiAmerica Technologies, Inc. (18662 MacArthur Blvd., Suite 200, Irvine, CA 92715). TokiAmerica and Mondo-Tronics (20090 Rodrigues Avenue #1, Cupertino, CA 95014) also sell a variety of economical project kits that demonstrate the characteristics of and applications for BioMetal.

SMA Applications

Many applications have been devised for nitinol. Some have not been commercialized or used in practical applications. For instance, NASA once proposed using nitinol to make lunar antennas that would deploy when heated by the sun or a heater. Many other applications have found commercial acceptance, to be sure. For example, nitinol has been used in eyeglass frames, dental alignment materials, miniature pumps and even an experimental artificial heart.

Another application that has been suc-

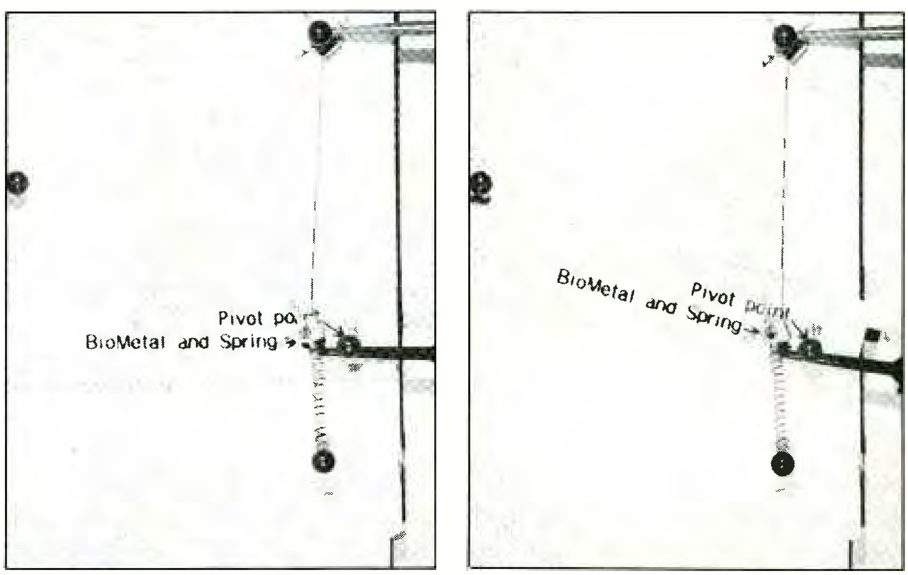


Fig. 2. A BioMetal-controlled lever in its resting (left) and actuated (right) positions.

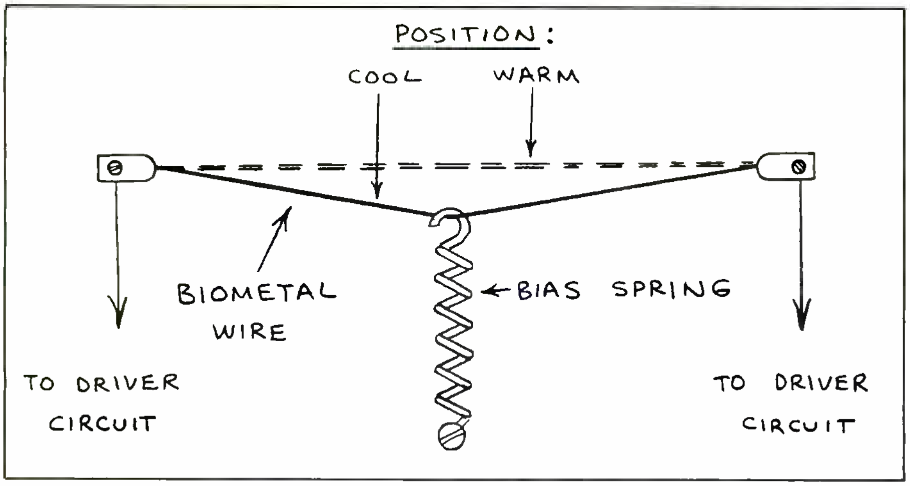


Fig. 3. BioMetal Demonstrator.

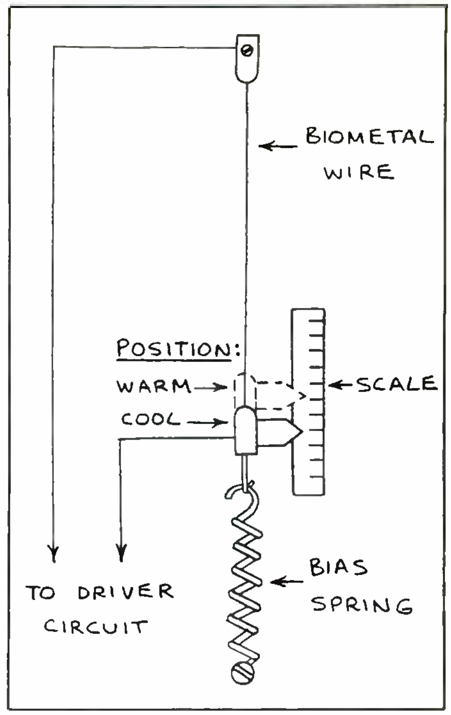


Fig. 4. Arrangement for measuring contraction of BioMetal.

cessfully implemented is nitinol pipe fittings for hydraulic couplers in jet aircraft. The nitinol used in this application has a transition temperature range below the normal ambient. Prior to installation, a nitinol pipe fitting is expanded by cooling it. After the fitting is installed, its temperature is allowed to rise to ambient, at which point, the fitting contracts and firmly secures the union.

Nitinol has many more applications when drawn into wire than when used in bulk or sheet form. This is in part because the resistance of nitinol wire is typically 10 times that of copper. Therefore, it can be easily heated simply by passing an electrical current through it.

BioMetal Wire Characteristics

BioMetal wire from TokiAmerica Technologies is currently supplied in a 6-mil diameter. This wire has a resistance of about 1 ohm per inch. BioMetal wire supplied with the project kits described above is either unterminated or terminated in a pair of maple connectors. Shown in Fig. 1 are both terminated and unterminated BioMetal wire. Compression terminators are generally required because BioMetal wire should not be raised to the heat required for soldering.

When heated, BioMetal wire can pull up to about 11 ounces as much as 10 percent of its length. For a maximum life of as much as a million cycles, the contraction of BioMetal wire should be kept to around 4 percent of its length. Thus, a 3-inch length of BioMetal wire can reliably contract 0.12 inch.

BioMetal wire has a remarkably fast response time. After it is heated to its transition temperature, it responds within a millisecond. When BioMetal wire is immersed in a heat-dissipating liquid, such as silicone oil, and a fast-rising current is applied to it, it can be made to contract and expand within a few tens of milliseconds.

BioMetal is harder than steel. Like stainless steel, it is compatible with body fluids. The 6-mil wire supplied by Toki-America has a breaking strength of around 6 pounds.

Nitinol Actuators

Among the most interesting applications for nitinol wire is in the production of simple actuators whose actions resemble that of a solenoid. TokiAmerica Technologies' BioMetal wire can be used to demonstrate many such actuators, all of which can be operated by means of the simple circuits described below.

Fig. 2 shows one of the experiments that can be performed with a Toki BioMetal Project Kit (No. DH-601: "Lines, Angles and Levers"). The experiment shows how a length of BioMetal wire biased by a small spring can move a lever over a substantial distance. In the left photo, no current is applied to the BioMetal wire. The right photo shows what happens when a current is passed through the wire, which contracts and pulls the lever upward.

Many other simple experiments can be performed with a few inches of BioMetal wire, a bias spring and a few other simple components. Figure 3 is a simple demonstrator that consists of a length of BioMetal wire mounted between two fixed supports. A bias spring pulls the center of the wire to one side. When the wire is momentarily heated by a direct current from a single 1.5-volt alkaline cell or by means of a pulse or pulses supplied by one of the circuits to be described, the wire contracts and pulls away from the spring.

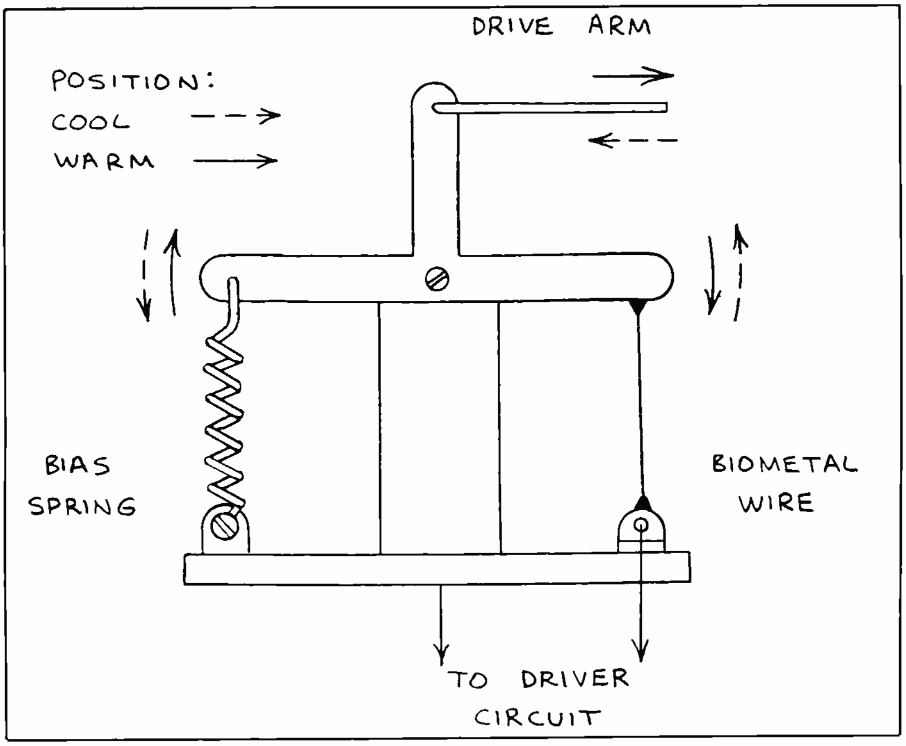


Fig. 5. Linear-motion actuator.

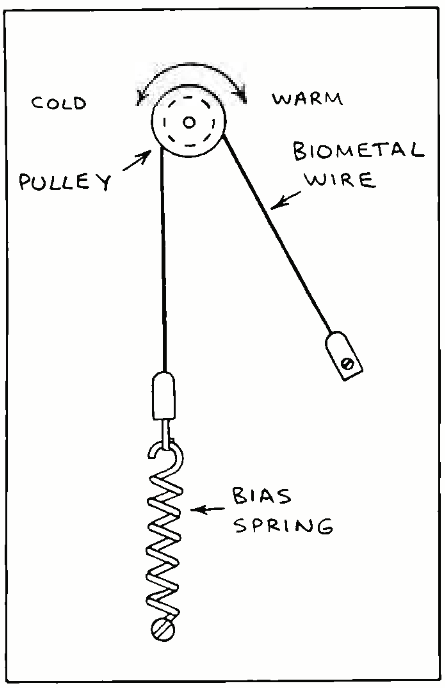


Fig. 6. Rotational actuator.

When current is removed, the wire cools and resumes its normal position.

Figure 4 shows an arrangement for measuring the overall movement of a length of BioMetal wire. Here, the bias spring is attached to one end of the wire and indicates the wire's movement on a scale. This simple arrangement demonstrates that BioMetal wire contracts when heated and resumes normal length after it cools to ambient temperature.

Figure 5 shows a linear-motion actuator whose key components are a length of BioMetal wire and a bias spring. When a current is applied to the BioMetal wire, the latter contracts and pulls the right side of the actuator down. This moves the actuator arm to the right. When the BioMetal wire cools, the actuator returns to its resting position.

How a BioMetal wire and a pulley can cause rotational movement is illustrated in Fig. 6. Once again, note that a bias spring is needed.

Figure 7 shows a compression or piston actuator made by installing a length of BioMetal wire inside a hollow tube. In this application, heating the BioMetal wire with an electrical current causes the inner tube to be pulled part way into the outer tube. A compression spring provides the needed bias force and returns the actuator to its normal position when the BioMetal wire is once again at ambient temperature.

An interesting three-movement flexor that produces remarkably lifelike movements is illustrated in Fig. 8. This device is made by threading a loop of BioMetal wire through two holes in a silicone tube. An ordinary copper wire is then threaded through a third hole in the tube and is wrapped around the loop at the center of the BioMetal wire. Applying a current between the copper wire and one end of the BioMetal wire causes the flexor to move to the left or the right. The flexor moves backward when a current is applied to both ends of the BioMetal wire.

BioMetal Wire Drivers

A BioMetal wire can be caused to contract simply by briefly connecting a 1.5-volt penlight cell across its ends. If power is applied for too long a time, however, the wire will overheat and possibly suffer damage. Therefore, it is best to use some form of regulated driver in BioMetal applications.

Many different methods are available for driving BioMetal wire by electronic means. For example, a power-supply chip whose output is connected across a wire can be gated on and off. Or the switching contacts of an electromechanical relay can be connected between the BioMetal wire and a power source. The relay's coil can then be actuated at any desired interval and duration by means of a simple transistor oscillator.

In the circuits to be described, current is switched through a BioMetal wire by means of a common 2N2222 switching transistor. In each case, the transistor is controlled by an equally common 555 timer IC. The transistor is rated for an

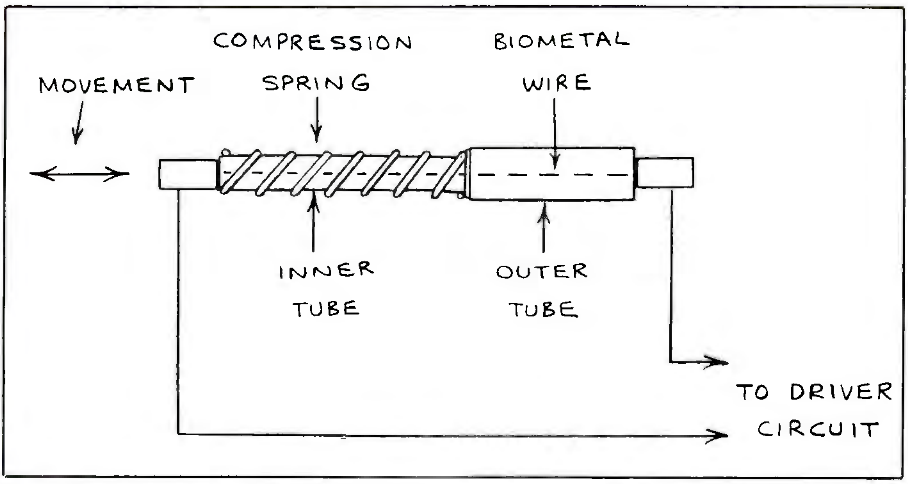


Fig. 7. Compression or piston actuator.

absolute maximum collector current of 800 milliamperes and absolute maximum output power of 400 milliwatts. Therefore, it will work well in each of the following circuits. For driver applications in which the BioMetal wire is heated for longer periods than by the circuits given below, it might be necessary to place a heat sink on the switching transistor or to use a power transistor. However, it's

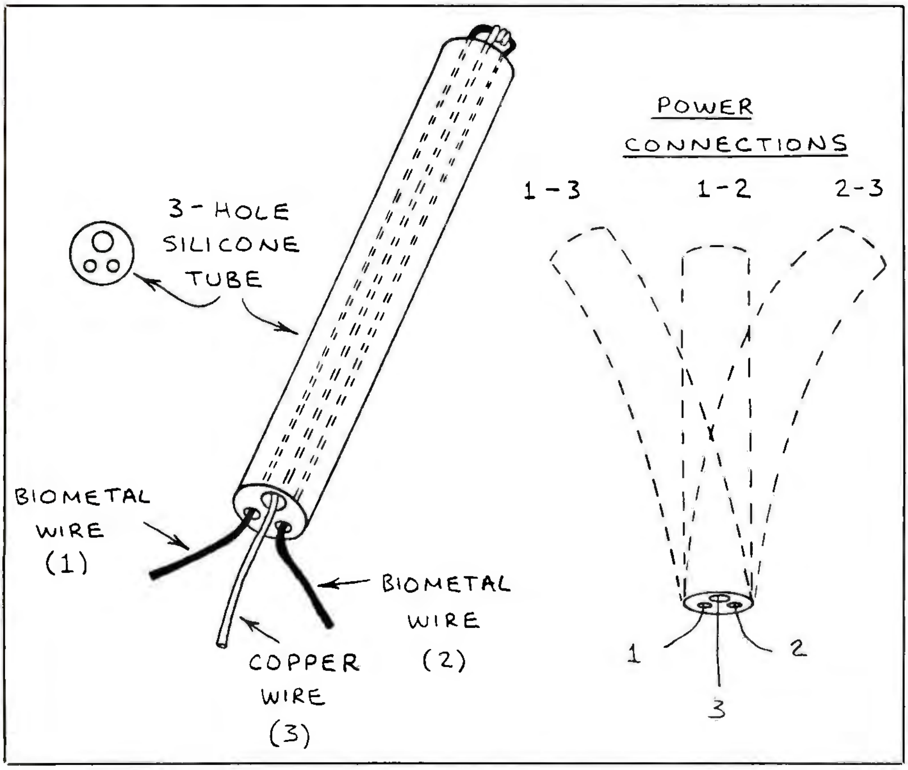


Fig. 8. Three-movement flexor.

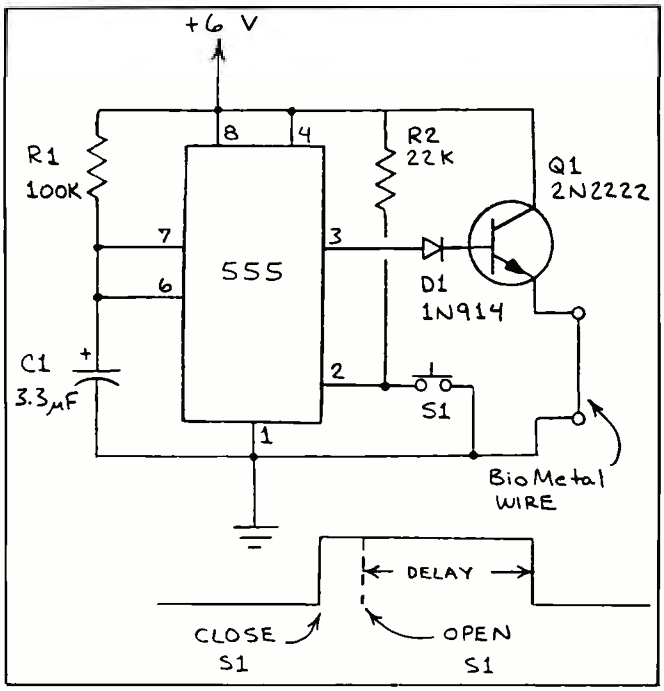
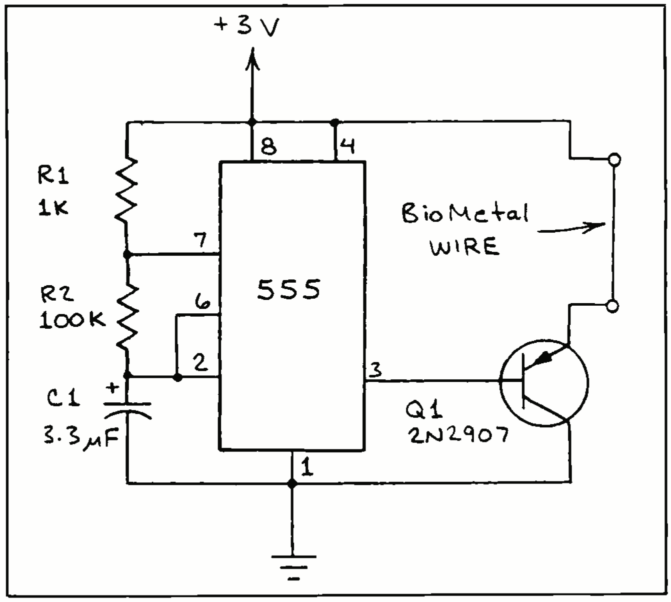


Fig. 9. Single-pulse BioMetal wire driver.

Fig. 10. Oscillating BioMetal wire driver.



likely that the BioMetal wire is being overdriven if the switching transistor becomes too hot.

When experimenting with the following circuits, it's good practice to use the same piece of BioMetal wire with each circuit, to permit the effect of each circuit to be compared with the others. The simplest approach is to install the BioMetal wire and biasing spring on a substrate, as shown in Fig. 4 or Fig. 5. Movements of the wire can then be easily seen.

Single-Pulse Driver

Figure 9 is the schematic diagram for a monostable multivibrator that delivers a single current pulse of fixed duration to a length of BioMetal wire. Ordinarily, the output of a 555 timer is low. In turn, this keeps *Q1* switched off. Closing and then releasing *S1* causes the output of the 555 to go high. This switches on *Q1* and permits current to flow through the BioMetal wire. When the charge on *C1* reaches approximately 4 volts, the output of the 555 goes low and switches off *Q1*.

The length of the output pulse from this circuit is controlled by *R1* and *C1*. With the values shown in Fig. 9, the pulse duration is approximately 100 milliseconds *plus* the length of time *S1* is closed. Therefore, for uniform results, keep *S1* closed for as brief an interval as possible.

The amplitude of the current through the BioMetal wire is approximately 460 milliamperes. Less current will cause less contraction of the wire. Current can be reduced by reducing the power-supply voltage or by inserting a small series resistance between the BioMetal wire and the emitter of *Q1*. For example, inserting a pair of parallel-connected 10-ohm resistors will reduce the current to around 300 milliamperes.

Oscillating Driver

Space Wings, a product of Mondo-Tronics, is a novel device that automatically flaps a pair of Mylar wings up and down approximately seven times a minute. The wings are moved by a short length of BioMetal wire installed across the hinge between them.

Figure 10 is the Space Wings driver circuit's schematic diagram. The circuit switches on and off *Q1* with a duty cycle of about 50 percent. The frequency of the pulses applied to the BioMetal wire can be increased by reducing the value of *R1* or *C1*. However, this will reduce the time for the BioMetal wire to cool between driving pulses. Consequently, the wire may remain warm between pulses and may not move as much as when it is allowed to return to room temperature before another pulse is applied.

Pulse-duration modulation provides an effective means for controlling the temperature of a BioMetal wire. Figure 11 shows a circuit that applies bursts of pulse-duration modulated pulses at a duty cycle of about 50 percent.

Like the circuit shown in Fig. 10, that shown in Fig. 11 will cause a length of BioMetal wire to alternately contract and resume its normal length. Unlike the Fig. 10 circuit, however, the Fig. 11 circuit permits the magnitude of the movement of the wire to be controlled merely by adjusting the width of the current pulses sent through it during each burst.

In operation, one of the timers in a 556

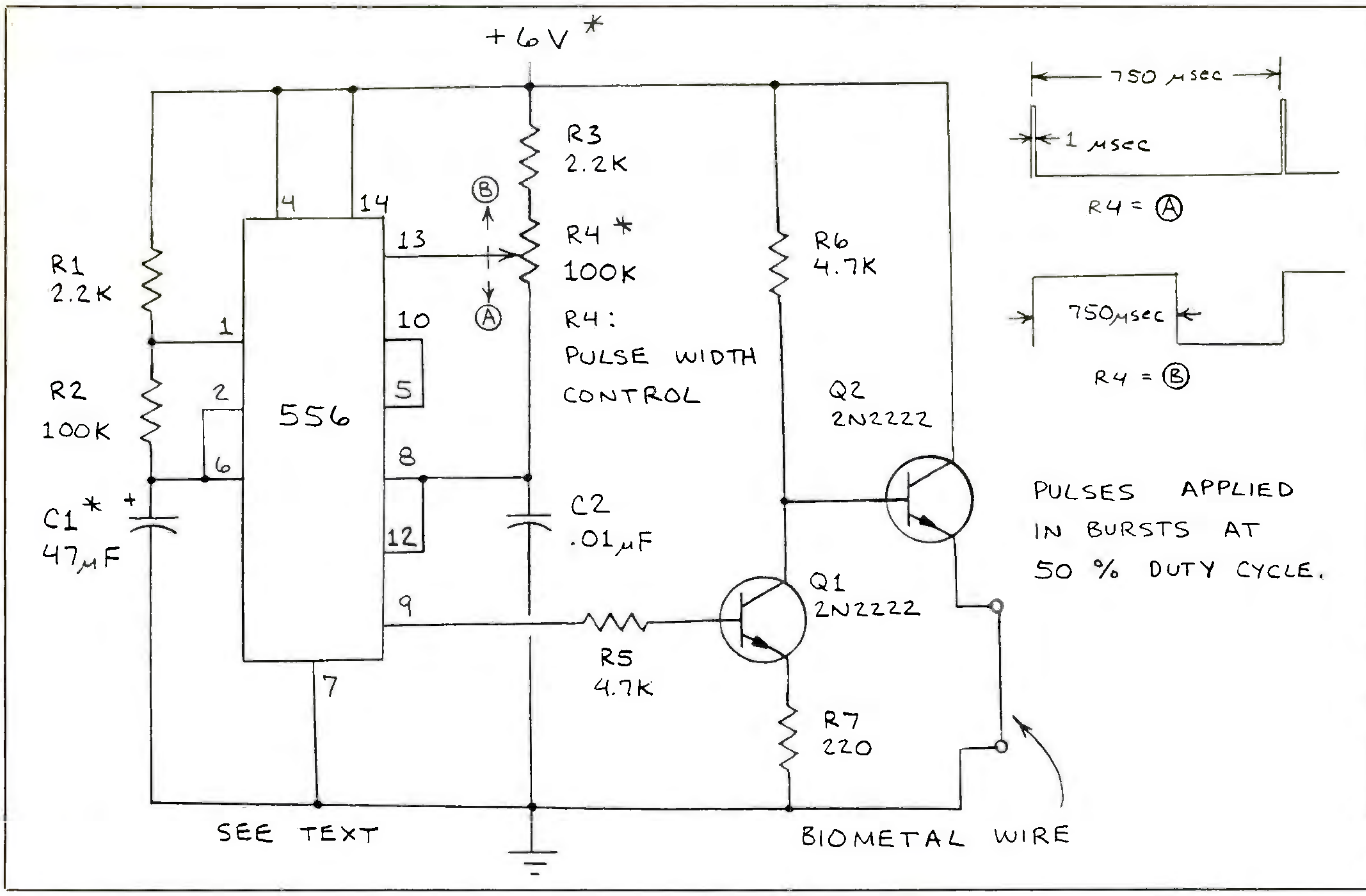


Fig. 11. A pulse-width-modulated BioMetal driver.

is connected as a free-running oscillator whose pulse duration is controlled by the setting of potentiometer *R4*. This timer will be referred to as "timer 2." With the component values given in Fig. 11, the duration of the individual pulses delivered by timer 2 can be varied over a range from 1 to 750 microseconds. The time between the onset of two successive pulses remains approximately 750 microseconds for any setting of *R4*.

The remaining timer in the 556, timer 1, is connected as an oscillator that repeatedly switches on and off timer 2 at a duty cycle of approximately 50 percent. This is accomplished by connecting timer 1's output (pin 5) to timer 2's reset terminal (pin 10). With the values given in Fig. 11, timer 1 switches timer 2 on for about 2 seconds, followed by a similar off period. The off/on time can be increased by making the value of *C1* larger.

The BioMetal wire is connected to the output from timer 2 through *Q1* and *Q2*. Transistor *Q1* inverts the output pulses from timer 2 and then toggles transistor *Q2* at timer 2's oscillating frequency. Transistor *Q2* then delivers current pulses through the BioMetal wire.

Going Further

Applications for shape-memory alloy wire, such as BioMetal wire, are virtually unlimited. It's an area ripe for exploitation by experimenters and garage inventors, as well as industry. Only small quantities of BioMetal wire are required to make functional devices, and many kinds of driver circuits can be designed.

The best way to begin experimenting with BioMetal is to purchase one of the TokiAmerica Technologies kits. For more information about these kits, write to the company at the address given above. Be sure to order the firm's "BioMetal Guidebook" when you do. This excellent manual describes in detail the characteristics of BioMetal wire. It also expands on most of the simple demonstrations and experiments presented here. And it describes some simple robotic devices and applications for BioMetal.

Perhaps some of the applications for BioMetal I am exploring will give you ideas for going further. They include a parachute ejection device for model rockets, a camera shutter tripper, a scanning mirror and a flap actuator for radio-controlled aircraft. **ME**