EXPERIMENTER'S CORNER

By Forrest M. Mims

Experimenting With a Servomechanism

A SERVOMECHANISM is an automatic control system. The word servo comes from the Latin *servus,* which means *slave.* The terminology is accurate, for under the proper conditions a servo (to use the normal short form) is totally obedient to any control or input signals applied to it.

In operation, a servo develops an output signal that is continually compared to the input signal. Any difference or error between the two signals is fed back to the input, thus causing the output signal to move toward and eventually match the input signal.

The feedback loop is shown in Fig. 1. This simplified diagram illustrates the operation of servos that are entirely electronic, such as phase-locked loops, and those that incorporate electromechanical devices, such as motors or solenoids.

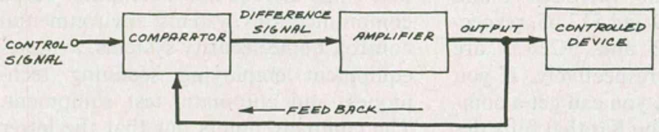

Fig. 1. A basic closed-loop servomechanism.

Previous installments of "Experimenter's Corner" have covered the operation and use of various kinds of phase-locked loops. See, for example, the installments of July and August of 1980. If you cannot find these issues of POPULAR ELECTRONICS at a library, both of the columns cited above are scheduled to be published by McGraw-Hill in *The Forrest Mims Circuit Scrapbook.* You may also want to refer to Howard Berlin's excellent book *Design of Phase-Locked Loop Circuits, With Experiments* (Howard W. Sams & Co., Inc., 1978).

The servos discussed in this column are electromechanical. Considering the increasing interest in robotics, radio control, and computer control, electronics experimenters should be fully aware of the operation and capabilities of such servomechanisms.

The Electromechanical Servo. Many kinds of electromechanical servomechanisms exist. Most incorporate a motor, a comparator, and a position-sensing transducer connected as shown in Fig. 2. In this figure, the input voltage is provided by one potentiometer of a two-axis joystick. The position-sensing transducer is a potentiometer whose wiper arm is rotated by the motor's armature. Both potentiometers are connected as voltage dividers.

To understand the operation of this servo, assume the voltages applied to both inputs of the comparator are equal. The output of the comparator will then be low and the motor will be off. When the joystick is moved so that the voltage applied to the noninverting input of the comparator exceeds the voltage from the position-sensing potentiometer, the comparator output will be high and the motor will be activated. This will cause the position-sensing potentiometer to deliver a progressively higher voltage.

When the two voltages are again equal or when the voltage from the position-sensing potentiometer is slightly higher than that from the joystick, the comparator will switch off and the motor will cease rotation. The end result is that the motor has *tracked* the position of the joystick. In other words, the physical movement of the motor's armature is directly proportional to the movement of the joystick.

The simple servo shown in Fig. 2 is not suitable for most practical applications since no provision is made for reversing the motor. Motor reversal can be achieved under mechanical control by using the dpdt switch arrangement shown in Fig. 3.

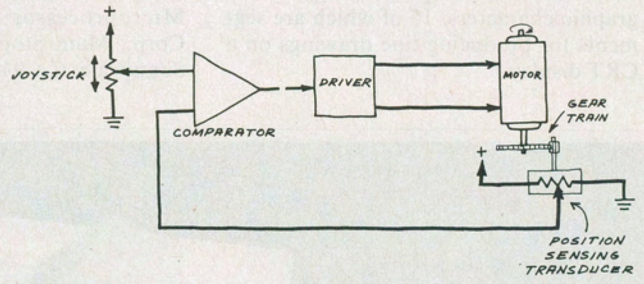

Fig. 3. Double-pole double-throw motor reverser.

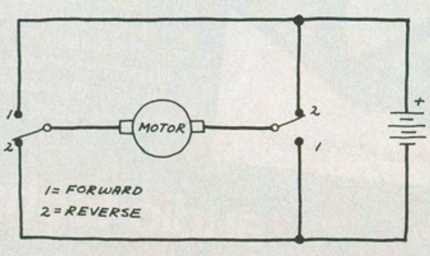

Fig. 2. Components of an electromechanical servo.

Forward-reverse operation can also be achieved by substituting transistors for the switches, as in Fig. 4. The circuit in Fig. 4 is actually the motor-driver portion of Signetics' NE544 Servo Amplifier, a chip designed specifically for controlling a dc servo motor.

Integrated Servo Amplifiers. The input to an NE544 and similar servo-amplifier chips is a train of variable-duration pulses. The output signal causes a small dc motor to rotate in proportion to the average duration of the incoming pulses. Pulse-duration (or width) modulation is used because it makes it easy to transmit signals via radio or infrared for remote-control applications. Even though this method is not a true digital-control system, it's commonly referred to as digital proportional control.

Figure 5 is a block diagram and connection network for the

Signetics NE543 Servo Amplifier. In operation, pulse-duration-modulated pulses from a receiver are applied to the input. If the pulse duration *exceeds* that of an internally generated pulse, the difference is stretched and applied to the appropriate output stage. This causes the motor to rotate the wiper of feedback potentiometer *R3*. The resistance of *R3* governs the duration of the internally generated pulses. When *R3*'s value has been altered so that the duration of the internally generated pulses matches that of the incoming pulses, the motor is deactivated.

If the duration of the incoming pulses is *less* than that of the internally generated pulses, then the difference is stretched and applied to the output stage that rotates the motor in the opposite direction. When the value of *R3* causes the duration of the

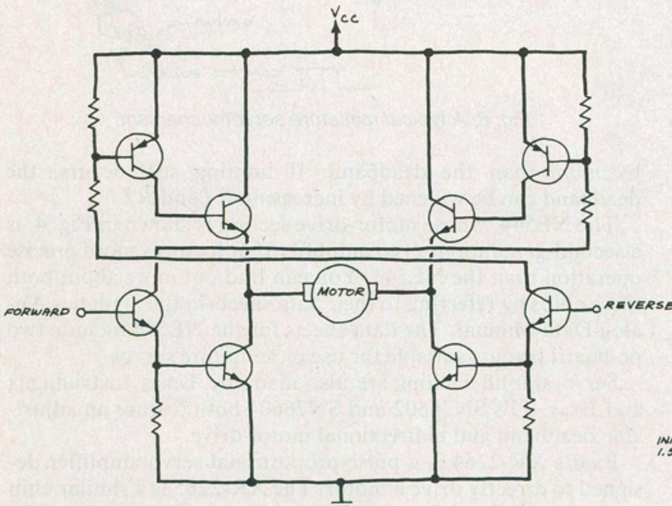

Fig. 4. Motor control circuit in Signetics NE544.

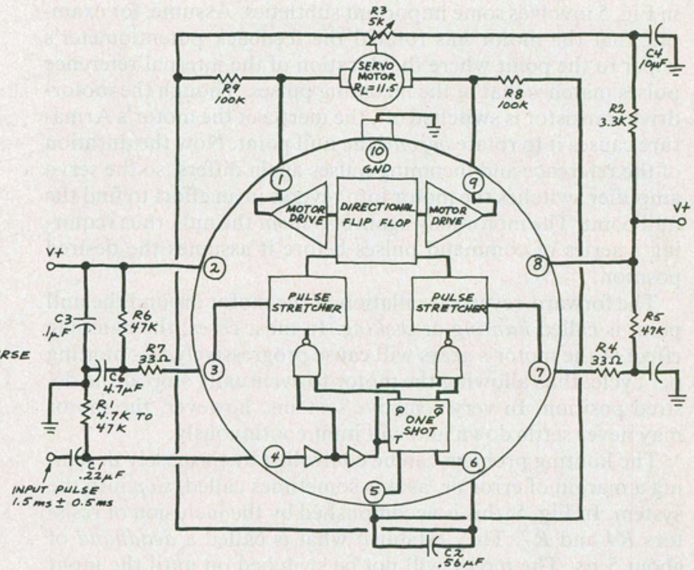

Fig. 5. Block diagram of NE543 servo amplifier.

internally generated pulses to match the incoming pulse duration, the motor is deactivated.

The net result of this feedback operation is that the motor armature position follows the duration of the input pulse. If the input pulses are received from a transmitter in which the duration of pulses is controlled by the position of a joystick, the armature position accurately tracks the joystick position, even though the two are separated by a considerable distance.

The successful operation of a servo amplifier such as the one in Fig. 5 involves some important subtleties. Assume, for example, that the motor has rotated the feedback potentiometer's wiper to the point where the duration of the internal reference pulses matches that of the incoming pulses. Though the motor-drive transistor is switched off, the inertia of the motor's Armature causes it to rotate *beyond* the null point. Now the duration of the reference and incoming pulses again differs, so the servo amplifier switches the motor into reverse in an effort to find the null point. The motor may again *overshoot* the null, thus requiring a series of command pulses before it assumes the desired position.

The forward-reverse oscillation of the motor around the null point is called *hunting* or *seeking*. In most cases, the damping effect of the motor's gears will cause progressively less hunting per cycle, thus allowing the motor to eventually stop at the desired position. In very sensitive systems, however, the motor may never settle down and will hunt continuously.

The hunting problem can be controlled by purposely designing a margin of error or, as it is sometimes called, *slop* into the system. In Fig. 5, this is accomplished by the inclusion of resistors *R4* and *R7*. They establish what is called a *deadband* of about 5 μs. The motor will not be switched on until the input pulse duration differs from that of the internal reference pulses

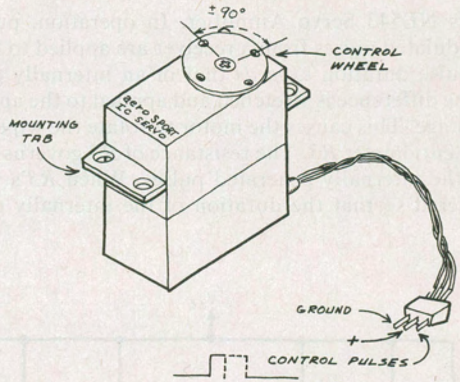

Fig. 6. A typical miniature servomechanism.

by *more* than the deadband. If hunting still occurs, the deadband can be widened by increasing *R4* and *R7*.

The NE544, whose motor-drive section is shown in Fig. 4, is a second-generation servo amplifier that features more precise operation than the NE543. You can find out more about both these chips by referring to their data sheets in the Signetics Analog Data Manual. The data sheets for the NE544 include two pc-board layouts suitable for use in miniature servos.

Servo amplifier chips are also made by Texas Instruments and Exar. TI's SN76602 and SN76604 both feature an adjustable deadband and bidirectional motor drive.

Exar's XR-2264 is a pulse-proportional servo amplifier designed to directly drive a motor. The XR-2265 is a similar chip designed to drive relays, optical couplers, and triacs. The XR-2266 is designed specifically to provide two control channels for radio-controlled cars. One channel controls the direction and speed of travel. The second controls the steering. The direction/speed control channel can also directly drive a pair of back-up lights to provide another degree of realism.

Experimenting With a Servo. Though it's possible to assemble a servomechanism from scratch, you can buy many different preassembled servos ranging in price from about $12 to $50 from suppliers of radio-controlled cars, boats, and planes. Nearly all these servos are installed in tough plastic cases no larger than two side-by-side 9-V batteries.

A typical inexpensive servo is shown in Fig. 6. For a device of such compact size and relatively low price (around $20), it is quite sophisticated. Typically, it contains a high-quality miniature motor coupled to a train of three or four reduction gears. The feedback potentiometer is mechanically coupled to the gear train. The electronics are installed on a small circuit board adjacent to the motor and below the gear train. The axle of the output gear passes through a bushing or ball-bearing assembly in the top of the servo case. Various wheels and arms can be attached to the axle by means of a small screw.

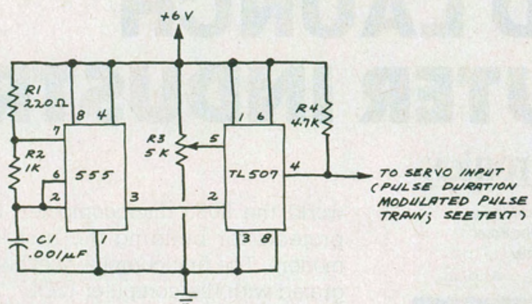

Fig. 7. Pulse-duration modulator for miniature servo.

A servo like the one in Fig. 6 weighs about 1.25 to 2 ounces and can deliver several *pounds* of thrust. It can travel through its rotational limit of 90 degrees in about half a second. Typical no-load current is around 80 mA, and stall current is approximately 450 mA.

Figure 7 is a simple variable-pulse-duration pulse generator I've used to drive an Aero Sport GS-ICR Servo. This servo, which is typical of those used in radio-controlled cars, boats and planes, responds to a pulse duration of from 1 to 2 ms. The servo is at its center (neutral) position when the incoming pulse has a duration of 1.5 ms. At 6V, it consumes around 25 mA at idle and around 80 mA when travelling. Its stall current is around 250 mA.

Resistor *R3* in Fig. 7 can be a potentiometer in a joystick assembly or a standard potentiometer. It can even be a variable-resistance transducer to give a mechanical movement in response to some environmental change. For example, a fixed resistor in series with a pair of electrodes inserted into soil will provide a transducer that gives a voltage output dependent upon soil moisture content. The servo to which this transducer is connected could open and close a small water valve to keep the soil moisture at any desired level.

Applications for Servo. By now you've probably thought of several applications for servomechanisms in addition to those mentioned thus far. Servos are used in remote-controlled television cameras, self-focusing film cameras, toys, industrial robots, and military hardware. ◇