A VERSATILE REMOTE CONTROLLER

Adding remote control to any circuit or device is not as hard as you might think. This article shows you how its done.

J. DANIEL GIFFORD

THE DREAM OF ADDING REMOTE CONTROL to appliances, gadgets, and projects is an old one in electronics. But because of the complexities involved, it is one that has been beyond the skills of many hobbyists. Now, as in so many other areas of electronics, *L*arge *S*cale *I*ntegration (LSI) IC's have come to the experimenter's rescue.

The Motorola MC14457 remote control transmitter and MC14458 remote control receiver IC's, by themselves, form almost 90% of a high-quality infrared or ultrasonic remote-control system that is capable of handling up to 272 commands. Although the IC set was developed for television remote use, and has some special pin functions for that purpose, it is highly flexible and can be used for a myriad of remote-control needs ranging from controlling TV and stereo gear, to remote arming of security systems, to remote programming of computers and robots.

The remote-control system

The MC14457 IC (see Fig. 1) needs only a keyboard, oscillator, output device, and battery to form a complete remote-control transmitter. Similarly, the MC14458 receiver (also shown in Fig. 1) needs only a power supply, input circuit, and oscillator to function. Both devices are CMOS, and thus require only a minimal amount of supply current.

The transmitter does not have or need an on/off switch. When a button on the keyboard is pressed, the clock oscillator starts up, the key is decoded, and the correct seven-bit data stream is transmitted via either an array of IR LED's or an ultrasonic transducer. Four of the transmitted bits are actually either data or a command; a fifth "function" bit lets the receiver know the nature of those bits (the function bit is not externally available). Two start bits are added to synchronize the transmission with the receiver. Table 1 shows the 32 possible keys, their codes, and their row/column location.

The data is transmitted in FSK (*F*requency *S*hift *K*eying) format, using two frequencies divided down from the 500 kHz control clock—38.46 and 41.66 kHz. That FSK transmission, other than using much higher frequencies, is similar in operation to the encoding process used by computer modems.

The 14458 receives the transmitted data through either a photodiode or an ultrasonic transducer, After the signal is amplified and conditioned, the receiver IC decodes it from its FSK form and, according to the state of the function bit, routes it to either the data or the command port.

If the function bit is a Ø, the four bits are read as data and are routed to the data port. The data port is two digits wide (each digit is made up of eight bits), and can be configured to accept either one or two digits as a full data word. After a full word is transmitted, a pulse appears on the data available (DA) pin. The data can be either BCD or hexadecimal in format, depending on the number of keys used in the transmitter, so data words from ØØ to 99 (Ø to 9 in single digit mode) or ØØ–FF (Ø–F) can be transmitted to the data port.

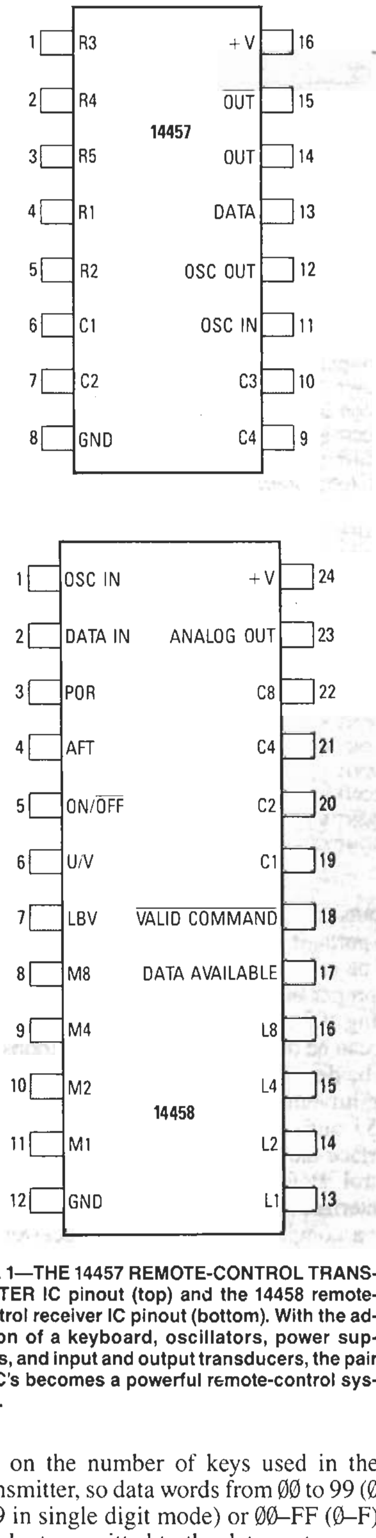

FIG. 1—THE 14457 REMOTE-CONTROL TRANSMITTER IC pinout (top) and the 14458 remote-control receiver IC pinout (bottom). With the addition of a keyboard, oscillators, power supplies, and input and output transducers, the pair of IC's becomes a powerful remote-control system.

If the function bit is a 1 instead of a Ø, the four data bits are read as a command, and are routed to the command port. A received command is latched into the 4-bit port, after which a pulse appears on the valid command ($\overline{\text{VC}}$) pin. Of the commands, four are internally decoded by the 14458, and twelve require external decoding to be useful.

With 256 data words and 16 commands, plus other specialized single-pin

TABLE 1—4457/4458 COMMAND ENCODING

Key	Row	Column	FB	C8	C4	C2	C1	$\overline{VC}$ Pulse
0	1	1	Ø	Ø	Ø	Ø	Ø	
1	1	2	Ø	Ø	Ø	Ø	1	
2	2	1	Ø	Ø	Ø	1	Ø	
3	2	2	Ø	Ø	Ø	1	1	
4	3	1	Ø	Ø	1	Ø	Ø	
5	3	2	Ø	Ø	1	Ø	1	
6	4	1	Ø	Ø	1	1	Ø	
7	4	2	Ø	Ø	1	1	1	
8	5	1	Ø	1	Ø	Ø	Ø	
9	5	2	Ø	1	Ø	Ø	1	
TOGGLE 1	1	3	1	Ø	Ø	Ø	Ø	X
TOGGLE 2	1	4	1	Ø	Ø	Ø	1	X
CONT 1	2	3	1	Ø	Ø	1	Ø	X
CONT 2	2	4	1	Ø	Ø	1	1	X
CONT 3	3	3	1	Ø	1	Ø	Ø	X
CONT 4	3	4	1	Ø	1	Ø	1	X
ANALOG DOWN	4	3	1	Ø	1	1	Ø	X
ANALOG UP	4	4	1	Ø	1	1	1	X
MUTE	5	3	1	1	Ø	Ø	Ø	X
OFF	5	4	1	1	Ø	Ø	1	X
A	2/5	1	Ø	1	Ø	1	Ø	
B	2/5	2	Ø	1	Ø	1	1	
C	3/5	1	Ø	1	1	Ø	Ø	
D	3/5	2	Ø	1	1	Ø	1	
E	2/3/5	1	Ø	1	1	1	Ø	
F	2/3/5	2	Ø	1	1	1	1	
CONT 5	2/5	3	1	1	Ø	1	Ø	X
CONT 6	2/5	4	1	1	Ø	1	1	X
CONT 7	3/5	3	1	1	1	Ø	Ø	X
CONT 8	3/5	4	1	1	1	Ø	1	X
CONT 9	2/3/5	3	1	1	1	1	Ø	X
CONT 10	2/3/5	4	1	1	1	1	1	X

outputs controlled by the data sent to the two ports, it's easy to see how that IC set can be used in dozens of different ways. By proper use of the data and proper decoding of the commands, almost anything that can be done with switches and knobs can be done over an invisible beam. The only limitation on the usefulness of the 14457 and 14458 is how well you can interface the receiver to the device under control. Before we get into the problems of interfacing and decoding, let's look at how a complete transmitter and receiver are built.

The transmitter

Since the 14457 is CMOS, it draws almost no supply current by itself. However, the clock oscillator and the output device are another story—the current drawn by both would normally make battery power impractical. However, the 14457 is designed to shut down the oscillator when it is not needed and the output circuitry draws power only when transmitting, which takes 0.1 seconds per data stream. Those features make both battery power and the lack of an on/off switch completely practical.

Being CMOS, the 14457 can operate from a supply voltage between 5 and 12 volts. The voltage and type of battery used will depend on the type of output. Since the ultrasonic type needs a higher voltage but much less current than the IR type, an ordinary 9-volt transistor battery can be used for power. The array of IR LED's, on the other hand, need a substantial amount of supply current, so four "AA" or "AAA" cells in series (for a total of 6 volts) should be used. In both Figs. 2 and 3, note that a diode is used to prevent damage to the IC from reversed battery connections and a 50-μF capacitor is used to filter transients from the supply line; those components should not be omitted.

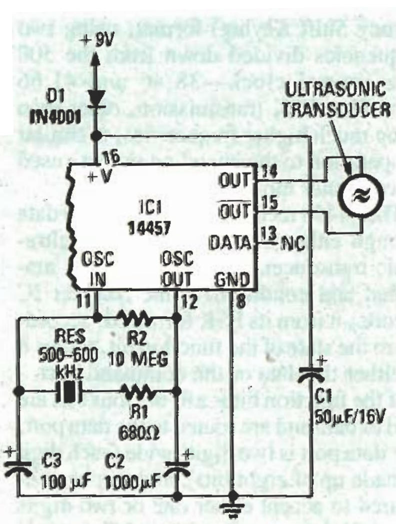

FIG. 2—THE BASIC CONNECTIONS for the transmitter oscillator. Note that this circuit uses an ultrasonic output.

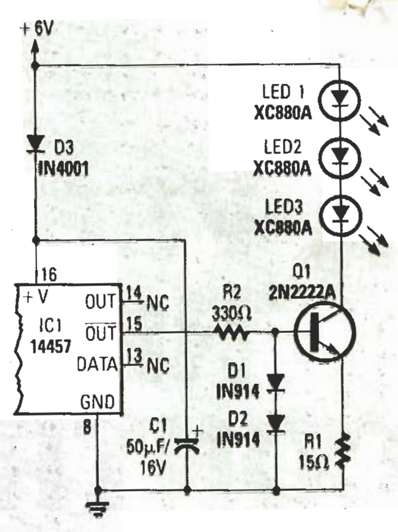

FIG. 3—THE OUTPUT CIRCUIT for an infrared transmitter.

The 14457 has an on-board oscillator circuit; the only external parts required are the frequency-determining components. Both the 14457 and 14458 require an identical control frequency of about 500 kHz. Instead of using a crystal to maintain the frequency, both units use a much cheaper, smaller, and more durable ceramic resonator. While ceramic resonators are less precise than crystals, they are more than accurate enough for many uses, this one included. The exact frequency of the resonators used is not important, as long as they are identical and of about the frequency specified. Suitable resonators are available from the source provided on page 67 (Ordering Information).

The ceramic resonator is used in exactly the same manner as a crystal (Fig. 2), requiring a tank circuit around it to force it to oscillate at the correct frequency. High-Q disc capacitors and metal-film resistors should be used in the tank circuit to promote stability. Note that the 14457 disables the oscillator by clamping pin 11 (OSC IN) to ground.

The output circuit of the ultrasonic transmitter is simpler than that of the IR type and requires no circuitry in addition to the ultrasonic transducer itself. The 14457 uses complementary push-pull outputs to generate a strong, balanced drive signal across the transducer.

The IR output uses only one of the two outputs, since a driver transistor is needed to provide sufficient current to the LED array. Three infrared LED's are used to increase the range of the transmitter. High-output LED's such as XC880A's or TIL906-1's should be used.

There is no real difference in performance or range between the two types of output. The IR output is decidedly cheaper, since a pair of ultrasonic transducers can cost $25.00 or more, and the parts are more widely available. On the other hand, the IR beam is limited to line-of-sight

Ordering Information

The following are available from Circuit Specialists, PO Box 3047, Scottsdale, AZ 85257: 14457/14458 transmitter/receiver pair, $17.00 postpaid; 455-kHz ceramic resonator (Mallory CU455), $8.50 each, postpaid.

operation, while the ultrasonic signal can bend around corners and other obstacles. In general, the IR type is recommended for hobbyist use.

Besides the push-pull transmitting outputs, the 14457 has another output, the DATA output, that can be used to give a visual indication of transmission. It follows the unencoded binary data used to modulate the FSK transmission. If a driver circuit and LED like that in Fig. 4 are added, the LED will flicker briefly each time data is transmitted. That load will contribute slightly to battery drain, but since it is impossible to see infrared or hear ultrasonics, the feedback of a visual transmission signal could be valuable.

The most difficult part of building the transmitter is the construction of the keyboard. The 14457 has four column and five row inputs, each with its own internal pull-up resistor. To transmit a data digit or command, one column and one (or more) rows must be simultaneously shorted to ground. The problem is that only one type of row-to-column-to-ground keyboard is commonly available, and it is for telephone use, and it has the familiar 12-button pattern. Since that type of keyboard is expensive and difficult to modify to the circuit needed here, it is not practical.

Fortunately, there is an alternative. The ordinary row-to-column type of matrix keyboard may be used with an array of NPN transistors to provide a path to ground. That allows use of the common, inexpensive membrane-type keyboard like that found in many calculators. The NPN transistors may be discrete 2N2222/2N3904 types, or a DIP array such as the CA3046/3086.

Actually, any type of SPST normally open switches could be used to build a keyboard, with one connection of each switch going to the correct row and the other going to the correct column. Although that type of keyboard will be more expensive and much larger than the membrane type, the keys can be laid out in any desired pattern.

The 14457 allows the use of up to 32 keys, 16 for the data digits Ø through F, and 16 for commands. Any of those keys and commands may be used independently, with or without any other keys. Also, any lesser part of the 32-key pattern can be used. Let's look at three such subpatterns, and the full 32-key version.

The simplest keyboard (Fig. 5) uses only 10 keys, those corresponding to the digits from Ø through 9. That pattern would be ideal for security system disarming, with the receiver input mounted behind a window or near a door. Note that the two unused column inputs are left unconnected; since they have internal pull-ups, no external disabling is required.

A somewhat more complex keyboard, the 20-key version (Fig. 6), is probably the best compromise between usefulness and too much complexity. That keyboard adds the following to the 10-key keyboard: OFF, ANALOG UP, ANALOG DOWN, MUTE, two uncommitted toggle-type commands, and four uncommitted continuous-type commands. (We'll talk about the command types in a moment.)

Since all of the available rows and col-

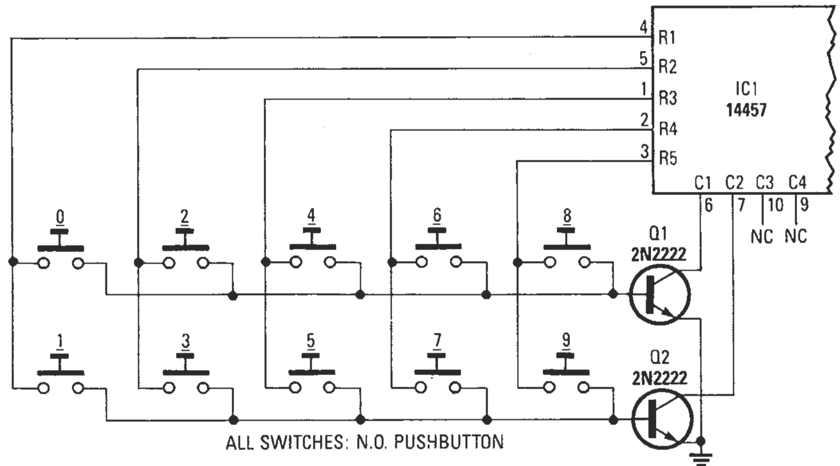

FIG. 5—THE 10-KEY keyboard. Each SPST normally-open switch shorts one row to one column. Note that the column 3 and 4 pins are left unconnected.

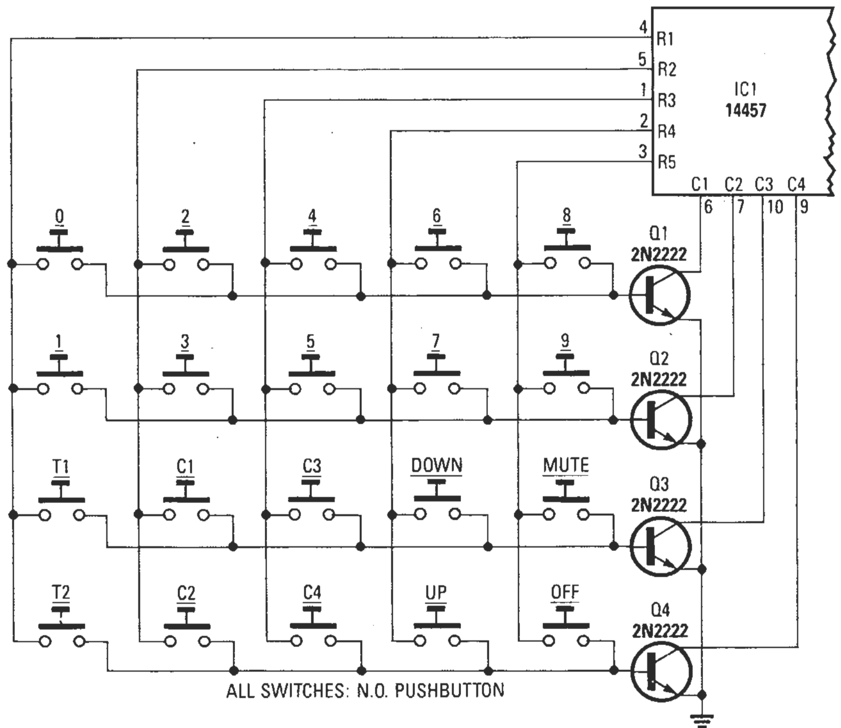

FIG. 6—THE 20-KEY keyboard. Either discrete transistors or an NPN IC array can be used.

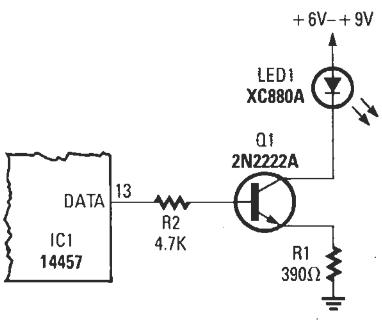

FIG. 4—THIS CIRCUIT can be added to give a visual indication of the transmitted signal.

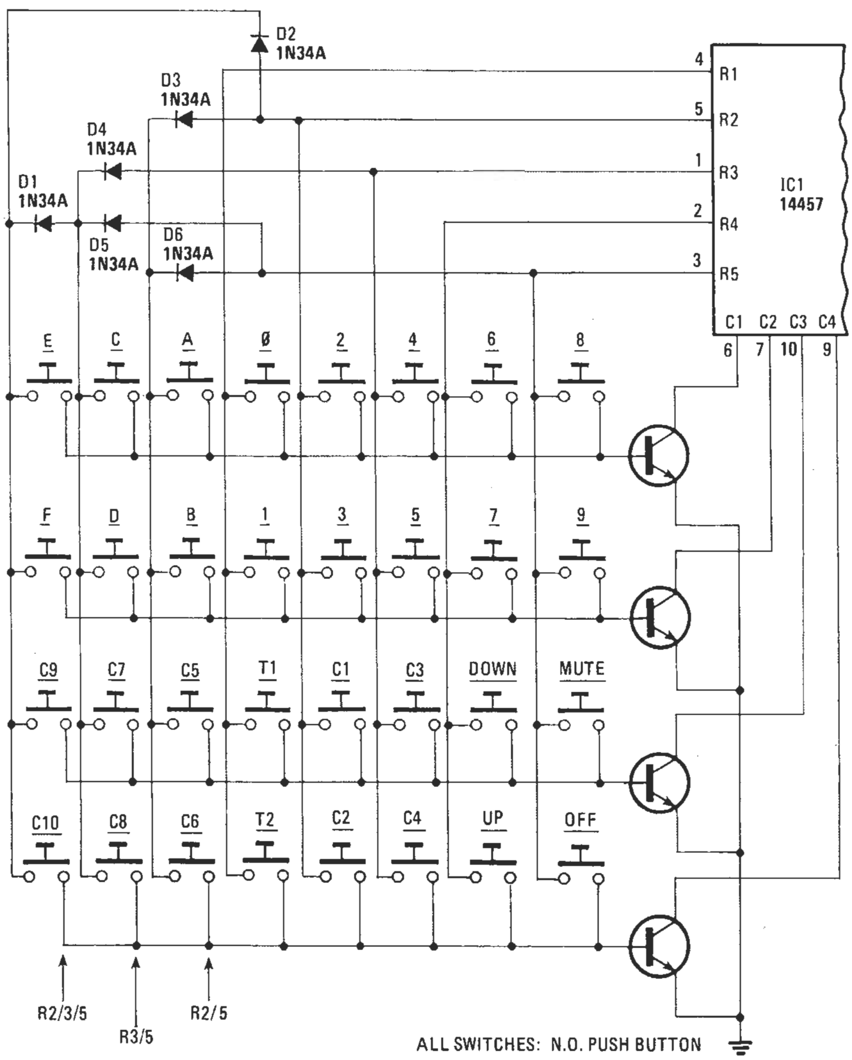

FIG. 7—THE 26/32-KEY keyboard. If the extra commands are not needed, switches C5–C10 can be deleted.

umns are used for the 20-key keyboard, three extra rows must be "synthesized" to access the remaining 12 commands. That is done by using an array of diodes (Fig. 7) to allow each of the new rows to short more than one of the existing rows to ground at the same time. The three new rows are labelled 2/5, 3/5, and 2/3/5, indicating the existing rows used to synthesize each.

If all 32 keys made accessible by adding those synthesized rows are used, six more continuous-type commands are available, along with the six hexadecimal digits A through F. If only access to the hex digits is desired, the six command keys can be deleted, leaving the 26-key keyboard. The only thing that determines whether BCD or hex data can be transmitted is whether or not the hex digit keys are available. If the 10- or 20-key keyboard is used, only BCD data may be sent; with the 26- and 32-key versions, either BCD or hex data can be transmitted.

The receiver

The receiver half of the remote-control system is slightly more complex. The 14458 requires a power supply between 5 and 6 volts, and thus can use a TTL power supply if one is available. If a voltage in that range is not available from the device being controlled, a higher voltage can be regulated down or a separate power supply added. Since the 14458 and it's outboard circuitry are CMOS, not more than 20–30 mA of supply current should be required.

The 14458 has three inputs, one for the incoming signal (DATA IN), one for the oscillator frequency (OSC IN), and one used for automatic power-on reset (POR). The POR input, pin 3, has an internal pull-up resistor and needs only a 0.22–0.47 μF capacitor between it and ground for operation. With such a capacitor in place, when power is applied to the 14458 all of its outputs and internal registers will be reset to 0.

The oscillator used in the 14458 (Fig. 8) is almost identical to that used in the transmitter, except that the receiver requires an external active element, a 4069UB inverter (the active element is internal on the 14457). The ceramic resonator used in the 14458's oscillator must be identical to that used in the transmitter.

The FSK signal is received, as described earlier, by either a photodiode or an ultrasonic transducer. The transducer can be directly connected to an amp input, but the photodiode requires a pull-up biasing resistor from 22K–220K, with the exact value determined experimentally once

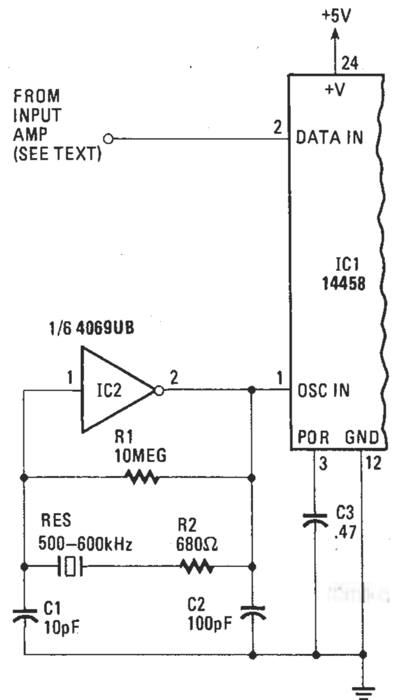

FIG. 8—THE BASIC CONNECTIONS for the receiver oscillator. For single digit operation, pin 9 (M4) would be tied to +5V, and pin 6 (U/V) would be grounded.

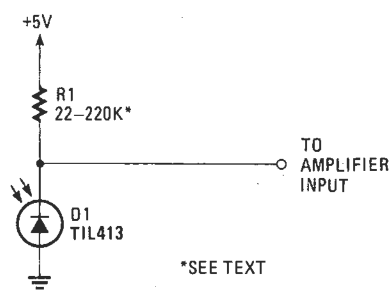

FIG. 9—FOR BEST SENSITIVITY and range, the value of the bias resistor, R1, must be determined experimentally.

the circuit is built (see Fig 9). That bias resistor controls the sensitivity and thus the pickup range of the photodiode. An infrared filter must be used in front of the photodiode to exclude ambient light and further increase its sensitivity. Although a piece of red plastic like that used for display filters can be used, a true IR filter will give better performance.

From the pickup, the signal is sent to an amplifier. We'll show you a suitable amplifier and finish things up. **R-E**

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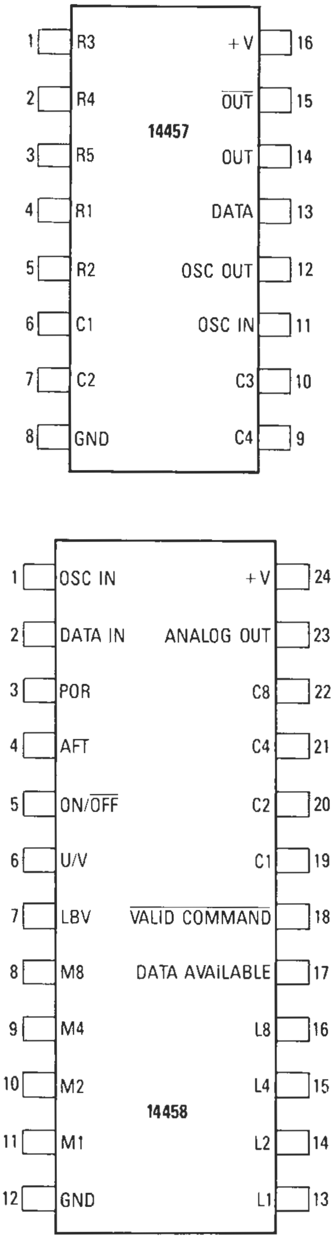

THESE TWO IC's form the heart of a versatile remote control system that can be added to almost any circuit or device.

Part 2 LAST TIME WE BEGAN to look at the receiver half of our remote-control system. Let's continue that discussion now.

The output from either the ultrasonic or infrared pickup must be amplified before being input to the 14458. One suitable amplifier design is shown in Fig. 10. That circuit takes the signal from either type of pickup, amplifies and conditions it, and clips its amplitude between 0 and 5 volts, producing at its output an exact duplicate of the signal applied to the transmitting LED's or transducer. Other amplifier designs could be used, as long as they have a high-impedance input and extremely high gain. However, the amplifier in Fig. 10 meets that requirement and uses some of the inverters already available.

As discussed earlier, the 14458 has two output ports, one eight-bit port for data, and one four-bit port for commands. The data port is actually two four-bit ports, one for the *M*ost *S*ignificant *D*igit (MSD) and composed of the outputs M1 through M8, and one for the *L*east *S*ignificant *D*igit (LSD), composed of the outputs L1 through L8.

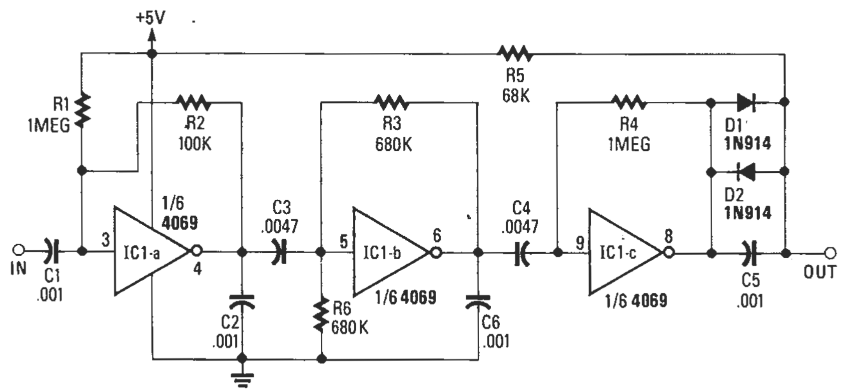

FIG. 10—THIS INPUT AMPLIFIER is ideal for use with the receiver. It can accept the output from either the infrared or ultrasonic pickup.

When data is transmitted, the first digit sent is routed to the MSD outputs, and the second digit to the LSD outputs. Both digits are latched in simultaneously and followed, after a 0.1 second delay, by a 0.8 millisecond positive pulse on pin 17 (DA). The data and the DA pulse may be used in any manner necessary.

Without any special connections, the 14458 is configured to receive two digits as a full data word. If desired, the receiver can be converted to accept a single digit as a full data word by connecting pin 9 (M4) to +V and pin 6 (U/V) to ground. In single-digit mode, the first data digit transmitted will be latched into the LSD outputs and followed by the DA pulse.

The command transmission situation is

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Also, the following are available from Dick Smith Electronics, PO Box 8021, Redwood City, CA 94063; telephone number 800-332-5373: Photodiode (catalog number Z-1950), $.60 plus shipping and handling; a matched pair (receive/transmit) of ultrasonic transducers (catalog numbers L-7050 and L-7052), $2.95 each plus shipping and handling. Note that this supplier requires a $10.00 minimum order.

somewhat more involved. If the function bit in the data stream is a 1, the four-bit code is identified as a command, and is routed to the command port. Once the digit is latched into the port, there is a 0.1-second delay and then a negative 0.8-millisecond pulse appears on the $\overline{\text{VC}}$ output, pin 18. All 16 commands and the $\overline{\text{VC}}$ pulse may be used as necessary; however, four of the commands are also internally decoded by the 14458 to control two specialized outputs.

When the key corresponding to command 09 or OFF is pressed, pin 5 on the 14458, ON/OFF, is driven low. That pin is also set low when the IC is powered up, and is driven high when any data word is transmitted. If the 14458's power supply remains uninterrupted, that pin can be used to turn the controlled device on and off. When the ON/OFF pin goes low or off, the rest of the 14458 goes into a standby mode, with commands being ignored until a data word is transmitted.

The other three commands decoded by the 14458 all control one output, pin 23,

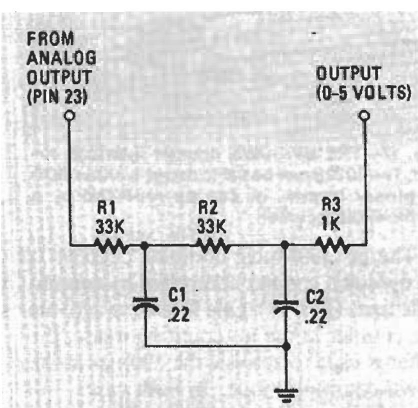


FIG. 11—THE LOW-PASS FILTER used to obtain a smooth DC signal from the ANALOG OUT output. An active filter and/or voltage follower can also be used.

ANALOG OUT. That output provides a variable voltage between 0 and 5, with a total of 64 steps between the two extremes. When the 14458 is powered up, the voltage is at 0. When the ANALOG UP KEY (command 07) is pressed, the voltage at the ANALOG OUT pin begins to step upwards at a rate of 10 steps per second, until the key is released or until the maximum of 5 volts is reached. The ANALOG DOWN key (command 06) operates in the opposite manner, stepping the voltage at the ANALOG OUT pin down at a rate of 10 steps/second until either the key is released or 0 volts is reached.

The MUTE key (command 08) when pressed once forces the ANALOG OUT voltage to 0, and when pressed again, returns it to its previous level. The ANALOG UP key will also return the voltage to its previous level and, if held down, continue to increase it.

The ANALOG OUT signal is pulse-width-modulated, and must be passed through a low-pass filter (Fig. 11) in order to obtain a smooth DC signal. If more than a few milliamps of output current are needed, an op-amp voltage follower should be added. The ANALOG OUT signal is intended to control a TV's volume, but can be used for any purpose.

There are two basic types of commands, toggle and continuous. The only difference between the two is that with the toggle type, the command is only sent once (with one $\overline{\text{VC}}$ pulse) no matter how long the key is held down, while with the continuous type, the command is retransmitted (each time with a $\overline{\text{VC}}$ pulse) every 0.1 seconds as long as the key is depressed. OFF and MUTE are examples of toggle-type commands; ANALOG UP and ANALOG DOWN are continuous types. There are twelve uncommitted commands, two of which are toggle-type and ten of which are continuous.

The 14458 also has three specialized outputs intended for TV control that are probably of little use otherwise. All three are controlled by the data sent to the data port.

Pins 6 (U/V) and 7 (LBV) are used to switch between tuners and bands in a TV set. When the data at the data port is between 14 and 83, the U/V pin will be high; it is low otherwise. If the data is between 02 and 06, the LBV will be low; it is high otherwise. When the data is between 7 and 13, both pins will be low.

The third specialized TV output is different in that it may have other uses. Pin 4 (AFT) is used to disable a TV's automatic fine tuning circuit briefly each time the channel is changed. Each time new data is entered into the data port, that output will

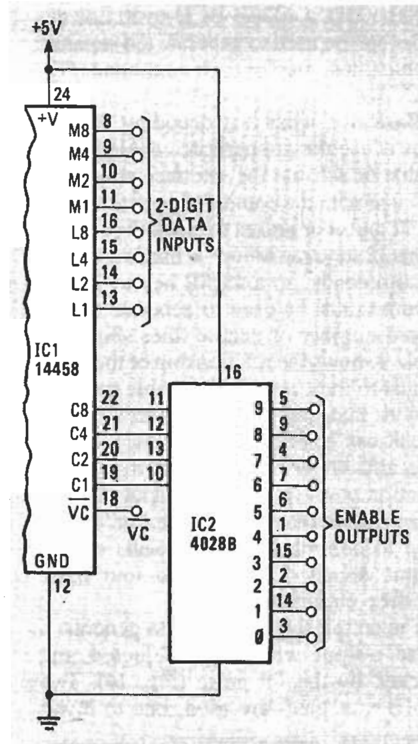


FIG. 12—THE OUTPUTS and decoding scheme for the receiver used in the 20- and 26-key systems. Each enable output is used to activate one output device.

drop low for 0.4 seconds. That could be used as an alternate to the DA pulse, or as a countering or resetting signal to it. The only problem is that four other commands (00, TOGGLE 1; 01, TOGGLE 2; 02, CONT 1; 03, CONT 2) also cause that pin to drop low, which could interfere with such reset functions.

Decoding and interfacing

The most difficult part of using a remote-control system built with the 14457 and 14458 is interfacing the receiver to the system under control. Since the idea here is not to tell you how to build a specific sort of remote-controlled device, we will not discuss specific sorts of interfacing. Instead, let's look at a universal system that can be used to decode the 14458's commands to control functions remotely. It is up to you to provide the final link between these decoders and the device you want to control.

If the 10-key transmitter is used, no decoding is needed as none of the commands are accessible. The only step necessary would be to interface the data port (either one or two digits) to the security system or other device. Note that although no direct OFF control is possible with that configuration, the OFF output can be driven high by transmitting any data word. The OFF output (and the 14458) could be reset by the controlled device by pulsing the POR input low.

With the 20- or 26- key transmitter, ten commands are available and must be decoded by external circuitry. Since the command codes fit the ten BCD digits (0000-1001), a 4028B BCD-to-10 line decoder can be used to generate ten separate enable lines, one for each command (Fig. 12).

Basically, what that decoding scheme does is use the appropriate enable line to enable or activate the interface circuit associated with the command, and then uses the $\overline{VC}$ pulse or pulses to clock the circuit. If the 32-key transmitter is used, there are 16 commands, so a 4514B hex-to-16 line decoder must be used to generate the required number of enable lines (Fig. 13). Table 2 shows the relationship of the commands to their respective enable lines.

With that basic approach, an interface circuit can be devised to interface the enable and $\overline{VC}$ lines to control the proper function on the controlled device. If necessary, more than one enable line can be used to control different aspects of one output device. Let's look at four basic interface circuit types.

The simplest type is used to generate a pulse output when it is selected and clocked by the $\overline{VC}$ pulse (Fig. 14). Two 4001B NOR gates are used, one to invert

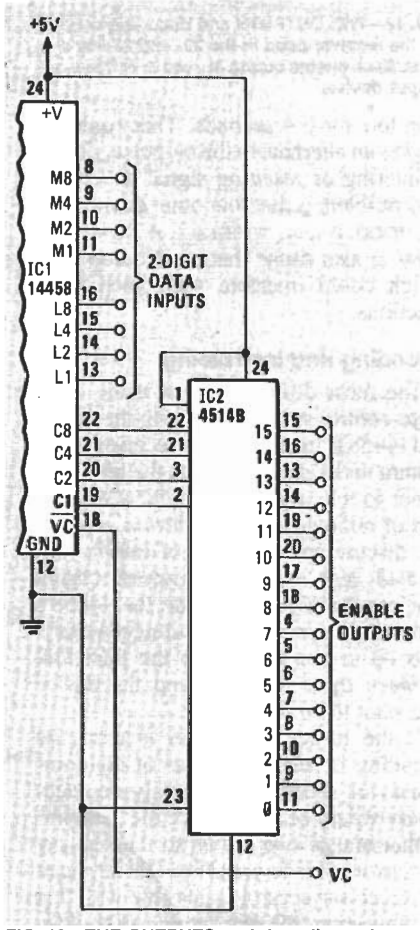


FIG. 13—THE OUTPUTS and decoding scheme for the 32 key system.

TABLE 2—ENABLE DECODER OUTPUTS

Output	Command
00	TOGGLE 1
01	TOGGLE 2
02	CONT 1
03	CONT 2
04	CONT 3
05	CONT 4
06	ANALOG DOWN*
07	ANALOG UP*
08	MUTE*
09	OFF*
10	CONT 5
11	CONT 6
12	CONT 7
13	CONT 8
14	CONT 9
15	CONT 10

*also internally decoded by the 4458

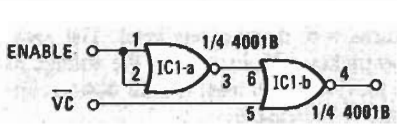


FIG. 14—THIS INTERFACE CIRCUIT outputs a pulse that can be used to control a device.

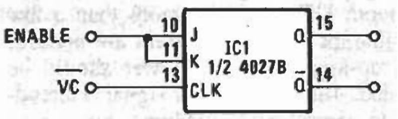


FIG. 15—THE ONE-BUTTON alternate-action interface circuit.

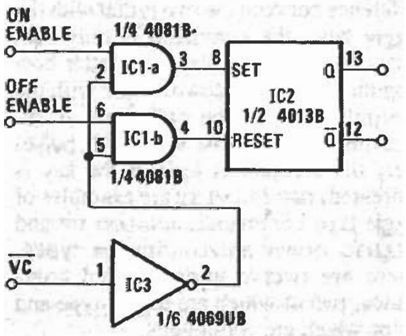


FIG. 16—THE TWO-BUTTON alternate-action interface circuit. Either a 4013B or 4027B type flip-flop may be used.

the enable line signal, and the other to act as a gate that will pass the $\overline{VC}$ pulse (in inverted form) when the correct enable line is high. The pulse will be an exact mirror of the $\overline{VC}$ pulse, 0.8 milliseconds wide, and positive in polarity. A third OR gate could be added to re-invert the pulse's polarity, and if a longer pulse width is desired, a 4528B monostable or 555 timer can be added to the output.

The basic on-off type of control is a one-button alternate-action decoder (Fig. 15). A 4027B JK flip-flop has its J and K inputs tied together and to the correct enable line, and its CLK input tied to the $\overline{VC}$ pin. If the enable line is low, a pulse on the $\overline{VC}$ pin will have no effect on its outputs. If the enable line is high, the pulse will cause the outputs to change states. That type of output device should be used with a toggle-type command to keep it from changing states more than once per key press.

A more positive such control is a two-button alternate-action decoder (Fig. 16). Either a 4013B or a 4027B flip-flop may be used in that circuit, since only the SET and RESET inputs of either are used. One enable line is used, via a 4081B AND gate, to allow the $\overline{VC}$ pulse to reach the SET input and drive the Q output high (and the $\overline{Q}$ output low, of course);another enable line and AND gate are used to similarly allow the $\overline{VC}$ pulse to reach the RESET input and drive the Q output low. Note that the $\underline{VC}$ signal is inverted in that circuit. The advantage of the two-button control is that it is impossible to mis-set the flip-flop if the correct button is pressed. Repeated pressing of a button or (in the case of a continuous command) repeated $\overline{VC}$ pulses will have no effect on the output; only pressing the opposite button will alternate the outputs.

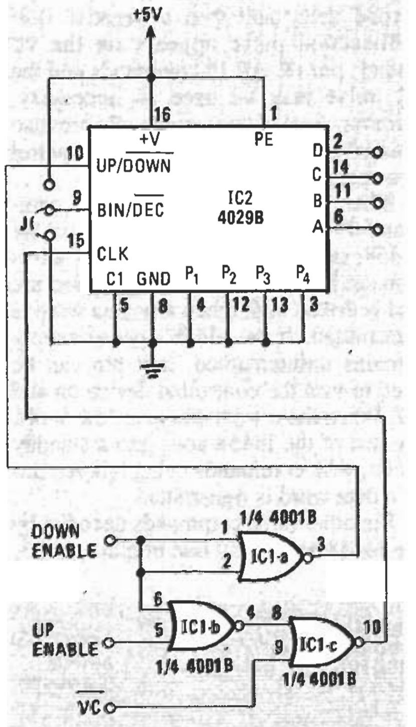


FIG. 17—THE UP/DOWN counter interface circuit. The 4029B can be set to count in either BCD or binary format, or can be replaced by a 4510B/4516B counter.

The last and most complex decoder is an up/down counter controlled by two enable lines (Fig. 17). One is used to activate the counter in the up-counting mode; the other is used to activate the counter in the down-counting mode. In both cases, the $\overline{VC}$ pulse is used to clock the counter in the desired direction.

(Continued on page 113)

REMOTE-CONTROLLER

continued from page 66

The example circuit uses the 4029B up/down binary/BCD counter, since that is the most flexible type available. Not only is that counter capable of counting up or down, but it can count in either straight binary or BCD formats. In addition, it is presettable and cascadable. If the alternate counting format is not needed, the similar 4510B or 4516B binary counters can be used.

Whichever of the three counters is used, a single device will give a total of 10 or 16 steps. All three types can be cascaded to a second counter, giving 100 or 256 steps. One continuous command should be used to step the counter up, and a second to step it down. Gating could be added to prevent over- and under-flow by disabling the UP enable when the maximum count is reached, and disabling the DOWN enable when the all-zero state is reached.

That type of decoder could be used in a number of ways, the most flexible of which is to interface its outputs with a resistor string or an IC digital-to-analog converter to obtain an analog voltage output. A series of optocouplers and such a resistor string could be used in standard D/A format to replace a potentiometer on the controlled device.

The data port has been left out of this discussion, since it is meant primarily to carry channel numbers, tuning frequencies, and other numerical data. However, if the controller is converted to single-digit operation, another BCD or hex 1-of-n line decoder could be added via that port, giving 20 or 32 separate enable lines.

There are a number of methods that can be used to interface the CMOS outputs of the various decoders to the controlled device; let's examine some of those next. If the device is digital and uses a matching 5-volt supply, often the outputs can be directly connected. However, if more current is needed, power drivers such as transistors must be added to the CMOS outputs. If different voltages are used in the controlled device, either power driver IC's or optocouplers must be used. Light-duty reed relays can be used without special driver circuitry.

It's now up to you to take the 14457/14458 remote control system and use those output devices (or a system of your own) to interface it to what you want to control, be it a TV, VCR, stereo, cable tuner, CD player, computer, or any other device or circuit that you can think of. Whatever that device or circuit is, it can be controlled by an invisible beam of light or an ultrasonic wave linking the two halves of this system! **R-E**

Reader's Circuit. Designed to switch off a conventional tape recorder/player automatically at the end of a reel, the control circuit illustrated in Fig. 1 was submitted by Richard F. Serge, ETR-2, aboard the USS Columbus (CG-12). Although intended for a specific purpose, the basic circuit is reasonably versatile and, with a little ingenuity, could be modified for more general applications.

Referring to the schematic diagram, common-emitter amplifier *Q1* normally is held in a conducting state by the base bias established by voltage-divider *R4-R5*, thus energizing *K1* (4- to 30-mA pull-in current) and permitting equipment operation. At the same time, base diode *D1* is held in a high resistance (non-conducting) state by a reverse bias obtained from a voltage-divider

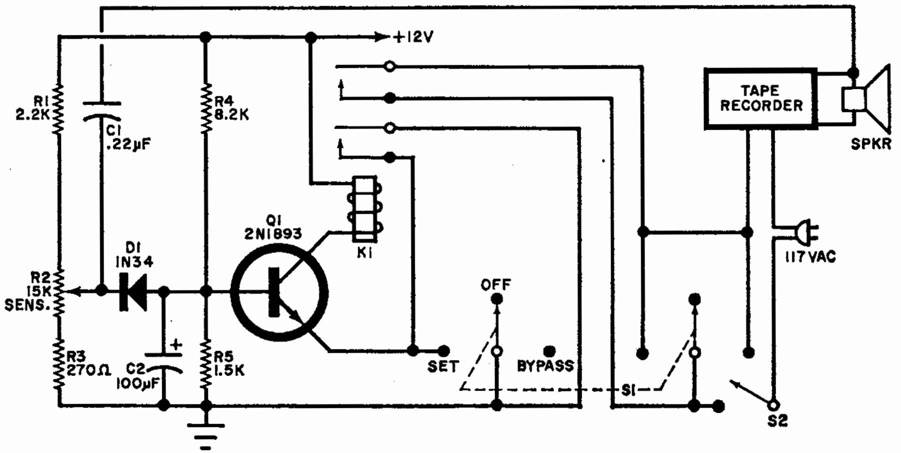


Fig. 1. The control circuit can be used with a battery-operated recorder with the same effect.

Multi-channel Proportional Remote Control

Use of t.t.l. in low cost system giving nine channels

*by M. F. Bessant**

The introduction of inexpensive servo torque units and integrated-circuit pulse-width servo amplifiers has opened up new possibilities in the field of low-cost proportional remote control for general laboratory or industrial use. Unfortunately the associated drive circuitry available commercially is intended for model radio control, and is often built on the same printed-circuit cards as a 27MHz transmitter and receiver. The cost-effective application of torque units and amplifiers to a system not requiring a radio link therefore depends upon the user's ability to construct suitable drive circuitry. This article outlines a remote control system offering a maximum of nine fully proportional channels, using medium scale integration t.t.l. to obtain a low component count and level of wiring complexity, at a lower cost than currently available construction kits.

Coder

The purpose of the coder is to scan sequentially nine parallel input commands (from potentiometers for fully proportional information and switched resistors for "go/no-go" or multi-step information) and present them to the single-line data link as a series of nine varying width pulses followed by a fixed width synchronisation pulse.

To understand the operation of the coder shown in Fig. 1, it is advisable to start on familiar ground with the collector-coupled astable multivibrator formed by transistors Tr_1, Tr_2, and Tr_3, then assume that on the initial application of power the decode counter holds a number between 0000 and 1001 (i.e. a b.c.d. number), say 0001. This will result in charging current being "pulled down" through channel 1 command resistor R_3 *via* pin 2 of the open-collector b.c.d.-to-decimal converter, thereby allowing astable action to commence. The coder's first output pulse (taken from the collector of Tr_3) will be in the 1–2ms range with an exact duration determined by the setting of R_3. The positive transition produced at the collectors of Tr_1 and Tr_2 by the termination of this pulse clocks the counter into the next state (0010) and after a 0.25ms delay fixed by the *CR* time constant at the base of Tr_3, the second coder output pulse is generated (the duration of which will this time depend upon the setting of R_4). All the command resistors will be sampled sequentially in this manner until a count of 0000 is reached, when a 0.5ms sync pulse is generated, thus "labelling" the next output pulse as a command function corresponding to channel 1 (or 0001 again).

When displayed on an oscilloscope the repeating train of nine 1–2ms varying-width pulses, with equal 0.25ms spacing, has a distinctive "concertina" appearance (see Fig. 2(a)), with each command function being sampled approximately every 20ms. (This coding is compatible with commercial radio-control equipment should interfacing become necessary.) In the event of a non-b.c.d. number being held in the counter at "switch on", resistor R_1 will enable the astable to free run at a low clock rate until one of the b.c.d.-to-decimal converter outputs goes low, preventing the system from locking up.

Fig. 1 shows channels 1–6 as fully proportional and channels 7–9 as "go/no-go" functions. This is only to illustrate the idea; in practice any mix of commands can be used, depending on the application.

Decoder

The decoder accepts the serial information from the coder (*via* some form of data link) and by detecting the sync. pulse, passes the

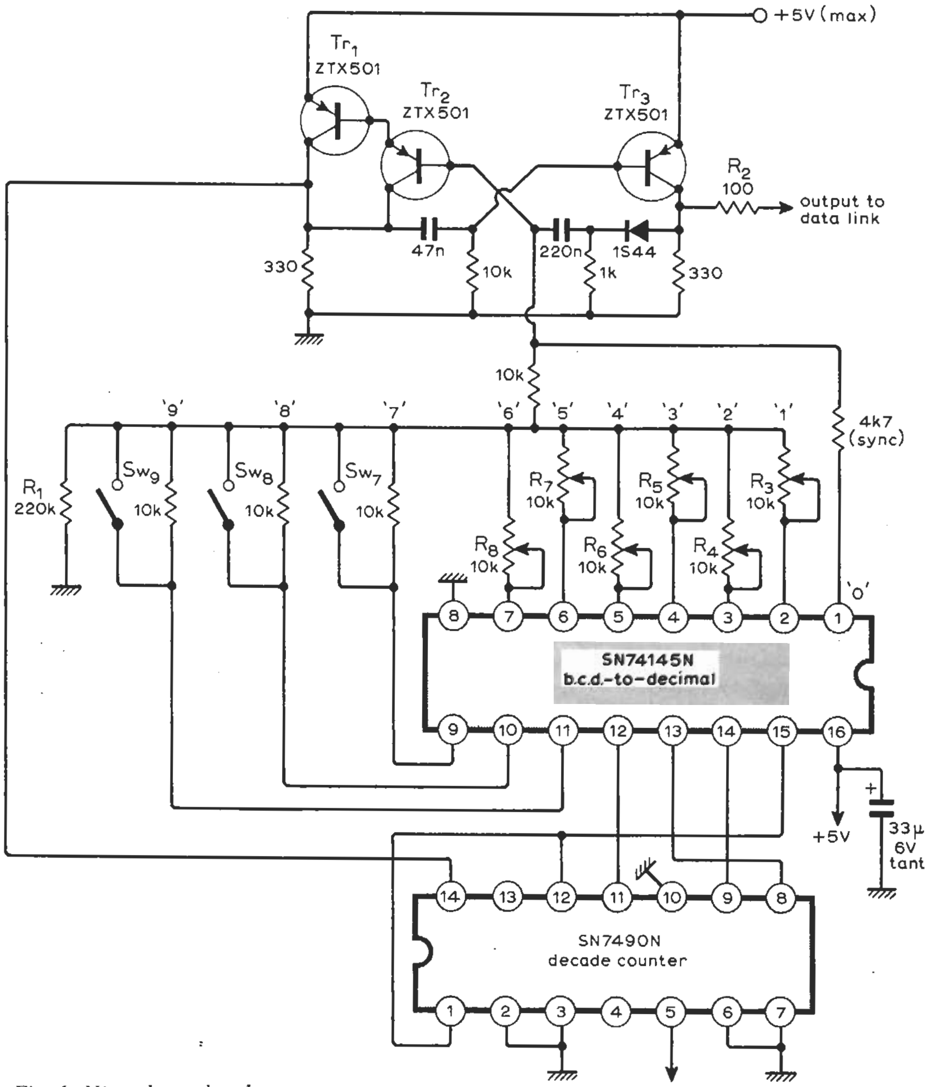


Fig. 1. Nine-channel coder.

*University of Bristol.

nine individual commands to their respective servo amplifiers. It can be seen from Figs. 2(b) and 3 that the operation of the coder and decoder is in many ways similar due to their both being effectively clocked by opposite collectors of the same astable. Both b.c.d.-to-decimal converter outputs will therefore be almost identical (the decoder output has a 0.25ms "offset") providing the counters are locked in step by the sync. detector clearing them both simultaneously. A change in the value of VR_3 for example will result in a corresponding change in the duration of the negative going pulse fed to channel 3 servo amplifier *via* pin 4 of the decoder's b.c.d.-to-decimal converter.

Detection of the synchronization pulse is achieved by comparing the length of inverted input pulses with the output of a 0.6ms monostable reference. Fig. 4 shows that as the minimum length of all command pulses exceeds 0.6ms only the 0.5ms sync. pulse presents the counter's internal "clear" NAND gate with two high inputs simultaneously, thus clearing the counter to 0000 before the arrival of the next channel 1 command pulse. A similar combination of reference monostable and gating could be used after the decoder to detect the "go/no-go" information pulses.

Data Link

If the data link between the output short-circuit protection resistor R_2 (Fig. 1) and the decoder's input consists of more than a simple cable link (optical coupling etc.) then care must be taken not to subject the decoder t.t.l. inputs to voltages outside the decoder's supply rail limits. Transistor Tr_4 (Fig. 3) has therefore to serve the dual purpose of logical inverter and voltage clamp.

Data link bandwidth limitations present no critical problems to decoder operation for the following reasons:

(a) command pulse width information is carried on positive transitions only;

(b) these transitions are reshaped before clocking the counter by the sync. detector's Schmitt/monostable. Deterioration of the incoming pulses will not, therefore, result in reduced counter noise immunity, although excessive "pulse rounding" will eventually lead to reduced servo resolution.

Compared with the widely used technique of cascading discrete-component monostables to produce "concertina" pulse trains which are then decoded by some form of shift register (s.c.r. etc.), the approach described in this article offers many advantages. One advantage not already stated is the ability to reduce the size or power consumption of the decoder simply by substituting the standard t.t.l. shown in Fig. 3 with low power or flat pack versions where appropriate.

Servo amplifier in t.t.l.

The system for driving six servo torque units from the m.s.i. decoder is based on torque units originally designed to provide radio control models with a reliable method of converting electrical commands into proportional mechanical movement.

A typical unit costing five pounds would

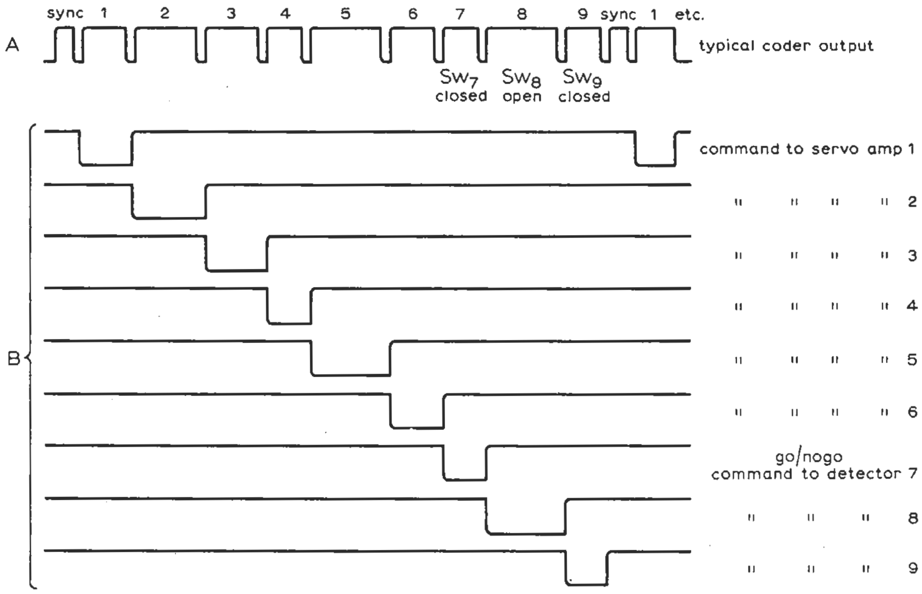


Fig. 2. Timing diagrams for (a) coder output, top, and (b) decoder output, bottom.

Fig. 3. Nine-channel decoder.

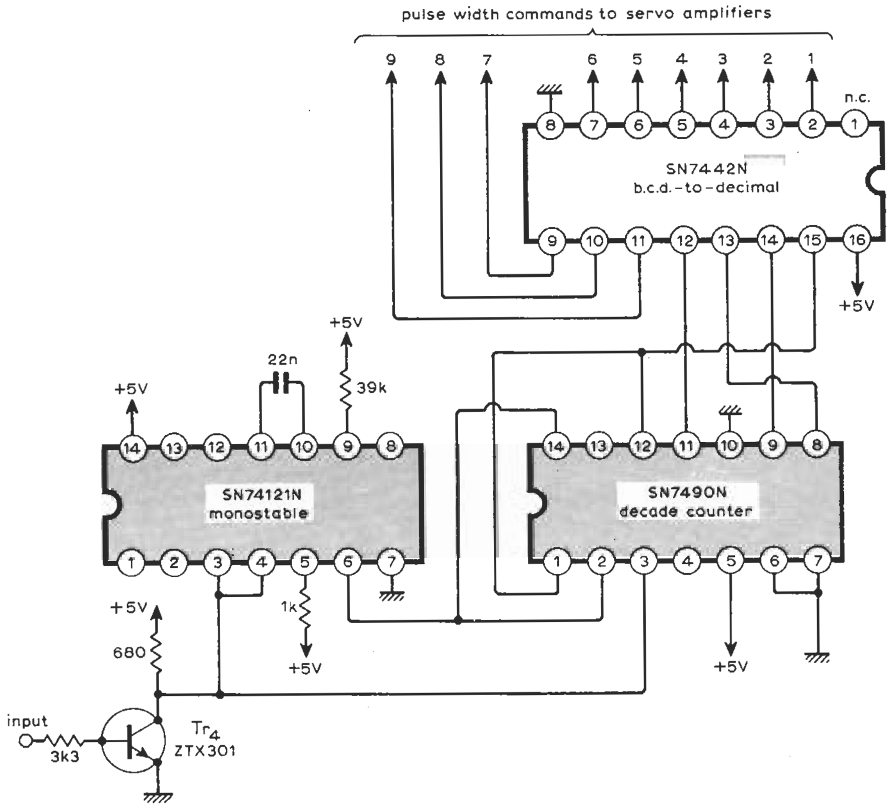
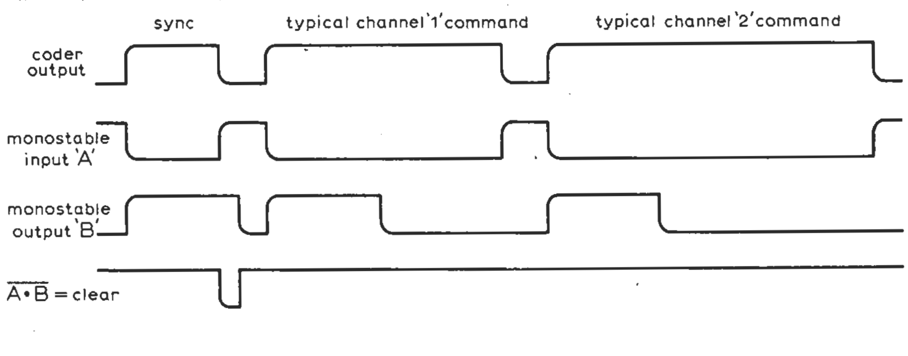


Fig. 4. Sync detector operation.



contain within its matchbox-size case a low voltage d.c. motor driving a reduction gear train, the final shaft of which connects at one end to a positional feedback potentiometer and at the other to mechanical output coupling. Backlash on this shaft would be less than 1° and stall torque approximately 15oz/in. Unloaded full drive transit time for 300° travel would be in the order of a second. These basic characteristics are compatible with low-cost, light laboratory/industrial servo applications.

The principle of pulse proportional servo control is now well established, with the most popular types of commercially available "amplifier" (for driving the motor in the required direction to cancel errors between command and feedback pulse length) falling into the following two categories:

(a) Discrete amplifiers using push-pull motor drive that require a centre-tapped supply. Apart from the high component count (typically ten semiconductor devices plus associated passive components) these amplifiers can, in the event of power supply voltage differences, have the added disadvantage of lopsided response.

(b) Integrated circuits, custom built for radio control servo manufacturers (i.e. not available directly from semiconductor manufacturers) have the obvious size and reliability advantage over discrete counterparts, plus in some cases a bridge motor drive. They are, however, rather specialized and not easily adapted to different motor voltage, gear ratio and potentiometer resistance combinations. Both fully assembled amplifiers cost between five and six pounds.

The amplifier shown in Fig. 5 is based on a t.t.l. pulse width comparator feeding a discrete bridge motor drive circuit. This combination offers a reduced component count compared with totally discrete amplifiers and improved flexibility (with comparable complexity) compared with custom i.c. amplifiers. A considerable cost saving can also be achieved if the components for all six channels are mounted on the same card (see Fig. 6). Under these conditions each t.t.l. servo amplifier will cost approximately £1.

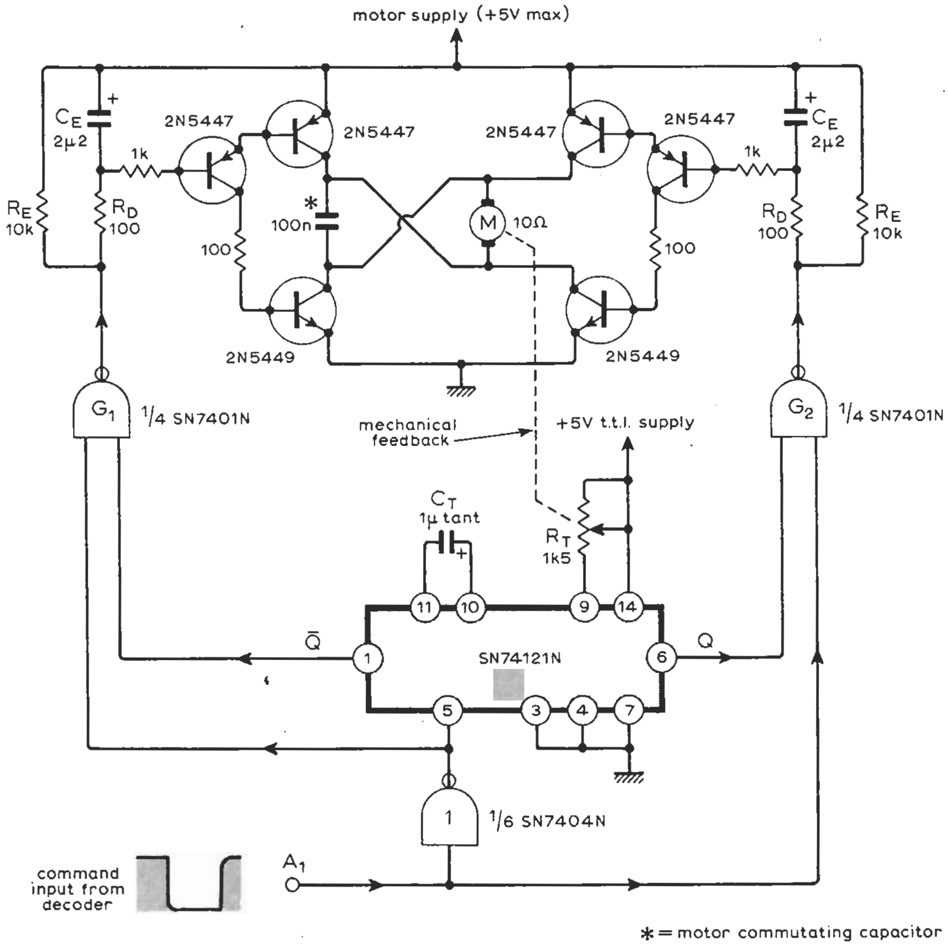


Fig. 5. Servo amplifier using t.t.l.

Circuit operation

The position of the torque units output shaft determines the value of R_T which together with C_T and a 2kΩ resistor, form the feedback monostable's timing elements. Decoded command pulses trigger the monostable *via* an inverter and are compared with the resultant Q and $\bar{Q}$ outputs. If the position requested by the command pulse differs from the output shaft's present position an error signal proportional to the difference in pulse lengths will appear at the output of either G_1 or G_2 open collector NAND gate depending on whether the feedback is longer or shorter in duration than the command (see Fig. 7). Provided that this error exceeds the drive amplifier's "turn-on pedestal", one side of the bridge will be turned on and the motor driven in the required direction (assuming the "sense" of the feedback is correct) to reduce the error below the turn-on level. When this is accomplished neither side of the bridge conducts and negligible current is drawn from the motor supply.

Expansion and deadband considerations

After being time-division multiplexed by the coder and decoder, an individual 1.25ms–2.25ms command will only appear at the input of its allotted servo amplifier approximately once every 20ms. In order to sustain motor current between commands it is therefore necessary to expand the pulse length of any error produced by the comparator. As the value of the expansion components R_E, C_D and R_D must be equal for symmetrical servo operation only one side of the bridge will be referred to below.

The pulse expansion ratio N depends on the charge and discharge time of C_E, together with the turn-on pedestal and is

$$N \approx \frac{R_E Z_{in}}{Z_{in}+R_E} \cdot \frac{1}{R_D}$$

where Z_{in} is the drive amplifier input impedance above the pedestal. In practice N must be a compromise between servo response time and "pile up" at the higher command repetition rates (i.e. all commands set to minimum width).

Resistor R_D defines the minimum error pulse capable of charging C_E to the drive amplifier's turn on pedestal and thus cause motor current to flow. An error below this level is usually referred to as being within the "deadband". In the circuit of Fig. 5 the width of the deadband t_d is

$$t_d \approx \frac{C_E R_D}{4}.$$

The minimum usable deadband width is limited by the motor and gear box inertia, which may be sufficient to cause "hunting" (oscillation about the requested position). The deadband is often expressed as a percentage of command pulse modulation. For the values given we have t_d approximately equal to 50μs with 1ms modulation; the servo is therefore said to have a 5% deadband.

Although the expansion and deadband component values shown are not critical and can be used with most commercial units in a multi-channel system, some trade off between response time and deadband may be necessary to optimize the servo for a particular application.

Complementary bridge

By using the complementary bridge configuration shown in Fig. 5 a wide range of motors can be driven (in either direction) from a single supply, and as any variation in this supply can only result in symmetrical changes in servo response time, the two main disadvantages associated with push-pull centre-tapped amplifiers has been eliminated. With the values shown the bridge is capable of saturation with motor stall current of up to 300mA (typical "motor run" current is approximately

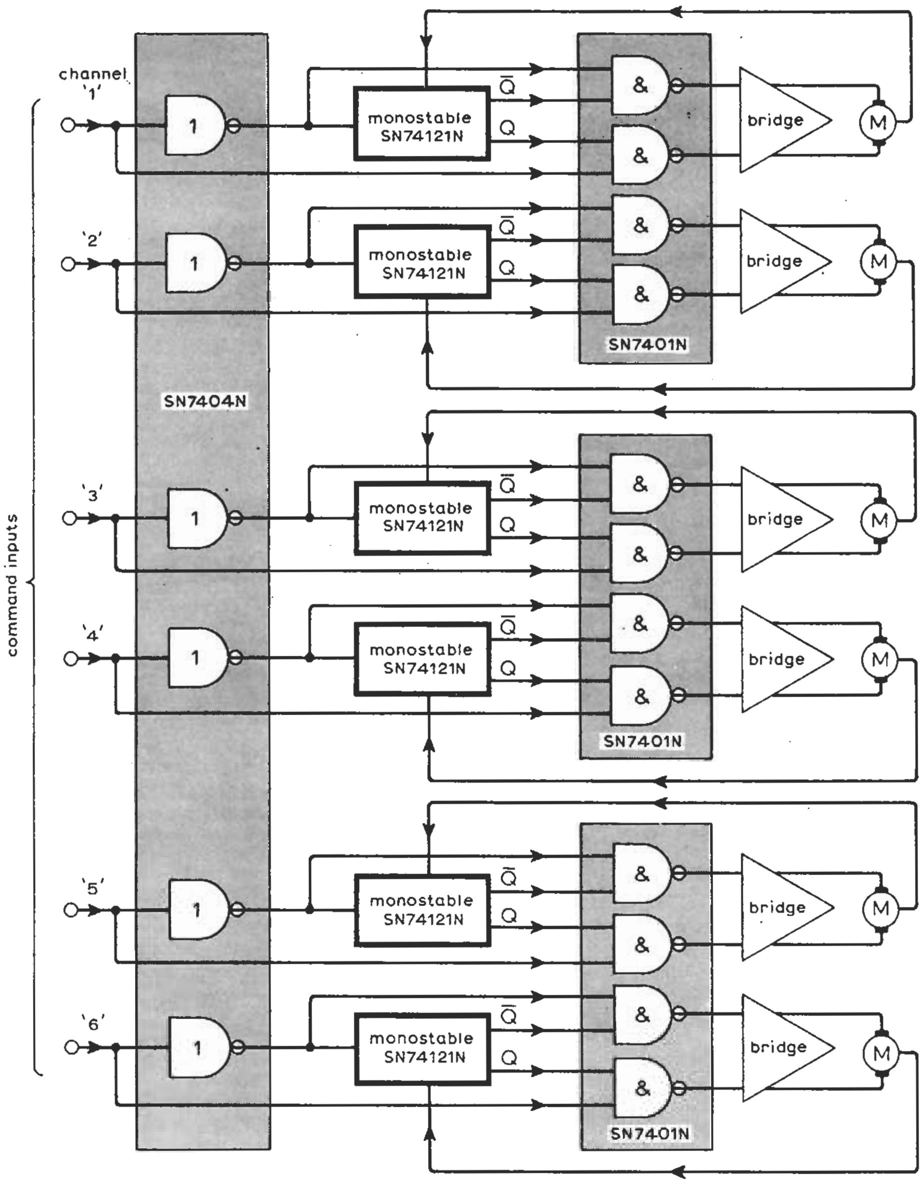


Fig. 6. Layout of components for least cost.

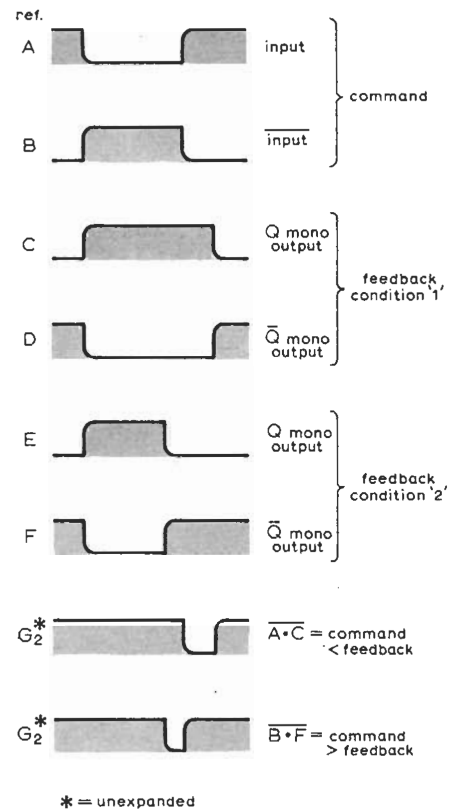


Fig. 7. Pulse-width comparator logic.

15mA). Small plastic-cased transistors are quite adequate even at higher stall currents due to the very efficient saturating nature of the bridge. In order to accommodate motor voltages in excess of the SN7410N 5-volt limit, as SN7401AN must be used, which has an open-collector rating of 15 volts. If the torque unit is capable of operating from the t.t.l. supply, decoupling between the motor and logic must be included to avoid instability.

Remote control servo

An alternative design to that proposed in M. F. Bessant's article on multichannel proportional control

by J. H. Cook

In a time-division multiplex system, the command to an individual servo amplifier has to be expanded so that the motor current will be sustained in the interval between commands, which in this case is approximately 20 milliseconds.

In the original design[1] this expansion is realised by charging C_E during the control pulse and maintenance of this charge keeps the motor turning. In practice, the charge leaks away after about 5 milliseconds. This causes the motor to turn slowly, since it is not supplied with current for most of the cycle time. Another disadvantage is that, as the servo nears its end point the pulse charging C_E becomes narrower; hence, there is less charge on C_E and the servo movement is even slower. Increasing the value of C_E to 4.7 μF. causes the servo to move faster but then the dead space becomes impractically wide and renders small, accurate movements of the servo impossible.

New design

The present circuit completely separates the mechanisms which set the dead space and which ensure that the motor is driven hard even when it is near its end point. It can be seen from the circuit in Fig. 1 that it is developed from the original and I_2, G_9 and G_{10} in Fig. 1 are equivalent to I, G_1 and G_2 in the original. G_5 and G_6, G_7 and G_8, G_{11} and G_{12}, G_{13} and G_{14} form set-reset latches, while I_1 and G_1, I_4 and G_3, I_5 and G_4 give negative-going pulses on a positive-going edge[2]. I_3 and G_2 are similar but the pulse length is longer and variable. This pair acts as a monostable which is used to set the dead space time.

It is necessary for G_{15} and G_{16} to be open-collector gates and one package can be saved by also making G_9 and G_{10} open-collector gates, providing them with 1kΩ resistors at their outputs. These four gates are in an SN7401N package. The rest of the gates are in

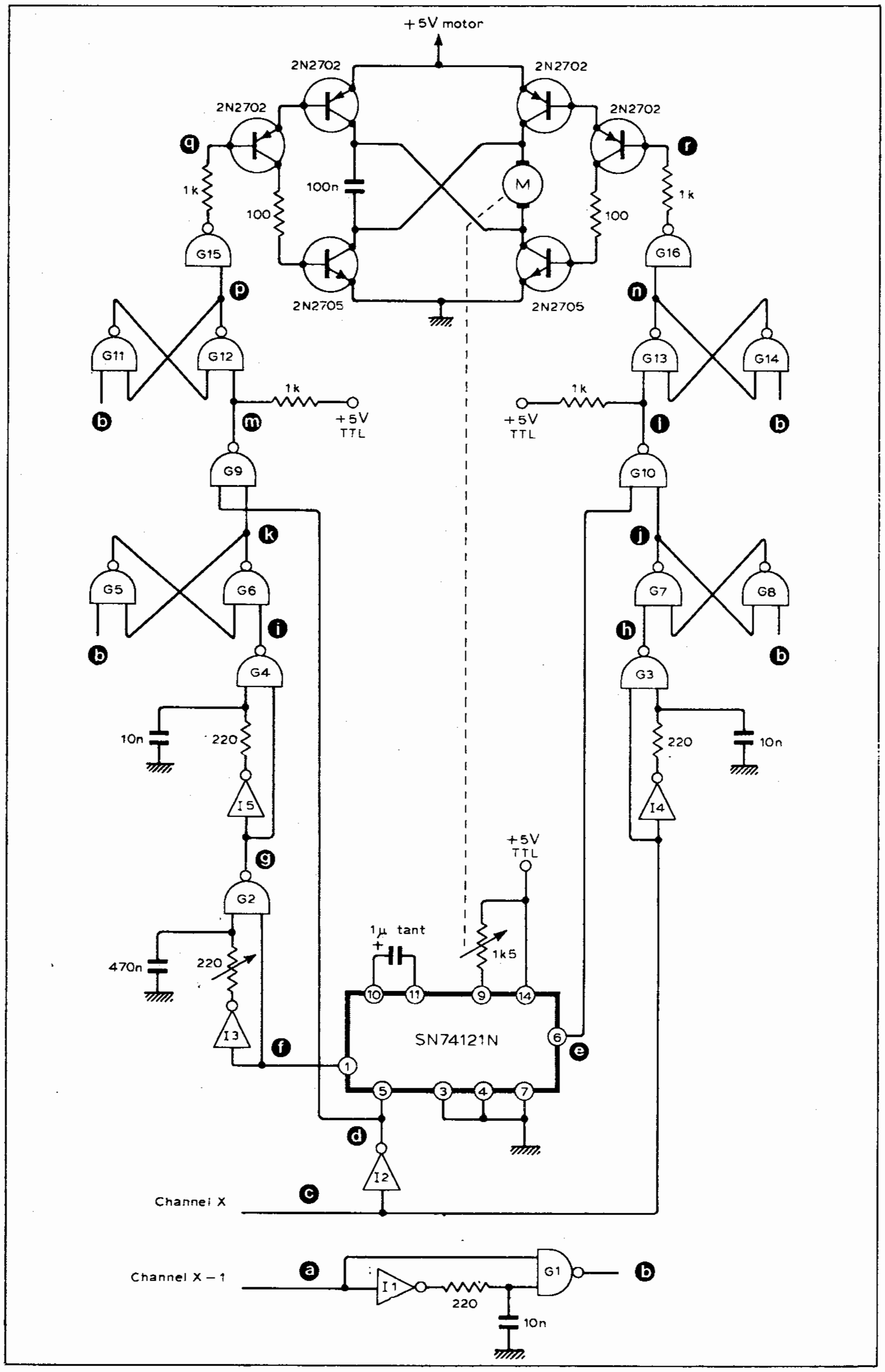


Fig 1. Circuit of improved servo design.

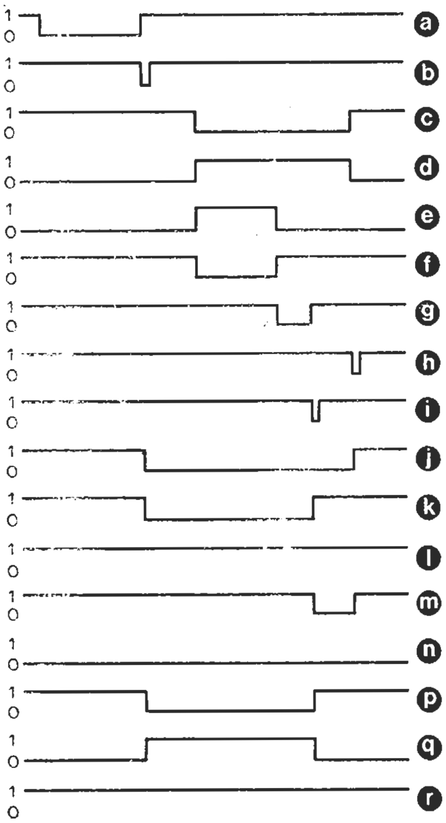


Fig 2. Waveforms when servo is stationary.

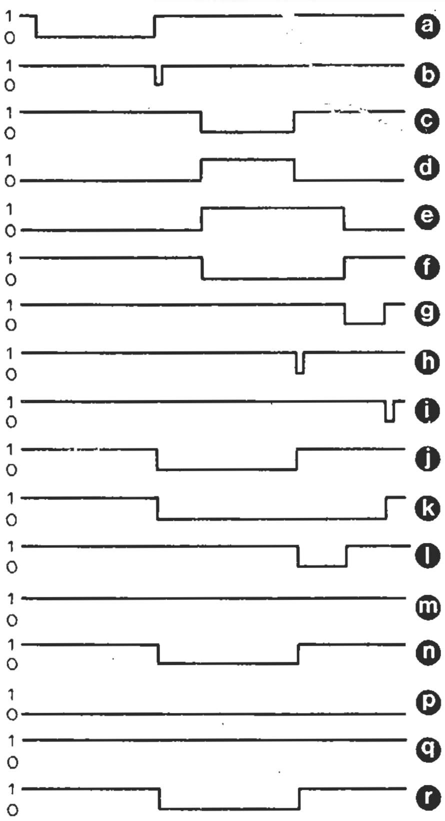


Fig 3. Waveforms when input pulse length at c is shorter than the output pulse length from the monostable SN74121N.

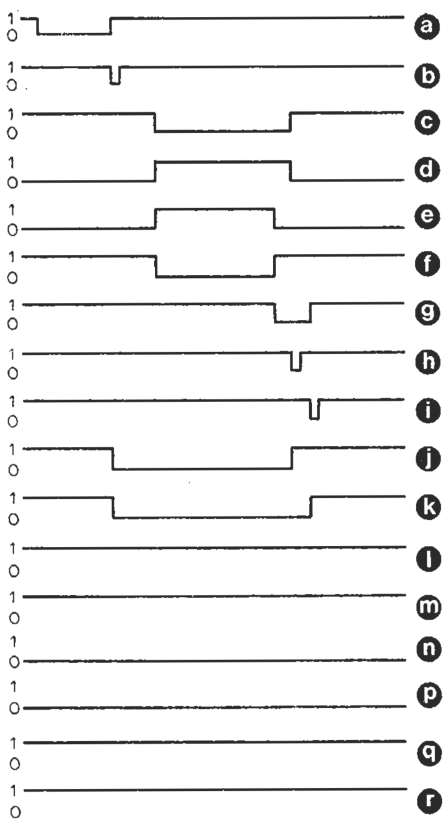


Fig 4. Waveforms when the output pulse from the monstable SN74121N plus I_3C_2 is shorter than the control pulse at c.

SN7400N packages and the inverters are an SN7404N.

Channel X is the channel currently controlling the servo and channel X-1 is the previous channel. If X is the first information channel, then X-1 is the synchronizing pulse.

The functioning of the servo circuit can best be followed by study of the waveforms at the points marked in lower case letters in Fig.1. These waveforms are shown in Figs. 2, 3 and 4 for different states of the servo; **b, g, h,** and **i** are shown longer than they actually are for clarity. Pulse **b** is derived from **a** as explained above and resets all the set-reset latches, while **c** is the control pulse for the servo.

Fig. 2 shows the waveforms when the servo is stationary. For the motor to turn there must be a negative going pulse at either **m** or **l** to set one of the latches G_{11}, G_{12} or G_{13}, G_{14}. In the conditions as in Fig. 2 neither of these things happen. It is arranged that **k** becomes logic 0 before **d** becomes logic 1. If both these are switched "simultaneously," there is sufficient propagation delay through the gates for a momentary pulse to be present at **m,** enough to set G_{11}, G_{12}. It is also arranged that **d** reverts to logic 0 before **k** becomes logic 1, again to ensure no pulse at **m.** (The same applies to **e, j, i,** G_{13} and G_{14}.) Hence both **q** and **r** remain at logic 1 and the motor does not move.

Fig. 3 shows the waveforms when the input pulse length at **c** is shorter than the output pulse length from the monostable SN74121N. In this case, **j** will revert to logic 1 before **e** becomes logic 0. Therefore a negative-going pulse will appear at **l.** This will set the G_{13}, G_{14} latch, which will cause **n** to go to logic 1 and **r** to become logic 0. This will turn on the motor, which will turn until the conditions in Fig. 3 prevail, when the motor will stop.

It can be seen that once the set-reset latch is set it will remain set for nearly the whole cycle time (20 milliseconds). It does not matter how short the pulse at l is, which means that the motor speed is independent of the distance from the end point.

Fig. 4 shows the waveforms when the output pulse from the monostable SN74121N plus I_3G_2 is shorter than the control pulse at **c.** In this case the servo is driven in the opposite direction, in a similar manner to that described above.

The dead space is adjusted by setting the 220 ohm trimmer to as small a value as possible compatible with the servo not hunting.

References

1. Bessant, M. F. "Multichannel proportional remote control," *Wireless World*, vol. 79, No. 1456, pp. 479-482, Oct. 1973.

2. Cole, H. A. "T.t.l. trigger circuits," *Wireless World*, vol. 78, No. 1435, pp. 31-32, Jan. 1972.

Announcements

Repairing semiconductors

On page 52 of the November 1976 issue we published a letter from a reader who had found it possible to remove the protective casings from some defective transistors and effect repairs. We have since received a number of letters pointing out that many semiconductor devices contain poisonous substances. The danger of beryllium oxide poisoning particularly concerned readers. It appears that semiconductor manufacturers are aware of this and other dangers – beryllium oxide is only one of many toxic substances used in semiconductors. At least one manufacturer, concerned about his liabilities under the Health and Safety at Work Act, wrote to his customers in October to point out that the dangers from breakage in use and disposal, though small, did exist and were worthy of the customer's attention. The equipment maker is responsible for any such danger and would normally be obliged to label the product accordingly. In the case of semiconductor components, however, there is usually no room for a label.

In view of all this we must strongly advise against any tampering with the packaging of transistors. We thank those who drew our attention to the problem.