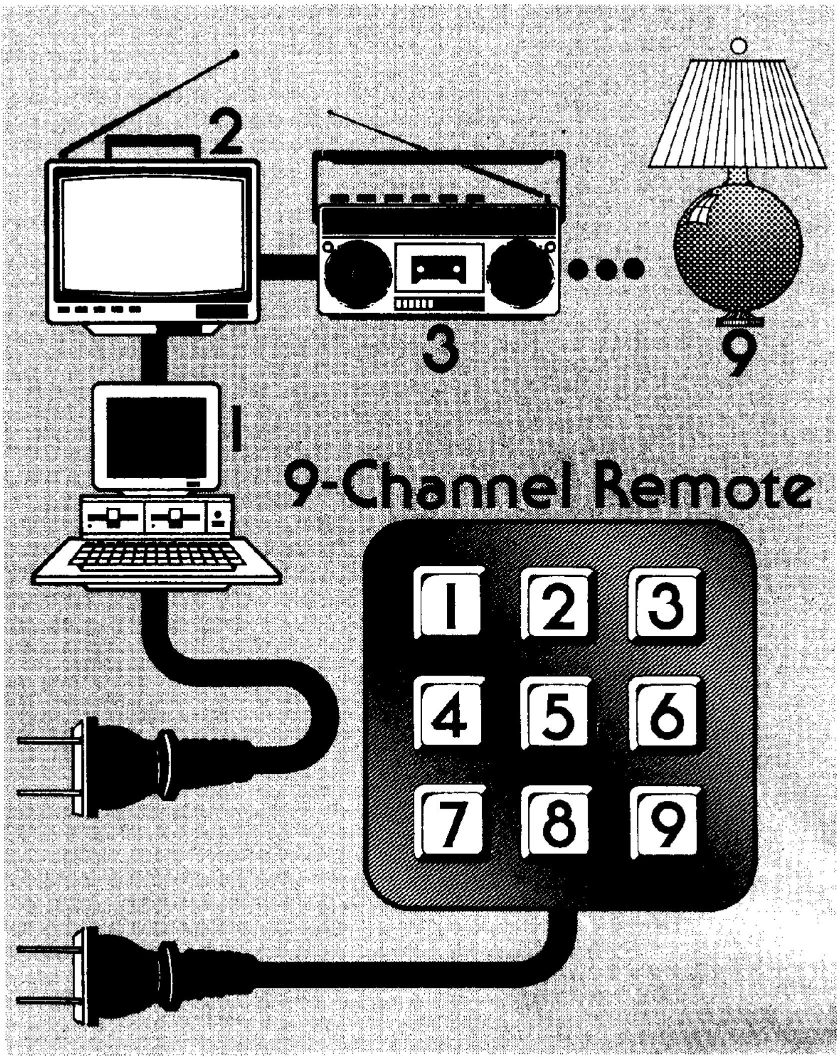
ANTHONY J. CARISTI

CARRIER-CURRENT REMOTE CONTROL



Control up to nine devices remotely with this versatile carrier-current circuit.

THIS WIRELESS REMOTE CONTROL system allows you to control up to nine electrical circuits (such as lights and appliances) with an RF carrier signal that is impressed upon and transmitted through your home's AC wiring. The transmission is called "carrier current" because the RF energy is not radiated, but conducted between transmitter and receiver by the AC wiring. Because no RF energy is radiated, no FCC license is required.

A typical remote control system will have one transmitter and several receivers. However, multiple transmitters can be used instead. Both transmitters and receivers can be placed anywhere within the home.

The transmitter and receiver are based on two Motorola application-specific integrated circuits (ASICs): an MC145026 remote-control encoder and an MC145028 remote-control decoder. Although the ICs can control as many as 19,683 channels using trinary (logic 1, logic 0, and open) data, the circuit described here has a simplified encoding scheme for the control of nine channels.

Both the transmitter and receiver are relatively simple, low-cost devices that operate directly from the AC power line. Power consumption is only 1 or 2 watts, allowing continuous standby operation with insignificant energy cost.

Although the receiver described here is a simple remote-control buzzer, any other kind of circuitry can be controlled as well. A typical receiver might operate as a simple on/off control unit or a momentary or timed-mode device. The extent of control circuitry is limited only by your imagination.

Fundamentals

The encoder IC encodes the inputs on its nine input lines and transmits the data in the form of a serial pulse train when it is enabled. To ensure reliability, the transmitter automatically transmits two complete code words containing the selected address data.

The decoder IC contains nine input pins that allow it to be user-programmed with a desired address. When the decoder detects incoming data, it checks the serial sequence to determine if it matches the preprogrammed code word.

If two identical transmitted words containing the correct address are received, the decoder will transmit a valid-transmission pulse. That pulse can then trigger auxiliary circuitry to provide the desired action.

Transmitter operation

Refer to the transmitter schematic diagram, Fig. 1. The power supply consists of a half-wave rectifier followed by voltage regulator IC1, which maintains a fixed 15-volt output. Most of the input power is consumed by power resistor R1. In-

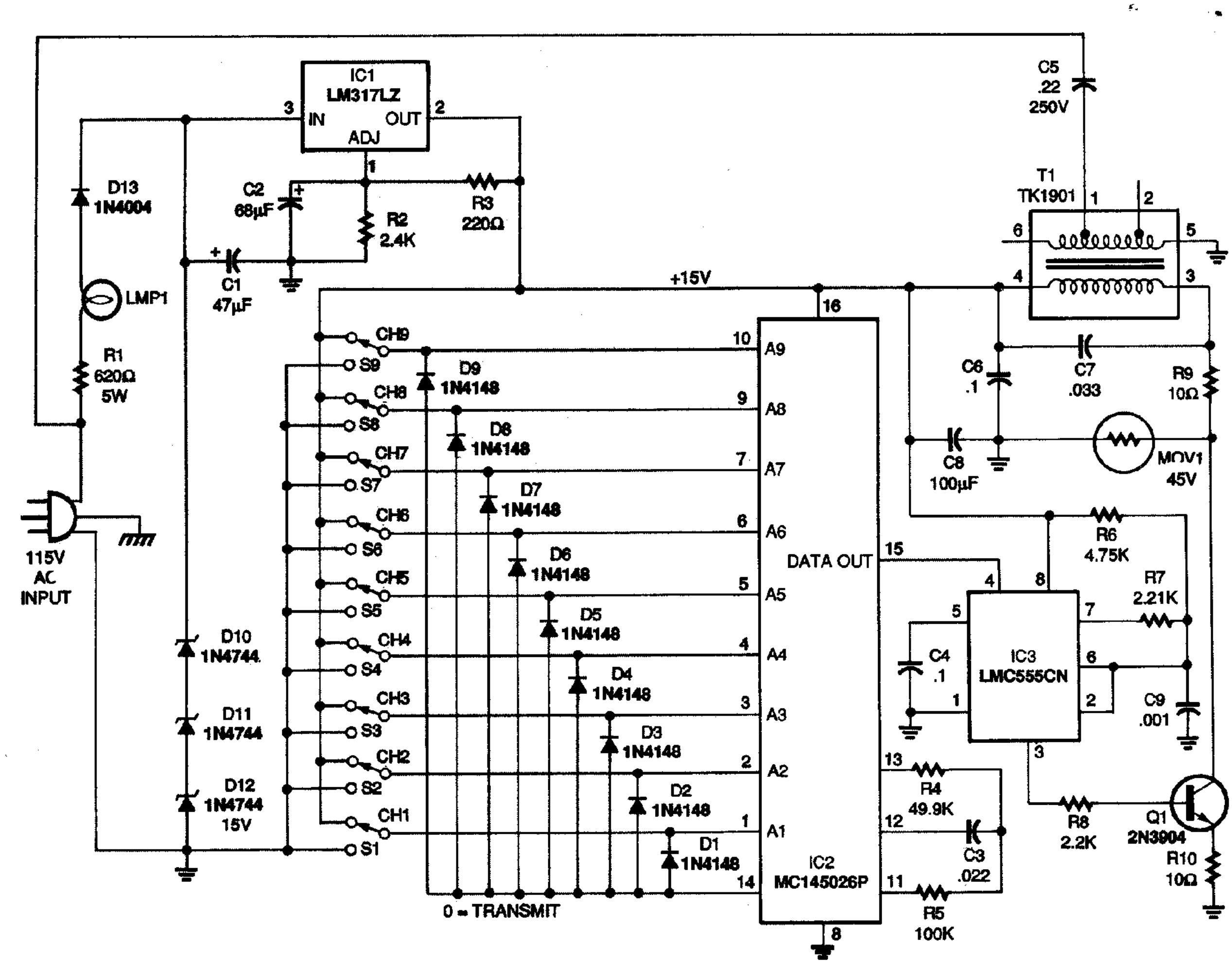


FIG. 1—TRANSMITTER SCHEMATIC DIAGRAM. Switches S1 through S9 activate the desired channel.

candescent lamp LMP1, connected in series with the input line, provides an additional voltage drop and also acts as a power-on indicator.

Three 15-volt Zener diodes (D10, D11, and D12) ensure that the voltage input to IC1 does not exceed its rated maximum allowable input. Three diodes provide sufficient power-handling capability. A fixed voltage divider composed of R2 and R3 sets the regulated output voltage of IC1 to 15 volts.

The heart of the transmitter is IC2, a Motorola MC145026P remote-control encoder. This chip contains all the necessary circuitry, with the exception of the timing components R4, R5, and C3, to generate a two-word pulse train containing the encoded information in accordance with the logic states of address inputs A1 through A9.

When the transmit enable (TE) input, IC2 pin 14, is forced to logic 0 by any of the transmit switches, the chip will transmit its coded sequence. If the TE terminal is held at logic zero, the encoder will continuously send the coded pulse train.

A different arrangement of channel transmit switches would allow the encoder to generate up to 19,683 different code sequences, as discussed earlier. Only nine unique code sequences are produced by this project, which is configured to take only one of the address inputs low while the remaining eight inputs are held high. (None should be left floating.) This is accomplished by nine single-pole, double-throw momentary switches (S1–S9) and nine switching diodes (D1–D9). When any one of the transmit switches is closed, the switching diode associated with the selected channel forces the TE input low, causing the encoder to send its word sequence.

A CMOS timer, IC3, is in an astable mode with a duty cycle close to 50%. The frequency of oscillation is determined by timing components R6, R7, and C9, and is set to about 125 kilohertz. IC3 oscillates only when its enable input, pin 4, is at a logic 1. Since this terminal is driven by the pulse train output of IC2, the RF carrier output frequency of IC3 is pulse modulated in accordance with the encoding of the selected remote-control channel.

The output of IC3, bursts of 125-kHz pulses, drives the base of Q1. The collector of Q1 feeds a matching transformer that converts the relatively high output impedance of Q1 to the low impedance presented by the AC power line. Capacitor C5 couples the output signal of T1's secondary to the AC line where it will travel throughout the 60-hertz AC wiring. The RF energy impressed upon the AC line is very small, but of sufficient magnitude to be detected by each of the remotely located receivers. Surge suppresser MOV1 protects the circuit from high-voltage transients that might appear across the AC power line.

Receiver operation

Refer to the receiver's schematic diagram, Fig. 2. A half-wave rectifier and Zener-diode regulator provide 15 volts DC to power the circuit. Resistor R12 drops the relatively high AC line voltage and limits the current through D15.

An RC network composed of R13 and C11 couple the low-power RF signal appearing across the power line to parallel-tuned circuit C12-L1. The resonant frequency of the tuned circuit (125 kHz) allows the RF signal to be coupled to the base of Q2 while attenuating all other frequencies. Transistor Q2 operates as a common-emitter amplifier, providing a very high gain to the RF signal appearing across the tuned circuit. The output of this stage is coupled to Q3 through C14.

Transistor Q3 is a detector whose base is driven by the RF signal. When Q3 is saturated, the voltage across R18 approaches 15 volts. Capacitor C15 provides sufficient filtering of the 125-kHz pulses to cause the waveform across R18 to assume the shape of the original modulating pulses generated by the transmitter encoder. The output of Q3 is fed through two NOR gates (IC4-a and IC4-b) connected as inverters to provide a clean digital pulse train to drive the decoder's serial data input.

Decoder IC5 contains nine address inputs, A1–A9, that are preprogrammed with binary data. Grounding any one of the address inputs sets the receiver to that channel. In this project, only one input is grounded, while the remaining eight are held high. The digital pulse train detected by the receiver is fed to the data input terminal (pin 9) of IC5. If the address contained in the data is equal to the preprogrammed address of the decoder, an output pulse is generated at pin 11. To ensure the transmission integrity, two identical transmitted words containing the correct address must be received consecutively before a valid transmission signal is issued.

The trailing edge of the positive-going output pulse at pin 11 of IC5 triggers a 555 timer (IC6) connected in a monostable configuration. The 1½-second long output pulse from IC6 drives piezoelectric buzzer BZ1 to indicate that a valid transmission has been received.

The valid transmission pulse output of IC5 or the output pulse from IC6 can trigger the auxiliary circuitry to provide the desired response on the external device which is under remote control.

Construction

Both transmitter and receiver are constructed on single-sided PC boards. Foil patterns are provided if you want to make your own boards. Point-to-point wiring is acceptable if good construction techniques are used. Follow the parts-placement diagrams for the transmitter and receiver boards in Figs. 3 and 4, respectively. Note that the timing and tuned-circuit components must be temperature-stable; use only the components specified in the Parts List.

Install all integrated circuits, except IC1, in sockets. Be careful when installing polarized components such as ICs, di-

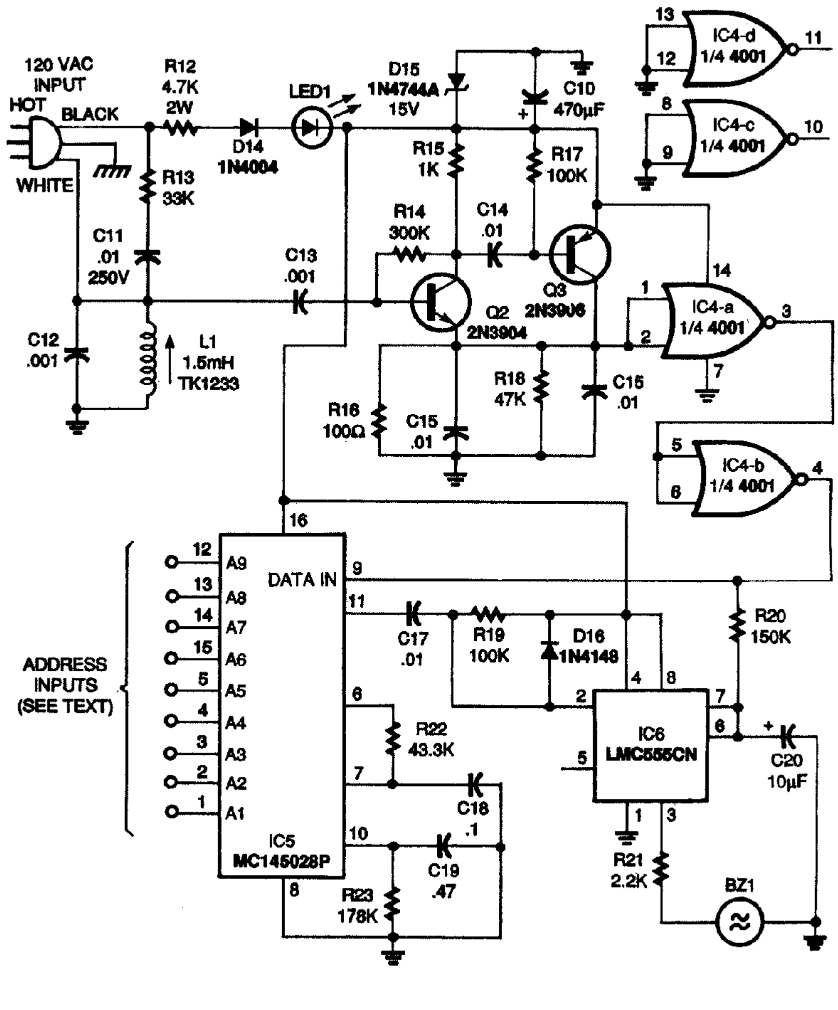


FIG. 2—RECEIVER SCHEMATIC DIAGRAM. Grounding one of IC5's address inputs, while keeping all others high, sets the receiver to that channel number.

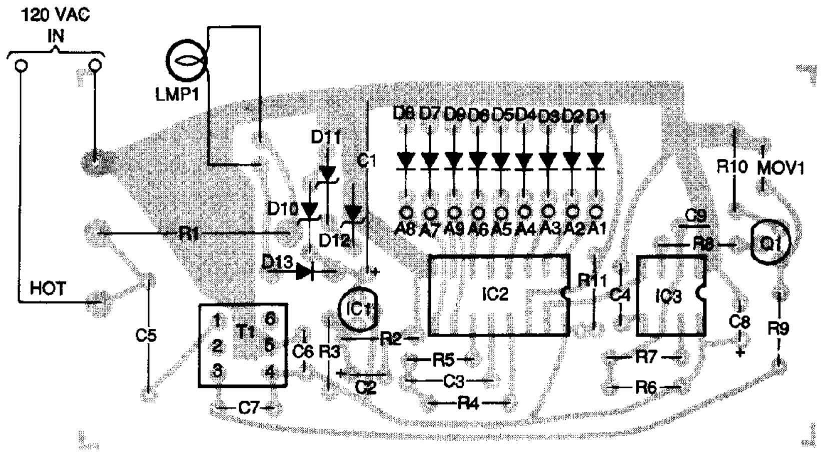
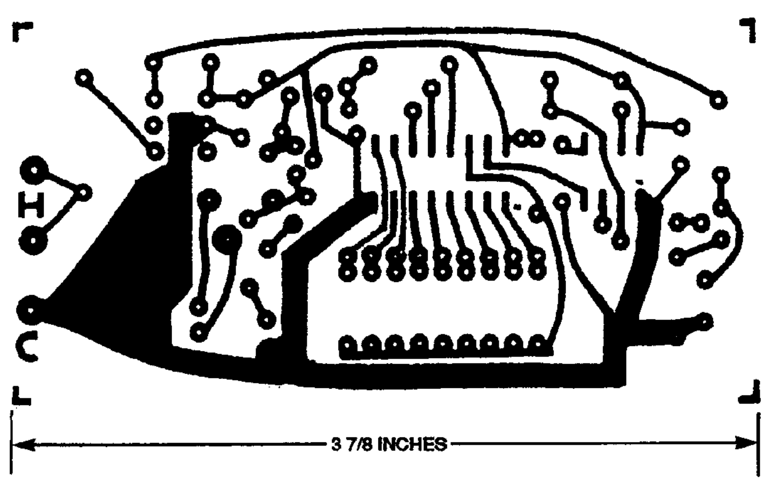


FIG. 3—PARTS-PLACEMENT DIAGRAM for the transmitter.



TRANSMITTER FOIL PATTERN.

odes, and electrolytic capacitors. It is also important that transformer T1 be placed correctly into the circuit.

The transmitter can control up to nine receivers, with one control switch (S1–S9) for each channel. If not all channels are to be used, you can leave out the unnecessary switches, in which case the inputs must be tied to +15 volts.

Because of the transmitter's very low power consumption, a power-on switch is optional. If desired, a double-pole double-throw switch can be substituted for each of the channel-control switches, with the extra pole wired to apply line power to the circuit only when needed. This option is illustrated in Fig. 5.

Power indicator LMP1 should be mounted on the front panel of the transmitter. This is easily accomplished by drilling a hole and securing the lamp to the panel with a small amount of epoxy.

As with the transmitter, the power-on indicator LED should be mounted to the front panel of the receiver to provide visual indication that the receiver is powered and operational. The extremely low power draw of the receiver eliminates the need for a power on-off switch in the circuit, but one may be added if desired.

Because this project is powered directly from the 60-hertz AC line without the use of an isolation transformer, proper safety precautions must be observed. A grounded line cord must be installed on both transmitter and receiver. Additionally, you must verify the polarity of the house wiring where the system is to be installed to make sure that it is correct. That can be done with an AC voltmeter set to read at least 150 volts AC, or a neon test light.

The AC wiring to any 120-volt receptacle should contain two conductors, plus a third conductive path (via a third wire or the BX cable's metallic sheath) to earth ground. One of the current-carrying wires is known as the "hot" lead, and this wire should be black. The other wire is known as the "cold," or neutral lead, and this wire should be white. Without removing the cover plate of the receptacle, verify that the polarity of the receptacle is correct by touching the common test lead of the voltmeter to the screw that holds the cover plate in place (this

TRANSMITTER PARTS

All resistors are ¼-watt, 5%, unless noted.

R1—620 ohms, 5 watt wirewound resistor
R2—2400 ohms
R3—220 ohms
R4—49,900 ohms, 1%, metal film
R5—100,000 ohms, 1%, metal film
R6—4750 ohms, 1%, metal film
R7—2210 ohms, 1%, metal film
R8—2200 ohms
R9, R10—10 ohms
R11—10,000 ohms

Capacitors

C1—47 µF, 63 volts, electrolytic
C2—68 µF, 10 volts, electrolytic
C3—0.022 µF, 50 volts, 2% polypropylene
C4, C6—0.1 µF, 50 volts, ceramic disc
C5—0.22 µF, 250 volts, metal film
C7—0.033 µF, 50 volts, 2% polypropylene
C8—100 µF, 16 volts, electrolytic
C9—0.001 µF, 50 volts, 2% polypropylene

Semiconductors

IC1—LM317LZ adjustable voltage regulator
IC2—MC145026P encoder (Motorola)
IC3—LMC555CN CMOS timer
D1–D9—1N4148 diode
D10–D12—1N4744A 15-volt, 1-watt Zener diode
D13—1N4004 diode
Q1—2N3904 NPN transistor

Other components

LMP1—14 volt, 0.08-ampere incandescent lamp
S1–S9—SPST momentary slide or toggle switch (see text)
T1—49.1 µH, 125 kHz output transformer (Toko No. 719VXA-T1060YUK, Digi-Key No. TK1901-ND)
MOV1—45-volt metal-oxide varistor (Panasonic ERZ-C05DK560 or equivalent)

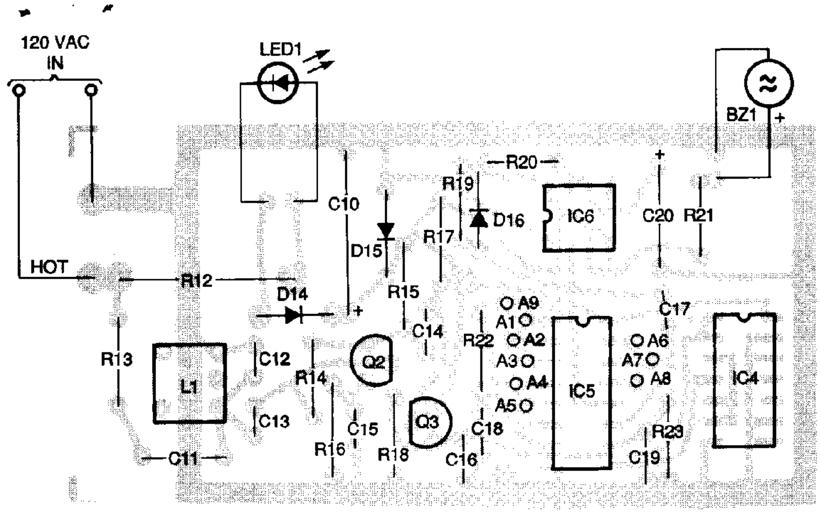
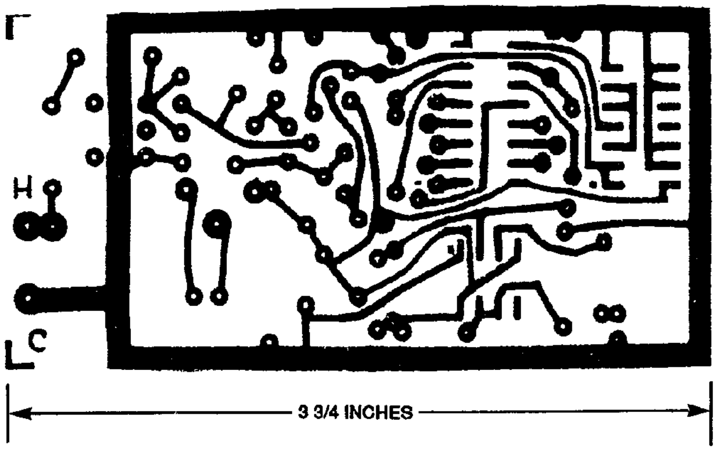


FIG. 4—PARTS-PLACEMENT DIAGRAM for the receiver.



RECEIVER FOIL PATTERN.

should be earth ground), and carefully insert the other test lead into each of the receptacle's slots. The narrow slot should be connected to the hot (black) wire, and should indicate a reading of about 120 volts AC—or it should light the test lamp. The wide slot should be connected to the neutral (white) wire of the AC line, and should give a reading of zero on the voltmeter—or it should not illuminate the test lamp. Be sure to check all AC receptacles that will be used with this system for proper polarity and ground

If you do not obtain the correct polarity readings of your AC receptacles as described, the wiring is in violation of electrical codes and should be corrected by a licensed electrician. Do not install the remote-control system until the electrical violation is corrected. Make sure that the line cords you install conform to local electrical codes as well. Once the polarity of the line cords has been determined, wire them into the transmitter and receiver. Connect the neutral (white) lead to circuit ground (the negative side of C1 in the transmitter and the negative side of C10 in the receiver). Connect the hot lead of the transmitter line cord to R1 and the hot lead of the receiver's line cord to R12.

If you install the receiver and/or transmitter in a metal enclosure, connect the ground lead of the line cord to it with a good, solid connection. If you enclose the transmitter in a plastic case, tape the ground lead out of the way so that it can't cause a short circuit. If you enclose the receiver in a plastic case, connect the ground wire of the line cord to the ground of the circuitry you are attaching to it.

RECEIVER PARTS

All resistors are ¼-watt, 5%, unless noted.

R12—4700 ohms, 2-watt metal-oxide
R13—33,000 ohms
R14—300,000 ohms
R15—1000 ohms
R16—100 ohms
R17, R19—100,000 ohms
R18—47,000 ohms
R20—150,000 ohms
R21—2200 ohms
R22—4330 ohms, 1% metal film
R23—178,000 ohms, 1% metal film

Capacitors
C10—470 µF 16 volt electrolytic
C11—0.01 µF, 250 volt metal film
C12—0.001 µF, 50 volts, 2% polypropylene
C13—0.001 µF, 50 volt ceramic disc
C14, C15, C17—0.01 µF, 50 volts, ceramic disc
C16—0.0047 µF, 50 volts, ceramic disc
C18—0.1 µF 50 volts, 2% polyproplyene
C19—0.47 µF, 50 volts, 2% polyproplyene
C20—10 µF, 16 volts, electrolytic

Semiconductors
IC4—CD4001BE quad 2-input NOR gate
IC5—MC145028P decoder (Motorola)
IC6—LMC555CN CMOS timer
D14—1N4004 diode
D15—1N4744A 15-volt, 1-watt Zener diode
D16—1N4148 diode
Q2—2N3904 NPN transistor
Q3—2N3906 PNP transistor
LED1—Light emitting diode, any color

Other components
BZ1—3-volt DC piezo buzzer
L1—1.5 mH coil (Toko No. RUNS-T1029Z, Digi-Key No. TK1233)
Miscellaneous: Enclosures, IC sockets, grounded line cords, wire, solder

Note: The following items are available from A. Caristi, 69 White Pond Road, Waldwick, NJ 07463:
- **Transmitter PC board—$12.95**
- **Receiver PC board—$12.95**
- **IC2—$8.75**
- **IC5—$8.75**
- **T1—$7.75**
- **L1—$6.75**
- **LMP1—$2.50**

Please add $5.00 S&H.

Transmitter checkout

The checkout of the project requires a digital multimeter or VOM. An oscilloscope is not necessary, but may come in handy. Remove all socketed ICs from the transmitter and receiver before proceeding.

To check the transmitter, ap-

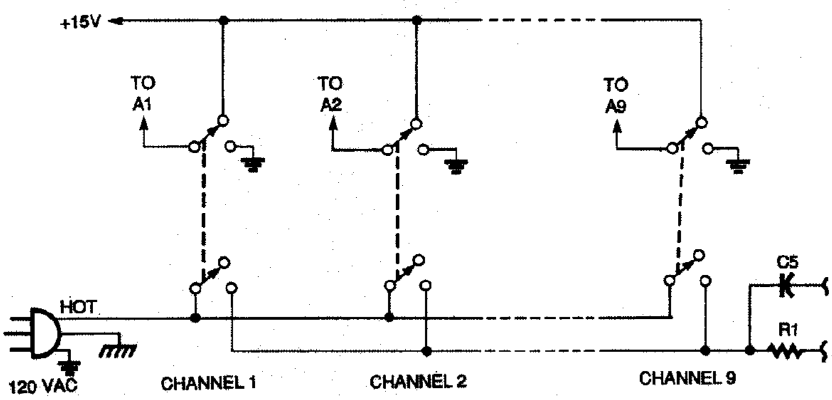


FIG. 5—A TRANSMITTER POWER SWITCH is optional. Double-pole double-throw switches can be substituted for the channel-control switches, with the extra pole wired to apply line power to the circuit only when needed.

ply AC power to it; the power-indicator lamp should glow. Measure the DC voltage across C1; a normal reading is about 42.5 to 47.5 volts DC. Also check the output of the regulator (pin 2) for 14.24 to 15.75 volts DC.

With power removed from the circuit, measure the resistance between the +15-volt bus and ground; normal indication is about 2.6 kilohms. If anything does not check out, do not proceed until the fault is found and corrected.

With power disconnected from the transmitter, carefully insert IC2 and IC3 into their sockets and apply power to the circuit. While observing the indicator lamp, push and hold any of the channel selector switches and verify that the lamp "pulses" in intensity at a rate of about 5 times a second. This indicates that the encoder is operational and is driving IC3 and transistor Q1.

You can connect an oscilloscope to verify that bursts of 125-kilohertz pulses, at about 3 volts peak-to-peak, are present at pin 1 of transformer T1. Adjust the tuning slugs of T1 with an insulated tool to attain RF pulses of maximum amplitude at pin 1 of T1.

Verify the proper operation of IC2 by examining the output pulse train at pin 15 while holding a transmit switch in the on position. A normal indication at that output will be a series of pulses at about 15 volts peak amplitude. Check pin 14 of IC1 to verify that the logic level at this terminal reaches about 0.7 volt when any transmit switch is actuated.

Verify the operation of IC3 by examining the output at pin 3. A normal indication at that output is bursts of 15-volt, 125-kilohertz pulses.

The waveform at the collector of transistor Q1 should be 125-kilohertz pulses at about 35 volts peak-to-peak.

Now put the transmitter aside and proceed with the receiver checkout.

Receiver checkout

With all ICs removed from their sockets, apply power to the receiver; the LED should illuminate. Measure the voltage across C10; it should be about 15 volts DC. Disconnect power from the circuit and measure the resistance between the +15 volt bus and ground; you should measure approximately 50 kilohms or more.

Insert all ICs into their sockets. Set the transmitter nearby to operate continuously with the chosen channel. Adjust L1 by observing the waveform at the collector of Q2 with an oscilloscope, while setting the tuning slug for maximum amplitude; a normal indication is 125-kilohertz pulses at 5 volts peak-to-peak. Check the output of Q3 for a pulse train at about 15 volts peak amplitude.

Verify operation of the receiver by momentarily actuating the correct transmit channel switch, and holding it on for approximately a ½ second to allow the transmitter to output at least two complete pulse trains. When the transmit switch is released, the piezo buzzer should sound for about a second or so.

If the receiver is operating as described, it may be placed in a remote location and operated to verify that it receives and detects the transmitted pulse train from the transmitter. If the receiver does not respond to the transmit signal, make sure that the correct channel has been actuated. Try all transmit channels to see if one of the other channels will actuate the receiver.

Verify the operation of decoder IC5 by checking the serial data input terminal (pin 9) for the 15-volt pulse train as detected by Q3. The valid transmission output terminal (pin 11) should go high as long as the correct transmit channel switch is held on. Check the logic levels at the address inputs of IC5; all inputs should be at about +15 volts DC except the selected input which should be grounded.

If the valid transmission output of IC5 (pin 11) is working, IC6 should be triggered when the transmit switch is released. That causes pin 3 of IC6 to go to about 15 volts, and turn on the buzzer.

Using the system

The transmitter is placed at any desired control location and plugged into a nearby AC receptacle. When it is desired to transmit a control signal, the appropriate transmit switch is actuated for at least a ½ second to transmit two complete pulse trains. The selected receiver will then respond.

The receiver, as described, is designed as a simple remote-actuated buzzer. One application for this would be a wireless doorbell system that requires no modifications. However, the circuit can be modified for many applications. For example, the pulse output of IC6 can operate a relay which then can control other devices. Ω