Infrared light-beam relay

Interested in capturing spectacular wildlife shots like the one on our front cover? You can, by building this new infrared relay unit. It uses only two CMOS ICs plus a few transistors, and can also be used as a shop entry monitor, an "invisible" burglar alarm, or even as a target game.

by RON DE JONG

Light beam relay systems are popular for many applications but most suffer the disadvantage of using a visible light beam. These circuits are invariably quite limited in range, are critical to set up and adjust, and can be falsely triggered by changing ambient light conditions. Indeed, most simple light beam relay systems are virtually useless in bright sunlight and are suitable only for fixed installations indoors.

All these problems are overcome in the circuit presented here. It uses a modulated beam of infrared light for greatly improved range and sensitivity, and will operate reliably in conditions ranging from total darkness to bright sunlight without adjustment. Other advantages include insensitivity to changing ambient light levels and the invisible nature of the beam itself (important in burglar alarm applications).

One of our photographers was quick to realise that the unit could be used as a camera trip for photographing wildlife. The receiver and transmitter are both battery powered so the relay and camera unit can be quickly set up and left unattended. If a bird or other animal interrupts the infrared beam, the relay triggers a motor-driven camera and flash and the camera winds on ready for the next unsuspecting subject. The results, as you can judge by our front cover and some of the other photographs in this article can be spectacular.

The invisibility of the infrared beam also makes the relay ideal for use as a burglar alarm. The relay could be positioned across an appropriate doorway or even across a whole room so that when the invisible beam is broken by an intruder, an alarm is activated. Since the unit is battery-powered, it is completely portable and easy to set up in any location. Alternatively, the unit can be powered from a 9V DC plugpack and the batteries used as a back up.

Conventional applications such as a shop entry indicator are also possible, or it could be used to automatically open and close doors. In the industrial field, an infrared relay can be used for counting objects on conveyor lines etc.

We also found that with a slight modification we could make the relay operate as a simple target game. In this case, the infrared source can be fitted inside a toy gun. When the gun is aimed directly at the sensor and the trigger pressed, a buzzer in the receiver sounds to indicate a "good shot".

Physically, the infrared relay consists of a transmitter and a separate receiver, both of which are housed in small plastic zippy boxes. Each unit is powered by its own 9V battery (Eveready 216 or similar) and these should provide about 50 hours continuous operation. Battery life can be increased by using alkaline cells if desired.

An open-collector transistor is used at the output of the receiver and can be used to activate an internal buzzer, a relay, or other low power devices. For

Taken from colour slides, these b&w reproductions do not do justice to the actual results. Note that the series is NOT in sequence.

photographic work, the open-collector output can be used to directly trigger most motor-driven cameras.

The range of the relay – ie the maximum distance between transmitter and receiver – is about five metres in sunlight. No lenses are used and no adjustment of sensitivity is required – just point the transmitter in the general direction of the receiver and you're in business. If greater range is desired, the transmitter current can be increased (more on this later).

HOW IT WORKS

Looking now at the circuit diagrams for the transmitter and receiver we can see that two CMOS ICs and six transistors are used. The circuit is more complex than the usual light beam relay – which typically includes a light bulb, a lens and a phototransistor – but then it has quite a few more features.

The source of light in the transmitter is an infrared LED and rather than merely providing a continuous source of light, it is flashed on and off at 10kHz. This is done so that the receiver can selectively amplify the signal from the transmitter and completely reject ambient light. The result is a high degree of sensitivity without any need of adjustment and it also allows us to use quite low current drive through the transmitting LED.

A standard three-inverter CMOS oscillator is used in the transmitter and consists of gates IC1a,b,c from a 4011 quad NAND package. The frequency of the oscillator is determined by the 4.7kΩ resistor and .0068μF capacitor and is nominally 10kHz. Gate IC1d permanently enables the oscillator, since its output is always high.

Some readers may be wondering why IC1d has been included in the circuit. Why not simply connect pin 2 directly to the positive supply rail? The reason is simply that the transmitter printed circuit board pattern is exactly the same as that used in a previous project (Infrared Remote Volume Control, October 1979). The circuit configuration, however, is slightly different and leaving IC1d in circuit happens to be the easiest way of adapting the board for its present application.

Either way, it makes no difference to circuit operation.

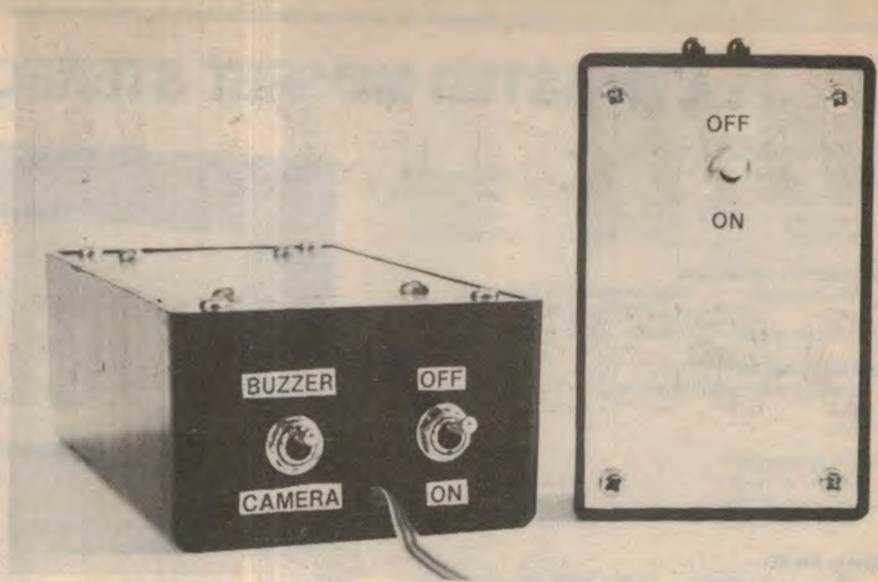
The CMOS oscillator drives an output stage consisting of a BC547 transistor (Q1) and two infrared light emitting diodes. The infrared diodes used are Philips type CQY89A. They are plastic-pack devices and are similar in appearance to the familiar red LED except that the plastic encapsulation is a deep violet colour.

Current drive through the two LEDs is limited by the 680Ω resistor. If greater range is required, this resistor may be reduced to a minimum value of 150Ω with a consequent adverse effect on current consumption. Do not reduce the value of the resistor unless you do require the greater range, otherwise the relay may not trip reliably close in due to reflections caused by the high light output.

Infrared light generated by the LEDs is picked up at the receiver by a special infrared photodiode. This is also a Philips device type number BPW50, and is specifically designed to match the CQY89A LED. The BPW50 also has an integral infrared filter that almost completely rejects visible light.

Referring to the circuit diagram of the receiver, the photodiode is connected with its cathode to the +9V rail via an RC decoupling network, while the anode is connected via a 470kΩ resistor to ground. In operation the photodiode acts as a current source, ie it generates a current proportional to the incident light. This current signal is converted to a voltage signal by the 470kΩ resistor.

Clearly the larger the resistor value is series with the photodiode the greater



The completed infrared relay receiver together with its companion transmitter (right). Both units are compact, battery powered and portable.

the voltage output. There is a limit to all good things though, and the maximum resistance we can use is set by the highest frequency we want to receive, the junction capacitance of the photodiode, and the input capacitance of the following stage.

We have reduced the junction capacitance to a minimum in this circuit by reverse biasing the photodiode. This theoretically results in a capacitance of about 10pF which, combined with the 470kΩ resistor and the 5pF (approx) capacitance of the following stage, gives a rolloff above 22kHz.

The signal from the photodiode is fed to the input of Q1, a 2N5485 JFET. The FET is connected as a "source follower" and offers a high input impedance, a low output impedance, and a voltage gain of 0.3 to 0.5. This sort of impedance matching would be almost impossible to obtain using transistors and the circuit would be more complex than the simple "self biasing" JFET circuit we have used.

Output impedance of the FET stage is about 100Ω and this drives a bandpass filter consisting of transistors Q2 and Q3. The centre frequency of the filter is about 10kHz and it has a Q of 10; ie the bandwidth is 1kHz. This bandwidth is wide enough to pass the 10kHz signal from the transmitter, even allowing for some mistuning, yet effectively eliminates interference from other sources (eg fluorescent lights).

Disregarding the two .0068μF capacitors for the moment, Q2 and Q3 form a two-stage inverting amplifier. Both transistors operate as common emitter amplifiers, with the second stage providing two separate outputs: one from the junction of the two 330Ω resistors and the second from Q3's collector. The first output has a low impedance and is used to drive the filter and to provide DC feedback via the 47kΩ resistor to bias Q2.

As already mentioned, the amplifier is used as a "multiple feedback" bandpass filter. The filter components are the two .0068μF capacitors and the 47kΩ bias resistor which, together with the low output impedance of the previous FET stage, determine the centre frequency and Q of the filter.

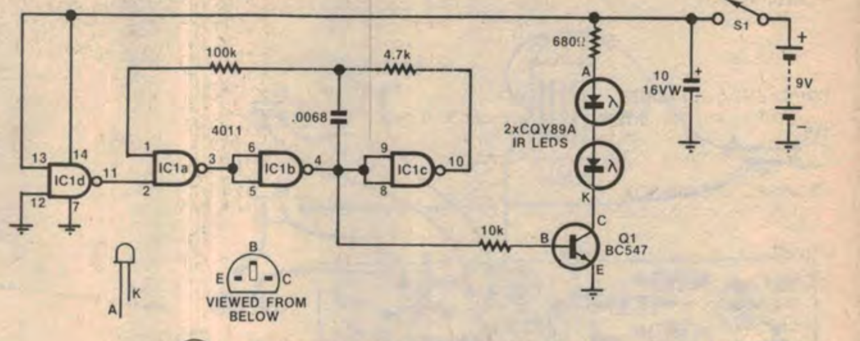
The collector output of Q3 provides an amplified version of the filter output. This output is DC-coupled to the next stage which consists of transistor Q4 in another common emitter amplifier circuit. Gain of this stage is at least 150. A 0.1μF emitter bypass capacitor is included to provide further attenuation of unwanted low frequency signals.

Following Q4 the signal is coupled to IC1a which is a CMOS Schmitt trigger. When the signal peaks from Q4 exceed the upper and lower trigger thresholds of the Schmitt trigger, the device will square up the signal and generate a constant 10kHz square wave output. If the infrared beam is interrupted, or the input signal drops below the trigger thresholds, the 10kHz output signal will cease and the Schmitt will remain in its last state; ie either high or low.

To convert the presence or absence of the 10kHz signal into a simple high or low signal, the output of IC1a is rectified and filtered by two 1N4148 diodes, the .0022μF and .01μF capacitors, and a 100kΩ resistor.

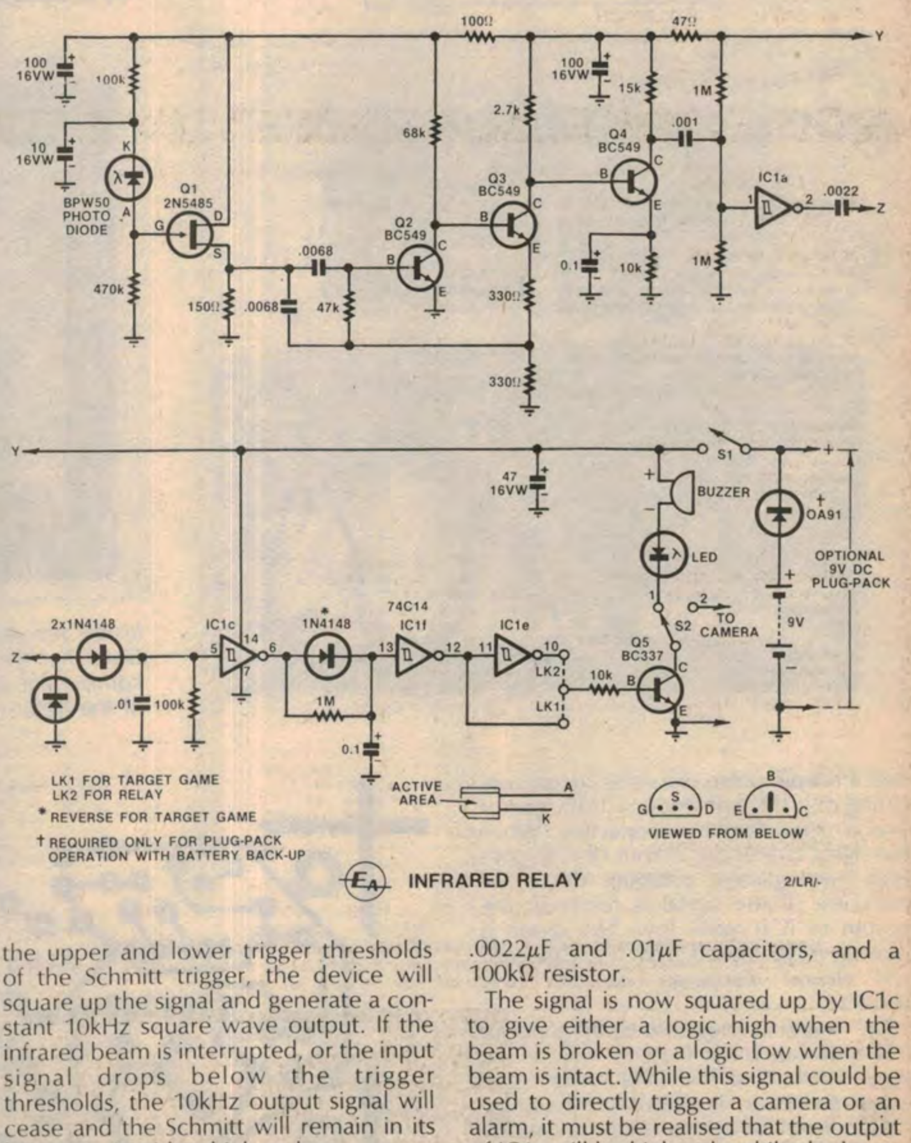
The signal is now squared up by IC1c to give either a logic high when the beam is broken or a logic low when the beam is intact. While this signal could be used to directly trigger a camera or an alarm, it must be realised that the output of IC1c will be high only while the beam is broken. If the beam is only broken momentarily, the alarm time will be very short or the camera may not trip.

To overcome this problem we have ad-

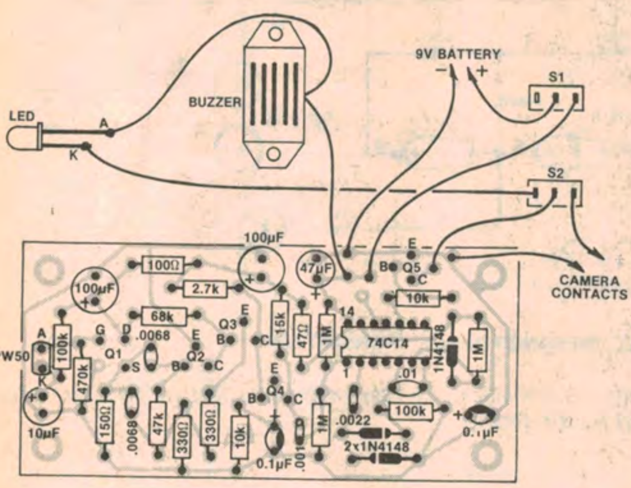


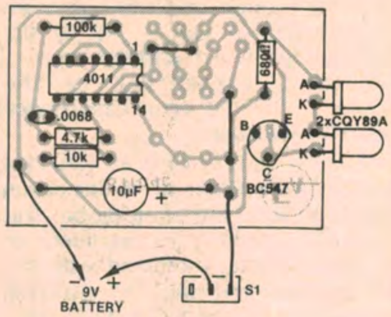
INFRARED RELAY TRANSMITTER 2/LR/-

Output from the transmitter is a 10kHz pulse train of infrared light which is picked up and selectively amplified by the receiver.

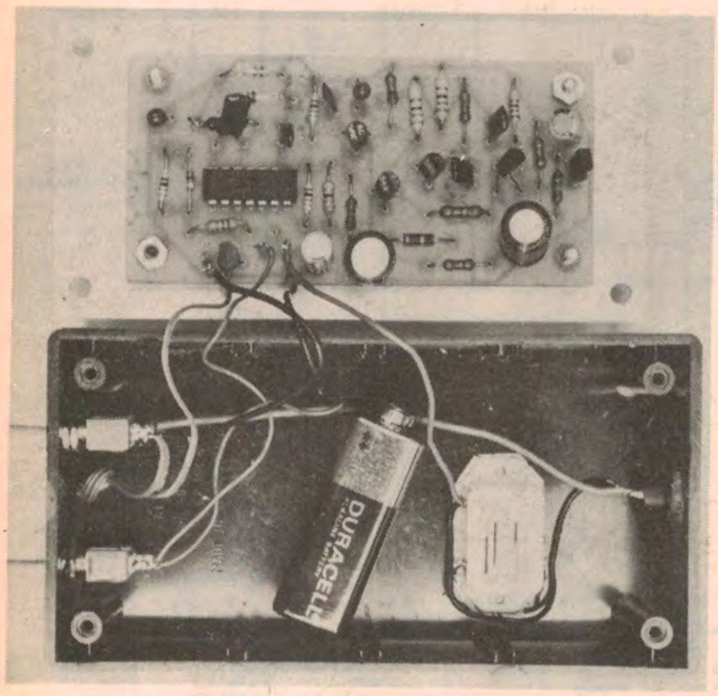


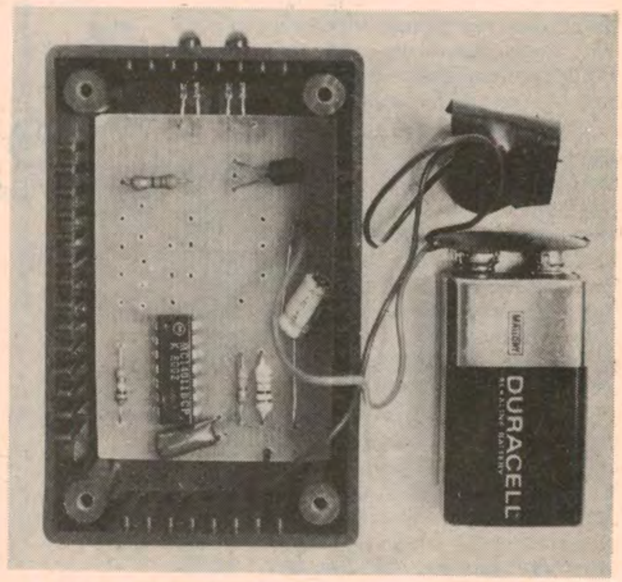
INFRARED RELAY 2/LR/-





Here are the wiring diagrams for the receiver (left) and the relay transmitter (right). The buzzer can be replaced by a 2.2kΩ resistor if not required.



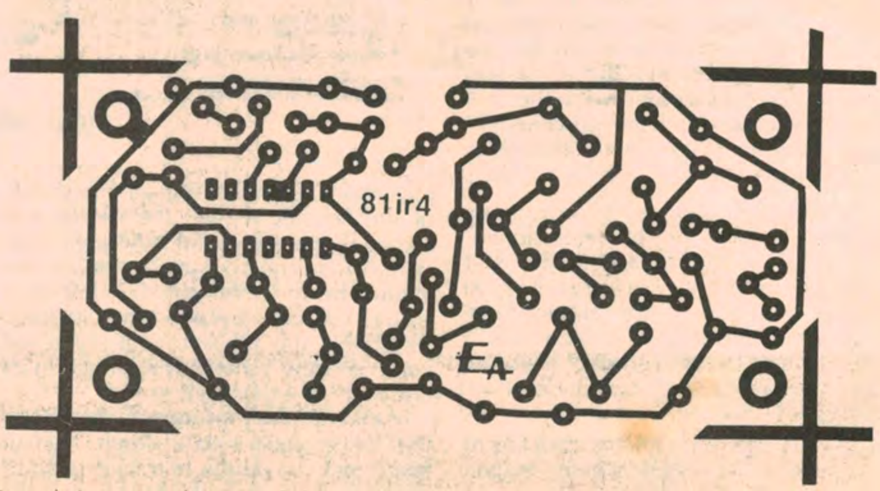


Inside the completed transmitter and receiver units. Note that the two wire links shown on the transmitter component overlay have been wired to the underside of the PCB.

ded a simple pulse extender circuit consisting of a 1N4148 diode, a 1MΩ resistor and a 0.1µF tantalum capacitor. When the signal ceases the output of IC1c goes high, immediately charging the 0.1µF capacitor. If the signal is restored, the output of IC1c goes low. The diode is now reverse biased and the capacitor will slowly discharge via the 1MΩ resistor.

The length of the pulse to the input of IC1f will thus be at least as long as the time constant of the 1MΩ resistor and 0.1µF capacitor, ie about 0.2 seconds. This is long enough to trigger a camera but the delay can be increased to two seconds for an alarm by changing the 0.1µF capacitor to 1µF.

IC1f and IC1e square up the signal from the pulse extender and drive transistor



Actual size reproduction of the receiver PCB pattern.

The infrared target game

By making a few circuit changes, the infrared relay circuit is easily converted to a target game. As shown below, we mounted a modified transmitter circuit inside a toy plastic gun and altered the receiver so that it now activates the LED/buzzer combination when a signal is received.

The game works as follows: normally, the transmitter is disabled and no infrared light reaches the receiver. To "hit" the target, one has to aim the gun directly at the photodiode in the receiver and press the trigger button to activate the transmitter. A hit is recorded when the buzzer sounds and the LED comes on.

The circuit for the target game is quite similar to the infrared relay, the main difference being the modified transmitter circuit. Two changes are also required to the receiver, and these are shown on the circuit diagram: ie, the diode connected to pin 6 of IC1c should be reversed and the 10kΩ resistor to the base of Q5 should be connected to pin 12 of IC1f instead of pin 10 of IC1e.

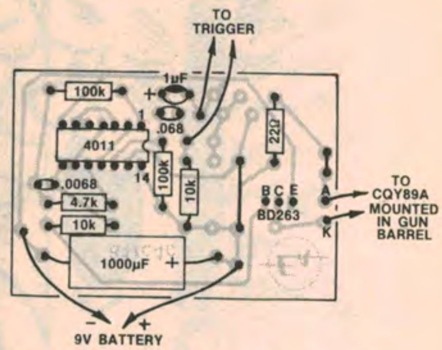
The effect of these changes is that the buzzer will now sound for a brief period whenever the transmitter signal is received. The duration of the buzzer will be about 0.2 seconds, but this can be extended to one second by increasing the 0.1μF capacitor connected to pin 13 of IC1f to 0.47μF.

The changes in the transmitter circuit are more complex, necessitating separate circuit and wiring diagrams. Referring to the circuit we can see that it still uses a 3-gate CMOS oscillator driving a transistor and an infrared LED. However, the LED current limiting resistor has been reduced to 22Ω, resulting in a much greater LED current and hence a greater infrared light output. We'll explain why this is necessary later.

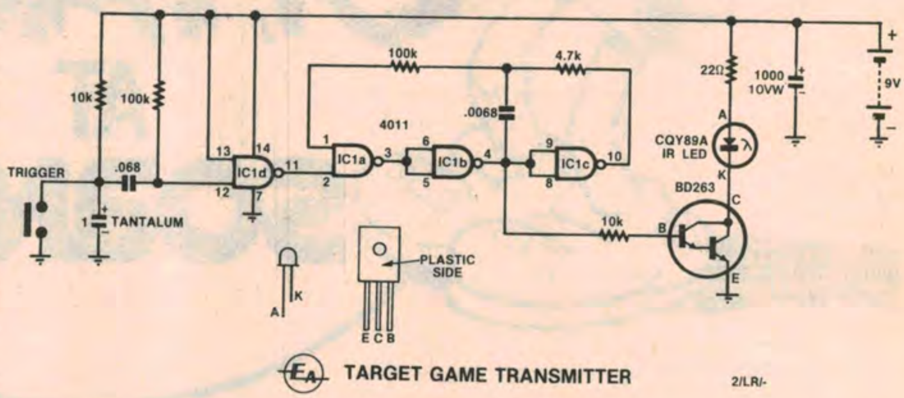
Another change involves the gating for the oscillator. Whereas the oscillator was always on in the relay, it is now only turned on for a brief 7ms period each time the trigger button is pressed. This is accomplished by IC1d, a NAND gate, which has its output connected to pin 1 of IC1a and so can enable or disable the oscillator. The input of IC1d, pin 12, is connected to an RC trigger network consisting of 10kΩ and 100kΩ resistors and a .068μF capacitor.

The trigger circuit works as follows: when the trigger switch is open circuit, both sides of the .068μF capacitor are pulled high due to the 10kΩ and 100kΩ pullup resistors. The output of IC1d will thus be low and the oscillator will be disabled. When the trigger is pressed the switched side of the .068μF capacitor is pulled down to ground and, because the voltage across the capacitor cannot change immediately, pin 12 of IC1d will also be pulled low, enabling the oscillator.

Eventually, the pin-12 side of the



Component overlay and circuit diagrams for the target game transmitter.



Q5 so that when the beam is broken Q5 turns on. The collector output can be switched to an internal buzzer and LED which can be used directly as the alarm in a shop minder situation, or as a quick indication that the unit is working when used as a camera trip. The output can also be switched to an external alarm (eg a Sonalert), or directly to a camera.

Some readers may wish to eliminate the internal buzzer, yet retain the LED indicator. In this case, the buzzer should be replaced by a 2.2kΩ resistor to limit the current through the LED (ie connect a 2.2kΩ resistor in series between the LED and the positive supply rail).

If the unit is used as a camera trigger, a motor driven camera is necessary for unattended operation. The actual contacts from the camera should be connected between ground and the collector output so that the transistor just looks like a switch. We found that this works quite well and has advantages over a relay output in terms of power consumption and speed — the only delay is the time taken for the reflex lens of the camera to swing down.

That virtually completes our discussion of the circuit. The only additional points to note are the optional 9V DC plugpack supply and the use of several decoupling capacitors in the supply to prevent feedback in the amplifier section. Note that the diode in series with the battery is required only for plugpack operation with battery backup, and can be omitted for battery or plugpack operation alone.

CONSTRUCTION

Most of the components in the receiver mount on a single printed circuit board (PCB) board coded 81ir4 and measuring 97 × 46mm. Mount the components on the PCB according to the component overlay diagram provided, paying particular attention to the orientation of transistors, diodes and electrolytic capacitors. The BPW50 photodiode has its sensitive area on the flat front of the package and its anode lead is longer than the cathode.

The receiver is housed in a small plastic zippy box measuring 130 × 68 × 41mm. When the board is completed it can be mounted to the aluminium lid of the box using machine screws and nuts. Note

The completed target game transmitter inside a plastic gun. Although the PCB layout differs from the overlay, the two are electrically identical.

.068μF capacitor will charge up via the 100kΩ pull up resistor to the transition voltage of the CMOS gate. IC1d's output will then suddenly switch low, disabling the oscillator. The total period for which the oscillator is enabled is set by the time constant of the .068μF capacitor and 100kΩ resistor, ie about 7ms.

The 1μF tantalum capacitor is included to provide switch debouncing.

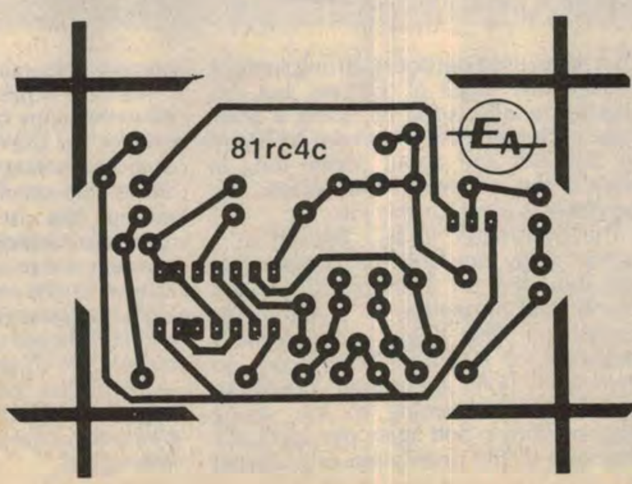
Whenever the trigger button is presed therefore, a brief 7ms 10kHz pulse of infrared light is emitted. This will normally trigger the receiver, regardless of the direction in which the transmitter is pointed. Clearly this is unsuitable for a target game so when the transmitter is installed in a suitable plastic housing, say a toy gun or rifle, the light output from the infrared LED has to be collimated or restricted to a narrow beam.

While the beam could be collimated with a lens, a far simpler solution is to use two or more opaque discs with holes drilled in their centres. If the LED and discs are lined up and spaced at say 4cm intervals, and if the holes are sufficiently small, quite a narrow beam results. A single disc made of aluminium foil with a small pin hole also gave good results.

Note that very little of the LED's output is actually used and this is why it is pulsed on so hard.

The case used for the transmitter is up to the constructor but as a guide we have included a photograph of one unit we built. We used a discarded gun from a TV game and found it quite easy to adapt to its new role.

Actual size artwork for the transmitter PCB. The same board is used for both the relay transmitter and the target game transmitter.



PARTS LIST

RECEIVER

1 PC board, code 81ir4, 97 × 46mm
1 zippy box, 130 × 68 ×41mm
2 miniature SPDT toggle switches
1 Solid state buzzer
1 large LED & mounting bezel
1 9V battery, Eveready 216 or equivalent
1 battery clip to suit
1 74C14 CMOS Schmitt trigger IC
1 2N5485N channel JFET
3 BC549 NPN transistors
1 BC337 or BC547 NPN transistor
1 BPW50 infrared photodiode
3 1N4148 diodes
1 OA91 diode (optional for battery back up)

RESISTORS: (¼W, 5%)
3 × 1MΩ, 1 × 470kΩ, 2 × 100kΩ, 1 × 68kΩ, 1 × 47kΩ, 1 × 15kΩ, 2 × 10kΩ, 1 × 2.7kΩ, 2 × 330Ω, 1 × 150Ω, 1 × 100Ω, 1 ×47Ω

CAPACITORS
2 100μF 16VW PC electrolytics
1 47μF 16VW PC electrolytic
1 10μF 16VW PC electrolytic
2 0.1μF 25VW tantalum
1 .01μF greencap
2 .0068μF greencap
1 .0022μF greencap
1 .001μF greencap

RELAY TRANSMITTER

1 PC board, code 81rc4c, 61 × 42mm
1 zippy box, 83 × 54 × 28mm
1 SPDT miniature toggle switch
1 9V battery, Eveready 216 or alkaline equivalent
1 battery clip to suit
1 4011 CMOS quad NAND gate
1 BC337 or BC547 NPN transistor
2 CQY89A infrared LEDs
1 10μF 16VW electrolytic capacitor
1 .0068μF greencap capacitor

RESISTORS (½W, 5%)
1 × 100kΩ, 1 × 10kΩ, 1 × 4.7kΩ, 1 × 680Ω

TARGET GAME TRANSMITTER

1 PC board, code 81rc4c, 61 × 42mm
1 suitable plastic gun (see text)
1 momentary contact pushbutton
1 9V battery, Eveready 216 or alkaline equivalent
1 battery clip to suit
1 4011 CMOS quad NAND gate
1 BD263 NPN Darlington transistor
1 CQY89A infrared LED
1 1000μF 10VW axial lead electrolytic capacitor
1 1μF 16VW tantalum capacitor
1 .068μF greencap capacitor
1 .0068μF greencap
RESISTORS (¼W, 5%)
2 × 100kΩ, 2 × 10kΩ, 1 × 4.7kΩ, 1 × 22Ω.

THE SETUP! (left): this retouched photograph shows the setup used by Sungravure photographer Bob Donaldson to capture the superb shot on our front cover. The transmitter and receiver units are mounted on wooden beams, and arranged so that the Infrared Relay is triggered as a bird comes in to land at a food table (centre foreground)!

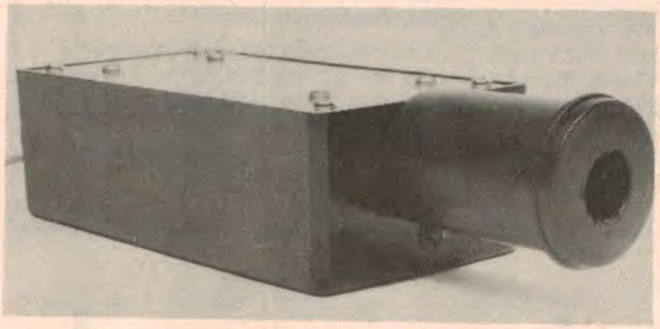
Photographic details are as follows: Camera — 35mm Leica R3 SLR fitted with motor drive (essential) and a 250mm lens; Flash rate — 1/2,500s (high speed necessary to freeze wing motion); Film — Kodak EPR ASA64; Aperture — F8.

In practice, the relay units are moved closer together than shown here — just outside the picture area — so that the subject will be correctly centred. The camera is mounted about 1 metre from the subject while two flash units with variable power ratio controls are used, one on either side of the camera.

that the earth track on the PCB goes to one of the mounting holes so that when the board is mounted the lid is earthed. This is to provide some measure of shielding.

Now drill holes in the box for the on/off and buzzer/camera switches S1 and S2, as well as an exit hole for the camera lead. Alternatively use a DIN socket to mate with a suitable camera lead. Drill a 10mm hole for the light beam to enter the receiver, positioning it so that the centre of the hole lines up with the centre of the BPW50 photodiode.

When the unit if fully assembled the photodiode should be recessed about 20mm from the light beam entry hole. This does not reduce the range of the unit but is intended to prevent direct light from falling on the BPW50 and thus reducing its sensitivity. We still found that when used outdoors, strong sunlight reduces the range of the unit, but this can be readily cured by fitting a small tube of non-reflective material 20-30mm in diameter and about 50mm long in front of the receiver. A black plastic film cannister is ideal for this job.



A plastic film canister makes an ideal light-tube for the receiver.

The transmitter is also housed in a plastic zippy box and the components are mounted on a single PCB coded 81rc4c and measuring 61 × 42mm. As mentioned, this board was originally designed for a remote control unit so quite a few holes are unused. Mount the components according to the wiring diagram shown and again pay particular attention to the orientation of polarised components, including the infrared LEDs.

The only holes which need to be drilled in the zippy box are two holes at one end for the CQY89A infrared LEDs and a single mounting hole on the aluminium lid for the on/off switch. This done, the wiring can be completed and the transmitter/receiver combination tested.

Switch the receiver on and switch the output to the internal buzzer and LED. With the transmitter off, both the buzzer and LED should turn on. Now switch the transmitter on and aim it at the receiver – the buzzer should stop. Finally, check that the buzzer/LED combination is activated whenever the beam is interrupted.

We estimate that the current cost of parts for this project is approximately

$40

including sales tax.