PHOTON TORPEDO

A low-cost alien exterminator with sound effects!

There you are warping among the deep space galaxies in the Starship "Enterprise" (or whatever other name takes your fancy) when you are attacked by hostile aliens. Are you worried? Not in the slightest — not when you've got a photon torpedo with fancy sound effects to defend yourself!

by JOHN CLARKE

For those who haven't already guessed, "Photon Torpedo" is our latest electronic game. It has all the ingredients necessary for a thriller – a space theme, a starship, hostile aliens, and a means of destroying the aliens. Add to that the realistic sound effects and you will almost be able to smell the smoke from the battle!

Of course, our new "Photon Torpedo" game will prove quite popular with those who cannot afford one of those fancy "computerised on-screen" games with its multi-coloured aliens. Or maybe you are sick of pouring money into the slot of a parlour-game machine, only to be quickly wiped out by a barrage of bombs and sundry missiles. Photon Torpedo overcomes these miseries – at around $24 it won't break the bank and, best of all, the aliens don't shoot back.

In fact, it's more like a turkey shoot. The aliens simply fly past and you try to zap them!

However, you don't have things all your own way. The alien craft are rather unpredictable and can move fast one moment and slowly the next. Consequently, it is quite difficult to hit the alien ships.

In addition, the alien craft are very quiet and sneaky so no sound effects have been provided for these. All the sound effects are generated when the photon torpedo is fired and when an alien craft is hit. The photon torpedo has a high-pitched whine when charging ("fire" button pressed) which dies away in frequency when fired ("fire" button released). When an alien craft is hit, a low frequency "groan" is produced to indicate death and destruction.

So the sound effects really add interest to the game.

To enhance the game even further, a Scotchcal artwork depicting a deep space background has been produced. A horizontal row of nine circular LEDs is used to depict the position of the alien craft, while the photon torpedo is represented by a vertical row of eight rectangular LEDs. The fact that the LEDs are physically butted together produces a good torpedo effect.

THE CIRCUIT

At the heart of the circuit are two 4017 decade counter/divider ICs (IC1, IC2) which drive the LED columns. These devices have 10 outputs, usually labelled "0" to "9". Only one of these outputs is high at a time and they turn on in sequence for a period of one clock pulse as the counter is clocked; from "0" to "9" then back to "0" and so on. They also have a reset input which can be used to reset the counter to zero at any point in this sequence.

IC1 drives the nine horizontal row LEDs via outputs "0" to "8" to represent the position of the alien craft. These LEDs are arranged on the PC board so that the eighth LED is intersected by the vertical column LEDs (the photon torpedo) driven by IC2. In both cases, there is a single extra LED immediately following the intersection.

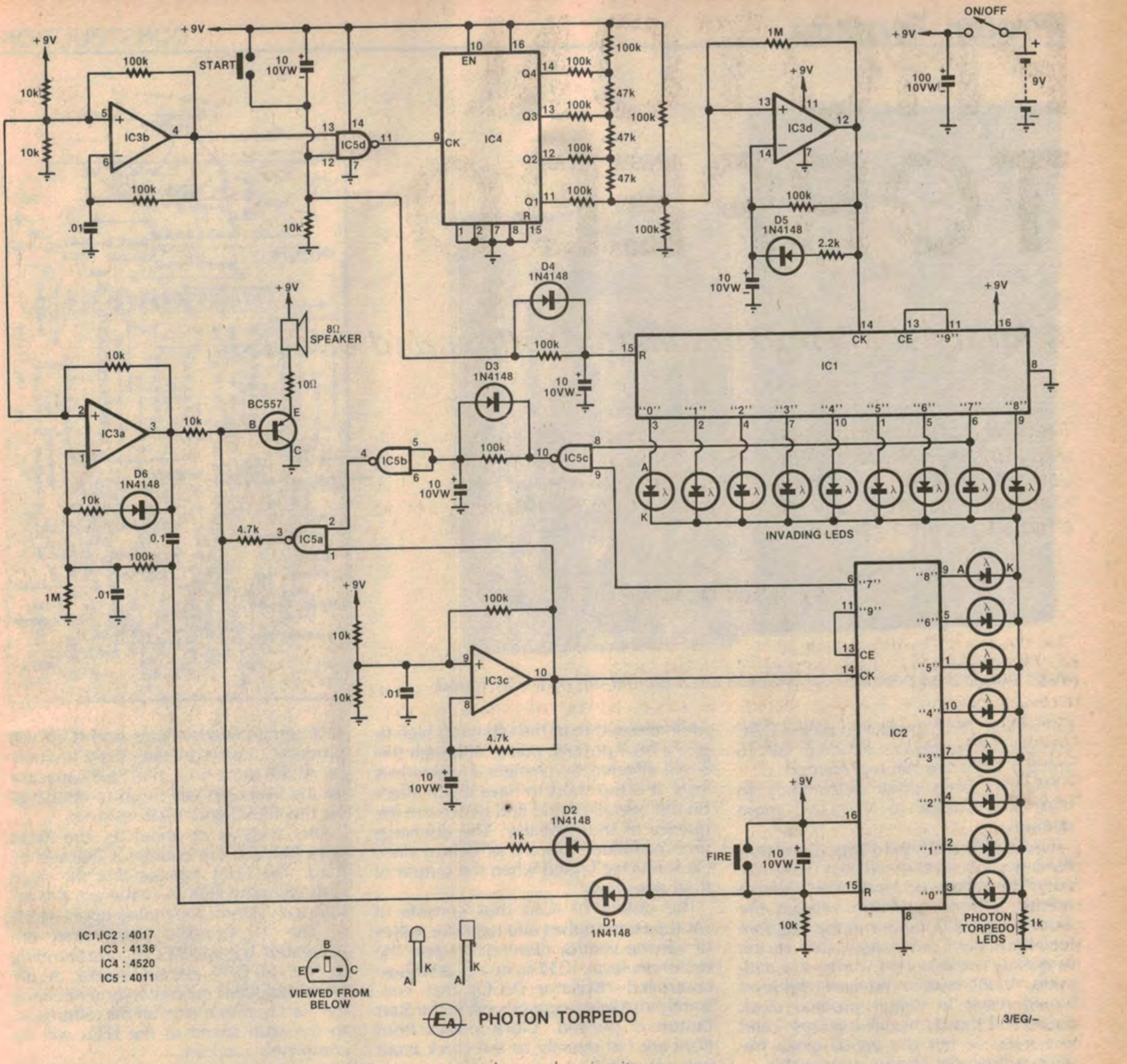
At the intersection, it is the row LED which is activated by output "7" (pin 6) of IC1. Since we cannot have two LEDs at the same point; the corresponding column LED for the photon torpedo is "ghosted". Instead of actually driving a LED, output "7" of IC2 (pin 6) is connected to one input of NAND gate IC5c.

The Start button initiates the alien attack and the Fire button exterminates them.

The other input to IC5c is taken from output "7" of IC1 (in parallel with the LED) and, when both inputs go high, the output of IC5c goes low.

Note that a single 1kΩ resistor limits the current through all the LEDs, the cathodes of which are tied together. When one LED is on, the remainder are reverse biased.

Clock pulses for IC2 are derived from IC3c, a 4136 op amp wired as a Schmitt trigger oscillator. A 10μF electrolytic capacitor connected to the inverting input is charged via a 4.7kΩ resistor towards the positive hysteresis point of the Schmitt trigger whenever the output (pin 10) is high. When this voltage is reached, the output of IC3c goes low and discharges the capacitor to the



Five low-cost ICs, 17 LEDs and a single PNP transistor make up the circuit.

lower hysteresis point. The output then switches high again and the cycle is repeated.

The hysteresis voltages are set by the 100kΩ feedback resistor between the non-inverting input and output, and by two 10kΩ resistors which hold the non-inverting input at half supply voltage.

When the fire button is pressed the Reset pin (pin 15) of IC2 is forced high, activating the "0" LED. Upon release of the fire button there follows a 100ms switch debounce period, after which the Reset goes low and the LEDs "fire" rapidly up to the final LED on output "8". When the "9" output subsequently goes high, the Clock Enable (CE) input (to which it is directly connected) also goes high, stopping the counter.

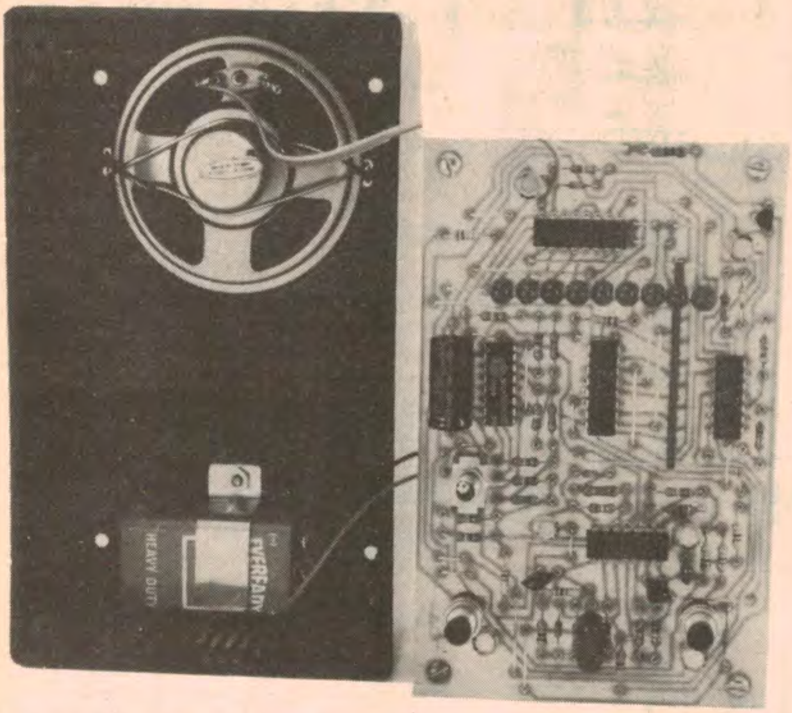
In other words, IC2 remains latched with output "9" high until the Reset pin is again forced high by pressing the fire button. None of the LEDs making up the photon torpedo are on during this standby condition.

The clock circuit used to drive IC1 is rather more elaborate than that used for IC2. In particular, we have added extra circuitry to achieve a random sweep speed for the horizontal LEDs.

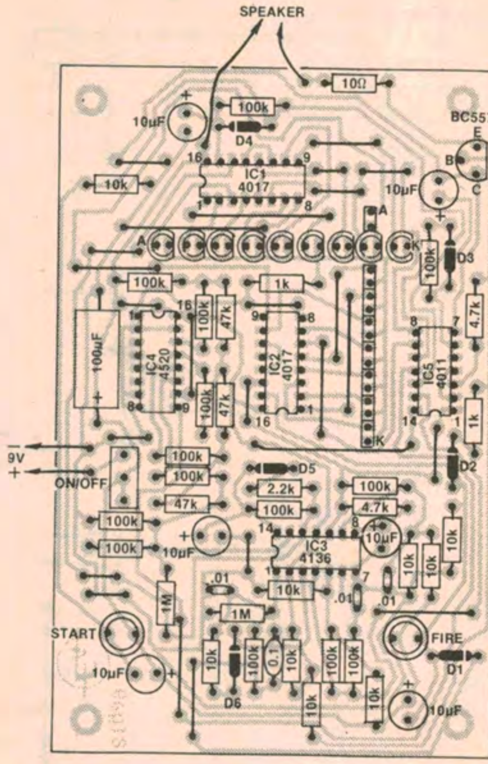
IC3b is a high-frequency Schmitt trigger oscillator, the output of which is gated by NAND gate IC5d. When the Start button is pressed, pin 12 of IC5d is forced high and clock signals from IC3b are gated through to the clock input of IC4. The Reset pin of IC1 is also forced high via a 1N4148 diode, thus preventing the row LEDs from traversing and keeping the "0" LED alight.

IC4 is a 4520 4-bit binary up-counter which continually counts while there is a clock input. The binary outputs Q1 to Q4 are connected to an R-2R ladder network to give a discrete voltage output representative of the the binary count number – in other words, a digital-to-analog converter (DAC). The output of the DAC is attenuated and biased to half the supply voltage by two 100kΩ resistors.

Normally, Q1 to Q4 are the reverse order to that used in our circuit, so that a linear ramp with 16 discrete voltage steps is produced. In our circuit, however, a linear ramp is not produced. By reversing Q1 to Q4, as we have done,



Make sure that all polarised components are mounted the right way round.



the voltage levels produced by the DAC are out of sequence, although all 16 voltage levels are still represented.

This has been done deliberately to make the output of the DAC more random.

IC3d is also a Schmitt trigger oscillator, the hysteresis level of which is determined by the voltage set by the DAC. With a normal Schmitt oscillator, without the diode and 2.2kΩ resistor in the negative feed-back path, an overall shift in the hysteresis points simply varies the duty cycle. An increase in the hysteresis level would result in longer positive clock pulses and shorter negative pulses – and vice versa – but the actual clock frequency does not change appreciably.

However, we want the clock frequency to change so that the row LEDs will scan at random speed. By adding diode D5 and the series 2.2kΩ resistor, the 10μF timing capacitor will charge rapidly when the output of the Schmitt is high to give a brief positive pulse. Although this is still affected by changes in hysteresis level, it is too short to have much affect on the overall period and hence the frequency of the oscillator. The discharge time continues to vary as before since D5 is reverse biased when the output of IC3d goes low.

The output of IC3d thus consists of short positive pulses and negative pulses of varying widths, depending upon the hysteresis level. IC3d is, in fact, a voltage controlled oscillator (VCO) that constantly changes frequency while the Start button is pressed. Clock pulses from IC3d are fed directly to the clock input (pin 14) of IC1.

When the Start button is released, pin 12 of IC5d is pulled low and no further clock pulses are passed from IC3b to IC4. Depending on just when IC4 is stopped, the output of the DAC will remain at a certain fixed voltage and IC3d will produce a corresponding fixed frequency. At the same time, the 10μF capacitor on the Reset pin will begin to discharge via the 100kΩ and 10kΩ resistors.

After a delay of about 1s, the Reset goes low and the counter is clocked by IC3d. The LEDs representing the alien craft will now light in sequence, the actual scan speed depending upon which of the 16 possible frequencies are generated by the VCO (corresponding to the 16 DAC output levels). A difference of a few milliseconds in releasing the Start button makes all the difference, so the scan speed of the LEDs will be completely random.

Note that the diode in parallel with the 100kΩ resistor is to allow an instantaneous reset when the Start button is pressed. When the Start button is released, this diode is reverse biased. As with IC2, IC1 is latched when the "9" output goes high (ie at the end of the scan) and remains that way until the counter is reset.

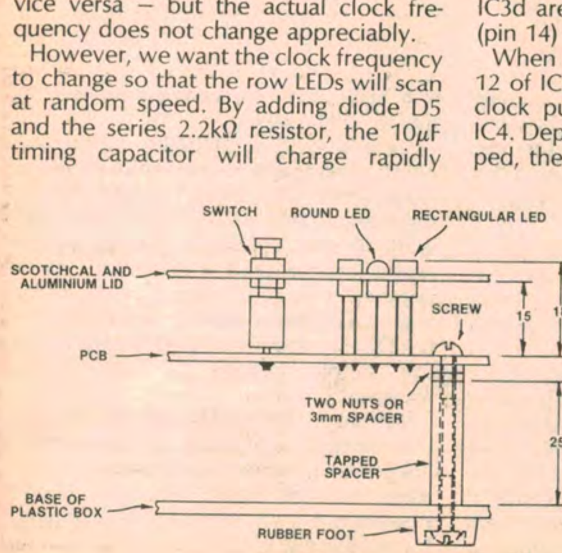


FIG. 1

Fig. 1: Diagram showing the general mechanical assembly of the game. The tops of the LEDs should be 18mm above the PCB.

SOUND EFFECTS

Let's now look at the sound effects circuitry. IC3a produces the Photon Torpedo sound, while oscillator IC3c is tapped off to provide the sound effect when the alien craft is hit.

Operation of IC3a is as follows: When the Fire button is pressed the 0.1μF capacitor is charged via diode D1, the inverting input is pulled high, and the output goes low. The .01μF capacitor on the inverting input then discharges through the 10kΩ resistor and diode D6 and the output switches high again.

This cycle is repeated, with the .01μF capacitor continually charging via D1 and the 100kΩ resistor and discharging via the 10kΩ resistor and D6. IC3a thus generates a constant output frequency whenever the Fire button is pressed and this provides the "charging" sound for the photon torpedo.

Upon release of the fire button, D1 is reverse biased and has no further affect on the circuit. The .01μF capacitor now charges through the 100kΩ resistor and 0.1μF capacitor and discharges through the 10kΩ resistor and diode. Because of the mismatch between the 100kΩ and 10kΩ resistors, the 0.1μF capacitor will eventually discharge and become positive at the output side of the op amp. As the 0.1μF capacitor discharges, the charging current supplied to the .01μF capacitor decreases and so the frequency of the oscillator decays.

This decaying frequency produces the sound when the photon torpedo is fired and is designed to stop when the last LED lights.

Refer back now to IC5c. Its output goes low when the row LED is "hit" by the photon torpedo (pin 6 of IC1 and IC2 both high) and this low is inverted by IC5b to give a logic high on pin 2 of

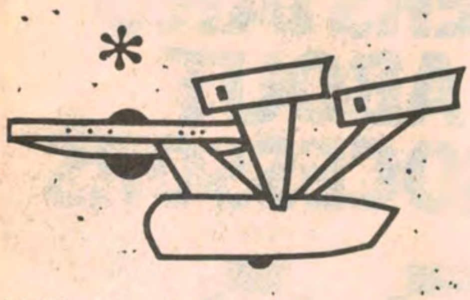
PARTS LIST

1 plastic utility box, 158 × 95 × 50mm
1 PC board, code 81ga9, 132 × 83mm
1 Scotchcal front panel, 91 × 154mm
1 57mm-diameter loudspeaker
1 9V No. 216 battery and clip
2 pushbutton momentary contact switches
1 SPDT miniature toggle switch
4 25mm tapped spacers
8 screws (15mm long) and nuts to suit spacers
4 rubber feet

SEMICONDUCTORS
9 5mm red LEDs
8 rectangular red LEDs
1 BC557 PNP transistor
6 1N4148 small signal diodes
2 4017 decade counter/divider ICs
1 4136 quad operational amplifier
1 4520 dual 4-stage binary up counter
1 4011 quad 2-input NAND gate

CAPACITORS
1 100μF/10 VW axial lead electrolytic
6 10μF/10VW PC electrolytics
1 0.1μF metallised polyester
3 .01μF metallised polyesters

RESISTORS (all ¼W, 5%)
2 × 1MΩ, 14 × 100kΩ, 3 × 47kΩ, 9 × 10kΩ, 2 × 4.7kΩ, 1 x 2.2kΩ, 2 × 1kΩ, 1 x 10Ω.



NAND gate IC5a. IC5a now gates through pulses from oscillator IC3c to give the "hit" sound.

This hit sound lasts for about one second and is held on by the 10µF/100kΩ delay circuit on the output of IC5c. (Note: the output of IC5c goes high again immediately after the "hit".) Diode D3 is included so that the 10µF capacitor discharges rapidly when the output of IC5c swings low.

A PNP transistor is used to drive the loudspeaker via a 10Ω resistor. The base of the transistor is driven from three sources: IC3a, IC5a and from the Fire button via diode D2 and a 1kΩ resistor.

IC3a drives the transistor when the Fire button is pressed. However, because D2 is forward biased, the signal drive is attenuated by the 1kΩ resistor between the base and D2. When the Fire button is released, D2 is reverse biased, the sound momentarily becomes louder, and the decaying photon torpedo sound is produced.

If a hit is made, IC5a drives the transistor via a 4.7kΩ resistor. Virtually no mixing of the IC3a and IC5a outputs occurs since IC3a stops soon after the hit.

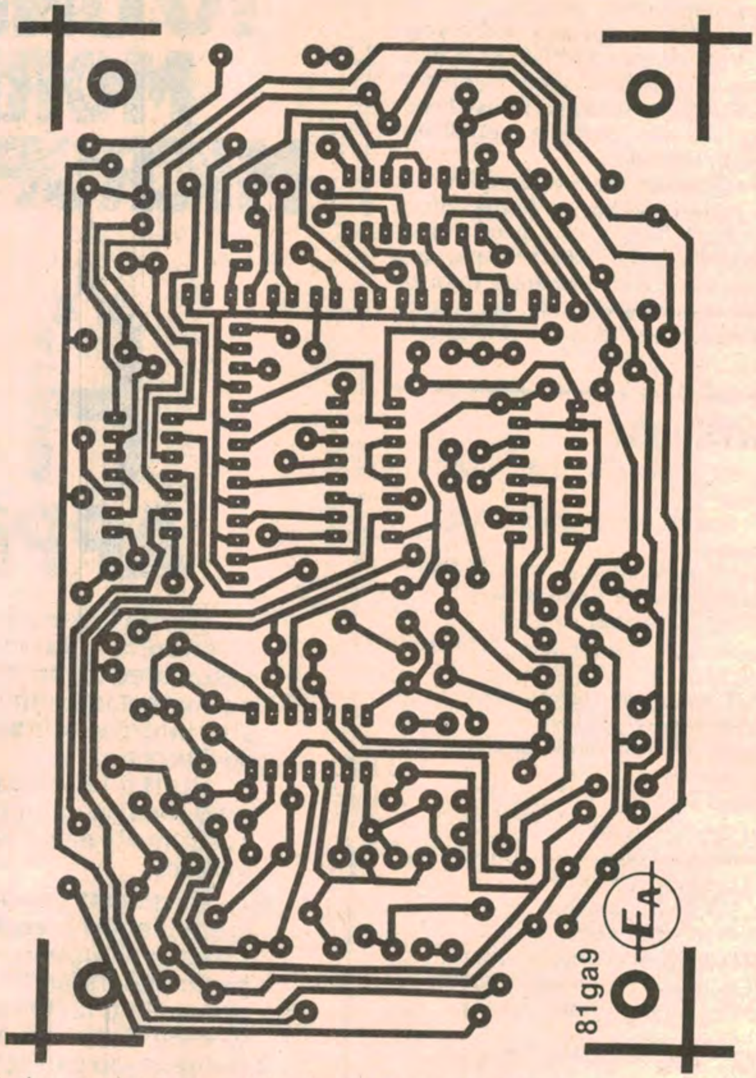
Power for the circuit is derived from a single 9V battery and is decoupled with a 100µF electrolytic capacitor. Battery life should be quite good. Four of the ICs are CMOS devices (and thus have low current drain), while the potentially "current-hungry" LEDs are only pulsed on for short periods of time.

CONSTRUCTION

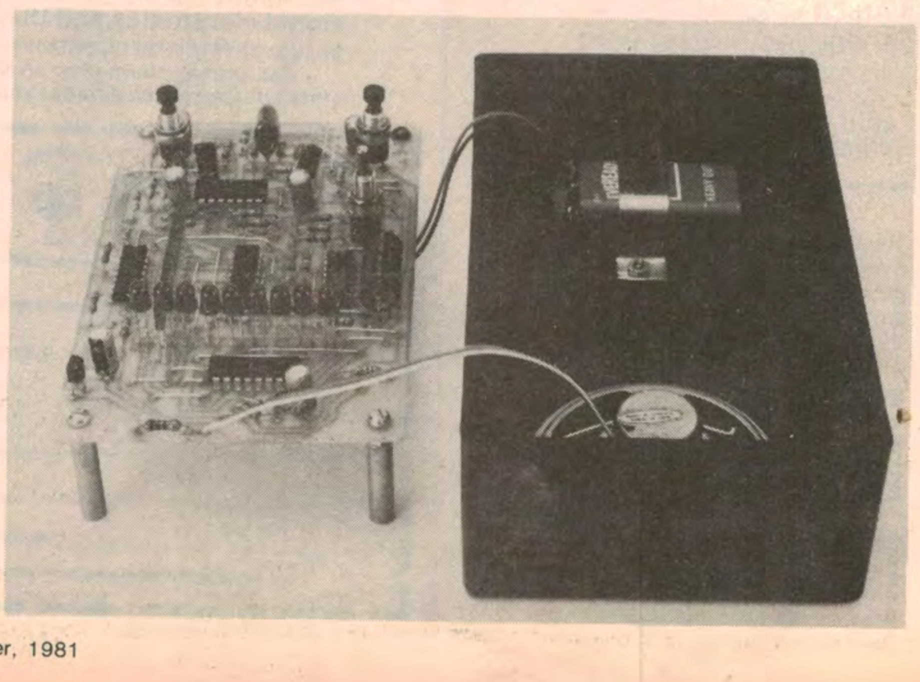
Despite the rather tricky operation of the circuit, the construction is simple. All components, with the exception of the battery and the loudspeaker are mounted on a printed circuit board (PCB) measuring 132 x 83mm and coded 81ga9.

Commence construction by mounting the various components on the PCB according to the component overlay diagram. Solder in the wire links, resistors and capacitors first, followed by the diodes and the transistor. Note that the link below the rectangular LED must be curved (or insulated) to prevent it shorting to the cathode of the adjacent LED.

The two pushbutton switches and the on/off switch are soldered directly to the



Above is the actual size artwork for the printed circuit board. View below shows the completed board, ready to be assembled into the case.



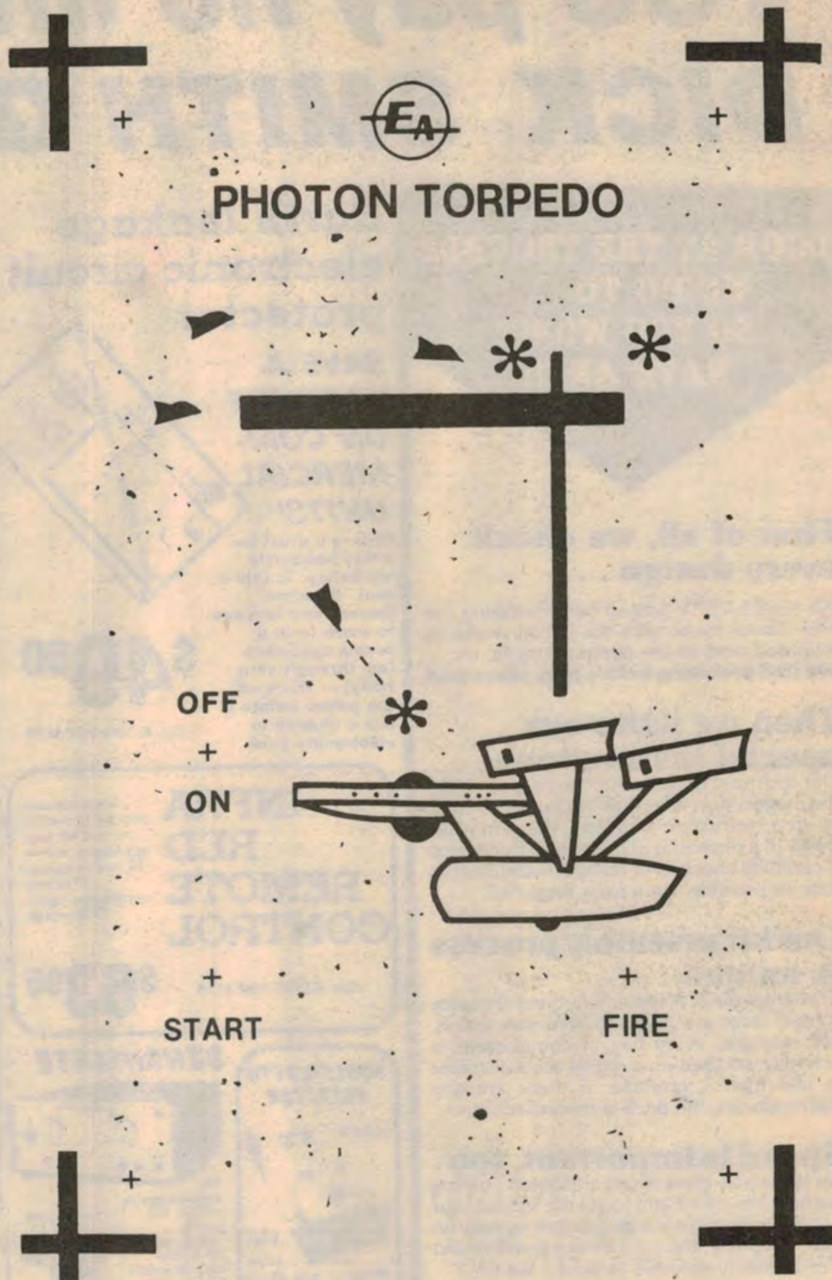
PCB. As shown in Fig.1, they should be mounted so that the top thread of the switch stands off the board by about 18mm. Note that the solder lugs may have to be narrowed with a file so that they will fit neatly into the holes provided.

The LEDs are best soldered in place with the aid of a template. Cut a piece of stiff cardboard 18mm wide by about 70mm long. Now solder the LEDs in position, one at a time, making sure that the top of each LED is 18mm above the PCB (use the template) and that the LED is the right way round. When all are in place, they should be at an even height with no gaps between them.

This done, the ICs can be soldered into circuit and connections made for the battery and loudspeaker leads. Observe the usual precautions when soldering the CMOS devices to protect them against damage from static electricity. Connect the barrel of your soldering iron to the earth track on the PCB (use a clip lead) and solder the supply pins first to enable the internal protection circuitry.

With the PCB completed, go back over your work, carefully checking for possible wiring errors. In particular, make sure that all polarised components have been correctly oriented. These components include the ICs, the transistor, LEDs, diodes and electrolytic capacitors.

We mounted the assembled PCB inside a plastic zippy box measuring 158 x 95 x 50mm. A Scotchcal adhesive label glued to the aluminium lid provides an attractive front panel for the game. This should be given a coat of hard-setting



Here is an actual-size reproduction of the front panel artwork.

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

$24.00

This includes sales tax.

lacquer, such as "Estapol", to prevent scratching.

When the lacquer is dry, the switch holes can be drilled and the slots made for the LEDs. The slots are best made by first drilling along the marked lines with a small drill and then filing to shape so that the LEDs are a neat fit. This done, place the lid in position and screw on the nuts for the switches.

Provided you've done the job neatly, the PCB, will just fit within the box with the lid in place.

Although not strictly necessary, we provided additional support for the PCB by attaching it to the base of the box using four 25mm and 3mm spacers. Fig. 1 shows the general idea. Note that the 3mm spacers are made up using machine nuts (two per spacer).

As shown in the photograph, the loudspeaker is held in position with stiff wire strapped across it and looped through holes in the bottom of the box. You will also have to drill additional holes in the box to provide a sound grille for the loudspeaker (before mounting the loudspeaker of course!). The battery is held in place with a piece of scrap aluminium fashioned into a bracket.

With the wiring completed; mount the PCB assembly inside the box, screw down the lid, and attach the four rubber mounting feet (see Fig 1). You are now ready to shoot down the attacking alien craft.

Finally, there are a few adjustments which can be made to the circuit to suit your own personal requirements. To make the torpedo travel faster, reduce the 4.7kΩ resistor between pins 8 and 10 of IC3c; to reduce the time the torpedo sounds, decrease the $0.1\mu F$ capacitor connected to pin 3 of IC3a; and to increase the pitch of the sound, reduce the $.01\mu F$ capacitor connected to pin 1 of IC3a.

The length of time the "hit" sound lasts can be adjusted by varying the 100kΩ resistor between IC5b and IC5c, while the maximum speed for the row LEDs is adjusted by varying the 100kΩ resistor in the negative feedback path of IC3d.