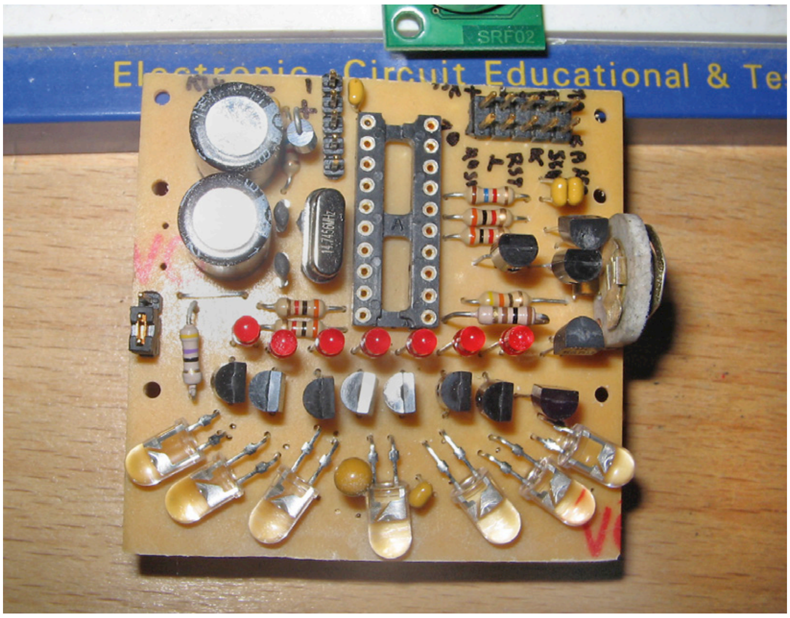
Fast IR Robot Bumper

Detect obstacles in all directions



By **Ralf Schmiedel**

This design is useful for speedy mobile robots and provides fast, contactless detection of obstacles ahead. Not only can it detect the obstacle, it also indicates in which direction it is. The project has a liberal sprinkling of both hardware and software sorcery

Mobile robots benefit from some form of bumper or obstacle detection system to avoid damage themselves or their surroundings. This design detects obstacles by scanning the area with IR beams. A semicircular array of IR LEDs driven by a microcontroller sends out a sequence of IR pulses. An IR receiver with a wide receiving aperture detects any reflected IR light from obstacles in the illuminated area. The receiver has a digital output so that it either detects the presence of reflected light or not. The microcontroller knows from timing information which of the IR diodes sent out the detected light pulse and therefore in which direction the obstacle is. We can build a special interface to the scanner hardware but why not use one that's already available? In this design we drive the seven IR LEDs sequentially using UART timing and connect the IR receiver output to the RXD UART input on the microcontroller. That way the receive word is made up, on the fly, as the LEDs send out scan pulses. This has the benefit of allowing you to simultaneously detect reflections

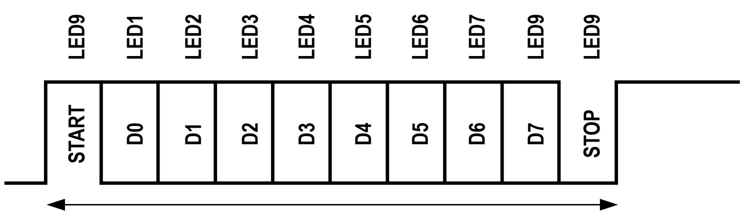


Figure 1.
LED arrangement for the 8N1 word format.

from multiple obstructions.
The design uses seven diodes each of which correspond to one bit in the UART 8N1 data word format (**Figure 1**). This leaves three more bits to be generated (altogether there is a start bit, 8 x data bits and a stop bit). These extra pulses are produced by another IR LED which points directly at the IR sensor. This has the secondary function of saturating the IR sensor amplifier to defeat the built-in AGC, but more on that later.
The scanning circuit uses the same UART interface which the bumper uses to communicate with the robot's host controller over which the obstacle detection measurements are also sent. The host controller in turn talks to the bumper controller using simple ASCII commands to configure the buffer's basic operating parameters.

IR diodes

This IR bumper design can be built to scan an area of 90° or 180°. Using the same principle it is possible to build a system using individual sensors and a controller in a small SO-8 package or a larger system able to scan the full 360° with a corresponding bigger AVR controller.
The fast TSOP7000 IR receiver from Vishay [1] is used here as the IR receiver. It is normally used to receive IR commands from a remote control handset. Unlike the other TSOP devices in the range which are sensitive to signals in the 30 to 56 kHz region, this model responds to IR signals modulated at 455 kHz. In common with all the other types, the TSOP7000 incorporates an amplifier with AGC (automatic gain control) after the front end signal amplifier. This compensates for changes in the received signal strength caused by the characteristics of different remote control transmitters and helps avoid overloading the demodulator. For our particular 'electronic bumper' application this AGC feature is counterproductive. Depending on the IR diode used and with the receiver's AGC active it is able to detect objects at a 20 m range and continually detects obstacles. The receiver is however also sensitive to fast signals and has a narrow receive band with good sensitivity. These properties are important for this application.
To defeat this AGC mechanism and produce a relatively constant gain setting this design uses one or two additional 'flash' IR LEDs aimed directly at the receiver. The flash intensity can be adjusted by PWM control and a trimmer. The AGC reaction time constant is relatively slow (several 100 milliseconds) so by saturating the receiver diode intermittently with blasts of IR light we can achieve a reasonably constant level of gain.
The IR transmitter diodes used are fast examples from Vishay [2][3] with a 10° beam width for use with the 90° bumper or 22° beam for the 180° bumper. The results using continuous scanning are shown in **Figure 2**. The TSOP7000 IR receiver has a 90° receive angle which means to scan 180° requires two sensors with their open collector outputs linked together to make an OR function.
The design uses a low cost AVRtiny2313 microcontroller with a built-in UART interface.

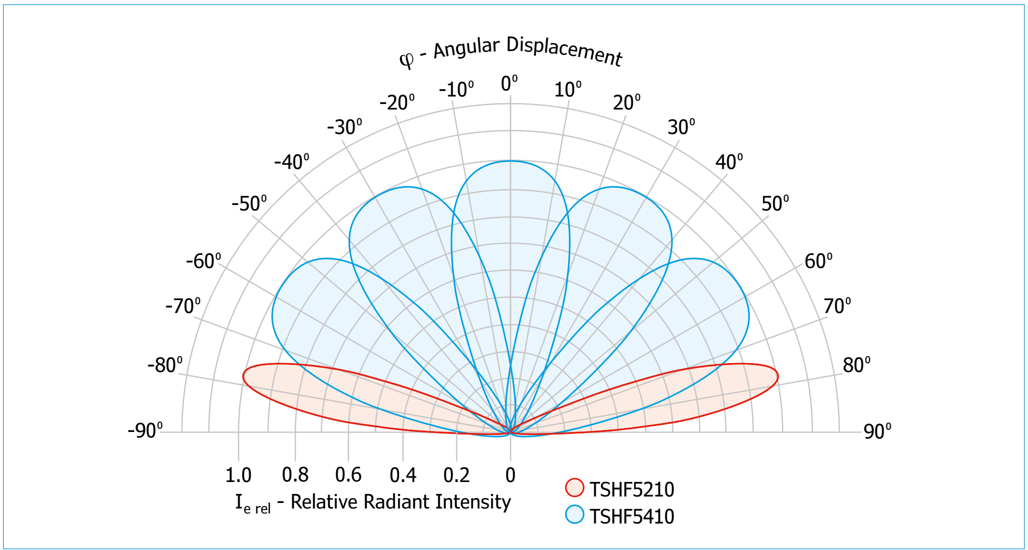


Figure 2.
Radiation pattern of the IR diodes for the 180° bumper.

The circuit

The circuit schematic can be seen in **Figure 3**. The controller pins PB0 to PB2 and PD2 to PD6 are configured as outputs to drive the diodes. The current needed to drive the IR LEDs LED1 to LED7 exceeds the available output current from the port pins so a transistor buffer stage is used to provide the drive current for each (or pair of) LEDs.

Seven red LEDs are also driven in parallel with each multiplexed IR LED to give a visual indication of the scanning process when a PC is not connected to the system. To reduce the circuit's overall current consumption the red LEDs can all be disabled by driving output pin PB6 high.

Port pin PB3 provides the PWM signal to drive the selected IR diode.

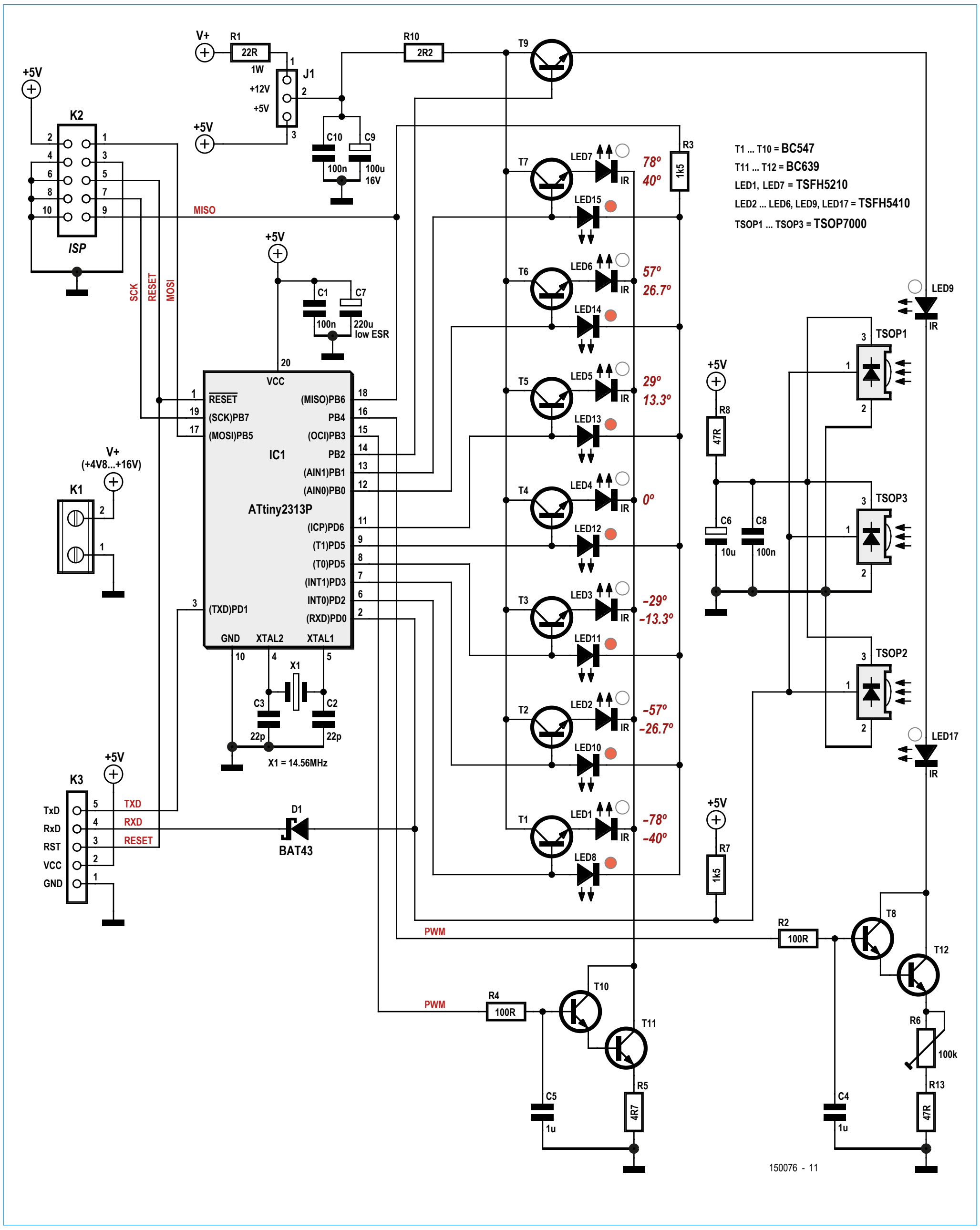


Figure 3.
The bumper schematic.

The digital control signal is low-pass filtered by the network formed by R4 and C5 to drive the Darlington combination formed by transistors T10 and T11 (BC547/BC639). Emitter resistor R5 provides a current sink to define the drive current for the IR LEDs.

Technical data

- IR diode modulation frequency: 455 to 460 kHz
- Scan transmit frequency: 19.2 kHz or 38.4 kHz
- Scan duration: 2 ms
- Scan frequency (free running): ca. 105 Hz
- Detection range: 20 cm to over 2 m, dependent on the reflectivity of the target. Only very dark objects will produce a noticeable reduction in range. Double the range can be achieved grouping 10° diodes in the 90° version.

The current can be calculated from:

I = (V_{CC} x duty cycle – 2 x V_{be}) / R5)

Resistor R3 connected to the common cathode of the red LEDs provides current limiting. Series limiting resistors are not required for the drive signals to the buffer transistors because the current limiting effect of the Darlington configuration. Base current is therefore automatically limited. This arrangement not only saves components but also reduces power losses when switching the IR LEDs!
The flash LEDs LED9 and LED17 are driven in the same way as the scan LEDs i.e. via PB4 and a Darlington current sink formed by transistors T8/T12. The flash current and with it the gain of the TSOP receiver stage can be set by trimmer R6.

As already described, outputs from the open-collector outputs of the IR receivers are wire 'OR-ed' together. The resulting common signal from the receivers is input to pin PD0 on the controller with R7 acting as a pull-up resistor. The received signal on this pin is made up of the reflected IR pulses and also received data from the host controller via connector K3. D1 isolates the host's RXD signals from the TSOP output signals.

Power for the controller is also supplied by the host. The circuit draws around 0.5 amp with the IR LEDs transmitting so the supply decoupling capacitor (C7) should have a low ESR to ensure good supply regulation.

Software
And so to the software. LEDs 9 and 17 produce the flash which sets the gain control in the TSOPs and also generates the start bit for the 8N1 protocol. The first seven data bits consist of the scan information while the eighth bit (always '1') and the 'stop' bit are produced by another flash.
The host communicates with the bumper controller using ASCII code which has a total of 127 possible characters represented by a seven bit code. The eighth bit in this communication is always '0'. This allows the software to differentiate communications from the IR sensor and the host.
Communications between the host and IR sensor are not synchronized so there could be the possibility of data collision unless permission to communicate is established. Here the host must first receive a prompt > (ASCII 62) before it is allowed to send any commands. The host requests a prompt by sending escape characters (ASCII 27). While sending five escape characters it should be fairly certain the host will receive a prompt, if not the procedure is repeated. Once a prompt is received by the host the interface is given over to communication and scanning stops. When scanning resumes, the host will not have write access to the bumper and evaluates the data sent by the bumper.

The program is written in BASCOM. A small section is written in assembler to achieve the 455 kHz switching rate. According to the data sheet the 455 kHz carrier frequency allows a modulation frequency of 20 kHz, which corresponds to the standard communication speed of 19.2 kBit/s. I have also found that 38.4 kBit/s can be processed and is implemented in software. Other communication rates are possible (see comments in the program listing).
The data received on the UART Rx input is continually read and responded to as necessary. **Table 1** shows the commands and functions available. It's very easy to make adjustments to the timing by introducing NOPs and also depends on the crystal frequency (see source text [2]). Check out comments in the program for using other crystals operating at different frequencies.
At the start of a scan the AGC circuits in the TSOP7000 receivers are flashed to adjust their

Table 1. Command Overview.

Command	Function	Typical value
A	Sets PWM_A of the controller. Controls power to the scan LEDs.	30 – 130
B	Sets PWM_B of the controller. IR flash intensity (also sets gain).	30 – 130
M	Set Mode: Individual bit functions described below. All other bits are unused. Bit2: PWM duty cycle changed at twice the rate. Doubles progressive scan speed. Bit4: 1= red LEDs on. Bit4: 0= red LEDs off.	
R	Radar, free running progressive scan mode.	Exit with ESC (ASCII 27), repeat if necessary.
F	Free running scan.	Exit with ESC (ASCII 27), repeat if necessary.
W	Sets the Wait time between scans in ms (2 ms minimum).	0..255
P	Progressive scan, single scan with increasing range.	
S	Scan once, single scan with the result returned.	
I	Set Initial command: One of the above commands will be automatically executed at start up. Any other ASCII value generates a prompt '>' for an input.	

Lower case letters can also be used to enter commands.

gain. Next the flash LED generates a pulse which serves as the start bit and then each of the seven scan LED sequentially send out a light pulse for each bit period of the UART serial byte. After that comes the eighth bit and lastly the stop bit, generated by the flash LED also. The TSOP receiver output is connected to the controller's Rx input of the UART TTL interface, it writes a '1' or '0' into this serial input as the scan progresses to indicate if an obstacle has been detected. BASCOM now has direct access to this scan result.

Construction and setup

It is important to use the IR LEDs specified (or equivalent) which can switch at the frequency used in this design. The characteristics of one of the more common IR LEDs type LD274 with a 20° beam angle make it unsuitable for use at this switching speed. In tests it could only achieve a maximum range of around 30 cm. The directional characteristics of the TSOP7000 IR receiver are given in the data sheet; its detection pattern is a single lobe with an acceptance angle of around 90°. This is the shape of the detection field when the bumper board is used to scan a 90° quadrant. The 180° version has two TSOP7000s directed at 45° and –45°. The combined characteristics show reduced sensitivity at the edges and also in the centre of the pattern.

In the diagram for the 180° scanning design the LED at either end of the line of LEDs is a TSHF5210 (10°) which has half the beam angle of the TSHF5410 (22°) used in the rest of the line. The narrower beam is more intense and helps compensate for poorer sensitivity at the edges of the sensor pattern, giving a more even coverage. If necessary the TSHF5410 can however be used for all the LED positions. With the more intense TSHF5210 used at either end of the scanning LEDs the area covered is more rectangular in shape but shows a dip in sensitivity around the center. To make the scanned area more semicircular an additional TSSOP sensor can be fitted pointing directly forwards between the other two (the position used in the version which scans 90°). The resulting pattern shows improved range along the axis and a more semicircular pattern.

Figure 4 and [5] show the obstacle detection patterns of a pen, a hand and a white sheet of paper (smallest to largest pattern respectively) using different PWM settings. The patterns are not completely symmetrical which may be a result of uneven flash illumination of the sensors or component tolerances. The curve can be corrected by mechanical adjustments to the flash LED and sensor distance or electrically by introducing a parallel shunt or trimmer across the LED.

The picture (**Figure 5**) shows the LEDs positioning after adjustments to make the detection zone more symmetrical.

When mounting the components make sure that the TSOP7000 IR receiver(s), above and below you can hook up the TTL interface to the host controller and apply Vcc supply to the board. Vcc can be supplied from the host system via K3. The IR LEDs can be powered from Vcc (jumper J1 in +5 V position) or from an external unregulated supply (4.8 to 16 V from a rechargeable battery for example). This has no effect on the transmitted IR power because the voltage at the emitters of transistors T1 to T7 is always around 4.3 V (Vcc-Vbe). The optional series resistors R1 and R10 reduce power dissipated in transistors T1 to T7 particularly during long periods of high speed scanning at maximum range. They can both be replaced by wire bridges.

For first trial you can use a PC running a terminal emulator program such a HyperTerminal and set the transmission to 8N1. The TTL UART interface can be connected via a USB/TTL converter or similar cable to the PC. In addition you will need a +5 V supply at K3

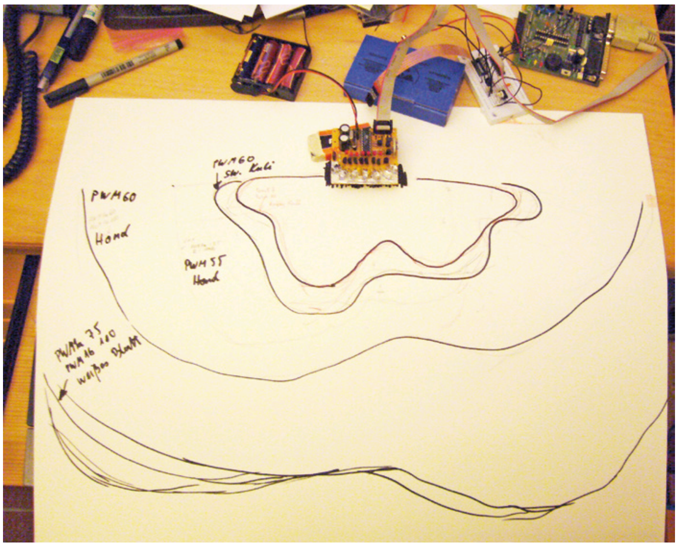


Figure 4.
Detection pattern for different obstacles.

LED 9 and LED 17 (for 180° scanning) are fitted to the underside of the board. The PCB must be optically opaque which can be achieved before mounting the components with the help of a copper layer, metal tape or a permanent black marker pen. Pliers can be used to make a 90° bend in the IR LED leads (grip the leads on the component side of the bend) make sure that the bend is in the right direction to ensure correct polarity when the LED is fitted to the board.

Once all the components have been fitted which can be derived from the USB port.

After switch-on the controller responds to a command in its 'Initial Command-Register' or sends a prompt. To get a prompt it is necessary to repeatedly send escape characters ESC (ASCII 27). Once established you can now send a command given in the table.

Commands R and P will produce progressive scans, here the sensitivity of the system is slowly increased with every scan. When an obstacle is detected, two values are produced; one is the direction of the obstacle and the

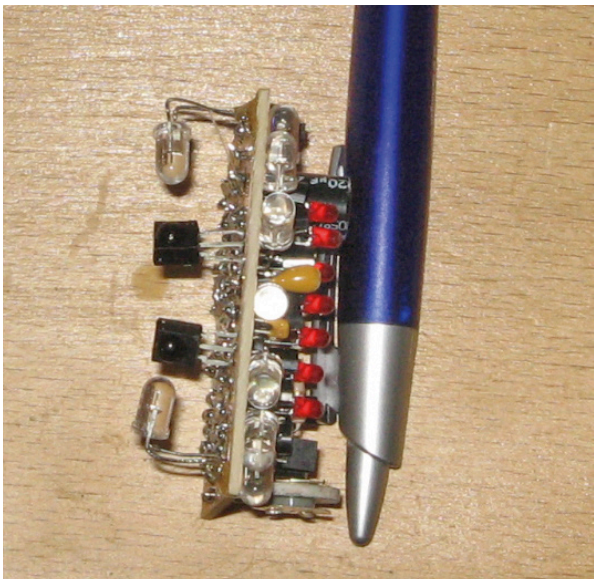


Figure 5.
On the left the ‘flash’ diodes at a ‘calibrated’ distance from the TSOP.

other represents the PWM value at the time of detection. The PWM value is incremented by small amounts so the time to detect an obstacle depends on the number of scans required. This can typically be in the range of 100 ms to 1 s.

(150076)

Web Links

[1] http://datasheet.octopart.com/TSOP7000.-Vishay-datasheet-595920.pdf

[2] www.vishay.com/docs/81313/tshf5210.pdf

[3] www.vishay.com/docs/81303/tshf5410.pdf

[4] Software: www.elektormagazine.com/articles

[5] www.youtube.com/watch?v=AAdm9u9GZCo