The Liverpool Ringing Simulator

Simulator Sensors Hardware Manual

Author: Andrew Instone-Cowie

Date: 17 January 2017
Version: 1.7

Contents

Index of Figures

Index of Tables

Document History

Version	Author	Date	Changes
1.0	A J Instone-Cowie	09/08/2015	First Issue
1.1	A J Instone-Cowie	15/08/2015	Added photo of Rev C magneto-resistive sensor PCB.
1.2	A J Instone-Cowie	30/10/2015	Revised ATtiny85 fuse settings.
1.3	A J Instone-Cowie	10/02/2016	Clarified construction and component details.
1.4	A J Instone-Cowie	13/04/2016	Added details of magnet mountings.
1.5	A J Instone-Cowie	12/05/2016	Added reference to SeeedStudio as an alternative PCB manufacturer. Added further details to magneto-resistive sensors.
1.6	A J Instone-Cowie	17/08/2016	Minor design change: Replace SA5.0CA bi-directional TVS diodes with SA5.0A uni-directional component. Change description of non-stackable/stackable magento-resistive sensors to “Type 1” & “Type 2”.
1.7	A J Instone-Cowie	17/01/2017	Minor updates.

Cover photograph: Rare earth magnet trigger for prototype magneto-resistive sensor, Liverpool Cathedral.

Licence

[1] http://creativecommons.org/licenses/by-sa/4.0/

Introduction

This Hardware Manual describes the design and construction of Sensor Heads for a ringing simulator interface which allows a sensor or sensors, attached to one or more real tower bells or teaching dumb bells, to be connected to a computer simulator package such as Abel[2], Beltower[3] or Virtual Belfry[4], via a Simulator Interface.

- Parts lists and schematics are provided. Links are also provided to suggested sources of parts, including ready-made printed circuit boards.
- Links are provided to the associated firmware source code, PCB CAD files and other supporting data hosted on GitHub.
- This is a build-it-yourself project. No pre-built hardware is available.

Design and construction details for the Simulator Interface itself are covered separately in an accompanying Hardware and Software Manuals.

Licensing & Disclaimers

Documentation

All original manuals and other documentation (including PCB layout CAD files and schematics) released as part of the Liverpool Ringing Simulator project[5] are released under the Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA),[6] which includes the following disclaimers:

> *Unless otherwise separately undertaken by the Licensor, to the extent possible, the Licensor offers the Licensed Material as-is and as-available, and makes no representations or warranties of any kind concerning the Licensed Material, whether express, implied, statutory, or other. This includes, without limitation, warranties of title, merchantability, fitness for a particular purpose, non-infringement, absence of latent or other defects, accuracy, or the presence or absence of errors, whether or not known or discoverable. Where disclaimers of warranties are not allowed in full or in part, this disclaimer may not apply to You.*

> *To the extent possible, in no event will the Licensor be liable to You on any legal theory (including, without limitation, negligence) or otherwise for any direct, special, indirect, incidental, consequential, punitive, exemplary, or other losses, costs, expenses, or damages arising out of this Public License or use of the Licensed Material, even if the Licensor has been advised of the possibility of such losses, costs, expenses, or damages. Where a limitation of liability is not allowed in full or in part, this limitation may not apply to You.*

[2] http://www.abelsim.co.uk/
[3] http://www.beltower.co.uk/
[4] http://www.belfryware.com/
[5] http://www.simulators.org.uk
[6] http://creativecommons.org/licenses/by-sa/4.0/

Software

All original software released as part of the Liverpool Ringing Simulator project is released under the GNU General Public Licence (GPL), Version 3[7], and carries the following disclaimers:

> *This program is free software: you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or (at your option) any later version.*
>
> *This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.*

The Liverpool Ringing Simulator Project

The use of simulators has great potential in the training of new ringers, and therefore the Liverpool Ringing Simulator Project seeks to promote the installation and take-up of simulators as a teaching aid in other towers. The project presents the work undertaken at the Cathedral, and other towers, and makes it freely available for ringers to build and install simulators at relatively low cost.

The project is based on work undertaken at Liverpool Cathedral to provide a 12-bell simulator for demonstration and training purposes. For more details of the background to the project, please refer to the main Simulator Interface Hardware or Software Manuals.

Acknowledgements

The Liverpool Ringing Simulator project relies extensively on work already undertaken by others, notably David Bagley (developer of the Bagley MBI), Chris Hughes and Simon Feather (developers of the Abel simulator software package), Derek Ballard (developer of the Beltower simulator software package), Doug Nichols (developer of the Virtual Belfry simulator software package), and others. Their invaluable contributions are hereby acknowledged. Sources used are referenced in the footnotes throughout.

Thanks are also owed to the Ringing Masters of Liverpool Cathedral and of St George's, Isle of Man, for their willingness to be the crash test dummies of simulator design and testing.

---

[7] http://www.gnu.org/licenses/gpl-3.0.en.html

Simulator Sensor Head Design

Overview

This manual contains the details of three separate Sensor Head designs:

- A Sensor Head adopted as the project standard by the Liverpool Ringing Simulator Project, based on a commercially available modulated infra-red detector unit, marketed as an "obstacle sensor" for educational robotics projects. These sensors are available quite inexpensively, and the Sensor Heads are very straightforward to construct.

- A magneto-resistive Sensor Head, based closely on a design[8] by Aidan Hedley, using a Honeywell magneto-resistive sensor IC[9], activated by a small, powerful rare earth magnet. This sensor has no moving or optical parts, and is completely free of optical interference. It also draws much less current than an optical sensor. A variation of this sensor is also suitable for integration into the One Bell Simulator Interface.

- An experimental, proof-of-concept infra-red Sensor Head using a 38kHz infra-red receiver. This Sensor Head design is aimed mainly at experimenters and prototype builders, and is not expected to be widely deployed.

Note: All the Sensor Heads described in this Hardware Manual are designed for connection via a Simulator Interface. They are not suitable for direct connection to a Simulator PC.

Compatibility

Simulator Triggering

There are generally two approaches used by Simulators when detecting signals from Sensor Heads:

- The twin trigger approach uses two triggers (for example, optical reflectors) on the shroud of the wheel of each bell, one of which triggers at the moment that the bell would strike at handstroke, the other at the moment that the bell would strike at backstroke. The Simulator triggers the simulated sound of the bell as soon as the signal pulse is received (triggered by the reflector travelling past the sensor as the bell is on its way up to the balance), and then ignores the next signal pulse (as the first reflector travels back past the sensor as the bell is on its way down), and so on.
- The second approach is to use a single trigger, which triggers as the bell passes through the bottom dead centre of its swing. A delay is then applied (either in the Simulator Interface or the Simulator Software Package) before the Simulator triggers the simulated sound of the bell. This approach is simpler to implement, and the single trigger is much easier to align accurately against the Sensor Head with the bell down. Work by John Norris[10] has shown that this approach can provide an acceptable degree of accuracy, with any errors considered too small to be detectable to the human ear.

[8] http://www.gremlyn.plus.com/ahme/mag_sen.html
[9] http://sensing.honeywell.com/product-page?pr_id=36114
[10] http://www.jrnorris.co.uk/strike.html

The Liverpool Ringing Simulator project's Simulator Interfaces adopt the single trigger approach, on the grounds of simplicity of installation and compatibility with other similar systems. More details of the design of a Simulator using this approach can be found in the accompanying Software Manual.

The Sensor Heads described in this Hardware Manual are intended for use with a single trigger system, although they could in principle be adapted to a twin trigger approach. Such adaptation is beyond the scope of this manual.

Sensor Head Electrical Interface

The Sensor Heads operate on a 5V DC power supply, and the output is at 5V logic levels.

- The output of the Sensor Head is inverted; in the normal untriggered state the output is held at +5V (logic HIGH), when triggered the output drops close to 0V (logic LOW) for the duration of the detected pulse.
- Pulse duration is typically in the range 5ms – 20ms, depending on Sensor Head type and installation factors.
- The Sensor Heads are not suitable for direct operation at RS-232 voltages.

Sensor Head Connector Pin-Outs

All Sensor Heads developed across the Liverpool Ringing Simulator Project use the same GX16-4 (also known as "aviation") connectors for the cabling connection to the Simulator Interface. These are of the same type and are wired following the same convention as other sensors, with an extension for dual-headed Sensor Heads.

The wiring of the male chassis plug connector is illustrated in the following diagram:

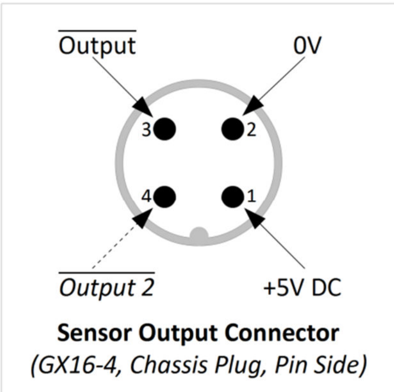


Figure 1 – Sensor Head Connector

In some installations cabling may be simplified by mounting two detectors in a single sensor head, for example where the Sensor Head is mounted between two adjacent wheels (examples of this approach are shown elsewhere in this manual). Pin 4 of the GX16-4 connector may optionally be used for the input from a second detector, with the appropriate modifications to the corresponding Sensor Interface connector.

Enclosures

The project standard Sensor Head enclosure is the WCAH 2855 black ABS box manufactured by Wisher Enterprise Co Ltd.

- This enclosure can be obtained from Maplin, ESR Components and Velleman, and measures 85mm x 55mm x 30mm (external) overall.
- Use of a standard enclosure simplifies PCB design, and allows different Sensor Heads to be swapped easily.
- Some variation has been used in particular installations for dual-headed Sensor Heads, and an alternative enclosure is suggested in the text.

Standard Infra-Red Optical Sensor Head

The Sensor Heads adopted as the project standard by the Liverpool Ringing Simulator Project are based on a commercially available modulated infra-red detector unit, marketed as an “obstacle sensor” for educational robotics projects. These sensors are available pre-assembled and relatively inexpensively, and consequently the Sensor Heads are very straightforward to construct.

The sensor emits and detects infra-red light modulated at high frequency. This makes the sensor much less sensitive than visible light or unmodulated infra-red sensors to interference from ambient lighting conditions.

The specification[11,12] of the detectors is as follows:

- Model: E18-D80NK
- Output current: DC / 100mA / 5V supply
- Current consumption: DC <25mA
- Response time: <2ms
- Angle: more than 15°,
- Effective distance: Adjustable from 3-80CM
- Working environment temperature: -25 °C ~ 55 °C

The actual current drawn by the detectors was found to be approximately 28mA in the triggered state, and 21mA in the untriggered state, after calibration for simulator use as described below.

The sense wire current was measured at approximately 130µA trigged, 0µA untriggered. The output is inverted, that is normally high (nominally +5V) when untriggered, dropping low (nominally 0V) when triggered.

The sensor and signal connector are mounted in a standard plastic enclosure.

Parts List

Table 1 – Standard Infra-Red Sensor Head Parts List

Component	Notes
WCAH 2855 ABS Black Enclosure	ESR Components 400-595, Maplin BZ72P, Velleman WCAH2855
No2 x 9mm Stainless Steel Self Tapping Screws	eBay
30mm x 20mm (Diameter) Black Plastic Conduit	
GX16-4 Chassis Plug (Male)	Signal Connector
SA5.0A	Transient voltage suppression (TVS) diode
E18-D80NK Infra-Red Sensor	eBay

[11] http://hobbycomponents.com/sensors/213-ir-infrared-obstacle-avoidance-sensor-e18-d80nk
[12] http://www.61mcu.com/?product-56.html

The components (excluding the TVS diode) of one standard infra-red Sensor Head are shown in the following photograph:

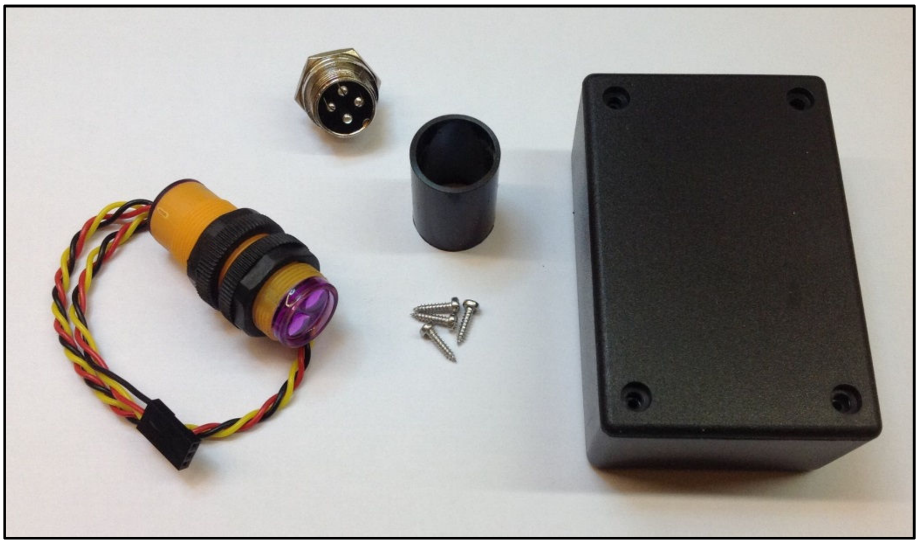


Figure 2 – Standard Infra-Red Sensor Components

Construction

Standard Construction

The infra-red sensor is mounted through the side of the enclosure using the plastic nuts supplied with the sensor. These should be tightened finger-tight only; do not use tools.

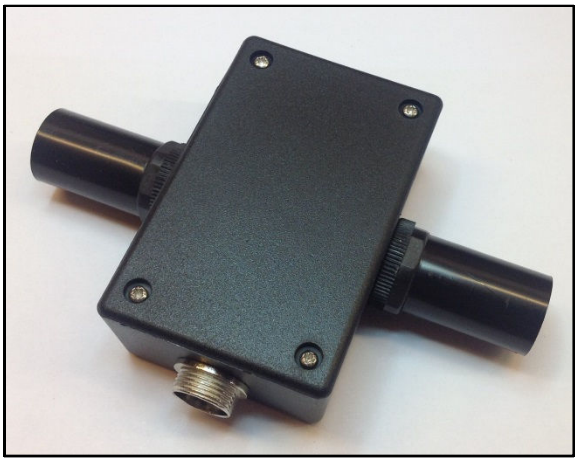
Once the sensor is installed, lightly file or sand the exposed threads so that the masking tube is a firm tight push fit on the end of the sensor.

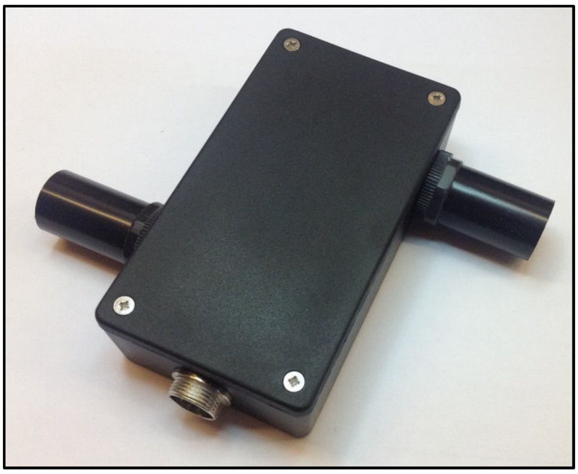
The GX16-4 connector is mounted through the end of the enclosure. As shown the drilling diagram below, it is necessary to remove the plastic PCB ribs from this end of the enclosure to accommodate the connector.

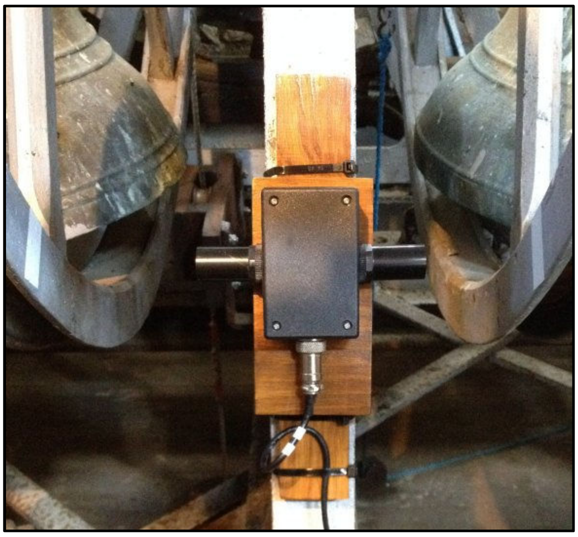
Alternative Construction

As noted above, in some installations cabling in the belfry may be simplified by mounting two detectors in a single Sensor Head, for example where the Sensor Head is mounted between two adjacent wheels. In this case the second sensor signal connection makes use of the spare pin of the GX16-4 connector, with the appropriate modifications to the corresponding Sensor Interface connector.

Two alternative versions are illustrated below. The example on the left is housed in the standard WCAH 2855 enclosure, the offset version in a larger Hammond 1591XXBBK ABS Enclosure, 113mm x 63mm x 31mm.







Enclosure

The suggested enclosure for the standard infra-red Sensor Head is the project standard WCAH 2855 black ABS box manufactured by Wisher Enterprise Co Ltd.

- This enclosure can be obtained from Maplin, ESR Components and Velleman, and is the same enclosure adopted as a standard for Sensor Heads across the Liverpool Ringing Simulator Project.
- The enclosure is 85mm x 55mm x 30mm (external) overall.
- Drilling large diameter holes with twist drills can result in bit grabbing and damage to the enclosure. Small diameter (16mm/18mm) hole saws are available at relatively low cost (e.g. on eBay), and these make the process of drilling the enclosure much easier and safer.
- Using a sharp chisel, carefully and gently remove the PCB ribs from the inside of the enclosure as indicated on the diagram below, to allow the Power/Data connector to be mounted. Using too much force may crack the case.

- It is recommended that the lid retaining screws supplied with the enclosure are replaced with stainless steel equivalents.
- The 4.5mm mounting hole is optional. Other mounting arrangements may be devised.

The following diagram shows the suggested drilling layout for the enclosure.

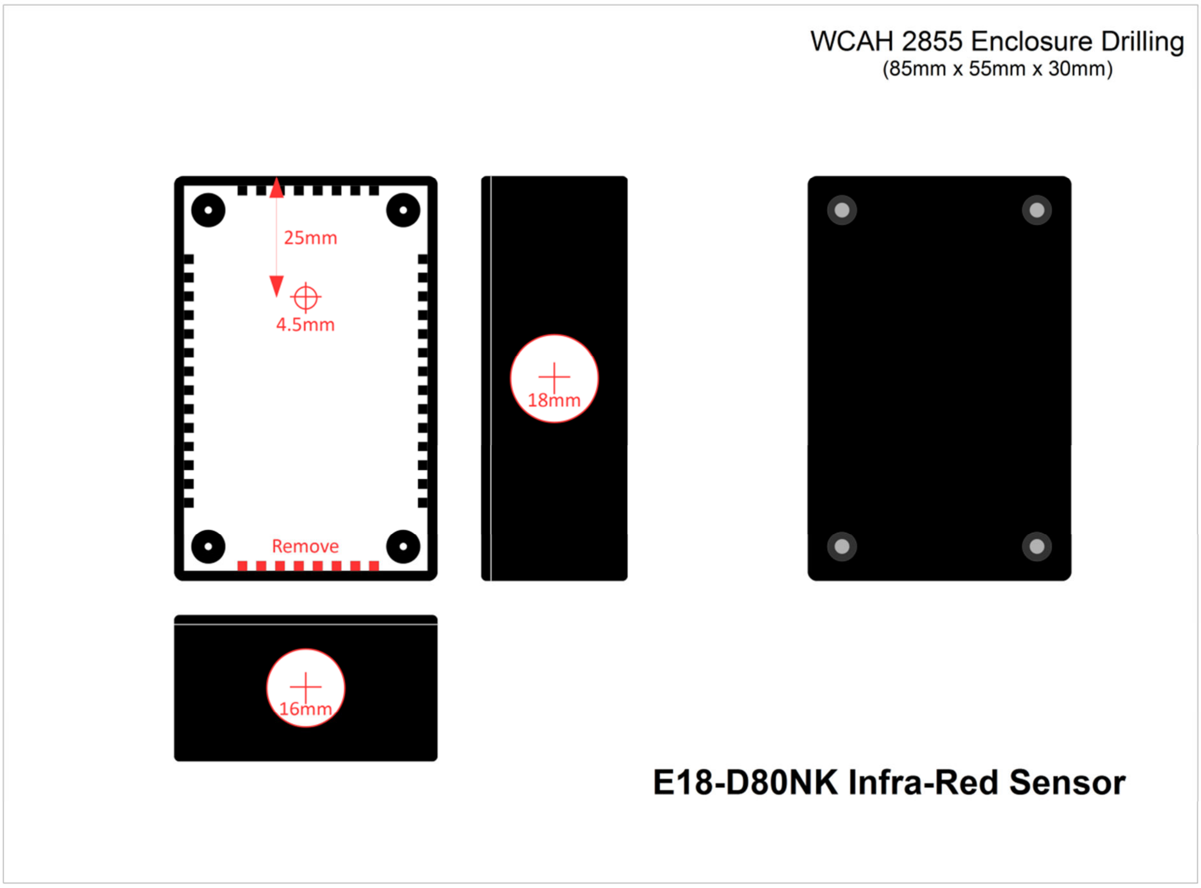


Figure 3 – Enclosure Drilling Guide

Internal Wiring

The wiring of the standard infra-red optical Sensor Head is very straightforward:

- The three-core sensor cable is integral to the infra-red sensor. This cable should be shortened to approximately 6cm, and soldered directly to the GX16-4 chassis plug following the pin-out shown above.
- Note that the sensor wires must be passed through the connector hole in the enclosure before being soldered; the sensor will not pass through the connector hole, and vice-versa.
- The SA5.0A TVS diode is soldered directly across the power supply pins in the connector. The cathode, indicated by a white stripe, must be connected to pin 1 of the GX16-4 connector[13].

[13] Note that prior to version 1.6 of this manual, the TVS diode was a non-polarised component.

The wiring of the standard infra-red Sensor Head is illustrated in the following diagram.

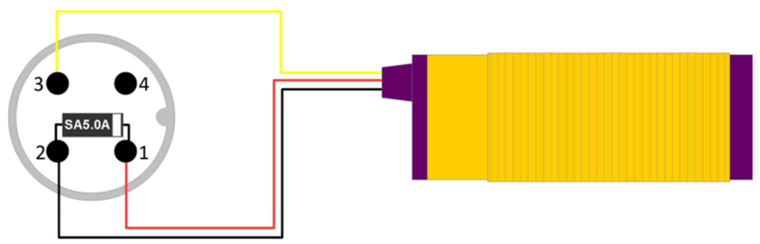


Figure 4 – Standard Infra-Red Sensor Cabling

The following picture shows one completed Sensor Head, with its cover removed. (The TVS diode has not yet been fitted to this prototype unit.)

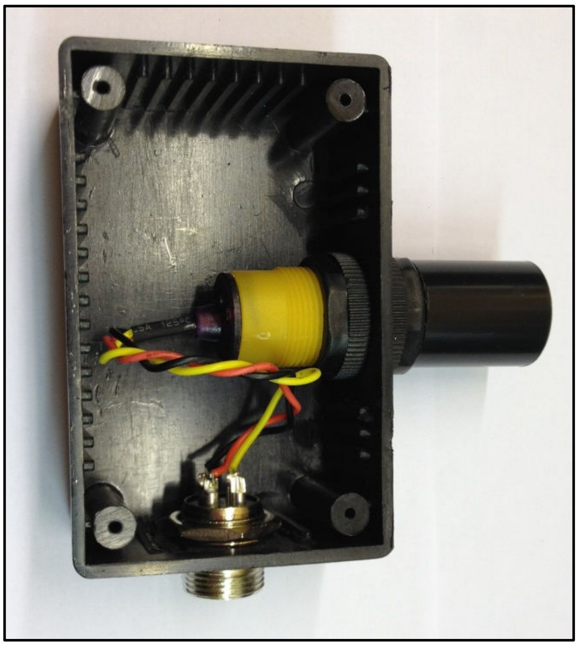


Figure 5 – Completed Infra-Red Sensor Head

Reflector

The sensor requires a reflector mounted on the shroud of the bell wheel, such that the reflector is opposite the Sensor Head when the bell is at the bottom of its swing. Consequently the reflector should be fitted when the bell is down.

The reflector is made from a short length of white reflective automotive styling tape, 25mm wide. This may be obtained from a car spares shop. This can be seen in the installation photograph below.

Calibration

As supplied, most of the infra-red detector sensor modules were found to draw approximately 55 – 60mA, much more than the specified 25mA, and were excessively sensitive. The small calibration screw on the end of the module may be used to reduce both the current consumption and sensitivity of the detector.

A useful starting point for sensitivity adjustment has been found to be to reduce the sensitivity of the sensor such that it does not trigger when placed perpendicular to a piece of grey card at a distance of 90mm from the end of the detector. The multi-turn adjustment screw is turned anti-clockwise until the indicator LED on the back of the module just goes out. This gives an effective maximum trigger distance with the reflective tape of about 300mm. This also reduces the supply current to approximately 21mA untriggered, 28mA triggered, although this is variable between modules.

The sensor should then be adjusted in the belfry for optimum sensitivity.

Installation

The Sensor Head is located in the belfry, attached to the frame in a location such that the sensor tube is perpendicular to the face of the shroud of the wheel, in the same manner as a standard Sensor Head. The reflector is positioned directly opposite the Sensor Head when the bell is down.

Figure 6 – Example of an Installed Simulator Sensor Head & Reflector

Magneto-Resistive Sensor Head

The magneto-resistive Sensor Head, which is based closely on a design[14] by Aidan Hedley, uses a Honeywell magneto-resistive sensor IC[15], activated by a small, powerful rare earth magnet mounted on the wheel shroud. This sensor has no moving or optical parts, and is completely free of optical interference. It also draws much less current than an optical sensor, prototypes were measured at approximately 8mA including a signal LED.

Using a magnet of the type suggested below, the maximum operating distance of the prototype was approximately 60mm (face of magnet to face of enclosure). In practice an operating distance of approximately 40mm should be reliably feasible, and this distance has been used successfully in a test installation of a sensor at Liverpool Cathedral, and on the Cathedral 6-bell Saxilby Simulator.

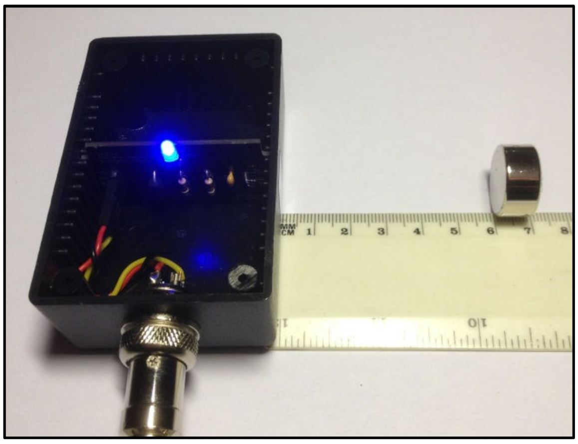


Figure 7 – Magneto-Resistive Sensor Demonstration

The sensor PCB contains all the components of the sensor, including the magneto-resistive sensor itself, an optional diagnostic LED, and associated components. The sensor and signal connector are mounted in the same project standard plastic enclosure as the other sensors described in this manual.

Eagle CAD and Gerber files for the board can be downloaded from GitHub. Gerber files are provided for two possible board manufacturers, OSH Park in the USA and SeeedStudio in China. There are two versions of the PCB, as is explained further in the *Construction* section below.

- https://github.com/Simulators/simulator/tree/master/hardware/magneticsensor
- https://oshpark.com/shared_projects/IJhg1jxK (Type 1)
- https://oshpark.com/shared_projects/AfsFCwFR (Type 2)
- http://www.seeedstudio.com

Both manufacturers have been found to supply boards of a high quality, although the Chinese boards are of a slightly lower specification (e.g. HASL finish rather than ENIG) but are considerably cheaper in quantity.

[14] http://www.gremlyn.plus.com/ahme/mag_sen.html
[15] http://sensing.honeywell.com/product-page?pr_id=36114

Sample boards from both manufacturers are shown in the following photograph.

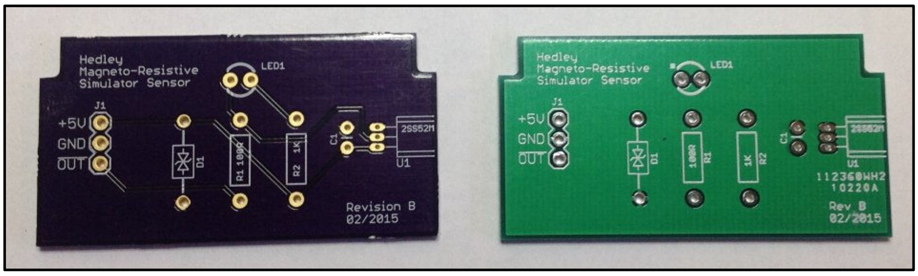


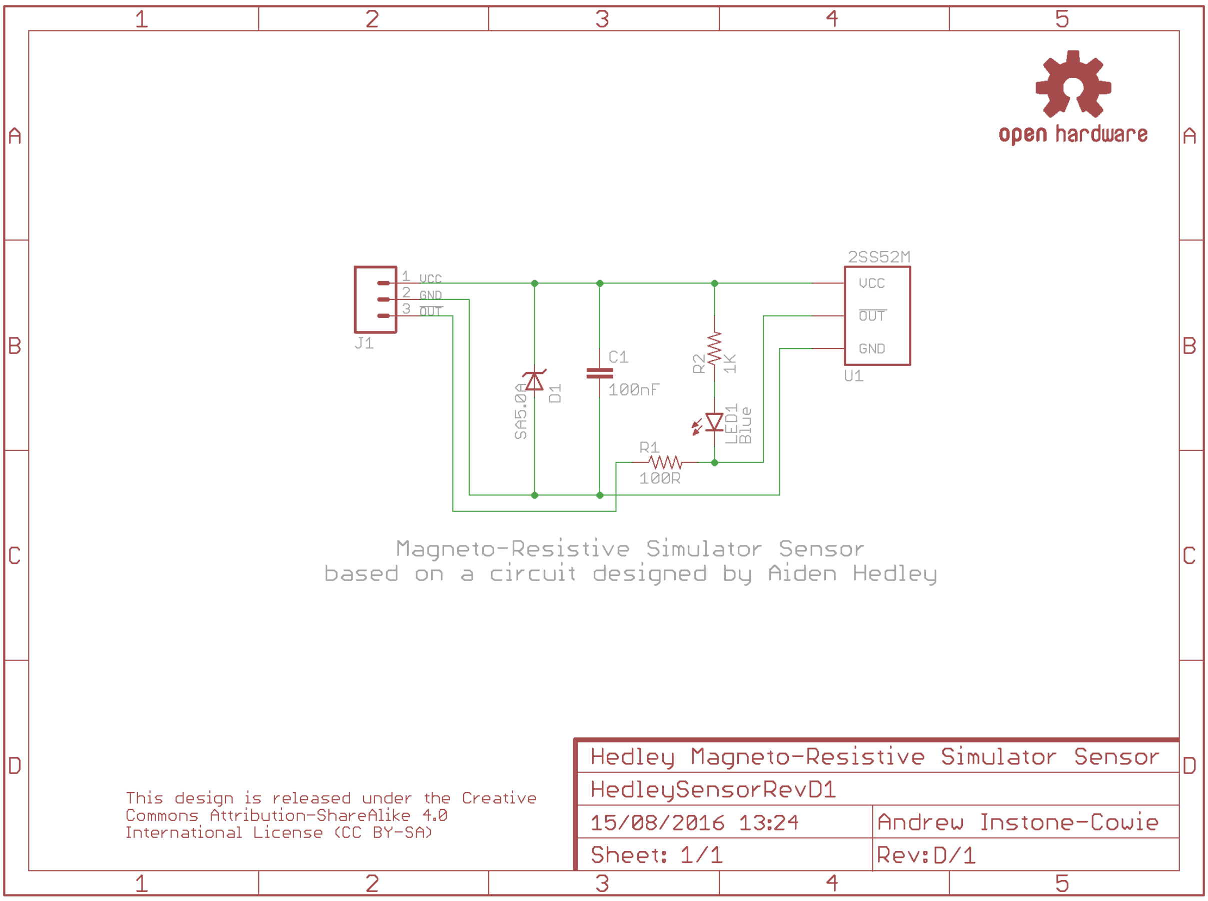
Figure 8 – Comparison of PCBs (OSH Park left, SeeedStudio right)

Parts List

Table 2 – Magneto-Resistive Sensor Head Parts List

Reference	Component	Notes
PCB	Magneto-Resistive Sensor PCB Rev D (Type 1 or 2 - see text)	
R1	100Ω 0.6W Metal Film[16]	
R2	1kΩ 0.6W Metal Film	
C1	100nF (0.1µF) 50V MLCC[17] (2.54mm Radial)	
D1	SA5.0A	Transient voltage suppression (TVS) diode
U1	Honeywell 2SS52M	Magneto-Resistive Sensor
LED1	3mm LED Blue	Optional – see text
Sensor Header	3-Pin 0.1" Male Header	See notes on Alternative Construction below
Enclosure	WCAH 2855 ABS Black	ESR Components 400-595, Maplin BZ72P, Velleman WCAH2855
Screws	No2 x 9mm Stainless Steel Self Tapping	
Magnet	N52 grade, 20mm x 10mm	eBay

Schematic



16 Carbon film resistors may be used as an alternative throughout

17 Multi-Layer Ceramic Capacitor

PCB Layouts

The following diagrams show the layout of the magneto-resistive sensor PCBs.

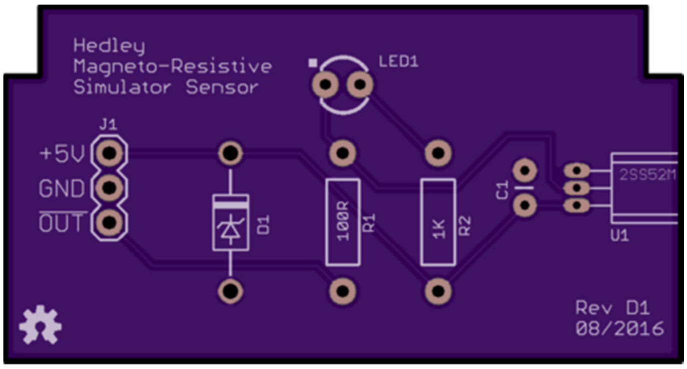


Figure 9 – Magneto-Resistive Sensor Board Layout (Type 1)

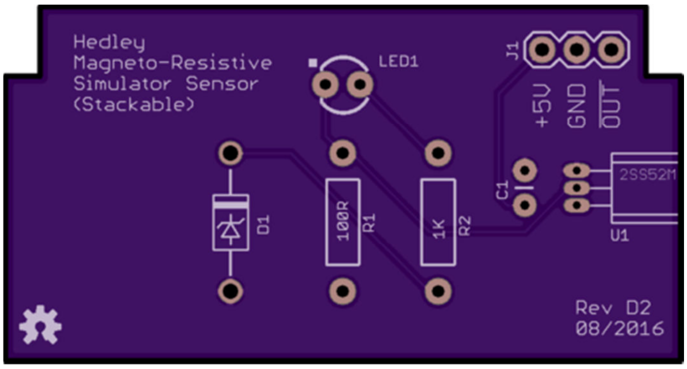


Figure 10 – Magneto-Resistive Sensor Board Layout (Type 2)

Construction

Standard Construction

There are two versions of the magneto-resistive sensor board:

- Type 1 is intended for self-contained magneto-resistive Sensor Heads connected to a separate Simulator Interface, and is the version shown in the examples in this manual.
- Type 2 is designed to integrate with the One Bell Simulator Interface board in a stacked configuration, as an alternative to an infra-red optical or other detector. This is described further in the One Bell Simulator Interface Hardware Manual.

All the components on the magneto-resistive sensor board are mounted on top, silkscreen, side of the board:

- The 2SS52M magneto-resistive sensor is mounted parallel to the PCB, approximately 2mm clear of the surface, flush with the end of the board and with the chamfers facing away from the board, so that the sensor will slide into the gap between the PCB ribs of the standard enclosure. This can be seen in the photographs below, and is intended to position the sensitive end of the sensor as close as possible to the inside of the enclosure.

- Fitting the diagnostic LED is optional, but strongly recommended. The LED is polarised, and must be mounted in the correct orientation with the cathode on the left. The cathode is usually denoted by a flat on the side of the moulding and by a shorter leg.
- Pay particular attention to the correct orientation of the polarised components D1, U1 & the LED[18].

A completed magneto-resistive sensor PCB is shown in the following photograph. Note that this is an earlier version of the PCB.

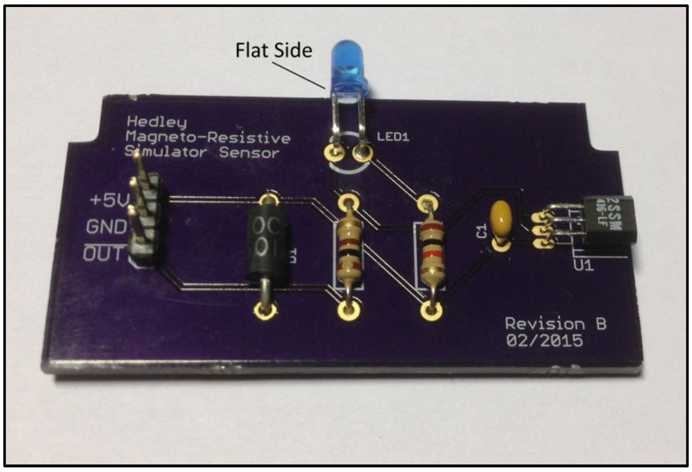


Figure 11 – Completed Magneto-Resistive Sensor PCB

Alternative Construction

PCB Type 2 may be used to build a magneto-resistive sensor which can be used with the One Bell Simulator Interface, as an alternative to the standard infra-red sensor. This version of the PCB is designed to stack behind the One Bell Simulator Interface in the standard enclosure.

When assembling the Type 2 PCB, the following changes are required:

- The 3-pin J1 male header pins are replaced with a 3-pin female header. This is still mounted on the top, silkscreen, side of the board. This will mate with the pins located on the back of the One Bell Simulator Interface PCB.
- D1 may be omitted. The One Bell Simulator Interface PCB includes a TVS diode.
- The LED may be mounted flush with the sensor PCB, or omitted altogether. The One Bell Simulator Interface includes a diagnostic LED.

[18] Note that prior to PCB Rev D, D1 was a non-polarised component.

This configuration is described in more detail in the One Bell Simulator Interface Hardware Manual. A completed Type 2 PCB is shown in the following photograph. Note that this is an earlier version of the PCB.

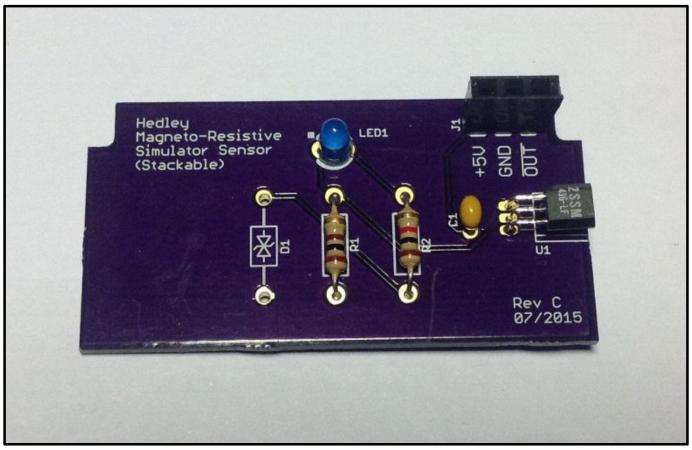


Figure 12 – Completed Stackable PCB (Type 2)

Reversed Configuration

In the construction shown above the sensor is on the right hand side when viewed with the lid removed and the connector at the bottom. Where belfry installation will require the sensor to be on the left hand side, the PCB may be reversed and the header pins mounted on the rear of the board. Right and left handed configurations are illustrated in the following photograph.

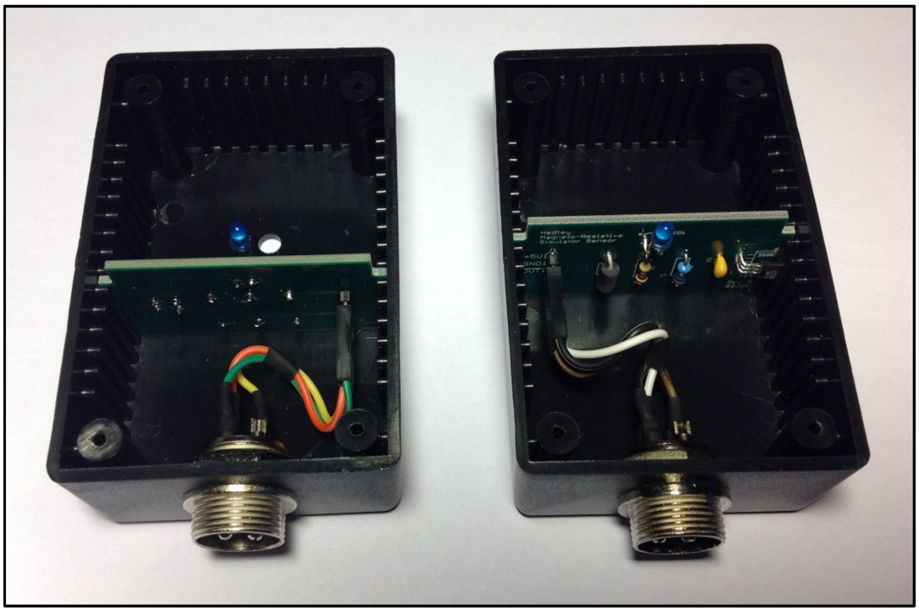


Figure 13 – Normal & Reversed Configurations

Enclosure

The suggested enclosure for the magneto-resistive Sensor Head is the project standard WCAH 2855 black ABS box manufactured by Wisher Enterprise Co Ltd.

- This enclosure can be obtained from Maplin, ESR Components and Velleman, and is the same enclosure adopted as a standard for Sensor Heads across the Liverpool Ringing Simulator Project.
- The enclosure is 85mm x 55mm x 30mm (external) overall.
- Drilling large diameter holes with twist drills can result in bit grabbing and damage to the enclosure. Small diameter (16mm/18mm) hole saws are available at relatively low cost (e.g. on eBay), and these make the process of drilling the enclosure much easier and safer.
- Using a sharp chisel, carefully and gently remove the PCB ribs from the inside of the enclosure as indicated on the diagram below, to allow the Sensor and GX16-4 signal connector to be mounted. Using too much force may crack the case.
- It is recommended that the lid retaining screws supplied with the enclosure are replaced with stainless steel equivalents.
- The 4.5mm mounting hole is optional. Other mounting arrangements may be devised.
- The 3mm hole for the LED is not required if the diagnostic LED is omitted or is mounted flush with the PCB.

The following diagram shows the suggested drilling layout for the enclosure for a Sensor Head using the Type 1 PCB.

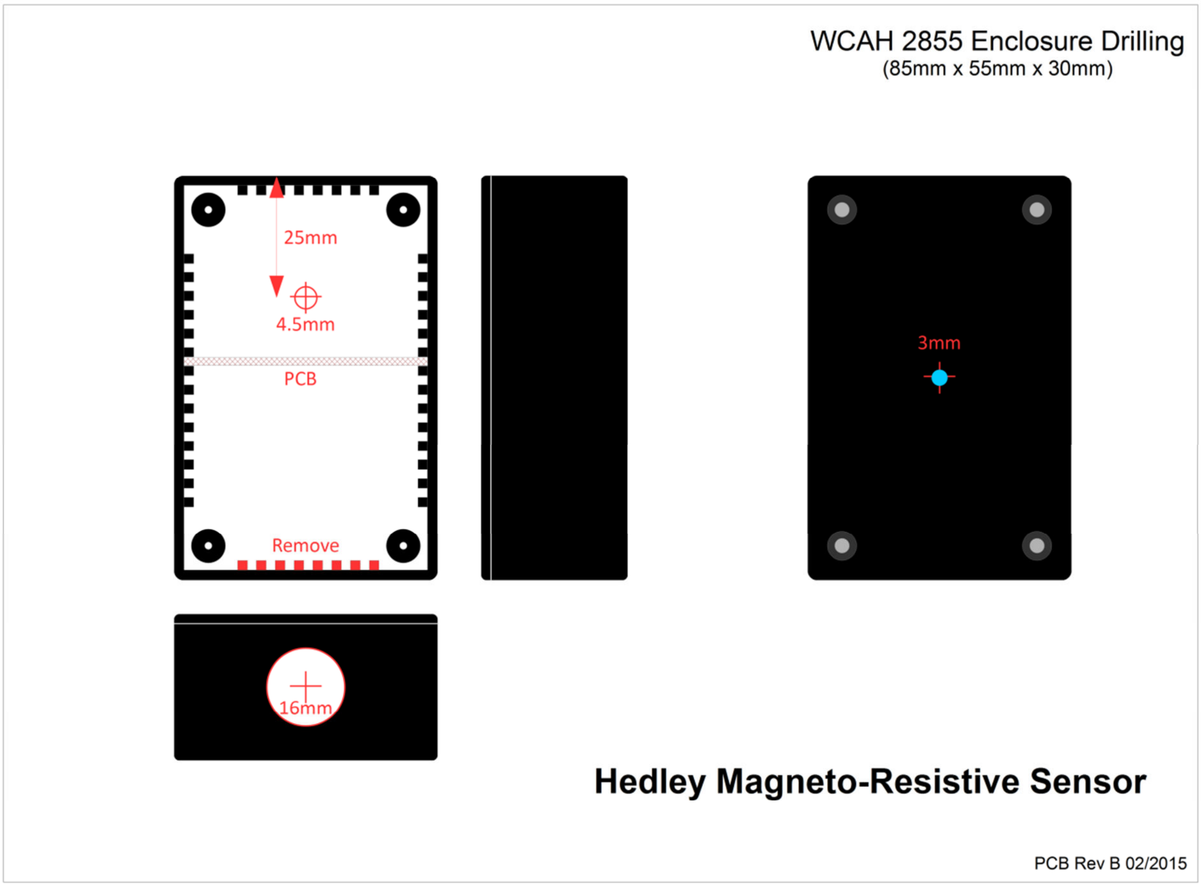


Figure 14 – Enclosure Drilling Guide

Internal Wiring

A Sensor Connector Cable is required within the magneto-resistive Sensor Head enclosure, to connect the sensor board to the external signal connector.

Parts List

Table 3 – Internal Cabling Parts List

Component	Notes
GX16-4 Chassis Plug (Male)	Signal Connector
Ribbon Cable	3-core
DuPont 0.1” Female Crimp Connectors	3
DuPont 0.1” Female Connector Shell	1 x 3-pin

While it is possible to make up the DuPont connector cables by hand, this is time consuming and not easy even if the proper crimp tool is available. An alternative approach is to buy ready-made lengths of ribbon cable with female DuPont connectors already crimped, and cut these down to make the required cables. These are readily available on eBay, and can save a lot of work.

Note that the core colours shows in this section are for clarity only, and have no other significance.

The Sensor Connector Cable has a GX16-4 chassis plug on one end, and a 3-pin female DuPont connector on the other, wired as shown the following diagram.

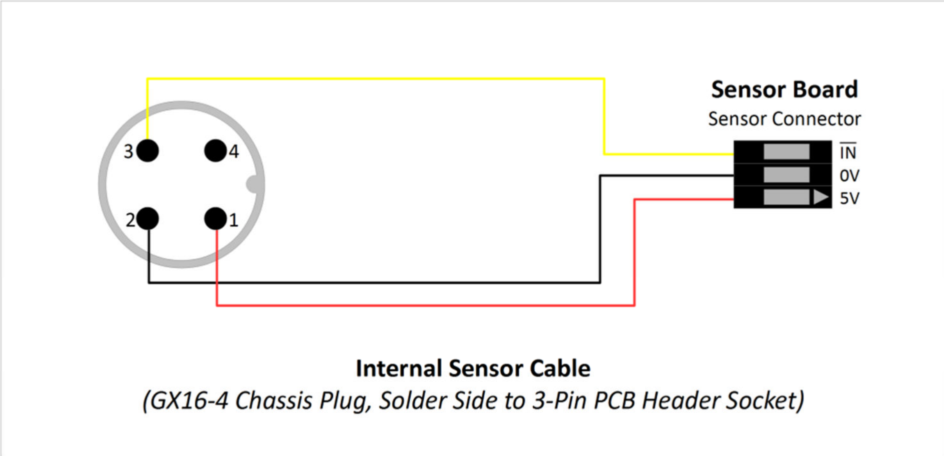


Figure 15 – Sensor Connector Cable Diagram

A suitable length of ribbon cable can be used for this cable, the required length is approximately 6cm overall.

The cable ends are soldered onto the GX16-4 chassis plug following the wiring the diagram above. A short length of heatshrink sleeve, 2.5mm unshrunk diameter, is recommended on each core to protect the soldered connection and provide some strain relief.

The Sensor Connector Cable can be seen in one of the following pictures, which show one completed prototype Sensor Head. The positioning of the sensor between the PCB ribs can also be seen.

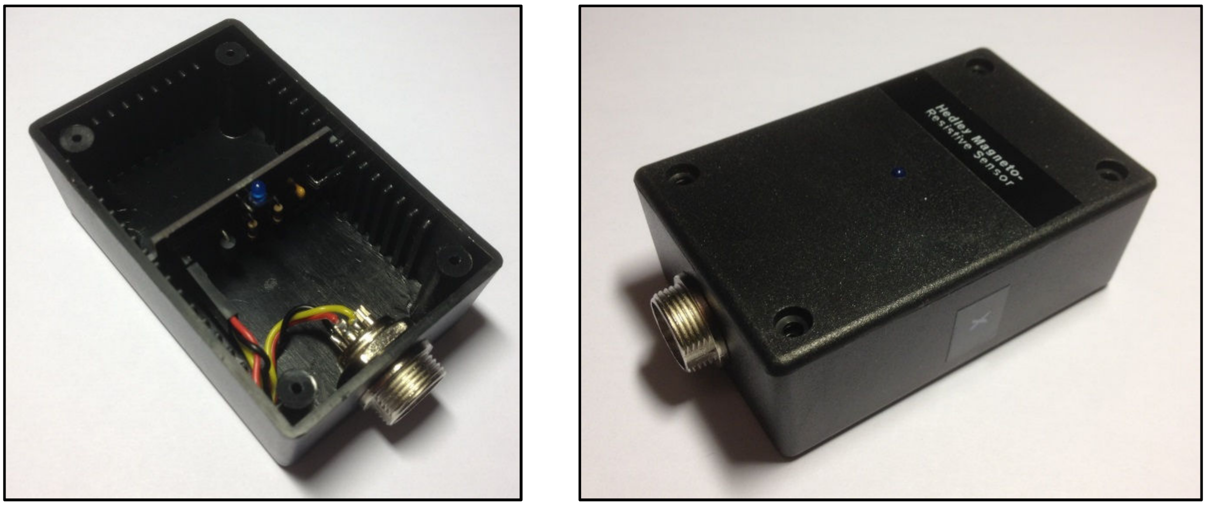


Figure 16 – Completed Magneto-Resistive Sensor Head

Magnetic Trigger

The magneto-resistive sensor is triggered by a small rare-earth magnet mounted on the shroud of the wheel, such that the magnet is opposite the centre of the Sensor Head (i.e., co-axial with the 2SS52M sensor IC) when the bell is at the bottom of its swing, similar to the alignment of a reflector and optical sensor.

The magnet used in the prototype installation is a N52 grade rare earth magnet, 20mm diameter x 10mm thick. For prototype testing a plywood cradle, illustrated below, was made which clamps around a spoke on the wheel. The magnet, here painted red, is fixed in a circular plywood mounting with epoxy adhesive.

Figure 17 – Prototype Magnet Mounting (Front)

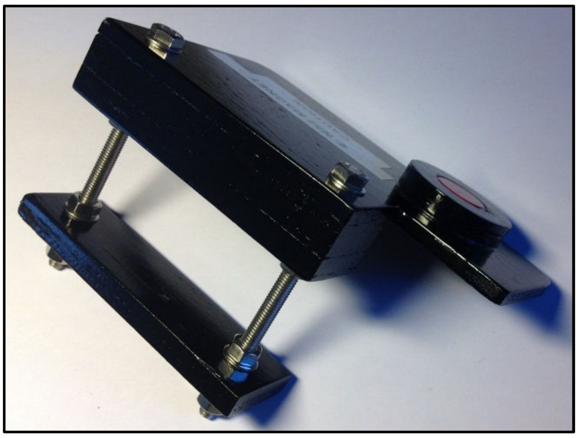


Figure 18 – Prototype Magnet Mounting (Side)

The following less elaborate mounting is suggested for a permanent installation.

The trigger magnet is mounted in a “flange” cut from 12mm WBP plywood, which is then fixed to the shroud of the wheel using stainless steel screws or double-sided tape.

The dimensions of the mounting flange are show in the following diagram:

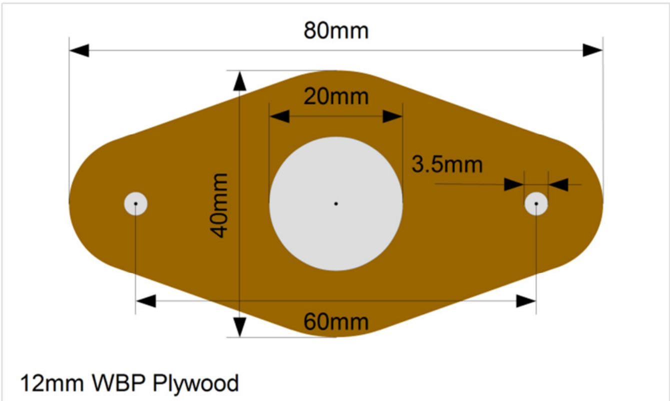


Figure 19 – Trigger Magnet Mounting Dimensions

The magnet mountings are constructed as follows:

- The shape of the mounting is marked out on a piece of WBP plywood, 12mm thick. A paper template may be printed out and stuck temporarily to the wood with glue or double sided tape. A suitable template is available from the GitHub repository as a PDF, and should be printed out full size with no scaling.
- The centre hole for the magnet is drilled out with a 20mm spade bit. This should be used in a bench drill press, if available, so that the hole is reasonably accurately cut and the magnet will be a close fit.
- If the mounting is to be fixed to the wheel with screws, the screw holes are also drilled. It is easier to drill all the holes before cutting the mount to size.
- The mounting is then cut and sanded to shape, and the remains of the template removed. Do not sand the inside of the central hole.

These steps are illustrated in the following series of pictures.

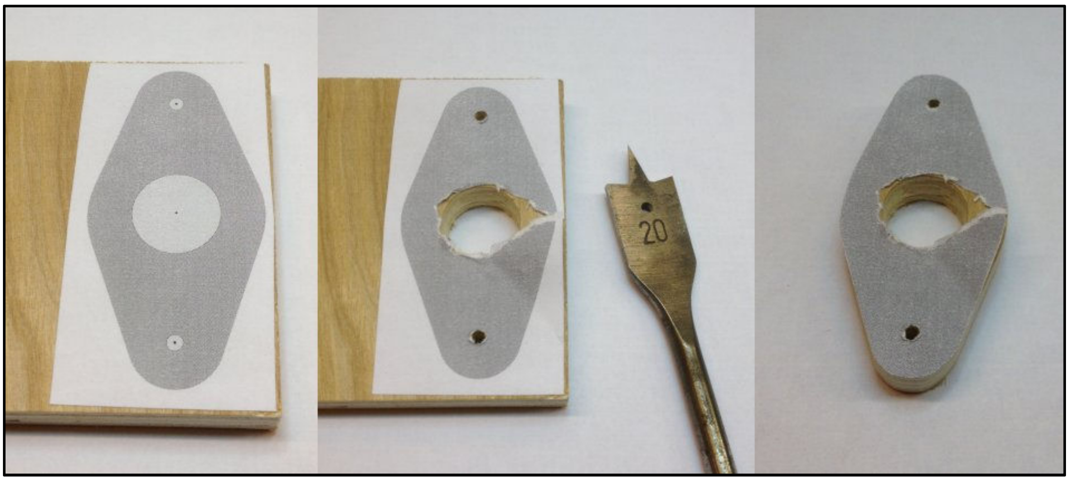


Figure 20 – Magnet Mounting Construction

The magnet is pushed into the central hole, and if necessary secured with a small amount of epoxy adhesive. The face of the magnet should be flush with the outer face of the mount, and note that for the Honeywell sensor the polarity of the magnet is not important.

The following picture shows a completed magnet mounting, ready for painting.

Figure 21 – Completed Magnet Mounting

Care must be taken when handling the rare earth magnets, because they are both powerful and very brittle and can strike a magnetic object with enough force to shatter the magnet. They are also susceptible to corrosion, so must be painted.

Once painted the mounting can be fixed the wheel with pan head stainless steel self-tapping screws 3.5mm in diameter and 20mm – 25mm long; the screws should not protrude through the shroud of the wheel. Alternatively the mount can be secured with double-sided tape.

Installation

The Sensor Head is located in the belfry, attached to the frame in a location such that the magnet is positioned directly opposite the axis of the sensor IC when the bell is down. The prototype installation at Liverpool Cathedral is shown in the following photographs. (The magnet is not visible because the bell is up; the installed cradle is shown in the cover photograph of this Hardware Manual.) Note the metal offset bracket fitted to bring the magneto-resistive sensor closer to the wheel than the standard infra-red sensor.

Figure 22 – Installed Prototype Magneto-Resistive Sensor Head

38kHz Infra-Red Sensor Head

Overview

The 38kHz Infra-Red Sensor Head is an experimental, proof-of-concept sensor, using a similar approach to the commercially available modulated infra-red detector unit used in the standard infra-red sensor. This Sensor Head design is aimed mainly at experimenters and prototype builders, and is not expected to be widely deployed.

The Sensor Head uses one of the timers on an ATtiny85 microcontroller to generate a 38kHz PWM output, which drives an infra-red LED, producing a modulated infra-red output. The specification of the LED is as follows:

- Lenses Type : Crystal Clear
- Case Style : 5mm Round
- Forward Voltage : 1.5v - 1.6v
- Forward Current : 60mA
- Wavelength : 940nm
- Viewing Angle : 25deg

A fixed current limiting resistor prevents the LED from exceeding the ATtiny85 maximum current rating, and a multi-turn variable resistor allows the sensitivity to be adjusted by varying the LED current.

This infra-red light is detected using a TSSP4038 infra-red receiver[19] via a reflector on the wheel. This type of sensor produces a steady output signal when a 38kHz carrier is detected[20]. The output of the receiver is monitored by the ATtiny85, and the state of the Sensor Head output pin is set to follow changes in state in the output of the receiver.

Another microcontroller output pin sets the state of the diagnostic LED to the inverse of the IR receiver output (i.e. the LED is on when the receiver output is pulled low during a signal pulse.

The total current drawn by the prototype sensors is approximately 8.5mA untriggered, 11.5mA triggered.

Eagle CAD and Gerber files for the board can be downloaded from GitHub, and ready-made boards can be obtained from OSH Park. There are two versions of the PCB, as is explained further in the *Construction* section below.

- https://github.com/Simulators/simulator/tree/master/hardware/38khzsensor
- https://oshpark.com/shared_projects/t9JGGOlP (Type 1)
- https://oshpark.com/shared_projects/QSL0oWyG (Type 2)

---

[19] http://www.vishay.com/docs/82458/tssp4038.pdf
[20] Other types of 38kHz receiver only generate an output when a valid stream of modulated data is received.

Microcontroller I/O Pins

The following table shows the ATtiny85 pin assignments for the 38kHz Infra-Red Sensor Head:

Table 4 – Microcontroller I/O Pin Assignments

Arduino I/O Pin[21]	ATtiny85 Physical Pin	Function
0	5	Yellow Diagnostic LED
1	6	Sensor Head Output
2	7	(Spare)
3	2	Infra-Red Receiver Input
4	3	Infra-Red LED PWM Ouput

Microcontroller Fuse Settings

The ATtiny85 microcontroller has a number of configuration registers known as fuses. These are used to control the behaviour of the microcontroller[22]. Fuse values are contained in the file *boards.txt* described in the section on uploading firmware below, and are only written during the *burn bootloader* phase of programming.

Warning: Setting incorrect fuse values can render the microcontroller unusable or prevent further reprogramming without specialist hardware.

The fuse values for the 38kHz Infra-Red Sensor Head are defined in the following table.

Table 5 – ATtiny85 Fuse Settings

Fuse	Value	Notes
Low	0xE2	8MHz internal oscillator, maximum clock startup delay.
High	0XD5	Enable serial programming, preserve EEPROM contents, Brown-out detection level 1 (2.7V).

[21] Pin numbers as referenced in the Arduino programming environment.
[22] Fuse tutorial (based on ATmega328P): http://www.martyncurrey.com/arduino-atmega-328p-fuse-settings/

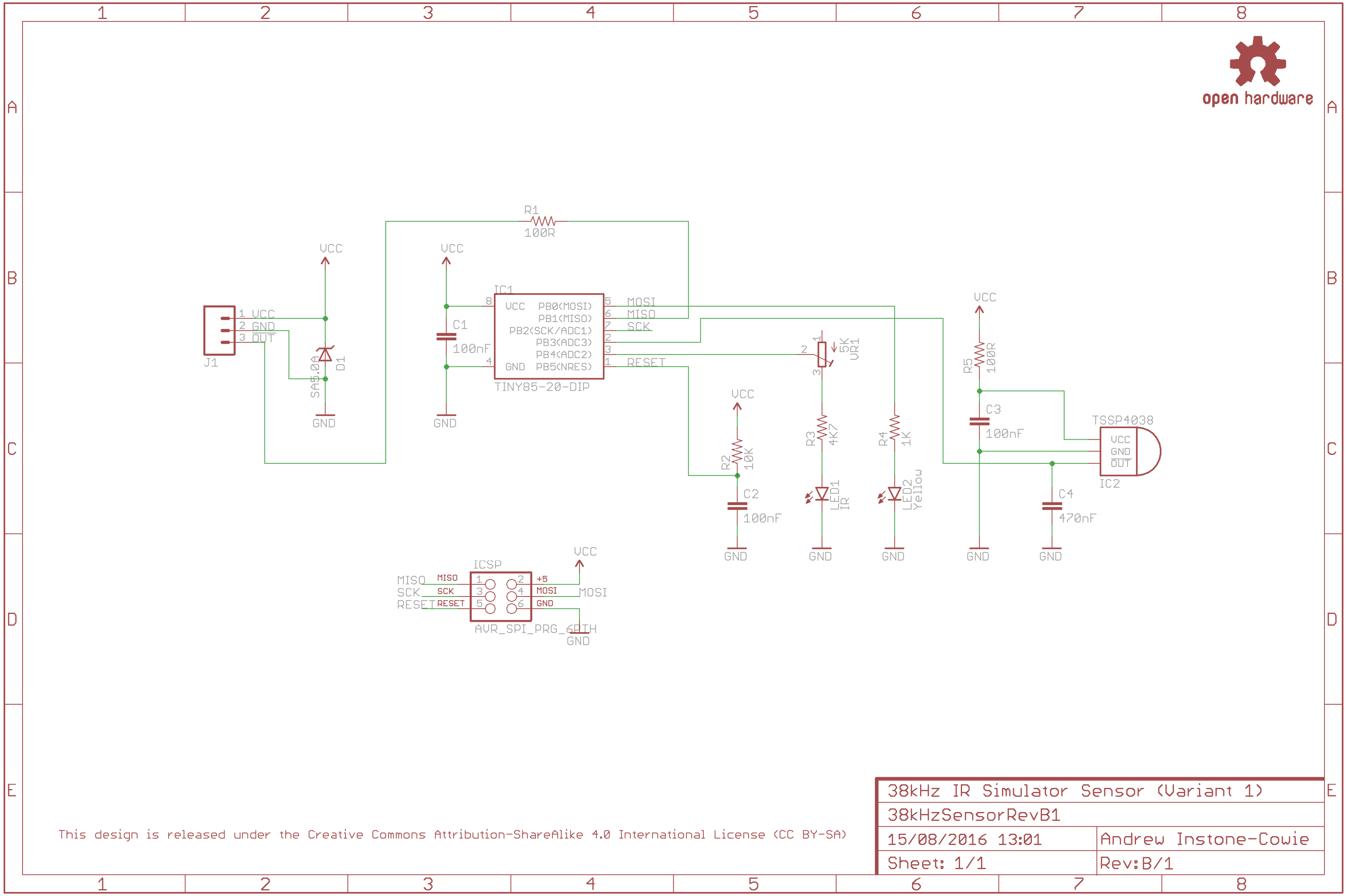
Parts List

Table 6 – 38kHz Infra-Red Sensor Head Parts List

Reference	Component	Notes
PCB	38kHz Sensor PCB Rev B (Type 1 or 2 - see text)	
R1, R5	100Ω 0.6W Metal Film[23]	
R2	10kΩ 0.6W Metal Film	
R3	4.7kΩ 0.6W Metal Film	
R4	1kΩ 0.6W Metal Film	
VR1	5kΩ multi-turn 3296X (Side Adjust)	Murata or Bourns
C1, C2, C3	100nF (0.1µF) 50V MLCC[24] (2.54mm Radial)	
C4	470nF 50V MLCC (5mm Radial)	
D1	SA5.0A	Transient voltage suppression (TVS) diode
IC1	Atmel ATtiny85	
IC2	TSSP4038 IR Receiver	
LED1	5mm LED Infra-Red	
LED2	3mm LED Yellow	Optional – see text
Sensor Header	3-Pin 0.1" Male Header	
ICSP Header	2x3-pin 0.1" Male Header	
IC Socket	8-pin, 0.3" pitch	IC1
Enclosure	WCAH 2855 ABS Black	ESR Components 400-595, Maplin BZ72P, Velleman WCAH2855
Screws	No2 x 9mm Stainless Steel Self Tapping	
Bezels	Kingbright LED Clip Recessed 5mm RTF5020	Optional – see text

[23] Carbon film resistors may be used as an alternative
[24] Multi-Layer Ceramic Capacitor

Schematic



open hardware
R1
100R
VCC
VCC
IC1
1 VCC
2 GND
3 OUT
J1
D1
SA5.0A
C1
100nF
GND
GND
VCC
PB0(MOSI)
PB1(MISO)
PB2(SCK/ADC1)
PB3(ADC3)
PB4(ADC2)
GND
PB5(NRES)
TINY85-20-DIP
MOSI
MISO
SCK
RESET
5K
VR1
VCC
R2
10K
C2
100nF
R3
4K7
LED1
IR
R4
1K
LED2
Yellow
VCC
R5
100R
C3
100nF
TSSP4038
IC2
OUT
C4
470nF
GND
GND
GND
GND
GND
ICSP
VCC
MISO
SCK
RESET
+5
MOSI
GND
AVR_SPI_PRG_6PTH
GND
38kHz IR Simulator Sensor (Variant 1)
38kHzSensorRevB1
15/08/2016 13:01
Andrew Instone-Cowie
Sheet: 1/1
Rev:B/1
This design is released under the Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA)

PCB Layouts

The following diagrams show the layout of the 38kHz infra-red sensor PCBs.

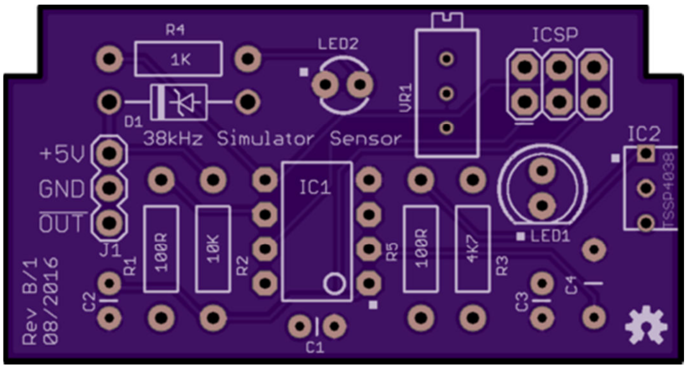


Figure 23 – 38kHz Infra-Red Sensor Board Layout (Type 1)

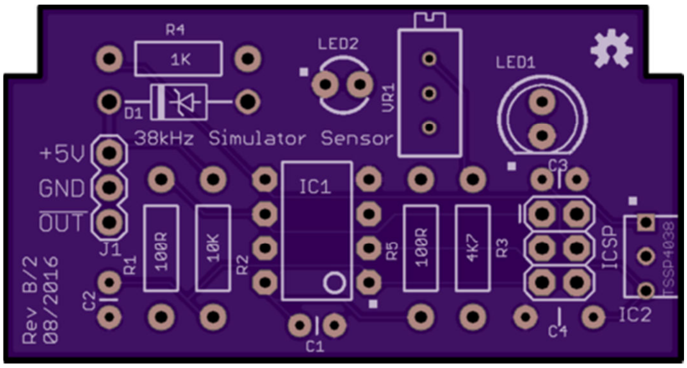


Figure 24 – 38kHz Infra-Red Sensor Board Layout (Type 2)

Construction

Two prototype variants of the 38kHz Infra-Red Sensor Head have been constructed. In Type 1, the IR receiver and IR LED are mounted on opposite sides of the PCB. In Type 2, they are mounted side-by-side on the top of the PCB. The objective of the Type 1 construction was to minimise the effect of side-scatter from the IR LED onto the receiver, early prototyping having suggested that this would be problematic; in practice the side-by-side Type 2 construction has been found acceptable with the body of the LED wrapped in a short length of back heatshrink sleeving.

The difference between the two board layouts can be seen in the following photographs.

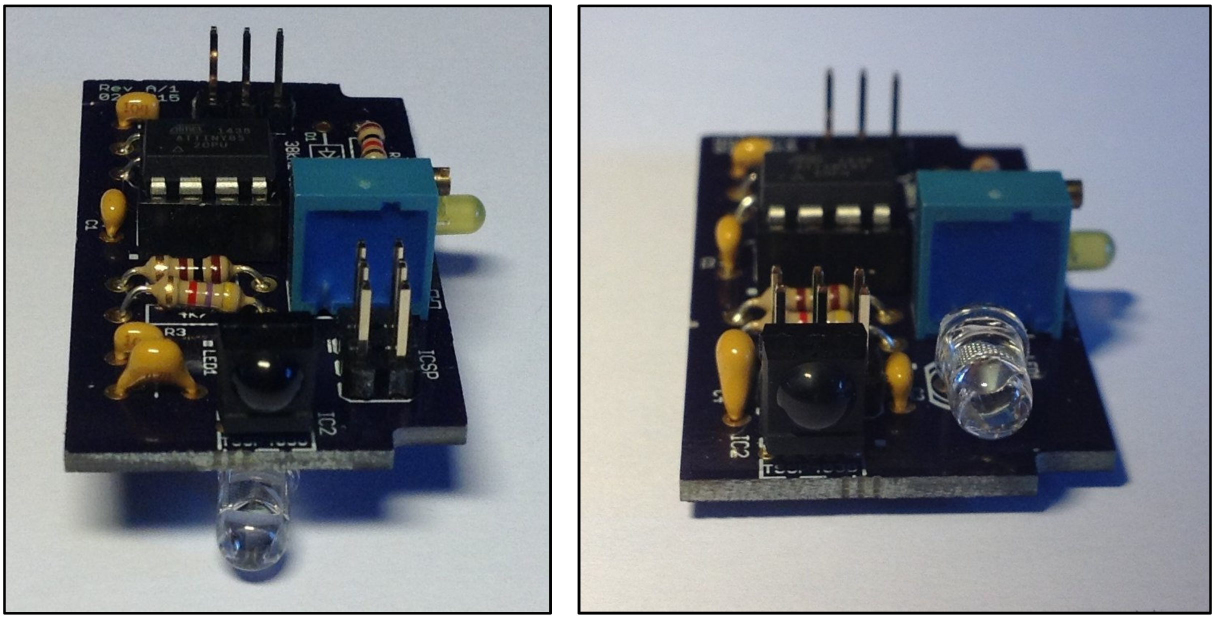


Figure 25 – End View of 38kHz Infra-Red Sensor Head PCBs

All the components on the 38kHz Infra-Red Sensor Head PCB are mounted on top, silkscreen, side of the board, apart from the IR LED on the Type 1 board.

- Start by soldering the components with the lowest profile (resistors, ceramic capacitors), then the remainder of the components in order of increasing height, ending with the variable resistor and header pins.
- The use of an IC socket for IC1 is optional, but strongly recommended.
- Fitting the diagnostic LED is optional, but strongly recommended.
- The LEDs are polarised, and must be mounted in the correct orientation. The cathode is usually denoted by a flat on the side of the moulding and by a shorter leg.
- Pay particular attention to the correct orientation of the polarised components D1, IC1, IC2 & the LEDs[25].
- Before fitting the socketed IC, connect the board to a power supply and check that +5V and 0V appear on the correct pins of the socket and on the correct header pins. Disconnect the power supply and fit the IC, observing that the polarisation dot/notch is at the bottom.
- If the board is powered up at this point, there will be no indication from the diagnostic LED. This is normal if the firmware has not yet been uploaded to the microcontroller.

[25] Note that prior to PCB Rev B, D1 was a non-polarised component.

Completed 38kHz infra-red sensor PCBs of each type are shown in the following photographs. Note that these are earlier versions of the PCB.

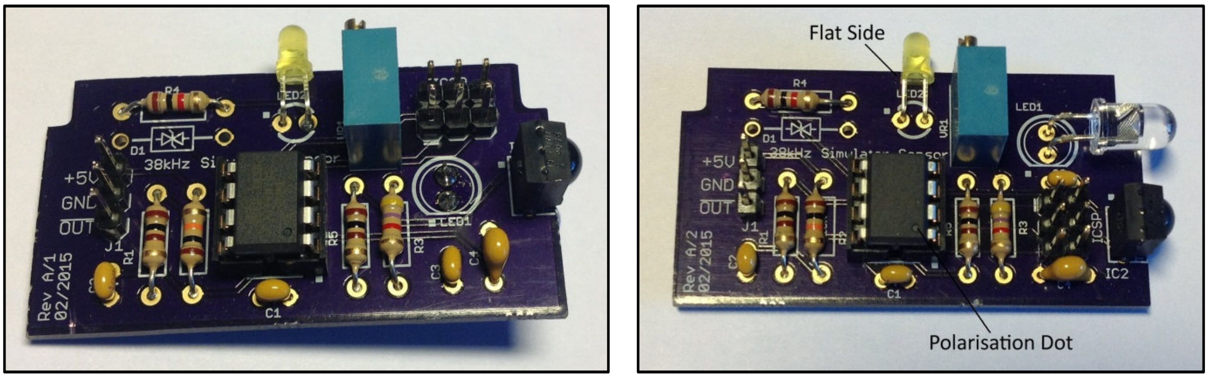


Figure 26 – Completed 38kHz Infra-Red Sensor Head PCBs

Enclosure

The suggested enclosure for both variants of the 38kHz infra-red Sensor Head is the project standard WCAH 2855 black ABS box manufactured by Wisher Enterprise Co Ltd.

- This enclosure can be obtained from Maplin, ESR Components and Velleman, and is the same enclosure adopted as a standard for Sensor Heads across the Liverpool Ringing Simulator Project.
- The enclosure is 85mm x 55mm x 30mm (external) overall.
- Drilling large diameter holes with twist drills can result in bit grabbing and damage to the enclosure. Small diameter (16mm/18mm) hole saws are available at relatively low cost (e.g. on eBay), and these make the process of drilling the enclosure much easier and safer.
- Using a sharp chisel, carefully and gently remove the PCB ribs from the inside of the enclosure as indicated on the diagram below, to allow the Sensor and Power/Data connector to be mounted. Using too much force may crack the case.
- It is recommended that the lid retaining screws supplied with the enclosure are replaced with stainless steel equivalents.
- The 4.5mm mounting hole is optional. Other mounting arrangements may be devised.
- The 3mm hole for the LED is not required if the diagnostic LED is omitted or is mounted flush with the PCB.

The following diagram shows the suggested drilling layout for the enclosure for a Sensor Head using the Type 1 PCB, and using LED bezels.

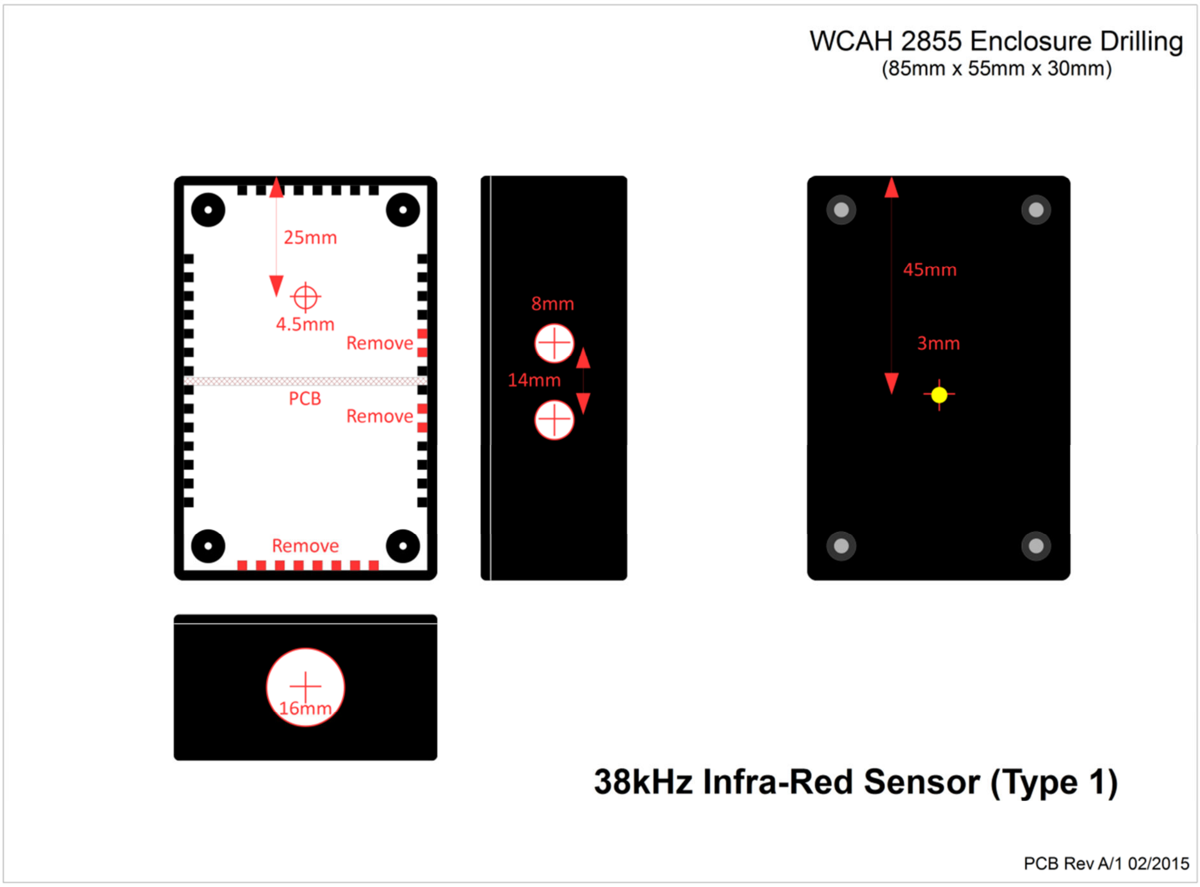


Figure 27 – Enclosure Drilling Guide (Type 1)

The following diagram shows the suggested drilling layout for the enclosure for a Sensor Head using the Type 2 PCB, with no bezels.

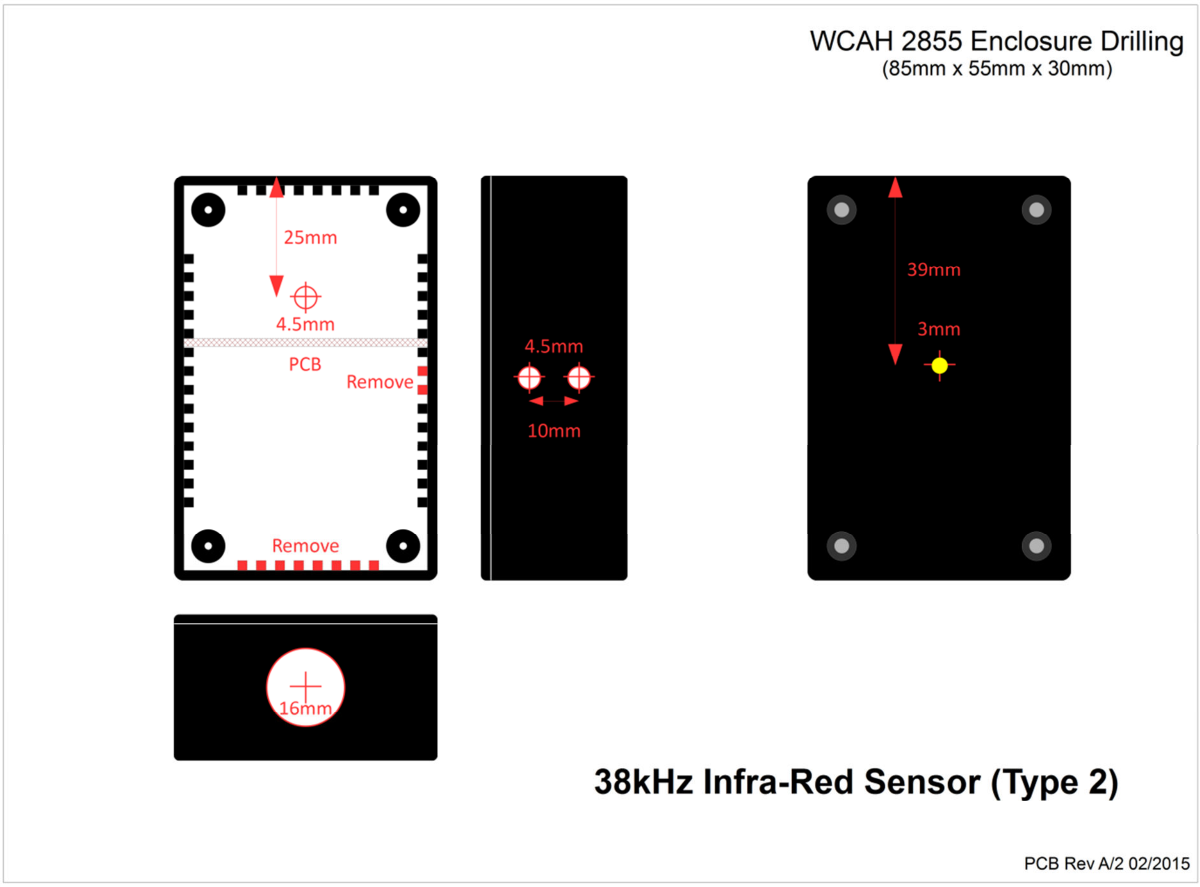


Figure 28 – Enclosure Drilling Guide (Type 2)

The initial Type 1 prototype was built with cut-down recessed LED bezels to finish off the LED and receiver apertures, as shown in the following photographs. This is a matter of aesthetics and does not affect the operation of the Sensor Head, and bezels were not fitted to the Type 2 prototype.

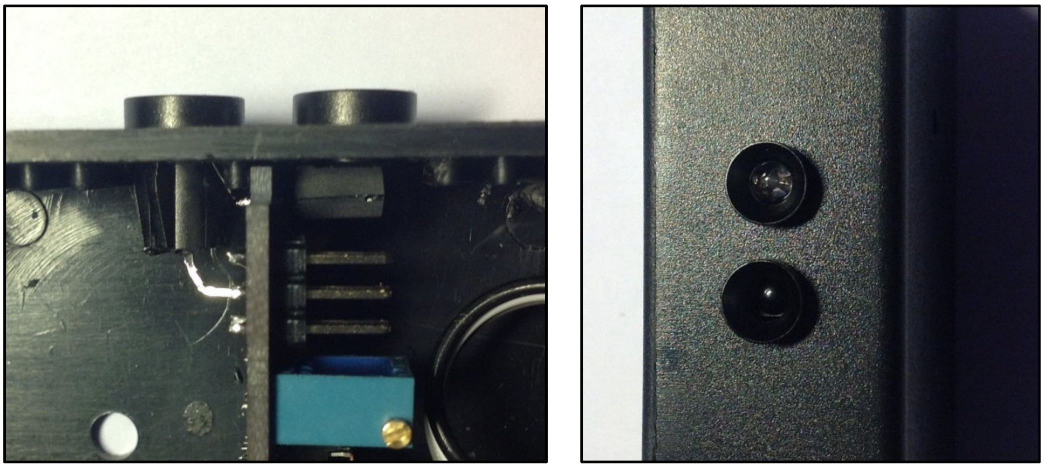


Figure 29 – Type 1 Construction – Bezels

Internal Wiring

A Sensor Connector Cable is required within the 38kHz infra-red Sensor Head enclosure, to connect the sensor board to the external signal connector.

Parts List

Table 7 – Internal Cabling Parts List

Component	Notes
GX16-4 Chassis Plug (Male)	Signal Connector
Ribbon Cable	3-core
DuPont 0.1” Female Crimp Connectors	3
DuPont 0.1” Female Connector Shell	1 x 3-pin

While it is possible to make up the DuPont connector cables by hand, this is time consuming and not easy even if the proper crimp tool is available. An alternative approach is to buy ready-made lengths of ribbon cable with female DuPont connectors already crimped, and cut these down to make the required cables. These are readily available on eBay, and can save a lot of work.

Note that the core colours shows in this section are for clarity only, and have no other significance.

The Sensor Connector Cable has a GX16-4 chassis plug on one end, and a 3-pin female DuPont connector on the other, wired as shown the following diagram.

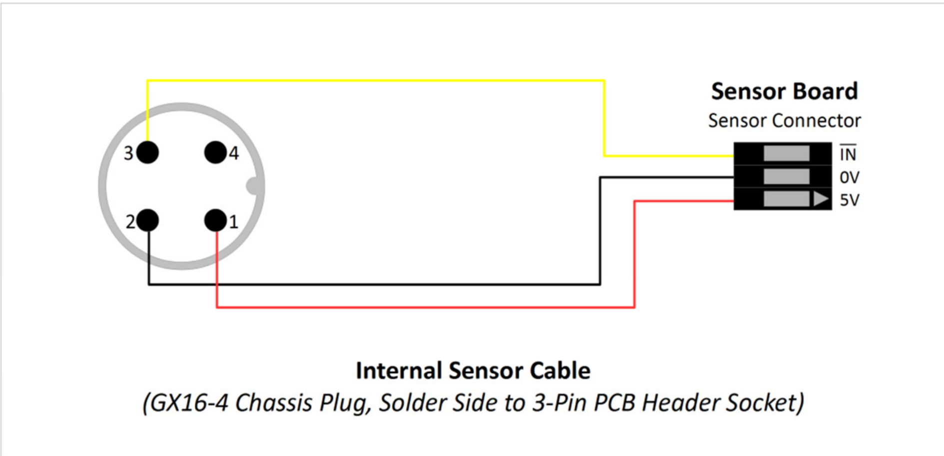


Figure 30 – Sensor Connector Cable Diagram

A suitable length of ribbon cable can be used for this cable, the required length is approximately 6cm overall.

The cable ends are soldered onto the GX16-4 chassis plug following the wiring the diagram above. A short length of heatshrink sleeve, 2.5mm unshrunk diameter, is recommended on each core to protect the soldered connection and provide some strain relief.

The Sensor Connector Cable can be seen in one of the following pictures, which shows both variants of the completed Sensor Head. The black heatshrink sleeving on the infra-red LED can also be seen.

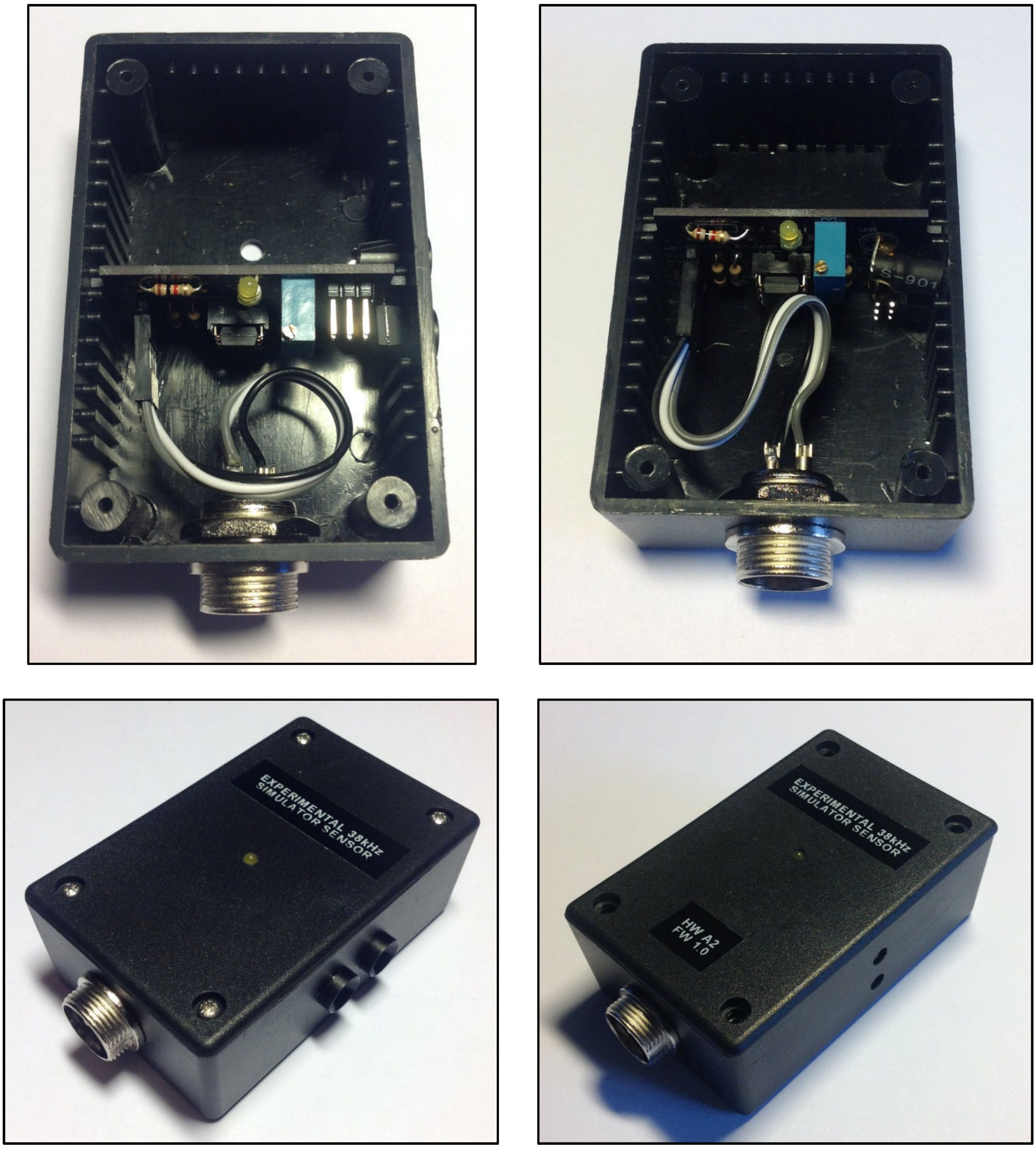


Figure 31 – Completed 38kHz Infra-Red Sensor Heads

Reflector

The sensor requires a reflector similar to that of the standard infra-red Sensor Head described above.

Calibration

The method of calibration of the 38kHz infra-red Sensor Head is similar to that of the standard infra-red Sensor Head described above.

Installation

Installation of the Sensor Head in the belfry is similar to that of the standard infra-red Sensor Head described above.

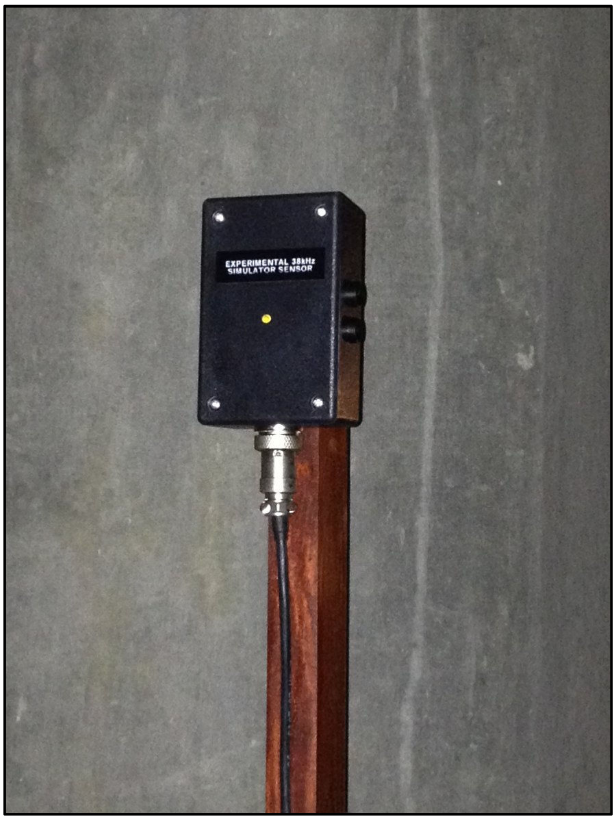


Figure 32 – Installed Prototype 38kHz Infra-Red Sensor Head

Firmware Upload

The firmware for the 38kHz infra-red Sensor Head released under the GNU General Public Licence (GPL), Version 3, and the source code and other supporting files can be downloaded from GitHub.

- https://github.com/Simulators/simulator/tree/master/firmware/38khzsensor

The firmware is very simple, and has only two functions:

- The onboard clock is used to generate a 38kHz PWM signal to drive the infra-red LED. Note that the values used assume that the ATtiny85 is being driven by its internal 8MHz clock.
- The main loop reads the state of the output from the infra-red receiver, and sets the state of the Sensor Head output to match. It also sets the diagnostic LED to the inverse of the IR receiver output state.

The Sensor Head firmware is held in non-volatile flash memory on the ATtiny85 microcontroller. It should only be necessary to re-upload the software in the event that the microcontroller is replaced, the flash memory has become corrupted, or the firmware requires updating.

The firmware code needs to be uploaded to the microcontroller on the 38kHz infra-red sensor PCB. The method of uploading the firmware using a hardware programmer via the ICSP header pins provided on the sensor PCB is exactly the same as that for the One Bell Simulator Interface, and is fully documented in the One Bell Simulator Interface Hardware Manual.

- The *38kHz Simulator Sensor Interface Boards (ICSP)* entry must be selected in the Arduino IDE Boards menu.

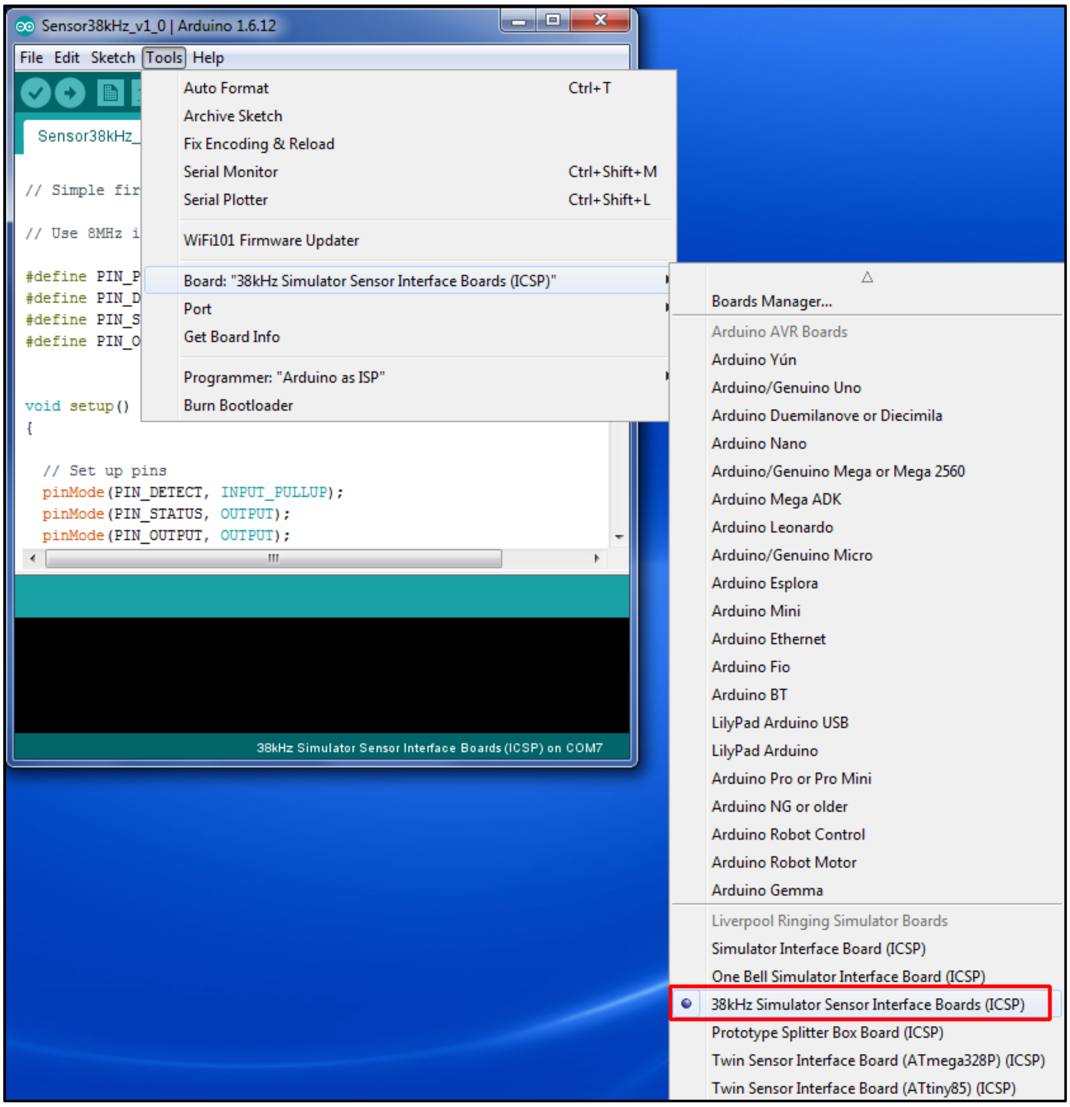


Figure 33 – 38kHz Sensor Board Selection

- Pin 1 of the ICSP header is at the bottom left on the Type 1 sensor board, top left on the Type 2 board.
- When the upload has completed the 38kHz sensor board will be reset, and on restarting the yellow diagnostic LED will flash twice in quick succession.