Georgia Institute of Technology
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Infrared LED Proximity Sensors

by

For
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The purpose of the infrared LED sensor is to detect objects or obstacles in close proximity (no more than six inches) to the sides of the autonomous vehicle. The sensor is a means of alerting the vehicle's microcontroller that a nearby obstacle is obstructing the path of the vehicle as it attempts a turn (i.e., checking the "blind spot"), or that another vehicle is, for example, threatening a sidelong collision. It is also useful in ensuring that the vehicle does not veer into a wall as it travels. Information of this nature is critically important to the safe operation of manned automobiles, and must be incorporated into the design of an autonomous vehicle. A summary of the design process and the details of the final design are given below.

The infrared proximity sensors were intended to be deployed on as many as three sides of the vehicle, at least two per side, and perhaps one on the rear. Consequently, cost and reliability were important considerations: the decision was made to use only industry-standard ICs and components.

Initially, the design was attempted with a Phase-Locked Loop IC. The circuitry was comprised of an infrared LED emitter/detector pair, a 4046 CMOS phase-locked loop (PLL) chip, and 351 op-amps. The VCO output of the PLL chip (pin 4) was buffered and then connected to the infrared emitter. The PLL's built-in VCO caused the LED emitter to oscillate at a frequency determined by the values of R1 and C (the pin for R2 is left open). The VCO output signal, a high-frequency square wave, was also shorted to pin 3 (Comparator In).
The detector signal was amplified by a non-inverting amplifier using a 351 op-amp. The detector signal was fed into the PLL at pin 14 (Signal In), at which point the detector signal was compared to the signal of the emitter by way of the PLL's built-in Phase Comparator.

The PLL should have outputted a square wave proportional to the phase difference (at PC Out pins). In this application, however, the phase difference was irrelevant; the key point was that the PC Out pins of the PLL would output a +5 VDC voltage whenever the detector “saw” the signal from the emitter.

In the lab however, this PLL circuit was not demonstrated to function as reliably as expected. While the PLL consistently outputted a square wave whenever the emitter

\[ \text{Output signal sent to controller} \]

\[ \text{Voltage-Controlled Square Wave Oscillator @ 1 kHz} \]

\[ \text{2nd-Order Multi-Feedback Band-Pass Filter (f_o = 1 kHz)} \]

\[ \text{Emitter} \]

\[ \text{Obstacle} \]

**Figure 1.** Model of the redesigned infrared sensor
and detector were facing one another at a distance of up to one foot, it frequently outputted the same signal even when the path between the emitter and detector was blocked. Once the detector picked up the frequency from the emitter, the PLL output stayed high, even after the emitter was turned off or blocked. It proved even more difficult to predict the circuit’s functionality when the emitter/detector were placed side-by-side, as they would be when implemented on the vehicle. Additionally, the VCO output of the PLL was unpredictable. At times, it would output perfectly for a short period of time, and then stop arbitrarily.

The PLL-based system was abandoned in favor of the system shown in Figure 1.

In this case, the output of an infrared detector was input to a series of buffers and very
Figure 3. Bandpass filter circuits

high-Q, bandpass filters. These were used to filter out all other signals except the signal at
the frequency emitted by the VCO. The filter circuit was a buffer amplifier followed by a
series of two second-order, infinite gain, multiple feedback, bandpass filters followed by a
variable gain non-inverting amplifier. The MathCAD calculations in Figure 2 were used to
calculate the element values for the filter circuits. The circuit diagrams for the filter
circuits are shown in Figure 3.
The infrared detector would intercept a reflected signal from an infrared emitter being driven by a VCO. The VCO circuit was designed as shown in Figure 4.

The project was begun with some fairly inexpensive infrared emitters and detectors from RadioShack.com. However, our circuits functioned much better after purchasing high-quality emitter/detector pairs from Agilent. The components are as follows:

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSDL-4220</td>
<td>30° viewing angle infrared emitter</td>
</tr>
<tr>
<td>HSDL-4230</td>
<td>17° viewing angle infrared emitter</td>
</tr>
<tr>
<td>HSDL-4400</td>
<td>110° viewing angle flat top low profile infrared emitter</td>
</tr>
<tr>
<td>HSDL-4420</td>
<td>24° viewing angle dome top low profile infrared emitter</td>
</tr>
<tr>
<td>HSDL-5400</td>
<td>110° viewing angle flat top low profile infrared detector</td>
</tr>
<tr>
<td>HSDL-5420</td>
<td>28° viewing angle dome top low profile infrared detector</td>
</tr>
</tbody>
</table>

This design was tested and shown to work correctly in the lab. A prototype of the VCO/emitter circuit was built on one protoboard; the detector/filter circuit was built on another. The detector could detect a reflected signal six inches away. A printed circuit board file for the final design was created as shown in Figure 5. This circuit board was designed using Super PCB. The designed circuit board file is included in this report.

Below are various views of the circuit board layout.

One issue that remains to be addressed is the conditioning of the output signal for processing by the microcontroller. The system described above outputs a variable analog signal depending on detection signal strength, interference, and noise. A voltage comparator could be designed and implemented using an op-amp at the system's output to deliver +5 VDC when the detection voltage exceeds a user-defined threshold voltage.

To assist in this procedure, the overall gain of the filter circuit may be adjusted by
adjusting P1. Also, it may prove beneficial to alter the circuits described above to accommodate a variable bandpass filter that self-adjusts to center around the frequency output by the VCO.

![Diagram](image)

Substituted 3904 BJT in parallel with 100k ohm resistor

**Figure 4.** VCO for 100 kHz
Figure 5. Super PCB circuit layout for infrared sensor