

Bluetooth technology, developed by Ericsson Mobile Communications, a worldwide telecommunications company based in Sweden, is fast becoming the worldwide standard for short-range wireless communication. The technology was originally developed to easily connect cell phones with peripheral devices such as personal computers. However, other potential applications for home and office quickly emerged. Today, over 2000 companies have joined the Bluetooth Special Interest Group, which coordinates the royalty-free licensing of Bluetooth technology. Bluetooth is growing so rapidly that Merrill Lynch predicts that by 2005 there will be more than 2.1 billion Bluetooth compatible devices on the market.

Bluetooth uses Radio Frequencies (RF) to transmit and receive signals in the ISM Band. This is an unlicensed frequency range operating between 2.4 and 2.48 GHz. The ISM band is used by a host of wireless applications including some cordless phones, 802.11 and HomeRF technologies, baby monitors, garage door openers and microwaves. In order to prevent interference with other devices, Bluetooth employs a spread-spectrum frequency-hopping technique which takes a narrowband signal and spreads it over a broader portion of the available radio frequency band. This spreading is accomplished by frequency-hopping, a technique developed for encryption that relies on the sender and receiver agreeing on a pre-defined "hop" sequence for frequency variation. Since only the intended receiver is aware of the transmitter's hopping pattern, only that receiver can make sense of the data being transmitted. Spread spectrum frequency hopping ensures Bluetooth's security and limits interference.

The Bluetooth 1.0 specification allows for a gross data transfer rate of 1Mbps. However, this is a theoretical maximum for half-duplex data transmission. Full duplex

transmission is accomplished at 432.6 Kbps. The Bluetooth specification can support three synchronous voice channels at 64 Kbps each. Bluetooth devices typically require 1mW of power to operate.

When two Bluetooth devices establish a connection, they create a network called a piconet. A Bluetooth piconet can contain up to eight Bluetooth devices, with one device serving as a master (DTE) and up to seven serving as slaves (DCE). All devices in a piconet share the same frequency-hopping scheme, which is established when a slave initially connects to a master. Bluetooth devices can operate in either a single slave piconet, in which a master connects to only one slave, multi-slave piconet, where a master connects to multiple slaves, or in a scatternet structure. A scatternet is enabled by masters and slaves with capability to connect to more than one device at a time (ie. two masters can connect to one another, and a slave can connect to more than one device at a time). See figure 1 for a diagram of this functionality.



Figure 1: Piconet Structure

FUNCTIONALITY:

The objective of the wireless communications portion of this project was to implement accurate, reliable, and secure serial communications. The first iteration of this project was to implement wireless infrared communications. Infrared communications were implemented using a high speed infrared communications chip from Reynolds

Electronics. This chip ramps up the voltage from TTL serial output to provide sufficient voltage such that an infrared LED will transmit signals to be picked up by an infrared receiver. The infrared transmitter circuit is found in figure 1. The oscillation was provided by a 20 MHz ceramic resonator, which was connected to pins 2-4, where pins two and three provided the oscillation, and the voltage on pin four determined the duty cycle. Data in was provided to pin six, and data out to pin seven. Two current limiting resistors and an NPN transistor inverted the output from the TX-IRHS chip.

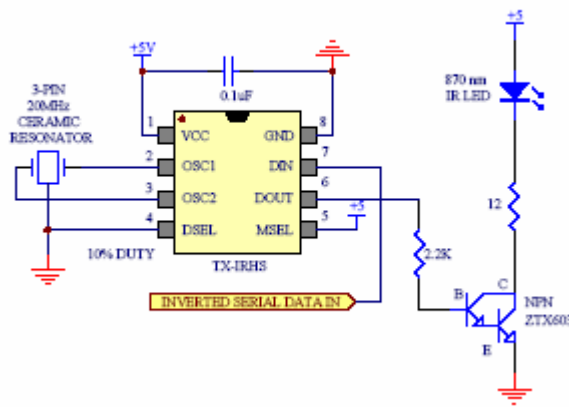


Figure 1 Infrared transmitter circuit.

Figure 2 indicates the receiving end of serial communications. Once again, a PNP transistor inverts the serial output, such that the output of this circuit is identical to the input.

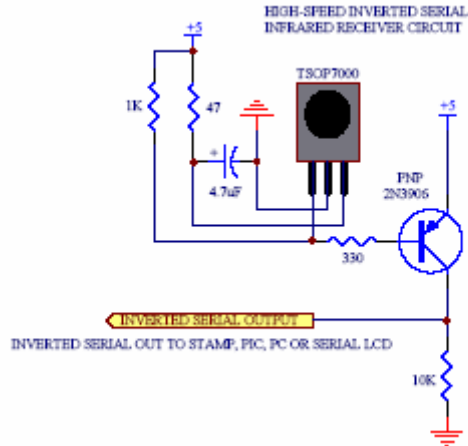


Figure 2 Infrared receiver circuit

These two circuits were built, but found to be highly unreliable in testing. The range was much shorter than the technical specifications suggested, and serial communications was only intermittently accurate. The “work around” solution in this first iteration was to send pulses instead of true serial signals. In other words, instead of sending several bytes of information serially, each stationary robot sent pulses corresponding to the position where it found the brightest light. The mobile robot would then interpret these pulses as angles, and calculate the location of brightest light. The most significant drawback to this method of communication was that the range was so small that the mobile robot had to be manually moved in range of each of the stationary robots before communications was successful. If the robots missed one or more pulses, they would calculate incorrect coordinates, and move to the wrong spot. Furthermore, this method was not secure, as other infrared sources could interfere with the functionality of the robots. Because infrared communications was not secure, accurate, or reliable, a better method of wireless communications was necessary.

The second iteration of this project involved the implementation of Bluetooth wireless communications. Bluetooth master/slave devices were purchased from Wireless

Futures “BlueWAVE” line of integrated circuits, which are designed to be “out of the box” Bluetooth solutions. In other words, this line of products is designed to be a simple one chip method of providing wireless cable replacement. These devices implement a point-to-point Bluetooth connection. Three types of Bluetooth devices were purchased, a dedicated master (DTE) device, a dedicated slave (DCE) device, and a device which could act as either a master or slave device (DTE/DCE). BlueWave devices can be configured with AT strings, and can support RS232 or UART signals.

The first step before connecting the Bluetooth devices to the microprocessor was to configure the device via a PC. The devices were configured via HyperTerminal. HyperTerminal is a Windows application used to send and receive communications directly through a PC’s COM ports. In HyperTerminal, commands were tested and device discoveries initialized. In order to connect two Bluetooth devices, the unique authentication code for every slave needed to be discovered. By connecting the master devices to the PC, and powering up the slave, it was possible to figure out which commands were necessary to connect two devices. Furthermore, the default speed for the Bluetooth devices was 19200 bps, which is faster than the maximum serial output of the PIC. The speed of all three Bluetooth devices was configured to 9600 bps via a PC.

Because a PIC sends and receives signals at TTL (between +5 volts and zero) levels, the UART pins were used to connect to the microprocessor and the RS-232 level signals were disabled (RS-232 operates between ± 12 Volts). Flow control was disabled for both RS-232 and UART communications by tying the CTS/RTS pins together. It was discovered that the flow control pins for the UART signals were not enabled, and that the RS-232 flow control had to be connected in order to send and receive TTL level signals.

Very little documentation or support was available for the UART communications on the BlueWave devices.

Once the UART pins were connected to the microprocessor, serial commands could be sent or received to the Bluetooth devices. The set of commands outlined in figure 5 were used to establish a connection to the Bluetooth device.

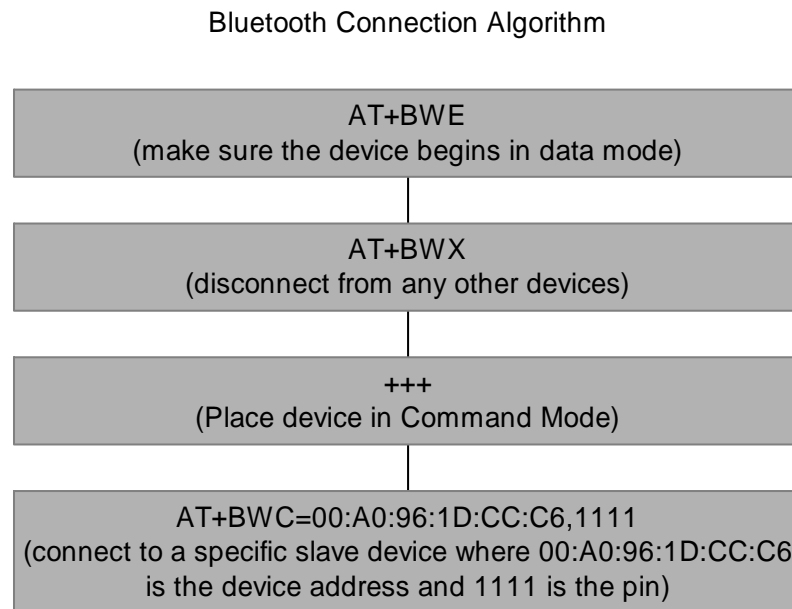


Figure 5: Bluetooth connection algorithm.

After the commands in figure 5 were sent, the program then waited for a “PAIR FAILED” or a “CONNECT”, which signifies whether the connection was successful. If the device was already connected to another device, a pair fail was returned. In the event of a pair fail, the connection was attempted again. In this way, the two stationary robots simultaneously tried to make a connection, and the unsuccessful one tried to connect over and over until it was successful. Once a successful connection was established, the master went into data mode (command “AT+BWE”), and transmitted the angle and its

numerical identifier (i.e. each stationary robot was assigned a numerical identifier signifying the left or right robot). Finally, “AT+BWX” was sent to disconnect the devices after data was sent.

On the receiving end, the mobile robot initially looped until both values were received. This functionality was much simpler. If the left/right identifier was received, the left/right angle value was set. Once both angle values were nonzero, the robot calculated the angles and moved to the corresponding coordinates. Because of the First-In- First-Out structure of the Bluetooth stack, the receiving device got the data bytes in the reverse order they were sent. In other words, the transmitter (stationary robot) sent the angle followed by the numerical identifier, and the receiver (mobile robot) received the numerical identifier followed by the angle.

TIMELINE:

December 2003- Pulse Controlled Infrared Communications established

January 2004- BlueWave devices arrive

February 2004- Devices connected via PC and connection between devices established.

March 2004- Full communications functionality realized and devices demonstrated.