Playing with Radio Controlled Cars

An experimental analysis of the radio communications system behind RC toys

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Introduction

This project spun out of a desire to build a simple radio-remote-control relay controller as an example project for the ENGR-162 class that I am teaching. Unfortunately, I was not able to complete the project in time for it to be useful during the present semester. I decided, however, to expand the scope of the project to be more exploratory, since I know very little about practical, inexpensive methods used for simple radio-controlled devices. Consequently, this document includes both the design/build aspect of my relay controller project, and some experimental results from looking at the radio communications circuitry.

The Device Under Test

The device selected for testing is a toy RC-Car manufactured by New Bright toy company. The particular car is a '69 GTO Judge 1/16 scale model, part number 1656/7, as shown in figure 1. The car is powered using a 6V rechargeable battery and operates on a frequency of 27.145 MHz, sitting right in between Citizen's Band channel 15 and 16. The car's remote falls under part 15 of the FCC rules, requiring it to not cause any harmful interference while accepting any that it may receive.

Figure 1: '69 GTO Judge RC Car

The car is "fully functional," meaning that the drive system (forward/reverse) can be operated independently of the steering system (left/right). This is significant in-so-far as the radio communications circuitry must be able to communicate drive commands at the same time as steering commands. The following table summarizes the separate states that the RC system must be capable of handling.

| STEERING	DRIVE
N/A	N/A
LEFT	N/A
RIGHT	N/A
N/A	FORWARD
N/A	REVERSE
LEFT	FORWARD
RIGHT	FORWARD
LEFT	REVERSE
RIGHT	REVERSE

Excluding the case where no action is required (i.e. – both controls are in the neutral position), there are eight separate commands to be handled. The implications of this fact will be explored later.

Exploring the Radio-Control Link

RC toys are typically inexpensive, unsophisticated devices by modern standards. That said, they are still an interesting case study in radio communications. Perhaps the simplest and most inexpensive method of radio communications is the use of On-Off keying (OOK), which is used by the RC Car's modulation method.

Reverse Engineering

In order to determine the method and specifics behind the radio link for the remote controlled car, an oscilloscope was used to view the signal at the output of the radio remote control. In order to do this, the 9V battery from the remote was removed and then re-connected to the battery terminals of the controller using alligator clips. The oscilloscope probe ground was then connected to the negative terminal of the battery, and the probe itself was clipped to the wire antenna on the remote. Figure 2 shows the setup.
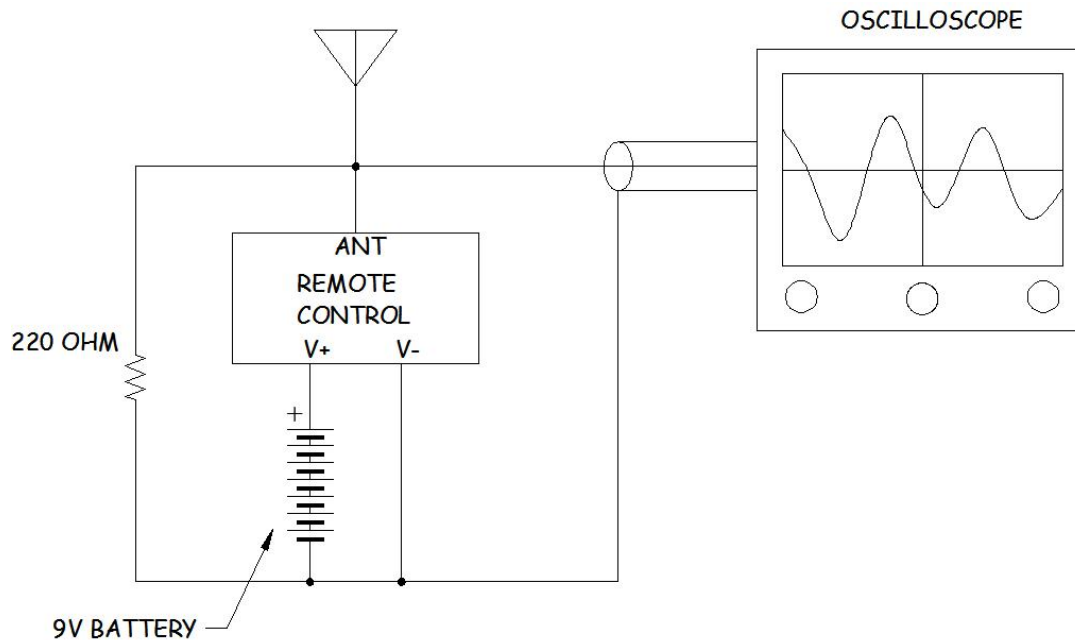
*Figure 2: Test Setup Schematic to view radio signal output from remote control*

Note that a 220Ω resistor was placed between the antenna and negative terminal on the battery. This prevented 60Hz alternating current, induced by nearby appliances. Without it, the otherwise square waveform would swim across the oscilloscopes screen. The resistor proved effective in shorting the high-voltage low-current AC signal to ground while affecting the RF signal from the remote very little.

By pressing the drive lever to the down position (Reverse), the waveform in figure 3 was observed on the oscilloscope. The time scale is 2ms per division and voltage scale at 0.1V per division. The oscilloscope scale has been redrawn over the display to provide clarity.
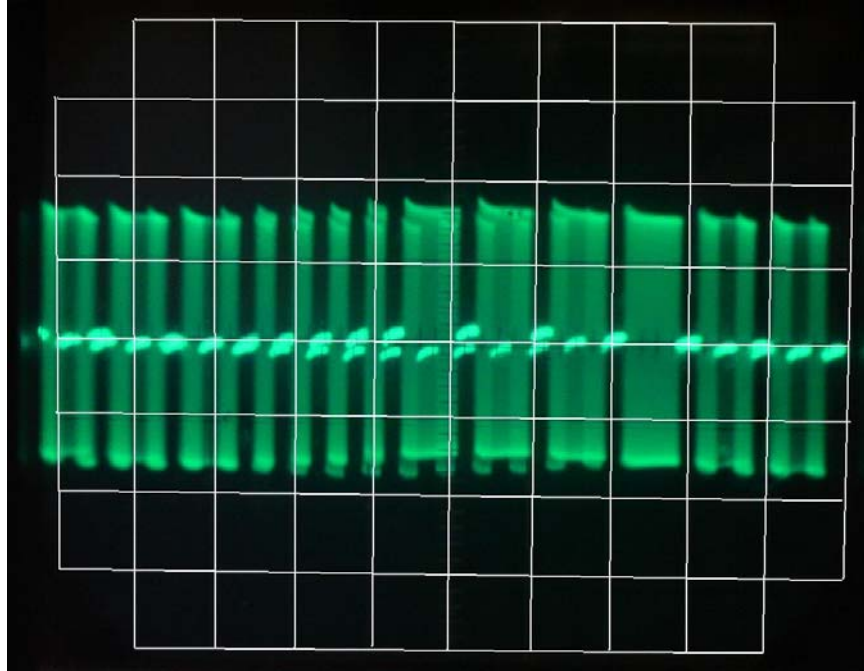
Figure 3: Oscilloscope Output from Remote Control

The peak-to-peak voltage of the signal is around 1.6V. By observation, the method of modulation is On-Off Keying of the carrier signal (27.145 MHz sine wave) at a rate of about 1.1 kHz. Narrowing the timescale down to 0.02μs per division, the sine wave carrier can be seen clearly in figure 4.
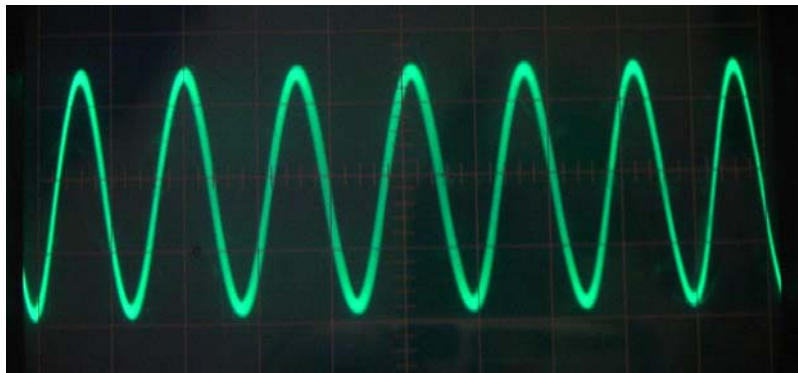
Figure 4: Carrier Signal viewed on Oscilloscope, Time Scale 0.02μs per division

The Results

A digital camera was used to take screen shots from the oscilloscope for each "command" (forward, back, left, and right) sent from the remote. (Individual sweeps were able to be photographed using a slow shutter speed, preventing confusing overlapping of data normally associated with an oscilloscope measurement.) Using this method, it was determined that the remote emitted a continuously on-off pulsed carrier. The cycle of pulses always start with four long pulses (0.92μs on, 0.46μs off) followed by a variable number of short pulses (0.46μs on, 0.46μs off). The figure 5 shows the waveform.
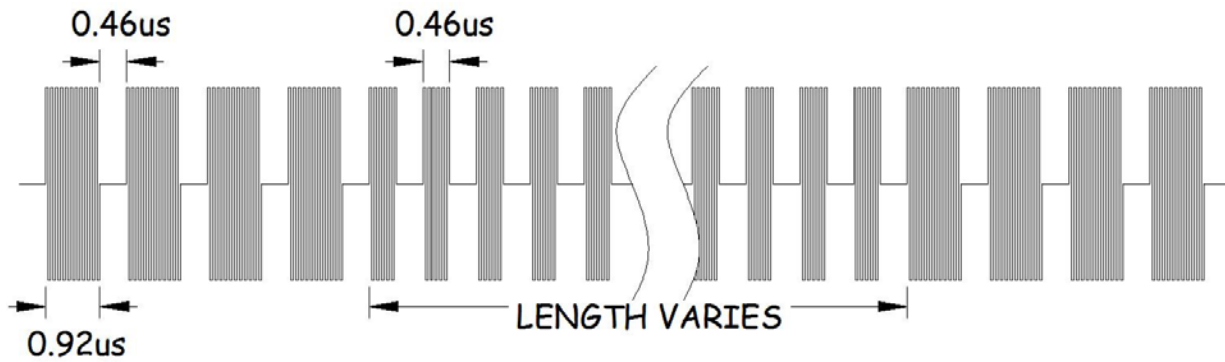
Figure 5: OOK Modulated Carrier

Figure 6 shows the waveform for a "Reverse" command being sent from the remote control. The time-scale is set to 10ms per division.
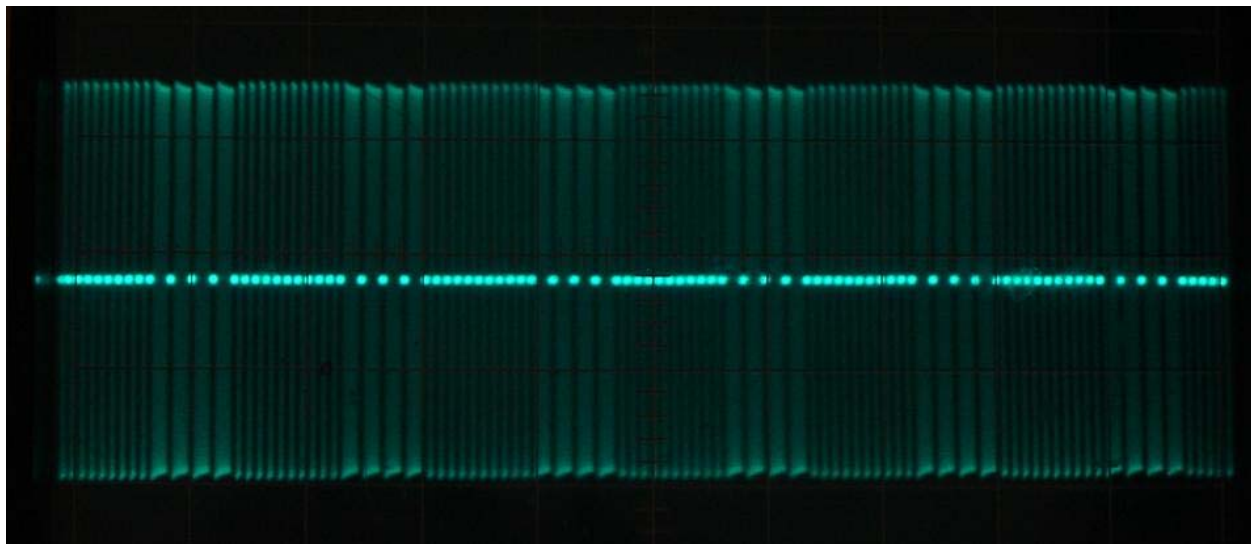

*Figure 6: Oscilloscope Output Waveform for "Reverse" Command*

By analyzing these photographs, the number of short pulses between the series of four long pulses could be measured and tabulated. Measurements were taken for each of the eight cases listed in the "Device Under Test" section.

STEERING	DRIVE	Period of Pulse Cycle (ms)	Number of Short Pulses in Cycle
LEFT	N/A	67	64
RIGHT	N/A	61	58
N/A	FORWARD	44	40
N/A	REVERSE	16	10
LEFT	FORWARD	49	46
RIGHT	FORWARD	55	62
LEFT	REVERSE	38	34
RIGHT	REVERSE	33	28

For each command, individual or paired, a unique number of short pulses are transmitted between the 4 long pulses. The number of pulses, or length of the cycle is interpreted by the circuitry in the receiver to determine which motor(s) to turn on in the car, and in what direction. It is not self-evident how the actual decoding circuitry works, as this circuitry is contained with a proprietary chip on the car's PC board.

Figure 7: Front View of Car's PC Board
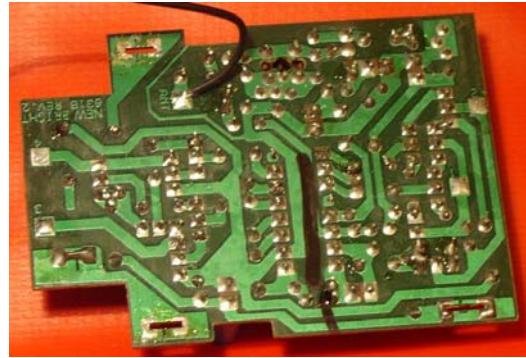
Figure 8: Underside View of car's PC Board

A possible method for decoding the transmitted signal would be using an envelope detector followed to filter out the carrier, followed by a microcontroller. The microcontroller could be programmed to count the number of pulses to determine which command is being transmitted. The method employed on this particular PCB is probably more primitive. The circuit probably "looks" for certain demodulated frequencies within the transmitted signal and then makes a logical decision based on these frequencies.

Building an Event Controller

The RC communications layer is transparent to the operation of the device, making it very useful for building what is known as an "event controller" – a device that can trigger an event to occur. Such devices are useful wherever wireless remote control is needed. In particular, this type of controller is useful for special effects in theatrical settings.

The Design

The car's PCB can be conceptualized down to a box with seven wires coming out of it: One for the antenna, two for power, two for steering, and two for the drive motor. In order to convert car into an event controller, the motors for steering and driving are replaced with relays. For added flexibility, four relays are used – each relay's coil is wired from one output wire to ground. Note that the relays' coil voltage must match the battery voltage for the car – in this case 6V. Figure 9.
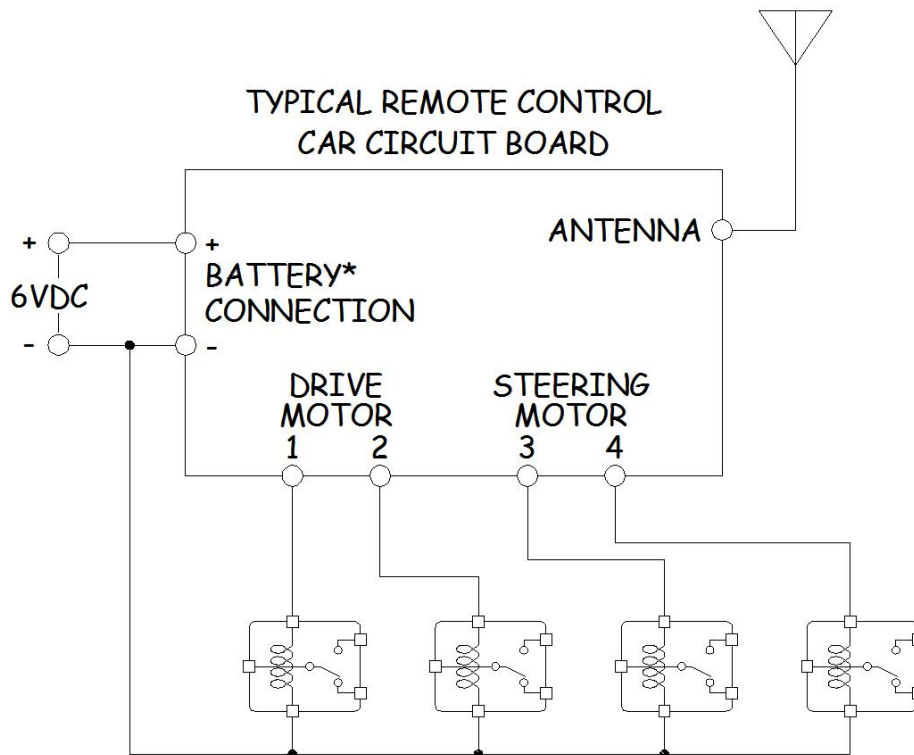
Figure 9: RC Relay Event Controller Schematic

In this manner, each direction (forward, reverse, left, right) corresponds to a different relay, providing four separate outputs. The one drawback to this design is that only two outputs are truly independent. Relays corresponding to the forward and reverse function cannot be activated simultaneously. Similarly, the relays corresponding with the left and right functions cannot be activated simultaneously. For that reason, the two relay outputs controlled by the drive motor output will be called outputs A1 and A2. The relay outputs controlled by the steering motor will be called B1 and B2. Since 12VDC is more commonly available as a power source, a voltage regulator was added to the circuit to allow it to operate at 12VDC.

Conclusion

Radio-Controlled toys such as RC Cars can provide an inexpensive, simple solution for a number of remote control applications. Their availability and license-free usage make them perfect for short development time.

References:

S. Gibilisco and N. Sclater, *Encyclopedia of Electronics,* 2nd ed. Tab Books, 1990.

Frequency Lists http://www.durhamradio.com/freq.htm