LEGO Power Functions RC

Version 1.20

Introduction

The purpose of this document is to describe the RC protocol supported by the LEGO Power Functions RC Receiver.

Attention!

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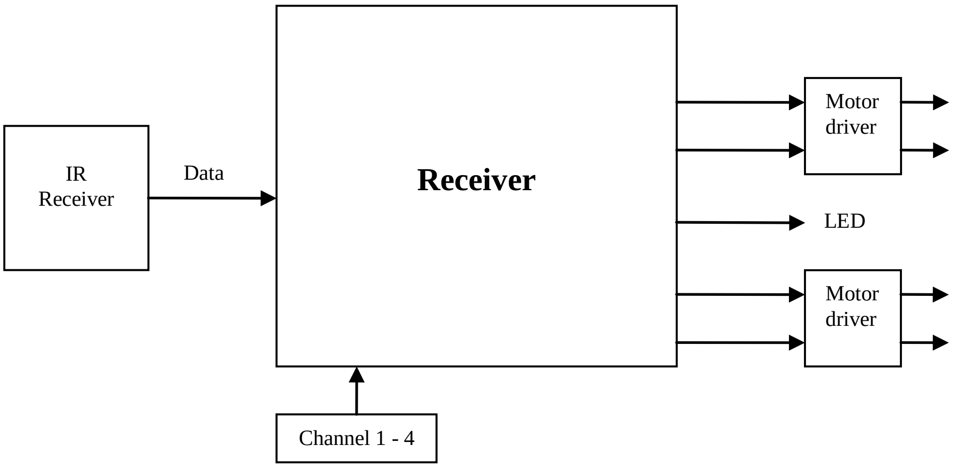
LEGO Power Functions RC Receiver

The receiver has input for IR data and channel switch and output for two LPF plugs and one LED.



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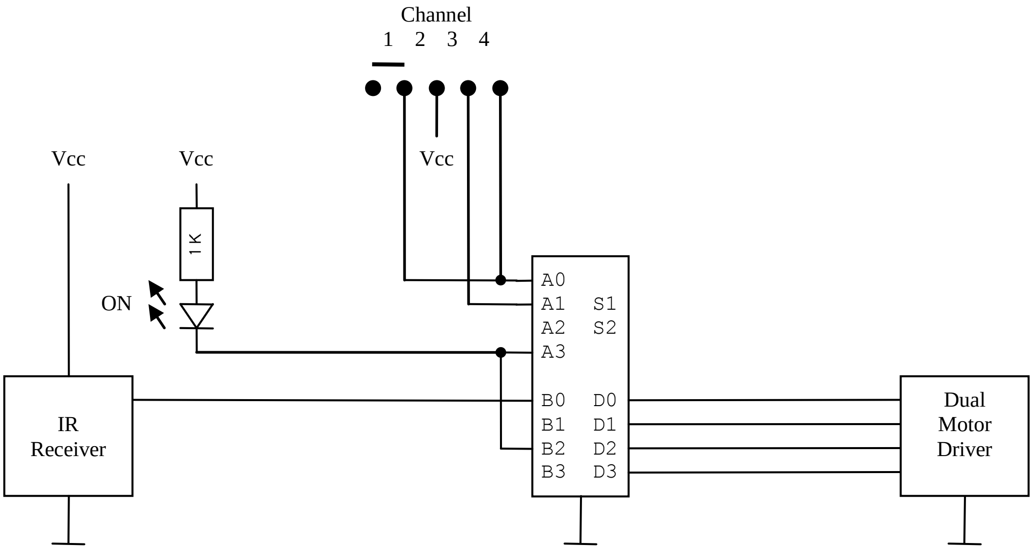


Description

This receiver firmware is capable of executing all commands in the “LPF RC Protocol” – acting in a variety of RC modes. Each mode implements a certain type of RC functionality.

When applying supply voltage the LED will give a short blink and then light up - the receiver is now ready. If a legal valid command of the right channel is received the LED will shortly turn off and indicate that the command is executed. The effect you will see is the LED blinking when messages are received.

The outputs of the RC Receiver are generic Power Functions outputs – in the following we will use motors as examples to describe the functionality of the control.

Depending on command the four output port pins will turn into two motor controls or individually controlled outputs. The motor outputs will either be forward, float, brake, backward – ON/OFF or PWM controlled. Some commands are timed out after 1.2 second when not receiving IR others are not. Default behavior is floating outputs.

The receiver does not power down and can only be turned off by removing its supply voltage.

LEGO Power Functions RC Protocol

The payload is: 1 toggle bit, 1 escape bit, 2 bits for channel switch, 1 bit for address, 3 bits for mode and 4 bits for various data depending on mode.
The address bit is intended for enabling an extra set of 4 channels for future use. The current PF RC Receiver expects by default the address bit to be 0.
A message consists of: A special length synchronisation start bit, payload and "Longitudinal Redundancy Check" to validate the entire message before executing the command and at last a stop bit to terminate the message.

Binary representation:

	Nibble 1				Nibble 2				Nibble 3								
start	***T***	***E***	***C***	***C***	***a***	***M***	***M***	***M***	***D***	***D***	***D***	***D***	***L***	***L***	***L***	***L***	***stop***
Start	Toggle	Escape	Channel		Address	Mode			Data				LRC				Stop

Start	***start***	Special synchronisation start bit (see description under "Encoding")	
Toggle	***T***	0-1	Toggling for every new command
Escape	***E***	0	Use "Mode" to select the modes listed below
		1	Combo PWM mode
Channel	***CC***	0-3	Channel switch 1 - 4
Address	***a***	0	Default address space (from power up)
		1	Extra address space
Mode	***MMM***	000	Extended mode
		001	Combo direct mode
		01x	Reserved
		1xx	Single output mode
Data	***DDDD***	0-15	Data: different meaning depending on "Mode"
LRC	***LLLL***	xxxx	= 0xF xor Nibble 1 xor Nibble 2 xor Nibble 3
Stop	***stop***	Same as Start	

Extended mode

This mode is able to control:
Brake, increment and decrement PWM in 7 steps on Output A and toggle Forward/Float on Output B. Toggle bit is verified on receiver. No timeout for lost IR.
From power up the address bit is always expected to be 0 (default address space). If the "Toggle Address bit" command is received (with a = 0) the extra address space is used and commands are from now expected to have the address bit set to 1. A new "Toggle Address bit" command (now with a = 1) will toggle back to default address space.
The "Align toggle bit" command has no action and is used to make sure the next command send is in sync.

Binary representation:

	Nibble 1				Nibble 2				Nibble 3								
start	***T***	***0***	***C***	***C***	***a***	***0***	***0***	***0***	***F***	***F***	***F***	***F***	***L***	***L***	***L***	***L***	***stop***
Start	Toggle	Escape	Channel		Address	Mode			Data				LRC				Stop

Function ***FFFF***

0000	Brake **then float** output A
0001	Increment speed on output A
0010	Decrement speed on output A
0011	Not used
0100	Toggle forward/float on output B
0101	Not used
0110	**Toggle Address bit**
0111	**Align toggle bit (get in sync)**
1000	**Reserved**

Combo direct mode

This mode is able to control: Two outputs float/forward/backward/brake.
This is a combo command controlling the state of both output A and B at the same time.
Toggle bit is not verified on receiver.
This mode has timeout for lost IR.

Binary representation:

	Nibble 1				Nibble 2				Nibble 3								
start	***T***	***0***	***C***	***C***	***a***	***0***	***0***	***1***	***B***	***B***	***A***	***A***	***L***	***L***	***L***	***L***	***stop***
Start	Toggle	Escape	Channel		Address	Mode			Data				LRC				Stop

B output	***BB***	00xx	Float output B
		01xx	Forward on output B
		10xx	Backward on output B
		11xx	Brake **then float** output B
A output	***AA***	xx00	Float output A
		xx01	Forward on output A
		xx10	Backward on output A
		xx11	Brake **then float** output A

Single output mode

This mode is able to control: One output at a time with PWM or clear/set/toggle control pins.
Toggle bit is verified on receiver if increment/decrement/toggle command is received.
This mode has <u>no timeout</u> for lost IR on all commands except "full forward" and "full backward".

Binary representation:

	Nibble 1				Nibble 2				Nibble 3								
start	***T***	***0***	***C***	***C***	***a***	***1***	***M***	***O***	***D***	***D***	***D***	***D***	***L***	***L***	***L***	***L***	***stop***
Start	Toggle	Escape	Channel		Address	Mode			Data				LRC				Stop

Mode	***M***	0	PWM
		1	Clear/Set/Toggle/Inc/Dec
Output	***O***	0	Output A
		1	Output B

Mode = PWM

Data	***DDDD***	0000	Float
		0001	PWM forward step 1
		0010	PWM forward step 2
		0011	PWM forward step 3
		0100	PWM forward step 4
		0101	PWM forward step 5
		0110	PWM forward step 6
		0111	PWM forward step 7
		1000	Brake **then float**
		1001	PWM backward step 7
		1010	PWM backward step 6
		1011	PWM backward step 5
		1100	PWM backward step 4
		1101	PWM backward step 3
		1110	PWM backward step 2
		1111	PWM backward step 1

Mode = Clear/Set/Toggle/Inc/Dec

Data	***DDDD***	0000	**Toggle full forward (Stop → Fw, Fw → Stop, Bw → Fw)**
		0001	**Toggle direction**
		0010	**Increment numerical PWM**
		0011	**Decrement numerical PWM**
		0100	Increment PWM
		0101	Decrement PWM
		0110	Full forward (timeout)
		0111	Full backward (timeout)
		1000	Toggle full forward/backward (default forward)
		1001	**Clear C1 (negative logic – C1 high)**
		1010	**Set C1 (negative logic – C1 low)**
		1011	**Toggle C1**
		1100	**Clear C2 (negative logic – C2 high)**
		1101	**Set C2 (negative logic – C2 low)**
		1110	**Toggle C2**
		1111	**Toggle full backward (Stop → Bw, Bw → Stop, Fwd → Bw)**

Combo PWM mode

This mode is able to control: Two outputs with PWM in 7 steps forward and backward.
This is a combo command controlling the state of both output A and B at the same time.
Toggle bit is not verified on receiver.
This mode has timeout for lost IR.

Binary representation:

	Nibble 1				Nibble 2				Nibble 3								
start	***a***	***1***	***C***	***C***	***B***	***B***	***B***	***B***	***A***	***A***	***A***	***A***	***L***	***L***	***L***	***L***	***stop***
Start	Address	Escape	Channel		Output B				Output A				LRC				Stop

Output B	***BBBB***	0000	Float
		0001	PWM forward step 1
		0010	PWM forward step 2
		0011	PWM forward step 3
		0100	PWM forward step 4
		0101	PWM forward step 5
		0110	PWM forward step 6
		0111	PWM forward step 7
		1000	Brake **then float**
		1001	PWM backward step 7
		1010	PWM backward step 6
		1011	PWM backward step 5
		1100	PWM backward step 4
		1101	PWM backward step 3
		1110	PWM backward step 2
		1111	PWM backward step 1

Output A	***AAAA***	0000	Float
		0001	PWM forward step 1
		0010	PWM forward step 2
		0011	PWM forward step 3
		0100	PWM forward step 4
		0101	PWM forward step 5
		0110	PWM forward step 6
		0111	PWM forward step 7
		1000	Brake **then float**
		1001	PWM backward step 7
		1010	PWM backward step 6
		1011	PWM backward step 5
		1100	PWM backward step 4
		1101	PWM backward step 3
		1110	PWM backward step 2
		1111	PWM backward step 1

LEGO Power Functions RC Encoding

To ensure correct detection of IR messages six 38 kHz cycles are transmitted as mark. Low bit consists of 6 cycles of IR and 10 "cycles" of pause, high bit of 6 cycles IR and 21 "cycles" of pause and start bit of 6 cycles IR and 39 "cycles" of pause.

Graphically drawn:

IR Mark 

Low bit (data = 0) 

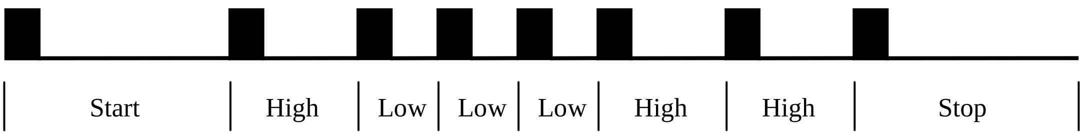
High bit (data = 1) 

Start/Stop bit 

The high pulse illustrates six 38 kHz cycles.

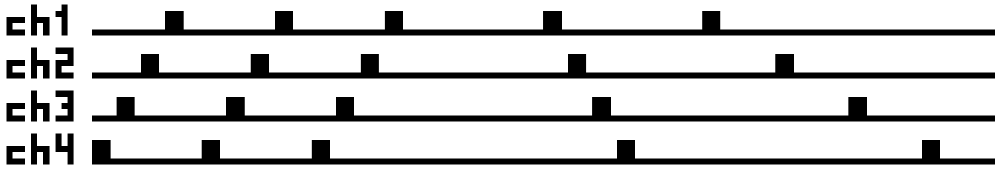
Low bit length	= 16 x 1/38K = 421 us
High bit length	= 27 x 1/38K = 711 us
Start bit length	= 45 x 1/38K = 1184 us
Stop bit length	= 45 x 1/38K = 1184 us

This example shows start bit, 6 bits and stop bit (not really the actual protocol).



Transmitting Messages

When a button is pressed or released on the transmitter the message is sent. Five exactly matching messages (if no other buttons are pressed or released) are sent accordingly in time intervals depending on the channel selected. This ensures that other transmitters are not interfering with all the messages.



When a button is held down and the protocol needs update to prevent timeout the message is send continuously with a time interval as between message 4 and 5. First after all buttons are released and this is transmitted the transmitter will shut down.

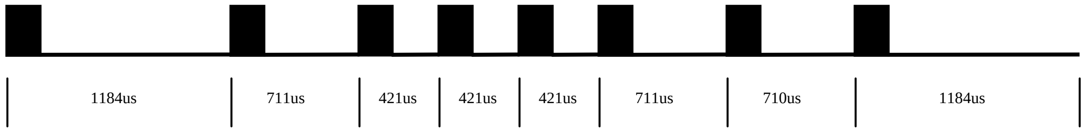
If t_m is the maximum message length (16ms) and Ch is the channel number, then

The delay before transmitting the first message is:	$(4 – Ch)*t_m$
The time from start to start for the next 2 messages is:	$5*t_m$
The time from start to start for the following messages is:	$(6 + 2*Ch)*t_m$

LEGO Power Functions RC Decoding

Decoding of message bits is done by measuring time from start of IR detection to next start of IR detection. Using only one, the active edge, stabilize the measured time nearly without influence of the automatic gain control in the IR receiver.

The example from above:



When the stop bits pause is reached the message is processed.

Receiving Messages

The receiving firmware looks for a start bit and when this is detected it samples 16 data bits, calculates and compares the LRC. If any of the sampled bits are too long the sampling is terminated immediately and a new start bit is searched for.
When a bit time is sampled (measured) its time is hold against some limits.

Low bit range	316 - 526 us
High bit range	526 – 947 us
Start/stop bit range	947 – 1579 us

Depending on the bit time a low or high bit is rotated into the receive buffer.