



Document title: LEGO Power Functions RC	Init: GMu	Date: 21.01.2008	Version: 1.0
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LEGO Power Functions RC

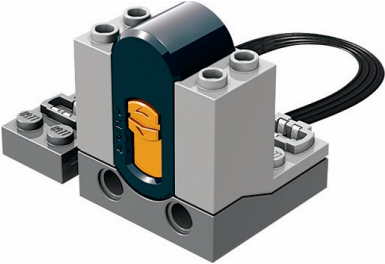
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Introduction

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



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Gaute Munch
LEGO Company 01/2008



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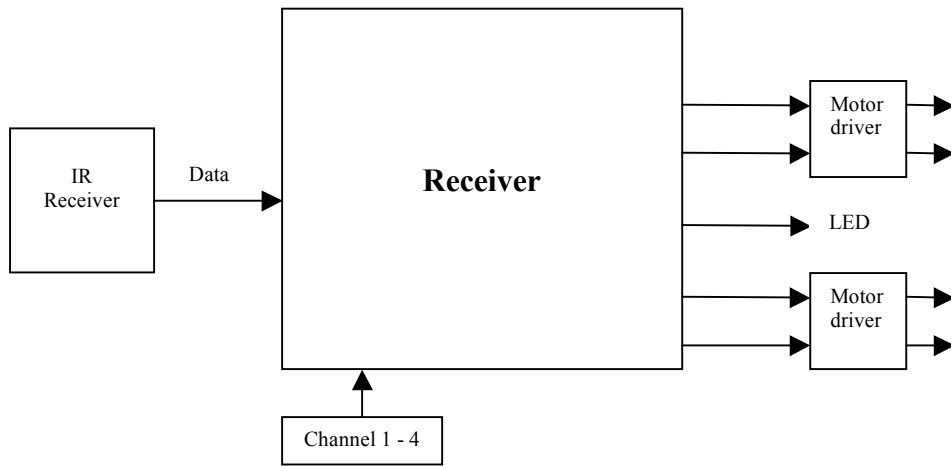


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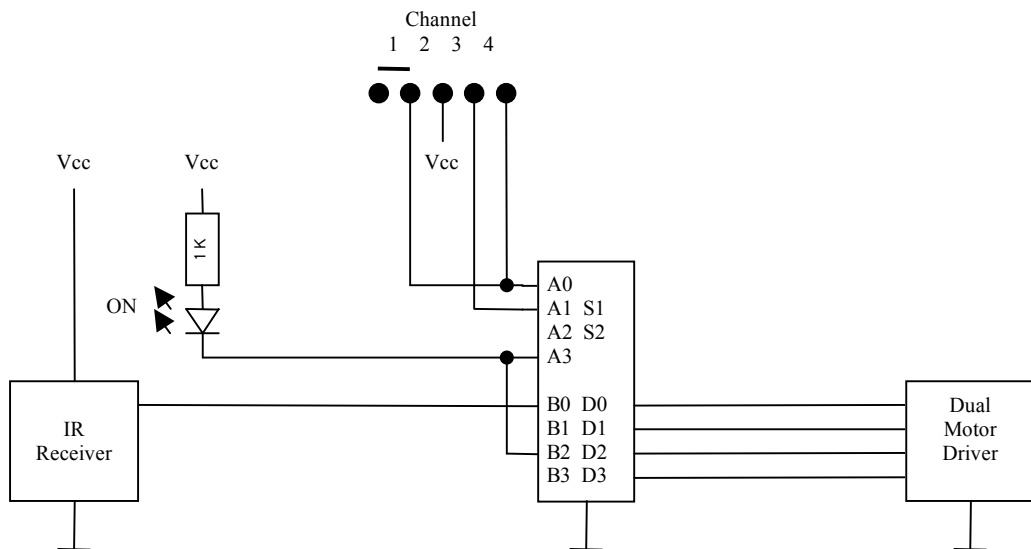
LEGO Power Functions RC

LEGO Power Functions RC Receiver

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



Application Schematics





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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 light and the receiver will be 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.



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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 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 (timeout)
Channel	CC	0-3 Channel switch 1 - 4
Address	a	0 Current address space (bonded configuration in RC Receiver) 1 Extra address space
Mode	MMM	000 Not used in PF RC Receiver 001 Combo direct (timeout) 010 Single pin continuous (no timeout) 011 Single pin timeout 1xx Single output
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



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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:

<i>start</i>	Nibble 1				Nibble 2				Nibble 3				<i>stop</i>				
	<i>T</i>	<i>0</i>	<i>C</i>	<i>C</i>	<i>a</i>	<i>0</i>	<i>0</i>	<i>I</i>	<i>B</i>	<i>B</i>	<i>A</i>	<i>A</i>		<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>
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 output B

A output *AA* xx00 Float output A
 xx01 Forward on output A
 xx10 Backward on output A
 xx11 Brake output A



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Single pin continuous Mode

This mode is able to control: Clear/set/toggle of an individual pin C1 or C2 on output A or B.

Toggle bit is verified on receiver.

This mode has no timeout for lost IR.

Binary representation:

start	Nibble 1				Nibble 2				Nibble 3				stop			
	<i>T</i>	<i>0</i>	<i>C</i>	<i>C</i>	<i>a</i>	<i>0</i>	<i>1</i>	<i>0</i>	<i>O</i>	<i>P</i>	<i>F</i>	<i>F</i>		<i>L</i>	<i>L</i>	<i>L</i>
Start	Toggle	Escape	Channel		Address	Mode			Data			LRC				Stop

Output	<i>O</i>	0	Output A
		1	Output B
Pin	<i>P</i>	0	Pin C1
		1	Pin C2
Function	<i>FF</i>	00	No change
		01	Clear
		10	Set
		11	Toggle



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Single pin timeout Mode

This mode is able to control: Clear/set/toggle of an individual pin C1 or C2 on output A or B.

Toggle bit is verified on receiver.

This mode has timeout for lost IR.

Binary representation:

start	Nibble 1				Nibble 2				Nibble 3				stop			
	<i>T</i>	<i>0</i>	<i>C</i>	<i>C</i>	<i>a</i>	<i>0</i>	<i>1</i>	<i>1</i>	<i>0</i>	<i>P</i>	<i>F</i>	<i>F</i>		<i>L</i>	<i>L</i>	<i>L</i>
Start	Toggle	Escape	Channel		Address	Mode			Data			LRC				Stop

Output	<i>O</i>	0	Output A
		1	Output B
Pin	<i>P</i>	0	Pin C1
		1	Pin C2
Function	<i>FF</i>	00	No change (sent to prevent timeout)
		01	Clear
		10	Set
		11	Toggle



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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 no timeout for lost IR on all commands except “full forward” and “full backward”.

Binary representation:

start	Nibble 1				Nibble 2			Nibble 3				stop			
	<i>T</i>	<i>0</i>	<i>C</i>	<i>C</i>	<i>a</i>	<i>I</i>	<i>M</i>	<i>O</i>	<i>D</i>	<i>D</i>	<i>D</i>		<i>D</i>	<i>L</i>	<i>L</i>
Start	Toggle	Escape	Channel	Address	Mode	Data				LRC				Stop	

Mode *M*

0	PWM
1	Clear/Set/Toggle pin

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
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

Data *DDDD*

0000	Clear C1 + Clear C2
0001	Set C1 + Clear C2
0010	Clear C1 + Set C2
0011	Set C1 + Set C2
0100	Increment PWM
0101	Decrement PWM
0110	Full forward (timeout)
0111	Full backward (timeout)
1000	Toggle full forward/backward (default forward)



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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:

start	Nibble 1			Nibble 2				Nibble 3				stop				
	<i>a</i>	<i>I</i>	<i>C</i>	<i>C</i>	<i>B</i>	<i>B</i>	<i>B</i>	<i>B</i>	<i>A</i>	<i>A</i>	<i>A</i>		<i>A</i>	<i>L</i>	<i>L</i>	<i>L</i>
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
 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
 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

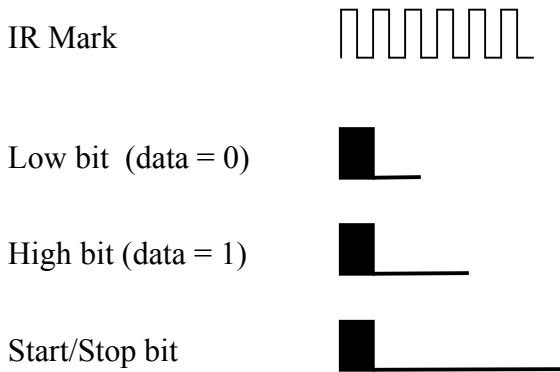


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LEGO Power Functions RC Encoding

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.

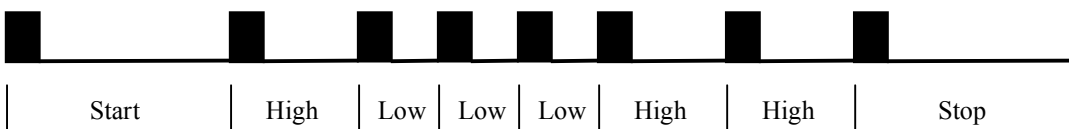
Graphically drawn:



The high pulse illustrates six 38 kHz cycles.

Low bit length = $16 \times 1/38K = 421 \text{ us}$
High bit length = $27 \times 1/38K = 711 \text{ us}$
Start bit length = $45 \times 1/38K = 1184 \text{ us}$
Stop bit length = $45 \times 1/38K = 1184 \text{ us}$

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

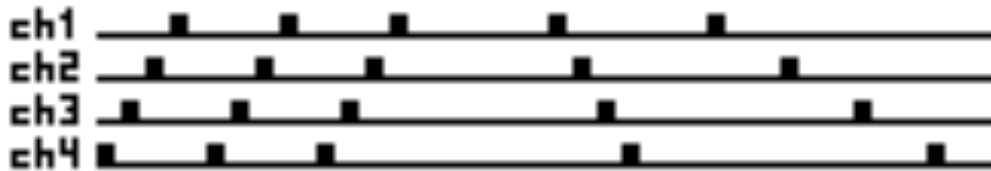




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Transmitting Messages

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: $(4 - \text{Ch}) * t_m$

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: $(6 + 2 * \text{Ch}) * t_m$

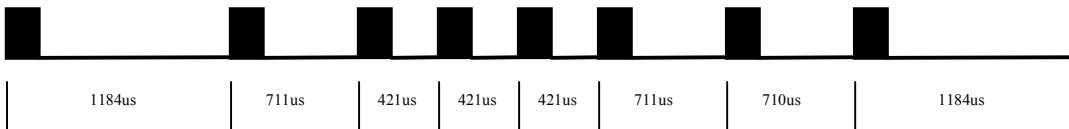


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LEGO Power Functions RC Decoding

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.