Model Train Dual Radio Control

Using low-power radio devices

By **Walter Trojan**
(Germany)

Here's the problem—two grandchildren each with a remote controlled train set but both IR remote controllers use the same channel! Short of banishing one to play in another room the author came to the rescue with the help of radio modules.

The Royal Express [1] is a cheap model train set manufactured in China and traded from Hong Kong by Golden Bright Manufacturer Ltd. It comes complete with steam locomotive, tender and wagons with trees, station, houses and rocks—in fact everything you need for a simple layout. Train control is via an infra-red remote controller which allows you to make the train go forward or backward, make noise, smoke and lighting. Above all the set runs from batteries so there is no risk from dangerous voltages. The set is advertised as suitable for children of ages 4 to 8. Above all it is relatively inexpensive so if anything goes wrong during the hacking process it will not be too much of a loss although there may be tears shed.

From IR to RF

For such a low cost kit it's probably a bit unfair to expect anything too sophisticated in the equipment design. The main problem for the author is that the IR remote controller units use the same "channel". With two layouts in the same room (or two trains on the same layout) signals from the remote controllers interfere with one another so the trains cannot be independently controlled.
First thoughts were to check out the remote controller to see if was possible to switch channels. With the covers off I couldn't identify any obvious wire links or pads on the PCB that could be bridged to change the channel. All of the train sets must work on just the one channel. Without a circuit diagram it was going to be difficult if not impossible to make the necessary modifications to the transmitter and receiver.
It just so happened that I had been experimenting with some wireless transceiver modules type RFM12. The planned home control system can be put on hold; harmony in the household gets higher priority. First it was important to find out

if there was room for additional circuitry. Under the roof of the engine tender there was space enough for a small PCB, more than enough for the radio receiver in fact.

So the solution was clear: an RF data link could be used to transfer control information. At the receiver end we just need to translate the received commands into the signals that would be produced by the standard IR receiver that came with the set. These will then be passed on to the train controller electronics. For the wireless link, RFM12 modules can be used which operate in the 433 MHz ISM radio band. In countries where 433 MHz is not allocated to license-exempt SRD (short-range radio), 868 MHz or 915 MHz modules should be used instead.

The first task was to work out the IR transmitter signals corresponding to the individual commands sent by the remote controller. Hooking up a logic analyzer to the IR receiver output it was possible to capture the control pulse patterns. The control message consists of a sequence of five pulses. The commands are coded by varying the pulsewidth and space ratios. The message pulse sequences are given in **Table 1**.
In place of the IR messages the new RF link will send command bytes that the receiver microcontroller decodes and translates into the pulse sequences recognized by the train's built-in controller. A secure RF messaging protocol had already been developed by the author (see the RFM12 Library article in this magazine) and is outlined in **Table 2**.
Some characters (such as 0xAA) are RFM12 control characters and can't be used in the message strings of version 1 of the protocol (in the mean time release 2.0 of the protocol has been developed which gives better transmission speed thanks to the use of Hamming-Code [2]). A transmission rate of 4800 Baud is more than adequate for this application.

Transmitter and receiver: almost the same hardware

The transmitter schematic in **Figure 1** is a combination of a 20-pin Microchip microcontroller type PIC18F14K22 (IC2) and a small transceiver module type RFM12B-433-D (MOD1) from Hope RF [3]. The module supplies a crystal-derived clock to the microcontroller pin 2 (RA5/Osc1). Data transfer between the chips is taken care of by

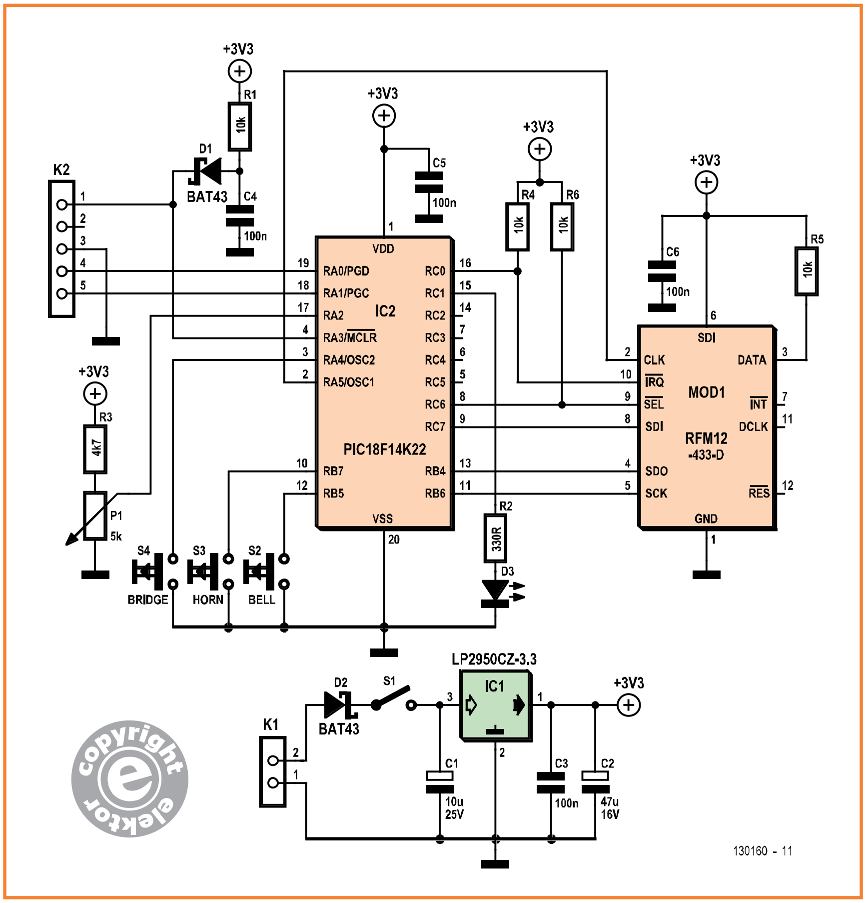


Figure 1. The transmitter circuit.

Table 1. Functions, IR messages and RF commands		
Function	**IR Message**	**RF Command**
Slow forward	I L I P I P I P I E	0x51
Fast forward	I P I L I P I P I E	0x52
Stop	I P I P I P I L I E	0x59
Slow reverse	I L I L I P I P I E	0x53
Fast reverse	I P I P I L I P I E	0x54
Sound1 Horn	I L I P I L I P I E	0x55
Sound2 Bell	I P I L I L I P I E	0x56
Sound3 Bridge	I L I L I L I P I E	0x57

Key: I = Pulse, active Low, 660 µs duration
P = short pause, High, 1130 µs duration
L = long pause, High, 2270 µs duration
E = End, High, 5 ms

Table 2. The RF communication protocol		
Byte	**Function**	**Value**
0	Target device address	0x22
1	Transmitter address	0x11
2	Message length	0x08
3	Command	0x51...0x59
4...6	Reserve bytes	0x55
7	CRC16 high	0xXX
8	CRC16 low	0xXX

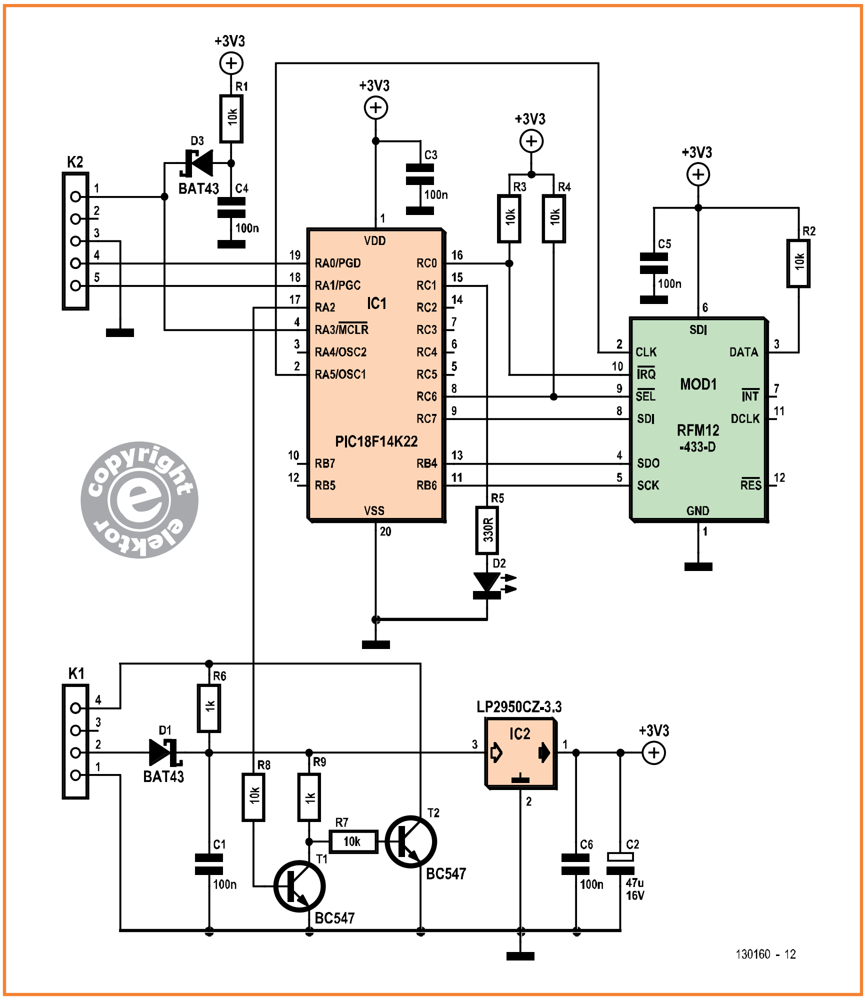


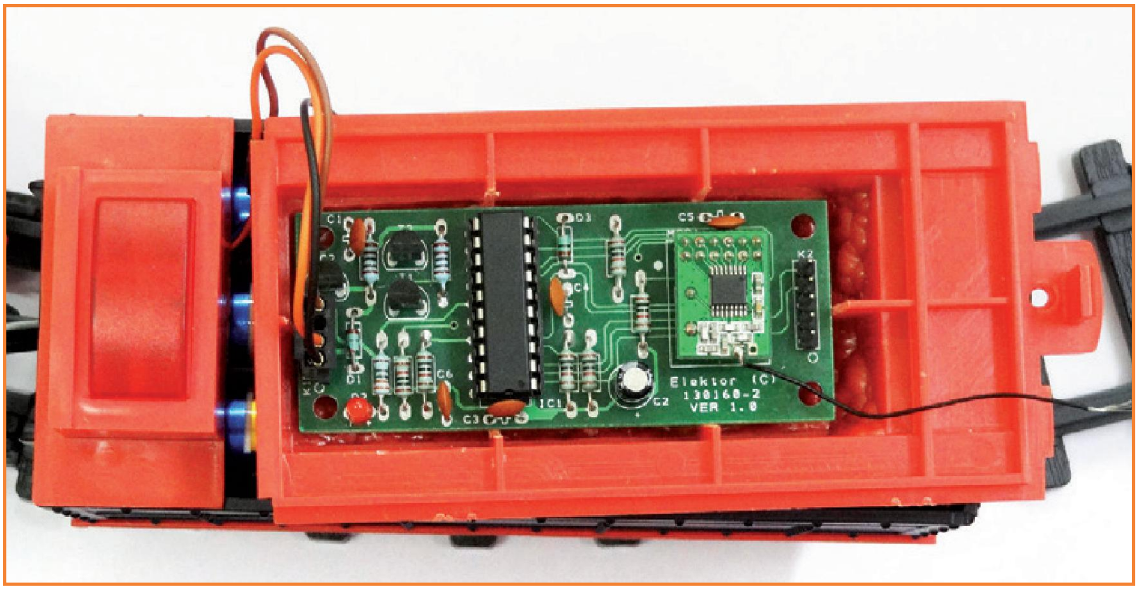
Figure 2.
Beware of confusion:
The receiver circuit is almost identical to the transmitter's.

an SPI interface connecting to the SDI, SDO and SCK of the RFM12 board. Generation of the SPI signals is taken care of by firmware. Signal nSEL/RC6 activates the transmitter chip and the signal nIRQ/RC0 indicates when the transmitter buffer is empty. Further tests on the PIC SPI interface indicated that the RFM12 board can handle a serial clock frequency up to 2.5 MHz. A quarter-wave length of wire is used for the antenna. Pull-up resistors R4, R5, R6 ensure the correct quiescent level on the Active-Low signals nSel and nIRQ.

Table 3. Relationship between control knob position and speed	
Value	**Command**
<22	Fast reverse
23 to 43	Slow reverse
44 to 82	Stop
83 to 104	Slow forward
>104	Fast forward

The controller is slightly modified from the original unit. A pot is now used in place of the five pushbuttons to provide slow/fast forwards and slow/fast reverse plus stop. The stop position is the control knob at mid-travel. Turning clockwise is slow forward and fully clockwise is fast forward. Counter clockwise from the central position achieves the same speeds in the reverse direction. Compared to the original controller it is more intuitive and the young train enthusiasts actually prefer to use it.

From the circuit function the analog input RA2 sees an input voltage varying in the range from zero to half supply voltage. The measured value is converted into an 8-bit digital value in the range of 0 to 128 by the A/D converter. This translates to 5 speed ranges (this is not an analog control function) given in **Table 3**.
Also on the controller are pushbuttons for the sound generator: Bell (S2), Horn (S3) and 'Bridge' (S4) (sounds like the train is passing over a bridge). These signals connect to inputs RB5, RB7 and RA4 (with pull-up resistors) on the microcontroller. The LED connected to RC1 flashes each time a command message is sent.
The double-sided transmitter PCB has been designed in the Elektor Lab using the DesignSpark [4] software. Component fitting should be quite easy; no SMD components are used in the design. The RF module is available with either SMD mounting pads or a DIP version with two rows of pin headers (at 2 mm grid spacing). This version can be soldered directly to the PCB. Note that the antenna, made up of a 17 cm (6.5-inch) length of copper wire (for 433 MHz), is soldered on the topside of the board by the SMDs (see **Figure 1**). For 868 MHz, the antenna length is 8.5 cms (3.3 inches)
A 9 V battery connected at K1 provides power to the circuit and low-drop regulator LP2950CZ-3.3 provides the on-board 3.3 V, ensuring that every last drop of juice gets used up from the battery. Diode D2 in the supply protects the circuit from accidental reverse polarity connection. The switch type for S1 is not important and depends on the type of housing you use for the transmitter. The transmitter circuit's current drain on the 9 V battery pack is 4.5 mA quiescent, rising to 11.8 mA when transmitting.
The PIC controller can be ordered (just like the PCB) ready programmed from [5]. It is also possible to program it yourself if you have a pro-



grammer. Free software downloads for this project from the Elektor site include the ready-assembled firmware and Pascal source file. Firmware for this project can be compiled using versions 5.60 or 6.01 of Pascal Pro from MikroElektronika [6]. The fully functional compiler is free to use for programs less than 2 KB in size. The microcontroller connector K2 hooks up to a Microchip PICKit3 programmer [7] for in-circuit programming.

The receiver circuit (**Figure 2**) corresponds quite closely to the transmitter circuit. Not only is there the same PIC18F14K22, RFM12B-433 combination, they are also identically connected. The microcontroller built into the train is controlled by active-low pulses from the receiver unit via a two stage transistor driver consisting of T1 and T2. The output control pulse sequences are given in **Table 1**.

Power is supplied by the battery pack (2 x 3 AA cells) in the train. The battery supply attaches to connector K1 through protection diode D1 and voltage regulator IC2. The 3.3 V output powers the circuit. LED D2 is a status indicator, it gives a short flash every 2 s while no data is received and extends to double the length when a message is received. The PIC is programmed in exactly the

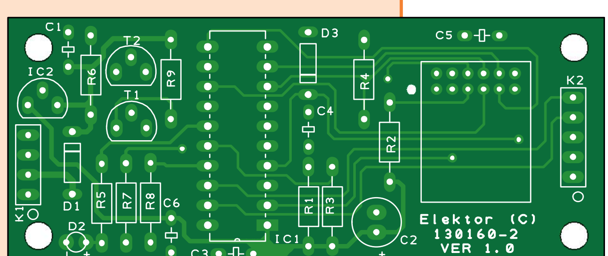
COMPONENT LIST, Receiver

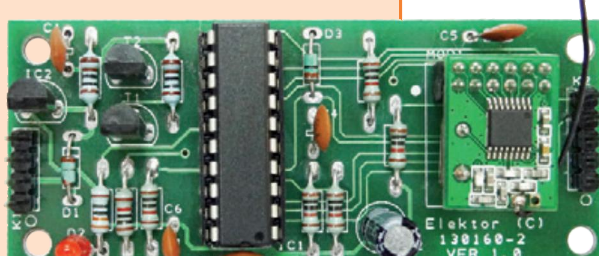
Resistors
R1–R4,R7,R8 = 10kΩ
R6,R9 = 1kΩ
R5 = 330Ω

Capacitors
C1,C3–C6 = 100nF
C2 = 47µF 16V

Semiconductors
D1,D3 = BAT43
D2 = LED, 3mm, red
T1,T2 = BC547
IC1 = PIC18F1422-I/P, programmed, Elektor Store # 130160-42, [5]

Miscellaneous
MOD1 = RFM12B-433-D, 3.3V version (Hope RF), or 868 MHz 3.3V version (country-specific)
K1 = 4-pin pinheader
K2 = 5-pin pinheader
PCB # 130160-2 [5]





same way as the transmitter unit using PICKit3 connected to K2.

The receiver circuit's current drain on the 4.5 V battery pack is 19.5 mA quiescent, rising to 21.2 mA during message reception.

Firmware

The transmitter firmware continually reads the value of the speed/direction pot and pushbuttons. When a change is detected the corresponding command is sent to the train receiver. After the PIC microcontroller and the RFM12-433 module have been initialized the firmware enters an endless loop where it reads the input voltage level from the speed control pot and generates a command. Note that 868-MHz modules may require different initializing codes. When this command is identical to the previous one nothing is sent out. It will only be sent if it is not the same. The microcontroller also takes into consideration the current status of the train: suppose you were to spin the pot quickly from say maximum forward to maximum reverse. The controller first sends out a Stop command and then a Slow Reverse command followed by Maximum Reverse. This puts less strain on the mechanism and pauses between the commands help to give a more realistic motion. In the second part of the endless loop the sound generator pushbuttons are polled. When the train is running the corresponding sound command is sent to the train.

Similarly the receiver firmware executes an endless loop after everything has been initialised. In the loop it checks if a new message has been received. When an error-free message is received the command byte is interpreted to select the corresponding message defining the pulse/pause sequence sent to the train's built-in controller. For security the process is repeated three times.

Now with the new controller working, peace has broken out in the playroom. The only source of conflict now is whose turn it is to use grandpa's controller.

(130160)

Internet Links

[1] Manufacturer: www.golden-bright.com/

[2] http://en.wikipedia.org/wiki/Hamming_code

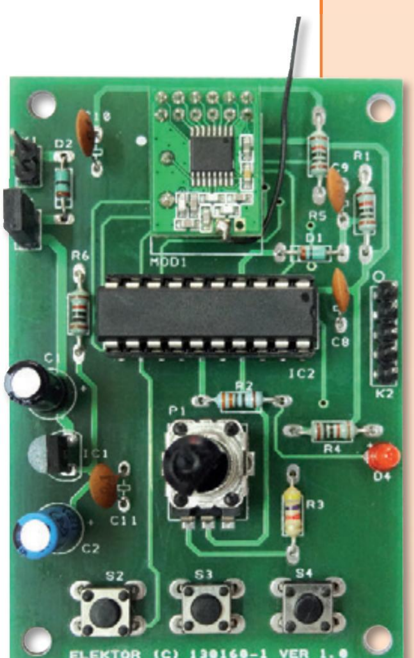
[3] www.hoperf.com/rf/fsk_module/RFM12B.htm

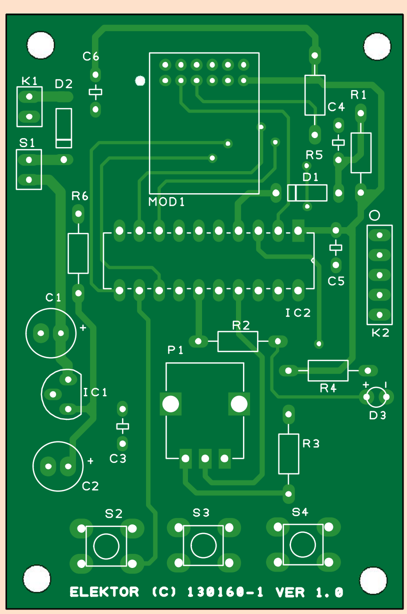
[4] www.designspark.com/eng/page/designspark-pcb-home-page

[5] www.elektor-magazine.com/130160

[6] www.mikroe.com

[7] www.microchip.com/pickit3





COMPONENT LIST, Transmitter

Resistors
R1,R4,R5,R6 = 10kΩ
R2 = 330Ω
R3 = 4.7kΩ
P1 = 5kΩ trimpot

Capacitors
C1 = 10µF 25V
C2 = 47µF 16V
C3–C6 = 100nF

Semiconductors
D1,D2 = BAT43
D3 = LED, 3mm, red
IC1 = PIC18F1422-I/P, programmed, Elektor Store # 130160-41, [5]
IC2 = LP2950CZ-3.3/NOPB

Miscellaneous
MOD1 = RFM12B-433, 3.3V version (Hope RF), 915 MHz or 868 MHz 3.3V version depending on area.
K1 = 2-pin pinheader
K2 = 5-pin pinheader
S1 = 2-pin pinheader and/or slide switch, 1 make contact
S2,S3,S4 = pushbutton
PCB # 130160-1 [5]