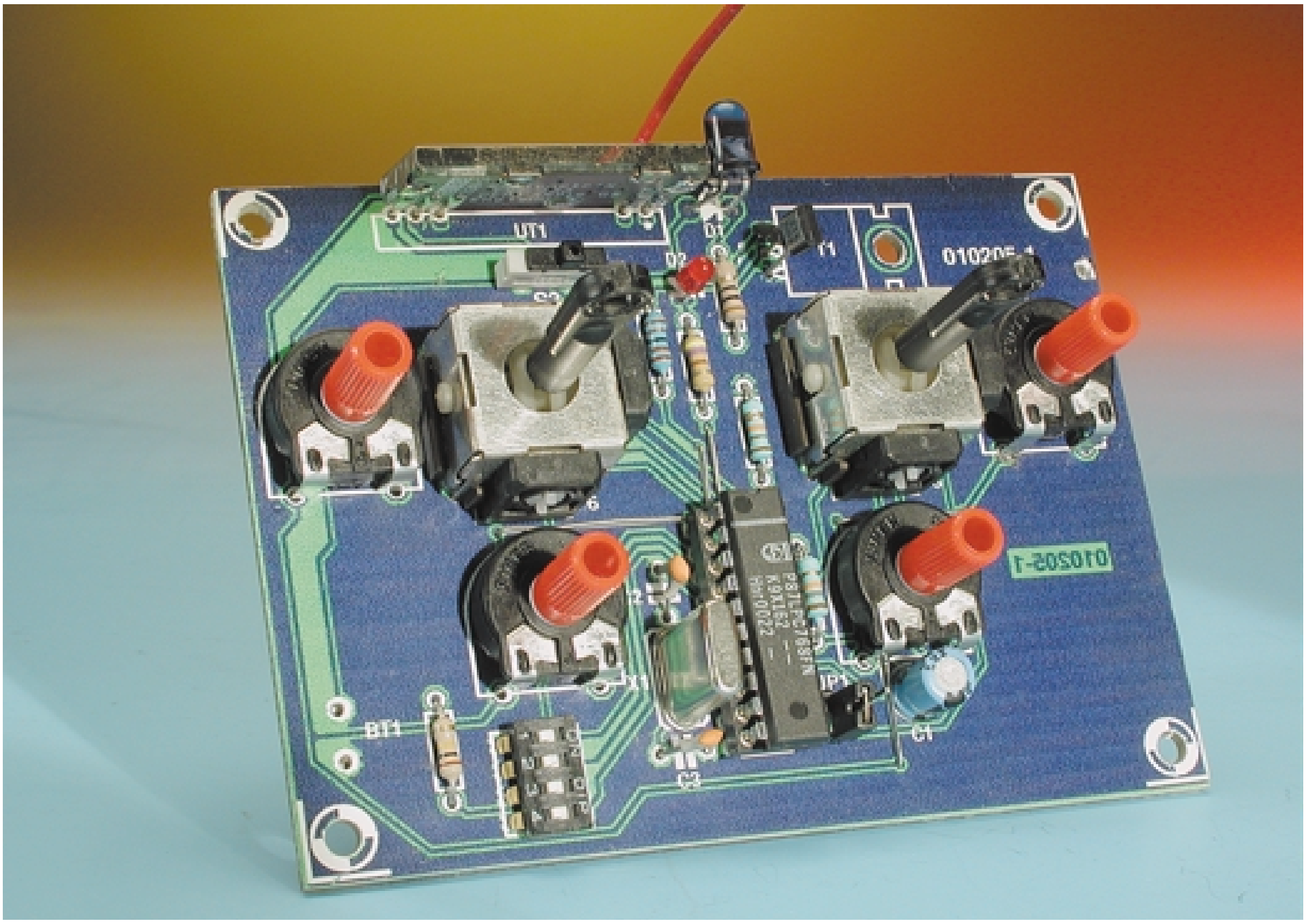
Miniature PCM Remote Control

part 1: transmit at 433 MHz and 950 nm!

Here's a design that should gladden the hearts of many model builders. A really small proportional remote control unit built using standard - low-cost components. It's ideal for loads of applications and so flexible that simply by changing on-board jumpers you are free to choose the transmission medium: radio, Infrared or two-wire!



Remote control main features:

- Lightweight
- Simple construction with no set-up or alignment
- 6 channels → 4 proportional and 2 digital
- Switched outputs for 5 A load
- Four standard servo connectors
- Trim function on 4 channels
- Small, light and compact
- PCM transmission method
- Selectable Infrared or radio operation
- Current saving transmission method
- Type-approved and licence-exempt 433MHz Tx and Rx modules
- Voltage supervision in both the transmitter and receiver
- Built-in speed regulator in receiver
- Built-in soft start switch in receiver
- Speed regulator and softstart controller suitable for loads <15A
- Battery Low indicator
- Servo reverse (change the servo travel direction) for all 4 servos
- Operating voltage: transmitter 3.3 V to 4.8 V (3x AA Alkaline cells or 4x Nicad cells)
- Receiver 5 V from on-board BEC voltage regulator

It used to be that constructional projects using RF transmitters and receivers would only be attempted by the more courageous electronics enthusiasts. Thankfully since the advent of complete integrated RF modules we can forget the tedious set-up and adjustment process and just treat the RF stage as another plug-in building block. The design described here is very flexible and can use these RF modules to implement a radio remote control. Microcontrollers are also employed in the transmitter and receiver to replace the discrete shift registers, clock generators and timing circuitry that you normally find in remote control designs. The result is a compact, reliable and low cost remote control unit. The low radiated power emitted by these licence-exempt radio modules limits the range of the units so this design is only really suitable for controlling indoor models.

A speed controller is also built into the receiver allowing direct connection to the models drive motor. Using the infrared control option a low-cost 4-channel proportional control system can be built that simply cannot be matched for price and performance by anything available commercially. The two-wire control option is useful if the device to be controlled is in a fixed location, for example the receiver could drive two model servos controlling the pan and tilt of a remote security camera.

This remote control design is a good demonstration of how microcontrollers can be used to implement features that not so long ago would require dedicated circuitry. The design need not stop here. If, for example you decide that a menu driven transmitter together with a keypad and LCD would better fulfil your needs then it is entirely possible to implement this. Many features of the microcontroller together with unused ROM are just waiting for an inspired programmer to make good use of them.

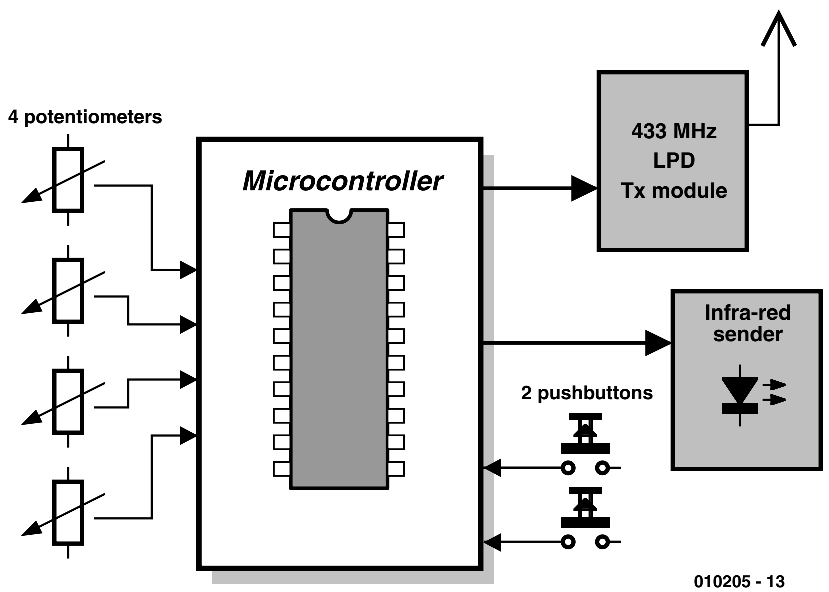


Figure 1. Transmitter block diagram.

The transmitter

The block diagram shown in **Figure 1** indicates that a microcontroller does most of the donkey-work. It digitises the analogue resistance values of the four input potentiometers, checks for push button presses, and generates the transmitted signal protocol. The signal can be transmitted at RF or by infrared.

Even if you are only intending to use the transmitter at RF it is worth fitting the infrared components to make the finished unit more flexible. The additional cost incurred by fitting the IR diode and its drive transistor is relatively low.

During initialisation the transmitters microcontroller will read the state of the input at port pin P0.7. If it is high (jumper JP2 not fitted) then RF control will occur. If it is low (jumper JP2 fitted) then signals will be sent using infrared. When the controller sends infrared signals the driver stage uses more peak current than with the RF option. The controller formats the output signal differently by modulating the Pulse Code Modulation (PCM) data at 36 kHz and reducing the data rate in order to prolong battery life. The same modulation is used by remote controllers for TVs etc and gives good transmission security.

The components used for the transmitter circuit shown in **Figure 2** are low-cost and widely available from numerous suppliers but its worth taking a closer look at some of the more unusual items:

The Joystick assembly

The remote control system should be small, economical, simple to build and suitable for

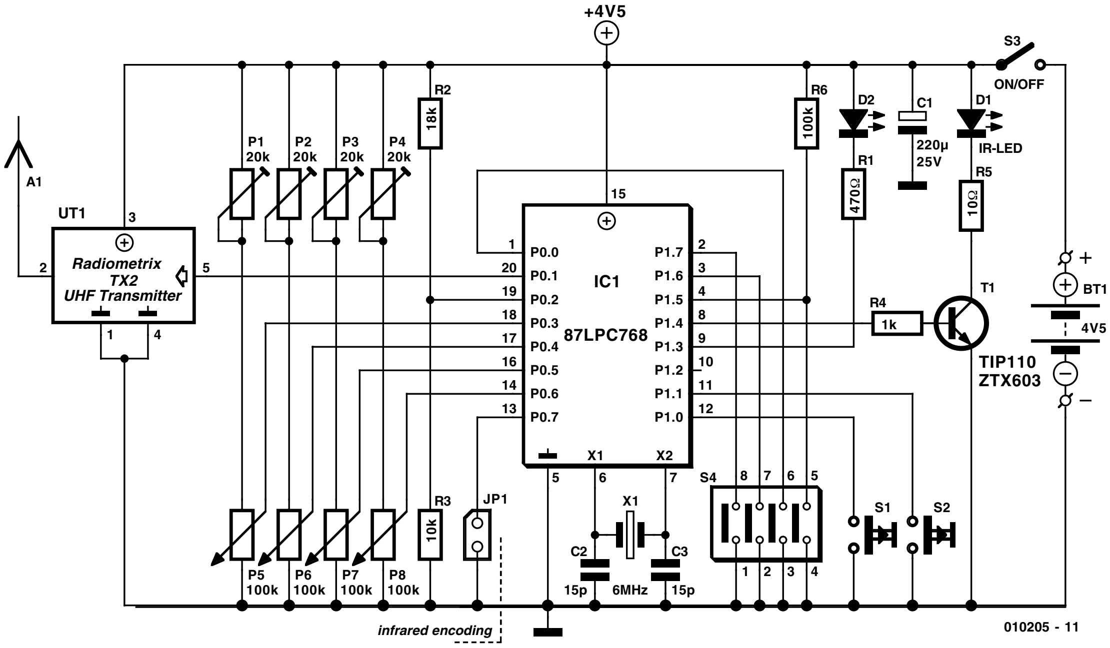


Figure 2. Transmitter circuit diagram.

use with standard model servos from Graupner, Multiplex, Futaba and Ripmax etc. One of the first hurdles in building this proportional remote control system was to track down an economical joystick assembly to use for control input. The US Company CTS produces a suitable assembly. Its miniature joystick is self-centring, has low mechanical 'play' and can optionally have a switch fitted (**Figure 3**).

The most important technical features of this joystick are:

- 1 Million operating cycles
- Sturdy metal housing
- 2 Potentiometers
- Available potentiometer resistor values between 10 kΩ and 150 kΩ
- Selectable potentiometer resistor tolerance from 10% to 30%.
- Available with in-built pushbutton switches
- Switch contact resistance less than 0.1 Ω
- Switch rating 50 mA @ 12 V
- Push button life: 100,000 operations

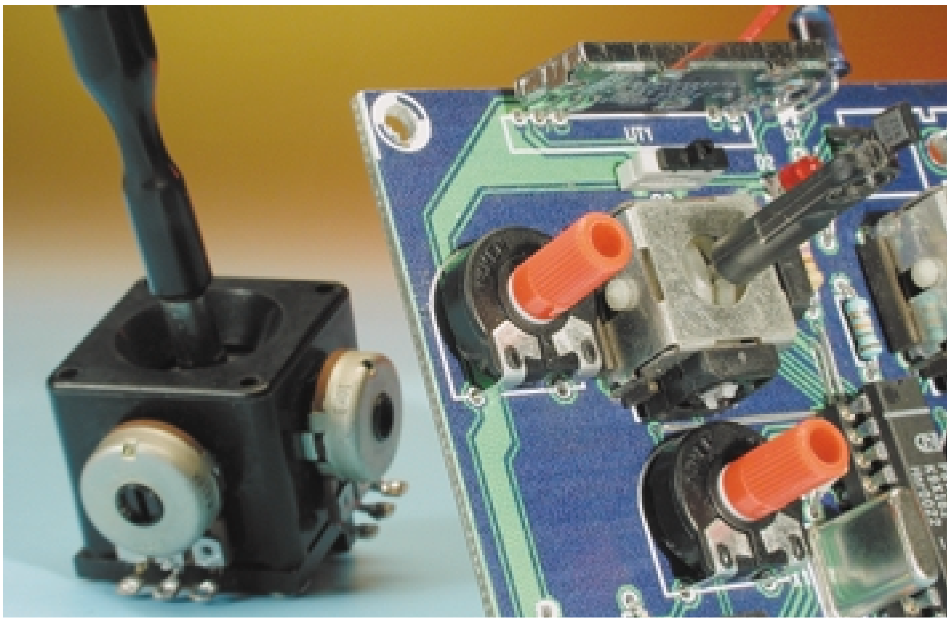


Figure 3. Miniature joystick assembly from CTS.

Unfortunately the joystick control paddle passes through a circular opening in its housing. This has the effect of limiting control when the joystick is moved to the extremes of both the X and Y axis simultaneously. The joystick housing will therefore require a little modification and most competent modellers will have no problem in 'squaring out' the opening to allow maximum deflection of the paddle at all positions. The paddle itself can also be modified to improve the feel of the joystick. On the prototype we used some drilled-out plastic guides from ball-joints to extend the sticks.

Standard linear or turn potentiometers can be substituted for the joystick assembly if the combined X-Y control is not necessary in your model. In series with the potentiometers are also trim pots that allow the servo position to be finely adjusted or trimmed out. This feature is useful for example when setting up a model car to ensure that 'hands off' it steers straight ahead.

Microcontroller

The central control element in the transmitter is the 87LPC768 microcontroller from Philips. This device inputs analogue values from the joy-

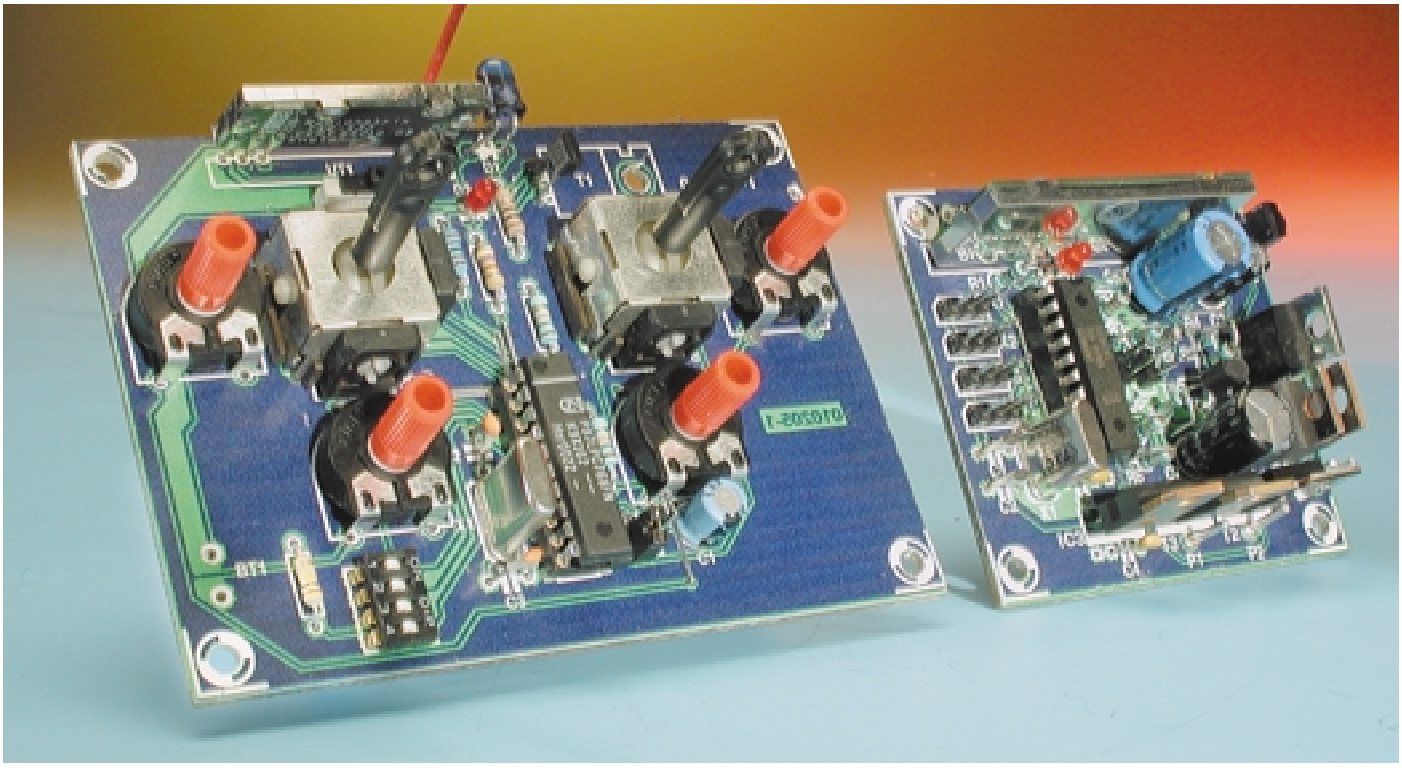


Figure 4. The 433 MHz transmitter and receiver modules.

sticks and pushbuttons and converts them into digital values using its analogue to digital (A/D) converters. A PCM signal is then produced and output to the IR diode or RF module.

The microcontroller is based on the well-established Intel 80C51 architecture so for programming there are many low-cost development tools including shareware available.

The 87LPC768 is described as a '*Low power, low price, low pin count microcontroller*'. A 6 MHz clock is necessary to cope with the processor intensive software routines and this produces a cycle time of 1 µs. The main controller features can be summarised as:

- 4 Kbytes ROM
- 128 Bytes RAM
- 32 Bytes Customer Code EEPROM
- Operating voltage 2.7-6.0 V
- Two 16 Bit Timer/Counters
- 4 channel Pulse Width Modulator (PWM) using 10 Bits
- 4 channel A/D converter, 8 Bit resolution, conversion time 9.3 µs @ 20 MHz clock frequency
- integrated reset
- Selectable internal RC oscillator.
- 20 mA driver current from output port
- 18 I/O-Pins maximum, when internal Reset and RC Oscillator is selected
- 2 analogue comparators
- I^2C interface
- Full duplex UART
- Serial In-circuit Programming

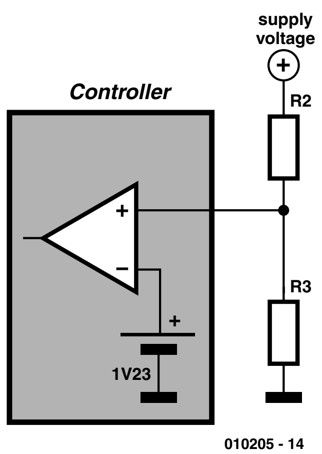


Figure 5. Internal comparator of the controller.

The RF Module

In recent times we have seen a big increase in the number of different applications using the 433 MHz band to send data. As well as supplying complete transmitter/receiver solutions some manufacturers produce integrated RF modules that can be used in many applications. The big advantage of these modules is that they do not require any set-up or tuning, they are supplied ready to go. The modules used in this circuit are produced by the company Radiometrix (**Figure 4**, together with the receiver module). The main features of the transmitter module are summarised in the following table:

Transmitter TX2

- Frequency 433 MHz, +9 dBm
- Modulation: FM
- Data rate 40 kbps max.
- Operating voltage 4.0 V to 6.0 Vdc
- Current consumption 6 mA

The transmitter RF module has five pins enabling it to be soldered or plugged directly to the PCB. The module will begin transmitting as soon as power is applied provided that the modulation input signal is high.

The Infrared transmitter

The infrared diode driver stage consists of Darlington transistor T1. The transistor is ideal as an LED power driver with a current gain of 2000 and a maximum collector current of 1 A. Two other alternative transistors are the BCX38 and TIPP110 but these have different pin-outs. Resistor R5 limits the diode peak current to approximately 240 mA. This figure was chosen as a trade off between battery life and transmitter range. R1 can be reduced to increase range as long as the peak forward current rating of the diode is not exceeded.

The IR LED type TSUS5201 emits IR light at 950 nm with a beam intensity of 230 mW/sr at 1.5 A with a half angle of ±15°.

In principle any IR LED can be used but if you do intend to use a substitute choose one with a beam intensity >200 mW/sr at 1.5 A and with a wavelength of 950 nm. The IR LED operating current is given by the formula:

$I_{LED} = (V_{BAT} - V_{CESAT} - V_F) / R1$

where:
V_{BAT} = operating voltage 4.5 V
$V_{CESAT} \approx 0.7$ V
V_F = forward voltage drop of an infrared diode ≈ 1.6 V

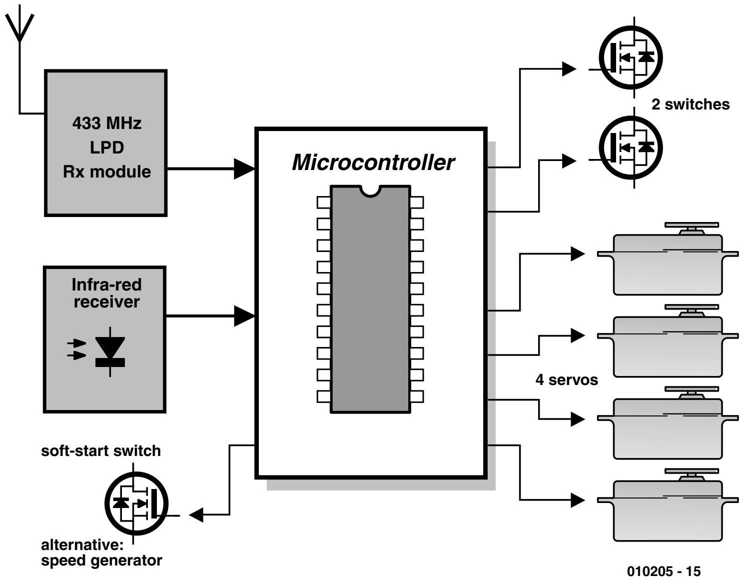


Figure 6. Receiver block diagram.

A crucial consideration affecting the reliability of the IR signals is the peak current that can be supplied by the battery. It is recommended to use either alkaline or Nicad cells to supply the high impulse current required by the IR driver stage. Cheap zinc-carbon cells may not be able to supply the necessary current.

Servo reverse

A 4 way DIP switch is conveniently included on the transmitter enabling the direction of travel of any of the

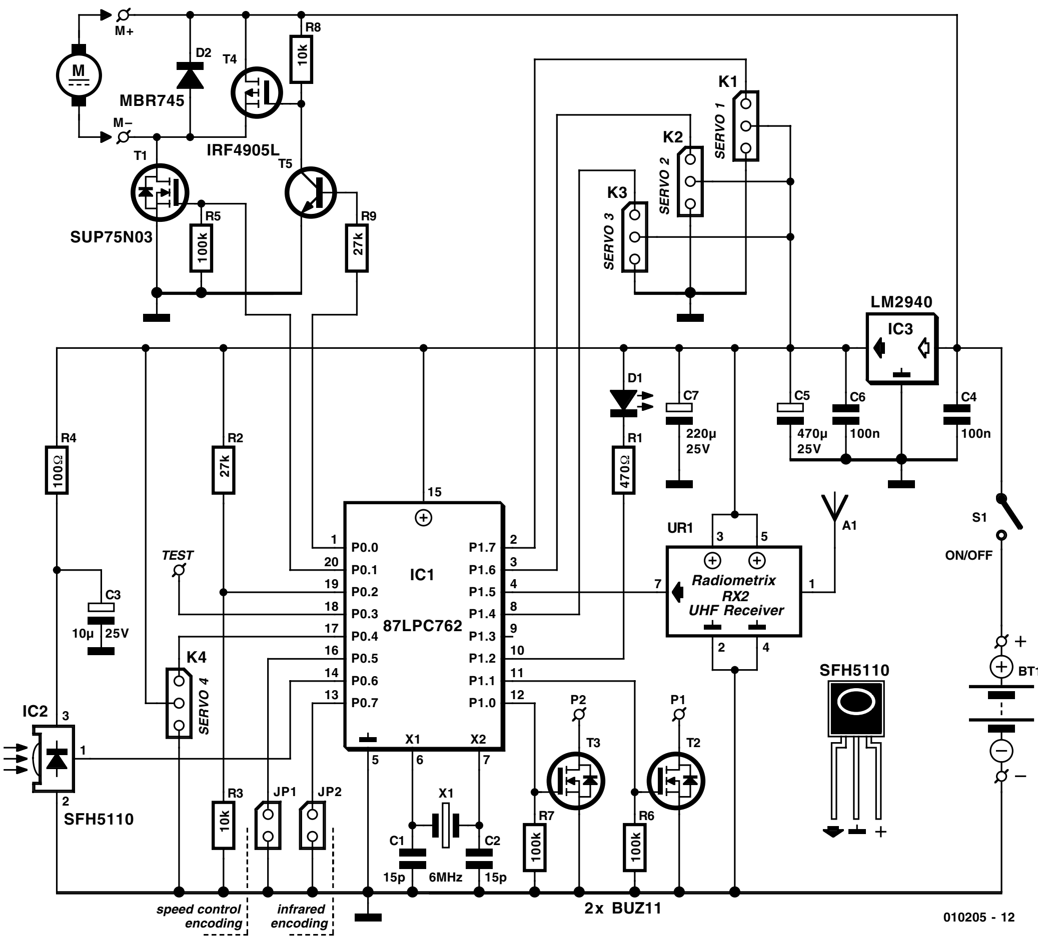


Figure 7. Receiver circuit diagram with two communication methods.

servos to be reversed.

Voltage monitoring
The minimum operating voltage of the microcontroller A/D converter is specified as 3.0 V. An internal comparator in the microcontroller is used to measure the supply voltage and detect when it gets close to this level. LED D1 is lit continually acting as a software watchdog but starts to blink when the supply voltage falls below 3.3 V indicating a low battery condition.

The microcontroller has an in-built comparator with a reference voltage level of 1.23 V (**Figure 5**). The values of external resistor R2 and R3 are calculated using the following formula:

Internal Reference = 1.23 V
R3 is chosen as 10 kΩ
R2 = 10 kΩ × [(threshold voltage/1.23 V) – 1]
R2 = 10 kΩ × [(3.3 V/1.23 V) –1)
R2 = 16.829 kΩ (nearest standard value: 18 kΩ)

The Receiver

The receiver block diagram shown in **Figure 6** is divided into several functional blocks like the transmitter.

The infrared receiver
Thanks to the growing popularity of infrared controlled equipment there are many integrated IR receiver chips on the market from different manufacturers all with broadly the same characteristics. The function of the IR receiver is to filter out any optical or electrical interference, demodulate the IR signal and amplify it. The receiver/demodulator IC's generally have three pins, two for connection to the power supply and one for the data output. The output pin can be connected directly to the input pin of a microcontroller. The IR receiver specified for this design is one of a family of devices that can operate in the frequency range from 30 kHz to 56 kHz. The main features of this device are:

– Integrated receiver diode and amplifier
– Electrically shielded
– Internal filter for PCM frequency.
– TTL and CMOS compatible.
– Active-low output.

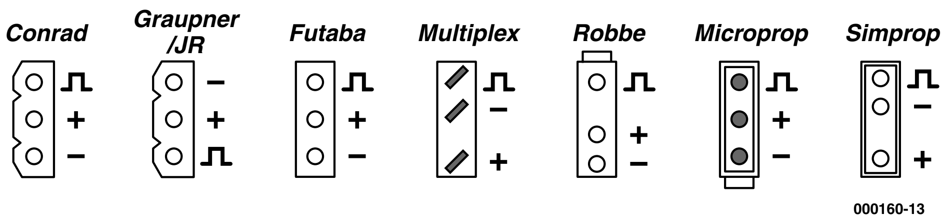


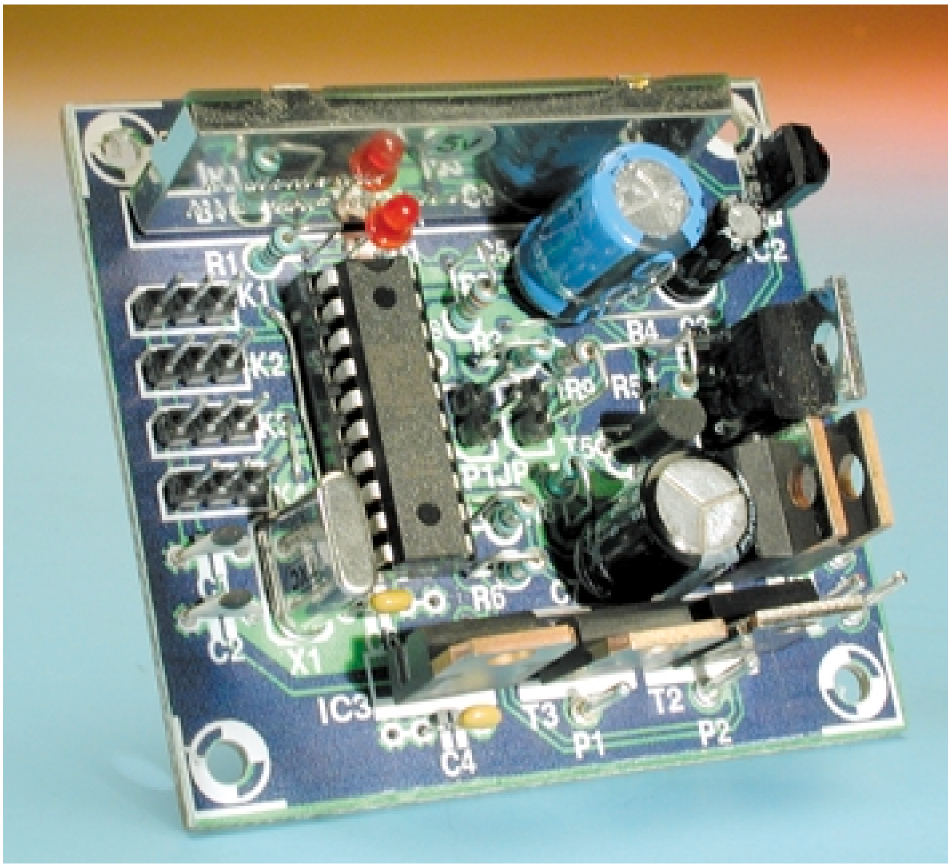
Figure 8. Pin-outs of different servo manufacturers.

– Low current consumption
– Interference suppression from continuous light sources (incandescent lamps or sunlight), or light sources pulsed at 36 kHz or other frequencies (fluorescent lamps).

The RF receiver for 433 MHz
The receiver module type RX2 from Radiometrix is the partner to the transmitter module type TX2. The RX2 consumes approximately 13 mA and is a very small, lightweight unit. A significant advantage for modellers is that at 433 MHz the antenna length needs to be only 15.5 cm long. The main features of the receiver module are:
– Receiver frequency 433.92 MHz
– Receiver type: double superheterodyne
– Sensitivity –107 dBm
– Operating voltage 3 V to 6 V
– Current consumption 14 mA
– Digital data output

As soon as power is applied to the RF receiver module it will be operational but without an in-range functioning transmitter module the receiver output will just be meaningless data.

The Microcontroller
Figure 7 shows the circuit diagram of the receiver. A central microcontroller is again used to do all the tricky stuff. It inputs digital control information from the transmitter signal and supplies control signals to four servos and two switched outputs.



The 87LPC762 controller used in the receiver is a slightly reduced version of the 87LPC768 used in the transmitter. It does not have the four channel pulse width modulators or the A/D converters and the size of the program ROM is only 2 kBytes. Apart from this the internal circuit is the same. A 6 MHz clock frequency is used once again.

Servo control

Model servos are pulse width controlled. A pulse width of 1.5 ms will cause the servo actuating arm to travel to its centre point and varying the pulse width between about 0.8 ms and 2.3 ms will move the servo arm from one end of its travel to the other. The actual maximum and minimum values of the pulse width vary slightly from one manufacturer to another but the difference is not critical. The pulse is repeated approximately every 20 ms.

The pulse width, pw, is calculated in the receiver microcontroller using the formula:

$$pw\,[\mu s] = \text{A/D value} \times 5 + 900$$

Where the A/D value is an eight bit value sent in the message from the transmitter (see the second part of this article in the coming month).

The output pulses are generated using a built-in timer in the microcontroller. The four output pulses are produced one after another in order to reduce the peak current that would otherwise occur if the pulses were sent simultaneously to all four servos. The microcontroller port pins connected to the servos are configured as push-pull outputs.

In the past, servos from different manufacturers had incompatible connectors. More recently equipment bought in the UK has standardised connectors conforming to the Futaba, Graupner/JR and Ripmax layout. The receiver PCB layout takes this into account so that the servo connector pins are suitable for this pin layout. If you are using older servos **Figure 8** gives information on the pin-outs.

Soft start/Speed regulator

The operating lifetime of motors and gearboxes can be extended by gently bringing them up to speed rather than switching them from zero to full power. Two methods of controlling the model motor are implemented in this design. Firstly if the 'soft start' option is selected (jumper at port pin P0.5 not fitted) the left joystick switch is connected to the transmitter input at port pin P1.0 and corresponds to port pin P0.1 at the receiver. This output is connected to MOSFET T1. When the switch at the joystick is activated the motor speed will be ramped up to a maximum in about one second. This is accomplished by the controller switching the MOSFET with a PWM signal where the on/off ratio of the waveform gets longer until the MOSFET is switched fully on.

If the 'speed regulator' option is selected (jumper at port pin P0.5 fitted) then the up-down axis of the left joystick will become the motor speed controller. Pulling the stick downward from its neutral position will cause the motor speed to increase.

The gate control voltage is 5 V so a logic level MOSFET is used. To ensure maximum power in the drive motor the MOSFET R_{DSON} should be <0.001 Ω. The SUP75N03 meets this criterion and can switch 15 A continuous current.

The gate inputs of all the MOSFETS are tied to ground by 100 kΩ resistors to ensure that the transistors do not become conducting during microcontroller initialisation when the port output pins are tri-stated. Schottky-diode D2 protects the MOSFET from large voltage spikes produced by the motor.

FET T4 is used to stop the motor suddenly when it is switched off. This brake function is necessary for power assisted model gliders to make the special propeller blades fold back at the end of the climb thereby reducing drag.

Switched outputs

The output port pins P1.0 and P1.1 have an on/off toggle action when push buttons S1 and S2 are pressed at the transmitter. Each press of a push button will cause the corresponding MOSFET T3 or T2 to change state. The BUZ11 MOSFETs specified here have an R_{DSON} of 0.04 Ω and will have no problems handling 5 A continuous current. If the MOSFETs are used to switch inductive loads like relays then it is important to add protection diodes across the load to prevent destruction of the MOSFETs. These two MOSFETs can simply be omitted if you do not want this function and need to save weight.

BEC

The receiver includes a BEC or Battery Elimination Circuit. This allows the receiver and servos to be powered from the same battery pack that provides power to the electric motor. The voltage of this battery pack will be typically 7.2 V or greater. A low-drop regulator type LM2940 (IC3) is used to supply the 5 V necessary for the receiver and servos. In some applications the BEC is not required in which case IC3 can be omitted and a +5 V supply is connected to point P1 on the PCB.

The power dissipated in IC3 can be calculated from:

$$P = (V_{batt} - V_{BEC}) \times I_{BEC}$$

V_{batt} will be the voltage of the battery pack while V_{BEC} is 5 V and I_{BEC} is the current to the receiver and servos. If this power dissipation is greater than that recommended for IC3 then it is necessary to fit a heat sink to IC3. A heat sink is certainly recommended if you are using high performance servos with this receiver. Lastly, for the BEC to function correctly the battery voltage must be greater than 6 V.

The main features of the LM2940 are:

- 1 V maximum drop across the regulator
- 1 A maximum output current @ 25 °C
- Reverse voltage protection
- 26 V maximum input voltage

Voltage monitor

Just like the transmitter, the receiver also monitors its supply voltage. When it dips to below 4.5 V LED D1 will begin flashing. In normal operation the LED will be lit permanently to indicate correct operation of the software. The potential divider chain formed by R2 and R3 is calculated identically as it was in the transmitter but this time with a threshold voltage of 4.5 V. When a low voltage condition occurs it is stored in volatile memory. This ensures that even if the battery recovers slightly after working at full load it still gives a correct indication that the battery requires recharging.

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In the second part of this article we will look at the assembly of the units, and take a closer look at the transmitter and receiver software.