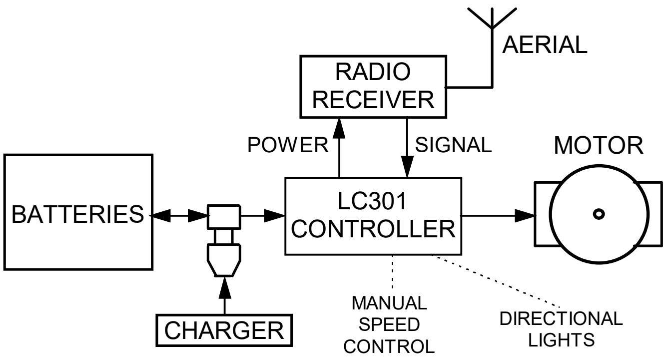
ANTENNA MODELS
BRANDON HOUSE TROON
AYRSHIRE KA10 6HX

Battery Operated Remote Control in Gauge O

1 Introduction

Radio control operation of model railways offers very considerable advantages over conventional methods. It allows true 'cab control' — you actually control each model from within the model itself, so there are no problems running more than one train on a track. There are no sectioning worries. If fact, there is no need for any layout wiring whatsoever, so if you go completely battery you can dispense with layout wiring altogether. (Actually, you don't even need track, but that would probably be going too far!) By the same token you can say goodbye to track cleaning, and since the power source is connected directly to the motor you can achieve better slow running than is possible when electricity is sent through the rails.

Compared to the complexity involved in trying to achieve the same level of operation from conventional wiring, the wiring of a radio controlled battery operated locomotive is relatively simple. The control system consists of the speed controller, radio receiver, batteries and motor connected as shown below



The basic system also requires a charger to recharge the batteries.

The transmitter sends radio signals to the receiver defining the speed required. The receiver passes this signal to the LC302, which controls the motor. The LC302 also provides the regulated voltage for the receiver.

2 How to Go Battery

This sections gives a short overview of the items you will need for radio control. You will need

a) A locomotive (!)
b) A suitable motor and gearbox
c) An LC302
d) A radio control transmitter and receiver
e) Batteries
f) Charging socket
g) Connecting wire
h) Charger

a) The Locomotive

The best type of locomotive is one which does some shunting, because it is with start/stop type operation that battery operation comes into its own. It doesn't have to be a tender loco — it is possible to fit a six volt motor, the receiver, LC302 and enough batteries for 3 hours operation into a small saddle tank. Sizes of each part are given under each section.

It is easier to convert to battery operation while building a kit than it is to convert an existing locomotive, and also saves on cost because there is no motor and gearbox to be replaced. You can operate models direct from the track by fitting pickups in the normal manner and a switch to switch between the radio and track systems. Using a six volt motor means that you have to fit a small diode bank to allow normal operation on 12 volt tracks. A suitable bank of diodes would occupy about ½" x ½" x 1" (12mm x 12mm x 25mm).

b) Motor and gearbox.

You need an efficient motor and gearbox. Unless you are converting an existing model with a coreless motor and spur gearbox (Escap or Slaters) you would be well advised to remotor with a 6 volt coreless motor and spur gearbox. If you retain a 12 volt motor battery positioning will be harder.

c) An LC302

d) Radio control transmitter and receiver

You will need a radio control system but without servos, so shop around until you can find someone who will supply it this way. Modern systems work on 2.4GHz and are very reliable. The LC302 will also work well with older narrow-band 27MHz AM and 40MHz FM systems which you may find second hand.

e) Batteries

You will need 5 cells for most 6 volt motored models, or 6 if you want a fast express locomotive. If you have a 12 volt motor you will need 10 cells. The cells should be tagged, and all be the same size. Basically, the larger the cell, the longer the duration, though don't overestimate your requirements. A 6 volt coreless motor will only need about 150mA per hour, and locomotives spend a surprising amount of time stopped.

f) Charging socket

You will need to fit a charging socket somewhere on the model. The type sold by Antenna are very small, and can be used as an 'off' switch by inserting a blank plug. If you have plenty of space, an 'off' switch would be a useful addition.

g) Connecting wire

Don't forget to leave at least some space for the wires! The wiring is very simple — the LC302 is fitted with leads for the batteries, receiver and motor. The charging socket should be fitted between the batteries and the LC302.

h) Charger

Older chargers use a fixed current to charge the battery, which works well but since the current has to be limited to prevent damage due to overcharging, takes up to 10 hours. Modern chargers detect small changes in battery voltage to detect when the battery is fully charged, and can charge batteries safely in between 30 and 60 minutes.

3) *Motor and Gearbox*

A battery operated locomotive has to carry all its energy on-board, so we need to be far more careful about how we use it. For a given size of battery, the lower the current the motor consumes the longer it can be run without recharging. Ideally, something like three hours continuous running is required from one charge as experience suggests this will give about a day's normal start/stop running on a layout.

This is where coreless motors come into their own. These motors are much more efficient than conventional motors. Even a good conventional motor is only likely to be up to about 50% efficient (i.e., the mechanical power the motor produces is only about half the electrical power going into it). The coreless motors used in model locomotives are up to about 80% efficient. They also have other desirable properties like producing much less radio interference and less mechanical friction.

Standard coreless motors are available in 3, 6, 9, 12, 15, 18 and 24 volt forms, although the ones commonly used for model railways are 12 volt types. NiMH batteries produce about 1.2 volts while they discharge. Generally, one big battery is more efficient (stores more power per cubic inch) than two small ones, and this and the sheer difficulty of trying to fit and wire up the 10 batteries needed for 12 volts means that a 6 volt motor is a better choice. The normal number of cells is either 5 (giving 5.8 volts maximum to the motor) or 6, giving 7 volts to the motor, which is still within the operating range of the nominally 6 volt motors.

The smallest practical number of cells is 4, giving 4.8 volts, which, allowing for the 0.2 volt lost in the controller, works with 4.5 volt motors. Even smaller motors can be obtained, and the controller will work with 3 cells, but the receiver needs at least 4.5 volts to operate.

If you are converting an existing model which already has a 12 volt coreless motor it is, of course, quite in order to keep this motor after conversion to radio control. In this case you would need to find space for 10 NiMH cells. However, if you are building a model from scratch we would recommend using six volt motors.

Conventional motors could also be used, but their higher current consumption is likely to lead to greatly reduced duration. However, where space is available, for example a large diesel, it may be cheaper to provide larger batteries than a more efficient, but more expensive, motor.

Having gone to the trouble of obtaining an efficient motor, it is just as necessary (if not even more so) to get an efficient gearbox. Worm gears are not very good in this respect, and research by the Gauge O Guild Technical Committee suggests that efficiencies of normal single stage single start worm drives are about 30%. High quality worm gearboxes, which are machined rather than formed and use multi-start worm drives (e.g the Stubbs gearbox) are much better and have efficiencies approaching 50%.

The best commercially available alternative is a spur gearbox where efficiencies approaching 60% are obtainable. ABC Gears (http://www.abcgears.co.uk) sells such systems.

4) *Motor Suppression*

The switching action produced by the commutator of the motor is a very good source of electrical interference. The LC302 has motor suppression fitted to reduce radio interference, and no further suppression will be required when coreless motors are used.

For best results all conventional motors should be fitted with three 47nF suppression capacitors, one between each terminal and the motor case, and one between the terminals. It would also be good practice to fit non-battery operated models with such suppression where they operate near radio-controlled models. This will also eliminate TV and domestic radio interference so your neighbours may be grateful too! Such suppression is neither necessary or desirable with coreless motors.

The circuitry within the LC302 which provides power for the receiver and itself is designed to prevent interference reaching the receiver through the power supply. For this reason, the receiver should not be connected direct to the batteries. However, if old, high current motors are used with an older AM radio system, the wires carrying current from the batteries to the LC302 and from there to the motor may transmit interference which the receiver may pick up through the aerial. If jerky running is found in such cases additional suppression can be included by incorporating ferrite beads in the wires to the batteries and motor. They must not be used on the wires between the LC302 and the receiver.

5) Batteries

Ni-cad (Nickel cadmium) batteries used to be popular for model applications, but contain the heavy metal cadmium, and now cannot be sold for this use. Nickel metal hydride (NiMH) batteries store more power for their size. Lithium Ion batteries are another option, but are more expensive and are less forgiving in a model railway environment, so nickel metal hydride batteries are the best choice. batteries come in a wide variety of sizes which should suit all models. While rechargeable batteries do not contain as much charge per cubic inch as non-rechargeable types, it would be impossible to remove the batteries easily from a model for replacement, to say nothing of cost considerations.

NiMH batteries of the same size do not necessarily have the same capacity. So-called ‘consumer’ varieties may have less than half the capacity of ‘industrial’ types. It pays, therefore, always to ask what the capacity of the battery is. Capacities are quoted in milliamp hours (mAh), basically the amount of current the battery could provide for one hour before it was discharged (to 1 volt per cell). A 2000 mAh battery can theoretically provide 2 amps (2000 milliamps) for 1 hour, 1 amp for 2 hours, 4 amps for 1/2 hour, etc. In practice, the capacity of the battery will depend on the current, i.e. how fast you are removing charge from the battery, and if you draw current at less than the one hour rate you will get slightly more capacity (and visa versa). However, NiMH batteries are reasonably immune to changes in output current so the difference only amounts to about 10% either way and the simplistic calculation works fairly well.

To confuse matters, battery manufacturers are allowed a 10% leeway when specifying the capacity of their batteries to allow for ‘international standardisation’. The actual average capacity, which can only be found from the manufacturer’s data sheets, may be up to 10% less than the quoted capacity. For models it is important to ensure the maximum capacity in the minimum space, and all the batteries we sell will give capacities about 5% greater than their quoted capacities.

NiMH batteries are available in two forms — untagged, which is the form you would find in shops, and tagged, which have metal tags attached to the ends of the battery so that wires can be soldered on. The batteries used in the model must be tagged, because they will need to be soldered together when fitted on the model to make fitting easier and reduce electrical losses, and soldering wires on to an untagged battery will damage it due to the heat. If you wish to use rechargeable batteries for the transmitter these should be untagged as the transmitter contains a battery box.

Radio controlled operating practice with 6 volt coreless motors suggests that engines use an average of 150 mA in an hour, so a stack of 450mA batteries will give 3 hours running time.

Batteries available from Antenna are shown below

Size code	Size (mm)		Capacity	
	Dia	Length	mAh	per cubic inch
2/3 AAA	10.5	28	300	2030
N	11.6	29.7	500	2265
1/3AA	14	16	250	1665
2/3AA	14	28.5	600	2240
2/3AF	16.5	28	1000	2740
SubC	22.4	42.4	3000	2790

Larger batteries have a higher capacity per cubic inch, which is why it is better to choose a lower voltage which needs fewer batteries.

Very regular use of NiMH batteries can induce a ‘memory effect’, where if a battery is only usually discharged down to half its capacity, it will eventually only be able to supply this amount in total. Fully discharging and recharging several times will normally restore the battery to full capacity. This effect is virtually non-existent on the batteries supplied by Antenna, but the varied use of railway models makes it unlikely in any case.

6) Charging

There are several different ways of recharging NiMH batteries. The most common is a slow charge using a current equal the ten hour discharge rate. (e.g. 60mA for a 600mAh battery). This will fully recharge the battery in 12 to 14 hours without any heating, ensuring a long life, and charging for longer periods at this rate will not cause damage to the cells, so it is also very safe.

One fast charge method stops charging when the battery overheats. While not as crude as it sounds in controlled environments, charging by such methods in a model is very risky.

The best charging method uses the fact that the battery's voltage falls very slightly when it is fully charged. Such chargers always charge to the full capacity of the battery, and take only an hour or less to do so. These chargers are fast chargers which do not have timers or a temperature probe to the batteries, and if you know your wiring you can make up a lead from such a charger to allow for fast charging in the model.

The final method of fast charging is to use a short timed charge, usually of about 2 hours. This method of charging is NOT recommended for models. It can be difficult to tell how much charge has been used up from the battery, since the motor will draw different currents depending on whether its going up hill, accelerating, etc. It is not easy to estimate the remaining charge simply by counting the time the model has been operating, and any overcharging at this rate will cause the battery to overheat and shorten its life considerably.

The voltage change method – often called delta V or ΔV – is the most complicated method but cheap electronics has made such chargers very affordable. It is important to get a charger which has a wire connection to the battery rather than requiring the batteries to be fitted into the charger for charging. Such chargers are sold for model cars, and usually work automatically with different numbers of cells, usually between 2 and 8. Some cheaper models will only charge 6 cells as that is the common number of model cars. Ones which charge 10 cells are harder to find – another reason for converting to 6 volts. For example, the Hobbymate RC Car Battery Charger for NiMH/NiCd Battery Packs charges between 2 and 8 cells of between 300 and 700mAh, and costs £15 on Amazon. The £18 Keenstone Airsoft Battery Charger covers a wider range of battery capacities and is another good choice.

7) Radio System

The radio systems used for model control are 'proportional' systems, where a movement on the joystick of the transmitter causes a corresponding movement on a servo connected to the receiver. The radio system does this by sending a pulse whose length depends on the position of the joystick. This pulse, repeated 50 times a second for each joystick, varies in length between half a millisecond and 2½ milliseconds. The transmitter generates these pulses, converts them to a radio signal, and sends them to the model. The receiver then recovers the pulse from the radio signal, and sends it to the servo. The servo measures the length of the pulse and moves accordingly.

The LC302 fits where the servo would normally go in the system, and instead of producing a mechanical movement in response to the varying length of pulses it varies the speed and direction of the model's motor.

Modern RC systems use 2.4GHz, similar technology to Wi-Fi. They are extremely reliable, and cope well with interference from motors. Many different systems can be used in the same area – transmitters and receivers are supplied paired, and a receiver will only respond to its paired transmitter.

It is possible to re-pair receivers, and so operate multiple models off the same transmitter. However, this is more trouble than it is worth. Receivers cost as much as a cheap transmitter/receiver combination, and usually the re-pairing process requires a button on the receiver to be pressed when the system is switched on, which is inconvenient when the receiver is built in to the model. It is easier to dedicate a transmitter for a specific model and allows use it for that model.

Older narrowband systems can also be used. These came in different types : 27MHz amplitude modulated (AM) and 40MHz frequency modulated (FM), as well as 35MHz for model aircraft, but by law, only the 40MHz FM system can be used for model railways. The actual frequency the system uses depends on the value of crystals inserted in the transmitter and receiver. These crystals come in pairs, and by having different frequency crystals you can have different models operating at once. There are 6 different crystal frequencies for AM systems, and 30 different ones for FM. If you are operating your models with your and you are using narrowband systems, all the models must have different frequencies. With any more than two modellers you will have to have a system like a noticeboard to note which frequencies are in use. This complication is a thing of the past with 2.4GHz systems as they use the same frequency but unique addresses for the receivers assigned through the pairing process.

The radio link is affected by 'interference' — spurious electrical signals which confuse the receiver. Modern radio systems are very good at ignoring this 'noise' as it is also caused, but beware of using older equipment. Electrical motors are great interference generators, so it is very important that adequate suppression is included to reduce it as discussed in the section on motors. The same applies to other motors operating near the radio controlled model.

A variation on this theme is 'rusty bolt noise'. This can prove most problematic to model railways as it is caused by intermittent metal contacts (chassis, wheels, rails, etc) acting as miniature aerials and picking up the transmitted signal, and then sending out spurious signals as they make and break contact with neighbouring objects. It got its nick-name as it can be caused by bolted joints in broadcast transmission aerials moving in the wind.

It is very unlikely that the model will go out of range, particularly with modern systems, but the narrowband systems may be affected by fading caused by the fact that the signal sent to receiver may be reflected off objects, so it is possible that the signal the receiver picks up is actually the culmination of several transmitted signals, each arriving by different routes and taking slightly different times to get to the receiver. In some cases, these signals may cancel each other out so that the receiver is unable to distinguish the transmitted signal. Flat stone walls make good reflectors, and you may find that there is a patch in the garden where you will be unable to control the model. This problem can be solved simply by moving the transmitter. Futaba quote the figures as 300 metres for AM and 500 metres for FM, but that is under ideal conditions. Practical ranges in a garden will be shorter, but will not be less than a couple of hundred yards.

Since modern 2.4 GHz transmitter/receiver combinations cost only about £35 new, there is little reason for using narrowband systems unless you have them already. However, the interference rejection algorithms in the LC302 will allow it to work with older narrowband systems.

Radios often come as a complete system of transmitter, receiver and servos. Since the LC302 takes the place of the servo, you do not need these, so ask to buy a system without servos (called a 'Combo' system).

8) *Mounting the Aerial*

The receiver will come with a length of aerial attached. **NEVER CUT THE AERIAL —** it is designed for a particular frequency, and cutting it will change that frequency, with unfortunate results. Unless you are modelling a DMU, you will have to bend the aerial to fit it in the model. The easiest thing to do is to coil it up. This restricts the aerials power but not drastically, and you can improve reception again by soldering a small rectangular plate to the end of the aerial wire. The aerial should never to connected to the metal body of the locomotive, so if you use a metal plate you will need to insulate this from the body as well.

9) *How the LC302 works*

At first sight would seem that all that is required of the LC302 is to measure the length of the pulse produced by the receiver and alter the speed of the motor accordingly, and there are many speed controllers from model boats and cars which do just that. However, if we use a simple circuit to do this we will hit some problems.

Even with the best radio system and an ideal aerial there will be slight variations in the length of the pulses the receiver produces. This does not matter for cars or boats since the variation is small and their large motors do not have time to react, but for locos where we after good slow running, the jerkiness this causes is quite noticeable. There is also the problem of what happens when the signal is lost.

These problems can be overcome by reducing the sensitivity of the circuits (which has the disadvantage of removing some of the proportionality of the system) and by using a separate circuit to regenerate the signal if it is lost, and at least one such system is already available for model locomotives. However, this approach is relatively inflexible, because even if we replace the lost signal we can only continue at some predefined speed and direction until the signal can be picked up again. This means that if the transmitter is switched off, say, the model will start off and run at the predefined speed and direction.

The Antenna approach is entirely different from radio conventional speed controllers in that it uses a tiny computer to measure the pulse and act upon it. This means that we can perform much more complicated functions than would be possible using conventional electronics and in a much smaller overall size. (A similar approach is used by Digital Command Control systems).

The LC302 records the length of the last 16 pulses it receives, which allows it to average out any small variations in the pulse length without losing any proportionality. It will automatically reject any pulse which varies from the average by too large an amount, and so will reject major interference and allow it to work in electrically noisy environments which would defeat other systems. Finally, if the LC302 looses the radio signal it simply carries on at the last speed that was set. This allows you to switch off the transmitter when you reach cruising speed no matter what speed or direction you are going in. The LC302 can also to told to stop if the radio signal is lost rather than carrying on regardless.

The LC302 also uses the latest technology E-line transistors which give a very small voltage drop of only 0.25 volts even at the maximum output current of two amps, and does all this in an incredibly small package.

10) Powering models from the track

It is possible to have the best of both worlds by switching between battery operation and operation from the track. There are two variations.

Conventional Control/Remote Battery Control

In this case, a switch is incorporated to switch both the leads to the motor between the track and the LC302, and the battery supply. A total of three poles are required — one to switch off the battery and two to switch the motor to the track. When on battery operation, the motor is isolated from the track to prevent interference, and when powered from the track, the LC302 is isolated from any reverse currents. A refinement for 6 volt motors is a small voltage reducer to stop the model running too fast if 12 volts is applied by the track controller.

Remote battery control/Remote track powered control

In this case, the supply from the battery to the LC302 is switched to come either from the track or the batteries. A small regulator unit is used to smooth the track current for the LC302 and prevent interference with the radio signal, and to limit its maximum to 12 volts. A refinement is to incorporate a relay so that the locomotive will automatically switch to track power if it is available.

This argument can be extended to the point where the batteries are removed altogether and all the power supplied by the track, with radio control selecting the direction and speed. However, unlike the shared scheme there are no batteries to take over when the locomotive meets a piece of dirty track, is a major benefit of battery operation is lost.

Radio control price list
Postage 95p per order

LC302 speed controller	£49.95
Charging socket	0.45
Blank plug	0.35
47nF Suppression capacitors	0.08 ea.

Tagged NiMH Batteries (each)

Size code	Capacity	Price
2/3AAA	300	£1.95
N	500	£2.45
1/3AA	250	£1.45
2/3AA	600	£2.45
2/3AF	1000	£2.95
SubC	3000	£5.95

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