Electronics for Model Railways

Chapter 11

RFID

By Davy Dick

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In memory of Margaret

Contents

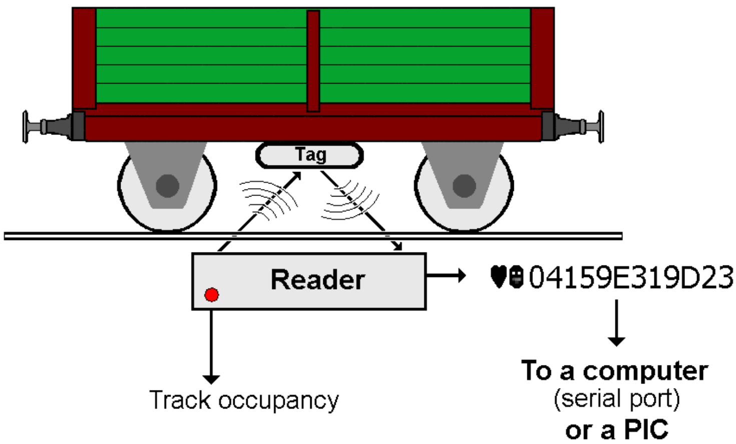
RFID

Radio-frequency identification is probably the most complex and most expensive of the various train detection systems.
It also offers the greatest possibilities, particularly when used for automation of layouts and other computer-controlled activities.
The system is covered in MERG Technical Bulletins A39/1 and A39/2.

> **Note**
> RFID is not a beginner's project, requiring some electronics and computing expertise.

How it works

Locos, coaches or wagons are fitted with *'tags'*. Each tag is a little transmitter that has its own unique code (ID).
A RFID reader module (a little radio transmitter/receiver) is placed under, or to the side of, the track. When the tag passes close to the reader it transmits its ID.
The reader receives this ID and lights a LED to indicate successful reception.
In this way, it acts as momentary track occupancy detector.



More usefully, the module passes the ID out for processing

- via a serial port, for processing by a computer
- via a PIC, for local/special activities

The reader may consist of two parts.
There is a module that is used to read and decode the tag's ID and there is a separate circuit that interfaces the reader to a computer.

Both these modules, and the tags, are available from the MERG website's KitLocker.

How it can be used

When linked to the programming power of a computer, the RFID system can be used for everything from a simple block detector system to hugely complex automated system.

Below are the most common model railway applications as provided by RFID users:

Control operations

- Move points; e.g. trigger point routing for express/shunter.
- Detect wagons coming detached, if last wagon is tagged.
- Detect a loco's DCC address, to control it (e.g. assigning the engine to a throttle).
- Generate switch lists (handling instructions) for operators of fiddle yards, goods yards, etc.
- Determine an item's location by looking back to the last reader it passed.
- Calculate the length of the train, if all rolling stock is tagged.
- Know when train has passed (tag in last wagon/coach).

Maintain stock lists

- Spot if a new loco has same DCC address as one on the track.
- Compile sidings contents (hump yards).
- Generate a list of cars on the train.
- Scan a manifest upon coming in/out of a yard.
- Generate a list of discrepancies (cars not on the train that should be; cars on the train that shouldn't be).
- Ascertain the location of missing cars between operating sessions.
- Sign in and sign out locos at club layouts/exhibitions.

Trigger sound effects

- Station announcements
- The fiddle yard one speaks out the destination of the approaching trains.
- Whistles / bells.

Trigger screen announcements

- On-screen timetable updates. Readers can pass information onto the fiddle yard/goods yard operators as to which trains are approaching them.
- On-screen display of loco picture/info and train info that describes the train that has just passed over a detector.

Tags

The tags used in the MERG kits conform to the EM4102 specification, which is the low frequency band operating at 125KHz. Tags are available in a range of outlines, including key fobs, wristbands, stickers and cards.
The most commonly used for our purposes are either discs (available in 20mm and 30mm) or glass tags (available through MERG in 12mm and 34mm lengths).

These are known as 'passive' tags, which means that they do not need a power supply to operate (very handy – no need for track pickups or batteries).

As the tag passes over the reader, the little coil (look inside the glass tag) passes power from the electromagnetic field generated by the reader to the circuit inside the tag. When charged up, the tag transmits its ID.

Every tag that is manufactured has a different ID number.   Don't worry, we won't run out of numbers any time soon, as there are 100 billion possible tag numbers!

Tag positioning

Since we are working with low power levels, the tag needs to be as close to the reader as practical.
The larger tags can harvest more power and therefore work over a greater range – which is OK when you are working with 00 upwards.   However, it takes a bit of ingenuity to fit a 30mm or 34mm tag in N gauge or smaller.
In most cases, the reader is mounted under the track (see later).
For smaller gauges, it is common to fit the tags as low as possible under the loco/ wagon/ coach This ensures that it is as close to the reader as possible.   It also minimises any losses caused by the presence of metal (e.g. weights placed in wagons).

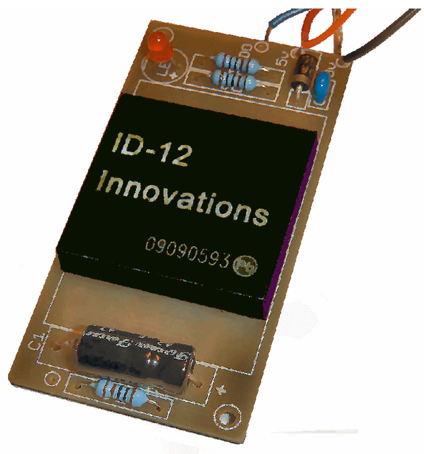
A glass tag is normally positioned from end to end along the length of the loco or wagon.
Alternative positions include:

- Mounting the tag vertically, where undercarriage space is restricted.
- Mounting the tag across the buffers, with the reader standing vertical to the track.
- Mounting the tag on/under the roof of the coach, with the reader on an overhead mount.

The larger tags and discs, due to their increased range, are often placed inside a coach or wagon's body (particularly if there is no metal floor on its chassis).
Lastly, it should be noted that if two tags are located too close to each other, neither will be read by the reader.

Readers

A number of 125KHz RFID readers are available commercially. The two that are used and sold by MERG are made by ID-Innovations and are the:



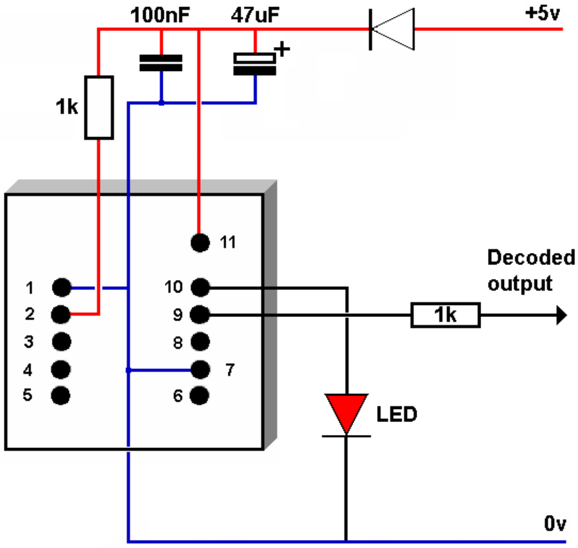
ID-12
Smaller (26 x 25 mm x 7 mm - approx 1" square by 1/4" thick)
Smaller working read range (12cm+)
Uses 30mA at 5V (4.6V min, 5.4V max)

ID-20
Larger (40 x 40 mm x 9 mm - approx 1.6" square by 1/3" thick).
Greater working read range (16cm+)
Uses 50mA at 5V (4.6V min, 5.4V max)

The advertised working ranges are over-optimistic due to the usual obstructions and reflections in railway layouts.

Both modules are cased in black plastic, with the connecting pins under the body.
The picture shows an ID-12 mounted on the MERG reader PCB (Kit 31).
Both these models have an internal aerial, with pins for connecting an external aerial.

Another model, the ID-2 has no internal aerial and is not used in MERG projects as external aerials tend to be bulky and therefore prone to picking up tags from adjacent tracks.
The ID-12 and ID-20 readers are both 11-pin devices and the circuit diagram shows the minimum connections used in the MERG reader PCB (viewed from underneath the reader).



When a tag is passed near the reader, the LED will light and the decoded ID will be sent out on pin 9. Pin 9 can also be used to sound a beeper, although the beeper should be driven by an added transistor.

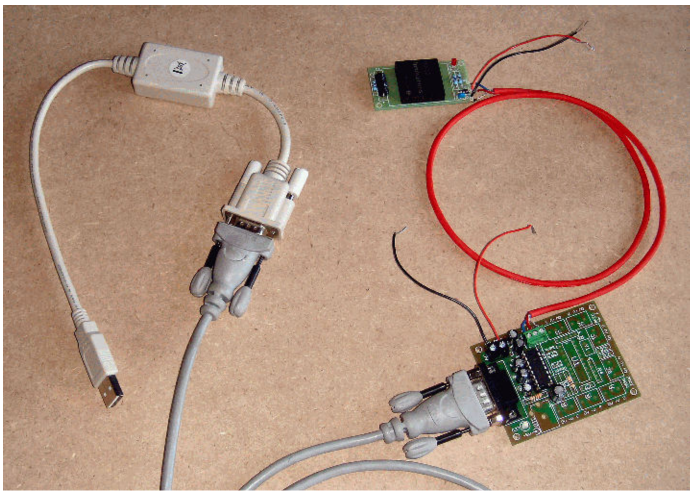
To use the reader with a higher supply voltage, a 5V voltage regulator would have to be included in the circuit.

Note that no dropper resistor is required in series with the LED.
Pins 3 and 4 are used if an external aerial is to be connected.
Pin 8 is the same decoded output as on pin 9, only inverted.

Connection to your computer

The output from the above circuit can be fed directly into a PIC, with no other circuitry in-between.
Of course, you then have to know how to write PIC programs to read the data being fed in.
More common is that the output is fed into a computer, using its serial port or USB port.
MERG Kit 30 includes a module that converts TTL level output from pin 9 to the RS232 signal expected by a computer's serial port.

The picture shows a typical setup for a single reader.



The reader (Kit 31) feeds its ID data into the MERG serial output module. The output from the serial output module is connected to a serial cable. If your computer does not have a serial port, a serial to USB converter cable can be used, as shown in the picture. How the computer uses the processed ID is looked at later.

Reader positioning

As with tags, the positioning of readers has a marked effect on performance. There is a trade-off between sensitivity and selectivity. On the one hand, we want the best sensitivity possible. On the other hand, we don't want to pick up signals from tags on adjacent tracks. For example, using 34mm tags increases the effective range but also increases the possibility of triggering neighbouring readers that are insufficiently spaced apart.
Ideally, the reader should be mounted under the baseboard, out of sight.
Depending on the thickness/density of the baseboard material, this may not be possible. Other alternatives include mounting it immediately under the track (removing some of the baseboard material), at the side of the track, or above the track in certain circumstances.

The picture shows an extreme case where the sleepers have been removed so that the reader can be as close to the rolling stock as possible.
User experience suggests that each reader should be allocated at least a 6” square area to itself – preferably more.

Other approaches include:

- Mounting readers slightly offset from the centre, with two adjacent tracks, to maximise the separation of the readers.
- Placing shielding materiel round the reader, to minimise unwanted pickup.

If you are using DDC on your layout, it would be advisable to minimise potential interference between DCC wiring and reader cabling. This could be aided by careful routing of the cables.
Also, as the reader connections are 3-wire (+5V, 0V and data), it is possible to use a screened single pair cable for the connections. 7/0.2mm screened wire can be used here.

Reading speed

Clearly, there is a trade off between the speed of the tag, the distance between the tag and the reader, the efficiency of the tag (usually its size) and the sensitivity of the reader used (e.g. ID-12 or ID-20).
The reader takes about 400mS to process a single read, so the reader has to be allowed that amount of time before having another tag passed over it. This determines the maximum reading speed for any given setup.

- If the tag is whisked past the reader too quickly, it may not be read properly.
- There is no such thing as reading tags 'too slowly'.
- Leaving a tag stationary over a reader, or moving it slowly across a reader, does not result in continuous readings. A tag has to leave the reading zone and re-enter again before it will be read again.
- If tags in rolling stock are not spaced sufficiently apart, both tags may be in the reading zone at the same time, preventing any being read successfully.
- Six inches to 8 inches has been suggested as a suitable distance between tags in different items of rolling stock. However, this might vary depending on the size of the tags and the efficiency of the reader. The 12mm tags used with the ID-12, for example, present a smaller reading zone than 34mm tags with an ID-20 reader.

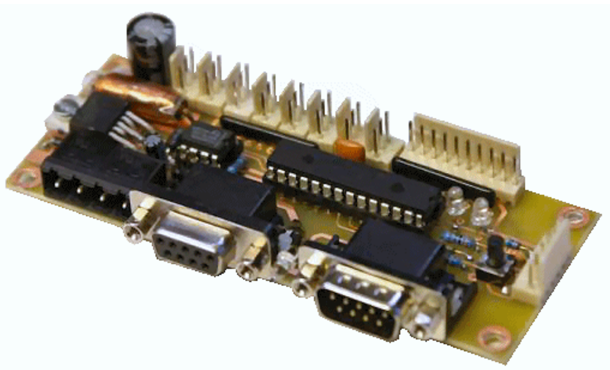
Concentrators

So far, we have looked at connecting a single reader. In practice, a layout will require multiple readers and we can't allocate a separate serial port for every reader.
The answer is to use a *'concentrator'*. This module accepts the input from eight different readers and produces a single serial output.
The data from individual readers are still able to be uniquely identified and processed (see later).

Kit 33a is MERG's complete concentrator kit or Kit 33b can be purchased to upgrade an existing serial output board into a concentrator module.
The MERG concentrator has a serial output and connects to a computer via its serial port, or USB port is a serial-to-USB converter adaptor is used.

When you need more than eight readers, you can wire extra concentrators to other serial/USB ports on your computer. The MERG concentrator kit includes 'bank jumpers' that allow multiple concentrators to be used with each being individually recognised by the software.
Clearly, for large layouts, there will be many readers and concentrators, resulting in extra cables between the layout and the computer and added complications in the computer software that handles them. Also, of course, you will eventually run out of computer ports.

Another approach, if you are a CBUS user, is to feed the outputs from the concentrators into the single CBUS cable.



In cooperation with the Rocrail team, Peter Giling has developed a range of hardware kits and PCBs that match the MERG CBUS specification.
It includes an 8-channel interface between RFID reader modules and CBUS.
It is known as the CAN-GC4 mergCBUS 8 Channel RFID

More details are available at:
https://wiki.rocrail.net/doku.php?id=can-gc4-en

The cables that connect the readers to the concentrators can be of a considerable length, providing a little care is taken with routing the cables away from power and DCC cables.
A quoted maximum "guarantee" limit of 15m has been stretched in practice to two or three times that distance which is more than enough for even the largest of layouts.

Reader output

The final output from a reader is a stream of RS232 serial data in ASCII format and this can be read by any terminal program. The terminal program has to be set to read at 9600 Baud, 8 data bits, no parity and 1 stop bit to match the format of the reader's output.

Older versions of Windows provided an application called *'HyperTerminal'*.
This handy utility was dropped in more Windows 7 onwards.
PuTTy is the most commonly used terminal emulator but you can see a review of 15 different emulators here:

https://www.puttygen.com/windows-terminal-emulators

If you are using an Arduino, you can view an RFID reader's output using the Serial Monitor.

The output format

Each time a tag is read, the reader module sends out 16 ASCII characters out on the RS232 connection. In fact, the actual ID is made up of only 40 bits (ONs and OFFs) but is packaged in a way that allows easy transmission and reception. Apart from the first and last byte, the contents of all the other bytes have an effect on the screen content.

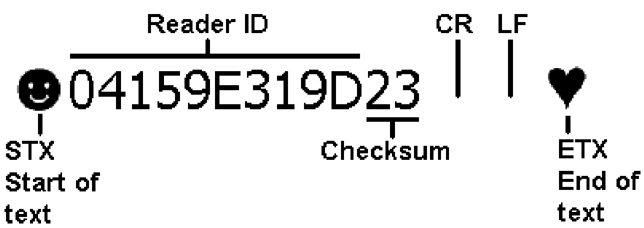
STX	Reader ID	Checksum	CR	LF	ETX
1 byte	5 bytes (40 bits)	2 bytes (16 bits)	1 byte	1 byte	1 byte
'smiley face'	10 characters	2 characters	Carriage return	Line feed	'heart'
Start of text (02h)	The ID shown as ASCII text	Check shown as ASCII text	Go back to start of line (0Dh)	Go to new line (0Ah)	End of Text (03h)

The STX byte informs the terminal program that a string of data is ready to be processed.
The 5 bytes of the reader ID are converted into 10 readable ASCII text characters.

Note

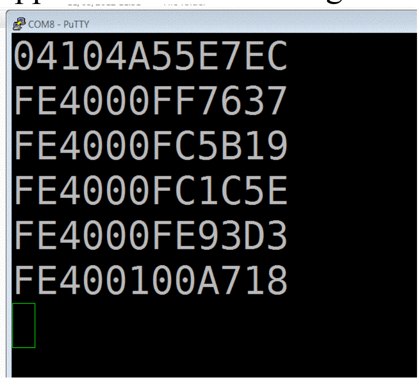
All the ASCII characters are in the range 0 to 9 or A to F. Why? Because these are the values for hex notation. It makes for simple conversion from bit patterns to hex characters. The 40 bits of the ID are split into ten groups of four bits (four OFFs and/or ONs). So, for example, if a group was 0011, then that represents the value 3 and the ASCII character '3' is transmitted. If the a group was 1011, that represents B in hex and the ASCII character 'B' is transmitted.

The illustration shows the construction of a typical ID.



The STX is displayed as a 'smiley' face, while the ETX is displayed as a heart shape.
In practice, using HyperTerminal, the effect of the CR and LF result in the ETX character appearing at the start of the next line, as shown in the next illustration.

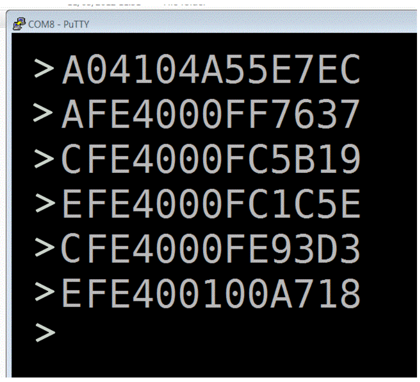
The checksum is generated by adding together all the values of the reader ID and sending this value as the checksum bytes. The terminal program also creates a checksum from the receiver ID. If both checksums are identical (it is called the XOR checksum method) then the terminal program knows that the ID has been received correctly, with no alteration due to interference, etc.
The CR and LF bytes are used to ensure that the next ID read appears on the following line on the monitor screen.
Finally, an ETX byte is sent to let the terminal program know that this is the end of that transmission.



This illustration shows the output as seen on the PuTTY screen. Note that it ignores the STX, CR, LF and ETX characters and only displays the 10 ID characters and the 2 checksum characters.

Concentrator output

The above illustrations and screenshots show the output from a single reader.
Where multiple readers are in use, the output has to indicate not only the tag ID but the reader that is sending the ID.
This is achieved by amendments to the ID string.
A concentrator can handle 8 readers and it recognise input 1 as 'A', input 2 as 'B', up to input 8 as 'H'
The STX character is then replaced by the appropriate letter.
So, for example, if tag FE4000FF7637 was read from input 4, the beginning of the string is changed from STX FE4000FF7637 to DFE4000FF7637.
The ETX character at the end of the string is replaced by the > character.



Now every character has an impact on the screen display; all the characters are printable, with the exception of the carriage return and line feed.

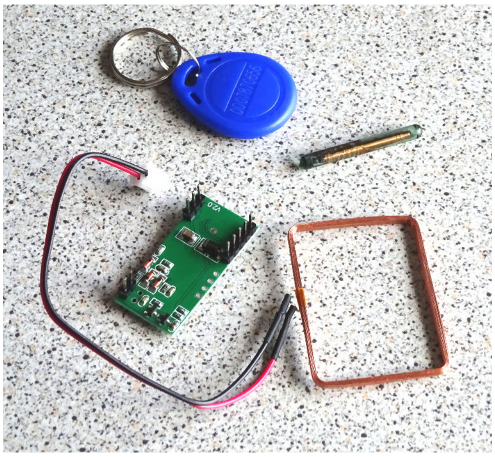
Software

Many existing layout control applications already support RFID input. These include RocRail, JMRI, Tcc and SSI. Users can use existing scripts, or create their own scripts, to handle a variety of tasks, including visual display updates, point switching, etc..
MERG members have also produced applications that are available for download from the MERG website.
Phil Herbert describes his Train Announcer program in the Winter 2010 Journal.

Mark Riddoch has written two programs.
One uses tag inputs to display different pages from a PowerPoint slide show (great for impressing visitors at exhibitions). The other is "an Excel application based around the concept of providing a timetable sequence to a fiddle yard operator. The RFID readers are used to feed information to the operator as to the train movements."
Although the most expensive and complex of systems, RFID offers the greatest scope for layout control; scan previous Journals and the MERG website for plenty of discussion and suggestions.

Station announcer

The chapter on Audio looked at the DFPlayer module.
An issue of the MERG Journal had an article on constructing a module that played a range of pre-recorded sounds. Each sound was triggered by a switch, or button, or electronic trigger.

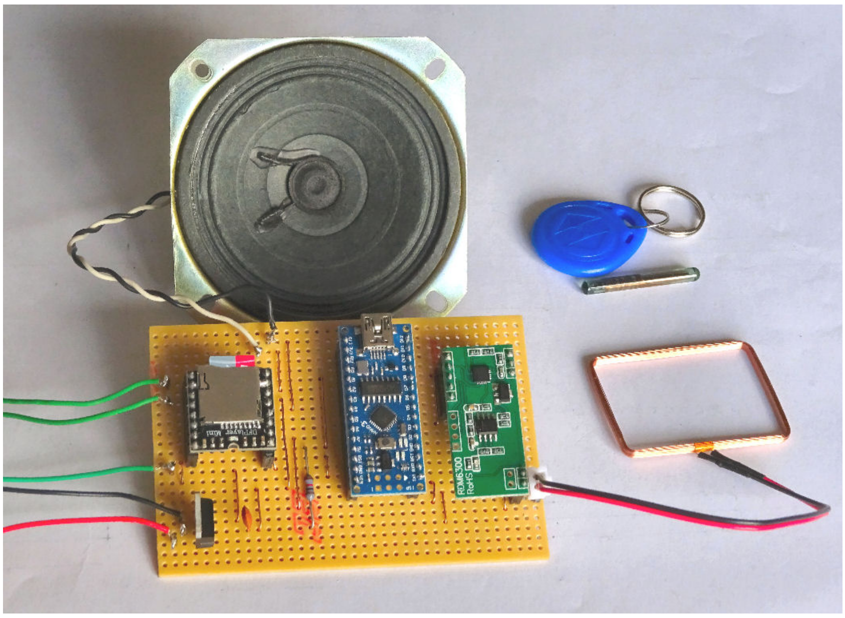


With RFID, you can convert the player into a module that makes station announcements relating to the particular train arriving at the station. Instead of a switch input, each sound stored in the sound player is played when triggered by its associated RFID tag.

The system uses a basic RFID reader that is very cheap on eBay; the tags are also cheap.
The image shows the reader the RDM6300 module and a couple of the tags that can be used with it.
The reader is placed in the track at the station and each train has its own tag fitted.
Since each tag has its own unique code, the Arduino can link a particular code to playing a particular audio clip.
The module will not activate sounds from the same tag twice unless 30 seconds has elapsed. That prevents multiple announcements while the train sits in the station.

Connecting the reader

Only five of the reader's pin are used in this system. Two connect 5V power to the reader. Another two connect to the antenna coil (approx 48mm x 35mm). The last pin takes the data read from the tags into the Arduino Nano on the DFPlayer.
This image shows the DFPlayer and the RFID reader mounted on the same board.

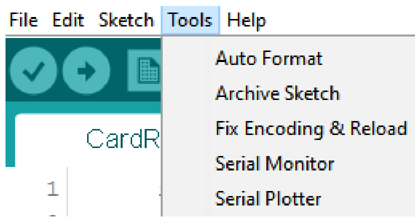


The steps for configuring the system are:

- Find out the unique codes of the tags you will be fitting.
- Fit the tags to the locos/coaches/wagons, noting the code used for each.
- Record your own station announcements.
- Match the tag codes to each announcement.

There are two sketches, *"CardReader"* and *"RFIDSoundPlayer",* that can be downloaded from the MERG Software Wiki.

Identifying tags



- Attach the Arduino Nano to the computer using USB cable.
- Open and Upload the *"CardReader"* sketch.
- Open the Arduino IDE's Serial Monitor window.
- Bring a tag close to the coil.
- Note down the 12 character code displayed for that tag.
- Carry on until you have a note of the code for each tag you intend to use.
- Open and Upload the *"RFIDSoundPlayer"* sketch.
- Fit the DFPlayer module.

Recording your audio tracks

It is unlikely that you will have the specific audio tracks available. Usually you will have to record your own announcements, in MP3 format. There are plenty of pieces of software that can help you. For example, Windows has a *'Voice Recorder'* utility and *'Audacity'* (free) allows you to trim your audio tracks, add echo, and other effects.
Once you have produced your audio tracks, name them 0001.mp3, 0002.mp3, etc., with all the files inside a folder called mp3. Copy the mp3 folder on to your microSD card and insert the card into the DFPlayer.

The code provides for a warning if a tag is read that is not currently in the favoured list. If you create an audio file that contains a "*beep*" or similar sound and name it 0099.mp3, the sound will play when an unlisted tag passes the reader coil.

Note

The tags take time to charge up before sending out their codes. The total time to take a reading is known as the *'acquisition time'* and is 140mSec. This makes the RDM6300 unsuitable for reading tags at faster train speeds, as its response is not fast enough. However, in this application, the train is entering a station at a slow speed and the reader works fine.