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Institution of Railway Signal Engineers

# MicroETS – A token system development on the Welsh Highland Railway


Roland Doyle and Ben Abbott

**The Welsh Highland Railway (WHR) is a 597mm narrow gauge line which runs from Caernarfon to Porthmadog in North West Wales, a distance of 25 miles (40km). It is owned and operated by the Festiniog Railway Company who also operate the Ffestiniog Railway (FR) from Porthmadog to Blaenau Ffestiniog, a distance of 13¼ miles (21km), and the two routes are connected at Porthmadog sharing a platform.**

The WHR makes use of some of the original WHR route which closed in 1937. The new lease of life for the WHR started in 1997 when the first section was opened between Caernarfon and Dinas, some 3 miles (5km) long but isolated from the Ffestiniog line by 22 miles (35km). This was built on the original main line to Afon Wen located on the Dovey Junction to Pwllheli line. The opening of the WHR was enabled by one of the last light railway orders and one of the first Transport and Works Orders, together with private donations, a grant from the Millennium Commission, and labour provided by contractors and volunteers. The Millennium Commission grant was for the first half of the line from Caernarfon to Rhyd Ddu (on the south side of Snowdon). The second half, from Rhyd Ddu to Porthmadog, was funded by further private donations and a grant from the European Regional Development Fund.

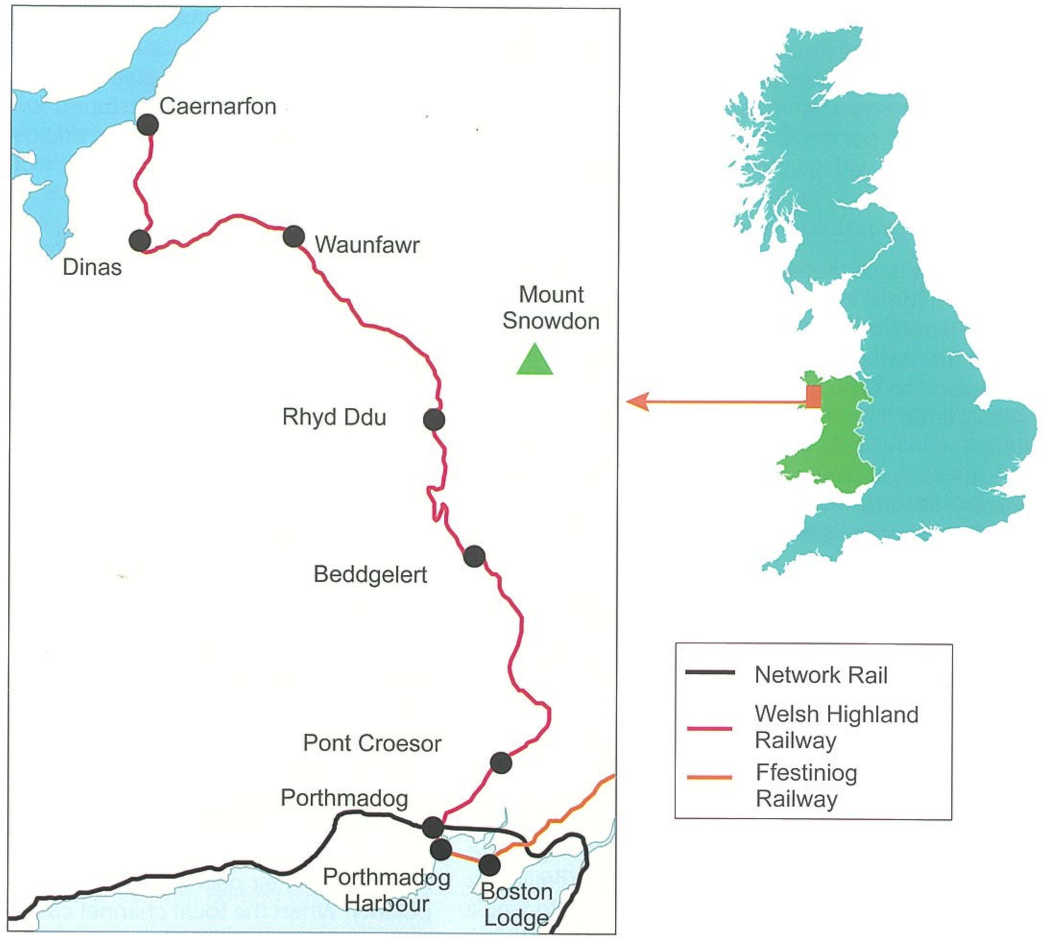
Volunteers played a big role in the restoration, especially with tracklaying, using a mixture of old and new materials procured globally. The collective name for the two routes is 'Ffestiniog & Welsh Highland Railways' or FfWHR for short. 'Festiniog Railway' is the railway's legal name with a single 'F' due to a spelling mistake made in 1832 when the act of parliament to build the railway was made. The Ffestiniog line is famous for its iconic articulated Double Fairlie steam locomotives weighing in at around 28 tonnes. The FfWHR line uses mainly 62-tonne 2-6-2+2-6-2T articulated NGG16 Garratt steam locomotives obtained from South Africa, one of which is stabled by rotation at Boston Lodge Works on the FR line; the Garratts are too wide to travel any further up the FR.

One of the iconic Garratt steam locomotives on the Welsh Highland line arriving at Beddgelert from Porthmadog.
*Photo Paul Darlington.*





The Welsh Highland Railway is situated on the picturesque north west coast of Wales, running past Wales' highest peak, Mount Snowdon.
*GB Map Maproom.*




From an operational perspective the Ffestiniog Railway is controlled by Electric Train Staff (ETS) machines, the first of which were installed in 1912. More information about the system can be found at **irse.info/rnaby** These provide the security of movement required by the single line sections as well as providing operational flexibility.

At the turn of the century, in his role as general manager of the construction company "Welsh Highland Light Railway Ltd" (a wholly owned subsidiary of Festiniog Railway Company, responsible for Caernarfon – Rhyd Ddu), Roland was involved in the process to consider which method of train control to use long term between Caernarfon and Porthmadog. The Caernarfon to Dinas section was open for traffic (3 miles) using One Engine in Steam working (OES), but this was just an interim solution. As on the FR, the tokens would be handled by the train crew, except for Porthmadog where the signal box would be manned. Staff and Ticket replaced OES but this proved to be very inflexible since the planned crossing of trains could not be changed to an alternative passing loop at short notice without the need to move tokens round by road.

The civil engineering contractor, Mowlem, had built Phase 1 from Dinas toward Caernarfon under a design and build contract, which was quick and efficient, but it was realised that more control was needed over the design process. To facilitate construction and ensure, in particular, that grant funding was correctly spent, two construction companies were created. Welsh Highland Light Railway (WHLR) was responsible for the first half of the route to Rhyd Ddu and subsequently Welsh Highland Railway Construction Ltd for the second half on to Porthmadog. WHLR's civil engineer, Mike Schumann, managed the consultants in subsequent phases. When the time was approaching to ask contractors to tender for the Dinas to Waunfawr earthworks and drainage contract (4 miles), Roland had the tender documents upgraded to include a cable duct to allow ETS to be installed. The tenders came back with the cable duct portion costing around £80K. The construction company board advised Roland that the cable duct portion of the tenders had put the contract price well above budget and so had to be deleted. As an alternative, Roland was asked to look into a radio dispatch signalling, similar to the systems in use at the Romney, Hythe and Dymchurch Railway in Kent and the Harzer Schmalspurbahnen in the Harz mountains of former East Germany. A radio survey was commissioned which determined that six radio transceiver masts would be needed to cover the route from Caernarfon to Boston Lodge (26 miles), with the final transmitter reaching up the FR as far as Penrhyndeudraeth. The six transceivers would have been linked using private wires leased from BT. Before working for the railway, Roland had worked as a BBC broadcast engineer and so knew about the costs involved in leasing private wires. The cost of private leased lines for the whole WHR system would have been in the order of £30K per year, every year, ad infinitum – not good business sense. In addition, planning consents under the control of the Snowdonia National Park Authority (SNPA) would probably not have allowed such masts. When incidents on other railways using radio dispatch were put down to 'human factors', it was no longer considered for the WHR.

Some years later, many 'S' type ETS machines were acquired from Irish Railways (See Figure 1). This resurrected the idea of lineside cabling, so a quotation for supply and placement of suitable cable was obtained. It had already been identified that telegraph poles were not permitted by SNPA, so any lineside cables would have to be at or below ground level. Unfortunately, this also proved to be beyond the project's financial means. A mobile phone service provider approached the company asking if they could lay a fibre optic cable along the full 25 miles between Caernarfon and Porthmadog, letting WHR have use of some spare fibres. This sounded like a great prospect, but adjacent landowner liaison was in its infancy and had not started between Waunfawr and Porthmadog, being 18½ miles long, some 75 per cent of the line. Resources were not available to negotiate with all those adjacent landowners in the couple of months available, so the offer from the mobile phone service provider was unfortunately not practical.

With the rapid roll-out of broadband internet in Wales starting a couple of decades ago, it became apparent to Roland that a method using the public internet or an intranet could be developed to link the staff machines. A FfWHR company director asked Roland to send him documents outlining his idea. Some weeks later, Roland was told the FfWHR Board were very interested in his idea and wished him luck as he set off to develop the system at his own expense. He started a limited company, HighRail Systems Ltd, to ring fence the project and provide a framework for his employment.

Roland was put in touch with three IRSE Fellows: Richard Stokes, Roger Short, and Philip Wiltshire (past president) who agreed to become ICPs (Independent Competent Persons) and assess the safety of MicroETS. They brought with them a wealth of knowledge and experience.

## Fundamentals of ETS as seen by a computer engineer

The ETS machines contain a two-pole changeover switch (commutator) that changes over each time a token is inserted, or extracted from, the machine. If we feed a voltage into the commutator in one position, the voltage exiting the commutator will appear exactly the same as the input. In the other position, after inserting or extracting a token, the voltage is inverted (wires swapped over). The two possible states are known generically as the polarity. If the ETS machines at either end of a single line section are the same polarity, we define that to mean 'Line Clear', whereas if they are different, we define that to mean 'Line Blocked'. In conventional ETS, lineside wires are used to carry the polarity of the remote ETS machine to the local ETS machine from which a token is being extracted, allowing the polarities to be compared. With MicroETS, a system of double encrypted IP messages is used to acquire the remote polarity enabling the comparison at the local end. The box of electronics to do this is called the Outstation; there is one Outstation for each ETS machine. The Outstations are contained in an enclosure locked away under the ETS bench so as not to detract from the heritage feel of the ETS machines.

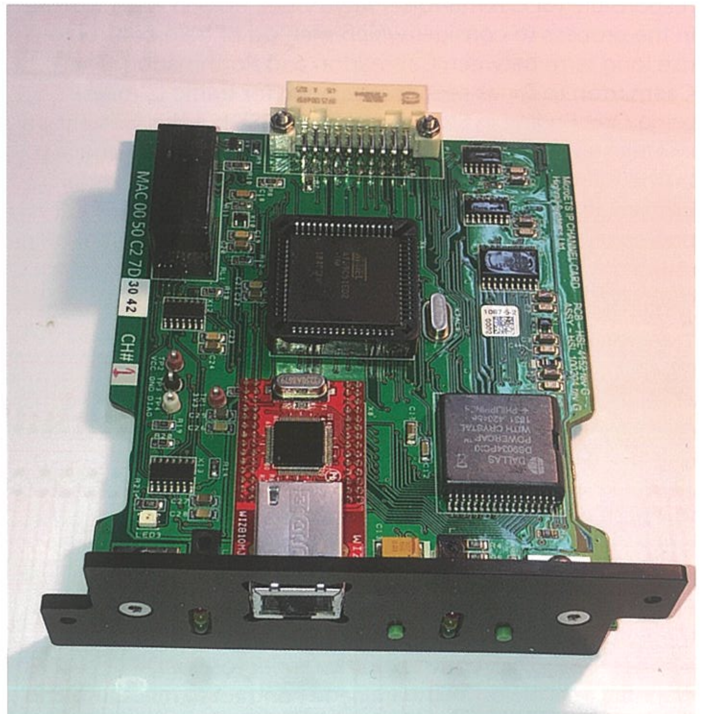
## Fundamentals of MicroETS

HighRail Systems has produced the firmware and designed and controlled the manufacture of the printed circuit boards within the Outstations, Remote Operator and Signalling Interface. To operate the system, after obtaining permission from Control, the operator (usually a member of the train crew) presses a button on the Remote Operator which initiates the 'MicroETS cycle' to acquire the remote polarity. Within a couple of seconds, the 'LINE CLEAR' or 'LINE BLOCKED' lamp should illuminate. If the former, a token can be extracted.

Each Outstation contains three channel cards (see Figure 2) for independent communication with the remote (peer) Outstation, using a dedicated protocol running on TCP/IP. The local channel cards, in the Outstation controlling the ETS machine from which an attempt to extract a token is being made, each send a message to the remote channel cards requesting them to inhibit the Remote Operator. The remote channel cards then reply with a message confirming they have inhibited their Remote Operator, which prevents a second instance of the message protocol from being started at the remote end as well. The local channel cards then send another message to their peers requesting them to return their remote polarity. When the local channel cards each independently receive the polarity of the remote ETS machine, they compare it with the local polarity, forming a three-out-of-three voting system; if all three channel cards decide the remote and local polarities are the same, the Line Clear lamp will illuminate and a BR960 relay is picked making a token available for a maximum of 20 seconds. The MicroETS cycle then terminates. Throughout the MicroETS cycle, the local polarity is sampled every 10ms. If a change occurs then the BR960 relay is dropped, relocking the ETS machine instantly.

Figure 1 – One of the original RSCo machines acquired from Irish Rail.


Figure 2 – Channel card, ready for fitting in an Outstation.







For the MicroETS message protocol to succeed, each Outstation needs to be able to communicate to its peer Outstation using IP on its own independent route. The MicroETS messages are double encrypted after being obfuscated (made unintelligible) with a unique 'magic' number; that number is needed at the destination Outstation to enable the decryption process to succeed. What this means in practical terms is that the chances of someone being able to guess the magic numbers in all three channels is roughly equivalent to the chance of winning the National Lottery, on three consecutive Saturdays. However, the magic number changes each time the system is used.

## Event recorder

The Outstation also contains an Event Recorder (See Figure 3). This records timestamped events generated by the channel cards and the signalling interface (which is described later). A cloud server is used to run the MicroETS Management Server (MMS) software to collect the recorded event data from all the Outstation Event Recorders and store that data to a database. The Event Recorders also return state information, such as the polarity of the Outstation, to the server. Authorised users have access to this data at various levels using the MicroETS Management Client (MMC) software, which runs on a Windows PC or can be accessed through a web app. This shows a mimic of the railway to indicate the status of each section. Users (with suitable access rights) can perform various functions, such as:

- Examine the event log for each outstation.
- Remotely cancel starting signals.
- Remotely inhibit token machines from issuing tokens.

Maintenance technicians and controllers can remotely 'virtually press' the Remote Operator of an Outstation and monitor the events in real time to see what the Outstation did; if a token extraction was not authorised, it will have logged the reason why. There is also a command to automatically test all Outstations on the system, which reports 'success' or 'fail' for each Outstation; if further information is needed, the mimic screen user can then examine the Event Log.

The MicroETS Outstations communicate with each other directly. Should an issue occur with the cloud server, the Outstations will continue working. The Event Recorder has a large local event log and can store around a year's worth of events before overwriting old events.

Some token stations on the WHR are also fitted with the Shunt Token System that allows running round within the shunt limits without possession of either section token. If the Shunt Token is out, both home signals show 'Stop', a Shunt Token lamp illuminates on the Remote Operator and MicroETS will not permit release of a section token for either section.

## MicroETS signalling interface

So far there are two variants of a token-interlocked signalling interface module, one of which controls the starting signal directly, the other uses trigger relays to indicate 'token in' or 'token out' to the client-provided relay interlocking system, which then controls the starting signals appropriately. The latter is installed on the WHR. The signalling interface also has a number of digital inputs which can be used to monitor signalling elements such as starting signals, home signals, train detectors and shunt tokens for example. Appropriate events are logged when the inputs change state. The state of the signalling system is represented on the mimic screen (see later) in the client software.

## Mimic screen

Example views from the Mimic screen are shown in Figure 4. As suggested by the MicroETS independent tester, if the signalling interface reports conflicting data such as the home signal being clear simultaneously with the starting signal being clear, the Mimic screen will highlight the conflicting signals and sound an alarm that has to be manually silenced.

Another useful function is the ability to remotely inhibit selected ETS machines from issuing tokens. The controller can select this function from a drop-down menu in the mimic screen; an icon then appears showing a token machine with a diagonal red stripe meaning 'issuing of tokens is inhibited

Figure 3 – MicroETS event recorder.

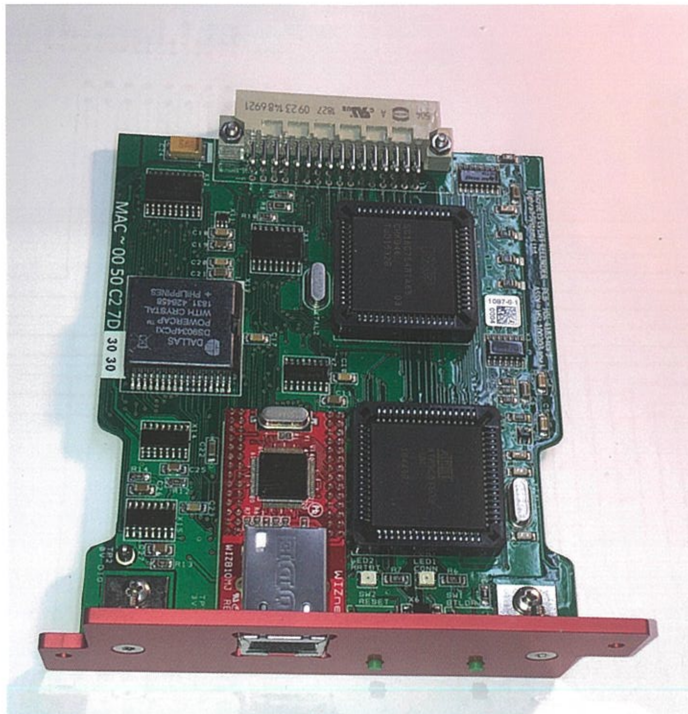
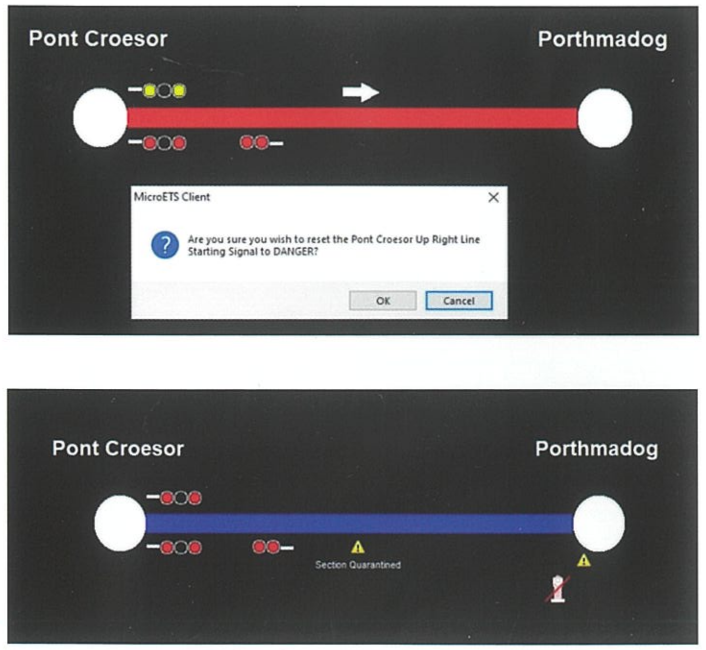


Figure 4 – Example screens of the mimic display. Top, train ready to depart Pont Croesor, Controller about to cancel starting signal due to a change of plan. Bottom, section in quarantine.



from this ETS machine'. If the remote operator button is subsequently pressed, a lamp flashes quickly for a few seconds meaning 'phone control'. The remote inhibit status will be remembered by the Outstation even if it were to be turned off and on again, though you need S&T keys to achieve this. Should an unplanned mains outage occur, the MicroETS DC-UPS will keep the system up for 24 hours. The remote inhibit can only be cancelled by the controller, or a technician with suitable access rights. The application and removal of remote inhibit mode are recorded as time-stamped events, together with the name of the operator.

When the remote operator has been pressed and it is displaying 'Line Clear', the local Outstation knows that no token movement should occur at the remote end, since that remote operator has been inhibited and there is no token out available for insertion. To keep an eye on this situation, a system of 'keep alive' messages are sent from the remote end to the local end to achieve the following: -

- Check the connection is still made.
- Check the remote polarity does not change.

If a change in remote polarity is reported then some sort of failure has occurred, possibly involving a failed ETS machine or 'rogue token'. In this case, the local Outstation will put the section into 'Quarantine Mode', whereby it inhibits its ETS machine, and the mimic screen alters the display of the section accordingly. The section can subsequently be taken out of quarantine by a user with suitable access rights. However, the situation will have been logged, together with the name of the user who took the section out of quarantine.

The client appointed ICPs advised that the token balance procedure should include the controller being asked to put the section into a special mode before the procedure is conducted. Once in token balance mode, which can only be initiated if the line is clear, the section's ETS machines are inhibited, as is the logging of token movement events ('IN' or 'OUT'), and the mimic screen shows the section in token balance mode.

## Approvals and installation

Over the system development phase, there has been a vast amount of work to do to get the system approved to accepted national (formally EU) standards. Such tests included EMC (Electro Magnetic Compatibility). EMC is best described by use of the following example: 'If you used your mobile telephone next to my Outstation, both the mobile phone and the Outstation must function normally without interfering in the other's operation. The EMC testing alone costs around £4000, with the risk that it may not pass. Fortunately, the Outstation passed on the first attempt.

We had to test the system's behaviour when the Remote Operators at either end of the section were pressed simultaneously. 'Simultaneously' in this case means "within a period of a few tens of milliseconds or so", not easily reproduceable by humans. Automatic testers, built from Raspberry Pi units, were used to 'press' the Remote Operator at either end of a section at two differing intervals, the two intervals being calculated to ensure that the 'presses' would occasionally coincide. The test was left to run for nearly three months and achieved a small number of simultaneous button presses; when this happened, each outstation acted as if the other was off-line and so a token extraction was not permitted.

## Refurbishment of the ETS machines.

Fourteen ETS machines acquired from Irish Railways were destined for use on the WHR. However, tight legislation exists for reusing second-hand safety-critical equipment, which puts the responsibility of ensuring the correct and safe operation of the equipment on the new owner, in this case Festiniog Railway Co. It is normal for the donor of the equipment not to provide any provenance records since it is up to the new user to start his own records to prove that the ETS machines are in good working order. The only way to obtain the data to start the provenance record is to completely strip down the equipment and check that each part is still serviceable and if not, repair or replace it. Figure 5 shows some machines in the process of refurbishment.

Figure 5 – Having dismantled the ETS cases, a contractor has grit-blasted them. Carol paints them as a batch.






It's a significant job on one machine, and a much bigger job on a batch of fourteen machines. A vital task was the cleaning and cataloguing of the parts of all fourteen machines – a role made more important because the machines were originally handmade and unique by today's standards, meaning that many parts were not interchangeable between machines. The switch boards were re-wired and polarity switch contacts were replaced with new 2mm diameter Sterling Silver wire soldered in then machined to length to give equal throw and correct contact open gap.

The cast iron cases of the ETS machines are formed from seven separate castings that had the mating faces machined flat. These machines were built decades before fixing bolts were made captive with Loctite thread retainer or lock washers. The fixing holes with the female threads had been deliberately tapped not quite deep enough so that the first couple of threads on the bolt were deformed when the bolts were forcibly tightened; these fixings had not been made to be removeable. The original bolts were removed and scrapped in the process. Shorter bolts couldn't be used, so the threads had to be tapped deeper, allowing replacement high-tensile bolts to be retained with Loctite thread retainer; very time consuming on a batch of fourteen machines!

Six of the ETS machines had broken glass in their galvanometers – the device on the front of the machine with a pointer that deflects when power is applied to unlock the machine, allowing a token to be extracted. The glass had been held in place by peening the brass bezel over the edge of the glass. The broken glass had to be replaced after opening up the bezel, inserting the replacement glass then re-peening. Any process involving glass and hammers is likely to end in tears if unskilled hands are involved. Success was obtained by using suitably skilled subcontractors (clockmakers).

All of the electromagnet coils needed the very fine corroded copper wire stripped off then rewound with 6500 turns of new copper wire. Permanent magnets had to be degaussed to remove the magnetism, then remagnetised to a known level and polarity. This work was contracted to R Baker of Liverpool.

When the machines were originally manufactured by The Railway Signal Company in Liverpool, some in 1928, others some unknown time before, six combinations of token shapes were available, lettered 'A' to 'F'. The fourteen ex-Irish Railways machines consisted of five 'A-pattern' machines, eight 'B-pattern' machines and one 'E' machine. The 'E' machine on its own wouldn't be much use without a partner and just having two other types didn't give enough token type separation between sections.

Roland came up with a method to convert some machines from one type to another to create a third, an essential requirement to ensure safety by physical separation between sections. The plan was to dismantle the five-disk assembly, turn one disk around on its vertical axis, then reassemble the disks with new 5/16" shafts, riveted over at each end. Unfortunately, due to the hand-made nature of these machines, the two assembly fixing holes in each disk weren't quite 180° apart. This meant that one new fixing shaft would go through the assembly, but the second shaft got part way through, stopping with a resounding 'clunk' when it found the edge of the now eccentric hole in the rotated disk.

The disks are made of iron cast a century ago or so; forcing the second shaft through would probably have damaged the castings. To resolve this, two new holes were drilled separately in each disk, with the pitch circle diameter rotated 90° from the original holes. Thus, there are now four holes in the disks with the new pair being at right angles to the old pair (see Figure 6). To ensure accuracy, a jig was made to hold one disk at a time, mounted on a vertical milling machine, with the new hole locations placed by using the machine's digital readout. Now WHR have the section separation required using machines of three types.

Having created several machines of the new type, there was a lack of thumb rests which show the new type letter. There was also a shortage of the maker's plates for two machines. A contractor created replica brass labels and thumb rests, using modern 3D CAD methods and lost wax casting. Roland's only input to that design process was to point out that on the

Figure 6 – The disk assembly has been modified and re-assembled. The new token type fits in with the correct tolerances

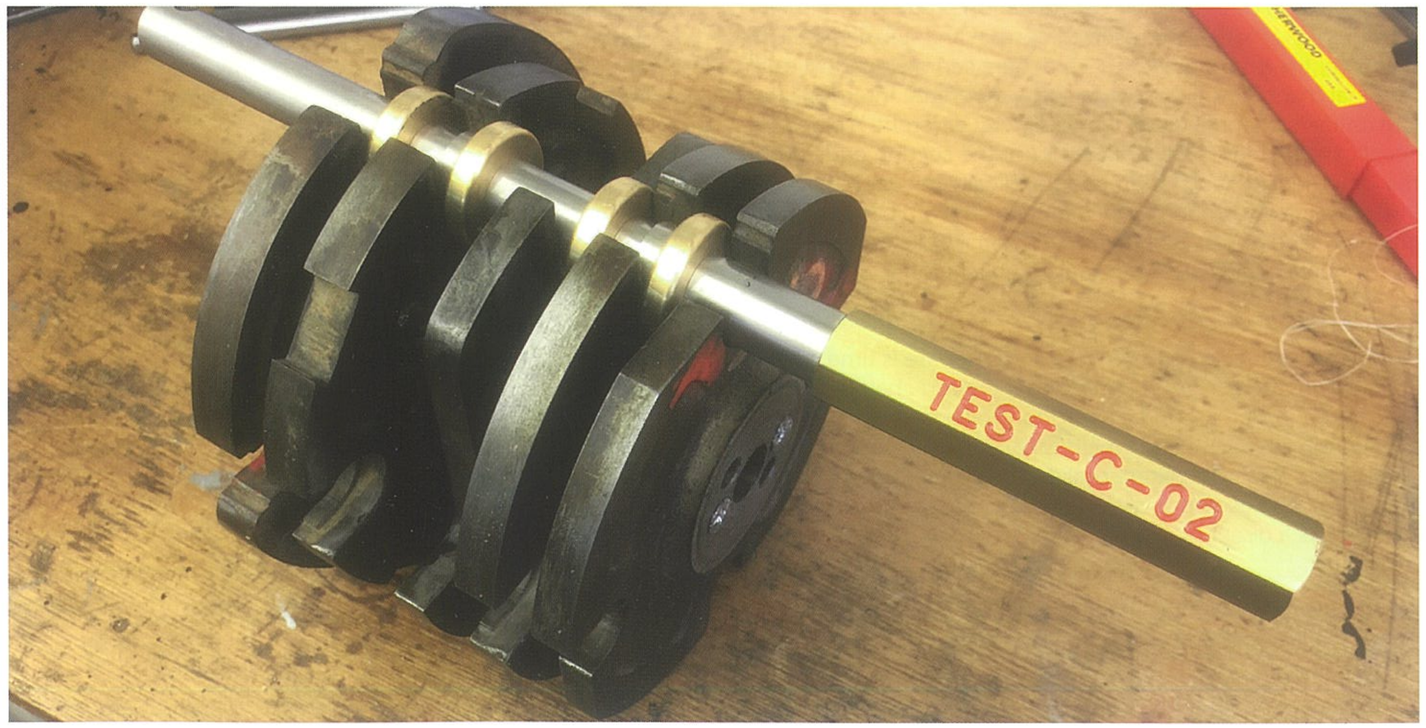



Figure 7 – Replacement name plates being finished off. The function of the mince pies is unclear!

maker's plates, the tiny full stop after the word 'LIVERPOOL' should be square and not round. The contractor sorted this out with a few clicks of the mouse. Figure 7 shows the end result.

## System installation progress

The MicroETS system is currently in use between Porthmadog and Rhyd Ddu, being the southern half of the WHR. The MicroETS Equipment for Rhyd Ddu to Caernarfon (the northern half) has been under production since September 2021 and is due to pass the factory acceptance test in July or August this year. Installation will occur sometime after, when a timeslot becomes available. The MicroETS system is being made available to other railways on a commercial basis, including training on use and maintenance support.

## Current developments

A new version of the MicroETS Outstation is currently under development that can be used to control an Intermediate ETS machine; the intermediate ETS machine can be identical to the terminal machines, it's only the software on the Intermediate Outstation's channel cards that is slightly different. A standard Terminal Outstation will be at either of the section ends, with the Intermediate Outstation geographically between them. The Intermediate Outstation will communicate with both the upline and downline peers, whereas the Terminal Outstations will only communicate with the Intermediate Outstation.

## Obsolescence planning

Since the production of hardware and software is time consuming, the design of the next generation channel card has started, based around a microcontroller that went into production late 2021, and which is part of a very large family of devices.. This is to ensure that if the current microcontroller becomes obsolescent, a replacement channel card will be available as a direct plug-in replacement.

## About the authors

Roland Doyle started his career in 1974 as an under-graduate apprentice electronics design engineer with Hawker Siddeley Dynamics in Hatfield working on military and commercial systems. Roland later went to work for the BBC as a broadcast engineer designing and operating studio-based broadcast systems. Having been a volunteer fireman then driver for the Ffestiniog Railway since 1971, he welcomed his next challenge, managing the construction of the first half of the Welsh Highland Railway in 1997.

Ben Abbott graduated from the University of York with a BSc (Hons) degree in Computer Science in 1998. He spent the next few years working first for an energy supplier in Oxford before moving on to a software development house in Cambridge. In 2009 he set up his own software consultancy business, Ben met Roland on his second day of volunteering on the Welsh Highland Railway and by the end of that day, he had been recruited to develop the server back-end software for the MicroETS project.

## IRSE News says ...

Roland, Ben and WHR are to be congratulated for engineering a creative, innovative, cost-effective solution using 'state of the art' comms to support a traditional way of working using MicroETS. It is also great to learn the design was safety assessed by IRSE Fellows the late Richard Stokes, Roger Short, and Philip Wiltshire.

The innovation is representative of other signalling projects being implemented by minor railways, so do any other heritage/minor railway have a similar story to share? IRSE News would love to hear from you and we recommend you pay a visit to the WHR and FR in North Wales.