LONDON UNDERGROUND SIGNALLING
A HISTORY
by Piers Connor
14. TRACK CIRCUIT DEVELOPMENTS

CENTRAL LONDON RESIGNALLING

The Central London Railway (CLR) always had aspirations to go the extra half-mile and extend their original route from Bank eastwards as far as Liverpool Street. This would give them a connection to a popular destination for passengers wishing to travel further east either on the Metropolitan Railway or the Great Eastern Railway from their respective Liverpool Street stations. Although the CLR had long had powers to build the extension, it was not finally opened until 28 July 1912. The Liverpool Street terminus was equipped with two platforms beyond which two long sidings were provided. There was a scissors crossover at each end of the station to allow either platform to be used in either direction.

The Liverpool Street extension also gave the CLR an opportunity to upgrade its signalling. The line was operating at the capacity of its Spagnoletti designed lock and block system that I described in Article 6 of this series. This limited the line frequency to 30 trains per hour (tph) – a train every 2 minutes – but it wasn't reliable and the CLR wanted to get this regularly and beyond and up to the 34-40 tph levels being achieved on the District and some of the London Electric Railway (LER) tube lines. They also realised that they could save a lot of money if they could eliminate the signal boxes at some of the stations. Automating their signalling was the obvious solution and the technology had moved on sufficiently to make the use of track circuits on the 3rd rail traction system used by the CLR a viable proposition.

Work on the upgrade began in 1912, starting with the new section from Liverpool Street to Bank and then working gradually westwards. Full automatic signalling was installed with alternating current (AC) track circuits and colour light signals, apart from two semaphores in open locations at Wood Lane. The equipment was supplied by Westinghouse. The old semaphore signals were replaced by Westinghouse 'Style A' AC colour lights and the mechanical trainstops were replaced with a new version of the "Long Tom" pneumatic trainstops used on the District and new tube lines (Figure 1). This type had the whole mechanism in line, with the air cylinder at one end and the trip arm at the other, rather than with the stop arm connected to the mechanism by a journal rod. The operating valve was separate, usually mounted on the tunnel wall. The resignalling work was substantially complete by the end of 1913.

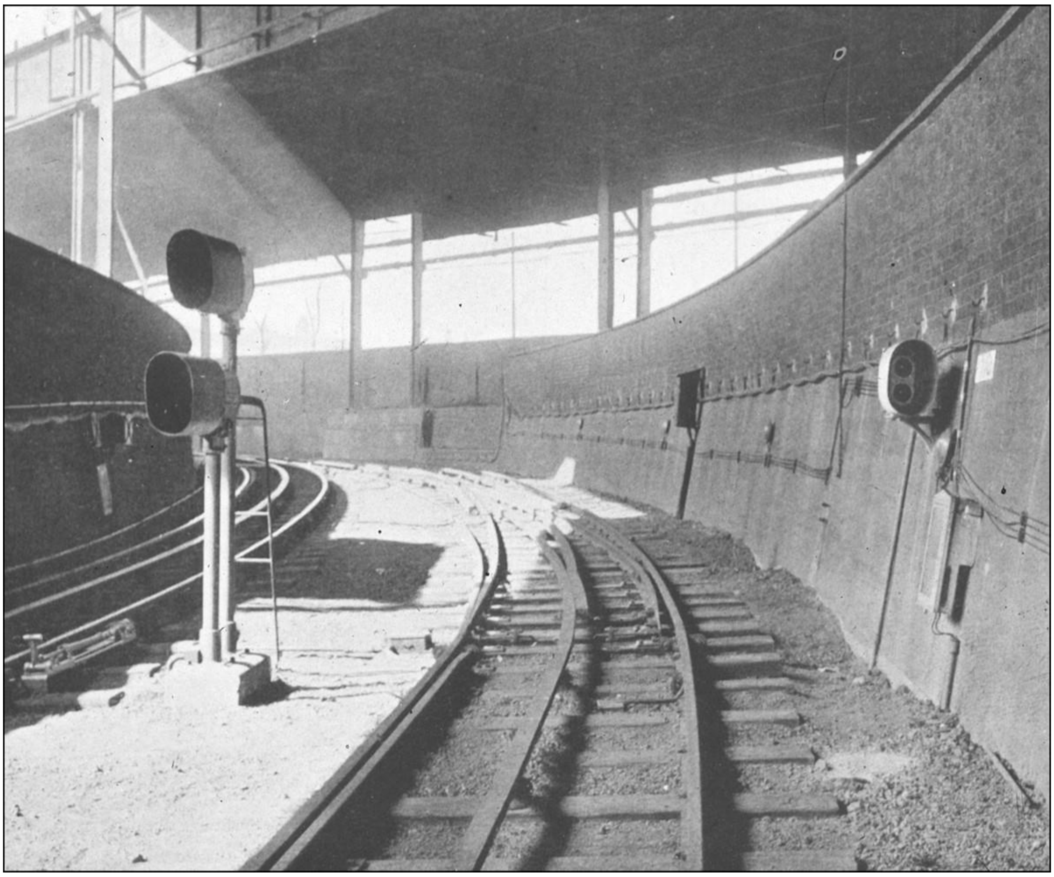

Figure 1: A view of the approach to Wood Lane station on the CLR ca. 1913. The camera is positioned over the depot eastern track, with the main loop track on the left. Service trains would come out of the tunnel from Shepherd's Bush and then go round the loop towards the station out of sight on the left. The two colour light signals on the left are a stop signal (upper) and a repeater for the next signal (lower). A CLR, in line, 'Long Tom' type trainstop can be seen next to the track. The signals are provided with hoods to protect the lenses from sunlight. The shunt signal for the right hand track has no trainstop. Photo: Westinghouse Archive & Chippenham Museum.

TRACK CIRCUIT BASICS

The Central London Railway signalling upgrade was made possible by the introduction of new electrical technology in the form of the recently developed AC track circuit with a new type of track relay to match. To see how these developments came about, we need to go back to the subject of track circuits. I touched on the basics back in Article 7 where I described the simple DC track circuit as used on the Great Northern & City Railway (GN&C). Then, in Article 9, I mentioned the DC track circuits used on the District and new tube lines and some of the problems in their development. The AC track circuit is the next step in the story and it provided another set of challenges. It's a complex subject, especially for those of us without much formal training in electrical theory but, with the help of several signal engineers, past and present, I have prepared a summary of the various factors and issues that drove track circuit design and development over the first 20 years of the 20th Century. Some of it is revision and some of it is a little technical but hopefully it won't be too painful. Let's start with the basics.

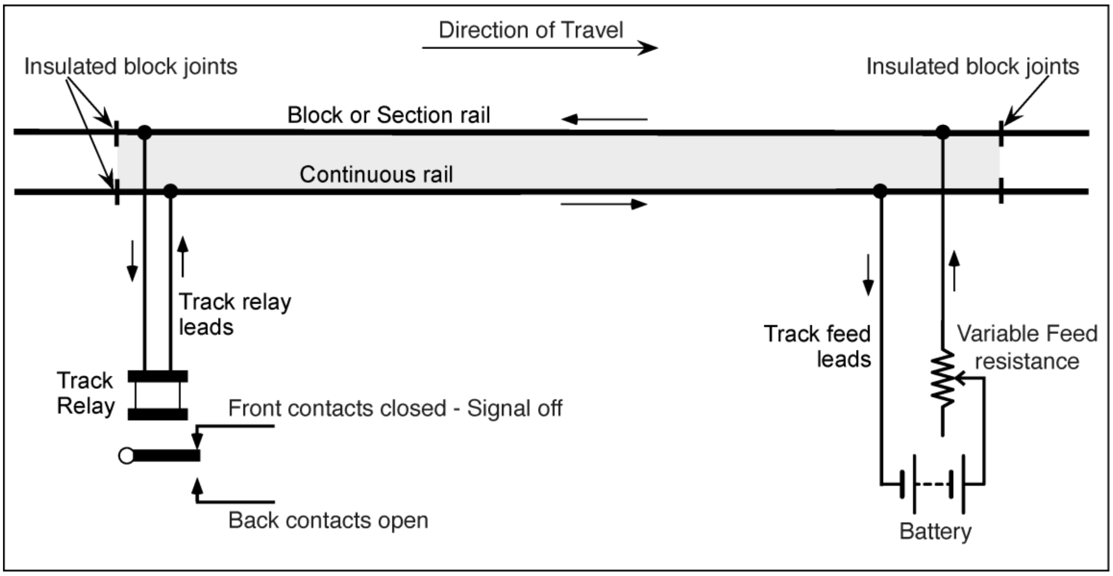

Figure 2: A schematic of a simple track circuit with a DC battery fed supply and both running rails insulated. It was known as a two-rail circuit. The arrows show the current flow. When the train entered the section, the circuit was shunted by the wheels, and caused the track relay to drop. This was the early type used on steam worked railways. It could not be used on electric railways. Drawing by P. Connor.

As we've seen in earlier articles, the track circuit was invented before electric traction arrived on the railways (Figure 2). It was relatively simple to get it to work but you did need to divide the running rails into insulated sections, you needed a stable electrical supply – then invariably a battery – and you needed good insulation between the rails, what is known as high ballast resistance. Ballast contamination from steam locomotive muck (ash, hot coal, oil, grease and water) was a big issue, as was bad drainage and wet weather. Any of these could allow the current to leak across the ballast from rail to rail and thus fail to energise the track relay so that the signal failed to show a proceed indication. It was therefore essential to keep circuit voltage low to prevent it getting across the ballast. An adjustable resistance was put into the circuit so that the voltage could be varied to compensate and to prevent the feed being short-circuited by a train's wheels.

Of course, the voltage had to be kept low enough to ensure that, when the track was occupied by a train, the wheels and axles of the train would shunt the circuit to de-energise the track relay and restore the signal to danger. It was normally in the range of 4-10 volts. To ensure the correct operation of the circuit, the feed was usually placed at the exit end of the section with the relay at the entrance. This ensured that the circuit was always active on the unoccupied part of the section in front of the train.

Another big issue was battery maintenance. In pre-electrification days, there were no mains supplies. Electricity was not available to anyone unless they were fortunate enough to live in an area of a city where there was a power supply company, or they were generating their own power, so batteries were the main source of power. As they were usually provided outdoors, they had to be protected from the weather, particularly rain and frost and they were often placed in trackside boxes or 'battery wells' dug into the ground. And they needed to be recharged. This was usually done offline and many railways had a weekly battery changeover regime. There were two batteries for each block section – one for the track circuit and one for the signal itself. Looking after them was more than a cottage industry, it was a full time industrial process. No wonder many railways were reluctant to adopt track circuits.

ELECTRIC RAILWAYS

With the arrival of electric railways, the track circuit game changed. It had to step up a level. New considerations affected their design and operation and new concepts and problems developed. As we know, the Metropolitan, District and the LER tube lines had a 'fully insulated' traction current system – the 4-rail system - with separate positive and negative rails which shared the voltage between them. Most other electric railways (like the Boston Elevated Railway, on which the Underground's signalling design was based) had a 3-rail system. So did the Central London Railway[1]. The positive rail carried the full voltage while the circuit return used one (or both) of the running rails to connect the system back to the substation to complete the circuit. This was often called the 'earth return' system. It was, at the time, simpler and cheaper than a 4-rail system but it did need a careful approach if you wanted to use a signalling system with track circuits. The Boston Elevated learned this very quickly.

In Article 9, I described how the original solution for the installation of track circuits on 3-rail electric railways was to separate the use of the two running rails. One rail was used for the traction return (the continuous rail) and one for the signalling (the block rail) as shown in Figure 3 below. On London Underground, who followed the same principle, the block rail became known as the section rail. The arrangement was called the single rail track circuit, as opposed to the double rail system used on steam railways.

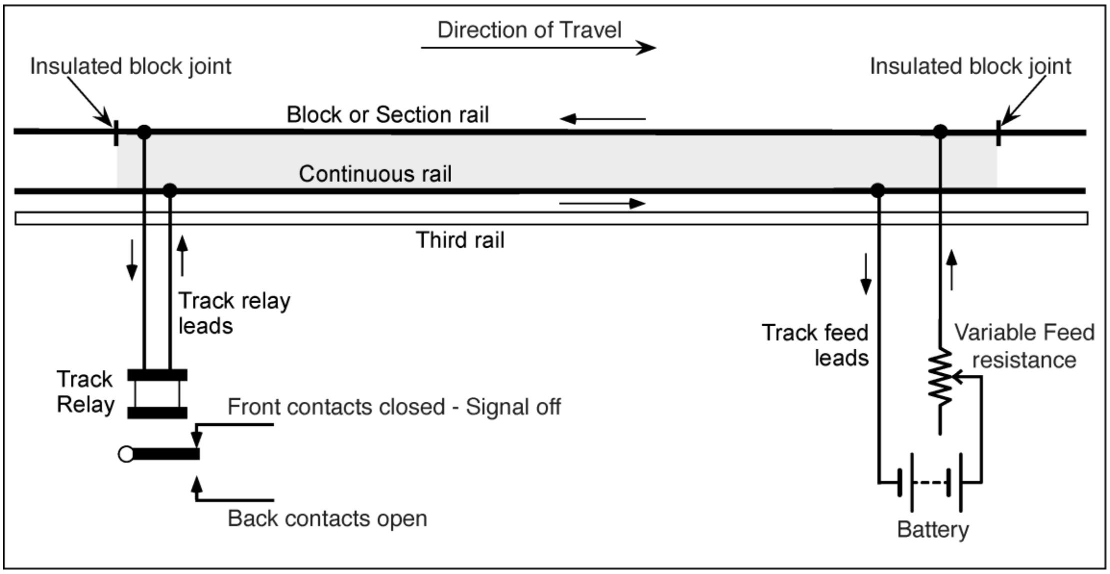

Figure 3: The same schematic as Figure 2, but showing the 3rd rail, the continuous rail next to it and the block rail on the other side. Here, only the block rail has insulated joints. The continuous rail carried both the traction return and the track circuit return. This worked as long as the single continuous rail was sufficient to carry the traction return current. Drawing by P. Connor.

[1] We can ignore the C&SLR for the time being as it didn't use track circuits until some years later.

In Article 9, I noted the problems with stray currents from the traction power supply that had occurred with the original design on the Boston Elevated. They also discovered that interference from local electric tramways and electricity supplies to factories could affect the signalling when these facilities suffered electrical faults, usually from poor insulation or earth leakage. I told how these had been mitigated by using two relays instead of one so that the signal would only clear if both relays operated correctly. This arrangement was imported to London for the Underground group's lines.

The Underground group used the single rail circuit, even though, at first sight, they didn't need it because they had the 'fully insulated' 4-rail traction system. However, the 4-rail system brought its own problems. One of these was that a long train in the middle of a DC track circuit and half-way between two substations could cause a momentary track circuit pick up, where a clear signal could be shown. It was rare but it could happen and it was eventually solved and eliminated with the AC track circuit but it was around for quite a while. It took until the 1950s to eliminate DC track circuits from the Underground[2].

A BETTER SOLUTION

Back on the 3rd rail lines, like the Central London, another problem was looming. It was discovered that if you ran a lot of trains closely together drawing a lot of current, expecting one running rail to carry all the return current didn't work too well. The current tried to find other ways to return to source and it often ended up using water pipes and telephone lines and, in the process, causing problems with corrosion and interference.

Running rails were smaller in profile and conductivity than current rails so, to match the current in the positive rail, you needed both running rails to carry the traction return. On the Central London Railway, they took a step further to improve the traction return by bonding the running rails to the cast iron tunnel rings.

This created another issue. If you used both running rails for the traction return, you had to wire them together but, if you did that, you couldn't use track circuits for your automatic signalling. They only got away with single rail traction return in Boston (and some other American cities) because the lines were elevated and were built on steel structures for the major part of their routes. The structures acted as part of the return circuit and took some of the electrical load[3]. For underground and surface railways, a better solution was needed. Fortunately, it soon arrived, in two parts, with the AC track circuit and the impedance bond.

AC TRACK CIRCUITS

The AC track circuit worked in basically the same way as the DC circuit but, because it used a different type of current, it would, it was thought, work safely on any railway with a DC traction system. To do this, it used a new type of relay known as a vane relay. It was called a vane relay because the moving part looked like a vane (Figure 4). The vane moved on a spindle that carried the circuit contacts to switch the circuits it controlled as required. The aluminium vane itself moved under the influence of the magnetic fields created inside the relay when the track circuit current flowed[4]. It was described in 1915 by Harold McCready as, "a true selective relay – one designed to respond to an alternating signalling current but to be absolutely free from the possibility of closing its contacts no matter how much direct current passed through its coils."[5] This rather dramatic description was how it was described as DC immune.

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[2] Bancroft, P., Ed, (1999) '*London Transport Railway Signalling*' Nebulous Books, p.16.

[3] I was a witness to this phenomenon when I worked in New York City. It was not unusual to see arcing dancing along the steel elevated structures as trains started up during wet weather.

[4] McCready, H, (1915), '*Alternating Current Signalling*,' Union Switch & Signal Co. Swissvale, PA, USA. McCready's book contains detailed descriptions of the various types of AC track circuits and associated equipment and it has proved a useful background source for this article. McCready was the manager of the New York office of the US&S and he wrote in a comfortable and readable style. He recognised the limitations of track circuits describing rails as, "a poor line over which to transmit power. The less power transmitted over it the better".

[5] McCready, H, (1915), ibid , p.13.

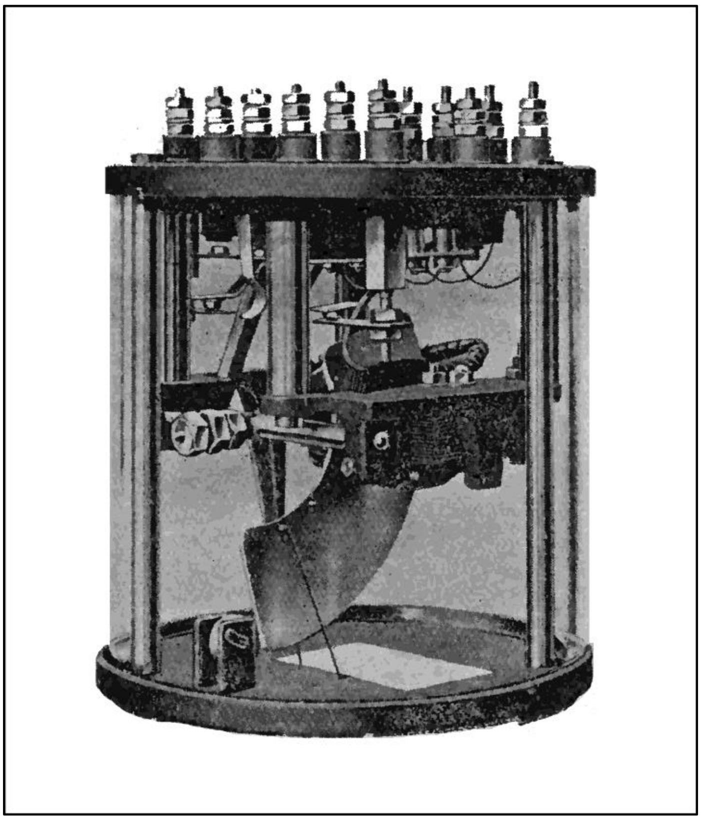

Figure 4: An early single element vane (SEV) relay supplied by Westinghouse of the type used on the Underground. The case is glass and the vane is in the de-energised position at the base of the relay resting against its rubber stop. The current coils can be seen either side of the vane and the circuit contacts are above the top of the vane. The external connections are on the top of the case. Source: Raynar Wilson, F, (1922), 'Railway Signalling – Automatic', Pitman.

The vane relay was developed by our friend Jacob B. Struble, the Union Switch & Signal (US&S) engineer who designed the original DC polarised relay used first for the Boston Elevated, as I described in Article 9. Struble's success was in devising a relay that would respond to AC circuit changes whilst remaining immune to the effects of the DC traction system. It was first tried on a section of a newly electrified railway in California known as the North Shore Railroad. They wanted to install automatic signals in order to avoid the expense of providing signalmen to staff lock and block operation over long sections of the line without points or junctions. They considered DC track circuits but, as the sections were long and not really suitable for lengthy DC transmissions, they went for the new AC circuits, doubtless encouraged by the salesman from US&S.

Then, in a huge leap of faith, in 1904, just a year after the San Francisco installation, the Subway builders in New York City specified AC track circuits for their new railway. They used single rail track circuits, despite the expected very high traffic levels on the line but they used the line's steel columns and roof supports as part of the traction return system, just like the elevated lines that used the steel structures upon which they ran. They installed over 500 track circuits plus signals and points, supplied by US&S[6]. It is interesting to remember that they were doing this at the same time that the Underground group were beginning to install DC track circuits on the District Railway. It took almost ten years for the message about AC to cross the Atlantic Ocean and see practical application in Europe.

SINGLE ELEMENT RELAYS

The new AC relay eventually became known as a single element vane (SEV) relay so as to distinguish it from the later, improved version known as the dual-element relay (DEV), of which more later. Both types used the movement of the vane to operate contacts in the signalling circuits. The single element relay was originally used on electric railways using single rail traction return but, when it appeared in London on the Central London Railway extension to Liverpool Street and for the subsequent resignalling of the line in 1912-13, there was a complication. The Central London, with its 3-rail traction current system, was running a high frequency train service and it had to use both running rails for the return current. Other electric railways in the US had had the same problem. There was no way for a track circuit to work under these conditions. However, an answer was quickly found; it turned out to be the impedance bond.

IMPEDANCE BONDS

The purpose of the impedance bond was to overcome the difficulty of single rail traction return by allowing both running rails to be used both for traction return and track circuits. The impedance bond allowed the running rails to be divided into sections for signalling but it connected the traction return from one section to the next without letting the AC track circuit through (Figure 5). The device consisted of two substantial copper windings on a hefty, laminated iron core, arranged on the track as shown in Figure 6 below. It was placed in the four-foot between the track circuit block joints with each winding connected to the rails on one side of the block joints. The two windings were connected to each other at their mid points to allow the traction return current to flow between them and bypass the block joints.

6 Howard, L.F. (1907) '*Track-Circuit Signalling on Electrified Roads*' Paper to American Institute of Electrical Engineers.

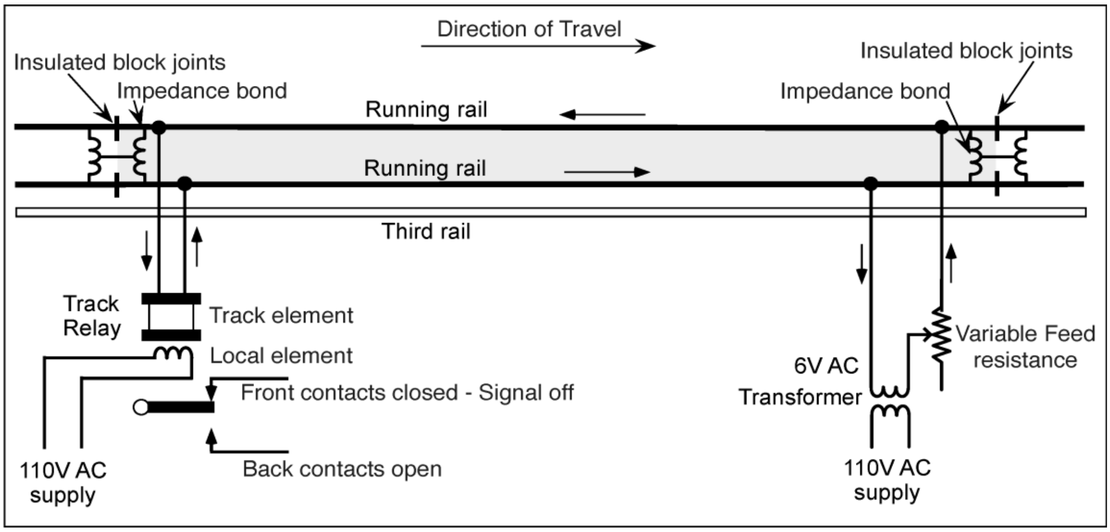

Figure 5: A schematic of a 3-rail electric railway with an early version of AC track circuit and impedance bonds. The track relay used was a 2-element galvanometer relay. Each relay has a 'track element' and a 'local element'. The flows of currents in these two circuits caused the relay to operate. This arrangement was used for the Central London resignalling of 1912-13 except that I have shown the current rail outside the running rails to help show the current flows more clearly. The CLR positive current rail was actually between the running rails. The track circuit limits between the block joints are shown by the grey area. The arrows show the track circuit flow. The traction return can pass through the impedance bond coils on each side of the insulated block joints but the track circuits cannot. This arrangement required what was known as the double rail track circuit, i.e. both rails had block joints in them. The Metropolitan Railway also used the galvanometer relay but they didn't need the impedance bonds because it was a 4-rail system so they used a single rail track circuit. Diagram by P. Connor.

The bond worked by allowing the heavy traction return current to be passed round the insulated block joints from one signal section to the next but it prevented the much lighter AC track circuit current from passing through. It was patented in July 1906 by two engineers in the US, Messrs Howard and Rice of Union Switch & Signal. An improved version appeared in a patent of December of that year by Messrs Thullen, Young and Townsend.

Impedance bonds were quickly adopted by 3rd rail electric railways around the world, wherever they wanted to use track circuits, which was most of them. The Central London was the first Underground line to use them (Figure 6). Sometimes, even today, people ask why the Underground doesn't get rid of the negative rail and just use the 3rd rail system and there have been a number of studies over the years to investigate the possibility despite the fact that it was discounted at least as early as 1927. A big factor against the idea was the cost of installing impedance bonds at every block joint and that's apart from the cost of modifying of trains and providing two-rail signalling.

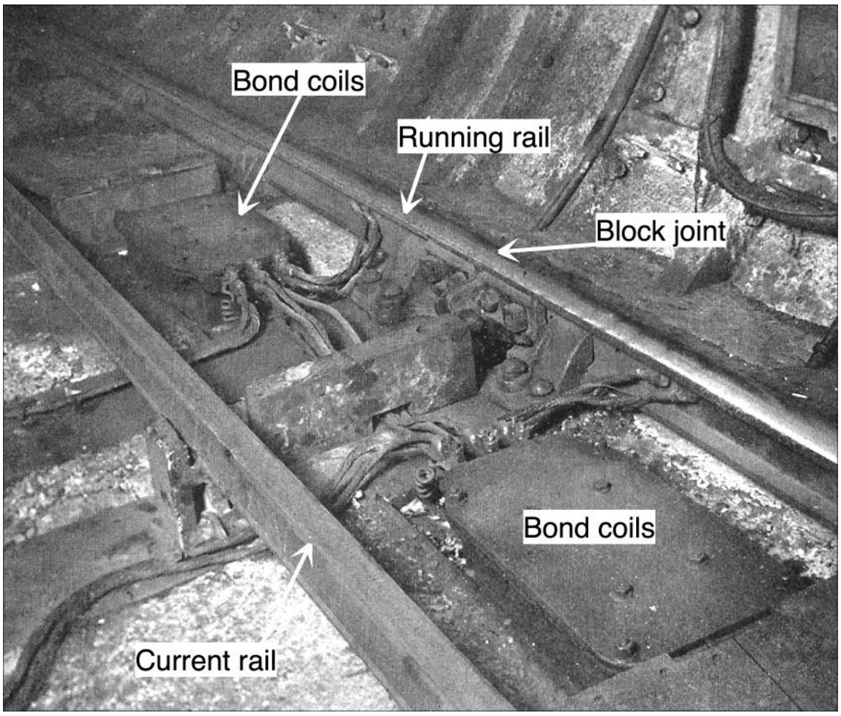

Figure 6: An impedance bond as provided for the CLR resignalling of 1912-13. The two parts of the bond and the cable connections to the rails can be seen. The area was covered by a wooden board for protection. The basic setup can be seen today on main line electrified railways, both AC and DC systems but they are better protected. Photo from Westinghouse booklet 1914, courtesy MRFS.

METROPOLITAN AC

In January 1913, when the Metropolitan Railway finally completed the 3-year long rebuilding of their station at Baker Street and the installation of the double junction connecting the branch to the main line, the new signalling that was installed with it used AC track circuits. This was despite the fact that they continued to use DC to drive signal motors and point machines in the same area.

This was the first instance of the use of AC track circuits on the Metropolitan. They used the Westinghouse single element vane relay, like the one used on the CLR. The circuits were supplied from a 240V AC main at 33⅓ Hz frequency, reduced to 6v by transformer and then brought down to the track rail by a resistor to operate at 1.5 to 2 Volts[7]. Later installations used a 440 volt main, stepped down to 110 volts at each track circuit location and then reduced again to 6 volts for the track feed.

DOUBLING UP

Electric traction on the Metropolitan Railway soon showed its benefits. By the start of the First World War in 1914, the number of trains passing along the 'main line' between Edgware Road and the City of London had doubled compared with pre-electrification levels and demand continued to rise. In an effort to get a more attractive service between the City and the outer suburbs, the Metropolitan decided to add two additional 'Through Tracks' between Finchley Road and Wembley Park. The plan was to run most trains fast over this section, so additional platforms weren't built at Finchley Road, West Hampstead, Kilburn or Dollis Hill stations. They were only added at Willesden Green and Neasden. The flat junction where the two tracks from Baker Street split into four was south of Finchley Road station but the two new tracks by-passed the existing station and continued on the north eastern side of the existing tracks.

The additional tracks were opened in sections between November 1913 and May 1915. The signalling equipment for the new tracks continued the Metropolitan's all-electric policy, supplied by Westinghouse as usual, who seem to have imported much of the electrical equipment directly from US&S (Figure 7). For the new installation, the Metropolitan used a 440 volt 33⅓ Hertz AC signal main instead of the 68-70 volt supply they used for the adjacent DC track circuited sections.

The new track circuits were AC but they used an improved relay. In place of the SEV relays used at Baker Street, they adopted a new type of dual-element relay known as a galvanometer relay (Figure 7). Although the SEV relays were an improvement on the DC relays used earlier (they didn't react to DC currents and they were suitable for short track circuits), they had a high current consumption and this tended to make it more difficult to get the necessary train shunt resistance under poor conditions like wet weather. This weakness led to the development of the dual-element relay. The galvanometer type didn't use a vane, it used an armature suspended inside an electro-magnetic coil and it achieved the requirement for a low current design. It had two windings (hence the dual element description), one supplied permanently from the power source – the 'local element', the other from the track circuit – the 'track element'. This arrangement had the effect of reducing the current required in the track circuit.

Figure 7: New AC track relays installed in their cases next to the newly opened four track section of the Metropolitan 'Branch' north of Baker Street. Close inspection of the original photo shows that the relays are of the galvanometer type and they have been directly imported from US&S. The glass fronts are marked with the word UNION. Photo: Courtesy Westinghouse Archive & Chippenham Museum.

For the upgraded section, the Metropolitan retained the existing full sized lever frames, suitably modified to accommodate the new layouts, in the signal boxes at Finchley Road, Willesden Green and Neasden. Points were still all mechanically operated. Signals were new, upper quadrant and electrically operated, using DC to drive the motors for the semaphore arms and trainstops.

Wembley Park got a new signal box with a 56-lever mechanical frame installed by the Metropolitan. The area was re-signalled and track-circuited entirely with AC relays. Sixteen point levers worked 25 sets of points mechanically. There were no fouling bars, locking being secured by the occupation of the track-circuit. This was following on from the initial scheme at Baker Street (as described in Article 13 in this series). The semaphore signals at Wembley Park were fitted with a new design of drive using AC induction motors. The signals were held in the off position by clutch coils and were restored to danger

7 Willox, W (1922) '*All Electric Automatic Power Signalling on the Metropolitan Railway*' Minutes of the Proceedings of the Institution of Civil Engineers (Vol. 214, No.1922, pp.55-76).

by gravity. Trainstops north of Neasden also had induction motors and alternating-current clutch-coils like the signals.

While the work on the new tracks was progressing, automatic signalling was being installed 'up country' on the two-track section between the north end of the controlled area at Wembley Park and Harrow South Junction. Again they used AC driven, upper quadrant electric semaphore signals and AC track circuits with galvanometer relays. The intermediate signal boxes at Tower Sidings, Preston Road and Kenton Road were closed in February 1914. The work was completed in August 1914, even before the 4-tracking south of Wembley was finished.

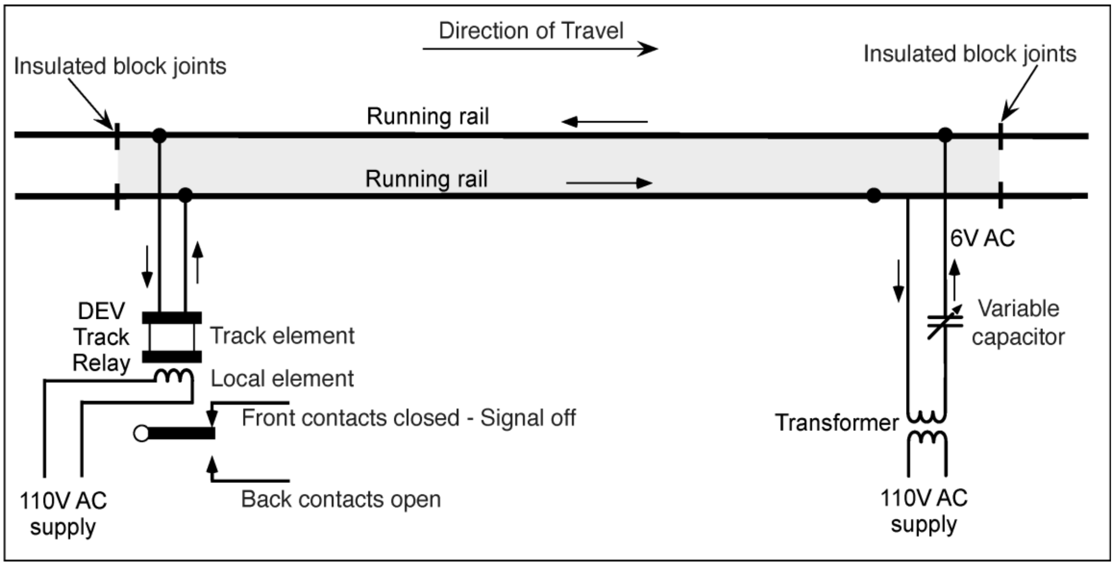

Figure 8: A schematic of an AC track circuit using the DEV relay introduced from 1920. The variable capacitor, formerly known as a condenser, was used in place of the resistor as a barrier to prevent DC traction earth faults from affecting the operation of the Track relay. It also ensured that the track feed was out of phase with the local element, necessary to make the vane work. Drawing: P. Connor.

AC track circuits with galvanometer relays were also used for resignalling the route between Praed Street and South Kensington, which was commissioned on 22 June 1919. This project saw the removal of the Sykes designed automatic system that the Board of Trade inspectors had not allowed to be used on sections where freight trains operated. It was only 10 years old but it was obviously more difficult to maintain and it didn't provide the opportunity to easily reduce block lengths that the new system did. The upgrade brought the whole of the Circle Line under 'fail-safe' automatic signalling, with Westinghouse electro-pneumatic equipment on the District Railway section and Westinghouse electric equipment on the Metropolitan side.

DEV RELAYS

In 1920, the Metropolitan introduced a new type of track relay, the dual element vane (DEV) relay. This was a development of the galvanometer relay. Like the galvanometer type, it used a local element and a track element but it reverted to the use of a vane to generate the mechanical operation of the switch contacts. They were supplied by Westinghouse. Westinghouse did an excellent sales job and they quickly started to supply them to the Underground group lines as well. It was reported that they had over 200 of them by mid-1924[8]. However, there were problems. Regulating the current feed to the track circuits using these relays was problematic. Various options were tried. They started with simple resistance control, then choke control and various other ideas were all used for a time, but persistent trouble was experienced because of intermittent failures of the track circuits due to stray current from traction faults on trains. Eventually, in 1922 the condenser feed idea proved to be the solution and it was adopted across the Underground (Figure 8)[9].

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8 Every, W (1924), '*Signalling on the London Underground Railways*' Proceedings of the IRSE, 1924 Part 2.

9 Dell, R., 1944. Developments in railway signalling on London Transport. '*Journal of the Institution of Electrical Engineers-Part II: Power Engineering*,' *91*(23), pp.400-415.

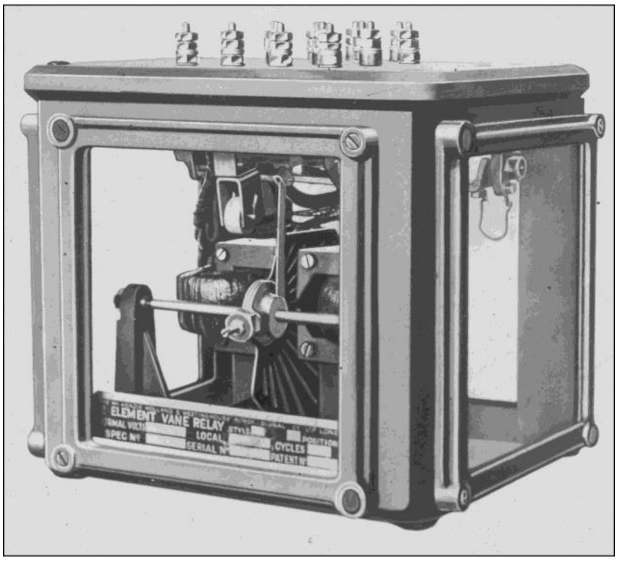

Figure 9: A view of the Westinghouse dual element relay showing the rear of the vane and the spindle around which it rotates. The contacts are at the top with the connection studs on the lid of the relay box. In 1927, an improved version was developed to allow the case top to be removed with all the connections This relay and gradually improving versions of it were to become standard across the Underground network and there are still many examples of them left in service. The relay containers soon became known as 'fishtanks'. Photo: Westinghouse Archive & Chippenham Museum.

We call condensers capacitors nowadays. Apart from being able to prevent stray DC traction current getting into the supply and causing a failure, it was also used to create the phase difference between the track element and the local supply element that was needed to drive the vane to close the circuit for the clear signal. Having the condenser adjustable was useful to allow the track circuit current to be 'boosted' if the ballast resistance fell to a low level and caused a signal to revert to red.

A modified version of this type of relay is still in use today. Experience with the original design showed up several mechanical issues that affected maintenance and reliability. In one example, it was discovered that the shape of the vane affected how hard it hit the bump stop when operated. Changing the shape reduced the strength of the last part of its movement in the magnetic field to give a soft stop and thus reduce the wear on the spindle and contacts. Attention to such details, seemingly unimportant to the outsider, was shown to reduce failures and, in turn, improve the reliability of the train service. The same sort of attention is still vitally important today and will have the same positive effects on the service if maintained.

The DEV relay shown in Figure 9 is labelled 'McKenzie, Holland & Westinghouse Power Signal Co.'. The company was re-organised in November 1920 and became the 'Westinghouse Brake & Saxby Signal Company'[10], which suggests that the DEV relay design was perhaps one of the last products to come out of the old company setup. Subsequent deliveries would have been labelled with the company's new name. I wonder if any of these original McKenzie, Holland 'fishtanks' survive.

To be continued …

[10] The Saxby name was dropped in 1935. Nock, O.S. (2006), '*A Hundred Years of Speed with Safety*', Hobnob Press.