LONDON UNDERGROUND SIGNALLING
A HISTORY
by Piers Connor
30. MOVING ON

MULTI ASPECT SIGNALLING

One of the many London Passenger Transport Board's 1935-40 New Works projects included a scheme to 4-track the section of the ex. Met. & G.C. line from north of Harrow to Watford South Junction. Although some preparatory work had been started before the Second World War, work on the ground didn't start in earnest until 1950 and even then, progress was slow and the new lines were eventually introduced in stages in 1961-62. With the new track came new signalling and, for the Underground, a new signalling system. This became known as multiple-aspect signalling or MAS.

The idea for multi-aspect signalling had its origins in the US where, in the 1880s, 3-position upper quadrant semaphore signals began to appear[1]. They were adopted by a number of railroads in America and, as I described in Article 16 in this series, in Britain on the Ealing & Shepherd's Bush Railway. The idea was to provide advance warning of block status and it was driven by the desire to increase train speeds and to improve line occupancy without sacrificing safety. In Britain, it was thought by some operators and engineers that three-aspect signals could do this around the country if design principles could be agreed and rules adopted and accepted by operating companies and regulators. In 1922, the Institution of Railway Signal Engineers (IRSE) set up a committee to examine the question and, within two years, they had endorsed the idea and they also suggested that a fourth aspect – the double yellow – should be added where necessary to allow shorter blocks over lines where there were both fast and slower trains were operating. The principles were quickly adopted by the Southern Railway who put in 4-aspect colour lights along their route between Holborn Viaduct and Elephant & Castle in 1926. Since then, both 3-aspect and 4-aspect colour light signalling have become standard systems in Britain. A schematic of the 4-aspect system is in Figure 1 below. I provided a schematic of the 3-aspect system in Article 16.

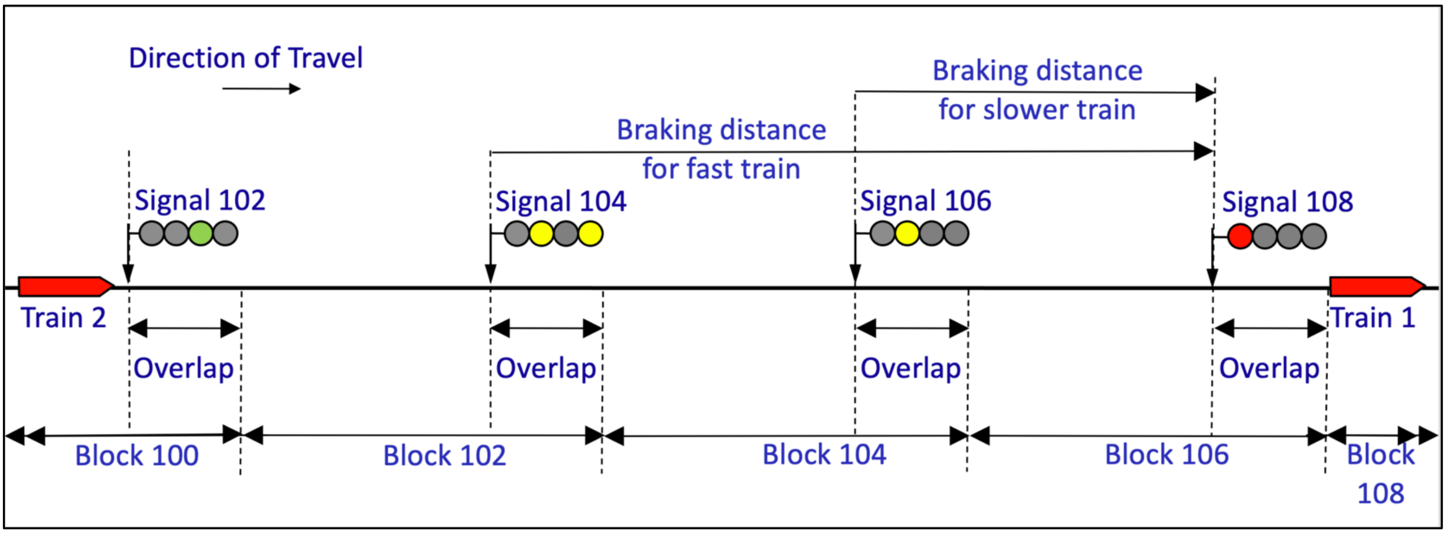
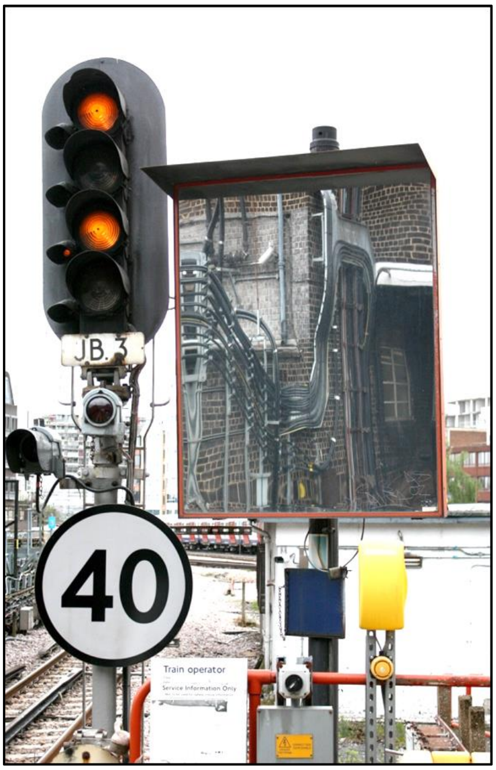


Figure 1: A schematic of a 4-aspect signalling system including overlaps. With Train 1 occupying Block 108, the signal protecting that block (Signal 108) is red, the signal in rear (106) shows a single yellow, indicating one vacant block before the red signal, Signal 104 shows a double yellow, indicating two vacant blocks ahead and Signal 102 indicates at least three blocks ahead are vacant. The double yellow provides the warning of a red signal ahead for fast trains, while the single yellow is sufficient for a slower moving train. Four-aspect signals on the Metropolitan main lines section between Harrow and Watford South Junction were normally spaced at 4,000 feet, or ¾ mile. North of Rickmansworth, most of the signals were 3-aspect. Drawing: P. Connor.

The Underground didn't need multi-aspect signalling for most of their lines but the Metropolitan adopted 3-aspects for their new signalling from 1925 (see Article 18) and, when the section north of Harrow was quadrupled and the line was electrified between Rickmansworth and Amersham in 1961-62, 3- and 4-aspect signalling was provided for some sections. The 4-aspect signals were provided to allow for

1 The word "aspect" in respect of a signal really means "display" for a colour light signal and early descriptions for multi-aspect semaphore signals usually called them "three-position" signals.

headways to be maintained. Thus, for example, from Harrow North Junction to Watford South Junction, the fast lines had 3-aspect signals, apart from two 4-aspect signals south of Pinner on the Up road and two at Harrow on the Down. Although the signals looked like standard main line signals, they were designed to LU standards with calculated overlaps. Over the 4-track section between Harrow and Watford South Junction, only the fast lines got multi-aspect signalling. The local lines had the usual Underground 2-aspect system. Largely because of the mix of LU and main line trains, there were some special arrangements. One of these was the provision of auxiliary aspects.



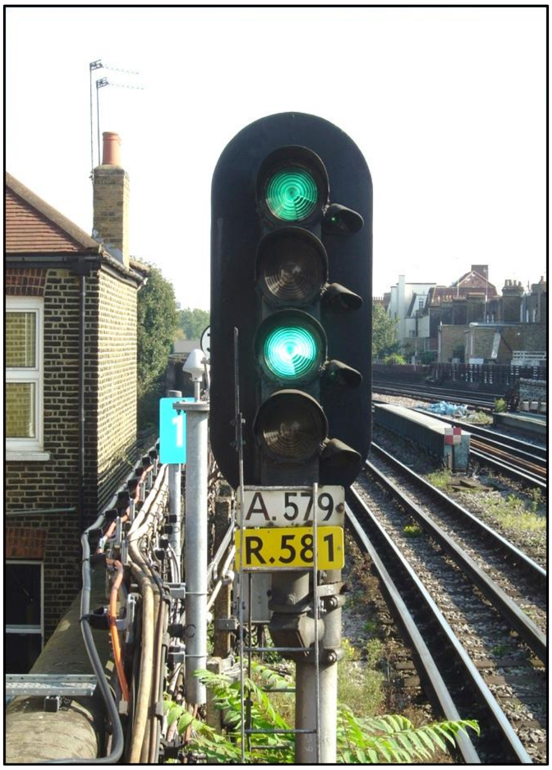


Figure 2: A comparison between a 4-aspect signal and a pair of two aspect signals on the same backplate. On the far left, JB3, the 4-aspect starting signal at Harrow-on-the-Hill Platform 1, shows a double yellow aspect, indicating two block sections ahead are clear. It also has an auxiliary red lamp below the main signal and a tripcock tester light to the left. On the left, two signals on a common backplate, at Stamford Brook (EB), both showing green. The upper green is for the stop signal while the lower one is for the repeater of the next signal. Photos by B. R. Hardy.

AUXILIARY ASPECTS

With the quadrupling north of Harrow-on-the-Hill, both Underground and main line trains shared the track. However, the main line trains didn't meet the Underground's standards for train protection since they didn't have tripcocks. At the time, this included a range of steam or diesel hauled passenger and freight trains. It was thought that some extra precautions should be taken to provide continuous signalling for main line trains in case a red aspect lamp or the signal main supply failed. This precaution is not necessary on the Underground normally since, if the signal main supply fails, all trainstops will correspondingly fail in the 'up' or 'on' position, the system being 'fail safe'. Similarly, even if a signal red aspect fails, the trainstop will be in the raised position and any train attempting to pass that signal will be 'tripped'.

With the lack of tripcocks on the main line trains, it was decided that an additional auxiliary aspect, which shows red when illuminated, should be arranged to come on automatically if either the main red (or yellow) aspect failed or the signal main supply was lost. If there was a supply failure, the auxiliary red aspect was fed from an emergency battery supply. Drivers were instructed that any signal at which this auxiliary aspect was illuminated must be treated as being at danger, no matter what the circumstances. This meant that main line drivers were always shown a red aspect at a signal which was at danger, even if the main aspect failed. All the 3- and 4-aspect signals were equipped with these auxiliary aspects. Additionally, if the auxiliary red was illuminated, the signal in rear would show a yellow aspect.

There was a degree of 'over overkill' about this arrangement. After all, train drivers have always been taught that the absence of a light on a signal must be regarded as a stop command. Despite this, it seems that the lack of tripcock provision was a problem for the Underground's signal engineer, Robert Dell and he seems to have been determined to mitigate the risk of a main line train overrunning a signal without an aspect. The auxiliary aspect was his solution. When the old Class 115 diesel units used on the Chiltern Line services were eliminated in the 1992, a rule came into use dictating that any trains coming on to the route had to be equipped with tripcocks. Eventually, the auxiliary lamps fell into disuse.

DISTANT SIGNALS

Another oddity introduced as a result of mixing main line and Underground trains was the distant disc signal. This was an externally lit, circular yellow disc with a black fishtail band (Figure 3). It first appeared on the Northern Line extension to High Barnet, which was opened on 14 April 1940. The branch to High Barnet was originally owned and operated by the London & North Eastern Railway (LNER) and the extension involved tube trains taking over the existing steam hauled passenger services. The line was resignalled to Underground standards with the usual two aspect signals, trainstops and electro-pneumatic point machines.

Figure 3: A disc distant signal provided on some lines where main line freight trains operated over the same tracks as Underground trains. This one is on the Metropolitan Line and, to clear, it required A761, A763A, A763B and A767 all clear (the Pinner starter, homes and the next intermediate signal to be off). Note that these signals were not numbered but they were named. They were often mounted on existing Underground signal posts. Photo: LURS Collection.

Despite this modernisation, the LNER continued to operate local freight services to serve the goods yards that remained at many of the stations along the route. They used steam hauled trains that were not always fitted with continuous brakes[2] and this meant long braking distances were required. Although the trains were subject to restricted speeds, because of the long braking distances, the drivers of these trains needed early warning of adverse signals, hence the introduction of the special distant signals. The purpose of the signals was to provide a distant indication that would be separate from the traditional Underground yellow repeater lamp. The yellow disc did the job perfectly and it used a standard Underground shunt signal e.p. motor so that the signal rotated through 45 degrees to show the “off” aspect. These signals were also provided on the eastern end of the Central Line and on the Metropolitan Line north of Harrow.

Figure 4: A distant colour light signal on the Chesham branch. This was a fixed yellow signal, with a ‘Distant” label in yellow in place of an R number. There were two of these on the branch and they were unique to the branch. Photo: B.R. Hardy.

There was one exception to the use of disc distants. This was on the Metropolitan’s Chesham branch, where colour light distants were used. One was provided on the approach to Chesham and one on the approach to Chalfont & Latimer. Both these signals were fixed at yellow as they approached areas where a stop or a reduced speed was required. Curiously, these signals were also originally provided with auxiliary lamps. These showed yellow if the main aspect failed. Like the ones on the Met. main, they fell into disuse.

Related to these distants were the special black on white banner repeater signals installed on the approach to Rickmansworth (Figure 5) for the 1961 resignalling. The approach to Rickmansworth on the up road (SB) from Chorley Wood is downhill and quite fast but it finishes with a serious curve into Rickmansworth station where there is a 25 mi/hr permanent speed restriction. The banner signals replaced the original yellow banner repeaters provided in 1925. These signals were unique on the Underground but banner repeaters are common on the main line and there are examples on the Wimbledon and Richmond branches.

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2 Up to 1930, only passenger trains had continuous brakes on all vehicles. Many freight wagons were not braked and trains relied on the locomotive + tender and a brake van (or vans) to provide braking. The speed of these trains was usually restricted to 25mi/hr. Eventually freight trains began to be provided with brakes but “unfitted” or “partially fitted” trains continued to run until the 1960s.

Figure 5: To give main line trains adequate warning of the position of the home and starting signals at Rickmansworth SB, two e.p. operated banner repeater signals were installed on the approach to the station. They replaced two yellow band mechanical banner signals. The new signals were externally illuminated discs, like shunt signals but with a black band on a white ground instead of a red band. The first was for the home signal given a standard Underground repeater number (RJP1, see here in the 'on' position), the second was RJP2 for the starter. Photo: B.R. Hardy.

AUTUMNAL WOES

The wonderful expression 'leaves on the line' has become well known to rail travellers in Britain over the last 50 years or so and it receives a good degree of mockery, since the whole concept of a train weighing several hundred tonnes being affected by a few leaves of the sort that the average householder might rake off their lawn in the autumn, is really not understood by the general public. It is, though, a serious issue and it has plagued the Underground and other railways since the early 1960s. There were several triggers for the problem, each with its own origins – the introduction of lighter trains, the use of non-metallic brake blocks, dynamic braking, stepped electro-pneumatic brake control and the almost total loss of vegetation management amongst them. For the main line, we can add the use of disc brakes to the list. The problems all relate to adhesion, or the lack of it and, separately or in combination, all these systems have combined to create a perfect storm – the reduced ability to stop a train and the resulting increases in braking distances – see box.

To describe the problems, their causes, the attempts to find solutions both for the infrastructure and the trains, and the successes or otherwise of the various responses to the leaf fall issues, would take us a long way from the scope of this article. However, the effects of leaf fall and the resulting loss of adhesion can be a serious issue if the signalling fails to work as intended or if the risk of collisions increases. This is largely related to the failure of the train to be detected because the mix of leaf mulch on the rail head can insulate the train from the track circuit. A secondary issue is the possibility of a train being unable to stop within the designed overlap. These two issues led to a decision being made to provide a modified arrangement for signal overlaps on the southbound Metropolitan Line between Chalfont and Latimer and Rickmansworth. The work was carried out during 1979 and the system was commissioned on 28 October of that year.

SALISBURY

If anyone doubted the seriousness of the problem of 'leaves on the line', they need look no further than the interim report on the collision that took place on 31st October 2021 at Salisbury Tunnel Junction. According to the report by the RAIB, a train approaching the converging junction at over 50mi/hr hit a train already proceeding over the junction under clear signals. The driver of the colliding train, approaching the red signal protecting the junction, had been applying the brakes of his train from over 1,700m before the collision point but the train failed to stop. A thick mulch of crushed leaves was preventing the train from stopping and it was skidding for most of that distance. From my own experience of driving trains under poor adhesion conditions, I can understand the horror of the poor driver, sitting at the desk knowing there was nothing he could do and that the collision was inevitable. He stayed at his post and was seriously injured in the collision.

The modification extended the control of a number of signals in the area to provide them with long overlaps. It was a manual system that was activated by the operation of keyswitches. There was one keyswitch in the Interlocking Machine Room (IMR) at Chalfont and another in the relay room at Rickmansworth. An example of how it worked is that, when the keyswitch was operated, the normal overlap of 1,407 feet (429m) of Signal A971 on the southbound approach to Rickmansworth became lengthened to 2,984 feet (910m), a 53% increase. Unsurprisingly, this had a restrictive effect on the train service and it led to special timetables being introduced for the leaf fall season to allow additional running time.

At Rickmansworth, the keyswitch also caused southbound signals A971 and JP1 to become approach controlled. Apparently, this was provided to make drivers approach these signals more slowly as it seems that there wasn't much that could be done to extend overlaps at Rickmansworth without adversely affecting the flexibility of the layout there.

SEQUENTIAL SIGNALLING

Not satisfied with the extended overlaps, an ever more cautious signal engineer introduced further protection against the unwanted effects of leaf fall using a system known as ‘sequential signalling’. Sequential signalling is a control system that ensures track circuits operate in the correct sequence as each train passes through the section. If this didn’t register, it prevents signals in rear clearing for the following train. The purpose was to provide an additional level of protection where it was felt that there was a risk of the track circuits showing a false clear with a train in section. The control was simply to hold a signal at danger until the previous train had cleared the section being protected and had entered the next track circuit ahead. The scheme was introduced on the Metropolitan in 1992-93.

Sequential signalling was introduced on the Bakerloo when that line went through a resignalling programme between 1988 and 1991. The use of sequential signalling here was a direct result of the decision to use Jointless Track Circuits (JTCs – see Article 28). There was a concern about the lack of diversity[3] in the microprocessor-based receiver (Rx) units and that this lack could produce an unsafe result, so the sequential signalling arrangement was added as a precaution.

Berth track circuits, where trains could stand for considerable periods of time, were a particular issue. They were always a concern, even with capacitor fed tracks, because of the risk of a relay being held in the energised position, sticking in that position and then failing to operate when the train departed. To overcome the problem, it was normal to wire two relays in the protecting signal circuit in series. For the Bakerloo resignalling, what became known as ‘GYR’[4] circuitry was provided in locations where diversity was needed. The GYR circuitry prevents a signal clearing until the disengaging track circuit has been occupied and then cleared in sequence.

Sequential signalling was also put in specially between Notting Hill Gate and Bayswater due to poor drainage on that section[5]. As well as the Met. and Bayswater installations, GYR circuits were also used on the Olympia branch after the installation of JTCs there in preparation for the electrification of the West London Line. Later installations of JTCs used alternative methods to get the diversity required, such as the Eastcote to Hillingdon auto section, which was resignalled in 1993 and used twin receiver units in series. On the Central, Waterloo and City, and Victoria lines, they used Programmable Logic Controllers (PLCs)[6] for sequence checking[7].

CURRENT SUPPLY

When considering signalling systems, we should not neglect the fact that they need their own power supplies and that these need to be available along the whole length of the line. They must be reliable too. Although the early electric installations used batteries strategically placed along the railway to supply signalling equipment, it soon became the practice to distribute Direct Current (DC) via motor generators placed in the substations and run it along the line side in a cable. Tappings were taken off as required to supply signal boxes, points and signals.

The supply voltage tended to vary from one place to another, so the Metropolitan originally had 130-volt and 60-volt supplies but later it converted its supply to 440 volts Alternating Current (AC). The Underground group followed much the same pattern, starting with DC supplies and then going over to AC. Eventually, the Underground standardised on 600 V AC. The system hasn’t altered much to this day, the basic layout of supplies appearing as in Figure 6 below.

One of the more complex issues for electrical systems in general and for railway signalling electrical systems in particular is electro-magnetic interference (EMI). There are two main aspects to this – one is that the earth acts as a conductor, so lots of systems are using it (some unintentionally) to provide circuit return and the other is that, if you pass electricity through one conductor that is close to another conductor, you can induce a current in the other conductor. Even if you understand these basics and design your circuits to account for them, a fault, like an “earth fault”, can cause a problem, so you have to protect against this too. On top of that, AC circuits behave differently from DC circuits and there are varieties of AC as well. There is a myriad of variations on this theme and they all have to be considered

3 Diversity here means having more than one path for a safety circuit to eliminate the possibility of a single fault causing an unsafe condition.
4 Signal Disengaging Relay, as per BS376
5 I recall, as a driver on the Circle Line in the early 1970s, water used to pour from the tunnel roof onto the track just east of Bayswater whether it was raining or not. No wonder the track circuits struggled.
6 A PLC is an electronic device that can be arranged to replicate the functions of a set of relays operating a logical sequence.
7 Crame, T, Notes on JTCs in email to author 6 April 2022.

when designing electrical systems. For railway signalling, being a safety system, such considerations form an important part of the design process.

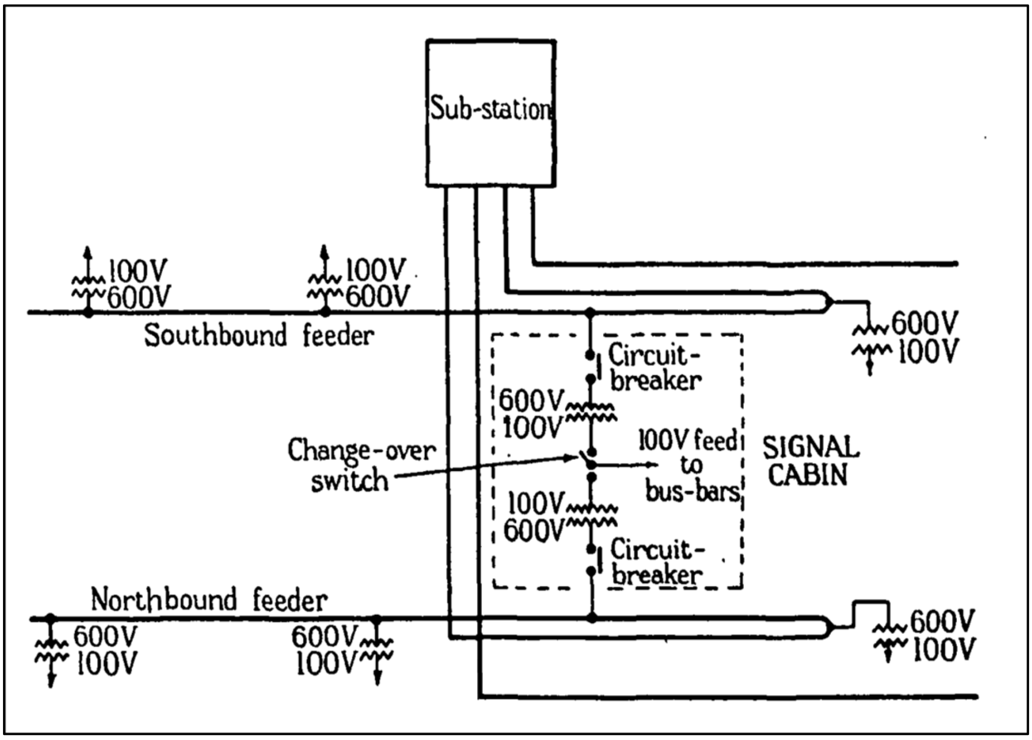

Figure 6: Schematic of Underground power supplies provided for the signalling systems and signal boxes. A transformer is provided at each supply point and links ensure that every tap becomes a point at which the supply can be isolated. Separate transformers were provided to step the voltage down to 100 volts for signalling and track circuits. Each could be isolated by means of the links while all remaining signal equipment was left in operation. Drawing from Dell (1944), Developments in Railway Signalling on London Transport Proc. Inst. Electrical Engineers.

An interesting example of this concerns the frequency of the AC supply. Both the Underground and the Metropolitan Railway originally generated their signalling supply current from their own power stations at a frequency of 33⅓Hz. This was different from the 50Hz generated by some other power suppliers and that was eventually chosen as standard by the National Grid. The National Grid was set up in 1926 to provide Britain with a system to connect the hundreds of power stations scattered all over the country, mostly in urban areas, and to provide a distribution system that could supply rural areas too. It was largely complete by 1938.

The West Ruislip extension of the Central Line was supplied at the 50Hz frequency from the Great Western Railway so, to allow the use of the standard 33⅓Hz Underground signalling equipment, frequency convertors had to be installed at each traction substation. When the Underground's Lots Road power station was updated over the period between 1963 and 1969, 50Hz generators were installed and again, frequency changers were installed in almost all substations to provide 33⅓Hz for the signal mains. The eastern end of the Piccadilly Line was supplied at 50Hz from the National Grid but, rather than switch over to 33⅓Hz, the signal mains were left at 50Hz too. The eastern end of the District Line had a different arrangement installed in the late 1950s to allow for the electrification of the London Tilbury and Southend Line at 25kV 50Hz overhead. It had 2 mains at 33⅓Hz. One was at 600v (known as the "clean feed") and one, restricted to track circuits, at 440v the "dirty feed" but electrically 90 degrees out of phase, so a Dual Element Vane (DEV) relay could be operated from each of the mains[8].

It turned out that having a difference between the signal supply frequency and that of the national supply had its advantages. Robert Dell, writing in 1944[9], told the story of how stray current from the national supply had been detected in some track circuits. This caused some head scratching at the time but, eventually, the cause was found. Some arches under a railway viaduct had been let to traders who had installed lighting attached to the brickwork. A faulty circuit in the lighting system allowed a leakage current with a difference of several volts above zero to be detected when test rods were inserted in the ballast of the railway above. This leakage had entered the track circuits but because of the difference in frequency there was no "improper operation", as Dell put it. Since 1965, the frequency for new or upgraded sections has been at 125Hz, again to eliminate the risk of interference from the 50Hz supply. It also replaced the 33⅓Hz supply in most, but not all areas still left with it between 2008 and 2011 in

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8 Immunisation of signal circuits where 25kV AC overhead line supplies operated near Underground lines is a whole subject of its own and a number of papers have been written on the subject. A good example is from, Nicholes A. & Jeffery, D., '*The Immunisation of LT Signalling from 25kV Traction Supplies*', The Signal & Electrical Engineers Technical Society, 1 December 1981.

9 Dell, R. (1944), Developments in Railway Signalling on London Transport, *Proc. Inst. Electrical Engineers.*

order to remove the risk of interference from electronic-based 'solid state' traction power systems being introduced on modern trains.

TRAINSTOP UPDATES

The traditional "long tom" or Style B type of train stop used on the Underground group's lines from 1905 onwards came in both 4-foot and 6-foot varieties. One of the problems of the design was that it was spread over three sleepers which meant that it was vulnerable to variations in packing and thus from track movement. It was also very exposed with the valve unit, operating rods, return spring and various links all subject to temperature variations, damp, ice and sunshine. It required regular greasing and adjusting to keep it in good condition. Also, some modifications and variations had crept in over the years, the most significant being the addition of a contact box to detect the position of the train stop operating head to provide trainstop proving.

As early as 1911, Westinghouse produced a design for an enclosed electro-pneumatic trainstop[10] but it was contained in a substantial rectangular steel box and it probably would have been difficult to fit without providing at least two extended sleepers at each location and it wouldn't have fitted in a tube tunnel. Also, it was too wide to fit in the 4-foot without cutting the negative rail. In 1931, a much improved enclosed design, more suited to conditions on the Underground, was offered by Westinghouse. This was the Style H trainstop. It came in two basic designs, described by Westinghouse as the H3 and the H4 (Figure 7). The H3 became known on the Underground as the HO, ('O' for outside) while the H4 became the HT ('T' for tunnel). The HO was designed for surface operation, comprising a long rectangular box with the trainstop arm protruding from the long side, while the HT had the arm at the end of the box. This was a more compact design and was immediately identified by the rear end of the box being angled. Photographs of the time suggest that the new Style H trainstops were first installed in 1932 for the Piccadilly Line eastern and western extensions.

Over the following decades, various improvements to these original designs appeared. They included the Style J outdoor type, an improved version of the HO with an oil pump for lubrication, the Style K tube tunnel design based on the HT, also with a self-lubricating system included in the unit, and a Style KC unit designed to fit on the wall of tube tunnels with restricted space at rail level as found on the Central Line. There was another version, known as the Style KF, which was a modified version of the Style K for use in areas with flat bottom rail[11]. A few locations were also provided with modified Style J designs. The Underground's designations for the variations in trainstop design included a modified outdoor Style H3 known as the H5 and a modified indoor Style H4 known as the H6.

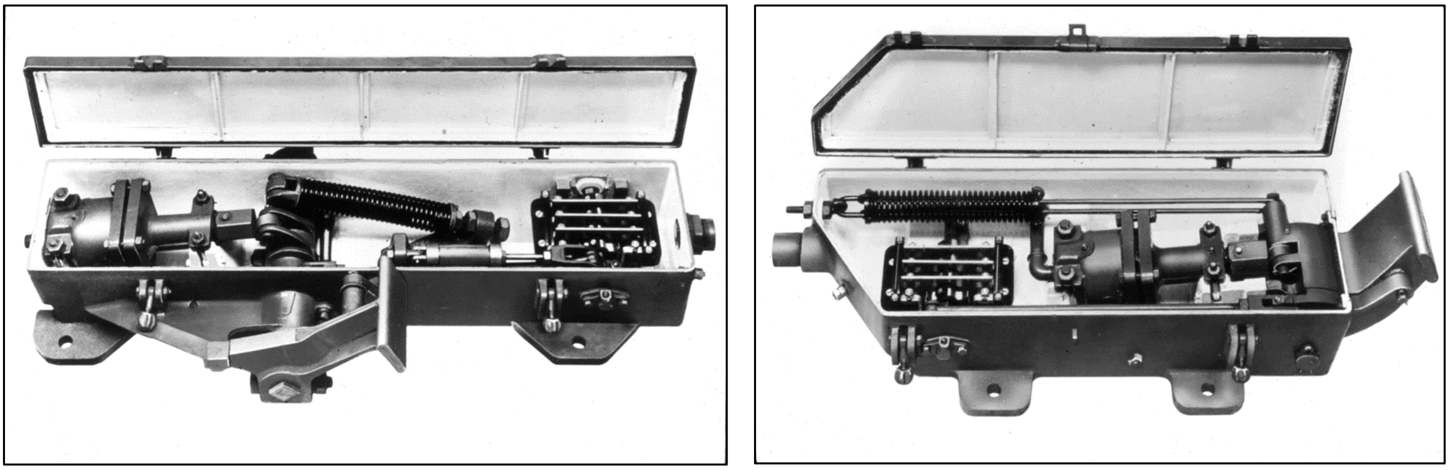

Figure 7: Westinghouse official photos of their new trainstop designs circa 1932. The HO type on the left is a straightforward rectangular box for outdoor use containing, from left or right, the air cylinder, the crank to operate the trainstop, the return spring and the detection contacts. The operating valve was mounted separately. The trainstop arm is on the side of the box. The HT type on the right is a more compact version designed for use in tube tunnels. The trainstop arm is at the end of the box. Photos: Westinghouse Archive and Chippenham Museum.

After a number of incidents in the early 1980s where trainstop arms failed to move down to the "off" position because discarded drinks cans had become wedged under the arm, a modification was introduced to protect the underside of the arm. It was simply a steel guard fitted in front of the trainstop

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[10] Westinghouse Drawing C726_2615, Electro pneumatic train stop machine Style D ,1911

[11] Signal Design Handbook, 1999, London Underground internal document, Vol. 2.

arm to protect it from debris. It quickly became known as the ‘can guard’ or ‘Roman helmet’. Guards provided at starting signals incorporated a ramp.

Now the trainstop is regarded as “old hat”, having been superseded by automatic train operation in various forms but it isn’t dead yet, since the original plan to automate all routes used by the Underground has been abandoned and there will still be a use for trainstops on some of the outer ends of the District and Metropolitan lines and on the Bakerloo and Piccadilly lines until these are automated.

AIR SUPPLY

The Underground’s reliance on electro-pneumatic signalling equipment meant that a network of compressed air supplies was required. Compressors were installed at all substations and provided a constant supply of compressed air to the 1½ inch diameter main air pipe run throughout the system. As with the electric supply system, it became the practice from the 1930s to duplicate the steel compressed air supply pipes so there was one on each side of a pair of tracks[12]. The pipes were mounted on concrete posts set alongside the track at 4-foot intervals and they were used as a rail that provided a convenient support system for the signalling cables. The pipes had special brackets hung off them on which the cables were slung. The pipes were supplied in 11-foot lengths and, where there was an e.p. operated device, it was connected to the main by a half-inch flexible hose. The compressed air output from the compressor was originally passed through cooling grids to encourage the moisture to drain off and isolating cocks are provided wherever a tapping is taken off to allow isolation in case of a leak. Later, the cooling grids were abandoned in favour of air dryers installed inside substations, although the grids were often left in situ. Of course, the pipework for the air mains had to be protected from temperature changes and special expansion joints were fitted in the pipes at intervals to compensate.

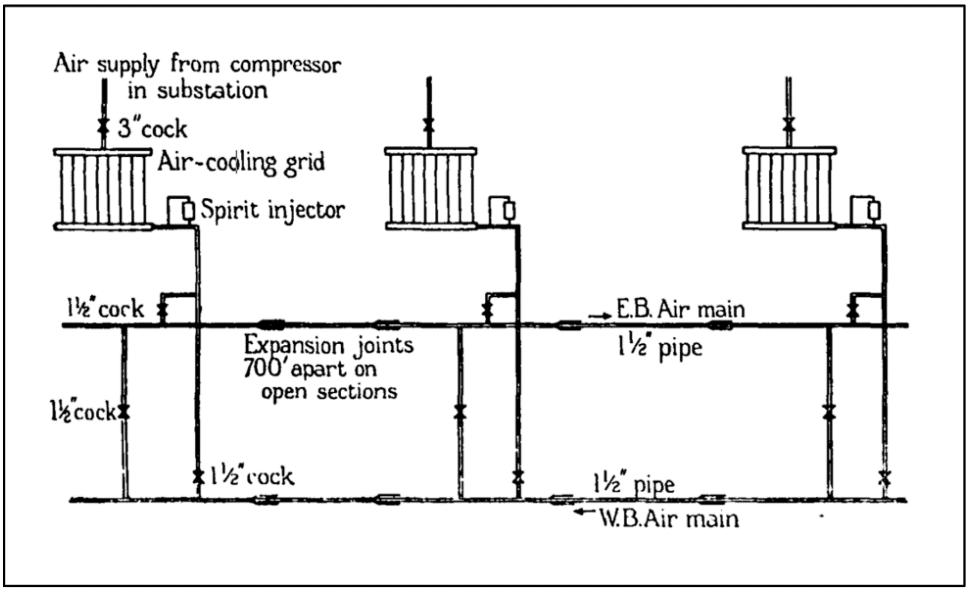

Figure 8: A simplified diagram of the standard Underground air supply system. Originally, de-icing spirit was used to stop the moisture from freezing in bad weather. Nowadays, they use glycol. Drawing modified by P. Connor from Dell (1944), Developments in Railway Signalling on London Transport Proc. Inst. Electrical Engineers.

The system proved one of the more reliable parts of the signalling system and failures from a burst pipe or other causes have been rare. However, the system is old and is now subject to more restrictive testing regulations for pneumatic systems and these issues have led to it gradually being removed on some of the lines that have been converted to automatic operation.

To be continued …

[12] Dell, Ibid.