THE UNDERGROUND ELECTRIC TRAIN

by Piers Connor

31 – TERMINALS, TIMING AND PROTECTION

CONTROLLED SIGNALLING DEVELOPMENT

The design and use of signalling in controlled areas has developed slowly on the Underground over the last 100 years. Looking at this development, we will take a simple 2-track terminus (Fig. 1 below), similar to, say, Elephant & Castle (Bakerloo), and see how it has evolved. The example is simplified but we can use it to demonstrate the progressive development of safety principles[1].

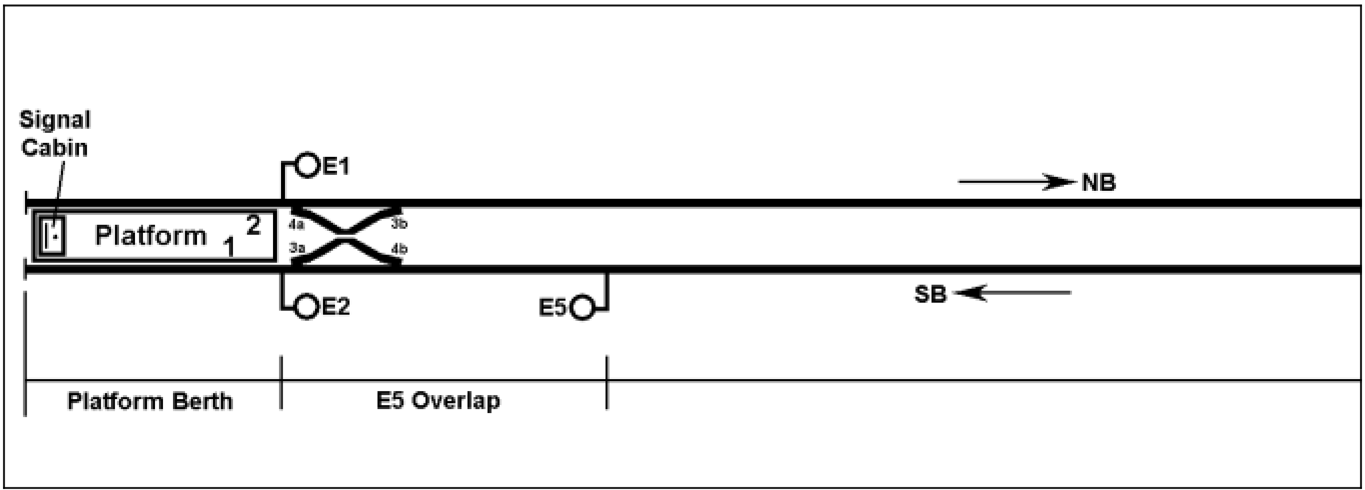

Fig. 1: Schematic of simple 2-track terminus equipped with a scissors crossover, a home signal (E5) and starting signals (E1 and E2) for each platform. The home signal (E5) is set back a full speed overlap from the platform berth so that if a southbound train is tripped it will stop before it could hit a train standing in either platform. The crossover is worked by two levers: Lever 3 works the points covering the exit from Platform 1 while lever 4 works the points for southbound moves into Platform 2.

In our layout, trains in the platforms are protected by the home signal (E5) being set back a full speed overlap from the platform berths. Thus, a train standing in either platform is protected from an overrunning train tripped at E5. However the design has one major flaw. If a train overruns E5 at full speed while a train is leaving Platform 1 over No. 3 crossover, there is a risk of a collision because it is within the overlap of signal E5. There is no “flank protection”. There is evidence to suggest that this was the original setup at least until the mid-1920s.

Eventually, it was realised that full protection for a departing train would require the signal to be moved back a distance equivalent to at least the crossover length. But this had a price. Moving the signal back increases the distance to the platforms. This would then increase the time required for a train held to await a free platform to start up from signal E5 and proceed into the station. The solution was to ensure that flank protection was provided for a full speed approach by stopping the train at the new signal position and then letting it draw up closer to the site of the original home

[1] There is the usual health warning here for signal engineers in that you will see I have omitted some details and simplified the principles.

signal. The train could then run into the platform as soon as it was free. Fig. 2 shows how this was done.

Our terminus now has two home signals, E5 and E6. E6 is positioned so that a train approaching at full speed and failing to stop will be tripped and come to a stand before it reaches the crossover. So the train can come closer to the station ready for it to run into a platform as soon as it is free, a timing track on the approach to E6 is used to ensure that the train occupies this section long enough to check it is not going to overrun E6 at full speed. Once this is proved, by a 15 second timing relay, E6 will clear to let the train draw up to E5. It should be noted that, in our illustration, if a train did overrun E5 while E2 was cleared for a departing train, the occupation of the overlap track would cause E2 to return to danger.

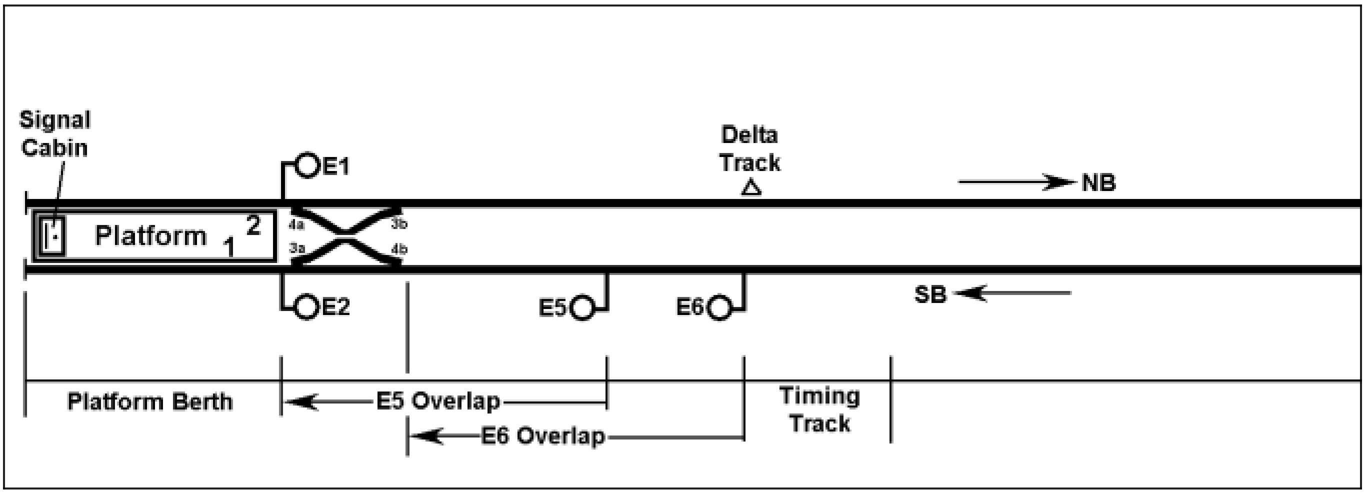

Fig. 2: Schematic of terminus with flank protection introduced. If both platforms are occupied, signals E5 and E6 will be at danger. A southbound train approaching will be tripped at E6 if it does not stop and the safe braking distance of the overlap of E6 provides "flank" protection for the crossover. To allow a train to approach E5, a timing track in rear of E6 will hold E6 at red until the train has occupied the circuit for a set time. It will then clear to allow the train to draw up to E5. Note also the Delta track on the exit of the terminus which provides "bobbing" protection as described in the text.

Next, we consider a train departing from Platform 1. The lever for No.3 points is reversed, the lever for E2 is then reversed and the signal clears. The train in Platform 1 can now leave. We hope it will leave quickly because we have a train standing at E5 and we want to get it into the terminus. However, we do have to wait until the departing train has passed through the crossover. While the train is occupying the crossover, its track circuit prevents the lever for E2 being restored to the normal position. This is called "backlocking". We need to do this to prevent the points being moved under the train. If we could get No. 2 lever back to the normal position, it would release the interlocking on points lever No. 3 and we could restore the points to normal before the train was clear of them.

So the track circuit for the points is important. However, crossovers are problematic in that they can sometimes fail to detect the train passing over them (vibration, bad packing under the sleepers etc.). This gives rise to what is called a "bobbing" track, where there is an intermittent loss of detection. It's not common these days but it can happen and signal engineers are very cautious people. They insist on diversity, so they provide an additional detection system. They use what is referred to as a "delta" track circuit.

A delta circuit is a 10kHz feed into a running rail over a short distance – a few metres – which detects the front of a train as it arrives. The circuit does not require insulated joints in the rail as the length of detection is small and uses a high frequency circuit.

When the front wheelset of the train is detected by the delta circuit, the backlock on the signal is energised and the lever can be restored to normal. Now the points can be changed and the next southbound train routed into the terminus. For routes which involve many sets of points, deltas are useful for allowing the release of each set of points as it is cleared by the train so that another route can be set up immediately. This is often called "sectional release".

BI-DIRECTIONAL TRACKS

A terminus has trains running in both directions, in to and out of the platforms. A train is designed to operate in both directions so it has a cab at each end, with a tripcock at each end on the right hand side of the leading bogie. From this we can see that a train entering either platform of our terminus (Fig.1) will have to pass over the trainstops of the starting signals E1 and E2. As the train runs in, the starting signal will be at danger. The driver won't see it because it is pointing the other way, ready for when he has changed ends and is waiting to depart. Since the signal is at danger, the trainstop will be up. The rear tripcock of the train, which will become the front tripcock when the driver changes ends, is on the same side of the track as this trainstop and if it stayed up as the train ran in, the train would be tripped on the rear tripcock – back-tripped as it is called. To prevent this, the trainstop automatically lowers as the train approaches and then rises again as soon as the train is clear of it. For this reason, trainstops of signals on bi-directional tracks are very close to the track circuit boundaries[2].

APPROACH LOCKING

At a diverging junction, where the driver has a choice of routes, mistakes can be and are made. The commonest is where the signaller sets up the wrong route, clears the signal for the train and the driver accepts it and goes the wrong way[3]. A favourite place for this is Hanger Lane Junction where the District goes left towards Ealing Broadway and the Piccadilly goes right towards North Ealing. Many a train has ended up in the wrong place over the years.

It would not stretch our imagination too much to suppose that a signaller, suddenly noticing that the wrong route is set up, would replace the signal to danger by putting the lever back towards the normal position so that he can restore the points to the position he wants and therefore send the train on the right route. However, if the driver has got too close to the signal to be able to stop before reaching the points, there is a risk the points could be moved under the train. This possibility is prevented by "Approach Locking".

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2 For more information on tripcocks and back-tripping, see Article No.17 in this series, *Underground News* No.539, November 2006.

3 More often than not, the mistake is not the signaller's fault. It is usually due to a "wrong description" being sent along the line because of a cancellation, late running or out-of-turn-working.

Approach locking simply means that the signal lever is locked when the driver reaches the sighting point of the signal. The track circuit detects the train as it reaches this point and retains the backlock on the lever to prevent it being restored to its normal position. However, the signaller can move the lever a short distance off the reverse position to get it to go back to danger. If he can stop the train, he will.

Once activated, the approach lock will be held until a time has elapsed – usually two minutes – sufficient for the signaller to be sure that the train is stationary before making any changes to the route. The signaller, if working in a signal cabin, has to "take a release" manually by a hand-operated screw device or a dedicated lever operating a time delay relay. In other installations, the time release is automatic. The driver, having seen the signal "go back in his face" as they say, will have got in touch by now anyway.

The approach track to a junction signal is also often used to clear the signal when the train has reached a certain point in rear of the signal. Although the route is set, the signal will not clear until the train has occupied the approach track circuit. This has the effect of causing the driver to pay attention to the signal showing red so that, when it changes to green, he will check to see that the route is the correct one for his train. Well, this is the theory anyway. WM21/22 at Hanger Lane Junction is like this but it hasn't prevented generations of drivers from accepting the wrong signal, with Picc's going round to Ealing Broadway and Districts to North Ealing. The same setup on an approach track also has the effect of causing the driver to reduce speed where a diverging route requires a speed limit.

TIMING CIRCUITS

Certain routes require train speeds to be reduced to "preserve the integrity of the train/track interface" – in other words, to prevent the train flying off the tracks. Traditionally, drivers are shown a speed limit sign which, traditionally, they usually adhere to, more or less, but which they can ignore. To enforce speed limits, the signal engineer introduced certain devices which persuade the driver to reduce speed, or at least to pay attention. The approach controlled signal at Hanger Lane Junction I mentioned above is one way of forcing a driver to reduce his speed as he approaches a junction. The approach to Watford South Junction used to be like this but, as drivers, we all knew the setup and I, for one, ignored it. I knew that when my train reached a certain block joint, the signal would clear. In five years of approaching it, it almost always cleared. On the few occasions it didn't I got the brakes on and stopped at the signal – just. But then, I knew I could since I had already adjusted the train speed to match the possibility.

This approach didn't work for everyone. The in-town part of the Central Line used to have several stations where there were three home signals on the approach. The outer home was approach controlled. If there was a train in the platform, all three would show red. When the driver saw them, he would slow down and, when he occupied the approach track circuit, the outer home would clear, even if the train ahead was still in the platform. There was no time delay. The idea was that, since the driver had slowed his train, he could approach the next signal at the lower speed and still have a safe braking distance if he got tripped.

One driver, approaching Holborn westbound on 9 July 1980, where such an installation was in place, knew the setup and assumed that the train ahead would leave as he approached. It had always done so before so why not this time. He approached at full speed. As he entered the approach track, the first signal cleared. He expected the next one to clear as the train in front left the platform. But it didn't and he got tripped at close to full speed. The overlap on this second signal was not designed for a full speed trip and the train ran through to the rear of the one in the platform and collided with it at about 12mph. It turned out that the train in the platform was delayed while the crew were attending to a sticky door.

Luckily, no one was killed but a valuable lesson was learned. If you devise a system which relies on the integrity of a wide variety of users, eventually one of them will find a way to abuse it. As a result, approach control of this type on Central Line outer home signals was quickly removed. Other similar sites along the line already had timers on the approach track, which retained the red aspect for 4½ seconds to ensure that the train would be tripped if it didn't reduce speed.

TERMINAL PROTECTION

Another accident, some five years earlier on 28 February 1975 at Moorgate, also arose as a direct result of driver error and also led to changes in the signalling system. The changes became known as terminal protection. This accident was a lot more serious than the one at Holborn and led to the deaths of 42 passengers and the driver. The circumstances were simple, the train ran through the station at 35mph and hit the end of the tunnel. The driver never made any attempt to stop and the guard didn't have time to react to stop the train.

Soon afterwards, the Underground began experiments with various forms of terminal protection. The eventual result was that all dead end platforms and reversing sidings were fitted with timing sections which forced a train to slow down during its approach to the buffer stops. Typically, the home signal has a timing section to make the driver reduce the train speed to 20mph and there are two "blind trainstops" in the platform or siding. A blind trainstop is one without a signal.

At the entrance to the platform, the first blind trainstop remains raised until the timing section detects the train speed is 18mph or less and, 30 metres in rear of the stopping mark, there is a second trainstop which requires 12mph or less before it will lower. There is also a fixed trainstop at the stopping point. Drivers usually end up watching the trainstops rather than the train speedo, since the latter is regarded as less reliable.

One serious outcome of the terminal and siding protection scheme has been a reduction in line capacity. Terminals are often the limiting factor for the capacity of a whole line. Nowhere is this more obvious than Aldgate where, because of terminal protection, 8-car A Stock trains have to creep across the junction into either of the two bay platforms, effectively blocking the route for Hammersmith trains. On other lines, some reversing sidings are now virtually disused as a result – Wood Green being a good example. The delay cause by the combination of detraining a terminating train and then waiting for it to creep into the siding just became unacceptable. Without Wood Green reversers, more trains had to be sent to Cockfosters to reverse but, of course, they have to negotiate the terminal protection there. Nowadays, as soon as there is a small delay to the Piccadilly Line service, congestion at Cockfosters can become a serious problem. This, combined with other factors like defensive driving[4] and one person operation, have led to a

[4] I referred to defensive driving in Article 7, *Underground News* No.529, January 2006. Defensive driving is where drivers are taught to drive cautiously, creeping into station and crawling up to

reduction in Piccadilly Line capacity of 20%. I will be looking at line capacity in more detail in the next article.

DRAW-UP SIGNALS

There are certain places on the Underground where two tracks converge or cross just beyond a station platform. The best known is perhaps Baker Street, where the double-track junction occurs just east of the station platforms. The overlaps of the starting signals of Platforms 5 and 3 actually extend over the junction, meaning that, if a train got tripped at speed at either signal, it would not stop before it reached the junction and could collide with another train which was passing on the conflicting route. To overcome this problem, "Draw-Up Signals" were introduced. Originally, they were called "Permissive Signals" but the name fell into disrepute during the late 1960s because the term "permissive society" became common and the Underground, it seems, was anxious not to be associated with perceptions regarding the lowering of public morals.

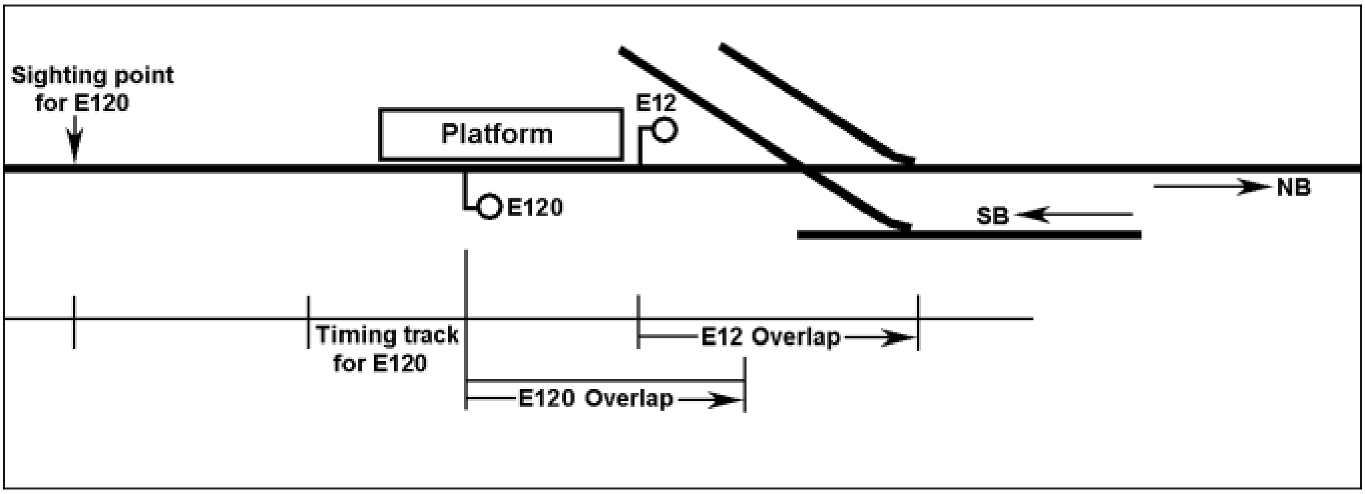

Fig. 3: Schematic of a layout where a conflicting route is protected by a draw-up signal. The overlap of the starter (E12) extends over the junction so that the junction is not fully flank protected if a train gets tripped at E12. The draw-up signal E120 is positioned in rear of E12 so that its overlap provides full protection. A train approaching the platform will brake before it reaches the platform so that it enters the timing track at reduced speed. A 4½s timer will clear E120 to yellow, lowering the trainstop to allow the train to draw up to E12.

A draw-up signal (Fig. 3 above) is a 3-aspect signal positioned in rear of the starting signal so that the driver will see it as he approaches the platform. The three aspects are red, yellow and green. If the starting signal is "off", the draw-up signal will also be green. If the starting signal is red, the draw-up signal will also be red. As he approaches the signal, the driver will reduce his speed and a timing track will detect the train and will allow the signal to clear to a yellow aspect, lowering its trainstop before the train reaches it if the speed is low enough. The draw-up signal is identified by the letter and number of the signal operating with it, plus a zero or two as necessary to bring it up to three digits.

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signals. I regard it as a waste of the infrastructure, a restriction on line capacity and a down-grading of the skill of the driver, who is relatively well paid and is therefore an expensive resource which should be optimised. Better training is the answer. Eventually, of course, ATO will take the driver out of the equation.

ROUND THE BEND?

I have already mentioned the "stop and proceed" rule[5], where a driver, confronted by a red signal which fails to clear after a set time will, if he can, seek permission to pass it and then proceed under extreme caution into the section ahead. With automatic signals, the driver can proceed without permission if he can't get it. As I've mentioned before, some drivers have taken a rather relaxed view of "extreme caution" and have gone too fast to allow them to stop in time when they see a train ahead of them. In some cases this resulted in deaths. Many cases involved trains negotiating curves in tunnels or in places where sight lines were poor. To help reduce these problems, additional stop signals were inserted in certain locations. Originally they were called "Stratford Signals"[6], after the Stratford accident on 8 April 1953 where a driver carried out the rule at a rather brisk speed and caused a collision which resulted in the deaths of 12 people. Later they became known as "Round-the-Bend signals".

Round-the-Bend (RTB) signals are only installed in tube tunnel sections where the curve radius is less than 300m and only in automatically signalled areas. They do not affect the normal headway and a driver would not usually see them at danger. Of course, if a driver has passed the previous signal under the rule, he would have to repeat the process when stopping at the RTB signal.

More recently, in some places where signal sighting is poor, countdown markers have been provided on the approach side (in rear of) the stop signal. I suspect these have been introduced as a cheaper alternative to RTB signals.

MODERN INTERLOCKING

In Article 30, I looked at interlocking for junctions, both in the lever frame and on the ground where the points are. These systems were entirely mechanical but, over many years, interlocking for railway signalling eventually progressed from mechanical systems to relay systems and more recently to microprocessors and computers. Although the main line railways had started using relay interlocking as early as 1929, London Underground stuck with mechanical interlocking for signal frames until the 1990s. Relays had been used for remote operation of sites like Wood Green but the safety was still enshrined in the mechanical lever frame. It wasn't until the resignalling of the Central Line in the early 1990s that the Underground saw the first full relay interlocking. It was introduced at West Ruislip in 1991 and several more sites were converted as the resignalling moved eastwards. Later installations had Computer Based Interlockings (CBI) instead of relays and some of the relay installations were later converted to CBIs as well.

As you would imagine, relay interlocking uses sets of relays in place of mechanical frames to prevent the setting up of conflicting routes. The main line railways' progress in this direction was driven by the growing need for huge mechanical frames at complex areas like London Bridge, where a 311 lever frame weighing 23 tons was required. Relays considerably reduced the weight and space required at such places. The Underground generally had smaller installations and, for a long time, it was the policy to keep sites small so as to reduce the impact of failures. With the Underground's smaller mechanical frames, the need for relays was seen as less urgent.

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5 Article No.17, *Underground News* No.539, November 2006.

6 My thanks to Mike Horne for reminding me of this.

Of course, relays bring their own problems, not the least being the need to have all vital (safety) circuits duplicated in such a way that a single wrong side failure could not set up an unsafe condition. For larger installations, thousands of relays were needed and the circuitry was complex. Design checking and circuit testing were very time consuming. Perhaps it was because the Central Line resignalling of the early 1990s was carried out by contractors (Westinghouse) and they held a large proportion of the risks for getting the safety systems right that London Underground were prepared to let them adopt relay interlocking.

The first conversion, at West Ruislip, was not a happy story. It was decided to re-signal the area and replace the track at the same time. Also, the signalling had to be set up for the new ATO system but trainstops and visual signals had to be retained for the old 1962 Tube Stock which was still using the line. This was the first contractor led signalling installation on the Underground and there was a lot of friction between the Underground signals people, who were used to doing their own thing, and Westinghouse who, not having done it before on LU, were actually learning installation as they went along.

The result was painful. The original plan was to close West Ruislip for a month and terminate the service at Ruislip Gardens. Those of us who remembered the 4-day Easter weekend resignalling changeover by British Rail at the huge terminus at Liverpool Street were horrified and complained that we would be the laughing stock of the industry if we closed the little two-platform terminus at West Ruislip for a month just for resignalling. Eventually the project team settled for 9 days over the August Bank Holiday weekend and up to the following weekend. With friction between the teams, some wrong-side failures during testing, changes to engineering management and safety requirements resulting from the Hidden Report[7] and the newness of the contractual arrangements, there were constant delays and stoppages of work. The resulting chaos meant that West Ruislip did not open again until 9 December 1991.

In the late 20th century, railways woke up to the fact that computers, or parts of them like micro-processors, could be used in signalling. As with relays, there was a cautious approach although, as early as 1974, LU tried one at Rickmansworth for the remote control of Watford, retaining the mechanical interlocking frame for safety. By the mid 1980s, electronics for safety systems were being considered in the form of vital processing of interlocking (VPI) on the main line railways and LU followed in 1987 when they had such a system installed at Northolt as a trial, working in parallel with the existing mechanical frame.

Of course development was slow. People were rightly nervous about using computers for safety systems. It was considered essential that some sort of real-time checking was in place in case the processor integrity failed, the programme corrupted itself or the original programme code contained unforeseen bugs. This led to the employment of multiple computer systems using two-out-of-two or two-out-of-three voting systems before a route could be cleared. Another checking technique is to use two or more processors with different individual logic programmes within the computer to maintain the diversity requirements of the vital systems. On main line railways, processor logic was developed for SSI (Solid State Interlocking), first tried

[7] "Hidden Report" – Investigation into the Clapham Junction Accident of 12 December 1988 by Anthony Hidden QC, in which a number of recommendations regarding resignalling projects were made and adopted by both BR and London Underground.

at Leamington Spa in 1985 and this evolved into CBI (Computer Based Interlocking) as later used on the Underground. In all of these systems, relays are still used for the interfaces with the trackside equipment.

To be continued …….