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11.1 Guide to TDL Testing

This section describes the operation of SSI Baseband and Long Line transmission links and provides information on recommended levels of testing, suitable test equipment and test methodologies to allow maintainers to carry out testing which meets or exceeds the requirements of RT/SMS Test 89.

11.2 Background

Experience has shown that, although generally reliable, SSI Data Link performance can become degraded as a result of events such as damage to cable insulation, Data Link Modules (DLM) and surge arrestors etc. Such events can be caused by, amongst other things, electrical storm activity, traction interference and traction fault conditions.

These faults can occur over a period of time and each may not cause total failure of the system but can degrade it such that intermittent failure or unstable system operation may result. These types of failure can also accumulate on systems and eventually cause a major failure e.g. when another Data Link fails and the system comes to rely on a degraded link. Under these circumstances the engineer could be faced by a plethora of detectable faults but would not know which of these had caused the final catastrophic failure and, as such, which to address first.

Unfortunately, it is also known that a level of degradation can exist that can cause signalling problems but may only result in sporadic reports from the SSI Technician's Terminal. It is also a fact that these reports may well not be helpful in tracing the root cause of the system reliability problems – particularly in the case of intermittent faults.

In summary, without completing some measurements and checks it may not be clear whether a Data Link is working properly or not. These potentially serious reliability issues can, however, be managed through completion of suitable maintenance.

The presence of latent SSI Data Link problems was recognised some time ago and prompted Network Rail to implement maintenance regimes capable of detecting and eliminating Data Link faults, often before they have chance to cause any system disruption. The recommended tests are documented in RT/SMS test 89. RT/SMS test 89 requires that the maintainer periodically completes assessment of the performance of SSI Data Links.

Although test 89 gives some guidance, many SSI system maintainers are unaware as to what constitutes a suitable level of testing, what equipment should be used and how it can be applied most safely and efficiently. The aim of this document is to set out best practice Data Link testing techniques which have been developed over a period of more than 15 years.

11.3 SSI and SSI Data Link systems

11.3.1 Solid State Interlocking (SSI) Central Interlocking (CI)

The first Solid State Interlocking (SSI) was commissioned in Leamington Spa in 1985 (a Mkl system). Since this time, SSI has been developed and has become one of the mainstays of UK signalling technology. The principle of operation remains the same in the latest generation systems as it was in the first. The Central Interlocking (CI) is a “2 from 3 redundant system” this safety critical computer arrangement is formed by Multi-Processor Modules (MPMs) in the CI. Each MPM is a single channel of the fail-safe interlocking computer. The CI normally operates in triplication, allowing for the failure of an MPM with no impact on the operational railway. A minimum of two working MPMs is required for continued operation of the CI. If this is not maintained, no data will be sent or received giving rise to a loss of the entire CI control area. The trackside equipment will, within two seconds of such a failure, adopt a fail-safe state.

The MPMs signal the railway by sending telegrams to trackside modules (controls) via Baseband and/or Long Line Data Links. Telegrams are generated by one MPM and checked by one or two other MPMs based on execution of a functional program; this carries out redundancy management and processing of the site specific geographic data. In order to do this, the MPMs need information about requests from the signaller (be that a person or another computer), and information as to the state of the railway. Requests reach the MPMs via duplicated Panel Processor Modules (PPM) – duplicated for availability. Information as to the state of the railway (indications) reaches the MPMs via Baseband and/or Long Line Data Links.

11.3.2 Signal / Points Modules (SM/PM)

The trackside equipment is controlled by specially designed processor modules. Signal Modules (SM) are used to control up to eight signal aspects or other loads, provide for current proving and contact detection. Points Modules (PM) permit the control of up to four point ends in a combination of two double-ended sets or a triple-ended / single-ended set across a maximum of two points numbers. Both the SM and PM have a duplicated fail-safe computer at their core and special interfaces to create a fail-safe input-output module suited for use in the railway environment. If either of the processors inside the SM or PM fails, the module will shut down and become inoperative. This results in right-side failure of the controls/indications associated with that module.

11.3.3 Technician's Terminal (TT)

The SSI CI is provided with built-in diagnostics in the form of the SSI Technician's Terminal. This terminal may be connected to up to six SSI

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CI's simultaneously and derives its data from the diagnostic processor within each CI. As there are few indicators in SSI, either at the CI or on the SM/PM, there is a clear requirement for the TT. The TT is good at the basics i.e. identifying failed lamps / points / modules etc. where the fault is persisting. The TT is less able to diagnose the root cause of intermittent faults and may well produce significant output which fails to identify any underlying cause in these circumstances.

11.3.4 Data transmission protocol

The SSI CI sends and receives fixed-length vital telegrams to/from the SM/PMs. Interlocking telegrams, those from the CI, contain control information and reply telegrams, those from SM/PMs contain indications information. The telegrams are sent and received via Data Links which are duplicated for availability; the SSI should be able to operate normally with only one Data Link operative.

Order is maintained on the data transmission systems associated with each SSI CI by the CI. The system is 'polled' in that the CI generates interlocking telegrams and only expects replies from uniquely addressed SM or PM – these modules only speaking when spoken to. The CI generates a sequence of 64 telegrams, numbered 0-63, in that order. All telegrams are generated on each cycle, called a major cycle, regardless of the number of SM/PMs attached to the system. After each interlocking telegram is generated there is a window within which the relevant module should respond before the next interlocking telegram is sent. In systems utilising baseband transmission the period between interlocking telegrams, called a minor cycle, will normally be between 9.5 and 30 ms - though it can legitimately go to 120 ms under conditions when a third MPM is introduced into an already duplicated system. Replies should be inserted in a 1.3 ms window starting no less than 4 ms after the first pulse of the interlocking telegram. In SSIs which utilise Long Line transmission the minimum minor cycle time is 12.85 ms – the maximum timings are the same as for baseband transmission. See the Data Link timing diagrams in Section 11.6.

Based on the quoted timings it can be seen that for a baseband system the minimum minor cycle time will be 608 ms; for a Long Line system 822.4 ms. In theory the maximum major cycle would equate to 64 times the usual maximum minor cycle time of 30 ms (1.92 s) but in reality there is an overall cap placed on the major cycle time of 1 s. This is done to ensure that each trackside module can tolerate missing at least one message from the interlocking and still remain on-line, and to ensure that major cycles occur at intervals that will ensure that indications are presented to the signaller within 2 seconds of occurring on the ground.

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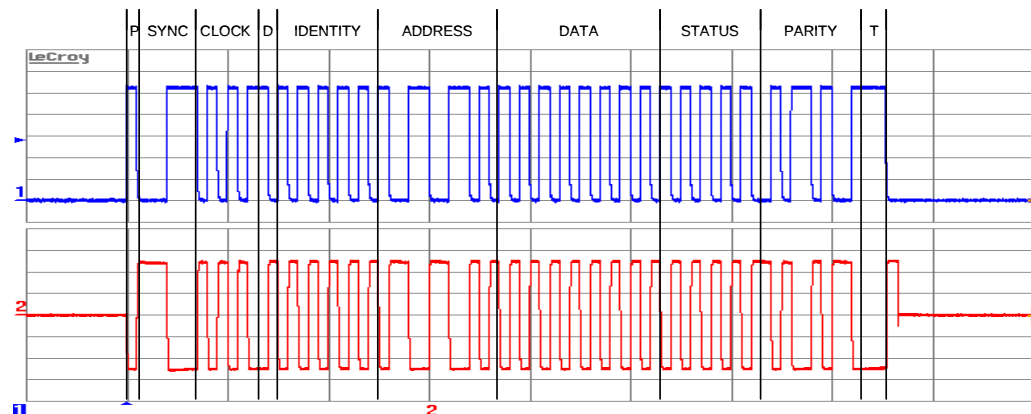
As stated, the interlocking and reply telegrams contain vital data. In order that corruption of these telegrams does not result in an invalid action, the telegrams are protected from misinterpretation in a number of ways.

The diagram below shows the construction of an SSI telegram. The nominal width of each pulse is either 50 μ s or a multiple of this figure – this gives a bit-rate of 20 kbits/s. It can be seen that the telegram starts with a precursor pulse to ‘wake-up’ any receiving equipment. This is followed by a synchronization sequence consisting of 3 pulse periods at 1 and 0. The synchronization pattern is unique in that nowhere else within an SSI telegram can the state of 1 or 0 be maintained for 3 pulse periods. Although the duration of the pre-cursor pulse is not validated, those of the subsequent synchronization pulses are. This ensures that any receiving equipment can be certain that, on receiving a valid synchronization pattern, it is seeing the start of a telegram as opposed to trying to receive part of a telegram that is already underway.

The synchronization pattern is followed by a series of clock recovery pulses which allow the receiving processors to synchronise with the incoming telegram and allow its contents to be accurately read. The pulses following this comprise the telegram information. The telegram information consists of a direction bit, system identity, address, data, status, parity and a terminator bit. The direction, identity, address, data, status and parity bits are all Manchester II coded. In Manchester II coding, each bit is sent as two ‘half-bits’. In order to send a logic 0 one would transmit a pulse period at logic 0 followed by another at logic 1. To send a logic 1, one would transmit a logic 1 followed by a logic 0. In this way two ‘half-bits’ have to be corrupted to their opposite state in order to affect the state of a single bit. The direction bit tells the receiving equipment whether the telegram is from the interlocking or a Trackside Function Module (TFM) i.e. an SM or PM. Interlocking telegrams set the direction bit to 0 and TFMs to 1.

The system identity is a 5-bit binary number indicating the identity of the system on which the telegram was generated. The 5-bit code allows for 32 combinations but 0 and 31 are never used in practice, thus there are 30 valid codes. The address is a 6-bit code that defines the address of the module that this telegram is for, or in the case of a reply, from. A 6-bit code allows for 64 addresses but address 0 is used by the SSI CI itself in order to send data to the Diagnostic MPM so cannot be used. The 8 data bits are used to transmit control or indications information to the TFM or CI depending upon telegram direction. The 5-bit status code is presently unused in the outward direction but is used to convey information about TFM and system performance to the CI in replies. The last part of each telegram is made up of 5 parity bits and a terminator. The parity bits provide the final level of protection after that provided by the synchronization and Manchester II coding. The parity bits form a Hamming code to catch both single and double bit errors. This is

accomplished by using more than one parity bit, each computed on different combinations of bits in the rest of the message.



Telegram construction diagram derived from a Digital Storage Oscilloscope trace recorded at 0.5 ms/div (Y axis)

As can be seen from the telegram construction diagram there are two traces. Both traces show the same telegram data. Trace 1, shown in blue at 0.5 V/div (Y axis), is recorded at current loop level. Current loop transmission is used within the CI cubicle, between Data Link Modules / TFMs, and on Data Link test points. Trace 2, shown in red at 1 V/div (Y axis), shows how this telegram appears when transmitted on an SSI baseband Data Link.

It can be seen that Trace 1 is a unipolar signal moving between 0 and approximately 2.5 Vpk this relating to the flow of current on the current loop interface. Current loop interfaces are reasonably immune to electrical noise over short distances but the unipolar nature of the waveform makes them unsuitable for long distance transmission. The effect of applying such a signal to a long cable would be rounding of the edges, significant losses due to resistance and d.c. level shift caused by the telegram 'charging' the cable capacitance. These effects would make the telegrams unrecoverable. Furthermore, current loop receivers utilise Light Emitting Diodes (LED). These receivers require significant current to operate and the impedances presented by these LEDs would make multi-drop circuitry unfeasible.

These problems are overcome by transmitting the telegrams in the bipolar form shown in Red in trace 2 using Data Link Modules (DLMs). The idea of this telegram makeup is that the d.c. sum of this message is 0 V. The size of the terminator bit is varied by one half-bit size in order to maintain this balance.

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11.3.5 Baseband Data Links

As stated, where transmission of the telegrams is required over longer distances, the telegrams are transmitted using Data Link Modules (DLM). These non-processor based units convert the unipolar current loop signals (typically 0 to 14-16mA or 0 to 2.5-3.5 Vpk) into bipolar signals (4.75 +/- 0.25 Vp-p but up to 6.0 Vp-p dependent on cable impedance) suitable for transmission on a cable with designed characteristic impedance of 50 Ω .

The DLM is provided with six four-wire current loop interfaces and two two-wire baseband bipolar interfaces. The DLM converts signal levels between the two. The DLM presents a high impedance to the line and can receive bipolar baseband inputs as low as 500 mVp-p. For reliable system operation it is best to maintain signal levels of at least 1 Vp-p.

One of the six current loop interfaces is usually wired to an external test point so that equipment can be attached for monitoring TFM telegrams. The DLM has its internal Echo facility enabled to ensure that even TFMs attached to other current loops on the DLM can be monitored.

Based on cable losses the maximum cabling distance is 10 km for a single plain section terminated by 100 Ω resistors at each end. Unterminated spurs of up to 1 km are allowed as long as the total section length does not exceed 10 km.

If a range beyond 10 km is required, DLMs can be used to form repeaters by wiring back-to-back. It is important to note that the telegram is not recovered and retransmitted (i.e. regenerated) by the DLM, it is merely converted to a current loop signal by one DLM and retransmitted by another. In view of the edge distortion and losses that occur on longer Data Link sections, the Data Link section length is restricted to 8 km where repeater configured DLMs are used.

Where repeater configured DLMs are used, the maximum number of repeaters is four; this gives a maximum range of 40 km where baseband transmission in copper cabling is used.

Full details of allowed cable distances and DLM configurations are shown in SS18500 Chapter D [\[Ref 3\]](#).

DLMs used as repeaters usually have their echo facility disabled to prevent messages from being echoed back, potentially clashing with other messages. Because of this it is not generally possible to monitor all TFM telegrams on current loop test points of repeater DLMs, and it is then necessary to find suitable test points on either side.

The baseband Data Link outputs of DLMs must be suitably terminated. If only one baseband interface is in use the other must be terminated. This is achieved by fitting a strap in the plug coupler between pins p-k.

11.3.6 Surge suppression

In order to protect the DLMs from electrical storm damage, some form of surge protection is always wired between the DLM baseband Data Link connections and the cable. This surge protection equipment has taken many forms since the inception of SSI.

Early schemes used discrete components to terminate the line and type 26A gas discharge Tubes (GDT) to provide protection against the pulses resulting from electrical storm ground currents.

The type 26A GDTs were supplemented by back-to-back zener diode circuitry. The principal of this design was that the back-to-back zener diodes would provide fast-acting protection against transient events, these would be supplemented by the slower acting, but higher power handling, of the GDT.

The reality was that both the surge protection equipment and DLMs were seen to be damaged by electrical storm or traction related interference.

As a result of damage sustained, improved surge protection was developed. All surge protection for new schemes is now of the 11-pin plug-in type. Where plug-in surge protection is used the 100 Ω line termination resistors are incorporated within the surge protection base.



11-pin surge protection base



Type 26A GDT

This is done such that line termination is retained even when surge protection devices are removed. Only one style of plug-in surge protection base exists and, as such, all contain the 100 Ω resistor. At the majority of sites there is no requirement for this to be in circuit – the

termination only being required at the two designated ends of the link. The termination is applied by fitting a strap between terminals 3 and 8 on the surge protection plug-in base.

The following types of 11-pin surge protection unit are known to have been, or are still, in use on Network Rail infrastructure:

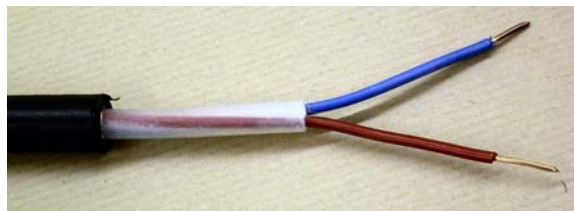
- BR1937 Furse (referred to as an SPU).
- BR1937A Furse (referred to as an SPU).
- BR1937 Clipit (referred to as an SPU).
- Jarvis Isolating Surge Protection Unit (ISPU) - four types designated A-D now obsolete.
- Park Signalling SP01(also referred to as an ISPU) - identified by its orange case and interchangeable with the Jarvis ISPU.

These newer generation surge protection modules can sustain damage but seem to protect the DLMs better than the first generation surge protection.

ISPU's are subject to fitment restriction due to the losses they introduce, and should only be fitted where indicated on the wiring diagram.

11.3.7 Data Link cable

Two types of cable were originally designed for use with SSI. The first was a two-core cable with drain wire which is understood to have been used at Inverness in Scotland. All other sites utilise a 2c 1/1.27 mm copper cable.



2c 1/1.27 mm cable

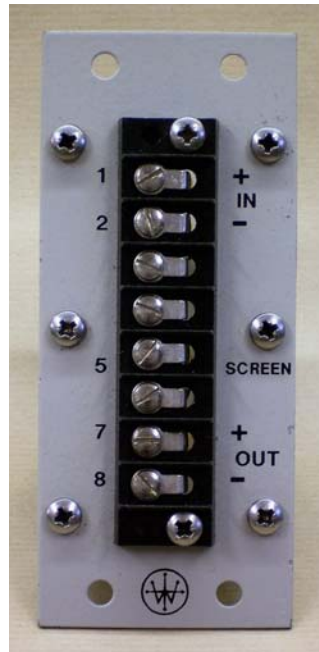
The 2c 1/1.27 mm cable is intended to provide for balanced line transmission i.e. each of the two conductors (red/blue) has a similar impedance to the other conductor and earth.

The red/blue wires are twisted and the cable has a foil moisture barrier or balancing screen that should not be connected to earth.

The characteristic impedance is achieved by the fitting of 100 Ω resistors at the designated ends of the Data Link section.

11.3.8 Data Link Isolation Transformer (DLIT)

The Data Link Isolation Transformer (DLIT) is used to isolate electrically SSI Baseband Data Link sections. This is done to limit section lengths in order to keep longitudinal induced voltages within safe limits.



Data Link Isolation Transformer

The DLIT can also be used to prevent common-mode interference from reaching DLMs.

It should be noted that although back-to-back DLMs do provide electrical isolation between Data Link sections, DLMs cannot be relied upon to isolate adjacent sections from each other for traction interference calculation purposes.

The DLIT is a non-adjustable 1:1 transformer with an inter-winding screen. The transformer is mounted on a plate which occupies a single BR930-series relay space on a standard rack.

There is a practical limit as to how many DLITs can be tolerated in a Data Link as they introduce losses and can introduce other problems such as overshoot.

For the purposes of Data Link design and the prediction of reply amplitudes during maintenance amplitude and symmetry survey planning, the DLIT should be considered to be equivalent to 600 m of cable. This figure is derived from the losses within the transformer and associated surge protection which should be provided for the DLIT.

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Since 2008, it is permissible to use an ISPU in place of a DLIT at back to back repeater DLMs and at the ends of baseband data link sections, where the ISPU will be in series with the line rather than attached as a spur. This is preferred since the ISPU introduces lower losses and can be considered equivalent to 400m of cable.

When completing non-intrusive earth leakage testing in accordance with the method shown later in this document, it should be noted that the presence of a DLIT (or ISPU where fitted in place of a DLIT) will limit the length of cable tested. This should be taken into consideration when planning testing to ensure that all sections of cable are tested.

Although the DLIT blocks the d.c. signal used during earth tests, the DLIT should not be seen as a section delimiter for the purpose of planning amplitude and symmetry tests.

11.3.9 Long Line Link (LLL)

As can be seen from the previous sections, the range of SSI is limited to 40 km when using the copper distribution with DLMs. The Long Distance Terminal (LDT) was developed to overcome this limitation.

The LDT allows SSI 20 kbit/s telegrams to be sent over a 64 kbit/s links. The LDT is provided with an SSI current loop interface, similar to that on the DLM, as well as a G703 contra-directional data interface. In order to maintain the vital nature of the SSI telegram whilst sending the data over a telephone network, the LDT must insert additional coding.

Each LDT free plug coupler is wired with a Control Centre Identity (CCI). The CCI is unique in the world and is required for each group of up to 30 CIs at a control centre. The CCI values are compared at the interlocking and trackside ends of a Long Line Link. If they do not match it is considered that the telegram data is not intended for that destination and is rejected.

In order to overcome the risks associated with bit errors that could occur in the transmission process, the LDT sends each telegram message twice. One message is sent 'normal' sense and one 'inverted'. The two messages are compared at the receiving end and the two halves subjected to a bitwise comparison. If each bit is not opposite to that of its corresponding bit in the second copy of the telegram, the message is rejected.

In order to send the additional information the Long Line Link must be faster than the SSI link. The long line link speed is 64 kbit/s – more than three times faster than the SSI 20 kbit/s link. The LDT must manage this speed change.

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The telecommunications network to which the LDT is connected allows for either point-to-point or multi-drop distribution of the data. In point-to-point distribution there is an interlocking LDT, installed in the CI instead of a DLM, and a trackside LDT. In multi-drop systems, or drop and insert as it is known to telecommunications engineers, there is an interlocking LDT in the CI and a number of trackside LDTs at the pre-determined drop and insert points.

Typical Long Line Link systems utilize LDTs for the long distance data distribution and then feed into baseband Data Link cabling as already described. By using LDTs, systems can be constructed with diversity of link routing. A typical Long Line Link system based on a point-to-point link would transmit data on one link to one end of the geographical area to be covered and the other link to the other end. The distribution of the Data Link from these points would then be arranged to feed towards each other from the ends in copper cabling using the techniques described above – passing in the middle.

An alternative to this, often used to limit section lengths, is to have multi-drop LDT sites with a number of localized baseband Data Links fed from opposite ends.

Sometimes an LDT and associated drop and insert node will be provided purely to drive up to five TFMs directly, possibly where TFMs are provided at a signal box or relay room as a vital interface to a panel or relay-based interlocking.

It should be noted that it is not possible to have one link purely DLM based and one link LDT/DLM based. They both have to be either all baseband or both have to be LDT/DLM based – even if this means having one Data Link feeding straight into and out of a transmission system within the same room.

The reason for this is to do with the way in which reply timing is dealt with in LDT systems. In pure baseband systems replies are transmitted by the TFMs following receipt of the relevant interlocking telegram and within the window of 4-5.3 ms from commencement of the interlocking telegram. In LDT systems the transmission delays are such that the system would have inadequate range if replies were to be received back at the interlocking in the minor cycle immediately subsequent to the relevant interlocking telegram.

To overcome this, LDT systems use what is called the n+1 protocol. In this system, the interlocking telegram is transmitted as normal by the CI. It is received by the interlocking LDT and when the LDT has received enough of the interlocking telegram to know that the telecoms systems will not 'out-clock' the arrival of the SSI telegram, transmission to the

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telecommunications system is released. Two versions of the telegram are then sent along with the CCI information.

When received by the trackside LDT, the CCIs and telegram data are compared bitwise and the telegram output to the baseband part of the SSI as long as the two halves of the telegram (normal and inverted) compare favorably. The TFMs then receive this telegram and respond accordingly as in a pure baseband system.

This reply is received by the trackside LDT which sends the reply back to the CI over the telecoms system. By the time this reply is received at the interlocking LDT, the next interlocking telegram will already be being produced by the CI. The reply received by the interlocking LDT is held until transmission of the next interlocking telegram is complete and the reply is then inserted in the minor cycle subsequent to the relevant interlocking telegram. This means that when viewed at the interlocking current loop test points the sequence would be telegram n, reply n-1, telegram n+1, reply n and so on. See the Long Line Link timing diagram in Section 11.6.2.

The LDT presents special problems in that it is connected to systems or equipment that may be maintained and/or owned by different companies. This means that different staff will be responsible for different parts of the transmission network. The LDT is provided with additional indicators in recognition of this problem and details of LDT indicators and their interpretation are shown later in this document.

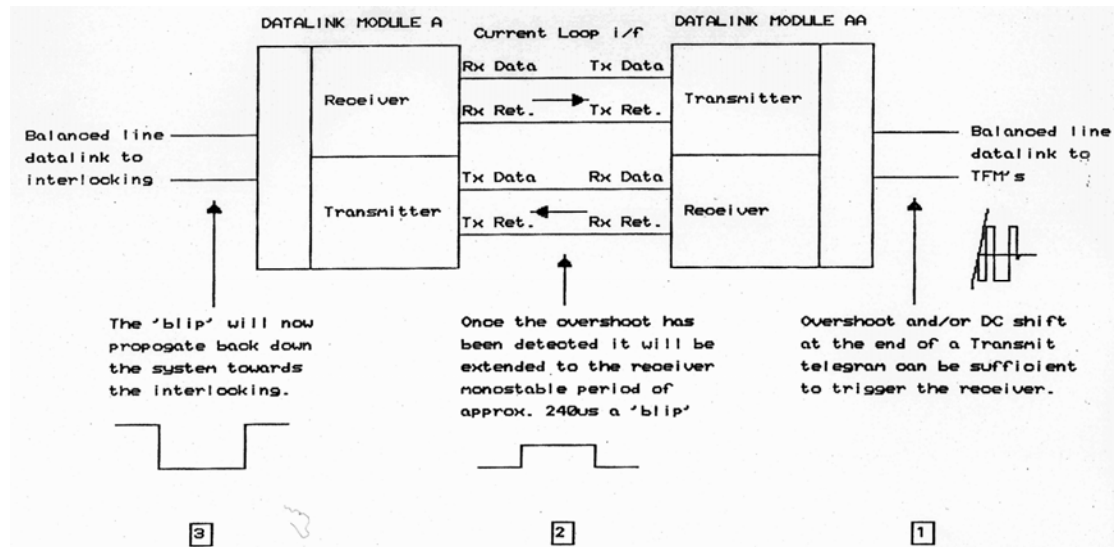
11.4 What goes wrong with SSI Data Link systems

11.4.1 Systematic anomalous pulses - mismatch by centre feeding / DLIT

Given that the 2c 1/1.27 mm cable has a loop resistance of $22 \Omega / \text{km}$ and the characteristic impedance is formed by two 100Ω resistors at each end of the link, the characteristic impedance will only be 50Ω on a Data Link of zero length. The worst case appears to be where the maximum cabling length of 10 km is used such that the impedance of a correctly terminated line would be 76Ω . This has an effect on the telegram launch levels observed on the Data Link. When observed from the point of transmission in the middle of such a link, telegrams may well be above the $4.75 \pm 0.25 \text{ Vp-p}$ limit. As long as no telegrams are above 6 Vp-p no problems should occur. At the extremities of any Data Link, the telegram amplitudes should not be below 1 Vp-p .

The impedance problem described above normally has no effect. However, if the site transmitting into an artificially high impedance happens to be a back-to-back repeater arrangement, then any overshoot on the last edge of the oversize telegram can trigger the receiver of the

transmitting DLM and cause the generation of anomalous pulses as shown below:-



Baseband Anomalous Pulse (Blip) Generation

These anomalous pulses, or blips, are of characteristic length and amplitude. The length will always be around 240 μ s and the amplitude will be that of the transmitting site. The amplitude can be used to identify the transmitting site as long as the anomalous pulse has not struck any other messages on the Data Link.

All DLMs used in current SSI systems are of the MkIII, or MkIIIA type. These DLMs have 2 possible modifications states 1 and 2. Modstate 1 DLMs are more susceptible to spurious triggering caused by the problem described above and it is best to replace any modification state 1 units with those of modification state 2 at least at back-to-back repeater sites. Modification state 2 introduces extra circuitry to reduce the incidence of anomalous pulse generation but do not eliminate the risk completely.

Another way round this problem is to split any centre-fed Data Links using the second baseband output of the DLMs; breaking the onward Data Link into two simple end terminated links.

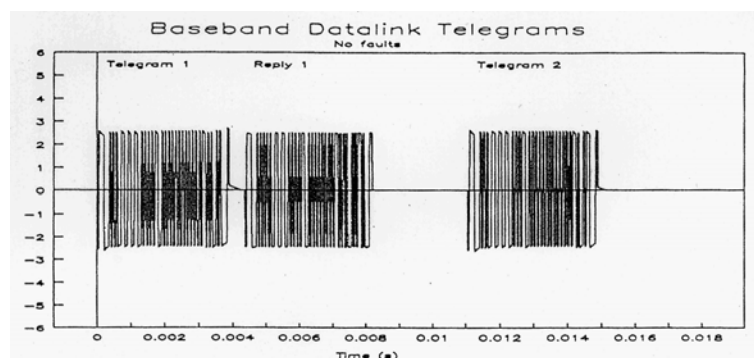
Another possible cause of systematic anomalous pulses is that related to connection of DLITs to a DLM output causing overshoot and the same problem as explained above. Again, modification state 2 DLMs offer one solution where the effect of the overshoot is less - though the overshoot itself is unchanged. Another possible solution is to use Park Signalling type SP01 Isolated Surge Protection Units (ISPU), which incorporate an isolation transformer, instead of a DLIT; though this would have to be recognized in the design.

11.4.2 Systematic anomalous pulses - damaged DLMs

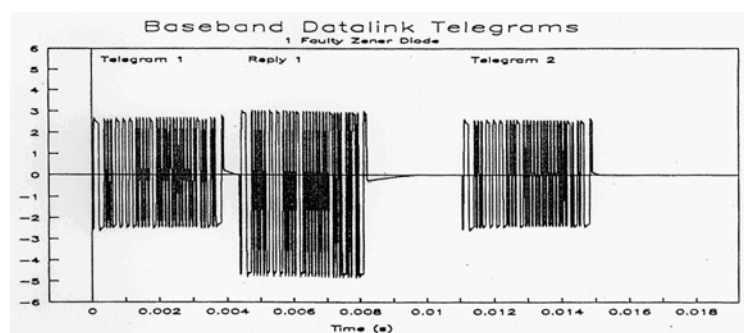
Under conditions of serious traction / electrical storm damage or as a consequence of an earth fault, DLM output damage may occur. Unfortunately, this damage usually manifests itself as short circuit Zener diodes on the DLM output which, although not causing outright failure of the DLM can cause serious problems. The Zener diodes are internal to the DLM and are in series with its output. When damaged, the output may be asymmetrical in either polarity or oversized. The waveforms overleaf illustrate these problems.

Such asymmetric or oversized telegrams can give rise to anomalous pulses by virtue of triggering systematic anomalous pulse production as a result of introducing d.c. shifts on telegrams or exacerbating overshoot by virtue of excessive amplitude, or both.

Faulty DLMs must be identified by regular maintenance checks in the form of Amplitude and Symmetry surveying as detailed later in this document. Once identified, any DLMs with asynchronous or oversized outputs should be changed.



Normal Telegrams (1 V/div. 1 ms/div.)



Normal Interlocking Telegrams with Asymmetric Reply – Note the Negative d.c. Shift at the End of the Reply (1 V/div. 1 ms/div.)