4 Lady Penrhyn Drive
Unanderra NSW 2526
Ph +61 2 4255 4300
Fax +61 2 4271 8990
www.ringway.com.au
ABN 47 087 315 179

WHY CHOOSE

RINGLINE?

DEFINITIONS

The following list defines terms and abbreviations used throughout this document.

RCA	Ringway Control and Automation
PES	Programmable Electronic System
PE	Programmable Electronic
SR	Safety-Related
EUC	Equipment Under Control
RCS	Ringline Control System
AS	Australian Standard
AS 1755	2000; Conveyors – Safety Requirements
AS 61508	2011; Functional Safety of Electrical, Electronic & PE Safety Systems
AS 62061	2006; Functional Safety of SR Electrical, Electronic & PE Control Systems
ISO 13849-1	2006; Safety of Machinery – SR parts of control systems – design principles
AS 4024.1xx	2006; Safety of Machinery
Category	(CAT) = Classification of SR parts of a control system with respect to their resistance to faults and subsequent behavior in the fault condition.
uP	Microprocessor
SF	Safety Function
SO	Safety Output
ELV	Extra Low Voltage
DC	Direct Current
EOL	End of Line
WRT	With Respect To

1 RINGLINE DISTRIBUTED EMERGENCY STOP SYSTEM

1.1 Introduction

Ringline is a programmable electronic system (PES) that can facilitate an emergency stop network of up to 96 distributed emergency-stop devices by interlocking them to redundant pairs of emergency-stop interlocks in the equipment under control (EUC). The status of pairs of electrical interlocks in all emergency stop devices is encoded onto the two-wire field bus (Ringline) by electronic field-transmitters. The Ringline control system (RCS) energises the bus to power all transmitters and decodes the status all emergency stop devices from the bus. By this process redundant Safety Function Outputs are controlled by the status of all emergency stop devices to either inhibit or allow conveyor running.
Ringway Control and Automation (RCA) has specialised in conveyor electrical control systems since 1990. In 1996 RCA developed the Ringline operating philosophy and design in response to the operational and functional safety weaknesses that were inherent in competing products. From that time Ringline has been extensively used to interlock emergency-stop lanyard switches and other field safety devices to the electrical control systems of industrial and mining conveyors.

Major Ringline users include Rio Tinto, Xstrata, BHP Billiton, Peabody Energy, Capcoal, NRE Gujarat, Anglo Coal, Centennial Coal, Port Waratah Coal Services, Gladstone Port Authority, Blue Scope Steel and Australian Bulk Minerals.

Ringline conveyor signal-line applications include conveyor systems for underground coal mining, diamond mining, salt mining, magnetite mining, ship loading (coal, magnetite, salt) and coal preparation plants. Diversified emergency stop installations include laboratory, mine-lift, moving walk-way and ski lift applications.

This document covers the advantages that the Ringline design and operating philosophy provide over competing systems. For detailed technical and operational information see the RL2EMERG, RLCONV and RLDISP2 user manuals.

1.2 Ringline Functional & Reliability Advantages

Ringline has demonstrable competitive advantages that result from a robust design specification and years of refinement. **Major strengths and points of difference include**;

1.2.1 NO 'DAISY-CHAIN' of SAFETY INTERLOCKS – ENHANCES SAFETY

Major strength and point of difference: The fundamental functional integrity and reliability of Ringline stems from the field bus remaining 'electrically unbroken' at all times. This was a Specified design requirement for Ringline because any system that relies on a 'daisy-chain' of normally-closed electrical interlocks (almost all competing systems) is exposed to both unsafe (functional) and safe (reliability) failures. Unsafe (functional) failures result from earth or cable faults providing an alternate electrical path that bypasses safety interlocks (e.g. due to cable squash or environmental ingress to devices). Safe (reliability) failures result from faulty /dirty interlocks and/or open circuits in the 'daisy chain' circuit, which result in trips without a location report and extensive downtime. This is comprehensively explained and demonstrated at 3.3.

- The vulnerability of 'daisy-chain' / EOL systems to defeat by cable faults, or earths created by environmental ingress (to devices) is particularly alarming **because cable damage and environmental ingress are almost certain to occur!**
- The potential for this failure type increases as field devices and cabling begin to deteriorate over time.

Note: 'Earthing' the 'common' leg (of 3-wire systems) could reduce exposure to safety function defeat by field earths, but would pre-dispose / expose the system to;

1. Downtime due to bus short-circuit (resulting from earth on either positive leg)
2. Lightning strike damage due to ground reference (see 1.2.4)
3. Differential electrical noise due to unbalanced circuit (see 1.2.6) or electrical energy from VVVF drives or other 'dirty' earth energy.

1.2.2 NO 'EOL' UNIT = ANY BUS TOPOGRAPHY – VERSATILITY WITH SAFETY

Major strength and point of difference: Ringline does not use an 'End Of Line' (EOL) transmitter or device. As long as all Ringline safety transmitters are connected to the bus any bus topography can be employed. Safety is assured because **all** safety transmitters must be transmitting a healthy data pattern at **all** times. This feature can more than halve maximum circuit lengths (WRT EOL systems), therefore greatly increasing system reliability and / or operating distance by reducing voltage drop.

'No EOL unit' was a Specified design requirement for Ringline because systems with EOL units (almost all competing systems) must,

- employ a daisy-chain of electrical interlocks (to open-circuit the EOL unit for every trip). See 1.2.1 above and 3.3 for why Ringline rejects 'daisy-chained' interlocks.

- guarantee that the EOL is actually situated at the end of line, but cannot!

Risk relating to the second bullet-point is accentuated by the fact that a main trouble-shooting technique used to locate an unidentified break in the 'EOL' circuit is to advance the EOL unit towards the drive-head until the conveyor starts! Thus demonstrating that the system can become 'healthy' wherever the EOL is connected!

This is comprehensively explained and demonstrated at 3.3.9 & 3.3.10.

1.2.3 TWO-WIRE CONFIGURATUON MINIMISES 'OPEN CIRCUIT' DOWNTIME

Major strength and point of difference: Ringline uses only two wires and all safety device transmitters are required to be connected and transmitting at all times. Therefore the location of any break in the filed bus can be located immediately because any/all transmitters located beyond any break cease transmitting. For open-circuits inside a specific device, the transmitter inside 'that' device will be the only unit not transmitting.

This was a design Specification for Ringline because the '3rd wire' circuit (in 3-wire systems) has always been highly susceptible to open-circuit trips that give no clue to their location and create extensive down-time (note that a break in the 'common' wire has same outcome). This is comprehensively explained and demonstrated at 3.3.1 & 3.3.2.

- At high value, high production facilities the cost of downtime caused by a single unidentified open-circuit can exceed multiples of the total initial cost of the whole signal line system!
- The potential for this failure type increases as field devices and cabling begin to deteriorate over time.

1.2.4 LIGHTNING PROTECTION IN EVERY DEVICE

Major strength and point of difference: Being 'balanced' and having no reference to ground minimises the potential for the Ringline bus to become a target for lightning. Regardless of this a protection device is built into every Ringline transmitter to instantly dissipate differential transient energy. The distribution and combination of these devices creates fast-acting electronic clamp across the bus that is capable of dissipating massive amounts of energy. Despite having extensive installations in lightning prone zones (e.g. tropics) and experiencing several known direct lightning strikes less than 6 Ringline field transmitters have been damaged by lightning since 1996 (all in one incident).

Protection against lightning and electrical transients was a design Specification for Ringline because **lightning is a known enemy of electronic systems** and we had witnessed multiple failures on existing systems due to lightning strike. We identified the main design weakness with these systems as having any reference to ground.

- Lightning strike on vulnerable electronic equipment controlling high value, high production facilities can lead to devastating downtime costs.

1.2.5 COMPREHENSIVE DIAGNOSTIC COVERAGE via SYSTEM DISPLAY

Major strength and point of difference: Ringline provides comprehensive system and diagnostic data via a dedicated local display. The Display also marshals the data to a slave port, for acquisition via a PLC or SCADA system. Diagnostic data includes;

- A 10-event Stoppage History Listing for each Safety Function uP
- The digital transmission status of all channels
- The analog transmission status of all channels
- The current-draw registered for each transmission

This level of diagnostic coverage was a design Specifications for Ringline because some systems provide no or too little diagnostic information, often relying on user-monitoring of asynchronous data to determine trip reason/s. In particular the Ringline Stop History was implemented to capture and store the exact reason for even the most intermittent trip.

- Comprehensive communications directly from Safety Function microprocessors is essential to system understanding and troubleshooting – some systems provide none. A Stop History log is an invaluable aid.

1.2.6 SIGNAL INTEGRITY & NOISE REJECTION BY DESIGN

Major strength: Ringline is a twisted-pair, balanced (current out = current back), low-energy field circuit with no reference to ground (is floating). When combined with differential amplification these features achieve very high common mode noise rejection. Signal integrity is further assured by using a 'current-over-time' transmission detection technique.

These were design Specifications for Ringline because three-wire systems are unbalanced, which can cause false detection if/when differential noise is amplified. Voltage detection methods are also more readily affected by noise imposed on the signal. Because of these design considerations Ringline has proved remarkably resistant to adverse effects from electrical noise.

Intrinsic Safety & Signal Integrity

Major strength and point of difference: Enhanced signal integrity is just as desirable for systems installed in hazardous locations. To this end Ringline was designed to achieve IECEx ia intrinsic safety (IS) certification using no barriers. This means that IS installations also 'float' above earth, are balanced and are not attenuated by barrier impedance. Competing systems require approved barriers (in the field bus) to achieve intrinsic safety. Barriers can introduce a reference to ground and attenuate bus energy due to barrier impedance. This reduces maximum operating distance and/or the reliability of operation at any given distance.

1.2.7 FULLY DOWN-LINE POWERED OVER GREAT DISTANCE

Major Strength: Ringline devices have very low power requirements and use simple but robust transmission and detection methods. This allows the system to achieve very reliable operation over very long distances (to 12k) while being fully down-line powered with ELV DC.

Low power and robust transmission techniques were design Specifications for Ringline to facilitate two-wire operation (excessive voltage drop and poor transmission detection were the historic drivers that lead to the 3-wire concept). This history is explained at 3.2.

1.2.8 NO 'STUCK AT' FAULTS - Continuous Hi / Low Operating Logic

Major Strength: Healthy Ringline transmission logic requires a Hi:Low (1:0) transmission pattern on adjacent Ringline channels from each safety device transmitter. When a device is tripped the Ringline transmitter is required to transmit a Low:High (0:1) pattern. Because both transmission 'states' (1 & 0) are performed by the same electronics in each device the ability to switch high and low is tested five times per second. This ensures that the 'tripping' capability of the electronics is always known.

This was a design Specification for Ringline because systems that transmit 'steady state' logic are not tested for their ability to change state until they are required to, by which time it can be too late to know that they cannot.

1.2.9 Robust Safety Function – REDUNDANT uP's & SAFETY OUTPUTS

Major strength: Every Ringline Safety Function is executed by one or more Safety Function Card (SFC). Each SFC has a pair of redundant Safety Outputs (SO's) jointly controlled by two independent microprocessors (uP's). This means that 'two out of two' voting is required to energise either SO. The redundant switching elements in each SO are physically diverse and are individually tested during the safety function process. This feature, plus cross-checking between uP's ensures that **both** Safety Outputs trip if **either** uP is unhappy.

This design specification for Ringline exceeds the architectural and system integrity requirements of the functional safety Standards.

1.2.10 Versatile – EASY ADDITION, REPLICATION & DISTRIBUTION

Major strength and point of difference: The Ringline operating philosophy **readily allows duplicate and/or different additional Safety Functions to be implemented anywhere** along the field bus. This is ideal for installations that require multiple (but different) Safety Functions at any location (e.g. Emergency Stop and Remote Isolation Control) and/or where the same function is required to be performed at multiple drive sites (e.g. long conveyors with 'head' and 'tail' drives and/or 'tripper' drives).

New or duplicated safety functions are created by installing an additional Safety Function Card at the required location. All functions have equal safety integrity because they use identical (duplicated) hardware and software. This means that every Safety Function node has its' own pair of Safety Outputs C/W dedicated controlling microprocessors.

Validation of a network to a specific Functional Safety target is greatly simplified because there are no external considerations (e.g. PLC hardware or software). This means that a distributed emergency stop system with a specific functional safety target can be configured for conveyors with distributed drives (e.g. Tripper or Tail Drives) using the Ringline system alone.

This was a design specification for Ringline to allow distributed drive motors and/or multiple distributed safety functions to be controlled with a safety integrity that is demonstrably equal. Other systems have single or limited Safety Function capabilities and/or an inability to demonstrate equal safety integrity at multiple locations.

1.2.11 Extended Safety Function – INTEGRATED FEEDBACK MONITORING

Major strength and point of difference: Ringline monitors Safety Output (SO) status internally as well as offering configurable monitoring of downstream elements being controlled by the Safety Outputs. The internal monitoring provides SO checking via both uP's and cyclic checking of the switching elements controlling both outputs (enhanced diagnostic coverage). External feedback inputs for each Safety Output allows downstream and/or final drive elements to be monitored for correct operation as follows;

- Mode 1: downstream elements must always follow Safety Outputs … or
- Mode 2: downstream elements must always successfully trip to enable system 'Reset'

This was a design specification for Ringline to increase diagnostic coverage of the Safety Function hardware and to integrate diagnostic coverage of the Equipment Under Control (confirm Safety Function outcomes). Competing systems do not provide this feature.

1.3 Configuration Advantages Summary

A full explanation of the shortcomings of the other field bus configurations and the advantages of the Ringline two-wire field bus (complete with explanatory circuit diagrams) is provided in **Why Ringline Uses Two Wires – see 3**.

In summary the most important distinctions between other field configurations and Ringline are that;

- Ringline is not exposed to the safety function being defeated by cable faults, earth faults or environmental ingress to safety devices. *Other systems can be and are periodically defeated by such faults.*
- Although Ringline conductors should never be open circuit, any open circuit fault in the Ringline bus is self-revealing. *Other systems regularly experience downtime due to open circuit faults that provide no indication*.

- Electrical supply to Ringline transmitters is better guaranteed because the bus does not pass through interlocks in any field device, minimising the chance of voltage drop (or open circuit) due to high resistance or faulty contacts.
- Although Ringline safety is not affected by field earths its' 'floating' bus simplifies earth fault location (by manual or automatic means), allowing faults to be detected and eliminated before they lead to downtime.
- Despite being absolutely critical (to safety performance) for any End Of Line (EOL) module to be connected at the end of the signal line, **alarmingly**, *EOL 'safety' systems will 'energise' with the EOL module connected 'anywhere'!*

  Rather than one (e.g. EOL) module being connected 'anywhere' the energisation of the Ringline safety outputs relies on every safety device transmitter being connected and transmitting a correct pattern.

1.4 Other Advantages Summary

1.4.1 Ease of Fault Finding

The Display Stoppage Event History captures the exact reason that the Safety Outputs were opened for the last 10 stoppages (transitions from Ringline Healthy to any fault condition). This tool is invaluable in identifying the most problematic faults, which are intermittent operations of the signal line that are too fast to be captured by any PLC or SCADA system.

It can be impossible for PLC or SCADA systems to determine such operations based on asynchronously gathered data, where capture relies on the (usually slow) data update time, plus the extent to which all possible events have been 'anticipated' by the PLC code. The result is that intermittent faults are often missed, plus some faults may always be missed.

Importantly Ringline display messages and the Stop History Log reveal the nature of each operation at the specific location (Ringline address) rather than indicating a generic 'error' from the address. Example messages include 'SYSTEM STOPPAGE AT (x)', 'NO TRANMISSION FROM (x)' and 'INPUT DISSAGREEMENT AT (x)'. Although '(x)' is the Ringline safety transmitter address assigned (to the safety device) a display line is reserved for installation-specific information e.g. 'LANYARD SWITCH 17'.

When combined with the simple operating principles of Ringline the comprehensive nature of the information provided by the system display has proved sufficient to assist personnel at remote sites who often have had little or no system training.

The information provided also greatly assists Ringway provide remote fault finding assistance over the phone. The simplicity of the system and the ease with which most queries can be handled remotely (by phone or email) is proven by the fact that there are many Ringline sites within Australia and Asia that we have never visited and that have never received or required any Ringline training.

The Display marshals the Stop History and other system data (e.g. diagnostic data - see following) to make it available to any monitoring PLC or SCADA system via the auxiliary communications port.

1.4.2 Advanced Diagnostics

Advanced diagnostic information provided by the display includes:

1. Tables showing the digital transmission status of all channels.
2. Tables showing the analog transmission readings of all channels
3. Tables showing the DC current being generated by the transmissions from each field transmitter

This data can be used directly by maintenance personnel for troubleshooting or can be monitored automatically / remotely via a PLC or SCADA system. The analog table is particularly useful in picking up even the most intermittent transmission error or disturbance from digital transmitters, while the DC currents generated by each transmission can help reveal and locate both short-circuit and high resistance faults in the field bus. Most importantly such trouble-shooting <u>can be done to prevent downtime</u>, rather than only after it has been experienced.

1.4.3 Standardised Operation and Fixed Response Time

Ringline equipment and devices have fixed functionality and a single ‘current release’ firmware version for each product. Our approach does not permit any site-specific variations. Any device or system configuration requirements (e.g. assignment of addresses for a specific conveyor or application), are firmware limited within strict parameters, <u>but key functionality is fixed and cannot be altered</u>. Because all controllers always behave in an identical fashion a ‘common spare’ concept applies at a site and across sites, avoiding risk management issues for users (some competing systems have user-preferred firmware and functionality variations across sites and permit user configuration of functionality).

Ringline is simple. All field transmitters are connected to the two-wire at all times with a positive and common wire. Each transmitter has a numeric address and two input channels (A & B). The ‘A’ and ‘B’ input channels are wired to independent interlocks in the safety switch or device being monitored. The Ringline controller requires each safety device transmitter to be always transmitting on its’ ‘A’ channel and never transmitting on its ‘B’ channel. Any operation or loss of a safety transmitter changes this logic causing **two fully redundant safety outputs** to de-energise. The response time for this operation is fixed because Ringline ***gathers <u>all</u> system data several times a second***. This fixed response time allows channels not used to control the safety outputs to be used by the PLC or SCADA at a known fixed update time.

1.4.4 Engineering Support

Ringway provides the highest high level of engineering support for Ringline, a product that it has designed and developed from the ground up. All design knowledge is retained in-house as is the manufacture of all components. Ringline has many experienced engineers and technicians who can solve most Ringline issues over the phone.

Ringline has been used by a growing list of satisfied customers since 1997. Our feedback indicates that customers are satisfied both with the performance of Ringline and with the level of technical support available. If required. Ringway may be approached for a list of users.

1.4.5 Product Development

Ringway continues to specialise in the specification, design, manufacture, installation, commissioning and maintenance of conveyor control systems. This allows us to keep abreast of industry best practice, changing requirements and performance issues relating to Ringline and to its' competitors. The knowledge gained informs what has been a continuous design and development process for our functional safety engineering and electronic systems.

We are continuously looking at ways to develop and improve the capabilities of Ringline and are always interested in receiving customer feedback including observations and ideas for improvements.

Examples of application and customer driven improvements include;

- An expansion of system channels to facilitate 96 dual-channel transmitters (previously 64) for better coverage of long or complex installations.
- Fully line-powered analog transmitters for bearing temperature monitoring.
- Time-delayed digital transmitters, allowing belt sway switches and chute probes to be interlocked to the safety outputs with a 'delay before trip' function.

1.4.6 Excellent Track Record - Reliable Performance at Every Installation

Ringline has been installed and used as a distributed emergency stop system for conveyors since early in 1997. Ringline has had no troublesome installations from that date until now. Ringline has been extensively installed alongside VVVF and Flux Vector Drives in many harsh environments and has remained unaffected by electrical noise at any installation.

During this time many systems have also survived several direct lightning strikes (on their conveyors), after which other equipment has been adversely affected.

Long-term Reliability Examples;

Example 1 - Port Waratah Coal Handling Services (PWCS) - Newcastle:

Ringline was installed as part of the Kooragang Island Coal Loader expansion project at Port Waratah. This coal loader was the biggest in the Southern Hemisphere and handles Hunter

Valley coal exports through the Port of Newcastle in 24hr, 7 day a week operation. Ringway was involved as an observer (one person) for one commissioning day only in April 2001. In the same month and year we provided one days training to a single 'train the trainer' operative from the facility.

In the interim period (04/01 to 04/14) Ringway has handled one call for assistance over the phone (in 2006) and made a one day site service visit (in 2007). Refresher training was provided subsequent to the 2007 visit. The site nominated (and used) the system for their expansion project, as well as the upgrade of their Carrington site.

Example 2 – Australian Bulk Minerals – Savage River - Tasmania:

Ringline was installed on an overland conveyor at Savage River (an Australian Bulk Mineral magnetite quarry on the West Coast of Tasmania) in 1998. ***In the period since the installation Ringway has provided a single 'one day' service call to the site*** (in 1999). Following the success of the system ABM purchased and installed Ringline for its ship loading facility at Port Latta on the North Coast of Tasmania – Ringway was not involved in the installation or commissioning of this facility and has had no assistance queries or requests from either site since (both still in full operation).

Example 3 – Bulga Coal Management – Hunter Valley N.S.W.:

In 1991 Ringline was installed on a 3klm overland conveyor and short bunker conveyor transporting coal from Colliery operations to the Coal Preparation Plant, providing emergency stopping down both sides of the conveyor and remote electrical isolation down one side only.

Ringway has had two 'telephone assistance' calls from this sight over the life of the installation to date. Both calls related to a direct lightning strike on the conveyor.

Neither incident required a site visit by Ringway personnel or resulted in the failure of any Ringline equipment. ***Normal operations were restored using telephone advice only*****.**

Several sites using other signal line systems have become so disillusioned with poor performance and downtime that they have opted for site-wide changes to Ringline. Although the option seems drastic and initially costly in all cases the expenditure was justified based on ***the cost of downtime being experienced with the less effective systems, plus the potential cost of safety issues arising***.

Each time Ringline has been involved in an evaluation process which has included presentations and full comparisons against competing products it has prevailed in the selection process. We are always happy and prepared to present our system either alone or in any comparison study against any other system or systems.

2 Standards Compliance

2.1 Australian Work Health & Safety Acts & Regulations

From 1/1/2012 the majority of Australian States and Territories commenced Work Health and Safety Acts and Regulations aimed at providing a balanced and nationally consistent framework to secure the health and safety of workers and workplaces. These Work Health and Safety Acts of Parliament and their enabling Regulations are aimed at protecting workers and other persons against harm to their health, safety and welfare through the elimination or minimisation of risks arising from work. To this end their guiding principle is that *workers and other persons should be given the highest level of protection against harm to their health, safety and welfare from hazards and risks arising from work or from specified types of substances or plant as is reasonably practicable.*

These Laws and Regulations impose a duty on designers, manufacturers, importers, suppliers and users of plant (equipment / machinery) alike, requiring them –

‘(a) to eliminate risks to health and safety, so far as is reasonably practicable; and
(b) if it is not reasonably practicable to eliminate risks to health and safety, to minimise those risks so far as is reasonably practicable.’

In relation to such duties "reasonably practicable" is defined as –

‘that which is, or was at a particular time, reasonably able to be done in relation to ensuring health and safety, taking into account and weighing up all relevant matters including –

- *(a) The likelihood of the hazard or the risk concerned occurring; and*
- *(b) The degree of harm that might result from the hazard or the risk; and*
- *(c) What the person concerned knows, or ought reasonably to know about –*
  - *i) the hazard or the risk; and*
  - *ii) ways of eliminating or minimising the risk; and*
- *(d) The availability and suitability of ways to eliminate or minimise the risk; and*
- *(e) After assessing the extent of the risk and the available ways of eliminating or minimising the risk, the cost associated with available ways of eliminating or minimising the risk, including whether the cost is grossly disproportionate to the risk.’*

While compliance with most Australian Standards is not mandatory, satisfying these 'catch-all' requirements of WH&S Acts and Regulations is the Law. Compliance with relevant Standards does however provide one of the best and most proven paths to minimising risks and demonstrating compliance with the duty of care imposed by WH&S Laws.

By way of demonstrating due diligence, it is also important to investigate and show consideration of 'industry best practice' in regard to the design, specification and application phases.

2.2 Australian & International Safety Standards

The fundamental function of a PES applied to conveyor lanyard-switch control is to **interlock** the status of the distributed **lanyard-line switches** and other connected safety devices **to the conveyor control system**. Standards have been developed to set minimum criteria, provide design rules, strategies and guidelines relevant to such tasks, to enable such interlocking to be achieved with a defined and demonstrable degree of functional integrity.

Using the Standards as a guideline the risk required to be mitigated by a safety system is estimated and the mitigation method/s (used to counter the risk) are designed, implemented, verified and fully documented. Following this process demonstrates and documents the 'duty of care' and due diligence required by the Standards and the **WH&S Acts and Regulations**.

2.2.1 Which Standards & Why?

There are a number of relevant Australian and International Standards that provide guidance in relation to designing, manufacturing, specifying, implementing and employing a programmable emergency stop system for industrial conveyors or similar machinery. Following is an introduction to the Standards consulted during the development of Ringline and their relevance to the process.

AS1755 – Conveyors – Safety Requirements is the relevant standard covering the safety requirements for conveyors installed in Australia. The release of the third edition (2000) of **AS 1755** made it allowable to use Electronic and or Programmable Electronic Systems (PES) for conveyor control and remote isolation purposes. This is providing they have *'a level of performance at least equal to that afforded by conventional hard-wired safety systems'* (**AS 1755 - 2.7.2 System integrity**).

AS 1755 also calls for conveyors and conveyor systems to be *'designed and constructed consistent with the relevant requirements of **AS 4024.1** and other relevant Standards.'* (AS1755 2.1 General).

AS 4024.1 – Safety of Machinery – is directly called on by AS 1755, which stresses the importance of complying with 'relevant clauses'. This Standard defines an approach to risk estimation and risk mitigation, wherein risk is 'categorised' into one of five Safety Categories (CATs), being CAT B, CAT 1, CAT 2, CAT 3 or CAT 4.

The main principles behind confirming the Category of a safety system are to demonstrate and document the reliability and fault tolerance achieved by the system. Reliability stems from the use of well-tried principles and components, while fault tolerance is determined by circuit architecture and the avoidance of common-mode or common-cause failures. For example CAT 3 & 4 safety systems must be single fault tolerant, which requires their circuit architecture to demonstrate redundant safety channels.

AS 61508 – Functional safety of Electrical / Electronic / Programmable Electronic safety-related systems – is a design and life-cycle Standard that outlines the procedures and responsibilities required to design, verify, implement, maintain, modify and de-commission an electronic safety system. AS61508 demonstrates how to quantify risk and risk mitigation as falling within one of three Safety Integrity Levels (SILs), being SIL1, SIL2 or SIL3 (also see AS 62061 following).

AS 62061 - Functional Safety of SR Electrical, Electronic & PE Control Systems - closely relates to AS 61508 and is specifically geared towards quantifying and achieving the risk mitigation required of electrical, electronic and PE control systems for machinery. As with AS 61508, AS 62061 methods quantify identified risk and required risk mitigation in terms of SIL.

The main principle behind confirming the SIL of a safety system is to establish (predominantly by calculation) the probability of a dangerous failure (within the safety system). To achieve the required SIL the probability calculated (for the safety system) must fall within the 'band' or range of probability (of dangerous failure) associated with the required SIL.

ISO 13849-1 Safety of Machinery – Safety Related parts of Control Systems – is an international Standard, which combines the circuit architecture requirements of Safety Category with the reliability quantification principles of SIL, to establish a Performance Level (PL) for the Safety Related parts of control systems. The standard sets out performance criteria, plus design and evaluation principles for achieving, or establishing, each of the five PL's (PL a, PL b, PL c, PL d & PL e). This Standard designates the circuit architecture required for each safety category (CAT). For a given safety system or circuit, 'CAT' fulfillment is combined with Diagnostic Coverage (DC) and Mean Time To Dangerous Failure (MTTFd) criteria to establish the PL (of the system or circuit).

A table in the Standard directly equates PL's with SIL's, which affords users flexibility when integrating PL systems to input devices or equipment under control, allowing either approach to be used.

2.3 Ringline Design & CAT 3 Compliance

The functional safety concepts of the Ringline system have been drawn from the Standards listed above. At the time (prior to 2000) the only Standard covering use of a PES for conveyor lanyard control was AS4024.1 (1996), which required any PES to provide *'a level of performance at least equal to that afforded by conventional hard-wired safety systems'* (Part 1 – 6.22.1 General). Then, (as now) this Standard required the functional safety assessment, design and validation criteria for *'safety-related parts of control systems'* to *'be in accordance with the requirements of one or more of the five categories'* (of safety as defined in the Standard - *AS 4024.1501 -2006 - 7. Categories, 7.1 General*). Risk assessments determined the risk to be mitigated (by a conveyor lanyard emergency stop system) to be **Safety Category 3 (CAT 3)** [1]. Accordingly Ringline was designed to meet the fault tolerance and reliability requirements of CAT 3. The process was guided by the 'lifecycle' design, documentation and validation structure promoted in AS61508.

In 2000 Port Waratah Coal Services (PWCS) commissioned Worley Parsons to conduct an independent engineering study to compare all available conveyor signal line systems (PES) in terms of functional safety performance to AS 4024.1 - CAT 3, general compliance with AS1755 and system reliability. Even though the study found Ringline to be the only PES that met all criteria, PWCS required final (and further independent) confirmation of the entire study process, including the determination of CAT 3 compliance.

All FMEA, HAZOP and Ringline design documentation, along with Ringline hardware was presented to Test Safe Australia (TSA) for independent review and analysis. The scope of the review was to confirm compliance with AS1755 and AS4024.1 Safety Category 3. The guiding Standard used to document the Ringline design (by Ringway) and conduct the study (by TSA) was AS 61508. The study confirmed AS 1755 and AS 4024.1 CAT 3 compliance to the satisfaction of Test Safe Australia, Worley Parsons and ultimately PWCS.

Only after issue of the TSA report was Ringline installed on all new and existing conveyors at PWCS Newcastle coal loading facilities, where it has provided incident free protection since 2001.

[1] Assessments assumed the conveyor design to be otherwise in accordance with AS1755 & AS4024.1.

2.4 Why CAT 3?

When correctly designed and installed to AS1755 and AS4024.1, exposure of personnel to hazards (nip-points, rotating rollers etc.) is prevented by physical guards. Personal safety is further reinforced by rules and signage. For conveyors it has been our experience that assessment of the residual risk (risk of operating the conveyor with guards only) invariably equates to a Category 3 rating under AS4024.1 or SIL 2, however this should always be confirmed by assessment for any given installation.

It should also be noted that the definitions of Safety Categories lower than CAT 3 allow that the safety function <u>may or may not be performed</u> when the system is operated.

The safety integrity of such systems relies heavily on periodic testing, which is highly undesirable.

2.5 CAT 3 Requirements

To meet the requirements of this Category a system must be proved to be 'single fault tolerant' i.e. the application of any single fault will cause the safety function to be performed (trip to safety), or leave the protection system operative. Faults are to be detected wherever reasonably practicable. Systems up to Cat 3 are also required to use well-tried and correctly rated components as well as employing well-tried safety principles.

Single fault tolerance is most commonly achieved and proven by the provision of redundant elements in the system. For one element to be made redundant by another, each must have suitable (usually equal) safety integrity. Equal safety integrity is usually provided by two items that are identical in design and function (e.g. the use of two normally closed interlocks connected in series). However care should be taken to ensure that a **common mode error** cannot defeat both elements simultaneously e.g. water ingress defeats both interlocks or two under-rated components fail simultaneously etc.

2.6 Ringline Mk 2 Expanded Specification

In 2005 the Ringline Hardware and Software Design Specifications were expanded to enhance the Functional Safety capability of the system. In line with the existing Ringline CAT 3 design and support documentation, the Specification revision centered on adding CAT 4 fault detection requirements. Additions included increased diagnostic coverage, cross-control of the Functional Safety Outputs and active (internal and external) monitoring of feedback from the Safety Outputs.

The changes required Safety Function microprocessors (uP1 & uP2) to **each control diverse switching elements in both Safety Outputs** and for the electrical (logical) status of **both Safety Outputs to feed back** into both uP1 & 2 f**or confirmation, cross-checking and diagnostic analysis**. Individual self-checks were required on the switching elements controlling the Safety Outputs and for the Mk2 Controllers to allow status monitoring of ‘downstream’ equipment energised by the Safety Outputs. The feedback to be used to automatically detect any failure (after tripping) or to be used in conjunction with a Manual or Automatic Reset function, so that ‘Reset’ is prevented in the event of failure of any downstream element.

These functional and self-diagnostic improvements were formalised in the RLCONV & Mk 2 Controller designs. In spite of the increased diagnostics and other logical improvements the system functional safety performance claim was kept conservatively in line with existing equipment at CAT 3.

Since 2005 Mk 2 Ringline systems have been widely deployed, universally well received and have maintained the Ringline reputation for remarkable reliability with simplicity.

2.7 Performance Level d & SIL 2

In 2012 Ringway responded to a number of user and integrator requests to ‘quantify’ the functional safety performance of Ringline in terms of a Safety Integrity Level (SIL). ISO 13849-1 stood out as an ideal Standard for this purpose because it combines CAT principles (already imbedded in the Ringline design) with the reliability and Diagnostic Coverage requirements of SIL to determine a system PL. Importantly, the Standard also allows the allocation of a SIL based on the PL achieved.

The result of the Functional Safety Review (FSR) process was that all nominated Ringline equipment was declared ISO 13849-1;

- PL d compliant
- SIL 2 compliant

Performance figures in terms of the average probability of dangerous failure per hour (PFH_D), Diagnostic Coverage (DC) and Safety Category (CAT) are provided in the compliance document.

Compliance under ISO 13849-1 offers system integrators the flexibility of using PL, SIL or CAT when combining / interlocking equipment and / or validating overall compliance.

3 Why RINGLINE Uses Two Wires – (2-Wire v's 3-Wire History and Comparison)

3.1 Introduction

Ringway has been involved during every stage of the adoption of Programmable Electronic System (PES) for conveyor lanyard emergency stops in Australia. Systems were first developed for underground coal mine applications in the late 1980's, and have subsequently spread to all industries.

Under the current Work Health and Safety Regulations (see 2.1) there is a clear and increasing focus on designing and building a demonstrable level of safety integrity into all electrical and electronic safety circuits. All designers, suppliers and end-users should satisfy themselves that circuits they are designing, supplying or using are free from foreseeable faults and can be shown to have safety integrity equal to, or exceeding, the risk/s identified.

To assist in this process this paper examines the underlying safety integrity of the lanyard-switch field circuit configurations currently employed on Australian conveyor systems.

3.2 Three-wire Lanyard-Circuit History

Prior to designing Ringline Ringway spent considerable time pioneering adaptation of the Dupline building management system as a conveyor signal line system at both Tahmoor and South Bulli Collieries. The objective was to create a reliable system of interlocking the lanyard switches to the conveyor control circuit, which was also intrinsically safe (Ex ia).

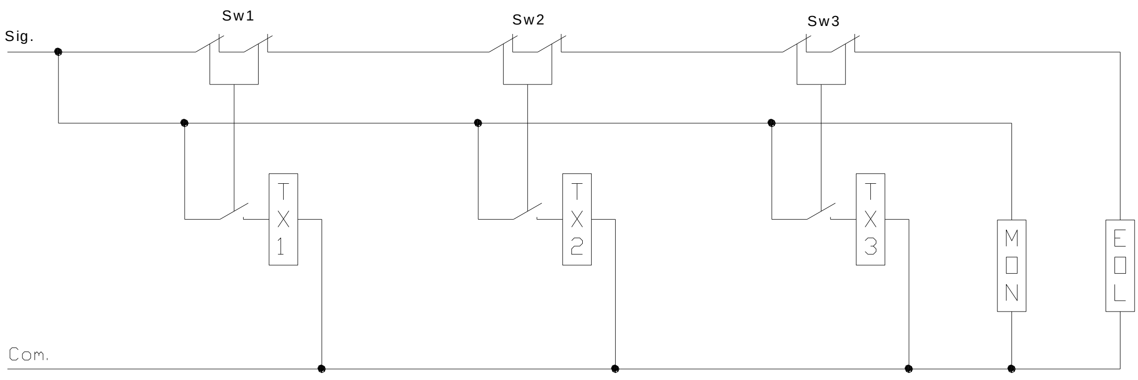
Until this point the Ampcontrol SLB (2-wire) system had been widely used for safety stopping but it provided no indication of which switch was operated. Bramco also had a 2-wire system that proved unreliable on long conveyors because component drift and poor discrimination caused false readings.

Earlier Dupline had been used for switch monitoring only, but at South Bulli Colliery a Dupline based'control' system was configured with the assistance of Ringway. This was a 2-wire 'AND' system requiring continuous transmission from every transmitter until a switch was operated. An 'AND' receiver (connected in the conveyor control circuit) would de-energise if any transmitter failed to transmit. Testing revealed that a partial short across the field bus simulated 'on' (healthy transmission) from every transmitter channel regardless of the state of the lanyard switches. 'OR' receiver circuitry was added to the conveyor control system to detect 'partial short' transmissions and stop the conveyor. However the system could also fail if two transmitters were assigned the same address because the alternate transmitter kept transmitting if either switch was operated. Therefore the system required 'procedures' to minimise the risk of this happening. This original 2-wire PES signal line configuration was in use and working reasonably well until conveyor lengths exceeded 2km and transmitter operation became unreliable due to voltage drop and because of waveform line reflections.

This distance limitation directly resulted in the current 3-wire signal line configuration, which was only configured to increase the distance capability of Dupline by drastically reducing the number of transmitters required to transmit for 'system healthy'. The outcome was reduced voltage drop (due to minimal current draw), **but also entrenched functional safety defects by design (see 3.3)**.

The 3-wire system uses an 'end of line' (EOL) transmitter, which is powered via a 'third wire' connected through a 'daisy chain' of interlocks in each lanyard switch (see the circuit diagram at 3.2.1 below). The operation of any lanyard switch cuts power to the EOL transmitter ('daisy chain' interlocks open) and also switches 'ON' an indication (location) transmitter (e.g. TX1 below) by switching it across the other two (monitoring) wires.

3.2.1 Circuit Diagram – Three-wire Lanyard Circuit



Typical 3-wire Configuration : Series connection to End Of Line - EOL & MON always transmitting - 'OR' Transmitters 1 - 3 report the switch location when a switch is operated.

This 3-wire field configuration has subsequently been imitated or adopted by the developers of other systems and is currently widely used throughout industry.

Ringway rejected this 3-wire design concept at the specification stage of Ringline on both functional safety and system reliability grounds (see arguments following).

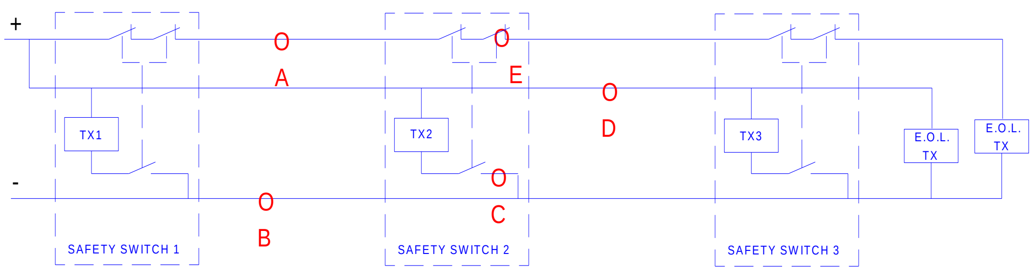
3.3 Shortcomings of the 3-Wire Configuration:

3.3.1 Unidentified Open Circuit Faults Create Downtime (Operational Issue):

Any invalid opening of the 'daisy chain' circuit (3rd wire) to the EOL transmitter (failsafe element) **proves to be the main reliability weakness** of the 3-wire configuration (see following diagram). Whether this is due to faulty switch interlocks (usual & caused by environmental ingress or vibration), loose terminations, high resistance joints or broken wire/s, the result is a conveyor stoppage without a report. This is because trips can only report their location when an 'OR' location transmitter (TX1 to TX3 below) transmits, meaning only valid switch operations are located!

This circuit provides opportunity for 5 types of open-circuit faults that are not reported or located by the system – see explanations below.

3.3.2 Circuit Diagram – Three-wire Undetected Open Circuits



Open Circuit at;

A = Loss of End of Line TX Trip, with no location report.

B = Loss of End of Line TX Trip and Mon TX Trip, with no location report.

C = Loss of End of Line TX Trip, with no location report when Switch 2 is operated.

D = Loss of Mon TX Trip, with no location report.

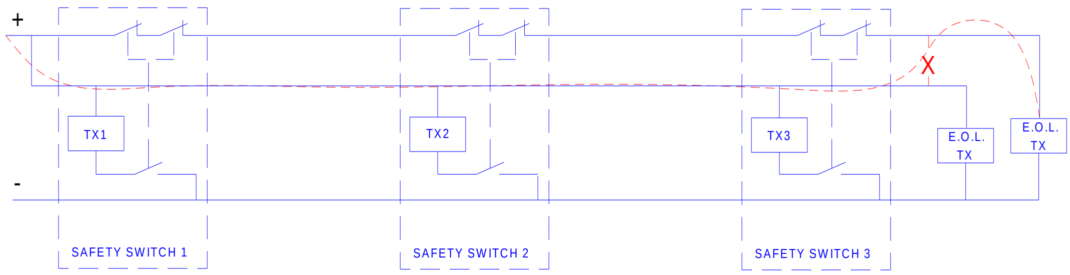
E = Loss of End of Line TX Trip, with no location report.

When it is considered that an unidentified open circuit fault could be anywhere on the lanyard circuit it is clear that the longer the system is the bigger the problem faced by an operator trying to locate such faults. **These faults always result in down-time while the fault is being located and the frequency of faults increases over time (due to wear and tear on equipment and cables).**

3.3.3 Short Circuits Compromise Functional Safety:

Because the third wire and the monitoring wire have the same electrical origin it can be seen that if they are shorted together at a point along the lanyard line then **safety interlock/s** in the 3rd-wire between the short and the electrical 'origin' **will effectively be bypassed** (see the following diagram).

3.3.4 Circuit Diagram – Three-wire Compromised by Short-Circuit

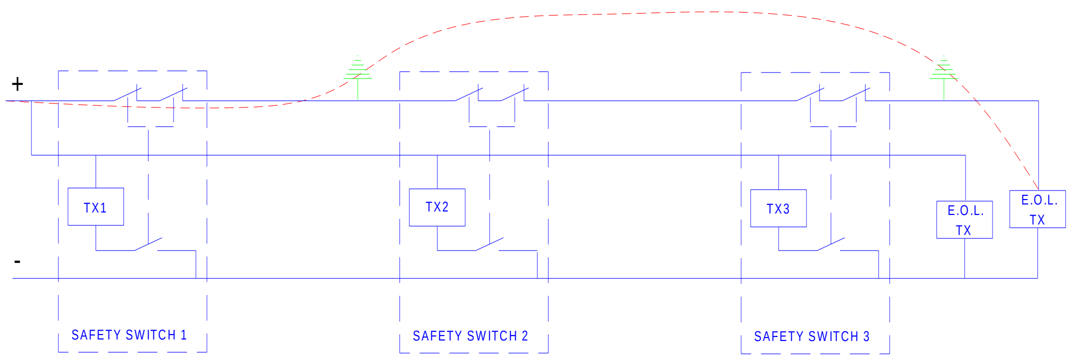


Such faults can result in the 'failsafe' EOL transmitter remaining powered despite safety switch(s) being operated!!

3.3.5 Earth Faults Compromise Functional Safety:

The most serious and common undetected dangerous failure of the 'daisy-chain' circuit (3rd-wire) can occur if / when there is an earth fault in the third conductor either side of a switch or a series of switches – see the following diagram.

3.3.6 Circuit Diagram – Three-wire Compromised by Cable Earths



Cable 'Earths' can provide an alternate electrical path around the safety interlocks in

lanyard switches, defeating their ability to interrupt power to the EOL Transmitter (see the dotted red circuit path in the diagram above).

Field earth faults become more common as systems age (especially in harsh environments). Such faults are dangerous, undetected and too common in 3-wire systems!!

3.3.7 Common Mode Noise Rejection (Operational Issue):

The simplest technique for enhancing common mode noise rejection is to use a twisted pair cable with balanced currents (same signal and energy in the outgoing and return conductors). Any induced noise is equal in both conductors and can be automatically filtered by system input circuitry.

A three-wire system is inherently unbalanced. Two active conductors deliver power to field transmitters while there is a shared return. Electrical noise in the conductors can become differential and be amplified by system input circuitry, which means that the three-wire configuration is inherently more susceptible to interference from induced electrical noise.

3.3.8 'Failsafe' Operation – (Functional Safety Issue):

When the location transmitters are configured for 'OR' operation (N/O interlocks) of concern is the fact that **any** 'location' transmitter failure cannot be identified until **after** a switch is operated. This means that any or all '**OR' transmitters can be removed, defeated, or be otherwise faulty and the conveyor can continue to run. This failure mode is undetected and dangerous.**

It is therefore clear that when the 'OR' configuration is used there is only one 'failsafe?' element, which is the EOL Transmitter. However the preceding documentation and diagrams have **already shown that the safety integrity of the EOL transmitter can be compromised by undetected and dangerous failure modes.**

Users requiring remote whole current isolation (or any additional failsafe function) via the signal line discover the limitation of having only one 'failsafe' element. This can/could be overcome by introducing a fourth wire with series connected switches and an additional EOL transmitter **(which also doubles system exposure to the unidentified dangerous failure modes already identified).**

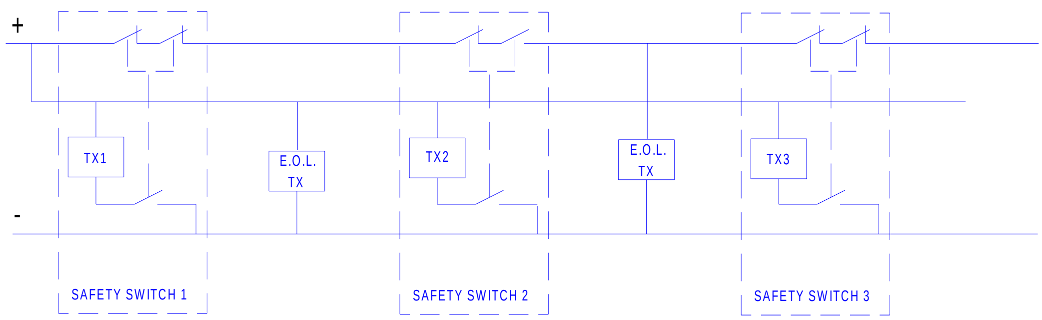
The option of using normally closed interlocks (AND system) is available for the alternate indication and tripping circuit, but this has only been viable on short conveyors because longer installations are challenged by voltage drop and line reflections (the reasons for adding the third-wire in the first place – see 3.2) or slower update times for systems running serial communications (too much data from too many stations).

3.3.9 Location of End of Line Transmitter – (Functional Safety Issue):

Notwithstanding the undetected dangerous failure issues already raised the integrity of a system that employs an EOL Transmitter as a 'failsafe' tripping element fundamentally relies on the EOL transmitter being installed beyond all of the safety interlocks (actually at the end of the circuit).

The 3-wire systems described herein are compromised because they cannot detect the location of the End of Line transmitter!

3.3.10 Circuit Diagram – Functional Safety Compromised by End of Line Location



A 3-wire PES controller connected to **the above circuit would indicate a healthy signal line system despite Safety Switch 3 having no control over the EOL Transmitter**.

It is also important to note that some systems cannot detect the presence of two EOL transmitters. These **systems can remain healthy if / when <u>either</u> of the transmitters is switched off!**

The weaknesses described above are all the **more critical because advancing the EOL transmitter** towards the Controller is the most common method used to locate undetected open circuits, which are also the most common system error mode.

Note: It is not always the actual EOL that is advanced, but can be a duplicate EOL transmitter, **which increases the chances of 2 EOL's remaining connected and creating an undetected dangerous failure.**

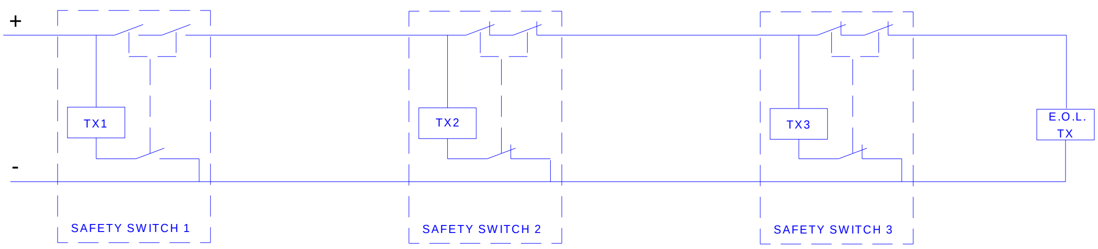
One system has ensured that the EOL transmitter has a unique identity (2nd unit will be automatically detected and cannot be used for troubleshooting). Unfortunately the 'unique' EOL can still be advanced during troubleshooting open-circuit faults, which demonstrates that the PES does not know where the EOL unit is positioned (EOL in wrong position becomes an undetected dangerous failure).

3.4 Two-wire Configuration Concepts

3.4.1 Two-Wire Configuration Using an End of Line Module

To overcome the operational difficulties (increased down time) generated by undetected open-circuit faults 'EOL' systems have been wired in the following two-wire configuration.

3.4.2 Circuit Diagram - Two-Wire Configuration Using an End of Line Module



Open-circuit faults detected - Unlike the three-wire system this configuration will detect and locate all open circuit faults, but only if the alternate transmitters (TX1, 2 & 3 above) are normally transmitting (does not suit long installations where voltage drop is an issue). However, **the configuration is not capable of indicating multiple operations** because transmitters beyond operated switches lose power and only switches ahead of the break remain indicating. The first transmitter that is 'OFF' is **either** inside the first switch that is tripped (e.g. Tx1 above) **or** is inside the first switch beyond a broken wire (broken wire not shown). Neither can be known until the switch is reset or investigated, nor can the status of any switch beyond the operated switch (or open-circuit).

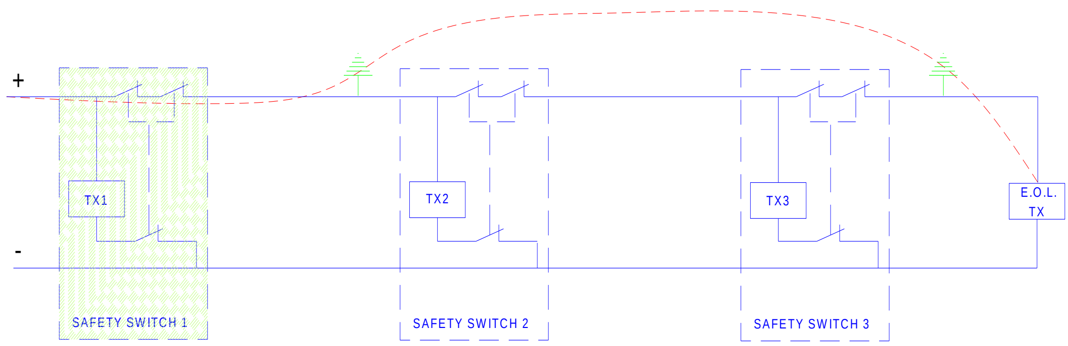
'Single-operation indication' is an extreme limitation when such a system is employed on long conveyors.

Increased power consumption – All transmitters need to be powered and transmitting to provide open circuit detection. Any system needs to be evaluated to ensure it can power the required number of transmitters (lanyard switches + other devices) over the installed length. **History has shown that this can prove problematic for some systems beyond 2km.**

The use of N/O interlocks to increase operating distance (as with 3-wire) would leave the system unable to locate any open circuit fault (as with 3-wire) i.e. only valid switch operations could be located.

The main functional safety issue with this 2-wire configuration is that **field earth faults can bypass the series connected safety interlocks (lanyard switches),** as illustrated by the dotted red line in the following circuit diagram.

3.4.3 Circuit Diagram - Two-Wire EOL Configuration Compromised by Earths



Normally Closed Interlocks Defeated by Water Ingress – The circuit diagram also illustrates that the exclusive use of normally closed interlocks can **expose safety interlocks to defeat due to environmental ingress** (e.g. water shorts safety interlocks of Safety Switch 1 above).

3.5 Ringline Two-wire Concepts and Specification

When designing the Ringline system Ringway rejected the use of three wires and/or series connected safety devices for the reasons outlined from 3.3 onwards above.

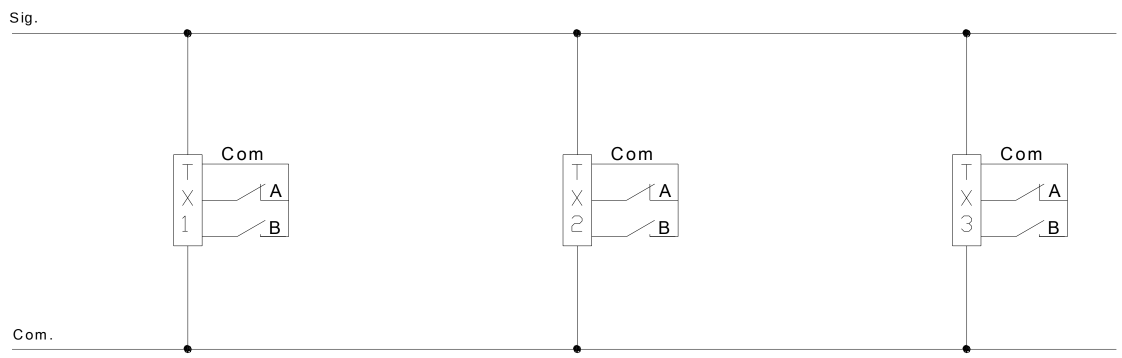
Based on our experience and knowledge of the existing issues the following system and configuration improvements were specified for Ringline;

- The use an unbroken 2-wire field bus with all devices transmitting continuously was considered to be the strongest and simplest solution, which would allow any open circuit to be detected and located as well as eliminating any possibility of earth faults bypassing safety interlocks.
- To have the two-wire circuit completely floating to limit possibility of circulating earth currents over great distances, to reduce exposure to electrical noise (e.g. VVVF drives), to be an unlikely target for lightning damage and to simplify locating cable earth faults.
- To fit lightning and transient protection into each transmitter or device connected across the field bus to effectively 'clamp' any electrical surge energy.
- To design a transmitter with minimal current draw to minimise voltage drop in long lanyard cables and allow continuous transmission from all transmitters at published distances using nominated cable CSA's (no more guessing). The capacity and operational distances of Ringline (over the various cable CSA's) to be confirmed by physical testing.
- To eliminate the functional safety issues surrounding 'series interlocks' and doubts as to the position of any EOL transmitter no End of Line transmitter is to be employed, requiring every safety transmitter to be 'failsafe' in its' own right (see next bullet point). No EOL allowing any field topography to be used (rather than exclusive 'Daisy-chain').
- Failsafe operation of each transmitter to be achieved by transmitting on two contiguous channels at all times. 'Device Healthy' requiring transmission a logical '1' followed by a logical '0' and facilitating failure mode detection in transmitter circuitry (permanent 'high' or 'low' failure would be detected immediately). 'Device Tripped' requiring '0:1' transmission and affording the same auto detection of circuitry failure modes. The other two transmission conditions to complete the diagnostic capability from each safety transmitter (0:0 = 'Device Missing' & 1:1 = 'Device Duplicated'). Given the dual-channel operation and the fact that device interlocks cannot be defeated by cable earths or environmental ingress each safety function transmitter acheives superior operational and functional safety integrity to the single 'failsafe' EOL element of the other systems. This allows multiple failsafe functions to be readily implemented on the same two-wire (e.g. Emergency Stop, Controlled Stop and Remote Isolation).
- Transmission detection method is to employ the integration of current over time (reject noise) in a variable window (combat slew) to make it impervious to voltage reflections and signal slew and reliably register the transmission status of field transmitters.

- To have a dedicated system Display to annunciate all operations and faults and to incorporate a 10-event Stop / Fault History that will capture and store transient operations, however fast and / or infrequent (e.g. intermittent open-circuit in the field bus).

The fundamental weaknesses of EOL configurations result from having a 'daisy-chain' of 'safety' interlocks in the bus cable. These systems regularly fail to trip (defeated by cable faults or device ingress) and trip with no location report (non-operational open-circuits create major down-time). The following diagrams and information show how the Ringline bus configuration addresses these and other fundamental short-comings.

3.5.1 Circuit Diagram – Ringline Two-Wire Configuration



Ringline 2-wire Configuration: Unbroken circuit with all transmitters transmitting on one channel - no End Of Line - no repeaters - no barriers.

Each Ringline transmitter is connected to the field bus at all times and is expected to be transmitting continuously on at least one (of the two) channels allocated to its' address. The following Truth Table shows the response of the Ringline System to transmitter channel operations. Note that there is only one condition that will allow the Safety Outputs to close, which is;

Every Safety Function transmitter must be transmitting on its' A Channel and not be transmitting on its' B Channel (see Green table entries).

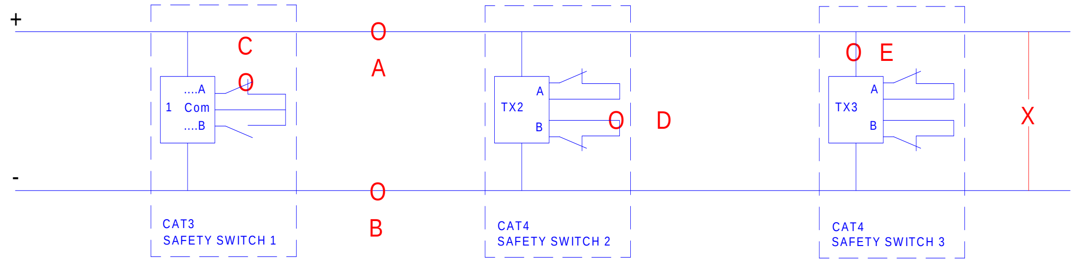
All other conditions results in a system trip!

Transmitter Address	Channel A Status	Channel B Status	System Response
All Safety Function TX's	On	Off	Close Safety Outputs
Any Safety Function TX	Off	On	Open Safety Outputs
Any Safety Function TX	Off	Off	Open Safety Outputs
Any Safety Function TX	On	On	Open Safety Outputs

Ringline System Channel Status Truth Table

The following diagrams demonstrate how open circuits on the Ringline Bus are self-revealing and how the safety integrity of the Ringline configuration cannot be adversely affected by earth faults.

3.5.2 Circuit Diagram - Ringline Response to Open Circuit Fault/s:



Using Ringline there are no open circuit (O/C) faults that are not located either immediately, or on operation of the safety system – for example (with respect to the diagram above);

Open circuit at;

A = All transmitters beyond TX1 cease transmission (Channel Status = 0:0) – System Trip location is an O/C between Safety Switch 1 & Safety Switch 2.

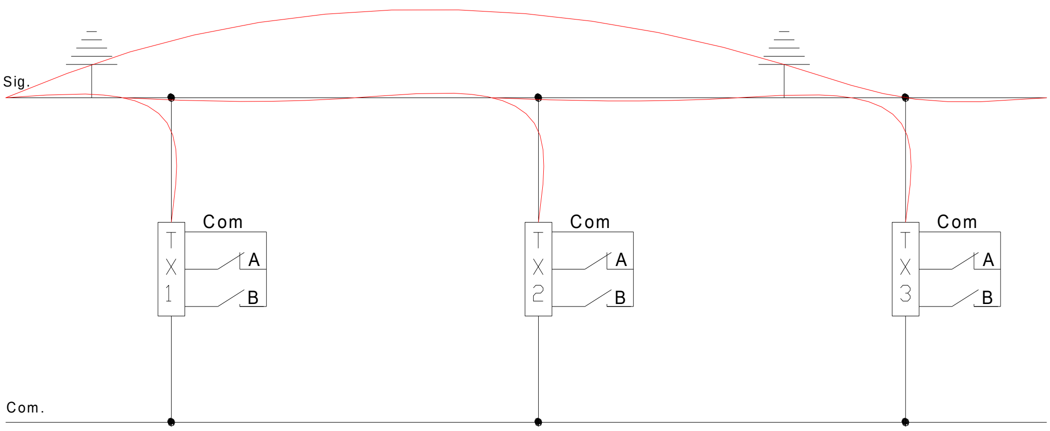
B = All transmitters beyond TX1 cease transmission (Channel Status = 0:0) – System Trip location is an O/C between Safety Switch 1 & Safety Switch 2.

C = TX1 (only) ceases transmission (Channel Status = 0:0) – System Trip location is O/C inside Safety Switch 1.

D = TX2 (CAT 4) inputs disagree - fault identified immediately (Chan.'s Report = 0:1) – System Trip located as 'input disagreement' inside Safety Switch 2.

E = TX3 (only) ceases transmission (Channel Status = 0:0) - Trip located immediately to O/C inside Safety Switch 3.

3.5.3 Circuit Diagram – Earth Fault/s on Ringline Bus:



Ringline 2-wire Configuration Earth Faults: Distributed earths have no effect on the operation because the Ringline transmitters remain powered and continue to transmit the status of the lanyard switch interlocks.

The earth faults demonstrated in the diagram above cause the normally floating Ringline Bus to behave like a grounded power supply (Sig = Earth). **Such earths have no effect on the normal operation of the system** other than to reduce noise immunity and to expose the system to 'noisy' earths. However, the transmission reception method used by Ringline controllers makes Ringline particularly impervious to induced noise. Other systems with references to ground are permanently exposed to these effects.

Should an earth fault developed on the other (Com) leg the result would be a 'shorted' supply. If the 'short' resistance was low enough the field transmitters would cease transmitting (due to lack of supply voltage) and the system would fail to safety (safety outputs open).

Notwithstanding that Ringline is not greatly affected by earths on a single leg, a transmitter has been developed to automatically detect earth leakage from either bus leg. Signals from this transmitter can be monitored to determine the need for maintenance to locate and remove the earth to reduce the potential for future downtime (e.g. should an earth develop on the alternate leg).

The **Ringline** two-wire field bus system was developed and implemented with all the above functional safety and performance issues considered. It **has been in use since early 1997** and **has proved extremely reliable in operation** in even the harshest environments. The system has proven virtually impervious to noisy electrical environments and has been installed alongside many VVVF and Flux Vector drive systems with no adverse effects. The system has **no troublesome installations** and **customer satisfaction is high**.

3.6 Conclusion:

The Ringline two-wire field bus configuration and operating philosophy has demonstrable performance and functional safety advantages over three-wire and alternate two-wire 'End Of Line' systems. These advantages are not incremental or minor and extend to fundamental features required of a distributed emergency stopping system, including;

1. **Increased System Availability** - any open-circuit fault is located – virtually eliminates downtime related to locating unidentified breaks.
2. **Increased System Diagnostics** – every safety function trip is recorded and stored in a 10-event Stop History for each Safety Function, however fast or intermittent - downtime is minimised.
3. **Increased Functional Safety** - safety interlocks cannot be compromised by earth faults, core to core cable faults or environmental ingress to safety devices – reduces risks to personnel and plant.
4. **Increased Operating Distance** – fully loaded systems can achieve operating distances up to 12km – no boosters, repeaters or external power supplies required – system can cover smallest to longest conveyors without 'adaptations'.
5. **System Integration Flexibility** – system compliance with ISO 13849-1 PL d means SIL 2, Safety Category 3 or Performance Level d principles can be used when integrating Ringline to the equipment under control – increases integrator options.
6. **Increased Safety Function Flexibility** – multiple failsafe functions with identical safety integrity can be implemented and distributed anywhere on the Ringline bus.
7. **End Of Line unit not employed** – not relying on an EOL means that there is no user onus to ensure that the EOL unit is always correctly positioned and is not duplicated – reduces risks to personnel and plant.
8. **Flexible Bus Topography** – no EOL means the field cable route is not restricted to a single 'daisy-chain' – the ability to branch in multiple directions can greatly reduce cable use and therefore voltage drop – reduces cost while increasing voltage to devices (improves margin of operation).
9. **IEC Ex ia Intrinsic Safety Compliance without barriers or external I.S. power supply** –means no signal attenuation and that hazardous atmosphere installations also enjoy the performance advantages outlined above.
10. **All digital devices can be interlocked to the Safety Function** – the digital transmitter range includes time-delayed units allowing tracking switches and chute probes (time delayed functions) to be interlocked directly to the Safety Function meaning all devices are covered by the system safety integrity and that the PLC can be removed from functional safety considerations.