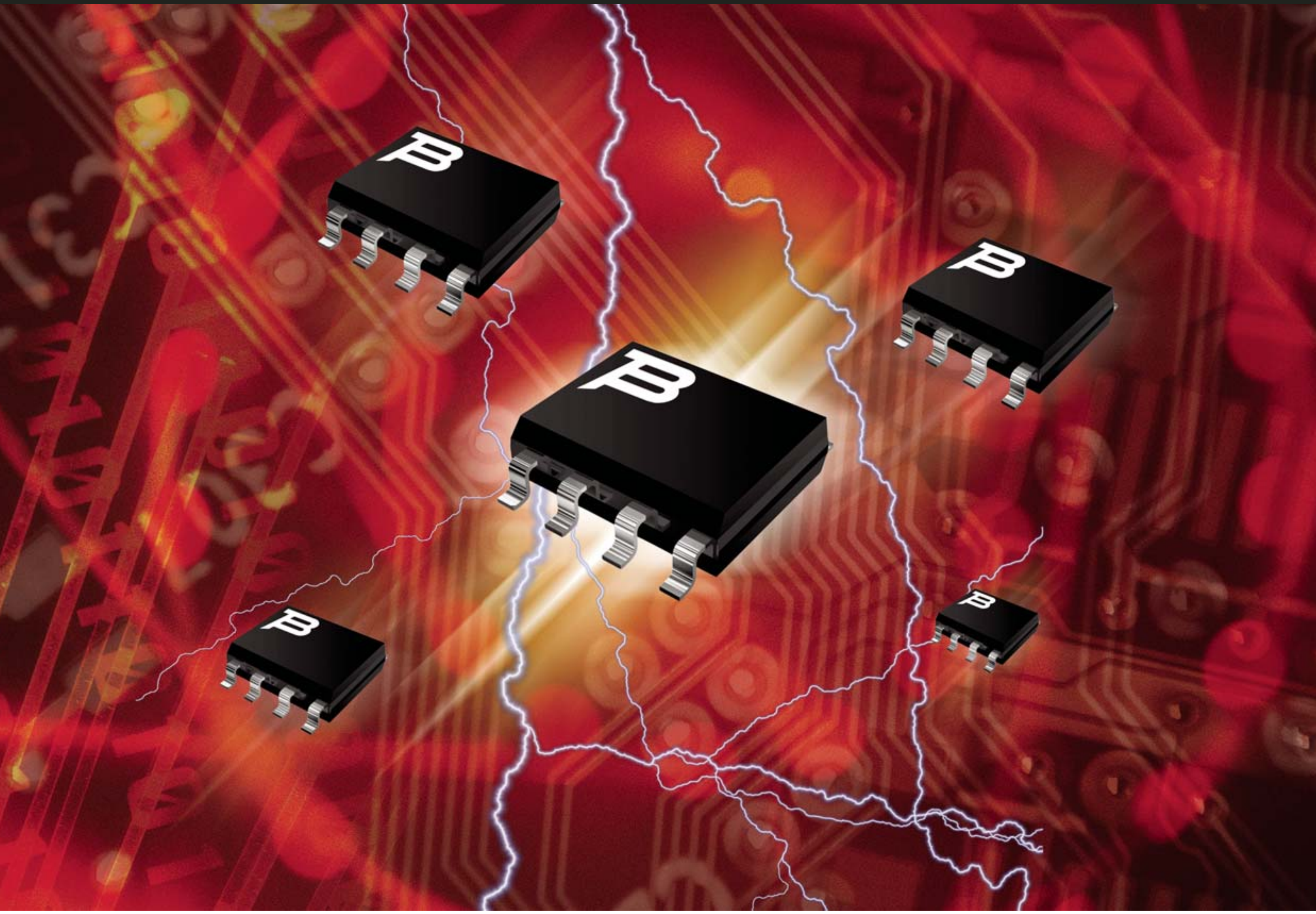
Protecting Silicon Laboratories ProSLIC® Family with Bourns® Circuit Protection Products

Revision 2



Circuit Protection Solutions

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Objective

Protection against lighting disturbances is a key concern for increased reliability of the equipment and ensuring telecom standards conformance. This Engineering document has been written to provide a first principles theory in protection. It will also provide protection solutions for Silicon Laboratories ProSLIC® family of subscriber line interface circuits (SLIC).

I would like to thank Silicon Laboratories in Austin, Texas for their support in the development of this document's content.

Designing Protection for ProSLIC® Family

The ProSLIC® family is built around the same architecture that uses external drive circuitry to generate the ring signal voltage. The ProSLIC® family utilizes a negative battery voltage V_{BATH} and uses balance ring techniques with or without DC bias. The normal working voltage of the SLIC needs to be clearly defined, as this will govern the performance of the external components. The Si3210 has an integrated DC-DC controller that dynamically regulates the single output voltage. The regulated voltage can be programmed up to -94.5 V, but a typical application requirement of –70 V for V_{BATH} is used for on-hook and ringing states. The low voltage is typically –24 V (V_{BATL}) for off-hook conditions.

The Si3211 and Si3212 ProSLIC® family requires external power supply sources for high voltage V_{BATH} / V_{BHI} and low voltage V_{BAT} / V_{BLO} battery supplies. These SLICs have been designed to switch between the two voltage options for the on-hook and ringing states. The regulated high voltage can be a maximum of -94.5 V and the low battery, 24 V. Both require a source current capability of 250 mA.

These negative ringing voltage topologies do not offer any positive voltage ringing signals with reference to GND. Therefore a protection solution deploying a thyristor crowbar in one quadrant and a diode to clamp positive transients in the reverse quadrant (TISP1, TISP5 or TISP6 families) can be considered in the design.

The ProSLIC® family requires an additional circuit to provide the external ringing and drive the telephone line under normal operation. This can be achieved by using a discrete component solution with bipolar transistors in a totem pole type arrangement. This option is still popular where higher ring voltages are used to extend the line reach capability of the voice POTS.

Silicon Laboratories also provides an integrated line driver solution called Si3200 and Si3201 that simplifies the design and reduces external component count. The Si3200 is for use with the Si322x (Si3220 and Si3225) Dual ProSLIC® family while the Si3201 is suitable for use with the Si321x (Si3210, Si3211, Si3212, Si3215 and Si3216) range of single ProSLIC® SLICs. The Si320x integrated line drivers have been designed to provide an absolute maximum battery voltage capability of -104 V to allow designers to utilize the maximum SLIC voltages of –94.5 V. These line drive circuits are the first point of contact for electrical disturbances on the telephone line and therefore are the key components to consider when selecting the overvoltage protection solution.

Discrete Line Driver Solution

The Si3210 and Si3211 ProSLIC® family for example have been referenced with an external discrete line driver solution in their application note as shown in Figure 1. The discrete bipolar line drive transistors (Q1, Q6 and Q2, Q5) will be prone to overvoltage conditions under an electrical disturbance and will govern the absolute maximum voltage window of the protection circuitry. The DC and AC sense pins are terminated with 200 kΩ which will protect these connectors from overvoltage conditions being applied to the Si2310 pins for example. This resistance converts the maximum voltage window into a maximum node current specification. If the V_{DD} supply is 5 V and the protection voltage of the protector is 115 V, the current into the resistor node will be 550 µA (110/200k) before possible damage will occur to the SLIC. Figure 1 shows a discrete line drive solution with a typical protection circuit based on the Si3210 SLIC.

The Si321x ProSLIC® family can also be used with the Si3201 integrated line feed solution and is covered in more detail on page 5.

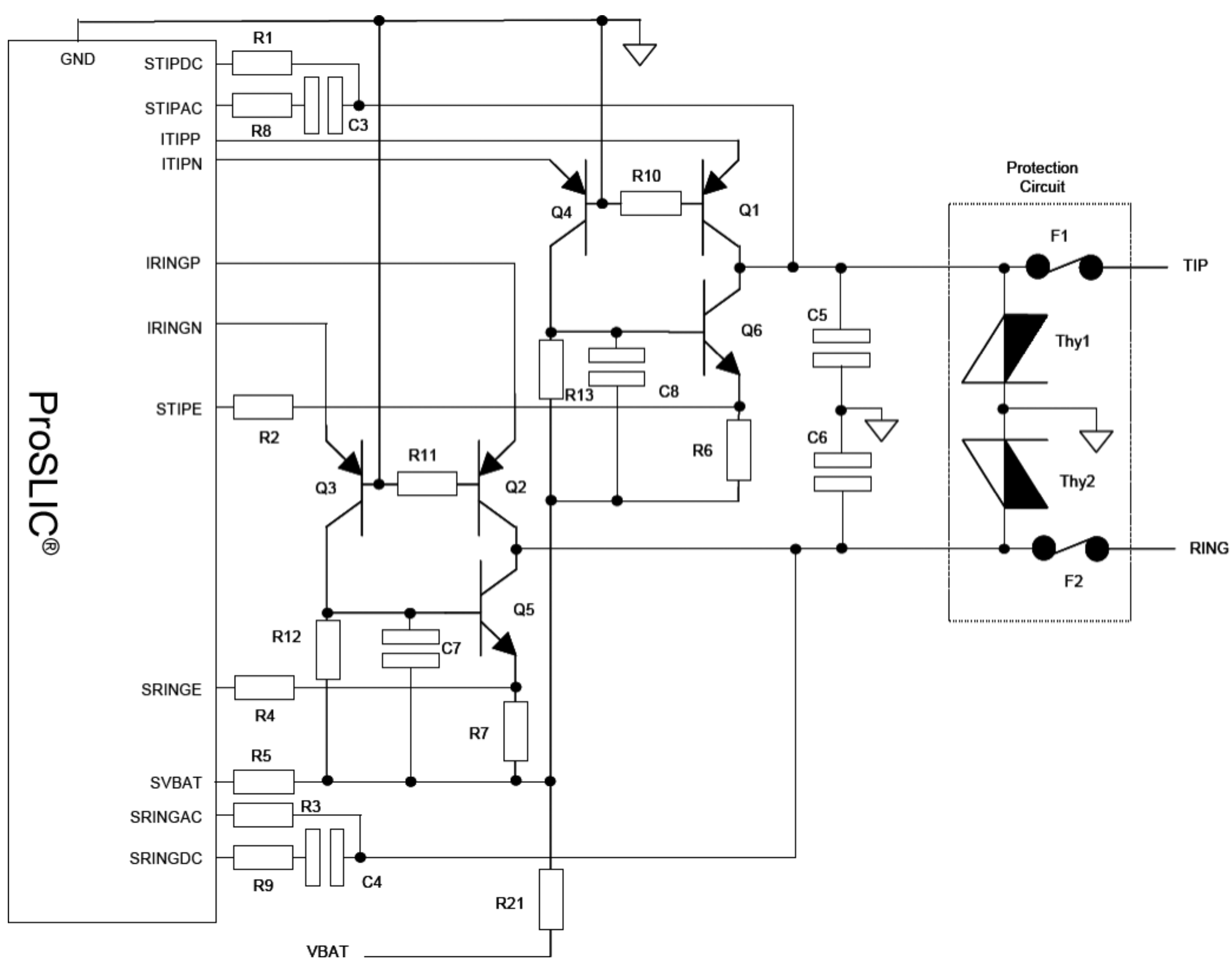


Figure 1: Si3210 ProSLIC® discrete line driver with protection

SYSTEM TRANSPARENCY UNDER NORMAL CONDITIONS

The overvoltage protection solution needs to ensure that it is transparent under normal conditions over the operating temperature range of the equipment. The leakage current of the protection circuit places unnecessary loading on the electronics and therefore needs to be as low as possible. The maximum off-state current, ID for the TISP5 family is specified at -10 µA max with a bias voltage, V_D of -50 V. The typical off-state current for the TISP® is two orders of magnitude lower at 0.02 µA at 25 °C and will typically not exceed 0.1 µA even at a junction temperature of 85 °C. This makes the TISP® look transparent to the system under standard working voltages. The TISP1, TISP5 and TISP6 (external gated) series are unidirectional thyristor protectors and therefore have a diode characteristic in quadrant 1. The maximum V_F is rated at +3 V maximum with I_F of 5 A.

The maximum working voltage (V_{DRM}) of the thyristor needs to be considered to ensure there is no clipping during normal system operation. Low ambient temperatures also need to be considered for reliable operation since the thyristor's V_{DRM} value decreases as the ambient temperature falls. For lower operating ambient temperatures, T_{AMIN}, the 25 °C ambient V_{DRM} selection can be calculated by using a temperature coefficient of –0.000846/ °C.

$$V_{DRM\,@\,25\,^{o}C} = \frac{V_{BATH(MAX)}}{1-\left(0.000846 \bullet \left(25\,^{o}C - T_{AMIN}\right)\right)}$$

For a system operating at a maximum V_{BATH} of –75 V, the V_{DRM} should be rated to at least -77 V at 0 °C or –80 V at –40 °C. A Bourns® TISP5115H3BJ with a V_{DRM} of –90 V can be considered in the design.

PROTECTION VOLTAGE OF THE LINE DRIVE TRANSISTORS

The thyristor protection voltage, $V_{(BO)}$ will increase as the die junction temperature increases. Under AC power line contact conditions, the protection voltage, $V_{(BO)}$ can increase by up to 7 %. This is characterized with the "normalized breakover voltage vs. junction temperature" curve in the data sheet. Fast rising impulse waveforms also increase the protection voltage of the thyristor. Thyristor protectors are sensitive to the rate of rise of current and therefore the di/dt of the impulse tests needs to be considered and is commonly known as the impulse breakover voltage. The overshoot of the TISP® is specified in the data sheet under Impulse Breakover Voltage (Electrical Characteristics) and is approximately +5 % of $V_{(BO)}$ at 20 A/µs. This $V_{(BO)}$ overshoot can increase by up to 10 % for 100 A/µs impulses.

To take this increase in the protection voltage under extreme temperatures under AC power fault and overshoot variations during the design, a general "Rule of Thumb" is to allow 10-15 % headroom on the $V_{(BO)}$ data sheet specification. This ensures extreme temperatures and overshoot variations are considered in the design during impulse and power line cross conditions. This increase in protection voltage is covered in more detail in the IEEE Std C62.37.1-2000, IEEE Guide for the Application of Thyristor Surge Protection Devices.

The protection voltage, $V_{(BO)}$ of the thyristor defines the working voltage (V_{CBO} and V_{CEO}) of the drive transistors, Q1, Q6 and Q2, Q5. Under normal working temperatures, the protection voltage of the thyristor will track the temperature coefficient of the bipolar transistors. In a fault condition, the junction temperature of the protector will significantly increase compared to the bipolar transistors. Therefore, a TISP5115H3BJ will require the transistors to be rated to at least 133 V (115 V x 1.15) to ensure safe operation. The stabilizing capacitors such as C5 & C6 should also be rated to this maximum impulse voltage to ensure reliability.

Si3200 and Si3201 Integrated Line Driver Solution

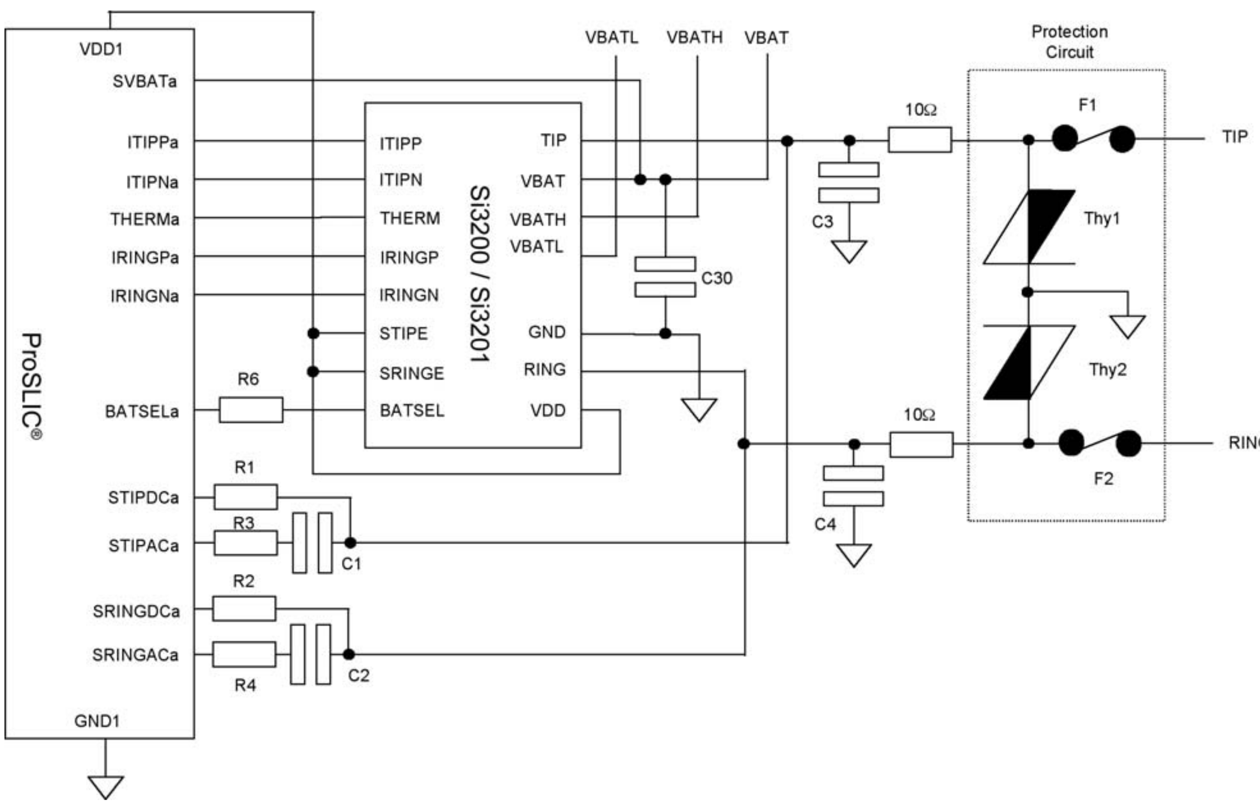


Figure 2: Si3220 ProSLIC® with Integrated Line Driver and Protection

The discrete line driver circuit has been integrated into a single IC solution called the Si320x family. The Si320x is rated for a continuous maximum voltage of -104 V. The maximum impulse voltage level is also expressed in maximum time vs. overvoltage referenced to the IC ground terminal. The dynamic overvoltage protection window of the protector needs to be within these parameters to ensure the SLIC is protected. A thyristor with a maximum protection voltage, $V_{(BO)}$ of -95 V (-104/1.10) will ensure the continuous voltage is not exceeded. The Bourns® TISP5095H3BJ has a $V_{(BO)}$ of -95 V with an off-state working voltage, V_{DRM} of -75 V at 25 °C. This sets the maximum V_{BATH} at ambient temperatures. For lower temperatures, the formula on page 4 can be used to find the maximum V_{BATH}. For example, for ambient operation down to -40 °C, the maximum $-V_{BATH}$ should be limited to a maximum of -71 V to ensure the voltage is not clipped during operation.

Independent tests by Silicon Laboratories have highlighted that the TISP5115H3BJ or TISP1120H3BJ are also suitable for protecting with the Si3200 and Si3201. The TISP1120H3BJ V_{DRM} of -95 V will also allow the maximum battery voltages of the ProSLIC® (-94.5 V) to be used at 25 °C. The minimum ambient temperature is still important to consider where the Si3200 for example is available in two temperature variants. The Si3200-KS series are intended for ambient temperature of operation from 0 °C to 70 °C and Si3200-BS series for -40 °C to 85 °C. The V_{DRM} of the thyristor would normally track the output saturation voltage loss of the Si320x over the ambient temperature range. However, there could be a situation where the junction temperature is higher on the Si320x due to its normal operation to provide a mismatch between the two. Therefore, V_{BATH} should ideally not be designed above -93 V for the K series or -90 V for the B series to ensure the TISP1120H3BJ does not clip the line voltage at the extreme negative temperatures.

Test Condition	Absolute Maximum Voltage
Continuous V_{BATH}	-104 V
<10 µs	V_{BATH}-15 V
<4 µs	V_{BATH}-35 V

SOLUTIONS FOR GR-1089-CORE FOR CO AND REMOTE ACCESS EQUIPMENT

Telcordia GR-1089-CORE impulse requires a first level test of 100 A 10/1000 µs and 500 A 2/10 µs where the equipment must operate after the tests. Therefore the overvoltage protection solution should be rated to at least these current levels. The Bourns® TISP5xxxH3BJ and the TISP1xxxH3BJ family guarantee these impulse capabilities and therefore a single blow fuse such as the Bourns® B1250T can be used as the overcurrent protector.

The fuse should have an I^2t rating to ensure the fuse does not operate under first level impulse tests. The B1250T guarantees these parameters by specifying the surge withstand ratings with the quantity of repetitions in the data

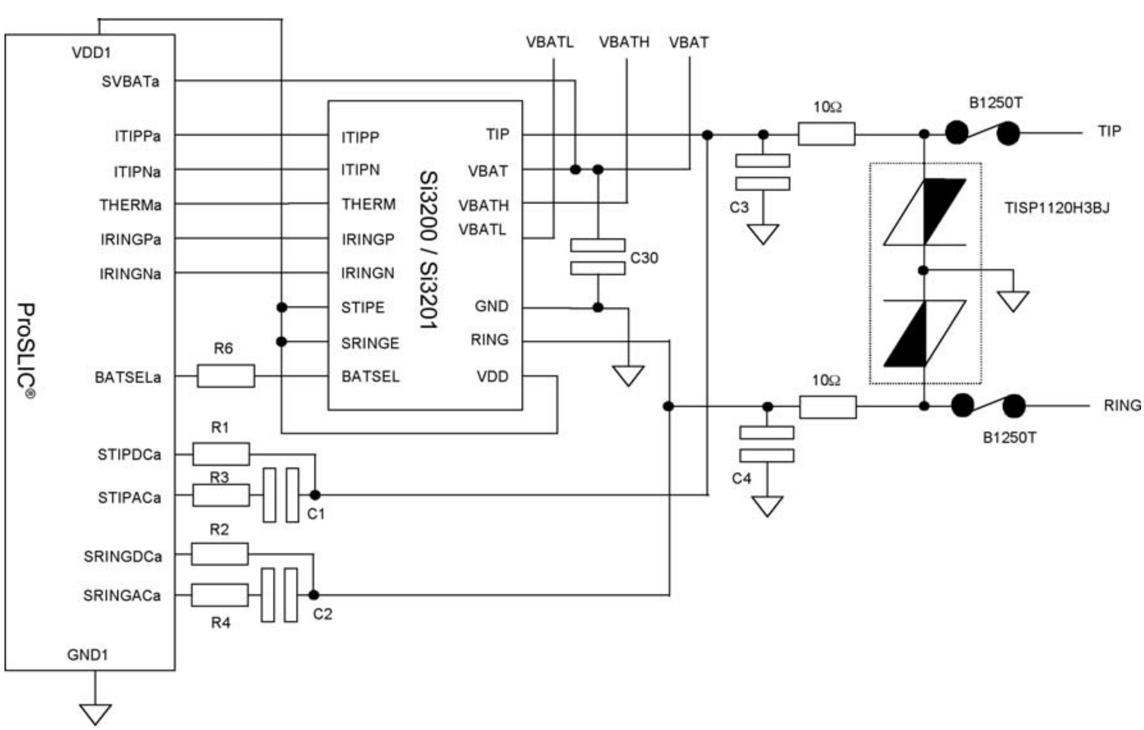


Figure 3: Si3220 ProSLIC® with integrated line driver for GR-1089-CORE applications

sheet. The overcurrent protection solution must not open under the first level AC power contact tests while failing safely under the second level tests. The B1250T specifies the clearing time under the key AC current test conditions. It is considered good design practice to ensure the overcurrent protector operates before the overvoltage protector fails. This requirement is not specified in Issue 3, but a fuse that is suitably coordinated with the overvoltage protector will ensure that the equipment fails open circuit rather than short circuit. Bourns highlights the typical withstand vs. current duration curve of the TISP4xxxH3BJ vs. the B1250T in the fuse data sheet to provide this confidence.

The equipment is also subjected to a current limit test where a current limiter indicator such as a MDL2.0A fuse is used between the generator and the equipment. The equipment must limit the current so that the indicator is not operated. The B1250T fuse will ensure that this requirement is achieved. The TISP5xxxH3BJ or TISP1xxxH3BJ with the B1250T provide a simple method to also pass the coordination test in GR-1089-CORE Issue 3. Figure 3 highlights a protection solution for GR-1089-CORE applications.

A discrete line driver solution as highlighted in Figure 4 using bipolar transistors can also be protected with either the TISP5115H3BJ (V_{BATH} to -90 V) or the integrated TISP1120H3BJ (V_{BATH} to -95 V). The B1250T fuse is the ideal overcurrent protector for Telcordia GR-1089-CORE applications. Higher V_{DRM} thyristor options will be released in the near future to allow increased V_{BATH} supplies. Please contact your local Bourns® circuit protection applications support team to discuss your requirements. Figure 4 shows a discrete line driver solution with the recommended protection components.

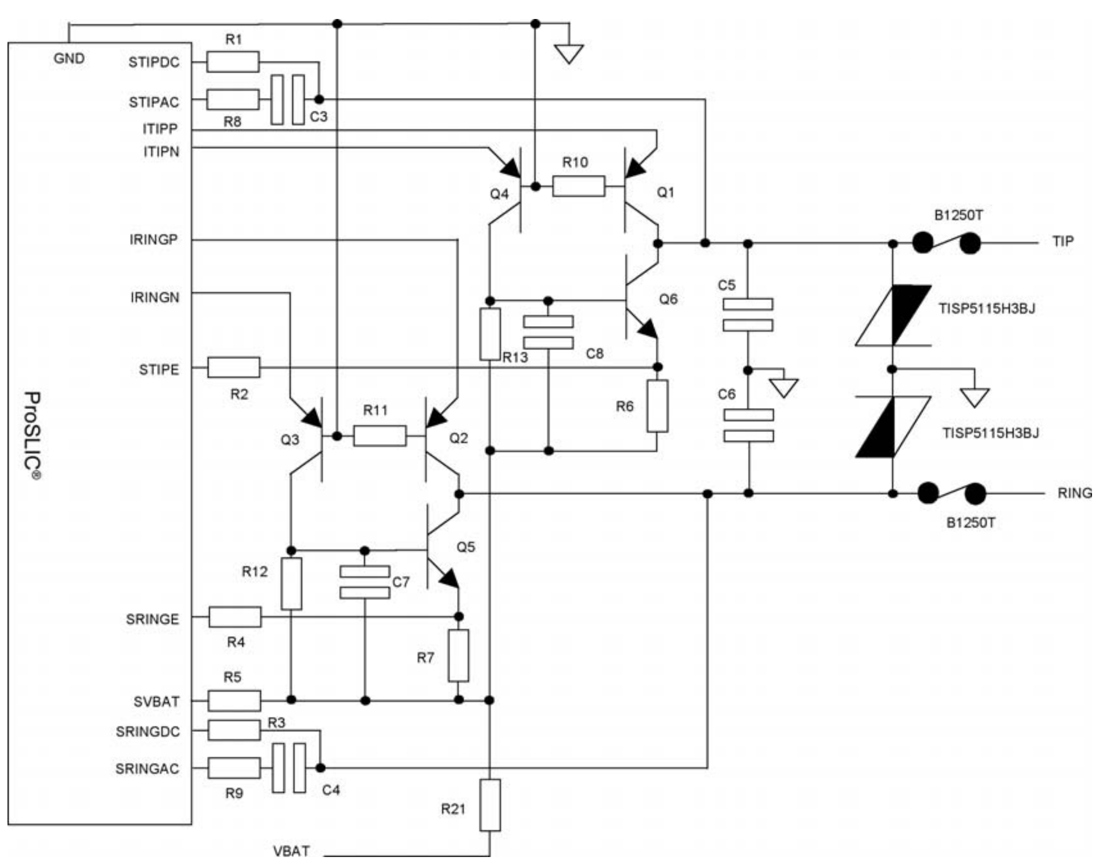


Figure 4: Si3210 ProSLIC® with discrete line driver with protection

SOLUTIONS FOR GR-1089-CORE INTRA-BUILDING

Telcordia GR-1089-CORE intra-building specifications have addressed protection for communication ports that do not interface with the outside world. Intra-building also addresses internal ports on equipment which have external ports interfacing with the outside plant equipment. These requirements are less stringent compared to the full GR-1089-CORE requirements where the equipment must support a 100 A 2/10 µs impulse without failure. The port is also tested with a second level 120 V rms, 25 A power contact test for 15 minutes where the equipment can fail in a safe mode. The TISP5xxxH3BJ or TISP1xxxH3BJ with the B1250T fuse can be considered for this protection solution. As the thyristor needs to only support 100 A 2/10 µs, lower impulse capability thyristor solutions can be considered in the design.

The 120 V rms power contact test allows 250 V rated Polymer Positive Temperature Coefficient (PPTC) thermistors to be considered in the design as this is a lower cost option to 600 V rated solutions. A typical protection solution for GR-1089-CORE intra-building is shown in Figure 5.

The TISP1xxxF3D is rated for 80 A 2/10 µs and therefore a PPTC with a minimum resistance of 4 Ω is required where the MF-SM013/250 can be considered as the overcurrent protector. The TISP1082F3D thyristor limits the maximum battery voltage to -65 V, but higher V_{DRM} voltage options can be manufactured on request. Please contact your local Bourns® circuit protection applications support team to discuss your requirements. A Bourns® B0500T, 0.5 A single blow fuse can also be used with the TISP1082F3D since its I^2t specification will ensure it does not operate under 2/10 µs impulse and fail safely under the AC power contact test.

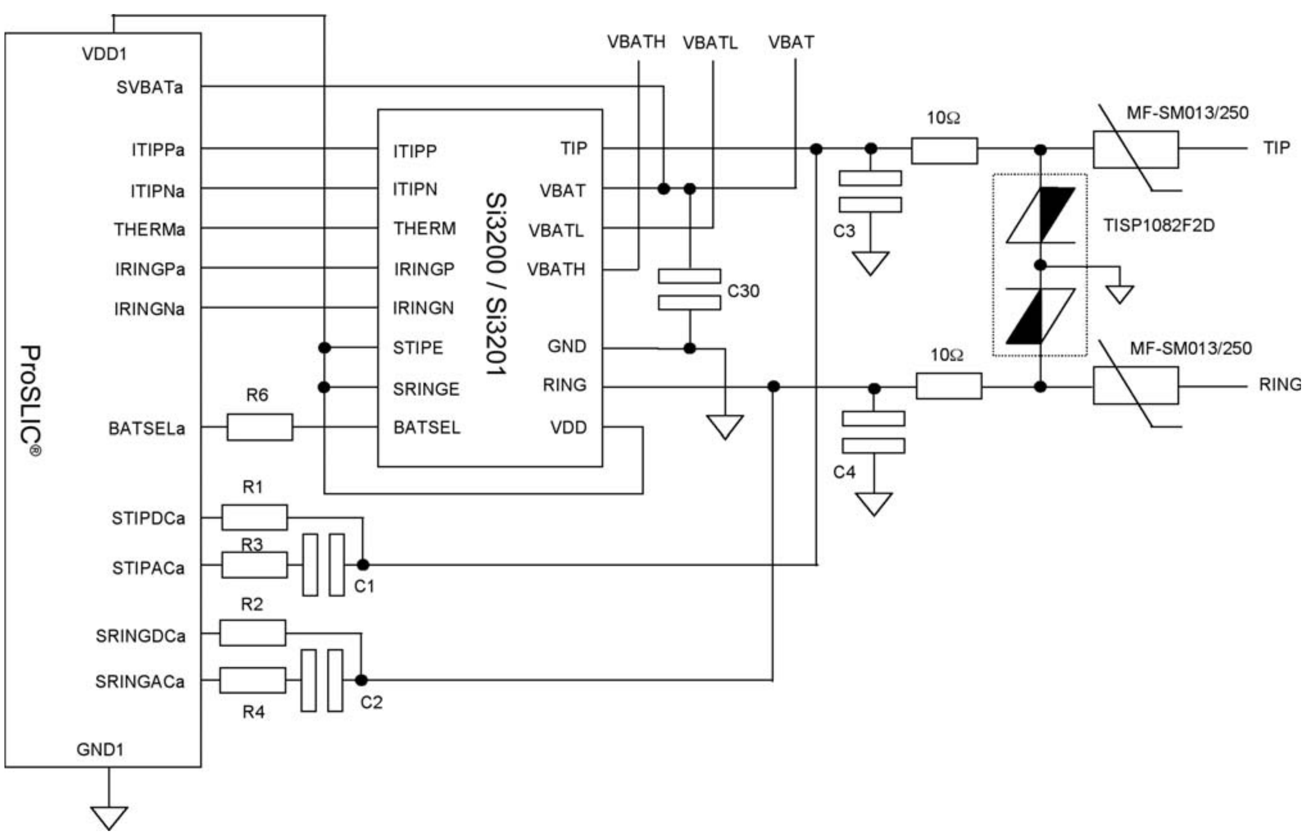


Figure 5: Si3200 and Si3201 integrated line driver for intra-building applications

SOLUTIONS FOR TIA-968-A AND UL 60950 FOR CPE

If a single blow fuse is used as the overcurrent protector, the I^2t rating needs to be considered with the type A and B surges. The TIA-968-A has a type A surge of 200 A, 10/160 µs for longitudinal applications where the equipment can fail safely. The I^2t needs to have a rating of 4.6 or less ($I^2t = 0.72 x I_{PP}^2 x t_D$). The B1250T will not open under this impulse and therefore the thyristor needs to be rated for this impulse current. Type A criteria allow the equipment to fail, but the fuse will need to open before the thyristor fails short. The Bourns® B0500T 0.5 A fuse has an I^2t rating of 1.4 and therefore will fail open under this impulse test.

Fuses don't normally specify their open times under impulse and therefore the simplest method is to design the thyristor protection so that it does not fail under the type A impulse conditions. The TISP5115H3BJ is rated to 250 A, 10/160 µs and 160 A 10/560 µs which allow a fuse to be used to meet the UL 60950 requirements under longitudinal and metallic conditions. The TISP1120H3BJ is rated for 200 A which also allows a fuse to be used. Applications operationally passing the type A surge will tend to use a 1.25 A telecom fuse, such as Bourns® B1250T.

Fuses for UL 60950 ideally need to have a characteristic of less that 100 A^2s characteristic to ensure conformance. Suitable fuses will be specified for interrupting capabilities of 40 A at 600 V AC where the fuses do not meet this 100 A^2s requirement. For applications that require coordination with the primary protector or where resettability is desired in the application, a PPTC thermistor can be used. The resistance increases significantly under an AC overcurrent condition, thus limiting the current into the circuit. The additional series resistance of the PPTC thermistor can also allow the use of a lower current rated thyristor to be considered. The current rating of the thyristor can be calculated using the following equation:

$$I_{PP} = \left(\frac{V_{GEN}}{R_{SERIES} + \left(\frac{V_{GEN}}{I_{PEAK}} \right)} \right)$$

The TIA-968-A type A surge for metallic conditions specifies a maximum voltage (V_{GEN}) of 800 V, with a short circuit current (I_{PEAK}) of 100 A. The impulse tester will have a fictive impedance of 8 Ω. Placing a 7 Ω current limiter in series with the generator fictive impedance will reduce the thyristor current to 53 A (I_{PPSM}). Therefore a thyristor rated lower than 100 A, but above 53 A could be used. An application using a PPTC thermistor with a minimum series resistance of 3 Ω would produce an I_{PP} of 73 A to allow for a 75 A 10/560 µs thyristor. The PPTC thermistor must also be rated to support the UL 60950 AC power contact tests without causing a safety hazard. The PPTC thermistor data sheet should guarantee operation of 2.2 A for 1800 s, 7 A for 5 s and 40 A for 1.5 s and ideally any current vs. time along its -100 A^2s curve. Alternatively, the data sheet should specify that the PPTC thermistor meets the UL 60950 AC power contact requirements.

A solution for protecting the Si3200 and Si3201 integrated line driver ICs for TIA-968-A type applications is shown in Figure 6. A discrete line drive solution can also be used as shown in Figure 4 for CPE type applications.

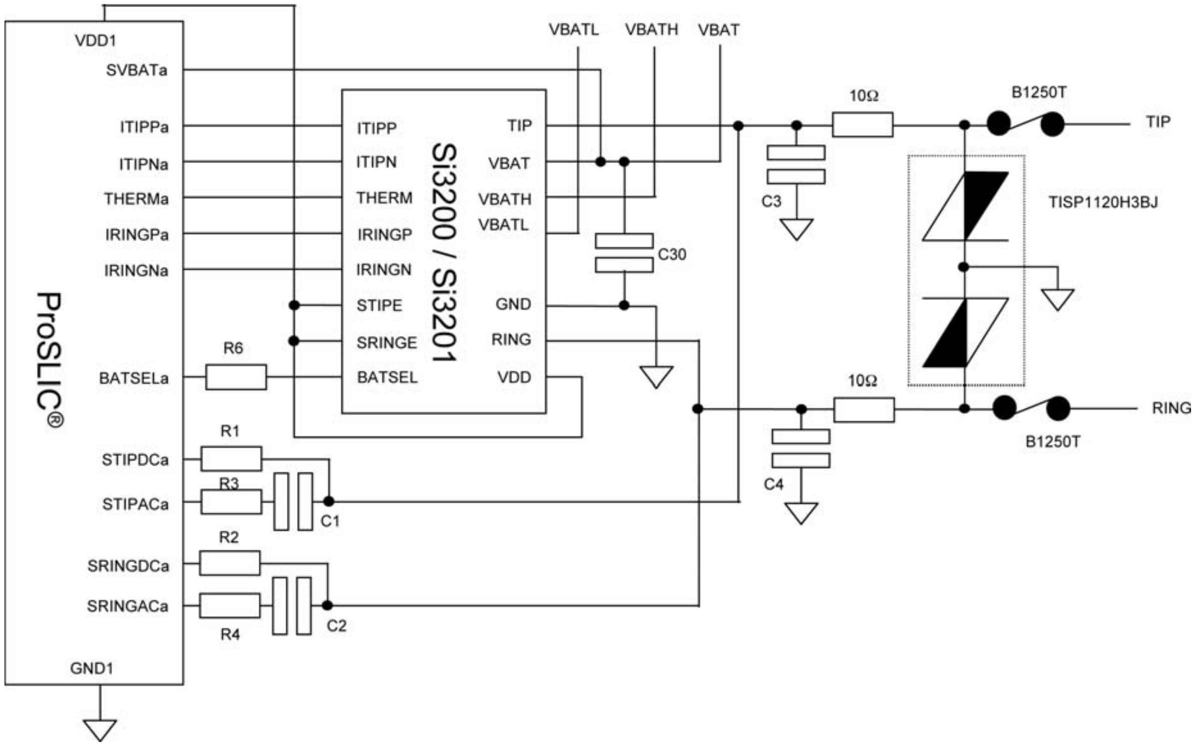


Figure 6: Si3200 and Si3201 protection solution for TIA-968-A and UL 60950 applications

SOLUTIONS FOR ITU-T RECOMMENDATIONS

The ITU-T coordination recommendation is tested with the recommended primary protector across the equipment terminals. The primary protector is monitored to ensure it operates under the test. The thyristor switches into a short circuit and therefore a resistor is required for coordination. The resistor allows the primary sparkover voltage to be developed across it since the secondary protector is protecting the system voltage. A minimum resistor to consider primary coordination is 7 Ω where lower resistor values may not coordinate, but still pass the customers requirements. The use of the series resistors can allow reduced impulse specifications for the thyristor. The series resistance value can be calculated by the following formula where I_{PPSM} is the maximum impulse rating of the thyristor:

$$R_{SERIES} = \left(\frac{V_{GEN}}{I_{PPSM}}\right) - R_{GEN}$$

ITU-T Basic Recommendations

The TISP1120H3BJ is rated for 150 A, 5/320 µs (10/700 µs open-circuit voltage), which makes it suitable for basic K.20, K.21 and K.45 impulse recommendations. To achieve the 4 kV, 10/700 µs basic coordination test, the series resistance needs to be at least 7 Ω. The TISP1120H3BJ is also suitable for ITU-T applications which need to pass the 6 kV 10/700 us coordination test without any additional series resistance being required. The current rating of the thyristor also allows low values of series resistance such as the MF-RX018/250 to be considered in the application. However, a clause is required to highlight that the protection is not intended to coordinate with the primary protector.

The basic AC power line cross tests are performed with a variety of series resistance (10 Ω - 1000 Ω) with a generator voltage of 230 V rms for 900 seconds. It is common to design with a 250 V rms PPTC thermistor to meet the test criteria. There is also a 600 V rms, 600 Ω induction test for 1 second that initially points to a 600 V rated overcurrent protector. 250 V PPTC thermistors can be considered provided they do not operate during the test. This indicates that the PPTC thermistor must be of a low resistance value so that it does not develop enough heat under the test to trip. Bourns® Multifuse® MF-RX018/250 can be considered for the basic AC power contact requirements. The Bourns® Multifuse® MF-SM013/250 family can also be considered where coordination is required with the primary protector. Figure 7 shows a typical application to meet ITU-T basic recommendations for the Si320x.

ITU-T Enhanced Recommendations

The TISP1120H3BJ or TISP5115H3BJ thyristor can support the enhanced K.20, K.21 and K.45 impulse tests of 37.5 A 5/320 µs. The enhanced coordination test will require a minimum series resistance of 4.2 ohm to ensure the GDT operates. The TISP1120H3BJ and TISP5115H3BJ can support the increased impulse current with the primary protector in place. The TISP1xxxF3D option can also be considered since it is rated for 50 A 5/320 µs. The 150 A, 5/320 µs (200 A for TISP5115H3BJ) rating for the TISP1120H3BJ allows the thyristor to pass the enhanced coordination test without a GDT being present and zero series resistance. This allows the overcurrent protector to be selected on just the AC power contact requirements.

The enhanced AC power contact tests range from 450 V, 2 s to 1500 V, 0.18 s with an agreed primary protector. Due to the test time, the PPTC should be rated to at least the DC sparkover of the GDT. Bourns® would recommend a 600 V PPTC solution such as the Bourns® Multifuse® MF-RX015/600 PPTC thermistor family or a line feed resistor module such as the 4B04B-523-100. If the requirement is to pass this test without the GDT present, the TISP1120H3BJ or TISP5115H3BJ can support the power cross test without an overcurrent protector being required. The Bourns® Multifuse® MF-RX018/250 PPTC thermistor is not recommended for enhanced AC power contact coordination requirements.

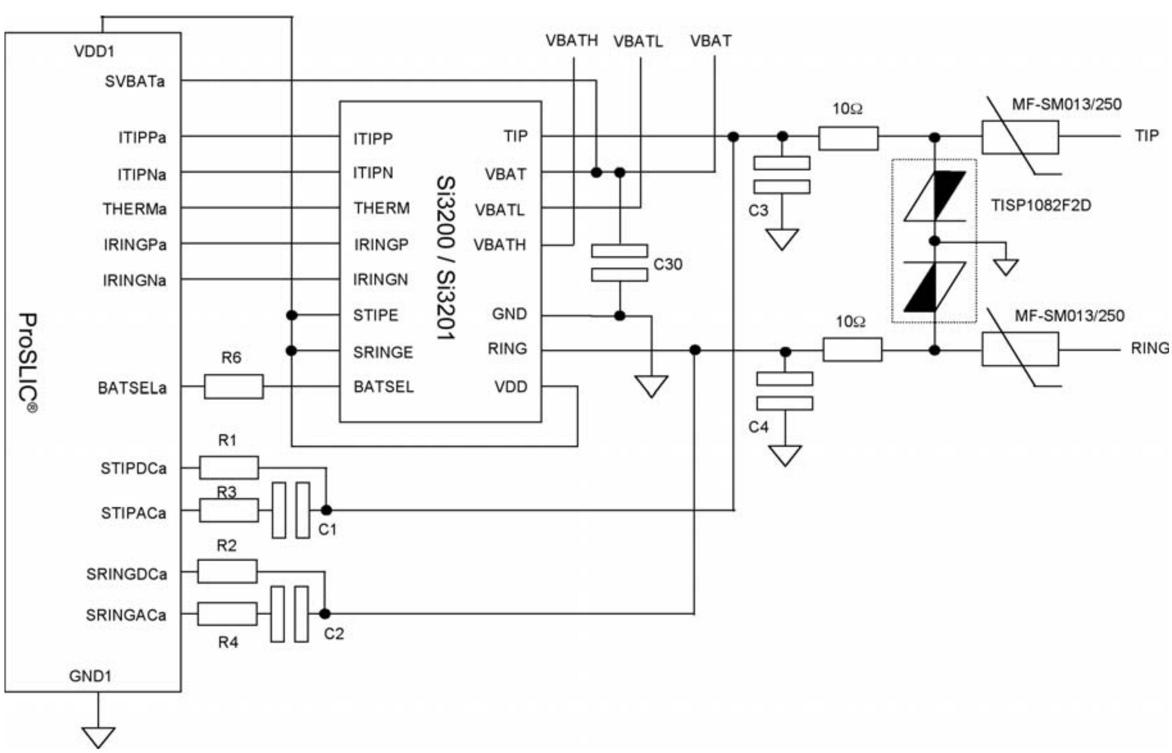


Figure 7: Si3200 and Si3201 for ITU-T basic and enhanced applications

Maximizing the Si3200 and Si3201 Ring voltage

The TISP1120H3BJ, with a maximum protection voltage ($V_{(BO)}$) of –120 V, limits surge voltages to within the Si3200 voltage rated limits. To avoid the TISP1120H3BJ protector from clipping the ringing voltage, the Si3200 SLIC should not be run at greater V_{BATH} voltages than –93 V for the K series and –90 V for the B series. These levels are set by the TISP1120H3BJ –95 V maximum off-state voltage (V_{DRM}) value. However, Si320x integrated line drivers can work with maximum continuous battery voltages down to –104 V. Using a fixed voltage protector (TISP1120H3BJ) has limited the maximum possible battery voltage by some 10 V. This means the ringing voltage is not as large as it could and this reduces the maximum line length that can be driven.

The ring voltage can be maximized in the system by using a gated thyristor that references to the Si320x negative supply voltage. The gated thyristor protection level is only a few volts greater than V_{BATH}, which allows the Si320x to be operated at supply voltages down to –100 V. Bourns® TISP6 series utilizes a buffer transistor on the gate of the SCR to reduce the gate drive current. This allows the system to be protected at the system voltage to allow tighter protection (3% or less). Gated thyristors provide the lowest overstress condition to the SLIC during an overvoltage stress condition.

MAXIMUM TIP AND RING TERMINAL RATINGS

The Si320x integrated line drivers have been designed to provide an absolute maximum continuous battery voltage of –104 V. The TISP61089BD has a maximum V_{GT} (gate-cathode trigger voltage) of 2.5 V. Therefore, the maximum battery voltage should be limited to –100 V for reliable continuous operation.

Limiting Protection Overshoots

The impulse breakover voltage specification of the thyristor is dependent on the di/dt of the impulse waveform. Bourns specifies a maximum gate-cathode impulse breakover voltage ($V_{GK(BO)}$) on the data sheets. For example, the TISP61089B is specified with a $V_{GK(BO)}$ of 12 V maximum with a 100 A 2/10 µs impulse. The Si320x integrated line driver is rated for a V_{BATH} -15 V for less than 10 µs and V_{BATH} -35 V for less than 4 µs. In this example, it is safe to highlight that the impulse performance is within the Si320x performance. However, the TISP61089HDM has an overshoot specification of 20 V under a 200 A 2/10 µs impulse. On first glance, it could be mistaken that this device is unsuitable to protect the Si320x family. The second important parameter is the length of time the overshoot is in the critical zone. This overshoot specification from the data sheet cannot be tied directly into the maximum terminal ratings of the line driver since the length of time during the 20 V overstess is not known.

The change in voltage with change in ambient temperature (dV/d °C) for the SLIC is standard for all semiconductors and therefore the thyristor protector will track the Si320x over temperature. This allows voltage definition of the protector to be initially done at 25 °C specifications. The junction temperatures between the SLIC and thyristor can differ under a fault condition that may need to be considered under extreme temperature conditions.

Note: *The overshoot of the thyristor is especially important when the line driver is operated close to its maximum supply voltage ratings.*

Gate de-coupling capacitors

Bourns gated thyristors recommend a typical gate de-coupling capacitor of 220 nF to be included in the design. During the initial rise of an impulse voltage, the gate current (I_G) is positive during approximately the first 20% of the I_K switch time as current is reflected into the gate from the cathode. The SCR gate then requires a negative drive current to switch the SCR in to a low impedance condition. This equates into a positive and negative gate charge Q_{GS} requirement. The required gate charge is supported with this capacitor to keep the overshoots to a minimum. For example, a 10 A/µs rate of impulse current shows a positive gate charge of about 0.1 nC. This equates to 100 nF capacitor for a 1 V battery voltage variation $\left(V = \frac{Q}{C}\right)$.

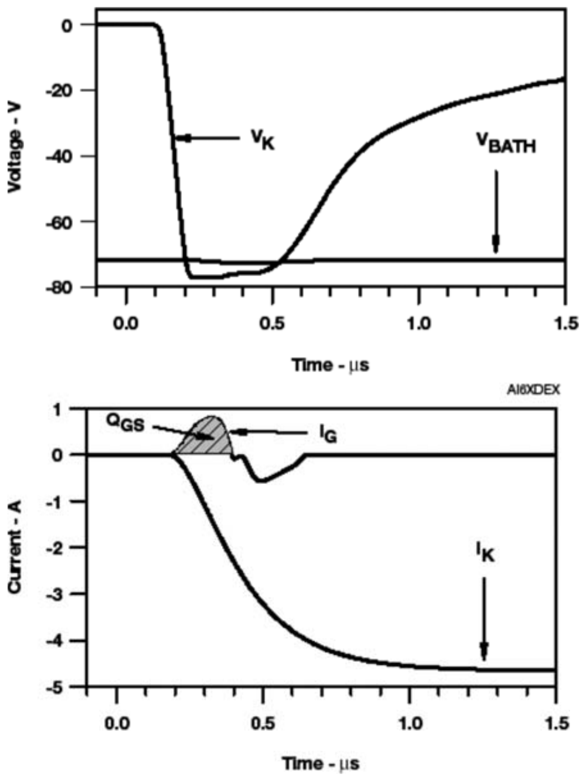


Figure 8: Gated thyristor switch characteristics

This is considered the minimum capacitance value in the data sheet for reliable operation with low overshoot properties. Reducing the value of this gate capacitor or eliminating it from the design will increase the overshoot of the thyristor. Faster di/dt impulses will also increase the Q_{GS} of the gated thyristor and therefore the minimum value of gate decoupling capacitance should be selected for the worse case situation.

Note: *The capacitor should also be placed as close as possible to the gate connector of the protector to minimizes inductive effects of the copper tracking.*

Grounding Techniques

PCB layout is critical to the performance of the protection circuit and can often be the culprit when the protection circuit does not work as intended. The over voltage protectors anode (ground) pins need to be connected as close as possible to the ground pin of the Si320x. The gated protector primary function is to limit the voltage stresses seen by the line driver so that it does not fail. Therefore, the protector needs to be referenced to the same ground to ensure minimum stresses.

Using short tracks between the thyristor and Si320x is important where the resultant voltage caused by the current in the track will be added to the overshoot of the protector. It has been found that during the initial rise of fast impulse (80 A/µs) can cause inductive voltages of 0.8 V in 2.5 cm of printed wiring track.

SOLUTIONS FOR GR-1089-CORE AND REMOTE ACCESS EQUIPMENT

Telcordia GR-1089-CORE impulse requires a first level test of 100 A 10/1000 µs and 500 A 2/10 µs where the equipment must operate after the tests. The overvoltage protection solution should be rated to at least these current levels when a fuse is used as the overcurrent protector. The Bourns® TISP61089HDM specifies these impulse capabilities in the data sheet and therefore a single blow fuse such as the Bourns® B1250T can be used. The fuse has an I^2t rating to ensure it does not operate under the first level impulse tests. The B1250T fuse has an I^2 second of 14 and also surge repetition withstand ratings to conform to GR-1089-CORE requirements. The overcurrent protection solution must not open under the first level AC power contact tests while failing safely under the second level tests. The B1250T specifies the clearing time under the key AC current test conditions. Figure 9 shows the proposed schematic to meet GR-1089-CORE applications.

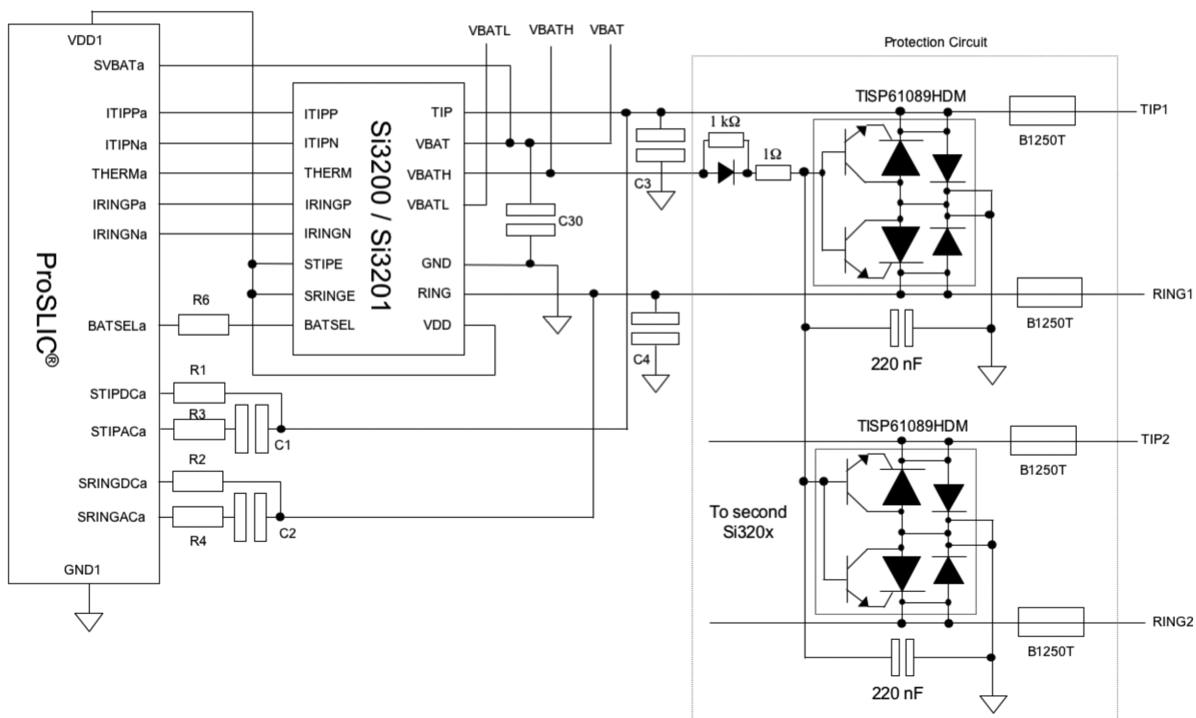


Figure 9: Si320x protection for Telcordia GR-1089-CORE applications

SOLUTIONS FOR GR-1089-CORE INTRA-BUILDING

These requirements are less stringent compared to the full GR-1089-CORE requirements where the equipment must support a 100 A 2/10 µs impulse without failure. The port is also tested with a second level 120 V rms, 25 A power contact test for 15 minutes where the equipment can fail in a safe mode. As the thyristor needs to only support 100 A 2/10 µs, lower impulse capability thyristor solutions can be considered in the design. The 120 V rms power contact test allows 250 V rated polymer Positive Temperature (PTC) Coefficient thermistors to be used. A typical protection solution for GR-1089-CORE intra-building is shown in Figure 10.

The TISP6NTP2CD dual port protector is rated for 90 A 2/10 µs and can be used in applications requiring dual port protection with the Si320x line driver. The minimum series resistance required is 5 Ω where the MF-SM013/250V (vertical PTC solution to save board space) has a minimum resistance of 6.5 Ω. The impulse rating of the TISP6NTP2CD is guaranteed from 0 °C to 70 °C to cover most applications within the building that do not interface directly to an external communication line.

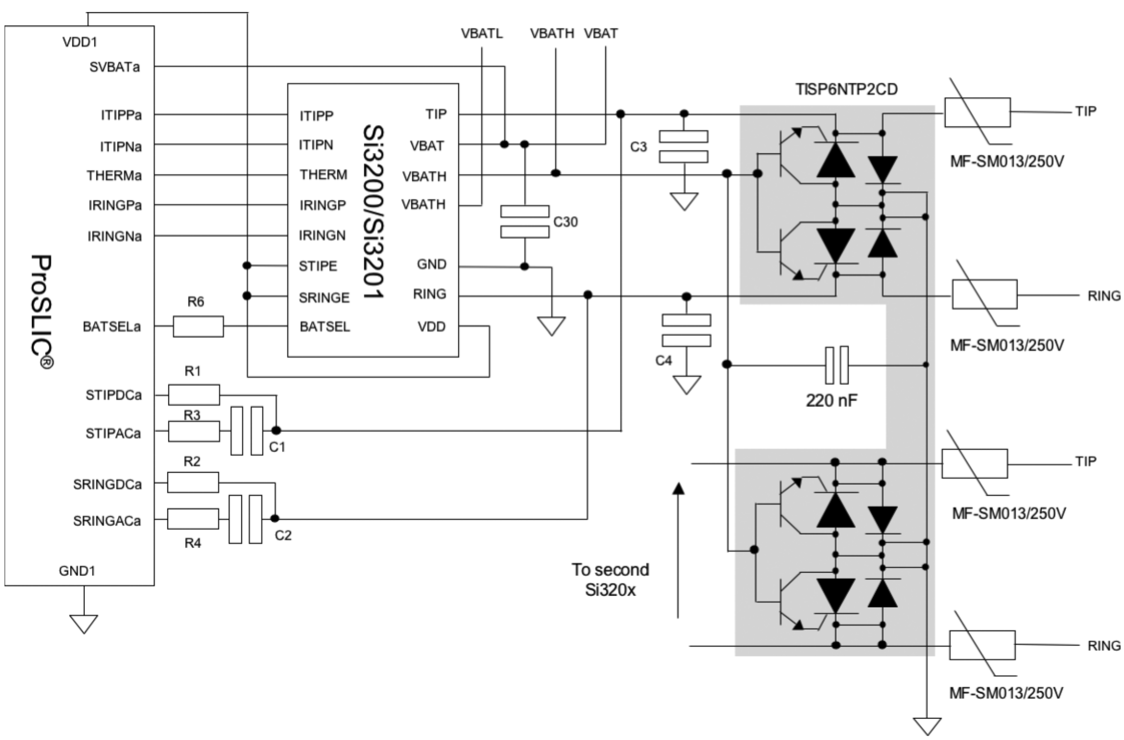


Figure 10: TISP6NTP2CD to protect dual port applications to GR-1089-CORE intra-building.

The TISP6NTP2CD shown in Figure 10 can be replaced by two TISP61089BDs if a B0500T single blow fuse is preferred. The layout needs to ensure that both K1 (pins 1 and 8) of the SOIC 8-pin package are connected together. The same needs to be done for K2 (pins 4 and 5) where this ensures the thyristor does not fail under impulse before the fuse opens. The coordination times of the fuse opening and the thyristor failing due to excessive load current under ac conditions is narrow and dependent on layout and therefore must be verified in the design.

SOLUTIONS FOR TIA-968-A AND UL 60950 FOR CPE

TIA-968-A has a type A surge of 200 A, 10/160 µs for longitudinal applications where the equipment can fail safely. The type B surge is 37.5 A, 9/720 µs (current of 4/245 µs) where the equipment must work after the test. The TISP61089BD is rated for 40 A under this impulse and therefore may be suitable as an overvoltage protector. TIA-968-A requires that the equipment must fail open under the type A surge and therefore the overcurrent protector should operate before the thyristor fails. Fuses do not normally specify their open times under impulse and therefore the simplest method is to design the thyristor protection so that it does not fail under the type A impulse conditions. However, the A^2s rating of the Bourns® 0.5 A B0500T fuse will open under this type A test and therefore the TISP61089BD can be considered with this solution. The B0500T will also clear safely under the ac power testing requirements of UL 60950. Should the Bourns® 1.25 A B1250T fuse or a low value of series resistance be used, the TISP61089HDM can be considered as shown in Figure 9. If a fuse is not desirable, the TISP61089BD will require additional series resistance that is suitably rated for 600 V and a minimum of 9 Ω.

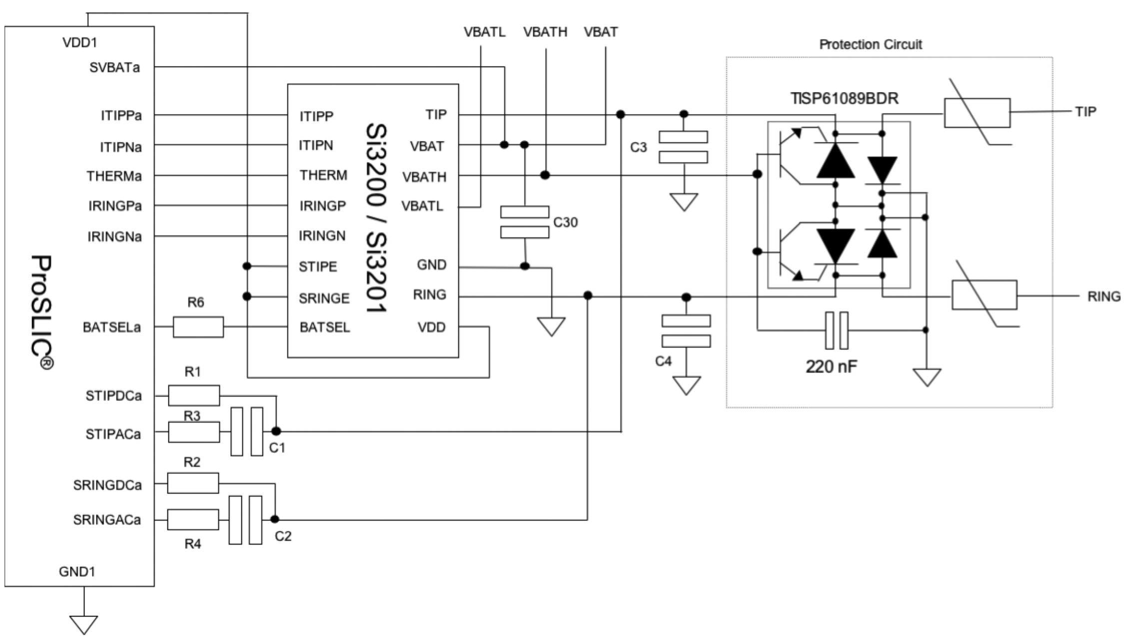


Figure 11: TIA-968-A and UL 60950 protection for Si320x line drivers

SOLUTIONS FOR ITU-T RECOMMENDATIONS

The ITU-T coordination recommendation is tested with the recommended primary protector across the equipment terminals. The primary protector is monitored to ensure it operates under the test. A minimum resistor to consider primary coordination is 7 Ω where lower resistor values may not coordinate, but still pass the customers' requirements.

The TISP61089BD is rated for 40 A, 5/320 µs (10/700 µs open-circuit voltage), which makes it suitable for basic K.20, K.21 and K.45 impulse recommendations. To achieve the 4 kV, 10/700 µs basic coordination test, the series resistance needs to be at least 7 Ω. The current rating of the thyristor also allows low values of series resistance such as the Bourns® Multifuse® MF-RX018/250 to be considered in the application. However, a clause is required to highlight that the protection is not intended to coordinate with the primary protector. The basic AC power line cross tests are performed with a variety of series resistance (10 Ω - 1000 Ω) with a generator voltage of 230 V rms for 900 seconds. It is common to design with a 250 V rms PTC thermistor to meet the test criteria. There is also a 600 V rms, 600 Ω induction test for 1 second that initially points to a 600 V rated overcurrent protector. Provided they do not operate during the test, 250 V PTC thermistors may be considered. This indicates that the PTC thermistor must be of a low resistance value so that it does not develop enough heat under the test to trip. MF-RX018/250 can be considered for the basic AC power contact requirements. The Bourns® Multifuse® MF-SM013/250 family can also be considered where coordination is required with the primary protector. Figure 12 shows a typical application to meet ITU-T basic recommendations for the Si320x.

Enhanced ITU-T test level requirement should be designed with the higher current rated TISP61089HDM gated thyristor to ensure the 6 kV 10/700 µs withstand.

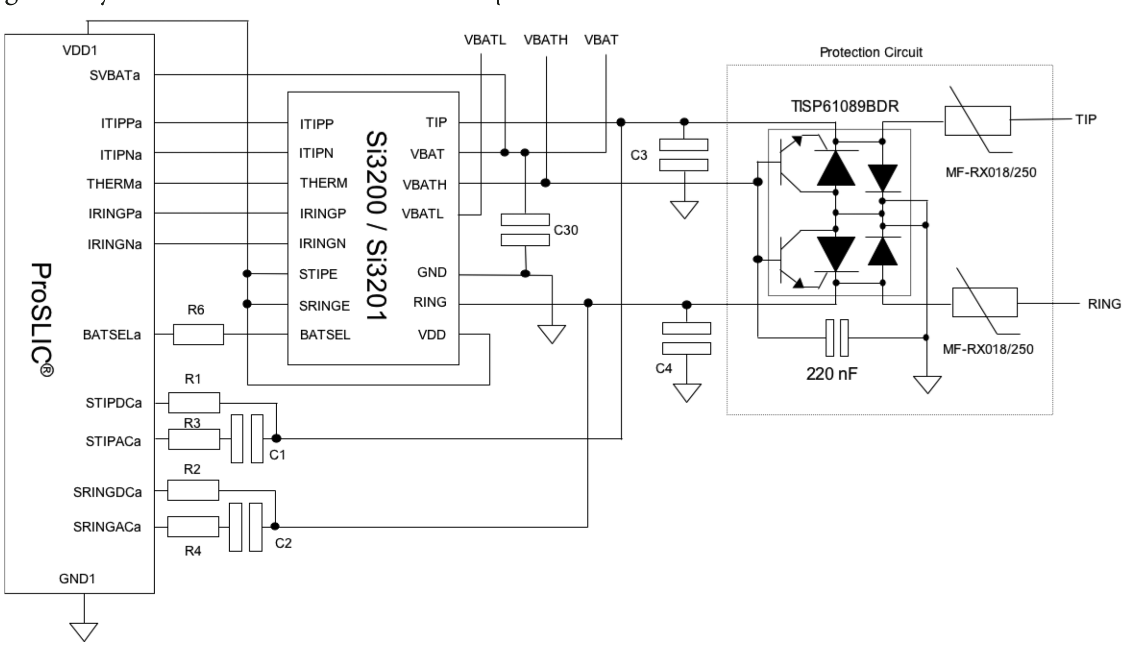


Figure 12: Basic ITU-T protection for Si320x line drivers

Telecom Standards

A country's standards or recommendations govern what protection is required for the equipment. Central office, remote access equipment and restricted access service provider equipment located on customer premises in the USA must conform to Telcordia GR-1089-CORE. Telcordia GR-1089-CORE intra-building requirements apply to customer premise or central office equipment ports that do not interface to external lines or serve off-premises equipment. Customer premises equipment (CPE) in the USA is required to meet TIA-968-A for lightning and UL 60950 (UL 1950) for AC power line cross. Most other countries have adopted the ITU-T (International Telecommunications Union) recommendations. ITU-T is a recommendation and therefore countries can modify this document to suit their own requirements. The ITU-T recommendations break out into a series of documents where K.20 covers central office, K.45 covers remote access equipment and K.21 covers CPE. The ITU-T test method is provided in a separate document and is covered in K.44. The ITU-T recommendations went through a major iteration in year 2000 to include a higher (enhanced) test level for locations that have severe lightning currents. The other significant addition is providing a primary and secondary protection impulse coordination test. Additional information is available on these standards in this section.

TELCORDIA GR-1089-CORE (ISSUE 3) REQUIREMENTS

The GR-1089-CORE standard (section 4) encompasses lightning and AC power fault test requirements pertinent for system protection. The GR-1089-CORE standards provide First level tests where the equipment must function after the tests. Second level tests allow the equipment to fail, but only in a safe mode and that is not harmful to the network. Unbleached cotton cloth also known as "cheesecloth" is used as a fire or ejection hazard indicator where sufficient damage to destroy the structural integrity of the cloth will be classed as a failure.

Two-wire interfaces require metallic conditions where T_{LINE} and R_{LINE} are connected to the test generator and longitudinal (T_{LINE} & R_{LINE} to GND) tests are to be conducted on the equipment.

First and Second Level Surge

Table 1 lists five first level tests (Table 4-2 of GR-1089-CORE section 4.6.7) where surge test 3 and 4 are normally performed on the equipment for approvals. Tests 1 and 2 can also replace test 3 if required by the equipment manufacturer. The 10/1000 μs is a high-energy pulse; multiple pulses could cause a progressive temperature rise resulting in overcurrent protection device failure. Therefore GR-1089-CORE specifies in section 4.6.1 that sufficient time may be allowed between surges to permit components to cool to ambient temperatures. Test 5 is to be performed on twelve or less T_{LINE} - R_{LINE} pairs

Test	Wave shape (t1/t2 μs)	Open circuit voltage	Short circuit current	Repetitions each polarity
First Level Surge				
1	10/1000	600 V	100 A	25
2	10/360	1000 V	100 A	25
3	**10/1000**	**1000 V**	**100 A**	**25**
4	**2/10**	**2500 V**	**500 A**	**10**
5	10/360	1000 V	25 A	5
Second Level Surge				
1	2/10	5000 V	500 A	1

Table 1: Telcordia GR-1089-CORE impulse

simultaneously and is used to test systems where telecommunication ports could share the same circuit protection solution. If the individual port protection meets tests 3 and 4, then test 5 only confirms the current handling capability of common paths (600 A max).

First and Second Level AC Power Fault

Power companies and the telecommunications service providers often share the same trunking to the facility or building and therefore there is a possibility that the telecommunication lines can come into contact with the electrical source. The magnetic field produced by the currents in the power line under fault conditions can also be induced through electromagnetic coupling with the communication lines. The characteristic of the fault condition will govern if the primary line protector such as the carbon block or gas discharge tube (GDT) activates or long, low voltage time fault conditions occur.

First and second level AC power fault tests as shown in Table 2 are performed under 50 or 60 Hz frequencies. The equipment is tested in metallic and longitudinal configurations. The 1000 V recommendations in issue 2 have been included as requirements in Issue 3. If the primary protector has not been defined in the system, the secondary protection circuit will need to support the full 1 kV test. This has been added to simulate the end of life carbon block characteristic in the field. Test 1a, second level AC power contact for 120 V rms, 25 A for 900 seconds is not required if the equipment has already passed UL 1459 or UL 60950 requirements.

First Level AC power fault			
Test	Open Circuit Voltage (V rms)	Short Circuit Current (A)	Duration (s)
1	50	0.33	900
2	100	0.17	900
3	600	1	1
4	1000	1	1 + *pri
6	600	0.5	30
7	440	2.2	2
8	600	3	1.1
9	1000	5	0.4 +*pri

Second Level AC power fault			
Test	Open Circuit Voltage (V rms)	Short Circuit Current (A)	Duration (s)
1	277	25	900
2	600	60	5
3	600	7	5
4	600	2.2	900

** Pri = Primary Protector is in place during test*

Table 2: Telcordia GR-1089-CORE AC Power Contact

Current Limiting Protector Tests

The current limiting tests are conducted at 600 V rms, with a range of short circuit currents of 15-minute durations under metallic and longitudinal configurations. An external current limiter indicator that is time/current dependent is used to ensure conformance, but time current measurements can be also taken. A MQD 1-6/10A or MDL 2.0A fuse manufactured by Bussmann or their equivalent has been recommended as a suitable external indicator. This places the emphasis on the equipment to ensure this indicator fuse is not damaged during test. Designing the system so that it will not fail is not a possibility without providing current limiting below the fuse indicator characteristic. Cheesecloth is also applied to the equipment as the fire hazard and fragmentation indicator.

Test	Short Circuit Current (A rms)	Open Circuit Voltage (V rms)	Duration (s)
1	2.2	600	900
2	2.6		
3	3		
4	3.75		
5	5		
6	7		
7	10		
8	12.5		
9	20		
10	25		
11	30		

Table 3:Telcordia GR-1089-CORE Current Limiting

All the tests highlighted in Table 3 are performed on the equipment where test 1 and 2 do not require the external current limit indicator to be present. The equipment passes the other tests if the equipment interrupts the line current to less than 50 mA and the external current limiter indicator is not open circuit. If the external current limiter indicator is open circuit, the equipment will require external current limiting protectors.

For applications where the manufacturer specifies the complete installation of the equipment from the network interface to the equipment, the wiring simulation is replaced with a 30 cm section of 26 AWG or coarser copper cable. This will allow a higher current limiter to be used in the equipment giving more impulse current capability for remote terminal environments that can have surge current stress levels exceeding 100 A, 10/1000 µs.

Intra-building Requirements

Intra-building specifications apply to communication lines that only stay within the building with no external connections. Lightning disturbance can enter the building through earth reference disturbance or electromagnetic coupling of lightning rods for example. If customer premises equipment has external connections to outside plant equipment such as an analogue modem port, then these ports are covered under TIA-968-A requirements. Communication lines to service off-site equipment will need to conform to Telcordia GR-1089-CORE in its entirety.

Two-wire communications lines will need to be tested with metallic surges of a 2/10 µs waveform with an open circuit voltage of ±800 V and short circuit current of 100 A. The equipment needs to withstand a longitudinal test with a waveform of 2/10 µs and an open circuit voltage of ±1500 V with short circuit current of 100 A. The equipment needs to withstand a single impulse of each polarity without damage under these tests. It is key to note that if the communication lines shield is terminated to ground at both ends, the impulse test does not need to be done. In practice, this is hard to enforce and therefore it is prudent to do the tests.

Intra-building has an AC power contact test (section 4.6.17, second level intra-building AC power fault tests for network equipment to be located on customer premises, page 4-37). The test is conducted with 120 V rms, 25 A for 900 seconds where the equipment can fail safely. An external wire simulator using a MDQ 1-6/10 A or MDL 2.0 fuse is used to ensure the equipment port does not consume excessive currents that can damage the interconnect leads.

Protection Coordination

Protection coordination is a new test for GR-1089-CORE Issue 3. This coordination references GR-974-CORE TLPUs (Telecommunications Line Protector Unit) for primary protection with secondary protection. The equipment communication lines will initially be tested at the specified primary voltage protector. If a primary protector is not defined, the test will start with an open circuit generator voltage of 1000 V and increased (in steps of 200 V or interpolated value) to a maximum of 2000 V or until one of the two following criteria is achieved:

A. *The communication lines are stressed to at least 1000 V peak (V_P) across the equipment terminals. For example, if the generator fictive impedance is 10 Ω (1000 V/100 A) and the equipment has an overcurrent resistor of 50 Ω, the generator open circuit voltage will need to be set to 1200 V to achieve 1000 V across the terminals. Series resistance of the primary protector such as a heat coil resistance is connected between the generator and equipment. This resistance will be effectively added to R_{SERIES} value when calculating the generator open circuit test voltage.*

B. *The peak current (I_{PP}) into the equipment terminals exceeds 100 A. This can be achieved by replacing R_{SERIES} with a fuse such as the Bourns® B1250T. The generator open circuit voltage will be set to 1000 V to achieve 100 A into the equipment.*

The equipment fails the coordination requirement if neither A or B is achieved with a maximum generator voltage of 2000 V or if the equipment is damaged and does not operate as intended. Figure 14 shows the setup and measurement points for the coordination test.

If the primary protector is defined, the voltage limiting specification can be a maximum of either 400 V (solid state primary), 600 V (GDT) or 1000 V (carbon block) at 1 kV/μs in accordance with GR-974-CORE. This primary protector will denote the initial generator start voltage and the V_P voltage to meet criteria A. The coordination test will be conducted with 10/1000 μs waveform where the test requires ten repetitions per polarity. The communication lines will also be tested to metallic and longitudinal procedures to ensure conformance.

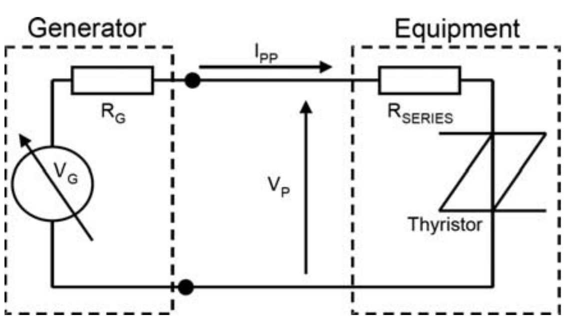
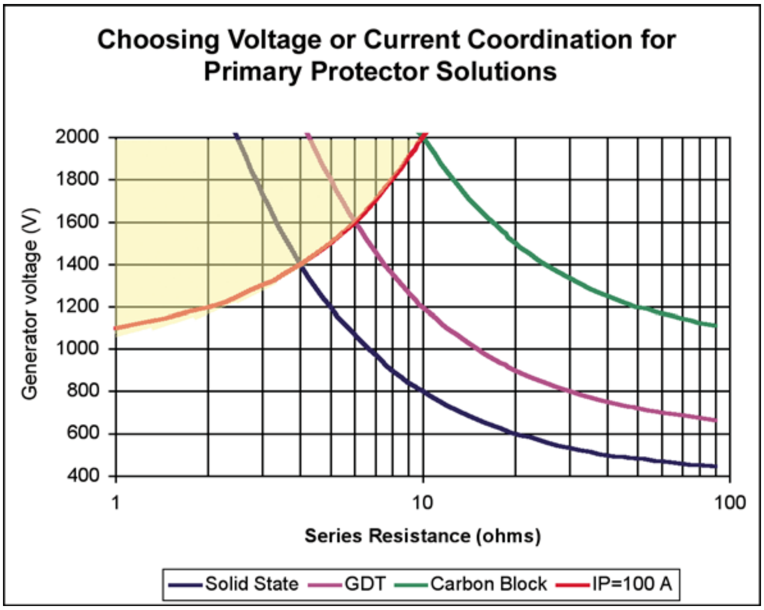


Figure 14: Coordination requirements

There is a trade-off between the generator voltage and the series resistance selected. For example, if the R_{SERIES} value is 10 Ω, the generator voltage will need to be adjusted to 2000 V to achieve coordination with a carbon block but if R_{SERIES} is 50 Ω the V_{GEN} would be 1200 V. Increasing the series resistance will increase the power dissipation requirements of the module under first level AC power contact tests. The first level 10/1000 μs impulse will generate 500 V with a series resistance of 10 Ω and the thyristor could be derated to 50 A. The new coordination requirements will provide a stress voltage of 1000 V across the series resistor where the thyristor will need to support 100 A. This will penalize high series resistance (15-50 Ω) that benefits true voltage coordination where the secondary protection resets after the disturbance.

Defining the primary protector can also reduce the stress of the circuit protection components. If a GDT such as the Bourns® 2026-35-C2F or 2410-31-G-MSP 5-pin module solution is specified as the primary protector, the maximum open circuit generator voltage will be 1200 V to achieve a V_P of 600 V. This will allow an 80 A 10/1000 µs rated thyristor to be considered in the application and the rating of the 10 Ω to be closer to the first level impulse test requirement.



Graph 1: Voltage or current coordination

Graph 1 highlights where the series resistance, R_{SERIES} will dictate a current or voltage coordinated application. For applications requiring voltage coordination, the additional series resistance, R_{SERIES} must be outside the shaded area (right of I_P curve). For current coordinated applications (left of I_P curve), the overvoltage thyristor protector must be rated to at least 100 A 10/1000 µs.

For example, an application using a GDT will be voltage coordinated with a series resistance of greater than 6 Ω and current coordinated with less than 6 Ω. The 600 V GDT sparkover voltage and 100 A impulse current is achieved at the crossover point of 6 Ω.

TIA-968-A AND UL 60950 REQUIREMENTS FOR CPE

The TIA-968-A has two types of lightning surge tests, A and B. Type A testing allows equipment to fail, but only in a "safe" mode that is not harmful to the network. Any protection failure must be an open circuit condition making the CPE noticeably unusable after the surge. Type A metallic (transverse) testing applies two surges (one of each polarity) between any pair of lines on which lightning surges may occur. This test will be applied between Tip to Ring connections. For a 4-wire connection that uses simplex pairs for signaling, an additional impulse test is required between Tip to Ring1 and Ring to Tip1. The impulse voltage and current waveform is 10/560 µs with an open circuit voltage of 800 V and current of 100 A. Equipment which interfaces to non-registered equipment ports are also surged between all the connector ports and use standard longitudinal tests between port to earth connections. Longitudinal testing uses a different 10/160 µs test waveform with a peak open-circuit voltage of 1500 V and short circuit current of 200 A.

TIA-968–A Specifications	Wave Shape (t1/t2 µs)	Open circuit Voltage (V)	Short circuit Current (A)	Surge Type
Longitudinal	10/160	1500	200	A
Metallic	10/560	800	100	
Longitudinal	9/720, (4/245)	1500	37.5	B
Metallic	9/720, (4/245)	1000	25	

Table 4: TIA-968-A impulse requirements

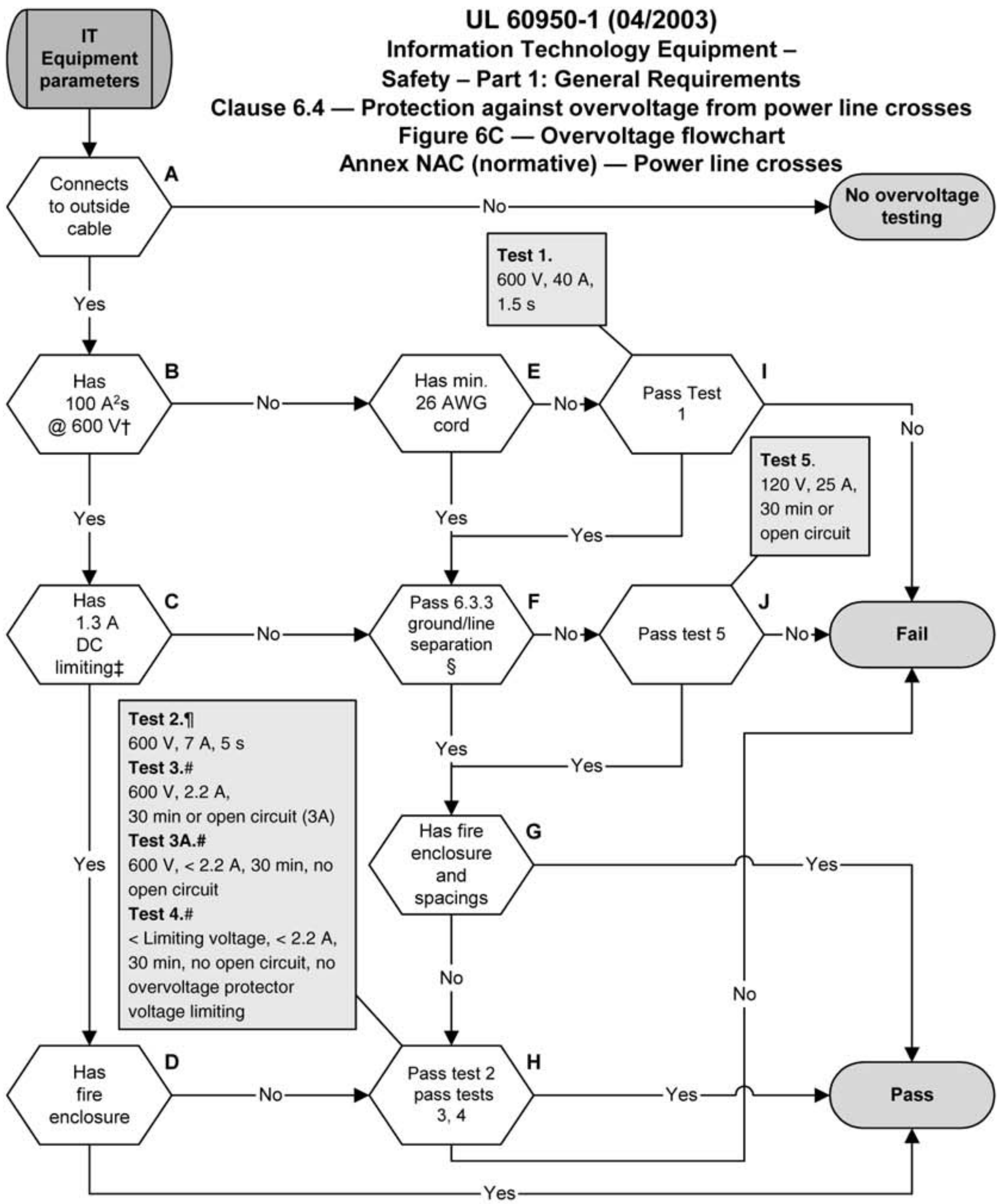
Type B surges reflect normal lightning surge exposure and the CPE must not degrade or fail during these tests. The metallic test (one of each polarity between Tip to Ring) uses a 9/720 µs, 1000 V open-circuit voltage with 5/320 µs, 25 A short circuit current. Longitudinal tests use the same generator, but with an open-circuit voltage of 1500 V and short circuit current of 37.5 A (for single outputs only). Table 4 shows type A and B the impulse requirements for US customer premises equipment.

UL 60950 Requirements

UL 60950 covers a wide range of safety and protection topics such as isolation, creepage, transient protection and AC power fault conditions that the protection circuit needs to conform to. The simplest method to pass UL 60950 is to ensure the equipment either limits the I^2t to less than 100 A^2s and has a fuse that operates below 1.3 A DC or uses a 26 AWG cable and the equipment case is a fire enclosure.

If the equipment does not limit the I^2t to less than 100 A^2s, and a 26 AWG cable is not specified, test one will be applied to the equipment. A MDL2.0A wiring simulation fuse is used with test 1 and 5 and cheesecloth indicator for all the other tests. Equipment passing the TIA-968-A type A surge in a non-operational mode, could use a fuse of 1 A or less and satisfy the 1.3 A limit. Equipment operationally passing type A surge will tend to use a 1.25 A fuse, such as the B1250T and the line to ground separation will be required. Fuses with ratings of 2 A and above may not operate before the wiring simulator fails and the equipment will fail. The UL 60950 flowchart on page 24 shows the equipment design options and the test steps to gain a pass.

Figure 6 UL 60950-1 Overvoltage flow chart



NOTES

† Overcurrent protector I^2t must must be lower than any other equipment element which carries the same current.
‡ UL states a fuse with a 1 A or less rating meets the 1.3 A criterion.
§ Pass for 120 V a.c. between telecommunication line and ground current < 10 mA.
¶ Test 2 not required if the equipment d.c. breaking is 1.3 A or less, see comment ‡ .
\# Tests 3 and 4 not required for equipment with less than 1000 m of outside cable.

Pass criteria	Test 1	Test 2	Test 3	Test 3A	Test 4	Test 5
No equipment cheesecloth charring	✔	✔	✔	✔	✔	✔
Insulation OK	✔	✔	✔	✔	✔	✔
50 mm of 32 AWG wire or MDL-2 A fuse OK	✔					✔
I^2t < 100 A^2s @ 600 V rms AC	✔					

Users must verify requirements against latest issue of UL 60950

ITU-T RECOMMENDATIONS

The ITU-T (International Telecommunication Union-Telecommunication Standardization Sector) K series protection recommendation is location based. K.20 covers central office equipment, K.45 for remote access equipment and K.21 for customer premises equipment (CPE). The test circuits for these documents are given in K.44. For 2003, the ITU-T K.15 (remote feed and line repeaters) and K.17 (power feed repeaters) are now addressed in K.45. K.22 (ISDN) is now included in K.21 and K.41 (internal interfaces) are in K.20. ITU-T is a recommendation and therefore the individual countries can modify these recommendations and add tests specific to their telephone networks.

External Port Impulse Tests

A recent addition to ITU-T is to include enhanced test levels for countries that want increased impulse and AC power fault conditions. The new enhanced recommendations increase the open circuit impulse to 1.5 kV for K.20 central office applications. Field investigation also showed that customer premises equipment was more vulnerable to impulse than central office equipment and therefore the enhanced impulse is specified at 6 kV compared to basic 1.5 kV. Multiple port testing uses a 10/700 µs voltage surge where the generator output is resistively divided between the ports. The individual port stress will be generally lower for multiple-port testing than for single-port testing unless the inherent overvoltage protector is shared across several lines. This test will result in the highest ground-return currents in the application that need to be considered in areas such as track thickness. Table 6 on page 26 provides a summary of the external port impulse requirements.

The latest 2003 ITU-T recommendations include new tests to stress the external port to internal ports of the equipment. In 2002 ITU-T, the internal ports such as USB, Ethernet connections on modems for example were left floating. Under the latest recommendation, the internal ports are coupled to the ground return of the generator. This will test the withstand capability between the external and internal ports when the primary protector is not used. All the untested ports are tested in their terminated or powered modes and then tested with them coupled down to ground.

Single and Multiple Port 8/20 µs Current Testing

2003 ITU-T tests for single and multiple ports have been extended to included applications that remove the need of an external primary protector by having the primary protection inside the equipment. The standard specifies 1 kA per wire where the additional external resistance is zero. As the additional output resistance is zero, the ideal test procedure is to use a generator with multiple outputs. This reduces the possibility of one line protector switching on first and all the test current going through the protector.

Coordination Requirements

Primary equipment protection coordination must now be verified during longitudinal and metallic (transverse) impulse testing as set out in K.44. If the equipment meets K.28 (solid state primary), this coordination test can be omitted. The new 2003 ITU-T recommendations have also included port to external port testing for K.21 and K.45 applications. The enhanced coordination recommendations for K.20 will be tested with 4 kV with an additional external resistance of 25 Ω for applications with less than 250 lines (125 ports). The additional series coordination resistance may need to be increased for applications. This is due to the impulse current path going through the tested port primary protector ground to another external port primary protector and returning to the generator through the external port coupling element. This will place the primary protectors in series so that a higher coordination voltage will need to be generated to operate the primary protection. The current path will be the same if the secondary protection to the equipment ground is used. When the GDT on the tested port operates, coordination is checked at the highest impulse level of 10/700 µs at 4 kV, 2 x 80 A (basic) or 6 kV, 2 x 120 A (enhanced) where the primary is verified to switch during the test. The equipment is tested five times in each polarity to ensure coordination.

Port	Test	Lighting Test	Basic test levels			Enhanced test levels			No. of tests	Primary protection
			K.20	K.45	K.21	K.20	K.45	K.21		
Single	2.1.1.a	10/700 µs longitudinal	1 kV R=25 Ω	1.5 kV R=25 Ω		1.5 kV R=25 Ω			5 at each polarity	No
	2.1.1.b	10/700 µs transverse						1.5 kV, R=25 Ω Case insulation tested to 6 kV		
	2.1.1.c	10/700 µs port to external port	NA			Note (see below)				
	2.1.2.a	10/700 µs coordination longitudinal	4 kV R=25 Ω			4 kV R=25 Ω		6 kV R=25 Ω		Yes special primary test protector
	2.1.2.b	10/700 µs coordination transverse								
	2.1.2.c	10/700 µs coordination port to external port	NA			Note (see below)				
	2.1.5.a	8/20 µs longitudinal	1 kA per wire R=0			5 kA per wire R=0				No
	2.1.5.b	8/20 µs port to external port	NA			Note (see below)				
Multiple	2.1.3.a	10/700 µs inherrant longitudinal	4 kV R=25 Ω			6 kV R=25 Ω				No
	2.1.3.b	10/700 µs port to external port	NA			Note (see below)				
	2.1.4.a	10/700 µs longitudinal	4 kV R=25 Ω			6 kV R=25 Ω				Yes agreed protector
	2.1.4.b	10/700 µs port to external port	NA			Note (see below)				
	2.1.6.a	8/20 µs longitudinal	1 kA per wire, R=0 Ω (limited to maximum 6 kA)			5 kA per wire, R=0 Ω (limited to maximum 30 kA)				No
	2.1.6.b	8/20 µs port to external port	NA			Note (see below)				

Notes:
- *Systems with greater than 250 ports do not need to be tested. Systems with less than 250 ports will be tested to K.45 requirements.*
- *15 Ω is the internal fictive resistance of the generator.*

Table 6: ITU-T Impulse

ITU-T impulse table was sourced from Compliance Engineering article "The 2003 ITU-T Telecommunications Equipment Resistibility Recommendations".

K.44 (appendix 1 of the testing procedure) covers increased coordination requirements by specifying a 10 kV, 25 Ω 10/700 µs impulse. This is required to address applications such as customer premises equipment (CPE) that could have poor primary protection. As the voltage coordination increases, the minimum coordination resistance reduces. This places the emphasis on the equipment coordinating at the basic 4 kV impulse test, but the coordination resistor meeting the higher stress levels induced with the 10 kV test.

Internal Port Impulse Tests

The 2003 ITU-T recommendations now include internal port testing where telecommunication lines do not leave the building or interface to outside plant equipment and is the same as Telcordia GR-1089-CORE intra-building requirements. A summary of the impulse test is highlighted in Table 7. ITU-T internal port testing only tests with 8/20 µs (1.2/50 µs voltage waveform) impulse and does not include AC power contact tests like GR-1089-CORE. Single port applications are tested with an additional external resistance of 10 Ω. The 8/20 µs generator internal fictive resistance is 2 Ω. For a two port ProSLIC® application, a single port will be tested, with the second port powered and terminated. The TIP and RING lines will be tested with its own external 10 Ω series resistor for single output generators to ensure the current is shared between both lines. The additional external 10 Ω series resistor changes the short circuit current to a 3.3/30 µs as the resistance of the generator is now 12 Ω. This provides a harsher requirement than the original 8/20 µs test.

Multiple port applications with unshielded lines are tested with the other ports powered, terminated or left open. The ports are tested with an 8/20 µs with an additional 10 Ω of external resistance.

Port	Test	Lighting Test	Basic test levels			Enhanced test levels			No of tests	Primary protection
			K.20	K.45	K.21	K.20	K.45	K.21		
Single	7.1	8/20 µs unshielded cable longitudinal	500 V R=10 Ω	NA	1 kV R=10 Ω	1 kV R=10 Ω	NA	1.5 kV R=10 Ω	5 at each polarity	No
Multiple	7.2	8/20 µs shielded cable longitudinal	500 V R=0 Ω	NA	1 kV R=0 Ω	1 kV R=0 Ω	NA	1.5 kV R=0 Ω		No
Note: 2 Ω is the fictive resistance of the generator. The 10 Ω is the additional external resistance required for the test.										

ITU-T internal or intra-building impulse table was sourced from Compliance Engineering article "The 2003 ITU-T Telecommunications Equipment Resistibility Recommendations".

Table 7: ITU-T Internal or intra-building impulse

Ports with shielded cabling are tested in the multiple port configuration where the individual lines and shield are connected together directly to 8/20 µs generator without any additional series resistance. The equipment is tested with a 20 meter length of shielded cable where the cable resistance is expected to ensure current sharing between the ports. Internal port testing does not apply to K.45 (remote access) where equipment ports rely on external port testing procedures.

AC Power Line Cross

The ITU-T recommendation specifies eight source-resistance values ranging from 10 to 1000 Ω to be tested with a 50-60 Hz 230 V rms generator. The test range can be narrowed if the worst case stress conditions of the equipment are known. Enhanced power contact testing uses the same resistance and voltage levels, but the equipment is also required to meet criterion A (equipment must not fail in operation) for the resistance ranges of between 160 to 600 Ω.

The inherent induction test is achieved with a 600 V rms, 0.2 s, 600 Ω applied to the equipment where the equipment must still operate as intended. Basic coordination testing increases the test time to 1 s, 600 Ω applied to the different configurations with the primary protector in place. Enhanced coordination testing is done with a 200 Ω generator source with various voltage and time values set between 1500 V rms for 0.18 s and 450 V rms for 2 s. The time vs. test voltage can be calculated by using the formula:

$$t = \frac{400{,}000}{V^2} \text{ seconds}$$

K.44 highlights testing at 450 V & 1500 V and then at least two intermediate levels between the two extremes should be sufficient if there are no transitions specified.

ITU-T does not distinguish between single and multiple ports under AC fault conditions and therefore each port is considered a single port solution. The table below shows the AC tests for single port applications.

Test No	Power test description	Basic test levels			Enhanced test levels			No of tests	Primary protection	Acceptance criteria
		K.20	K.45	K.21	K.20	K.45	K.21			
2.2.1.a	Induction inherent longitudinal	$I^2t = 0.2\ A^2s$ 600 V rms max R = 600 Ω t=0.2 s						5	No	A
2.2.1.b	Induction inherent transverse									
2.2.1.c	Induction port to external port	NA			Note (See below)					
2.2.2.a	Induction inherent coordinational longitudinal	$I^2t = 1\ A^2s$ 600 V rms max R = 600 Ω t=1 s			$I^2t = 10\ A^2s$ 450 V rms to 1500 V rms R = 200 Ω t=0.18 s to 2 s $t=400k/V^2$			5 at each test level	Yes agreed primary or special primary test protector	
2.2.2.b	Induction inherent coordination transverse									
2.2.2.c	Induction coordination port to external port	NA			Note (See below)					
2.3.1.a	Contact longitudinal	230 V rms, R = 10, 20, 40, 80, 160, 300, 600, 1000 Ω t=900 s for each resistor value			230 V rms, Criteria B for R = 10, 20, 40, 80, 1000 _. Criteria A for R = 160, 300, 600 Ω t=900 s for each resistor value			1 set	No	B
2.3.1.b	contact transverse									
2.3.1.c	Contact port to external port	NA			Note (See below)					

Note: Systems with greater than 250 ports do not need to be tested.
Systems with less than 250 ports will be tested to K.54 requirements.

Table 8: ITU-T single port AC power cross

ITU-T single port AC power cross table was sourced from Compliance Engineering article "The 2003 ITU-T Telecommunications Equipment Resistibility Recommendations".

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