

High Voltage Protection Techniques with TP3210 Subscriber Line Interface Module

National Semiconductor
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1.0 INTRODUCTION

The objective of this application note is to demonstrate a solution which removes some of the traditional accuracy constraints on the protection components without impacting performance. It then goes on to develop protection schemes which are completely resettable. The note begins with a brief discussion of the protection problems associated with subscriber line interface circuits, and outlines the basic requirements which these devices meet. This is followed by a discussion of the National Semiconductor Subscriber Line Interface Module (SLIM™) device, demonstrating the unique advantages this part has over the more conventional solutions. Finally, two protection systems are analyzed in detail, and the measured performance of these is shown. These results, combined with the information contained in the note, will allow a linecard designer to completely specify the protection components required to meet the desired performance level.

2.0 SLIC PROTECTION PROBLEMS

To understand the problems in protecting line circuits, a basic review of the traditional protection layout is useful in appreciating the direction in which protection technology is moving. The line interface protection networks are traditionally split into primary, secondary, and tertiary protection components. Figure 1 shows the layout of a conventional switch protection scheme for both subscriber and trunk lines exiting the central office. The secondary and tertiary levels are normally combined at the linecard. The protection levels are typically 1000V peak after primary protection and around 80V peak after secondary protection. This value is, of course, dependent on the clamp voltage of the shunt protection element used in the secondary circuit.

2.1 Primary Protection

The primary components are responsible for handling the large disturbances such as a lightning strike close to the central switch location. They are normally situated on the main distribution frame (MDF), where the subscriber cables

enter the office. All disturbing currents arrested by the primary protection components are directed away from the main body of the switch, via a separate protection ground connection and are discharged harmlessly to earth. A typical implementation of primary protection would employ gas discharge tubes (GDT), which limit the voltages exiting the MDF to less than 1000V peak. The benefit of positioning primary protection on the MDF is twofold.

Firstly, it avoids having large transient currents flowing in the office wiring. This ensures that the current rating of the wiring is never exceeded, and also ensures that the voltages present after the MDF are relatively low (less than 1000V peak), which avoids any damaging secondary arcing between adjacent points inside the office. Secondly, by ensuring that the energy is shunted safely away to earth, the operation of the majority of the switch remains unaffected. This is especially important when serving large rural areas with a high incidence of thunderstorms.

2.2 Secondary Protection

The secondary protection components reside either on the linecard itself, or immediately on the backplane adjacent to the card connector, and are designed to handle the residual current which passes the primary protection. This consists of power cross currents and power induction products which are of sufficiently low voltage to pass through the primary protectors. The secondary protection schemes employ two separate elements to protect the sensitive line card components. Firstly, a series element which limits the current flowing onto the linecard, and secondly, a shunt element which limits the voltage. This shunt element can be a simple bridge rectifier connected between the battery terminals which shunts the current to either battery or ground, or more commonly, an active thyristor device which shunts the current to protection ground only. This device, when triggered, returns transient energy either to the local protection ground connection at the linecard or, preferably, returns it to a remote protection ground, usually the same as the protec-

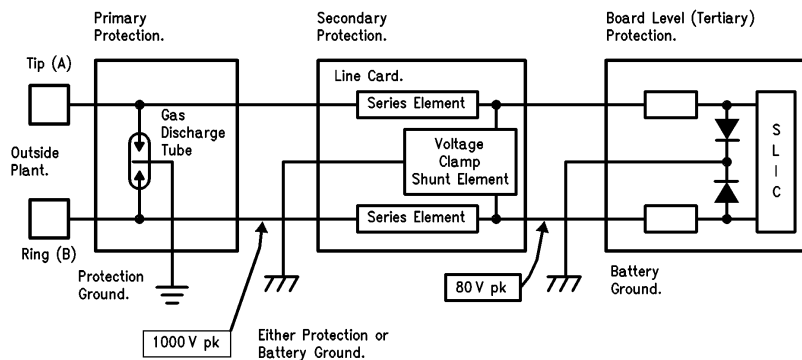


FIGURE 1. Conventional Switch Protection Arrangement

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tion ground used on the MDF. When using remote grounds, this can give rise to 1000V differences between Battery ground and the protection ground. This configuration is popular in North America and specialized knowledge and design techniques must be employed to cope with this since the voltage stress on the line card components is high. The **SLIM** device is one of the few devices which can meet this requirement and thus is especially useful for applications using separate ground systems.

While providing the necessary protection, the protection components must not degrade the transmission characteristics in any way during normal speech and signaling modes. It is this area that compromises between good protection and meeting specifications are frequently made, but these are avoided when using the **SLIM** device.

3.0 PROTECTION COMPROMISES

There are two areas which affect the selection of the protection components used. These are the DC voltage headroom requirements for the electronic SLICs to operate correctly, and the Longitudinal Balance requirements imposed on the circuit by the transmission specifications.

3.1 DC Headroom Limitations

The DC headroom implications are shown in *Figure 2*. In order for an electronic SLIC to function correctly, a certain voltage headroom is required for linear operation. This means that there is an interaction between feeding line current to the maximum long loop requirement, and allowing sufficient headroom for SLIC amplifier operation. From *Figure 2*, it can be seen that line current flows from the amplifier via Rprotect, the series protection elements. If the values of these are not carefully chosen, the voltage headroom may be impacted, and hence maximum long loop requirements compromised.

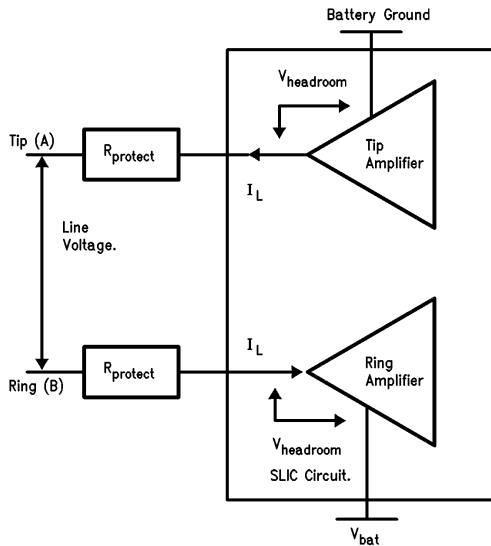


FIGURE 2. DC Headroom Limitations

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The longitudinal balance tests are probably the most stringent requirements placed on the front end of the line interface circuit, and are normally directly affected by the selection of the protection resistors. In order to meet these requirements, the matching of resistance from the Tip(A) and Ring(B) legs of the circuit to ground must typically be better than 1%. In most circuits, the burden of this precise matching requirements is placed directly on the series protection elements. This results in escalating costs for these components, but with the **SLIM**, these precise requirements are eliminated.

However, the problems of DC headroom and longitudinal balance can be eliminated if resourceful design techniques are employed to desensitize the series protection elements from impacting the feeding law. These techniques are employed in the new National Semiconductor **SLIM** which, by optimal use of complementary technologies, removes much of the restrictions on accuracy requirements from the protection components.

3.3 SLIM Protection

The National Semiconductor **SLIM** device is a completely new concept in subscriber connections to the central switch which uses a mixture of technologies to attain an optimal performance/cost ratio. This ratio is not just in the component cost required to implement the SLIC function, but the total manufacturing cost. The **SLIM** device is designed to minimize the number and cost of external components resulting in a substantial cost saving on a complete line circuit basis. This system cost reduction philosophy is particularly prevalent in the way the protection scheme is implemented. The tolerances for the protection components are orders of magnitude less than normally required to attain the performance levels which this part achieves, with a corresponding reduction in the cost of these components. A working knowledge of the principles employed to allow this will now be presented, followed by some results showing how insensitive the technique is to changes and mismatches in the protection components.

Conventional protection schemes, outlined in *Figure 1*, separate the linecard protection into secondary protection and tertiary protection. Using the **SLIM** approach, the module itself carries the tertiary protection components, and the series elements of the secondary protection are included in a sensing loop which cancels any errors which may arise due to poor matching of the resistance values as shown in *Figure 3*. The benefit of this approach is that the burden of matching these components is removed to a large degree from the board manufacturer.

This approach is only possible using a careful mix of technologies which enable the voltage ratings at the primary/secondary interface to be met. This is achieved by manufacturing SLIM on a thick film hybrid module which will stand in excess of 1000V peak without failing. By using these thick film techniques, and by accurately trimming, a very high degree of longitudinal rejection can be maintained. Typical figures of 75dB are measured at the final test stage of the completed module using 100Ω, 1% protection resistors.

Since the module employs a control loop to guarantee the longitudinal balance of the system, it can also synthesize the longitudinal terminating resistance on each leg of the subscriber line, i.e., the resistance from each leg to ground

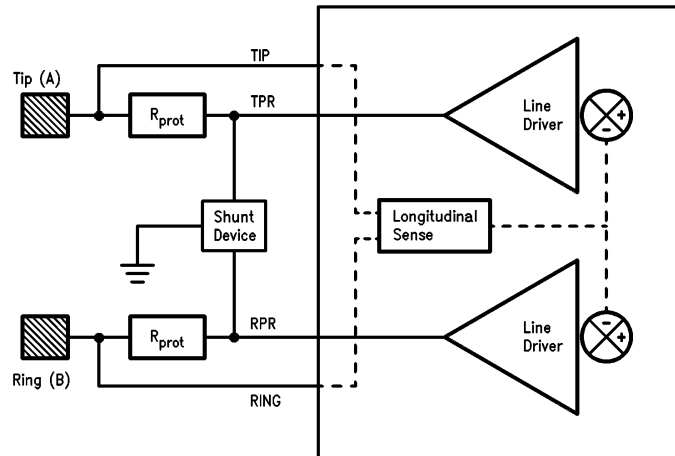


FIGURE 3. SLIM Protection Arrangement

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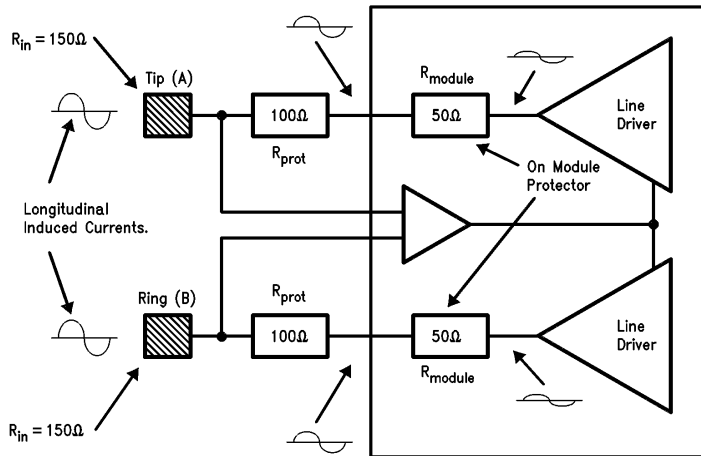


FIGURE 4. Synthesized Longitudinal Resistance

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in response to longitudinal signals. The advantage of synthesizing this resistance is that the control of longitudinal voltages appearing at the line terminals is much tighter, maintaining a more consistent longitudinal balance figure. Secondly, and more importantly, by carefully matching the synthesized resistance with the physical resistance consisting of the on module resistance and the external protection resistance, an improvement in signal handling capability in the presence of high levels of longitudinal current can be achieved. Figure 4 shows this graphically.

Referring to the conventional protection layout in Figure 1, it is important that the module protection is sufficient to withstand the currents which are allowed to pass through the secondary shunt protection device. Using the SLIM, the module has series protection elements incorporated in the design which are capable of surviving in excess of 80V each leg. The applications advantage of this is that the shunt pro-

jector can be directly connected across the output of the SLIM device at the TPR and RPR terminals.

Overall the SLIM device has been designed with the end application in mind. The optimum mix of technologies has been used to achieve the most cost effective solution to the OEM, not just in component cost, but also in the external components and manufacturing costs. This philosophy can be seen in the way in which the protection function is partitioned, enabling the user to achieve previously unattainable levels of performance from wide tolerance components. It is this systems approach to the problem which enables SLIM users to obtain a competitive advantage compared with conventional solutions to the protection problem. The remaining sections of this applications note will deal with the results of laboratory tests, followed by an examination of the various protection options available with this versatile device, outlining the strengths and weakness of the different solutions.

4.0 LABORATORY MEASUREMENTS

The previous sections have concentrated on the effectiveness of the **SLIM** device in meeting longitudinal requirements while incorporating very loose tolerance protection components. However, as yet there have been no quantitative measure of the performance which can be attained with the part. The results which are presented here were measured under laboratory conditions using a Wilcom T207E Longitudinal Balance Test Set, measured in accordance with IEEE 455-1976 Recommendations. The tests were measured on typical devices from standard production runs, and are representative of the results which can be expected from a **SLIM** based line circuit.

The tests were designed to investigate the behavior of the part under 3 different line conditions, while varying the protection resistances, $R_{protect}$. The graphs show results for 3 different test frequencies to allow appreciation of the sensitivity of the results. The devices were tested for sensitivity to the absolute value of resistors (both resistors matched to within 0.1%) and then the mismatch sensitivity between the two protection resistors, one resistor being held constant and the other was reduced in value. This second test was carried out with the fixed resistor having the values of 120Ω, 100Ω, and 80Ω, the other leg having resistors 20% different.

The results presented below are the worst case results of the devices tested. The measurements were made at 0 mA, 20 mA, and 42 mA line current. These correspond to on-hook, 1900Ω loop resistance, and 750Ω loop resistance.

4.1 Absolute Value Sensitivity

Figures 5, 6 and 7 show the results of Longitudinal Balance against Resistor Value of $R_{protect}$ both resistors matched to within 0.1%. These results are measured at 62 Hz, 1000 Hz, and 3400 Hz for the 3 stipulated line conditions.

The overall trend of these results indicate that the Longitudinal Balance is better than 60 dB for all values of protection resistor between 90Ω and 120Ω. Values substantially greater than 120Ω are not recommended since these will reduce the operating voltage headroom of the output amplifiers as explained earlier.

4.2 Matching Sensitivity

The tests for the matching sensitivity were carried out in a similar fashion except the resistor in one of the legs was held constant. The results recorded in Figures 8, 9 and 10 indicate the worst case result between the two legs. The results shown in Figure 8 illustrate the trade-off between resistor matching ratio and the longitudinal balance which can be achieved for $I_{loop} = 0$ mA, while Figures 9 and 10 show $I_{loop} = 20$ mA and 42 mA respectively. This is shown for fixed resistors of 120Ω, 100Ω, and 80Ω while the other leg was varied. The graphs show the results for 20% mismatch between legs. From the graphs, it can be seen that the longitudinal balance achieved using very loose tolerance parts is very high. If tighter specifications are required, slightly closer tolerance resistors may be specified, but these are still cheaper than the high tolerance devices required to meet these specifications using conventional line circuits. It is important to note that during all these tests,

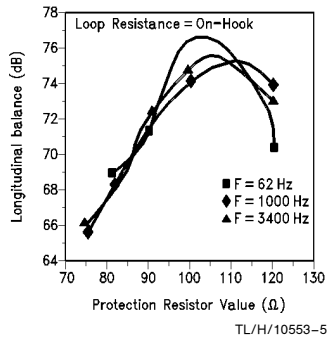


FIGURE 5. Longitudinal Balance vs Resistor Value

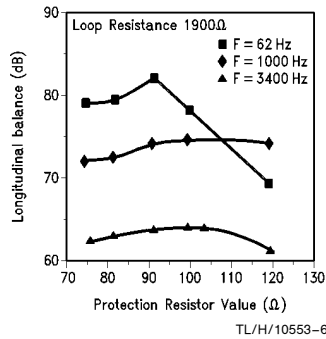


FIGURE 6. Longitudinal Balance vs Resistor Value

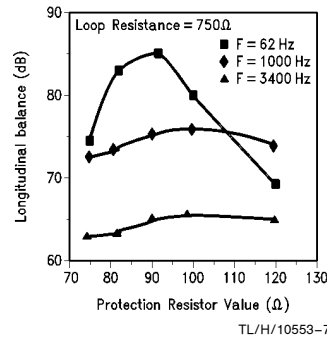


FIGURE 7. Longitudinal Balance vs Resistor Value

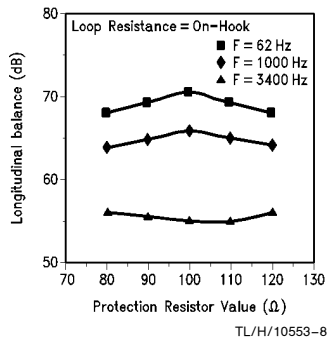


FIGURE 8. Longitudinal Balance for 20% Mismatch

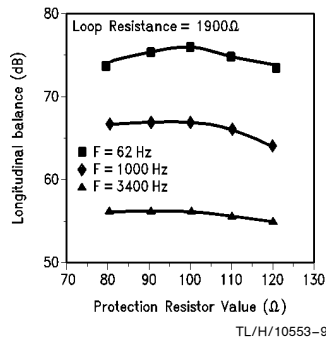


FIGURE 9. Longitudinal Balance for 20% Mismatch

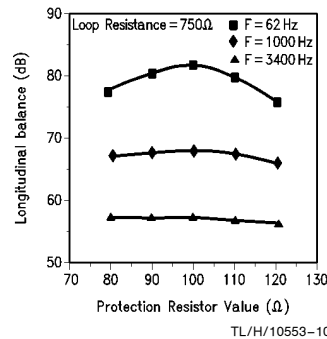


FIGURE 10. Longitudinal Balance for 20% Mismatch

the module passed all the longitudinal capability tests, easily handling the 21 mArms per leg specified in the Datasheet.

Summarizing the results presented in this section, the absolute value of the resistors can be in the range 80Ω to 120Ω , with a matching tolerance up to 20%. However, in order to meet the more stringent requirements such as Bellcore, and to cope with the long term effects of Lightning and power cross, the resistors should be 100Ω , $\pm 5\%$. This will ensure meeting the requirements at end of life. These results now enable protection options to be examined in detail, and with an understanding of the capabilities of the SLIM device, a prediction of the effectiveness of these options can be made.

5.0 PROTECTION OPTIONS

These options can be split into roughly two areas, which follow slightly different philosophies regarding the purpose of protection. These are Fusible, or manual resettable systems, and Auto-resetting systems. Both of these consist of the same elements. The difference between these is the type of series protection element used. Before discussing the differences in detail, a study of the individual protection components is worthwhile.

5.1 Shunt Protection Devices

The shunt protection device in this application can be any one of three configurations. *Figure 11* shows the least expensive shunt protector available for the application. It consists of a bridge rectifier connected across the subscriber wires, and returning the fault current to either the battery ground or the battery supply, dependent on the polarity of the fault current. This system is very effective at protecting the line circuits since the voltage transitions are restricted to approximately a forward diode voltage beyond the supply rails, however, the injection of large fault transients onto the battery supply is not desirable for many administrations. This is particularly a problem when the negative battery potential is generated using a switch mode power supply, which while capable of sourcing large currents, is incapable of sinking current. A fault condition which dumps substantial current into the battery could increase the battery potential causing damage. If this protection system does prove adequate for the application, then the required specification for the diode bridge is 20A surge capability (2A continuous), 100V rating.

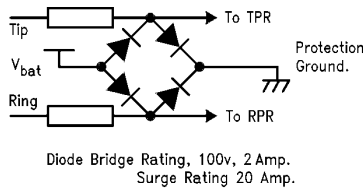


FIGURE 11. Low Cost Shunt Protector

The second shunt protection configuration, *Figure 12*, is designed to avoid dumping the fault transients into the office battery supply, thus ensuring that the battery potential remains unaffected during a fault condition. In this circuit, the positive going transients are returned to battery ground connection as in the diode bridge, but the negative transients are passed to a transient surge protector.

This 2 terminal device operates as a voltage/current sensitive thyristor. When the voltage appearing at the terminals

of the device exceed the zener voltage (V_Z) rating of the device, the unit enters a voltage clamp region. If the fault voltage continues to rise, the current into the shunt protector will rise correspondingly through the series protection element, until the breakover current threshold (I_{BO}) is exceeded. At this point the device fires, causing the voltage across the device to collapse, and returning all the current to the battery ground terminal. The device remains in this state until the current has reduced to below the holding current of the device, whereupon the protector resets itself.

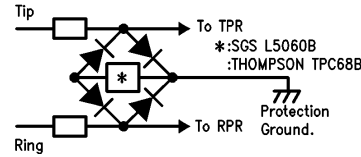


FIGURE 12. Protection Using a Shunt Suppressor Device

To aid understanding, the V-I characteristics are shown in *Figure 13*, highlighting the important features on the characteristics. This diagram also shows the characteristics of the two basic types of suppressor; namely symmetric and asymmetric types. The Asymmetric (shown dotted), have the advantage of a forward diode characteristic in one direction which reduces the power dissipated by the SLIC during a fault condition.

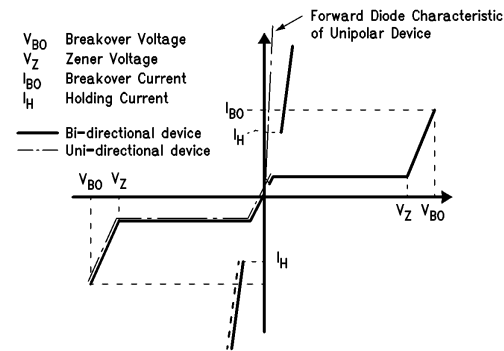


FIGURE 13. Shunt Suppressor V-I Characteristic

The final shunt protection scheme, *Figure 14*, is a development of the circuit shown in *Figure 12*. In this circuit, the diode bridge is discarded, and the two shunt components are replaced by a single device. This 3 terminal device protects against faults occurring between the two subscriber wires and to ground. These devices are slightly more expensive than the previous option, but are competitive when the savings in board area and assembly costs are taken into account.

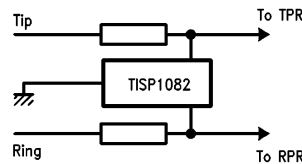


FIGURE 14. Terminal Shunt Protector

For use with the **SLIM** module, the ideal type of shunt protector is the unipolar type since this limits the potential to within a forward diode voltage (V_{BE}) of the battery ground potential. The advantage of this is a limitation of the power dissipation on module during a fault condition. The break-over voltage should be 85V or less, but the breakover current is not important for correct **SLIM** operation. The choice of 2 or 3 terminal can be made on a purely financial basis of whether the addition of a diode bridge circuit increases the cost over the 3 terminal device.

5.2 Series Protection Elements

To complete the protection function, a method of limiting the current into the shunt device is required, and this is the task of the series elements. These elements, one in each of the subscriber wires operate by, in the case of fusible systems, interrupting the current flow after it exceeds a predefined value, or, in the case of auto-resetting systems, by reducing the current level to a safe level when hot. To ensure that the choices are not constrained, the strengths and weaknesses of both manual and auto resetting systems are put forward, thus allowing the designer to appraise both systems and choose the most suitable one.

The choice of series protector must be made with the protection specifications in mind. Many specifications require that the protection components must withstand a particular level of disturbance without damage. Usually it is these which govern the choice of series element. The principle factors affecting the choice are the power dissipation of the device during a fault condition, and the rupturing current in the case of fusible systems. However, if there is a time constraint placed on the test conditions, the thermal mass of the device must be incorporated into the calculations, though this can often be done by referring to the manufacturers datasheet which contains this information.

The choice between a fusible and a resettable system is one which is often governed by the specifications, usually because the resettable systems cannot achieve the long term balance requirements. As has been shown in the results section previously, this constraint does not apply to users of the **SLIM** device, thus opening new opportunities to users who desire auto-resetting protection without the compromise on balance performance.

5.3 Fusible (Manual Resettable) Systems

The benefit of employing a manual resettable system is that if a fault occurs on a particular line, after the protection has been fired, the line is disconnected from the switch until the fault is cleared and the system reset. This means that the remainder of the switch can function completely, without the board heating problems etc. which may occur using other protection systems. However, the disadvantage of the manual system is the requirement for human intervention to replace or reset the line protection. This is especially important in a distributed switch system where the protection circuits are not all in the same location.

Figure 15 shows the schematic for a fusible protection circuit. The series elements can be fuses, resistors, or circuit breakers which are triggered if the rupturing current of the device is exceeded. For the **SLIM** device, the maximum current which the element must pass for correct operation is the maximum line feed current plus the worst case longitudinal current which may appear on line. However, many authorities require that the protection elements can withstand a short term power cross for a finite period of time, a typical

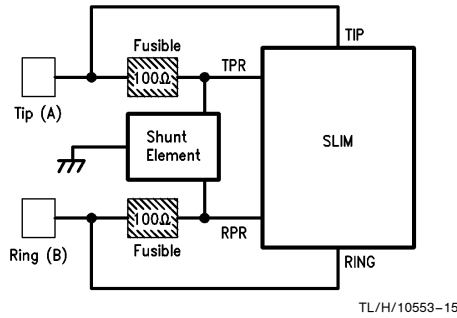


FIGURE 15. Fusible Resistor Implementation

example may be 200 Vrms, from a generator impedance of 150Ω for a period of 5 seconds. The reason for this is to ensure that the protection systems do not trip on short term faults caused by a transient power cross situation, but survive long enough for the electricity supply authority circuit breakers to respond to the fault, thus avoiding a false or unnecessary failure.

Until now, the manual resettable or fusible systems have been most popular in the industry since the matching accuracy of the series elements can be carefully controlled to ensure good balance. The problem in the future using this type of protection is the expansion in distributed switching systems employing local street furniture. The costs of replacing protection in these locations is much greater, but it is argued that the incidence of faults will also reduce due to the shorter line lengths. In order to reduce this cost to a minimum, and improve the time taken to reinstate service to the client, auto resetting systems can be more effective, and these are described in the following section.

5.4 Auto-Resetting Systems

The Auto-Resettable protection system has always been attractive to line card designers. The inherent advantage is the system guards against any fault which may occur on the line, and after occurrence, resets automatically, without any requirement for human intervention. Unfortunately, the compromises to achieve this were traditionally too great to warrant the change to auto systems. With the advent of the **SLIM**, these compromises are not necessary, and the implementation of automatic protection becomes a realistic possibility irrespective of the severity of the longitudinal balance specification.

The basic principle behind these protection schemes is the use of a PTC device as the series element in the secondary protection circuit. During a fault condition, this device dissipates power which causes self heating. The temperature increase of the device causes the resistance to increase, thus regulating the current flow. Eventually, thermal equilibrium is reached, and this state is held until the fault condition is removed. The device then cools and normal service is re-established. The choice of the PTC device is relatively painless once the critical parameters are decided, but to understand the impact of these parameters, an appreciation of the operation and construction of the device is useful.

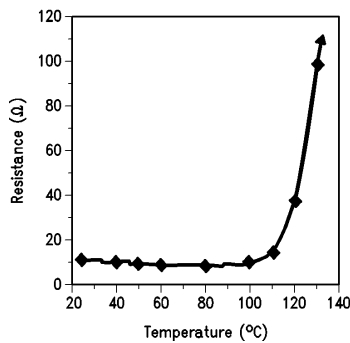
6.0 PTC CONSTRUCTION AND OPERATION

Positive temperature coefficient devices come in a variety of forms depending on the application required. For the line card protection application, the devices required are designed to act as switching elements with a carefully defined,

abrupt switching characteristic. The most common method of implementing the switching function is to use thermistors. The operation of these is now discussed.

6.1 Thermistors

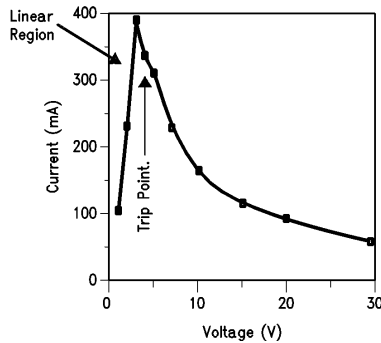
Switching type PTC thermistors are made from semiconducting barium titanate ceramic material. This material exhibits a temperature-resistance characteristic as shown in Figure 16. Over the lower portion of their characteristic, the thermistor resistance is low and relatively constant (a slight negative coefficient is present at low temperatures due to the intrinsic negative temperature coefficient from the semiconducting material). As the temperature is raised above the Curie point, the magnetic domains in the material realign themselves, and the material becomes more resistive until eventually the material approaches an insulator. In a switching type of device, this action is designed to take place abruptly over a 10–15°C temperature change. Over this range, the resistance of the thermistor changes by five or six orders of magnitude, from say 10Ω to 1 MΩ.



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FIGURE 16. Thermistor Temperature-Resistance

If, instead of using external temperature as the heating source, current flowing through the device is used, the traditional V-I characteristic for this type of device can be measured, see Figure 17. This curve has two distinct regions which are important for the application.



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FIGURE 17. V-I Thermistor Characteristics

First the linear region. This is the area of normal operation where the device does not exhibit any switching behavior. If

current value less than the value of the trip current, it, is flowing through the device, the temperature rise of the thermistor is insufficient to trip the device. If however, the current is increased above the trip level, the temperature rise is sufficient for the resistance to increase. To ensure correct operation in the application, the thermistor chosen must be rated so that the Trip Point is never exceeded during normal operation at the maximum ambient temperature.

6.2 Maximum Ratings

When using thermistors it is imperative never to exceed the manufacturers ratings for the device. These ratings give the maximum voltage and current which the device is capable of switching. The voltage rating is principally defined by the thickness and resistivity of the device. The switching current rating is very important since exceeding this value will cause the device to fracture. This is caused by the physical properties of the material which have an intrinsic energy-time product capacity. If attempts are made to dissipate an excessive amount of energy, the differential expansion inside the device due to local heating set up large stresses in the brittle ceramic material which consequently shears and fractures. In general the larger the cross sectional area of the device, the greater the switching current can be handled, and this parameter is one of the most crucial in selecting the correct device.

If these limits are not exceeded, the resistance value of the thermistor is very predictable, and will return to the initial starting value repeatedly, independent of the number of switching cycles the device has undergone. In lab tests, a thermistor was repeatedly hit with a 30 second burst of 250 Vrms mains voltage, sufficient to stress it at the maximum ratings, then allowed to cool for 5 minutes, after which a resistance measurement was made. This cycle was repeated over 450 times, and the results logged. The resistance of the device did not vary more than ±0.5% over this test.

Hopefully, this is sufficient to dispel the myth that thermistors are unstable devices and are not repeatably resettable after undergoing numerous switching operations. Now that the basic operating principles of thermistors have been explained, the limitations from an applications point of view can be appreciated, and put into context.

6.3 Specifying Thermistors

As outlined in the above section, thermistors have five basic parameters which must be specified on ordering. These are:

1. Operating temperature range. Normally for telecom equipment this is 0°C to +70°C. This does not need to take the temperature rise due to self heating into account.
2. Maximum operating current (non switch). This is normally in the range 80–100 mA, for most telecom applications. It is important to rate this parameter at the maximum operating ambient temperature.
3. Maximum voltage rating. This parameter is set by the voltage which the device must withstand when the source resistance of the generator is zero. This is important when the resistance of the device increases to a high value, (much greater than the source resistance of the generator), when the rating should be equal to or exceed the test voltage.

4. Maximum current capability. This parameter must be chosen dependant on the peak cold current the device will be required to handle at the instant a fault occurs.
5. Finally, the cold resistance of the device. This will be defined to a large extent by the previous parameters, but if a choice exists, should be chosen to be as large as possible in order to increase switching time, and reduce the currents injected into the line card during a fault.

7.0 WORKED EXAMPLE 1

Take the case of a linecard which must survive a mains cross fault of 250 Vrms for 15 minutes, from a source resistance of 30Ω , after which the part must reset to normal operation. Assume that the longitudinal specification must exceed 50 dB across the frequency band 50 Hz to 3400 Hz. Operating temperature range 0°C to $+70^{\circ}\text{C}$.

First, referring to the performance graphs in the measurements section, it can be seen that the absolute value, and the matching requirements to meet this spec are very loose, so we have a relatively free choice for the value of device we eventually choose.

1. Temperature Operating Range: 0°C to $+70^{\circ}\text{C}$.
2. Operating current. The **SLIM** device has a maximum feed current of 43 mA. Modulating this, the worst case longitudinal current, say 20 mArms, gives maximum operating current of 48 mArms. Therefore require a thermistor which must be able to handle 48 mArms at the maximum operating temperature (70°C). Note the use of RMS currents since we are interested in the heating effect of the current.
3. Voltage spec for device: 250 Vrms (min). (Since the resistance of the series element will increase to become much greater than the source resistance.)
4. Peak current handling requirements. Given that the test condition has a 30Ω source impedance, then short circuit current capability of the source is 12 Apeak (8.33 Arms). This suggests a fairly large thermistor to withstand a peak current as high as this. A suitable device which has a current rating close to this is YS960 which has a peak current rating of 10A. This device has a cold resistance of 10Ω , which when added to the source resistance gives a total resistance of 40Ω across the 250 Vrms source. This gives a peak current of 8.83A.

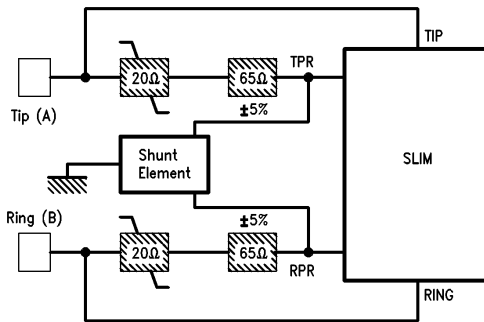
An alternative method is to choose a thermistor with a higher cold resistance. This increases the resistance in series with the source resistance thus reduces the peak current handling requirements. If a thermistor has a cold resistance of $40\text{--}50\Omega$, it only requires to handle a maximum current of 5A in the example given, and has the added advantage that the current flow into the protection ground is also reduced. This tradeoff is dependent on the availability of suitable thermistors. The calculation of this parameter must always be done using this somewhat iterative method to arrive at a suitable device.

The choice of a suitable device is often restricted by the limitations of one of the test requirements, and experience shows that this is often the peak current requirements. After the device has been selected, the predicted performance level can read off the graphs plotted in the results section checking the validity of the selection.

8.0 WORKED EXAMPLE 2

If the longitudinal requirements are much more strict, such as those imposed by the Bell specifications, the value se-

lected becomes more critical. Referring to the results graphs suggests a value of $75\text{--}120\Omega$ for the series elements. In the case of the thermistor selected in the first example, this is not so, but can be made very easily. Since the shunt protector device is connected across the junction of the series elements and the module pins, anything behind this node is protected by the secondary protection. In order to improve the longitudinal balance performance of the circuit, it is necessary to place additional resistance in series with the thermistors to increase the combined value of the resistance closer to 100Ω . This can be done with two resistors which would raise the resistance to around 85Ω overall. Care should be taken in the power rating of these resistors since during fault conditions, these must cope with the difference in shunt protector trigger voltage, V_{bo} , and the battery supply. This can cause a substantial amount of power to be dissipated in this condition. A schematic showing the implementation of this technique is given in *Figure 18*.



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FIGURE 18. Protection Schematic for Stringent Longitudinal Requirements

9.0 CONCLUSIONS

At the outset of this applications note, the objective was to show the ease of designing protection networks using the **SLIM** module. Due to the philosophy behind the **SLIM** of reducing the cost of the overall application, the protection constraints are much less stringent than in conventional line interface circuits, which allows previously unavailable protection schemes to be employed. Below is a summary of the advantages and disadvantages of the fusible and auto-resetting systems.

Fusible Systems

Advantages

1. Low Installation Cost.
2. Low Power dissipation on board during fault conditions.
3. Total disconnection of subscriber wires when fault occurs.

Disadvantages

1. Relatively high replacement costs.
2. Labor intensive, especially in distributed switching systems.
3. Non-resettable, thus causing unnecessary out of service time for users.
4. Possibility of operating due to transient fault.

Auto Resetting Systems

Advantages

1. Good for remote locations.
2. No unnecessary down time for users.
3. Completely automatic.
4. Low maintenance.
5. Low instances of transient operation.

Disadvantages

1. Increased Installation costs.
2. Small amount of on-card heating due to thermistor dissipation (2-3W).
3. Line not totally disconnected during fault condition.

Given these choices, and bearing in mind the industry moving toward decentralized switches, the auto resetting systems technique is more applicable to the requirements of the market where maintenance costs are at a premium. There are now companies taking advantage of this opportunity and manufacture complete modules containing the thermistors and shunt protectors designed for direct mounting onto the line card. These modules are ideal for applications attempting to minimize the board footprint for compact systems employing 16 lines on a card, but do incur a slight cost penalty.

Finally, included as an appendix to this note is a list of suppliers of shunt protectors, series fuse elements, fusible resistors or fusible links, and a supplier list of thermistors. This list is not intended to be exhaustive, but more a starting point for those who are interested in pursuing the subject further. It is hoped that in writing this note that the author has highlighted the major problems in trying to design protection schemes for line card applications, and helped in dispelling any misconceptions in the application of thermistors in this area.

APPENDIX

Below are listed suppliers of protection components. Suppliers of Fusible series protection components.

1. Welwyn Electronics.
Bedlington, Northumberland NE22 7AA England
Tel. (0670) 822181.

2. International Resistive Company, Inc.
Post Office Box 1860,
Boone, North Carolina, 28607-1860 USA
Tel. (704) 264-8861.

Suppliers of PTC Series Elements.

1. Raychem Corporation,
Polyswitch Products, 300 Constitution Drive
Menlo Park, Calif., 94025-1164 USA
Tel. (415) 361-6900.

2. Mullard Ltd.
Mullard House, Torrington Place
London, WC1E 7HD

3. STC Components
Thermistor Division,
Crown Industrial Estate,
Priorwood Road,
Taunton,
Somerset,
TA2 8QY.
England.
Tel. (0823) 335200.

Suppliers of Shunt Protection Devices.

1. Texas Instruments,
Power Products Division.

2. Teccor Electronics Inc.
1801, Hurd Drive,
Irving, Texas 75038-4385 USA
Tel. (214) 580-1515.

Lucas Semiconductors Ltd.
Garett's Green Lane,
Birmingham.
B33 0YA.
England.
Tel. (021) 784-6855.

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