TELEPHONE COMPANY LINE PROTECTION

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A paper on the protection of telephone plant and equipment from the effects of excessive voltage and current. A review of the evolution of protection technology and an analysis of the attributes and deficiencies of various protection techniques in use today.

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Years ago, persons employed in improving protection equipment and methods had one of the least glamorous occupations in the telephone industry. It was much like the Dutch boy who held his finger in the dike and saved the town. No one remembered the kid's name. People who worked at protecting the huge capital investment in telephone equipment and safeguarding the employees who work on that equipment never made the headlines either. But that's history. An era of increasing equipment sophistication and sensitivity has placed the science and art of protection on center stage. Persons performing the protection job are now recognized as having a tactical and strategic value seldom matched in other areas of the telephone business.

The undivided focus of the protection specialist is to safeguard the integrity and continuity of the communications network. Communications is the flow of *electrical* signals from a transmitter to a receiver. Pretty basic stuff, but it's important to understand that telephony is vitally dependent on electrical power to perform its function.

Ironically, while electrical energy, at relatively low levels, is at the very heart of communications technology, *excessive* electrical energy also happens to be its worst adversary. And man and nature have combined to make excessive electrical energy pervasive in our environment. Nature unleashes tremendous amounts of energy via lightning, and man and nature create smaller versions of lightning through the discharge of static electricity. The normal everyday operation of electric utilities supplying society's demand for creature comforts — lights, air conditioning, etc. — regularly impose changes on the power grid that have a direct and sometimes deleterious effect on the voltage levels introduced into communications channels.

Since we can't legislate against the basic physics creating the excessive electrical energy in our environment, we're learning to live with it — and deal with it. And in communications parlance, "dealing" with excessive energy levels means protecting telephone company people and equipment from its harmful effects.

Generally, telephone companies have recognized that protection technology must advance proportionately to the advancing sophistication and sensitivity of the equipment being protected. The job, then, becomes one of keeping pace with communications technology — a technology pushing its limits to the extreme at every turn. In this paper we'll explore the evolution of protection theory and devices, the events that prompted the move from one technology or device to another and where the industry stands today.

REVIEWING THE NEEDS

Line protection starts with reliable bonding and grounding, a subject suitable for a paper of its own and one not to be detailed here. Suffice it to say that solid bonding and grounding are fundamental to providing secure protection against overvoltage and overcurrent.

Overvoltage and overcurrent differ in their impact on communications circuits. (see Current Versus Voltage sidebar) And engineers originally developed separate and unique methods for restricting the damage each caused.

Overvoltage is generally considered to be any voltage over that used in network operations. Nominal ringing voltage, for example, can range from 90-130 volts A.C. and talk battery is about 48 volts D.C. These voltages along with other essential network voltages cumulatively amount to a maximum of approximately 250 volts. By telephone company definition, then, overvoltage is anything in excess of 250 volts.

CURRENT VERSUS VOLTAGE

Historically, telephone company protection has concentrated on two characteristics of electrical energy: overvoltage and overcurrent. While both are closely related, they're quite different in the impact they have — and the damage they cause. Overcurrent generates heat, and an excessive amount of current may cause conductors to melt. It follows that overcurrent can also cause a fire, and the overcurrent limiter's function is to prevent those fires.

Overvoltage manifests itself in a different way: It causes sparks. When voltage potential builds high enough, it will arc from one conductor to another. The resulting damage takes the form of surface pitting or flaking. The effect on a surface and the residue caused by the pitting and flaking action is microscopic. As overvoltage continues to attack a surface, the more pronounced its effect. Eventually, overvoltage penetrates surfaces to cause small holes. As overvoltage proceeds unabated, the damage is compounded as the pits or holes grow larger and the flakes of material caused by displacement accumulate to make new electrical paths or interrupt old ones.

Given the increasing sophistication of central office equipment and protection technology, it is necessary to take a much closer look at the components of "normal" and "over" voltage.

The primary source of network voltage to which protectors must be sensitive is A.C. ringing voltage. A.C. ringing is typically superimposed on the talk battery D.C., although COs still exist where battery is lifted when ringing is applied. And since ringing is A.C., it should be measured at its peak voltage (RMS x 1.414). The peak voltage is then added to the D.C. bias. The cumulative voltage should also be considered under "worst case" conditions. A central office could generate 100 volts D.C. battery (long loop operation) with an additional 100 volts A.C. superimposed. In this example, the minimum level at which the protector could fire without interfering with normal network operations is 100 + (100 x 1.414)=241.4 volts. Add 10% for voltage generation variance and the minimum climbs to 265 volts. Thus overvoltage in this case would be that in excess of 265 volts and consequently would require a protector with a minimum firing level above that. Some special application protectors clamp as high as 1000 volts, and a number of arrestors are available that clamp as low as 75 volts for applications where ringing current is absent.

The other potential source of equipment damage is overcurrent. Overcurrent is any current that exceeds the normal levels used in network operations. Amperage levels on the network rarely exceed 70 milliamps. Therefore, any amperage over 100 milliamps plus a 50 milliamp guard band is, by definition, overcurrent.

Originally, protectors were designed to handle overvoltage situations and separate heat coils were the primary central office devices used to protect against overcurrent. Today, both protective functions can be combined in one device.

HISTORICAL PERSPECTIVE

The development of protectors over the years has been driven by the need for improvement in three major areas:

faster firing speed for reduced let-through, tighter firing tolerances with improved repeatability and improved longevity of the protector. Ultimately, the improvement in protection devices can be traced directly to the intensified research devoted to finding solutions to these problems. In the meantime, new needs are being uncovered which are sure to drive the development of even better solutions.

Firing Speed

Instantaneous firing has always been an unfulfilled dream of persons responsible for telephone equipment protection. (see Myth of Instant sidebar) The rationale goes like this: The sooner a protector clamps, the lower the let-through voltage that gets beyond it to damage equipment. In recent years this issue has assumed a great deal of significance. As equipment has become more intelligent and complex, it has become more sensitive to lower level voltage spikes.

The earliest protectors were nothing more than brass blocks separated by a perforated mica film. When the voltage on one side of the brass device reached several hundred volts, the difference in potential was enough to cause the energy to arc across the gap to the other brass element where it was conducted to ground. It was a relatively primitive scheme, and the brass blocks would tend to fuse when subjected to even moderate energy levels. The clamping level on brass gap devices was not

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THE MYTH OF INSTANT

A protector's primary — and only — function is to divert unwanted energy away from telephone operating equipment before that energy can reach the equipment and damage it. The operative words in this mission statement are "reach" and "damage." A perfect protector would be nothing less than "perfection itself." When it sensed unwanted energy, the perfect protector would react instantaneously — super instantaneously — to prevent ***any and all*** of the unwanted energy from reaching the equipment.

The quest for an "instant-on" protector has become the goal of many manufacturers. But the search may be analogous to the proverbial irresistible force meeting the immovable object. Physical laws are unyielding, and "instant" simply doesn't exist — and it probably never will.

All protection devices require time to perform their functions. The amount of time it takes them to react is based on their design and technological makeup. The important point to remember is that some interval — no matter how slight — must pass between the time a protector starts to protect and the time it actually protects. In that short space of time, inevitably, some voltage the protector is designed to stop is "let-through" to reach the equipment being protected.

The search goes on. And the telephone industry is the beneficiary. Manufacturers are continuing their search for faster firing protectors. Perhaps this single pursuit has contributed the most to the development and improvement in protection technology over the years.

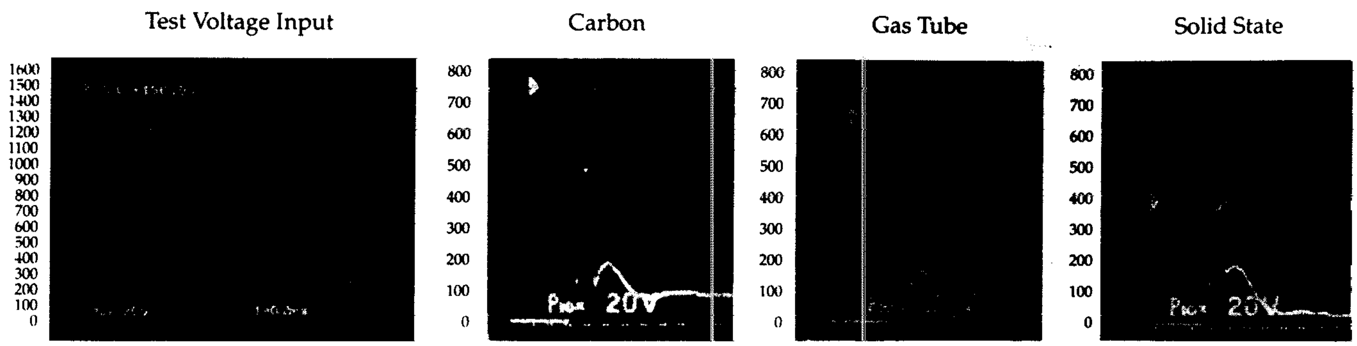
very predictable by today's standards, and their actual firing level was in the 600-800 volt range with a repeatability variance of several hundred volts.

Carbon blocks soon replaced brass protectors. And if tenure is a measurement of acceptance or success, carbon is a winner. While the original design has changed somewhat, in many parts of the country carbon blocks continue to outnumber any other type of line protection. Carbon blocks are separated by a physical air space or gap. When the voltage level on one side builds to a nominal 350 volt level, the voltage arcs across the gap to the carbon block on the other side and is shunted to ground. Carbon block devices are a vast improvement over their brass predecessors because of their increased longevity, but their firing speed and resulting let-through remains about the same.

While the energy that got past the carbons had little effect on robust electromechanical equipment, the introduction of solid state switching technology in central office equipment brought with it a critical need for even better protection. These new demands prompted another advancement in the technology: gas tube protectors. A gas tube protector's construction starts with a small ceramic cylinder filled with an inert gas. The conducting elements are encased in the cylinder. The gas gap improves upon the air gap by permitting a wider separation of the elements in a controlled environment to allow tighter firing tolerances. When the firing level is reached, the gas ionizes and a spark jumps between the elements where it's conducted to ground.

While succeeding devices in protection evolution reduced the allowable voltage level that triggered them, they all shared a common operating principle: The protection was based on a physical gap separating the two conductors. All of these gap-dependent devices required the voltage potential to rise to a specific level before the arc fired. And, of course, while the potential was rising, lower voltage levels were getting through to impact the solid state equipment that had replaced electromechanical switches.

The introduction of solid state protectors brough
major improvement in response time. The electrical path
through a solid state protector leading to ground normally has high impedance. But when the voltage level reaches the protector's switching point, the path to ground changes to low impedance and safely shunts the overvoltage. By avoiding the requisite voltage build-up necessary for gap devices, solid state protectors have improved firing speed to nanoseconds, nearly one thousand times faster than gap devices. The let-through from solid state devices is significantly lower than that of gap-dependent devices.



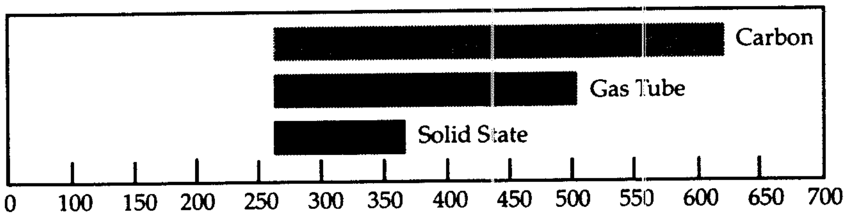
Each succeeding technology has brought about a reduction in the amount of let-through that gets by the protector before it is in a fully operating mode. In these oscilloscope tests, a 1500V @ 10/1000 µsec was input to a carbon arrestor, a gas tube arrestor and a solid state device. The resulting let-through was then recorded for each.

Tolerance & Repeatability

The development of tighter firing tolerances has also been a driving force in the search for superior protection. And piggy-backed to the desire for tighter tolerances is the desire for improved *repeatability*. Fresh from the factory, a protector can be expected to fire somewhere within its stated tolerance. Repeatability denotes where in that firing range the protector will actually fire and how far from that voltage it will stray on repeated firings.

Each succeeding technology has improved the protector's firing tolerance by lowering its *maximum* clamping level, the minimum clamping level obviously remaining above normal network voltages.

D.C. Breakdown Voltage Firing Tolerance By Technology



Each succeeding technology has brought about tighter firing tolerances. While the low end firing level can't be further reduced, the upper firing end has been steadily lowered. Current solid state protectors offer a firing tolerance more than three times as tight as their carbon based cousins.

Each succeeding technology also improved the repeatability characteristic of the protector, but solid state devices introduced unprecedented repeatability precision. Gap dependent technologies, by definition, are limited in their ability to provide tight firing tolerances. And following the dictates of the laws of physics, the arcing caused by the sudden discharge of overvoltage exacts a price on the arcing elements. Every surge of voltage energy and the accompanying arc results in some deterioration. Deterioration changes tolerances and makes a tight repeatable firing range virtually impossible. (see

TOLERANCE VERSUS REPEATABILITY

The precision inherent in solid state manufacturing methods dramatically improves the preciseness and predictability of solid state operation. Nowhere is this better evidenced than in solid state protectors. In fact, solid state's consistency has prompted the introduction of a new criterion for measuring a protector's performance: firing repeatability. Firing repeatability, in turn, complements the traditional criterion of firing tolerance.

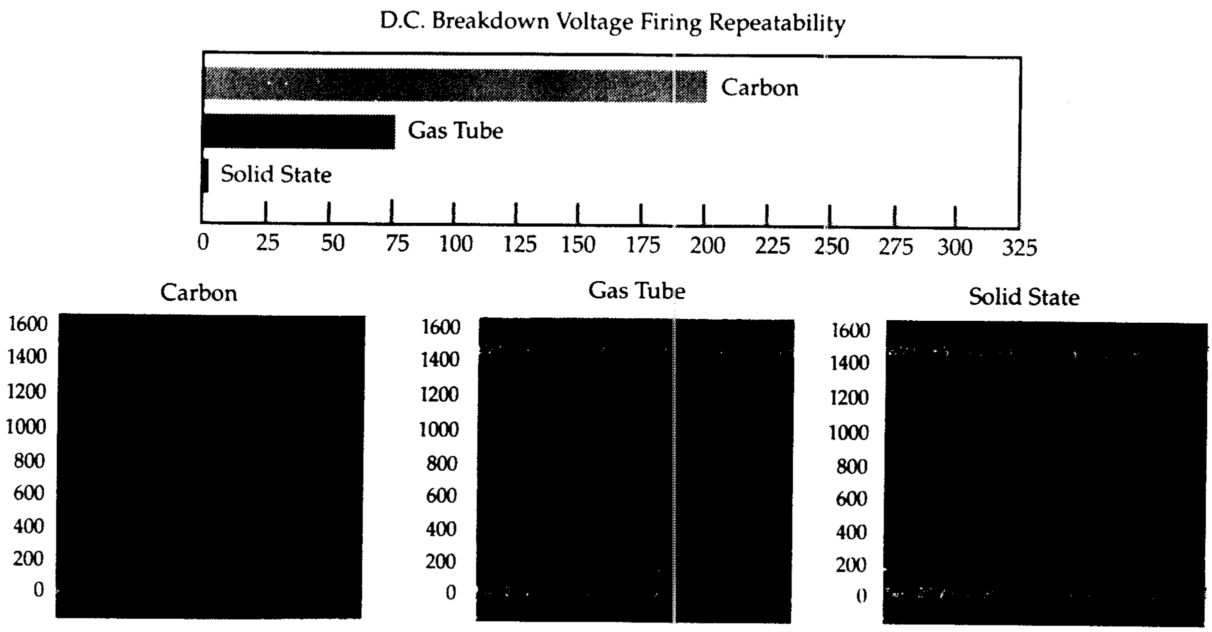
Firing tolerance is the range in voltage, i.e., "not lower than x volts and no higher than y volts," within which the line of protectors as a whole can be expected to operate. Firing repeatability is a narrower voltage range within the protector's firing tolerance that, once a specific protector's firing voltage is known, predicts the voltage level at which it will fire on subsequent occasions.

The evolution of protector technology — from carbon to gas tube to solid state — has been accompanied by enhanced performance in both firing tolerance and firing repeatability. Because carbon arrestors and gas tubes are gap dependent devices, their firing tolerances and repeatability attributes are about as tight as their technology will permit. Solid state protectors' firing tolerance and firing repeatability, on the other hand, can be further improved, but at a higher cost. As solid state protectors become more widely used, larger scale production and competition will undoubtedly reduce costs and encourage more refinements in this area.

An arc across a carbon gap will cause either small valleys or elevations of carbon on the surface. As these carbon blocks are subjected to repetitive voltage arcs, the prescribed distance between the surfaces, set to handle a specific amount of voltage, grow either closer or more distant. The valleys enlarge the gap and the elevations close the gap. In either situation, the protective value of the carbons is seriously undermined. In the early days, carbons were frequently "cleaned" following a thunderstorm to "reset" their gaps. The process was relatively simple. Carbons were removed, rubbed against a concrete wall or floor to smooth the surfaces that were pitted during the storm and returned to service. The glitch was that the rubbing wore the surfaces and enlarged the gap between carbons. After this maintenance routine was repeated a few times, the gap was considerably wider than the tolerances necessary to provide adequate protection.

Gas tube technology was a major advancement in the search for tighter firing tolerances and also provided some improvement in repeatability. The controlled environment of its enclosed chamber, containing electrodes at a fixed distance, permitted repeated firings before affecting the separation between them. But eventually the action of the arc within the tube was subject to the same law of physics as its gap-dependent predecessors. Conductors deteriorate to some degree each time an arcing action occurs. As the conductors within a gas tube are subjected to arcing energy, minute particles of the conductors fly off and cling to the tube's ceramic wall. The effect can either enlarge the gap or, when the particles create new traces on the wall of the ceramic surface, close the gap — in either case the firing point of the gas tube changes. And there are occasions, albeit rarely, when gas leaks from the tube to significantly raise the firing voltage of the protector.

The introduction of solid state protection elevates the standards for firing tolerances and repeatability to new levels of technical achievement. Most important, solid state devices do not rely on a physical gap to route overvoltage. And the stability of silicon provides naturally for tighter firing tolerances. Consequently, these types of protectors *do not* suffer the effects of arcing and deterioration. And since they don't change their composition with continued use, the original tolerances, already significantly tighter than gap dependent devices, remain unchanged. Even after thousands of operations, the firing voltage remains virtually the same.



Shown above are two graphic depictions of protector repeatability. The upper chart shows the variance that will occur on each subsequent firing of a protector. For example, while a gas tube fresh from the factory can be expected to fire somewhere between 265 volts and about 500 volts, the firing level of each *specific* protector will fire repeatedly within a range of about 75 volts of the broader technology tolerance.

Also shown are the firing repeatability of randomly selected samples of each technology. Each type protector was fired one hundred times with the firing voltage of each twentieth firing recorded. (1500V @ 10/1000 µsec)

Longevity

The lower the amount of let-through allowed by a protector and the longer a protector survives and fires repeatedly within the tightest possible tolerances, the higher its intrinsic value. When assessing the longevity of gas tube and carbon protectors, the question centers on how much the protector can deteriorate before the equipment it is designed to protect is endangered. The point here is that *broad firing tolerances, non-repeatability and deterioration are inherent characteristics of gap-dependent devices.* A review of most telco line protector specifications still in use confirm the fact that these limitations are accepted—and thought to be inseparable from—protection technology available today. Yet the evidence appears contradictory. Solid state protectors, because they are not gap dependent, fire faster, do not deteriorate with use and will fire repeatedly at the same voltage level regardless of the number of times they function. And the range in which they fire is significantly tighter than those of earlier technologies. For these reasons, modern sideactor solid state protectors are generally thought to offer a much higher degree of protection in most applications.

Solid states' shortcomings are generally considered to be their limited current handling capability and their sensitivity to extreme cold. Earlier model solid state devices were also plagued with an increased capacitance problem which has been solved through the use of sideactor technology. Originally, solid state protectors incorporated tranzorb devices that introduced thousands of picofarads of capacitance and frequently interferred with data transmissions. Today's sideactor technology limits capacitance to less than one hundred picofarads and effectively makes capacitance a non-issue for present day transmission systems.

When comparing the current handling capacity of protectors, solid state takes a back seat. Gas tubes and carbons can withstand energy strikes containing thousands of amperes from a typical lighting suge without being destroyed. Solid state protectors available today have a threshold of approximately 100 amperes in a typical lightning surge wave shape. If surges are below the rated current carrying capacity, solid state protectors will continue to function indefinitely. If the current surge is over a solid state's or gas tube's rated capacity, the protector will fail safe and must then be replaced.

Solid state protectors revert to their fail safe status at energy levels significantly below those of carbon or gas tubes. However, even this apparent disadvantage provides a unique measure of added reliability. Solid state devices allow for only two possibilities, they either work or they don't work. Head scratching and recurring "phantom" service problems are eliminated. When something goes wrong, the protector fails. Gas tubes and carbons, in contrast, can deteriorate to a point where the protection is seriously impared and may exist only in the form of the fail safe backup. Since most companies do not test protectors on a regular basis, a deteriorated gas tube or carbon is usually discovered only after receiving a customer's trouble report.

Solid state's 100 amp limit has been subject to debate. Some believe that 100 amps is adequate for central office protection but not for high exposure areas. Others say that 300 amps would be adequate. Some specifications call for a 2000 amp level in high exposure areas. And at least one highly publicized study of lightning surges in three high lighting area southern states found the highest recorded hit to be 27 amps during an eight month period. This same study computed the probability of a 100 plus amp hit to be one event in 360 years for a 20,000 line CO or one event every 1.4 years for the entire rural plant of the telco. Based on such conflicting opinions and data, it's necessary that each organization determine its own needs based on environmental circumstances.

The second area where solid state appears to be deficient is its reduced current handling capability in extremely cold weather. Solid state protectors incorporate simiconductor junctions, and the silicon's conductivity is impaired as the temperature drops. While the fast acting overvoltage switching capability of the protector remains intact and its firing tolerance increases by only a few volts, the low temperatures inhibit the spread of current over the surface of the silicon. The effect is a concentrated current which may burn a hole in the chip. In addition, a fast thermal change places tons of stress on a chip and this could result in a crack on the chip's surface. For example, a lightning strike can cause a chip's temperature to change instantly from -25° C to as high as +95° C.

Solid state proponents argue that the probability of a lighting strike at extremely low temperatures is very remote. And experts in the industry predict that new silicon chips may be introduced soon that are capable of carrying 100 amperes at -40° C. One manufacturer is working on a design they believe will handle as much as 300 amperes. At any rate, because solid state's sensitivity is so well known and defined, its performance can be readily predicted and users can easily determine if it's appropriate for a specific application. And solid state's attributes are needed most in the protection of ultra sensitive electronics—almost always located in a controlled environment.

Fail-Safe

All arrestors require a fail-safe mechanism that permanently grounds tip and ring when the overvoltage mechanism is stressed beyond its current handling capacity. These fail safe devices are designed to protect personnel and equipment and are a standard UL requirement for protectors used in building entrance applications.

Most fail-safe devices rely on small metal pellets that melt under extremely high or sustained current. The melting action energizes a spring loaded contact to permanently engage a ground strap or pin. Other techniques employ heat coils to perform the same function.

Protectors with separate fail-safe mechanisms for tip and ring may allow one side to fail but still maintain continuity on the other side. Several balanced gas tube protectors and at least one solid state arrestor prevent this possibility by offering balanced fail-safe devices. The balanced fail-safe design employs a single melting element common to both tip and ring , and if either side fails, its destruction assures that the spring activated grounding strap permanently secures itself to both tip and ring.

The fail-safe mechanisms in gas tubes and carbons are backed up by a secondary gap intended to carry away overvoltage hits in case the primary gap, inherent in these devices, has widened to a point where it is no longer effective. For gas tubes, the backup gap, designed to fire at 1500 volts, also provides security against non-performance caused by cylinder leakage. Since solid state protectors are not gap dependent, they do not require this backup.

Holding Current

Carbons, gas tubes and solid state arrestors are subject to "D.C. hold-over current", or "impulse reset." All three types of protectors can fail to reset to their idle state following a surge if there is a sustained current flow present on the line. With gas tube protectors, this condition is referred to as a "glow mode" because the generated heat causes the ceramic cylinder to glow red.

Early versions of solid state protectors performed poorly in this area because specifications for D.C. hold-over were inadequately considered. Today, solid state is generally thought to provide superior protection against hold-over conditions. While gas tubes can handle higher current levels, their hold-over characteristics range from very low to very high and are subject to change as the protector ages. Solid state protectors hold-over at lower current levels, but their parameters are better defined and are far more predictable.

Overcurrent (Sneak Current)

While protectors are designed to detect and clamp on voltage, they do not respond to overcurrent conditions (they are in parallel with the line rather than in series). This has laid the foundation for the introduction of other devices to safeguard equipment from the effects of overcurrent. The most common types of overcurrent protection devices are fusible links, heat coils and fuses. They have a singular purpose: to react to overcurrent and prevent fires. All operate on a "limited resistance" principle, i.e., a low resistance conductor in the device melts or destructs when it is subjected to excessive heat. Fuses are utilized when a "fail open" condition is desired and heat coils are used when a "fail to ground" is required.

In the electromechanical era, the excessive current allowed to pass before the protective device reacted to the heat seldom had an impact on the equipment. But as time marched on, equipment was designed with ever increasing sensitivity. Overcurrent protection specifications, however, hardly budged. Even now, a heat coil is within specifications when it can carry 350 milliamps of current for five hours or 500 milliamps for about three minutes. At 800 milliamps, an overcurrent device is expected to react immediately. Yet, given the design of choice equipment in use today, circuit cards can go up in smoke before these current limiters recognize a problem exists.

Overcurrent limiters are now incorporated in overvoltage protectors. Heat coils and fuses are built into five-pin gas tubes and solid state protectors during the manufacturing process. While this feature eliminates the need for a separate overcurrent protector block in the central office, the integrated overcurrent protectors still permit the amperage levels described above to reach the equipment before interrupting the circuit.

Protectors incorporating "fail to ground" overcurrent limiters use separate heat coils to protect tip and ring. This can lead to one side failing to ground while the other side retains continunity. At least one manufacturer of solid state devices has overcome this possibility by offering balanced overcurrent protection. The balanced design employs a single melting element common to both heat coils on tip and ring. If either heat coil activates to melt the pellet a spring activated grounding strap permanently secures itself to both tip and ring.

Another obvious limitation to the integrated overvoltage and overcurrent protector is the self-destructing aspect of heat coils and fuses. Once the overcurrent element of the device operates, the entire protector must be replaced.

The newest current limiting device is called a PTC, or Positive Temperature Coefficient resistor. It's a major step forward in overcoming both the delayed reaction time and the self-destruction limitations of integrated protective devices. PTCs incorporate a unique low resistance material which can change its molecular structure to high resistance when it senses current above a predetermined level (as a function of temperature). For example, its composition could be programmed to change its resistance characteristic when it senses current above the 150 milliamp level. Using this example, at 150 milliamps the device would change itself to a high resistance state, effectively opening the circuit.

Along with a PTC's faster response and capability to activate at a lower current level, a PTC does not self-destruct. When the overcurrent condition ends, the PTC returns to a low resistance state and normal operation.

PTCs are fabricated from either ceramic or polymer. Each material has its own attributes and shortcomings. Polymer is limited to a maximum of about ten recycles; when a polymer PTC exceeds this usage level, it must be replaced. In contrast, ceramic PTCs are capable of performing an unlimited number of times. But a ceramic PTC has its own shortcoming: It cannot handle the same high voltage levels accommodated by polymer. Voltages over 500 volts will cause the ceramic PTC to fail. A reasonable solution to the ceramic PTC's 500 volt limitation is to place it behind the overvoltage shield of the protector. The protector will then act as a voltage buffer to prevent damaging energy from reaching the PTC. Thus, when the voltage protector fires at 300 volts, the ongoing good health of the ceramic PTC is assured.

One final item should be remembered when evaluating PTCs. By their very technology, PTCs cannot fail to ground. For telcos requiring overcurrent protection that fails to *ground*, traditional heat coils should be considered. PTCs "fail" in a high resistance state. About 10 milliamps is allowed to flow through the material to maintain their resistance state. When the fault is removed, the PTC returns to its original ohmic value.

ADDRESSING CONCERNS OF HIGHER TECHNOLOGY

As telephone equipment became more susceptible to damaging outside influences, so too did protection specialists more clearly delineate the various sources of damage to equipment and people. Real and potential damage is now grouped in three major categories, often referred to as the "three Ds": disruption, degradation and destruction.

Disruption/Degradation/Destruction

Disruption: A momentary interruption in the continuity of communications transmission. Ordinarily, disruptions are brief and considered minor service problems by customers and telephone companies. Disruption of data transmission messages usually goes unnoticed because of sophisticated error detection and correction schemes.

Degradation: Repeated electrical interference on a communications channel has a deleterious effect on many of its components. The resulting wear and tear eventually causes a service outage. The effect of degradation is insidious because it builds up slowly and is seldom isolated or diagnosed as the result of electrical interference.

Destruction: Destruction is the most easily identified of unwanted electrical energy. By definition, it means a component has been destroyed and must be replaced to restore service.

Many protection people believe that today's highly sensitive equipment is being damaged by voltage levels that, in another era, were not considered harmful. It is argued that it's not just the level but the rise time of these voltages that can be damaging. Higher speed transients will "couple" into adjacent pairs or logic circuits. The coupling effect is unique to fast rise transients and can occur easily from power lines into telephone lines. The damaging effects of transients, however, are largely unsubstantiated since very little study and documentation is available on the impact of low voltage on electronic equipment. Telephone companies rarely perform post-mortems on circuit packs which were installed behind fully operative protectors.

Historically, research on electrical interference has concentrated on destruction; however, the focus needs to be broadened to include degradation and its cumulative effect on equipment. Logic dictates that unabated degradation inexorably leads to destruction. And the ounce of prevention invested in slowing or preventing degradation is worth several pounds of effort spent ex post facto fixing the effects of destruction.

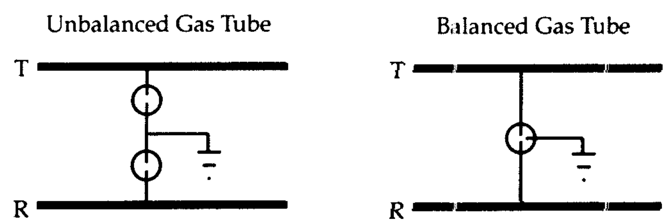
Balanced Versus Unbalanced

Prior to the introduction of twisted pair cable, unequal voltages would frequently occur on tip and ring, producing an unbalanced circuit. Tip and ring were separated wires served by individual protectors, each operating independently. Electrical surges coming into central office pairs often contained unequal voltages (an unbalance). If one of these voltages was at its protector's firing level, only that side of the circuit would clamp to ground. The overvoltage on the other side would bypass the ground to strike the equipment. In addition to allowing one side to fire without the other, the imbalance also introduced noise on the line, typically in the form of AC hum.

The introduction of twisted pair cable corrected the imbalance problems by equalizing (or balancing) the induced voltages on tip and ring. Twisted pair effectively eliminated the line noise and equalized the voltages striking the independent protectors.

Since the introduction of twisted pair, an unbalanced condition is typically the *result* of the protector. The inability of the individual devices on tip and ring to fire at precisely the same time creates an unbalanced condition from a previously balanced one. These independent protectors are also deficient in clamping tip to ring, requiring a voltage level double that of tip to ground or ring to ground. Independent devices eventually became known as "unbalanced" protectors to differentiate them from three element devices (later introduced and referred to as "balanced" protectors).

In the 1970's, a gas tube protector was introduced which offered a solution to the unbalancing effect of existing protection devices. The gas tube contains three electrical conductors in a single chamber: tip, ring and ground. An electrical spike causes both tip and ring to fire simultaneously, thereby stopping excess energy levels equally on both sides. The firing voltage of tip to ring was reduced to the same voltage that fired tip to ground or ring to ground. The three element device further reduced the amount of let-through before the protector fired.

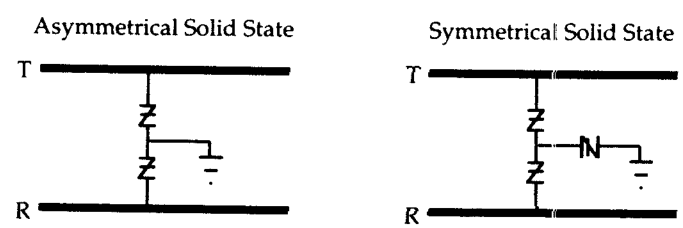


The placement of the tip, ring and ground elements in a common chamber produced a superior performing protector. Not only did it insure that both sides fired simultaneously, it reduced the firing voltage across tip and ring to that of tip to ground or ring to ground.

While the balanced gas tube provided superior protection, some fundamental issues in the protection area were being questioned. The position of many protection engineers was that circuit card manufacturers had a responsibility to harden their equipment so the cards would be unaffected by electrical energy which slipped past a protector. A large number of protection specialists continue to maintain this opinion. However, another school argues that such a position is contrary to the very essence of central office design. Main frames were originally introduced to provide a safe haven for the dissipation of high energy levels and were located away from the more sensitive switching equipment. And ironically, even those who continue to believe the responsibility lies with the manufacturer admit that hardened circuit cards continue to be damaged. The experience of most telephone companies speaks for itself. Twenty percent or more of the circuit cards sent for repair are returned with "no trouble found" reports. The relatively large proportion of "no trouble found" reports supports an intriguing premise: the inability to find and correct the problem doesn't mean that trouble isn't there, but that the manufacturer's testing procedures are not sensitive enough to determine the cause of the problem. In normal operation, some components may be called into play very seldom and they may not respond to a manufacturer's routine testing. However, what remains irrefutable is that when the card was removed, tagged, bagged and returned to the manufacturer, it was certainly thought to be defective.

The introduction of a three-element gas tube protector was an acknowledged improvement in the protection art. It was a true balanced device and insured that when tip to ground fired, ring to ground fired simultaneously. The gas tube still suffered, however, from the slower reaction time inherent in gap-dependent devices. It also continued to be subject to the degradation which is inextricably tied to spark induced firing. Finally, gas tubes can develop leaks so they eventually become inoperative.

The introduction of a balanced solid state protector was welcomed because, like the balanced gas tube, the firing level of a solid state protector's tip to ring was reduced to that of tip to ground or ring to ground. The firing tolerance was tighter and the repeatability superior to a balanced gas tube and the amount of let-through was reduced even further. And the components are not subject to the effects of degradation inherent in the gas tube variety. A growing number of protection engineers believe "balanced" or "unbalanced" are inappropriate terms for solid state devices, preferring instead to call



The introduction of a three chip solid state device reduced the tip to ring firing voltage to that of tip to ground or ring to ground. Protection engineers prefer to call these devices "symmetrical" or "asymmetrical," them "symmetrical" or "asymmetrical."

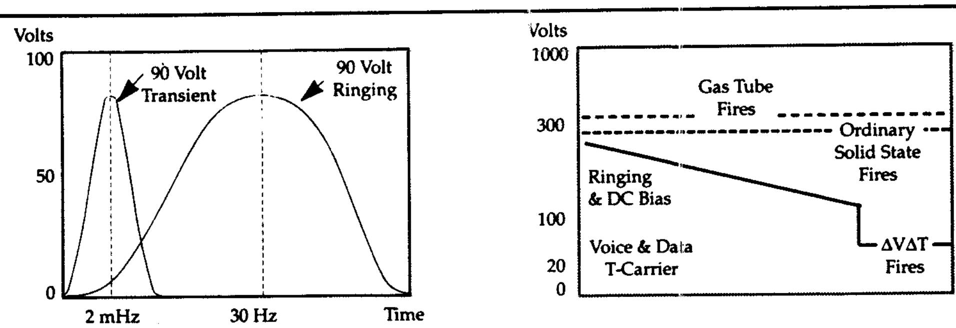
Transient Filtering

Protection concerns associated with modern central office equipment include the potential impact of low level transient voltages. Since electronic equipment utilizes extremely low voltages in its normal operations, it follows that low voltage that slips past a protector can cause extensive damage. A spike as low as 50 volts with a frequency of only 100Khz (10 µs) can have a disruptive effect on modern microelectronics. At one extreme, a call may be lost or disconnected, and at the other extreme, a software program may fail and affect a major portion of the office.

Protectors today fire at a nominal firing threshold of 260-300 volts. In the meantime, unnecessary and unwanted low level voltages are slipping past the protectors to impact the equipment. These low level transient voltages must be filtered or controlled to provide good quality service. Why? Because these transients are at least *a thousand times faster* than the voltages necessary for network operation. Fast rising transients move very efficiently and easily couple with adjacent pairs or logic circuits. And their constant attack on equipment ultimately causes degradation — and failure.

Voltages used in network operations are much slower than transient voltages. For example, ringing current rises to its peak voltage in ten milliseconds; bias voltage, because it's D.C., has zero rise time and thus has no change. Transients, on the other hand, rise to their peak voltages in ten microseconds or less. It's this extremely fast change in voltage that can be so damaging to electronic components in a circuit card. And in cases where immediate damage cannot be ascertained, some degradation, measurable or not, is probable. If we accept the fact that transients do cause damage, either by the energy's immediate impact or through deterioration, there is little the protector technology we've described so far can do to prevent it.

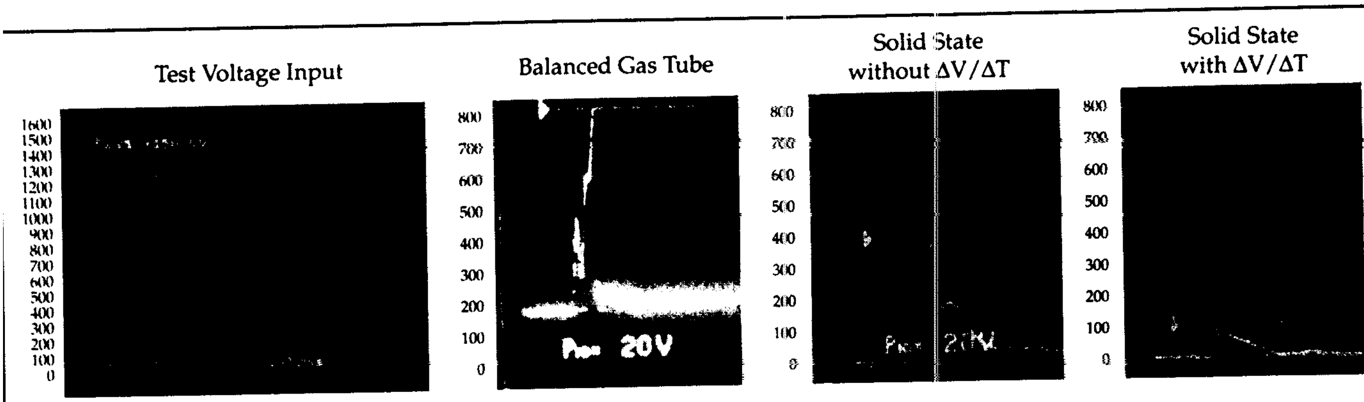
Conventional protectors do not differentiate among the voltages they permit to pass. For example, they are incapable of distinguishing between 90 volts of ringing current and a 90 volt transient. One protection technology appears to address this issue. These are called ΔV/ΔT (Difference in Voltage/ Difference in Time) protectors. ΔV/ΔTs have a distinct edge over other protection devices because they distinguish between transient and necessary voltages.



ΔV/ΔT technology reads the rate of rise over time to determine if the low level voltage should be filtered out. A 90 volt ringing current has a very slow rise when compared to that of a transient and is easily differentiated. Fast edged transients as low as 50 volts are filtered out using this technique.

ΔV/ΔTs differentiate between the two voltages by comparing the incoming voltage's rate of rise over time. Voltages below the normal clamping level of the protector, yet marked by a rapid rise in voltage level are identified and brought under control by both clamping them to ground and slowing the *rate* of rise and fall of transient energy. They now become no more damaging than a standard ringing signal.

Another interesting characteristic of ΔV/ΔT technology is that, while its primary function is to detect and clamp on relatively low level, fast edged transients, it also dramatically reduces let-through from high energy spikes. ΔV/ΔT devices allow only about one-sixth the let-through that gets by a balanced gas tube, and less than one-quarter the amount of let-through allowed by an ordinary solid state protector.



In addition to effectively filtering out fast edged transients as low as 50 volts, ΔV/ΔT also provides superior protection against let-through. In a 1500V @ 10/1000 µsec test, the ΔV/ΔT solid state protector reduced let-through to just over 100 volts, about one-quarter the amount permitted by a solid state arrestor without ΔV/ΔT.

ANCILLARY FEATURES

In addition to the basic safeguards afforded by the advanced technology incorporated in today's protectors, a number of features have been added that make the protectors much easier to use in day-to-day operations.

Protector Failure Indicator

The "on" and "fail-safe" alternatives in solid state protectors mean that its operating condition can be signaled very easily. Carbon and gas tube protectors can deteriorate to a point where they are effective only via their fail safe mechanism — with no obvious change in their appearance. Some solid state protector manufacturers have incorporated a visual failure indicator in the product so its condition is known at a glance.

Reaction to the feature is mixed. Some managers explain they don't have people walking around central offices looking for failed protectors: "Besides, we'll know when a protector is out of service when the customer calls repair." Others view the feature favorably: "You know the line is fully protected—it's either yes or no—no guess work." One engineer commented,"At the very least, I guess it could save some head scratching when you shoot trouble."

PTC Indicator

One solid state protector manufacturer is contemplating another feature that signals when the current limiting protection is in operation. The PTC technology described earlier forms the basis for its operation. Very simply, an indicator signals an "on" condition when the device is functioning. After bringing the current under control, the indicator is extinguished. The positive indicator provides an added measure of safety for employees to avoid "live" overcurrent circuits. Some engineers found a number of interesting applications for this feature — in addition to the obvious "don't touch" admonition. One said the feature could expedite trouble shooting: "If all the indicators on a given cable are lighted, it might indicate a high tension line lying across our cable inducting A.C. into the pairs." Another suggested that if all the signals in a hunt group were lighted, the customer was a probable source of the overcurrent. And another said the lighted signal would "be hard to ignore" as a reminder to test the circuit before replacing the circuit pack — to avoid blowing a *second* pack because the line was *still* loaded with overcurrent.

Access Points

Holes in the protectors permit inserting a monitor set into tip and ring contacts. This feature is especially valuable if the block on the frame is without tip and ring monitor points of its own.

Gold Versus Tin

Five pin protectors are available with both gold plated and tin plated pins. Some engineers believe that gold plating is more resistant to corrosion in high humidity conditions. For example, a company in the southeast found that "noise on the line " trouble reports would automatically clear once the sun burned away the morning fog. They switched to gold plated pins to solve the problem. Other protection engineers have been equally vocal in their support of tin plated pins. They say that tin provides more than adequate conductivity and the added expense of gold plating is unjustified. Others add that the improvement gold plating provides is only evident when the female connector is also gold plated, so that, in order to maximize gold's conductive value, the protector block would also require gold plating.

THE DECISION MAKING PROCESS

Without exception, protection professionals have a singular objective: to get the most protection at the lowest cost. The perceived investment for this protection ranges from pennies for carbons to several dollars for state-of-the-art silicon devices. As with most new technologies, solid state devices were relatively expensive when first introduced, ranging upwards of ten or eleven dollars per arrestor. Silicon based protectors today are cost competitive with their gas tube equivalents and can be expected to drop in price as larger scale production and competition drive down costs. Solid state protection will eventually cost less than gas tube protection because the protectors are less complex and the base materials less costly.

Notwithstanding the wide variation in price perceptions, there's little difference in the belief that "price" pales in importance when compared to the protector's "lifecycle cost." If protector "A" costs twice as much as protector "B", and "A" performs equally well and is three times more durable, protector "A" has a better lifecycle cost. And since protector "A" has a longer life, it will undoubtedly demand less replacement labor than its shorter lived competitor "B." And if "A" can demonstrate superior equipment protection, even more positive chips are tossed in "A's" lifecycle pot. The pile of chips keep growing in proportion to the list of additional benefits, like "fewer line cards replaced," "reduced amount of labor hours invested in repair and replacement," "fewer cable repairs required," "I&M visits reduced," etc.

Throughout the country, telephone companies are using economic models to determine the payback on investments, e.g., Internal Rate Of Return, Hurtle Rate Analysis, Discounted Cash Flow, etc. Yet, the most difficult job is not selecting the type of analysis to be used, but gathering accurate data.

Ideally, the data used in the financial analysis is obtained by field testing and a stringent comparison of existing protection performance to the product(s) under consideration. The other alternative is the use of data from a company that already performed similar in-house testing. The third alternative is to analyze the data supplied a manufacturer and verified by a third party.

Performance changes are best reflected in trouble reports and repair records. Performance data relating to improvement in speed, accuracy, balanced protection, longevity, etc. can all be found in cable and central office trouble reports with relative ease. Sub codes and cause codes can be requested and compared on a before and after basis. Protectors discarded because integrated heat coils melted and/or line card resistors failed can also be identified.

The weak link in the data stream is the accuracy of its input. "Garbage in, garbage out" is as appropriate here as anywhere. Data recording procedures may have to be reviewed to insure the cause of the failures is accurately assessed and input.

Information about damage caused by low voltage transients and other unbalanced protection is difficult to obtain. This category of damage is almost always caused by degradation, insidious by nature and not easily traced to its true source. And while most experienced protection people *think* transients and unbalanced spikes cause damage, no detailed studies have been undertaken. Some persons have conducted informal studies in this area, but they have seldom been successful in documenting sources of damage.

Transient voltage is believed to cause damage at levels as low as a circuit card's "gate level." If the defective gate is called into use only once in several hundred or thousand operations, it's easy to understand why trouble can be cleared by removing and re-installing the same card. Tracing and pinpointing the source of trouble in these circumstances is extremely difficult and may require an entirely new category of rating and trouble reporting.

The value of other ancillary features is more difficult to quantify. Their attributes will vary by each operating company as unique circumstances arise. For example, there is an intrinsic value in being able to identify an out-of-service protector by simply looking at it rather than having to remove it for testing. But for most companies it will be difficult to place a value on "reduced head scratching."

The same can be said for a visual indication of an overcurrent condition. A lighted signal will undoubtedly provide an extra measure of safety for workers and trouble identification, but its contribution in terms of payback will be difficult to calculate. For example, it will probably be difficult to have a frame person confess to burning a second card because it was replaced before testing for an overcurrent condition.

The use of probe holes and gold plated pins is more a function of the needs of each telco rather than the feature's cost justification. Those frames without T&R access holes in the blocks will find the probe holes in the protector to be indispensable. And those telcos whose experience demands gold plating for high humidity locations will not feel obligated to cost-justify them.

Solid state protectors have made their mark on the telecommunications industry. And while a surprisingly large number of companies continue to use carbon protectors and gas tubes, the movement to silicon protection is inevitable. Solid state protectors provide the best protection for sensitive electronic equipment and for the people who work with the equipment. Solid state has demonstrated superiority over gap firing devices in terms of tighter firing tolerances, absolute firing repeatability, reliability and reduced let-through performance.

AND FINALLY...

Relegating protection to second class status can only be termed high risk. No industry is more capital intensive than the communications industry. And it makes sense to investigate any technology that could offer potentially superior protection.

Each class and type of protection device has its own merits and shortcomings. The ultimate question lies in the intrinsic and long term value of each technology and the specific features of a product. Interestingly, this will always remain an open question because the needs of the industry will change along with advancement in protection technology. But it's obviously too dangerous to sit around thinking about how we're going to lock the barn door as we wait to lose the horse. The capital investment is too big to risk losing, and now is the time to lock the protective door as tight as we can — using the best technology available to us.

ADDITIONAL READING

A number of excellent references are available to those wishing to study protection theory and application in more detail. Most of the references in the bibliography on the following page are available without charge from the author organizations.

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