The Lenkurt® Demodulator
NEWS FROM LENKURT ELECTRIC
VOL. II, NO. 3 MARCH, 1962

Surge Protection of Transistorized Circuits

The increased use of transistorized equipment in telecommunications has imposed new problems in protecting the equipment from voltage and current surges caused by lightning and other sources. The low power drain and small size of semiconductor circuits encourages their use in remote, exposed locations: they are also becoming much more widely used in switching centers. Unfortunately, neither type of environment is "healthy" for semiconductors, due to their sensitivity to voltage surges. This article reviews traditional methods of protecting communications equipment and discusses more recent methods of protecting transistorized equipment.

Open-wire and cable transmission equipment is subject to dangerous "overvoltages" from several sources. Perhaps the most common is induction, which can occur when a telephone or telegraph line passes through the electromagnetic field of a nearby power line. In most cases, induced currents are held within safe limits by maintaining good line balance so that induced currents in each wire of a pair cancel each other. Similarly, balance of the power transmission line helps reduce induction. However, serious induced surges can result when one wire or phase of a power line is accidentally short-circuited or grounded, thereby destroying the balance of the transmission lines. The amplitude of the voltage induced into nearby communications circuits will depend on the current of the power source and the degree of coupling.

Another possible source of overvoltage results from accidental direct contact of communications lines and power wires. Such contact usually occurs, de-

"DEMOD" BEGINS SECOND DECADE OF PUBLICATION
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spite all precautions, as a result of sagging conductors or structural failures during storms.

It is lightning, however, with its terrible destructive force, that causes greater damage to transmission facilities than any other source. In areas where electrical storms are common, lightning is also the most frequent cause of overvoltage difficulties.

Foreign voltages caused by direct contact with a power transmission line or by induction, are normally rather constant in value. By contrast, a surge caused by lightning is *impulsive* in nature; both types of overvoltage may range from a few volts to many thousands of volts. The current in a lightning stroke is primarily dependent on meteorological conditions and is not greatly affected by the earth's impedance at the point of entry. Most strokes average around 12,000 amperes, although crest values over 200,000 amperes have been recorded.

A lightning stroke has a wide range of effects on a transmission facility, depending upon whether it is a direct hit or a near miss. A direct hit on an open-wire line, of course, places an unusually high voltage directly on the conductors. Conventional lead-sheathed aerial cables are quite vulnerable to a stroke, since they attract lightning from a distance that is approximately equal to their height from ground. Aerial cable can usually withstand a minor stroke, since the current flows along the cable to a ground point where it is readily dispersed. However, even a small stroke can induce potentially dangerous transients into the inner conductors of a cable.

Buried or underground cable is not completely immune to the effects of a lightning stroke, although it is much less vulnerable than aerial cable. Once the lightning discharge strikes the ground, the current fans out in all directions, and any buried metallic object,

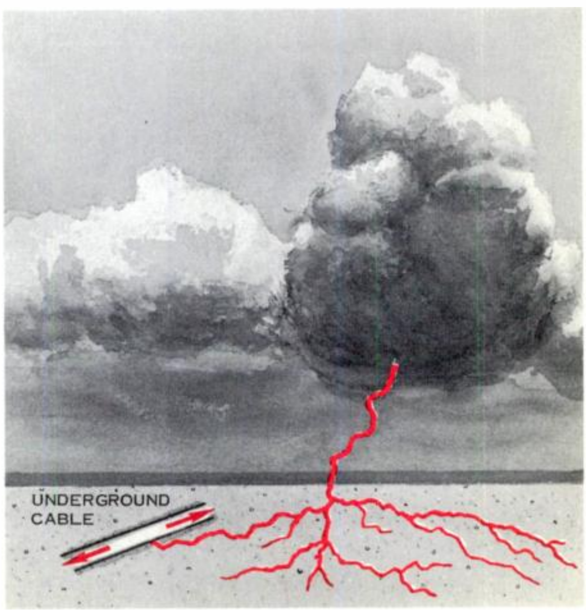

Figure 1. Tremendous voltage and current in lightning strokes can cause dangerous surges in wire and cable, even at great distances from the point of strike. Even if cable sheath acts as a shield, substantial currents may be induced to flow in the pairs within.

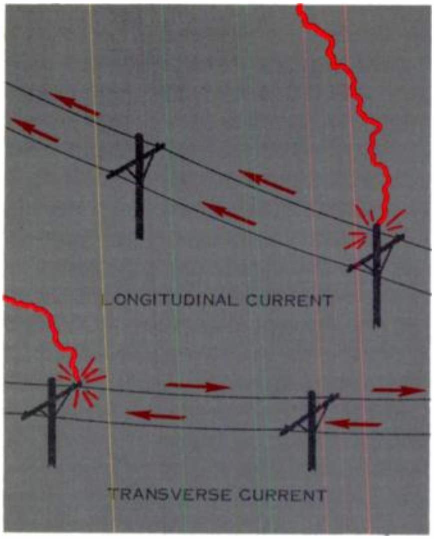

Figure 2. "Near miss" by lightning strokes may induce large equal voltages in both wires of a pair to produce "longitudinal" currents. When surge is not equal in both wires, a "transverse" current flows around the loop. Many other causes for both types also prevail.

such as a telephone cable, presents a low-impedance path to the current flow. If the lightning strikes close to the cable, the voltage drop developed between that point and the cable may break down the insulation of the intervening soil. For a 20,000-ampere stroke, the range of attraction in a clay soil is about five feet. Once soil resistance has broken down, the stroke travels in both directions along the cable sheath, attenuated more and more as the distance increases. If the earth resistance is high, the current will travel farther along the cable, since loss due to leakage to ground is relatively low.

Surges or overvoltages appear on a transmission line as so-called *longitudinal* currents or as *transverse* or "metallic" currents. Both types can be caused by direct contact, induction, or lightning.

Longitudinal currents result from equal voltages appearing on both wires of a balanced pair. Since the circuit must be completed by some path other than the conductors themselves, they usually appear as a voltage between the line and ground.

Transverse (metallic) currents result when the currents in the pair flow in opposite directions. The currents complete their path by flowing down one wire and returning by the other. Even if currents in the separate wires flow in the same direction, a net transverse current can result if one current is larger than the other. Normal voice or carrier currents are transverse.

Surge damage is not confined to cable and open-wire communications lines. Many remote microwave radio and telephone carrier installations receive their a-c operating power over aerial power distribution lines, a notorious collector of lightning strokes. The power supplies which convert the power to a useful form, are often vulnerable to voltage surges in the power line.

Whatever the nature and origin of voltage surges, communications facilities must be protected from them. It follows that any protective device or circuit must be able to cope with a very wide range of impulsive or standing voltages.

Protection Methods

Conventional practices for reducing surge damage include the use of lightning arresters at intervals on an open-wire transmission line, or a grounded parasitic line placed parallel to and above an open-wire line to divert lightning. Cable is protected by careful bonding and grounding of the sheath, and by using special types of cable armor to suit varying degrees of lightning exposure. To minimize power line induction, both the communication and power lines are transposed at predetermined intervals, thus improving balance and reducing the inductive effect.

Various devices are also available to protect equipment from surge damage. Most are a variation of the air-gap or carbon-block protector, which has been in use for many years. It usually consists of two carbon electrodes separated from ground by an air gap as shown in Figure 3. Each electrode is connected to one conductor of the wire pair. A voltage that exceeds the protector rating will ionize the air in the gap and arc across to ground. This provides a low-impedance path away from the equipment to be protected, but which disappears once the excess voltage has been dissipated.

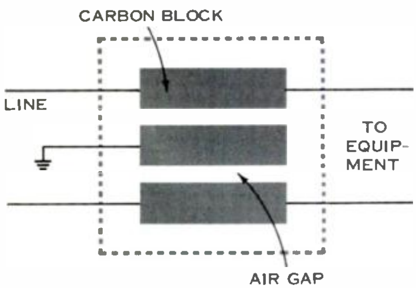

Figure 3. Simplified diagram of carbon block or air gap protector. Gap between blocks is set at time of manufacture. Slight differences between gaps may cause one to arc over before the other when equal voltages are present, thus causing a transverse surge.

The arc-over ratings of carbon protectors may range from 450 volts to 3,000 volts. In the telephone industry, an air gap of about 0.003 inch has been established as a standard for central office protection. This spacing results in a peak breakdown voltage of about 500 volts. Once the arc has been established, it will continue to conduct with a much lower voltage differential. Protectors designed for less than 400 volts are not considered to be practical, since more closely spaced electrodes tend to short-circuit permanently, thus requiring excessive maintenance.

Air gap protectors can also be used to reduce surges that enter an installation on the a-c service mains. In such an application, a calibrated gap is used in series with a non-linear resistor, across the a-c line. A surge exceeding the protector rating will arc across the gap, thus connecting the non-linear resistor directly across the line or equipment to be protected. The non-linear resistor offers a low resistance to this high voltage, and the surge is equalized and absorbed on the transmission line. Although system current also flows through the conductive gap, this flow ceases once the a-c voltage waveform passes through zero, due to the high resistance of the resistor at low voltages.

Another protective device, now usually restricted to local telephone trunks is the *heat coil*. Heat coils are similar to the "slow-blow" fuses in some electronic equipment, and are used in series with each wire of a transmission pair. They protect against fairly heavy standing currents such as could be caused by induction or accidental contact. The device consists of a small coil of wire, wound around a tube. A metal pin within the tube is spring-loaded and held in place with solder of low melting point. If enough current flows through the coil to melt the solder, the pin is released and either opens the line or grounds it. Heat coils are usually combined with carbon air gap protectors

THE Lenkurt Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 1 NO. 1

MARCH, 1952

Introducing

A NEW PUBLICATION

For Carrier Communications

This is the first issue of a new Lenkurt publication. Each month it will bring you information about carrier systems, related products, and the Lenkurt factory and organization. We hope this publication will be of value to those interested in carrier equipment by providing information for which there has been no regular channel in the past.

Contents

Through these columns we will tell you about new equipment, special problems of carrier operation, interesting installations, forthcoming products, new literature, current delivery schedules, and price changes. In short -- we will provide better and more up-to-date information to the purchasers and users of Lenkurt equipment.

The name "Demodulator" has been chosen to indicate the publication's objectives: to select the important facts from available data on carrier subjects and present it in a readily understandable manner.

In this issue we tell you a little about our present factory and organization. Readers who have been our friends for several years but have not visited us recently will be glad to see how we have grown; others who have only recently become acquainted with Lenkurt products will be interested to know that we have a large and well equipped factory specializing in the production of telephone and telegraph carrier equipment.

The article beginning on page 4 discussing the various types of filters used in Lenkurt carrier systems is an example of the feature articles planned for future issues. Subjects to be discussed include various aspects of carrier equipment for radio transmission, signaling systems, pilot regulation, and similar topics.

We will be glad to have readers suggest topics of interest to them.

Circulation

To serve its purpose well, the "Demodulator" must be available to many people in the telephone and electronics industries. You can help us reach these people by sending us the names of other men in your company who would be interested in receiving this periodical. We'll be glad to add them to our mailing list.

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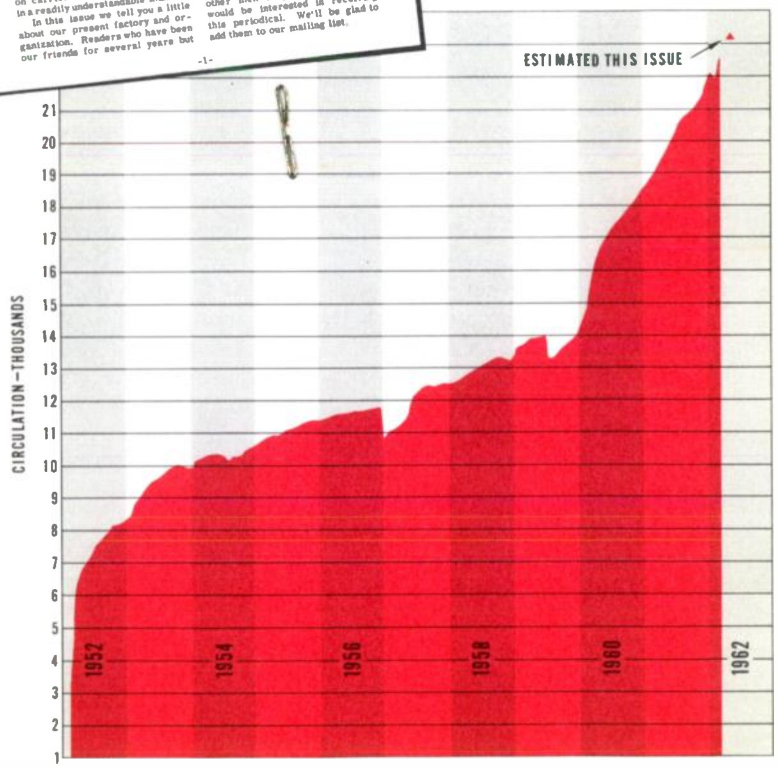

DEMODULATOR BEGINS ELEVENTH YEAR

With this issue, THE LENKURT DEMODULATOR enters its second decade of publication. The first issue, reproduced at the left, appeared in March, 1952 and went to some 2000 readers, mostly in the telephone industry. Today, the DEMODULATOR goes to more than 22,000 readers in 92 countries, and the number is growing faster than ever. A special issue is published in Canada, and a Spanish-language edition is distributed to some 30 nations.

Numbers alone don't adequately define our readership. We think it is very elite. Virtually every facet of communications is represented. Although the majority of readers are in communications companies, the number from transportation, utilities, and other industrial fields is growing very rapidly. More than a third of all readers represent management or the highest technical supervision in their companies.

Unlike many publications, the DEMODULATOR's purpose is not to provide "catalog" information or advertise products, except incidentally. Instead, our aim is to provide a source of information and education about the fascinating, dynamic field of telecommunications which we serve. By stimulating interest and building good will, we think our interests are well served.

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equipment and the line, as shown in Figure 5. Since longitudinal voltage appears on both wires of the pair, these tend to cancel each other and are grounded through the center-tap on the transformer winding.

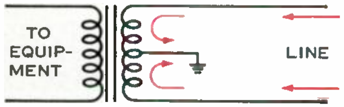

Figure 5. Line isolation transformer or "longitudinal coil" dissipates longitudinal voltages to ground through center tap of winding, but couples desired signal through to equipment. This method provides little protection against transverse surges.

In systems employing repeaters powered over the line itself, the return path for the power may be provided by the grounded center-tap of the line-isolation transformer. Under these circumstances, the power sent through the line can vary considerably or include voltage transients caused by lightning or earth currents. This can be overcome, as in Lenkurt's Type 81A exchange cable carrier system, by returning the repeater power through one of the other pairs in the cable, thus allowing the system to "float" above ground potential and avoid surges that might harm the equipment.

Transverse voltages are more difficult to overcome since they may pass through the line-isolation transformer as though they were part of the signal. Some degree of protection can be built into the circuit itself by taking advantage of the properties of the components used. For instance, line isolation transformers may be designed to have poor response to frequencies below the signal frequencies, thus sharply attenuating 60-cycle power voltages acquired by induction or contact.

Ironically, carbon block protectors themselves may be an important source of harmful transverse voltages. When a longitudinal surge builds up the potential between the two side carbons and the center ground, one side usually arcs before the other, thus unbalancing the pair and causing a sharp transverse voltage. For this reason, in certain types of installations, it may be undesirable to use carbon protectors with transistor equipment. It may be possible to omit carbon block protectors, provided some sort of alternate protection is available. In the case of multi-pair cable in which only a few pairs are used for carrier, and the rest used for voice-frequency circuits, carbon protectors on the voice-frequency circuits may be able to dissipate the voltage surge adequately for *all*

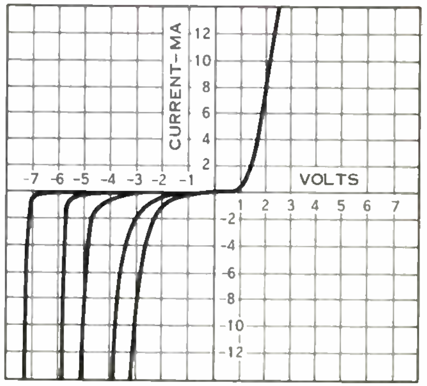

Figure 6. Typical forward and reverse conductivity characteristics of several Zener diodes. Note that breakdown is much sharper in diodes designed for greater negative voltages. Forward characteristic can also be used for low-voltage limiting.

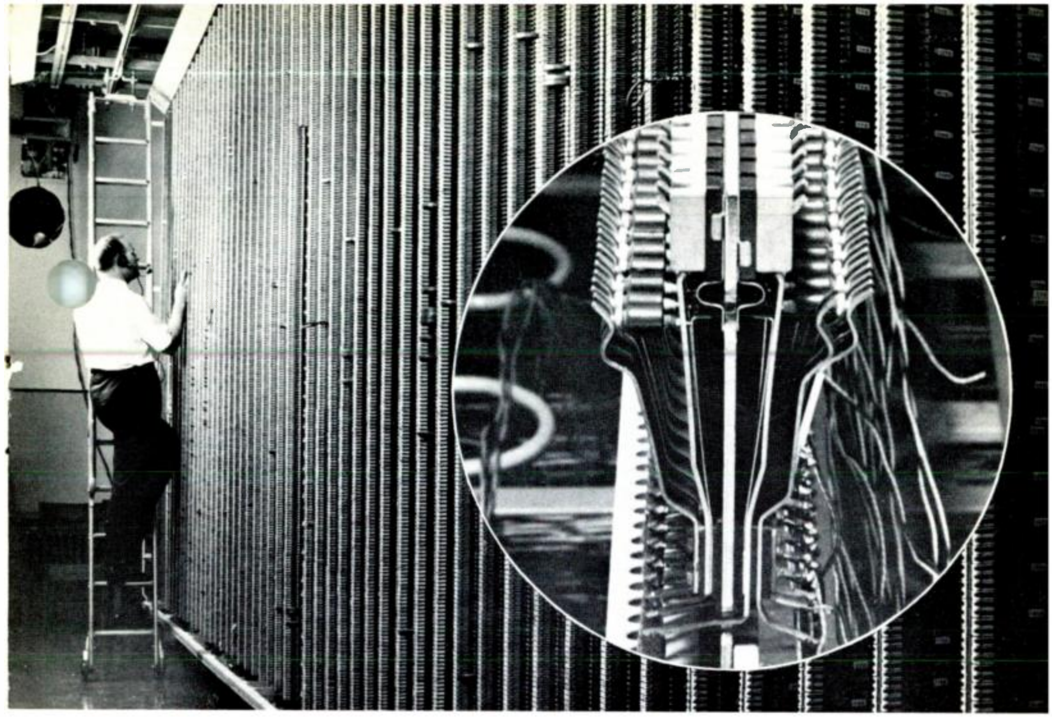

Figure 4. Great numbers of protectors are required in telephone office. Heat coils are mounted adjacent to carbon blocks. Only grounded blocks are exposed; side blocks and air gaps are concealed by porcelain insulators.

to form an integrated device such as shown in Figure 4. The heat coil is not generally used on carrier circuits because of its inductance. In addition, it cannot be conveniently used in circuits which employ repeaters powered over the line itself.

Semiconductor Vulnerability

In most present-day circuits using electron tubes, carbon block protectors are useful in protecting against excessive longitudinal voltages, but are ineffectual against voltages too low to arc across the carbon protectors. Fortunately, electron tubes and their associated circuitry have sufficient current-carrying capability and dielectric strength to be insensitive to these smaller voltages. By contrast, a relatively minor surge may destroy a transistor. One manufacturer's specification for a typical high frequency transistor quotes a breakdown rating of ½ volt across the base and emitter, and 20 volts across the collector and emitter. These values, while quite conservative, provide some indication of the limited surge tolerance of some transistors. For this reason, older protection methods are often inadequate for transistorized equipment, and an additional stage of protection is needed to reduce surges to a level that the transistors can withstand.

One simple way of protecting transistorized equipment from longitudinal surges on open wire and cable is to use a balanced transformer between the

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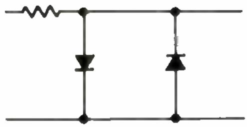
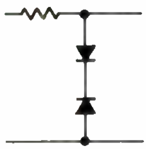


FORWARD CONDUCTION LIMITING



ZENER BREAKDOWN LIMITING

Figure 7. Typical circuits which use forward or reverse conduction characteristics of Zener diodes for limiting voltages in pair of wires.

pairs, thus permitting protectors to be omitted from those pairs used for carrier transmission.

Diode Protectors

Semiconductors themselves afford one of the most effective means of protecting other semiconductor circuits. A special type of semiconductor diode called a *Zener* or *avalanche breakdown* diode is used to shunt voltages exceeding a certain critical value. The Zener diode is designed to have a very sharp reverse breakdown characteristic, as shown in Figure 6. Note that the Zener diode has extremely low conductivity in the reverse direction over a wide range of voltages. However, when the reverse voltage reaches the critical "breakdown" value, the diode's ability to hold back the current virtually disappears and the diode can pass large values of reverse current without damage (unless the diode junction temperature becomes excessive). When the voltage drops below the breakdown voltage, the diode again becomes nonconductive. Zener diodes are available with breakdown ratings ranging from about −3 to −150 volts.

It is also possible to use the forward-conduction characteristics of a semiconductor diode to protect circuits where the normal circuit voltage levels are quite low. At approximately +0.5 volt, a silicon diode undergoes a significant change in forward junction resistance. Although the transition from high to low resistance is less sharp than in the reverse direction, it is still enough to provide effective voltage limiting at very low voltages. Figure 7 shows typical voltage-limiting circuits using forward- and reverse-conduction characteristics of semiconductor diodes.

In protecting lower frequency transistor circuits, diodes are much faster than conventional mechanical or electrical protection methods. Diodes, however, have a significant limitation in high-frequency applications. A high-frequency transistor has a much smaller junction area (and consequent faster switching time) than many Zener diodes. As a result, the high speed transistor may react to a voltage transient and be damaged before the protection diode is able to "turn on" and protect it.

Typical Arrangement

A typical plan for protecting transmission equipment on cable or open-wire lines is shown in Figure 8. In this arrangement, air-gap protectors rated at 2000 to 3000 volts are used at intervals from the midsection of the cable or open-wire link, toward the end terminal or repeater location. At the pole or access point adjacent to the office, a 700-volt protector is used. The terminal equipment itself is protected by conventional 500-volt air-gap protectors. Current-limiting resistors are often placed

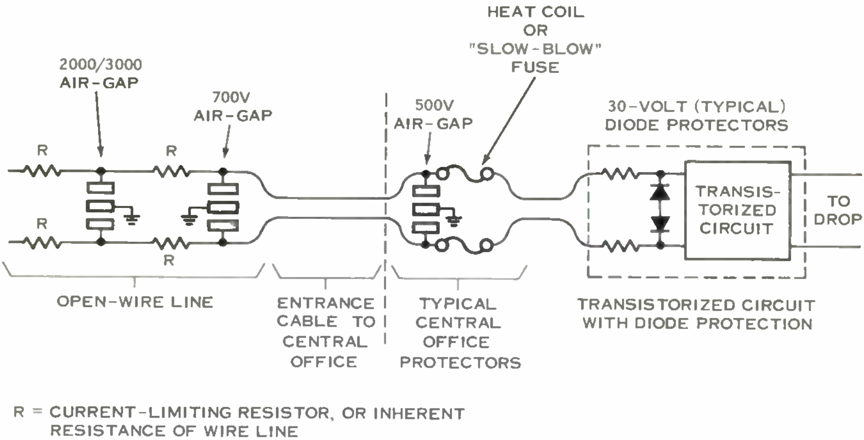


Figure 8. Typical arrangement for reducing surges in wire or cable to safe value in gradual steps. Fuses or heat coils are not normally used if repeaters are powered through cable or if high frequencies are used. In some applications, air gap protectors are dispensed with on selected pairs in order to avoid transverse surges.

between the source of interference and the individual protectors to limit surge currents. The inherent resistance of the wire or cable pair often provides sufficient limiting. In this way, most heavy surges are sharply restricted before reaching the equipment, since lightning strokes or other sources of foreign voltage will usually occur at some distance from a protector. However, nearby or direct hits will usually damage protective devices, and an occasional destructive hit from time to time must be expected.

Another semiconductor protection circuit employs a silicon controlled rectifier ("SCR") to shunt excessive voltages. The SCR has the advantage that it can be made to conduct at any predetermined voltage, and is therefore the equivalent of an adjustable air gap. It has, however, the disadvantage of requiring a relatively complicated control circuit.

In normal operation, the SCR will not conduct in the forward direction unless triggered by a small positive pulse on its control lead. Once triggered, it will continue to conduct until the voltage across its cathode and anode has disappeared, or until a reverse voltage is applied briefly. When conducting, it has a very high current capacity and very low internal resistance, thus making it particularly useful as a protector. (For a more detailed account of the SCR, see DEMODULATOR, *January*, 1961).

A typical circuit designed for low voltage d-c lines is shown in Figure 9. In this circuit, capacitor C1 permits impulsive line surges to pass, but isolates the protector from any standing voltages on the line. The SCR is connected across the line to be protected, but passes no current until triggered. The voltage at which the SCR will be triggered is determined by the

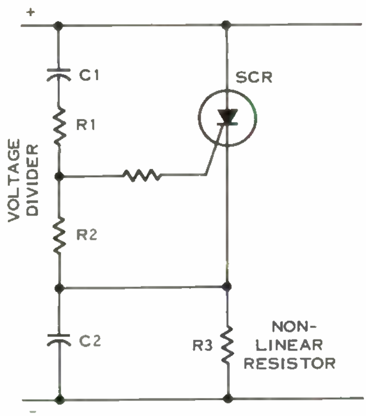


Figure 9. Surge protector using a silicon controlled rectifier protects d-c line against voltage transients. Values of R1 and R2 determine at what voltage SCR "turns on." Capacitor C2 and non-linear resistor R3 provide means for turning SCR off after surge has ended.

values assigned to the voltage divider, R1 and R2. Capacitor C2 and non-linear resistor R3 provide the mechanism for turning the SCR off after the voltage surge has passed.

Once the rectifier is in full conduction, shunting the excess current to ground, C2 charges to a potential higher than the voltage normally standing on the line. As the overvoltage dissipates, non-linear resistor R3 (which has a low resistance to high voltages) increases its resistance. The charge on C2, now higher than the voltage at the cathode of the SCR, appears across R3, and effectively places a reverse voltage across the SCR, thus turning it "off."

Conclusions

Logical extensions of the protection methods described should prove to be adequate for most communications applications for some time to come. The trend in new transistor design is toward higher operating voltages, therefore, transistors used in the normal frequency and power environment of low-frequency communications may prove more rugged and surge-resistant than ever before. However, new, ultra-high-frequency transistors present another problem. Transistors capable of operating at frequencies of 70 mc and above, are still so sensitive that even minute surges can cause damage, due to the small junction area. The future, therefore, demands continuing research toward improving protection techniques, and in increasing the surge tolerance of high-frequency transistors. ●

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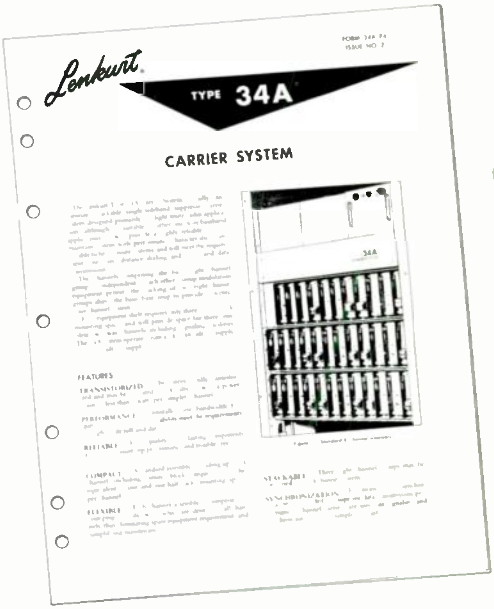

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