CONSIDERATIONS FOR TRANSIENT AND SURGE PROTECTION IN CATV SYSTEMS

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ABSTRACT

Abnormal operating conditions created by transients and surges is one of the most common causes of CATV system failures. Because of the importance of this aspect of system operation much work has been done to "immunize" systems to lightning transients and power line surges. To properly evaluate various protection schemes, the nature of the disturbance needs to be understood, as well as the physical behavior of the protection device.

This paper covers background material necessary for understanding how transients and surges enter and propagate in a transmission system. The characteristics of selected protection devices and their applications are also discussed.

INTRODUCTION

Protection of man-made structures from the effects of lightning has reached a high state of development since the time of the invention of the Franklin lightning rod more than 200 years ago. Overhead power transmission facilities, for example, have been designed to withstand "direct-hits" of lightning. Unfortunately, power transmission systems do not prevent the resultant surge voltage of a direct-hit from propagating and entering other systems which can be damaged by over-voltages. Modern CATV systems are particularly vulnerable to over-voltages because the solid state devices used have inherently low breakdown voltages and low peak power dissipation capabilities. Although lightning is not the only cause of surge voltages in CATV systems, it is, either directly (by direct-hit) or indirectly (via lightning-caused power system transients), responsible for most surges. Power system surges are also caused by switching transients of load-sharing, faults, and power turn-on following an outage. It is reasonable to say, therefore, that the main cause of surge voltages in CATV systems is power system surges. The optimum surge protection scheme for a CATV system depends on many factors. One of the most important is geographic location. Some areas of the country require much more surge protection than others. Also some parts of a system are more vulnerable than others and warrant employment of every useful protection technique.

In the following sections the characteristics of the most common surges in CATV systems are examined, as well as some of the more useful surge protection devices.

CHARACTERISTICS OF SURGES IN CATV SYSTEMS

1. Lightning Transients

The characteristics of lightning have been studied in detail over the past 50 years [1 - 7]. A "typical" lightning stroke is shown in Figure 1. It is characterized by a risetime which ranges from less than 1 μs to more than 10 μs, fall time on the order of 100 μs, and a residual, nearly constant current flow for 100 ms. The peak current for this typical stroke is 20 kA with residual current flow from 20 to 200 A. About 85% of all strokes are caused by electron flow from clouds to the earth, hence a negative-going voltage is produced with respect to earth ground. (About 15% of all lightning strokes have charge flow in the opposite direction, so positive-going surge voltages must also be considered.) Since the waveshape closely resembles an exponential pulse, the frequency spectrum of a lightning stroke can be approximated by the Fourier Transform of the exponential pulse. The power spectrum is the familiar Lorentzian spectral shape. For a waveform with fall time of 100 μs most of the energy is contained in frequency components below 1.6 kHz. However, the peak currents under consideration are so large (~20 kA) that there is appreciable energy at frequencies two or even three decades above this. For a faster fall time stroke (say 10 μs) the half power bandwidth is correspondingly greater (16 kHz) and there is appreciable energy at frequencies to 1.6 MHz and higher.

The single stroke lightning discharge just described is the most common lightning occurrence. Multiple discharges can also occur and when this happens, the waveform consists of a sequence of the single stroke discharges occurring about 1/10 second apart. For multiple strokes the most common number of strokes is six, although as high as 40 have been observed [4].

For protection against direct hits it is clear that the resistance to ground (R) from the strike point must be as small as possible. This means high quality ground bonding should be used at frequent intervals along the line. Fortunately, most aerial CATV cables use utility poles for support. They are, therefore, shielded throughout most of the route by other wires and cables and the brunt of a direct strike is usually borne by the power system wires.

Lightning strikes can cause current flow through the cable sheath to ground without actually striking the sheath. This occurs when lightning strikes close enough to the cable that an induced current flows in the sheath. The magnitude of this inductively coupled current is usually much less than from a direct hit since the coefficient of coupling is low. The induced current depends mainly on the stroke orientation with respect to the line, as well as its proximity. The waveshape of the induced current will be similar to that of the stroke itself but reduced in amplitude.

The main feature of both induced and direct lightning strikes is that they contain energy to quite high frequencies. Since this current is conducted to ground through the cable sheath, a voltage difference which depends on the sheath resistance to ground will develop between the sheath and center conductor., It is, therefore, very desirable to have fast acting voltage limiters at the rf ports of line amplifiers to keep the sheath to center conductor voltage within acceptable limits. This should not be used as a substitute for good grounding, however, since no protection device is completely effective. The better the system grounding, the lower will be the stress on the system protective devices.

2. Power Line Surges

The prime means of introduction of abnormal operating conditions in CATV systems appears to be via surges in the powering system. Although lightning is responsible for many of these power line surges, the mechanism of entrance into the CATV system is usually not stroke induction through the cable sheath but rather conduction through the ac powering system. The powering system is inherently low pass (more precisely, bandpass from 60 Hz to several hundred Hz) and since the lightning stroke contains a large amount of low frequency energy, the filtered lightning surge will be conducted into the rf amplifier housing. The most severe lightning surges are those occurring when a low voltage line is struck. A 20 kV surge on a 240 kV line is barely felt. If the 20 kV surge occurs on a 12 kV line, the situation is severe and even worse when a 240 V line is struck, but this rarely occurs.

Power line surges are also caused by switching transients of load-sharing, line faults, and power turn-on following an outage. These inflict severe stress on the CATV system because they frequently involve over-voltages of about three times normal for times from 1 ms to more than one second. Protection from power line surges can be accomplished using relatively slow devices (e.g. relays, thermal effects and high capacitance protectors). They must, however, be able to withstand high average power dissipation or have a high enough breakdown voltage (say five times that needed for normal operation) to enable network decoupling without voltage breakdown.

CRITICAL SYSTEM PROTECTION POINTS

Some critical points in a CATV system are indicated in Figure 2. From the foregoing discussion it is clear that probably the most important point for system protection is at the power supply station. Here power system surges can be eliminated before they can enter the coaxial cable. A second critical point is the bonding to earth ground. Frequent, high quality ground bonds will greatly reduce direct lightning surge problems. Another critical location is the amplifier station input port, especially if the input is line powered. Surges occurring from sheath current flow must be constrained to tolerable limits at both the power supply input and the rf ports.

SURGE PROTECTION DEVICES

There are many surge protection devices now available that can be used in various combinations to achieve a high degree of surge immunity. Some of the more useful devices are discussed below.

1. Silicon P-N Junction Diodes

   Relatively low capacitance diodes (3 pF each) provide limited surge current capability ($\gtrsim$ 0.5 A) and only for short durations ($\sim$1 μs). However, transients can be clamped with back-to-back diodes in 2 ns to $\sim \pm 1$ V. This technique is used mainly for narrowband amplifier protection and applications not involving line powering.

2. Zener Diodes

   Zener diodes have intermediate capacitance values ($\sim$30 pF for 1 W devices) and relatively fast switching times ($\sim$40 ns, depending on junction capacitance). They have low surge current capability ($\sim$0.1 A) because of their power dissipation limitations.

   Breakdown voltages range from 4 to 200 V and zener diodes are frequently used to trigger other devices which can handle large surge currents (such as SCR's).

   Zener diodes can also be used in tandem to provide bipolar limiting to any voltage from 4 to 200 V.

3. Miniature Gas-filled Surge Suppressor [8, 12]

   These devices offer low capacitance ($\sim$2 pF), bipolar clipping for voltages $\gtrsim$ 70 V. Lower breakdown voltages are not possible because of the characteristics of Paschen discharge in low pressure gases. Gas-filled surge suppressors have an intermediate response time (~1 μs turn-on time). They can handle large current surges of low duty cycle (~1-5 kA) for 100 μs but do not stand up well under continuous current discharge over 20 A. If their discharge current is limited to 1-5 A, they have a long life. They are useful for limiting peak voltages to ±70 V or so.

4. High Power Gas-filled Surge Suppressor

   Because of their larger size these devices have higher capacitance than the miniature types. (Capacitance ~7 pF). They have high peak current capability (20 kA) and can withstand correspondingly higher continuous currents.

5. Diac, Triac, SCR's

   These devices rely on external circuitry (resistors and zener diodes) to provide accurately controlled turn-on. They have moderate power dissipation capability (~100 W) and find wide application for power supply protection.

6. Time Delay Power Relays

   During a power surge these devices disconnect the applied power. They are slow acting (~0.1 to 1 second) and can be programmed to reconnect power after a prescribed waiting time.

7. Varistor [9]

   These are metal oxide devices that have a voltage variable resistance. They have high capacitance (~1000 pF) and fair peak current capability (~1 kA for 7 μs). Breakdown voltages range from ~170 to 1400 V.

8. Thyristor, Thyrector, Thyrite [15]

   These are mainly silicon carbide devices. They have high capacitance and good surge current capability.

PROTECTIVE DEVICE RELIABILITY

Unfortunately all protective devices will fail if subjected to stresses outside their design limits. It is, therefore, imperative that surge suppressors be prudently used and their operability periodically monitored if maximum system reliability is to be achieved.

SUMMARY

The most common and destructive surge in CATV systems appears to be those from the ac power system. Many power system surges are associated with lightning but they can also be caused by transients of switching and faults. Protection from direct lightning strikes is greatly aided by having frequent, high quality grounds in the system. Additional protection is afforded by voltage limiting devices at active station ports, especially at the power supply input. Power line surges are best controlled at the ac powering stations. Since several locations are usually powered from one point, it is economical to employ quite elaborate protection networks here. The details of protection vary from system to system and even from one part of a system to another. The optimum protection scheme, therefore, must take local conditions into consideration, as well as the characteristics and cost of the protection devices.

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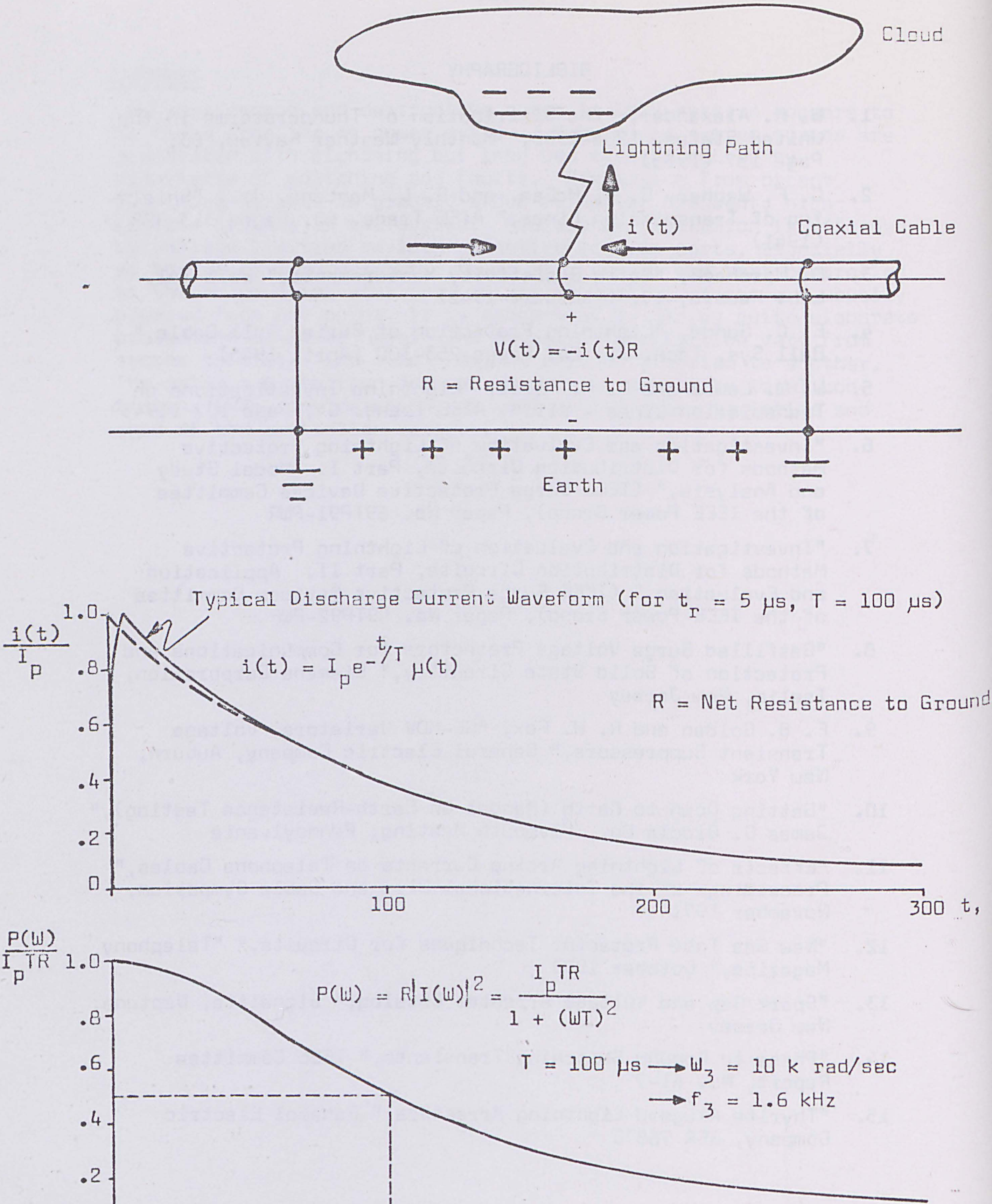

FIGURE 1

NATURE OF LIGHTNING DISCHARGES

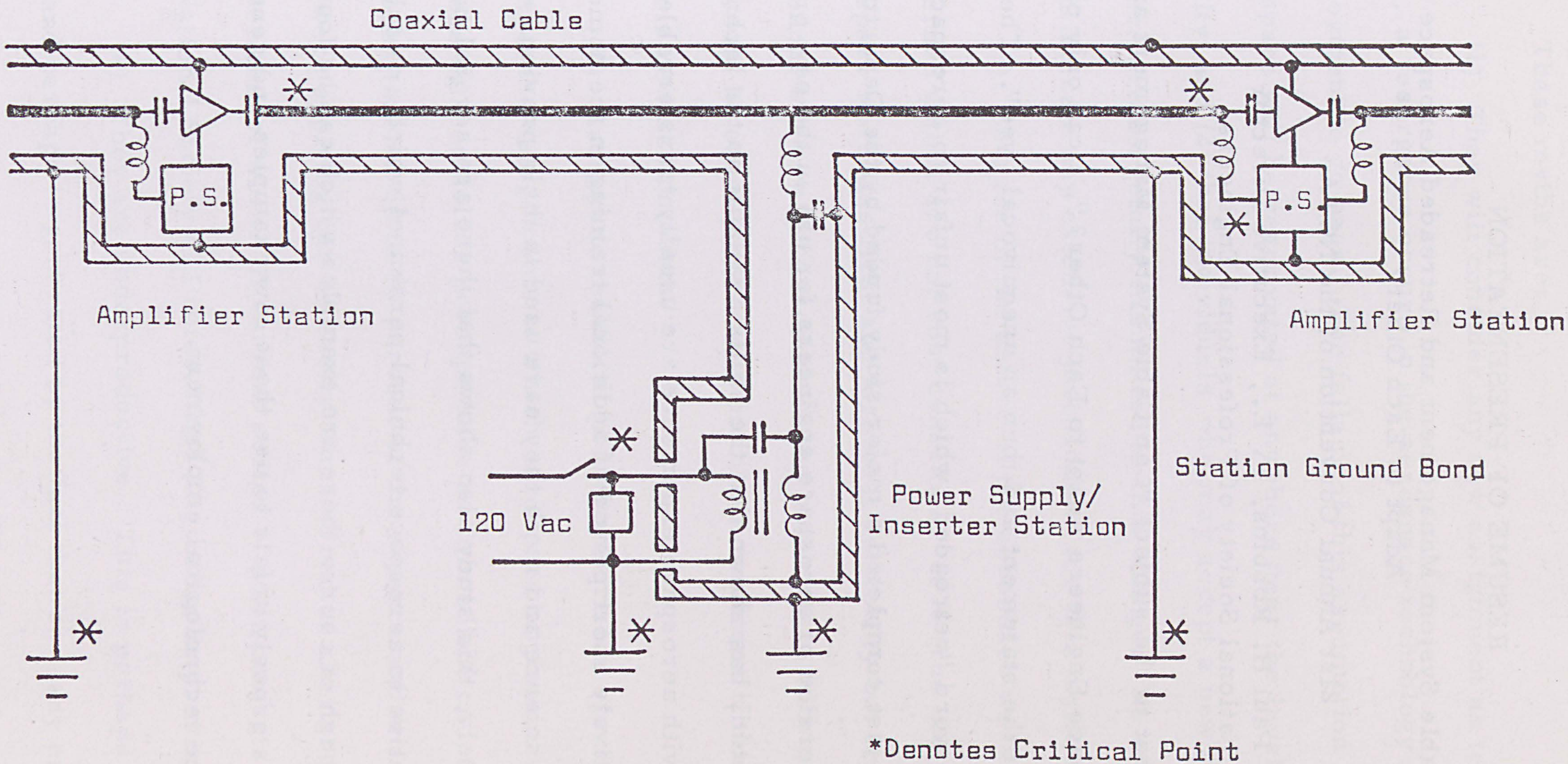

FIGURE 2

CRITICAL SURGE POINTS IN A CATV SYSTEM