

Application of Surge Protection Devices for Very Low Voltage Devices

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Every year we are subject to more and more losses of equipment and down time due to over-voltage events. This increase in damage is due to both the increased usage of microprocessors in a greater range of products, and the continuing miniaturization of these microelectronic components. This paper offers a three point method for simplifying the Surge Protection Device (SPD) selection process, while pointing out the necessity for studying the application in its entirety.

The typical Very Low Voltage (VLV) device discussed in this paper is supplied with power in the form of voltage under 50V, and communicates via cable output of some sort. Typical examples range from the ubiquitous desktop PC or external modem, through industrial applications such as programmable logic controllers and on to video cameras mounted for security applications.

There are two avenues for over-voltage to enter our device and cause damage. One is through the power supply, typically a 230V AC feed transformed and rectified to anything from 3-48V DC. The other entry point for damaging over-voltage is through the communication lines; telephone, video, Ethernet- a plethora of configurations.

There are two sources for destructive over-voltage. Atmospheric events such as lightning causes damage through both inputs, power supply and communication line. Switching events cause damage primarily to the power supply input, though it should be noted that switching high-current LV and MV events do create electromagnetic fields that induce voltage in the immediate area surrounding the switch, such that electrical switching can cause over-voltage damage to communication lines even though there is no galvanic connection what so ever between the power lines being switched and the communication lines passing near by.

Protecting our VLV device from the power supply input is a matter of complexity requiring an understanding of the grounding system used in the building, the parameters of the electrical distribution system, the potential short circuit at various points in the system, the relative immunity of the VLV device and the operating principles of the different proffered protection devices. However, it is relatively simple compared to the task of protecting our device from the communication input, which is the topic at hand in this discourse. For all the parameters necessary to correctly protect our device from the power supply input, some parameters are constant. The input voltage almost always originates from "wall voltage"; the standard AC low voltage distributed for residential and commercial purposes, i.e. 230V AC at the standard frequency of 50Hz. Secondary voltages, should they be of interest in the defensive design scheme, may vary, but they are invariably of a single frequency-DC. The current passing through the conductor into the power supply input of our device is for the sole purpose of supplying energy to the system. Any change of current or voltage wave-form incurred by the nature of the chosen Surge Protection Device (SPD) is of little consequence.

This is not the case when dealing with a conductor feeding the communication input of our VLV device. The voltage and current are carrying a signal. Clamping the peak to peak voltage, changing the frequency or other wise interfering with the signal is

contrary to our ultimate goal- ensuring uninterrupted communication at all times, even during transient surge events. Introducing an SPD on a communication input may save the device from damage, but it may also interfere with the stated purpose of the device- communication.

The methodology described in this paper simplifies the process of choosing the correct surge protection device by framing the protection viewpoint with three questions:

1. From what are we protecting our device?
 - ◇ What type of surge is expected?
2. How much of the over-voltage must we clamp in order to protect our device?
 - ◇ What is the inbred immunity of the device?
3. What type of communication are we dealing with?
 - ◇ What are the characteristics of this communication protocol?

These three questions will now be addressed in detail.

1. From What Are We Protecting Our Device?

The primary cause of over-voltage events in the communication input of our VLV device is lightning. Understanding the physics and mechanics of a lightning discharge is of great value in designing a proper defense against this damage; however this is outside the stated scope of this paper- the application of the SPD. For the purpose of application, we shall suffice with the definition of two types of lightning events, a direct hit into the superstructure containing our VLV device, and a lightning strike that is not a direct hit.

Since we are dealing only with the communication input, switching over-voltages do not interest us in so far as they are defined as over-voltage between any two high current carrying conductors produced by making or breaking their circuit. Communication current circuits are not usually switched, nor do they carry high current. Any over-voltage induced by the electromagnetic field produced by opening or closing nearby circuit breakers in power distribution systems will be similar to atmospheric-induced over-voltages such as indirect lightning strikes.

1.1 Direct Lightning Strike

A lightning discharge into a superstructure, such as a building or antennae mast, can be quantified simplistically for the purposes of this paper as flowing to earth with an amplitude that can reach 100kA. The rise time of the current is taken to be 10 μ s while the decay time to half the amplitude is considered to be 350 μ s. The energy dissipated during this stroke is estimated at 2.5 MJ/ Ω ¹.

This lightning current flowing to earth creates a voltage drop on the lightning path to earth directly relative to the impedance of the path, according to Ohms law $U_{OV}=I_{imp}\times Z_{path}$. Figure 1 demonstrates that if we assume the path to earth as being as good as 1 Ω , we still have an over-voltage of 100kV between the incoming cable

¹ DIN V ENV 61024-1 (VDE V 0185 Part 100)

grounded at its point of origin, where the voltage of the ground is considered 0V, and the elevated point of the lightning strike.

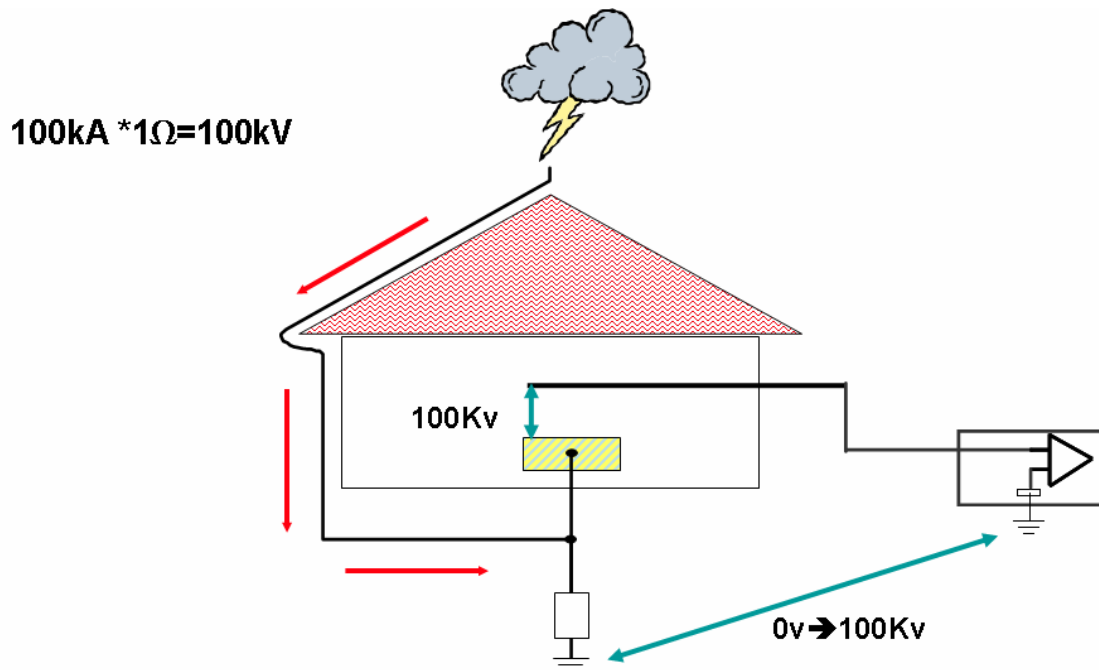


Figure 1: Over Voltage Due to Direct Lightning Strike

The conclusion we reach from this analysis is that if a cable from outside the influence of our grounded structure is connected to our VLV device, and that a lightning strike can go to earth through our grounding system, then we must choose a device that can deal with a very high energy transient event.

Just how high the over-voltage and how much current will be directed to ground on the terminals of our device depends on how many conductors enter the structure, since the total voltage and current is divided equally between all incoming conductors. The amplitude of the over-voltage and resultant current are not as important to us as the wave form of the current, since the wave form carries the destructive energy- current over time.

When dealing with a direct lightning strike that raises the potential of the communication input due to being referenced to ground outside the influence of our local ground, we look for SPD characteristics that can handle a 10/350 lightning impulse current.

1.2 Indirect Lightning Strike

Just as every current flowing through a conductor produces an electromagnetic field that induces voltage in any other nearby conductor, so too does the lightning stroke produce an electromagnetic field that induces voltage into any conductor in the vicinity. A lightning strike of 100kA from cloud to cloud or to ground can induce as much as 2kV in every meter of conductor at a distance of 100 meters. Even at a kilometer, 200V can be induced in every meter of conductor².

² Source: Clark, O.; Gavender, R. : Lightning Protection for Microprocessor based Electronic Systems. Record of Conference Papers Industrial Applications Society, 36th Annual Petroleum and Chemical Industry Conference 11-13 Sept. 1989, San Diego, CA, USA

The current created by the voltage induced by an indirect lightning strike is considered to have a rise time of $8\mu\text{s}$ with a decaying period of only $20\mu\text{s}$ to half the initial amplitude. This 8/20 wave form is what we will look for in current carrying capabilities of any SPD that is not expected to withstand the current due to a direct hit into a grounded installation.

Figure 2 displays the difference between direct and indirect lightning strikes vis a vis the current carrying capabilities of the SPD. It is evident that even though the amplitude of the two wave forms are the same, the amount of energy residing under the 10/350 waveform is many times more destructive than that under the 8/20 waveform.

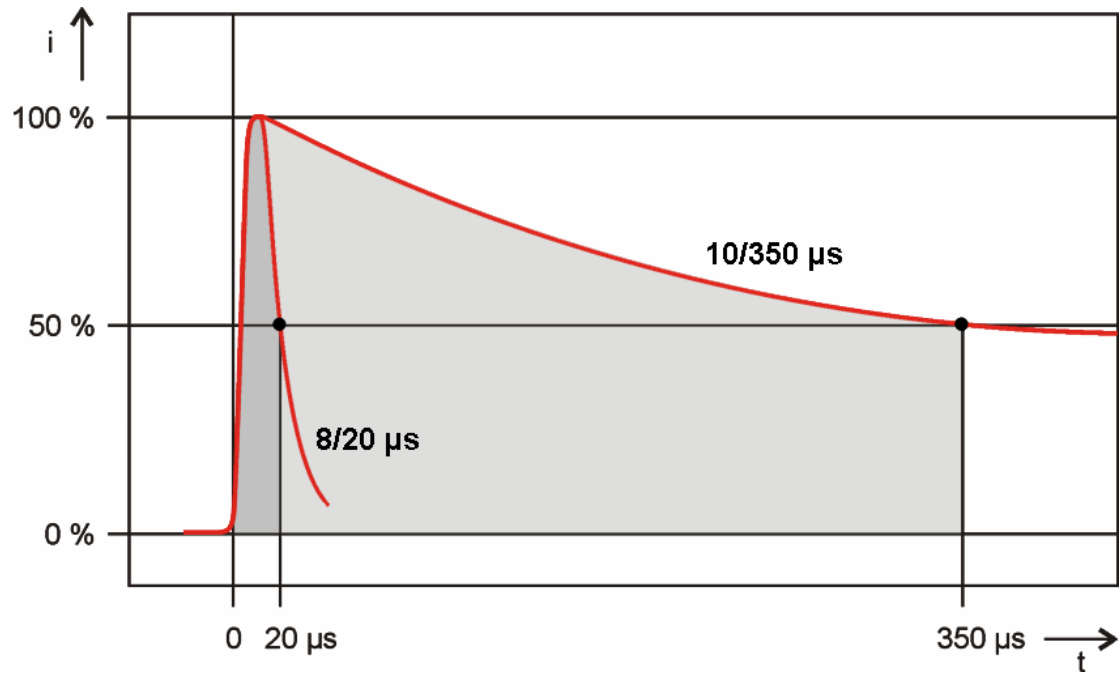


Figure 2: Comparison between Direct and Indirect Lightning Strikes

1.3 Differentiating Between Direct and Indirect Lightning Strikes

As a rule of thumb, if our building has any likelihood of being hit by lightning, due to it having a lightning down-system that will take the lightning to ground swiftly, and the cable connected to our VLV device originates (or terminates) from outside our building- we specify an SPD with 10/350 current capabilities. It is important to realize that down-systems that attract lightning are not always built intentionally. Most modern day construction is of reinforced concrete columns built on reinforced concrete footings or piles. This construction is a natural lightning down-system. If the reinforcing steel is not connected efficiently by welding, the lightning path is still evident, but instead of an impedance of 1Ω , the impedance will be greater, leading to even higher over-voltages.

The remaining case is that of a VLV device connected to a cable that does not originate or leave the building. In this case, we suffice with an SPD capable of dealing with the energy inherent in an 8/20 waveform.

Figure 3 nicely portrays the SPD selecting concept. The drawing demonstrates many aspects of lightning protection design, most of which stray from the stated purpose of this paper, however it is unhealthy to divorce one aspect of lightning protection

engineering from the whole picture. According to the concept of lightning protection zones³ (IEC 61312) the building is divided into zones of decreasing susceptibility to electromagnetic energy. For our purpose, we shall define these zones as follows:

1. LPZ 0_A- An area that is susceptible to a direct lightning strike
2. LPZ 0_B- An area that is exposed to the elements, but can not be directly hit by lightning due to the existence of a preferred lightning path.
3. LPZ 1- An area separated from LPZ 0 by a Faraday cage
4. LPZ 2- An area separated from LPZ 1 by a Faraday cage

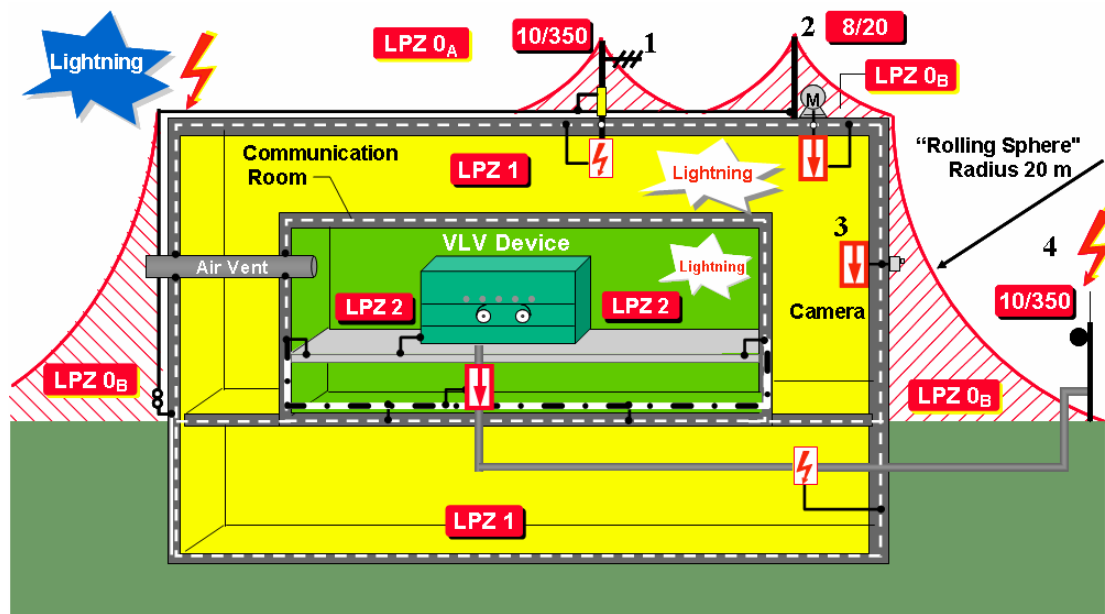


Figure 3: SPD Selection in a Properly Designed Faraday Cage

Lightning striking the building goes to earth through the structure, creating a potential difference between the building earth and the distant earth from where the cable arrived, while simultaneously creating a strong electromagnetic field as it flows to ground. This electromagnetic field propagates through the building and induces voltage in all conductors in its path. If we place our VLV device inside another grounded Faraday cage, this cage will route this induced voltage to ground- as current- creating another, smaller electromagnetic field that propagates inward.

If we examine example number 4 in Figure 3, we understand that if the signal cable attached to the antennae is grounded at the mast, the cable will introduce the distant ground into our building when struck by lightning. We install, therefore, an SPD of 10/350 capabilities at the point of entry. When the cable reaches the input of our VLV device, we are concerned only with the induced voltages created by various electromagnetic fields propagating through the building during a lightning storm. Consequently, we require an SPD of 8/20 capabilities on the device input. Calculation of the amplitude at the input requires examining the current loop created by the signal carrying conductors, the cable shielding, and the power supply conductors and ground.

³ Hasse, Peter : Overvoltage Protection of Low Voltage Systems 2nd Edition IEE London UK pg.79

Example 1 in Figure 3 also requires 10/350 capabilities due to the antennae, mast and/or cable shielding being exposed to direct lightning strike. This current must be directed to earth through the most efficient path- the lightning down-system.

Example 2 and 3 in Figure 3 are exposed to the elements, yet can not be hit directly by lightning due to the erection of a preferred lightning path. Lightning can strike in extremely close proximity, yet the current carrying capabilities of our SPD need not handle more than 8/20.

2. How Much of the Over-Voltage Must We Clamp?

From analyzing the external threat, we go now to examining the inbred immunity of our VLV device. Whereas analyzing the threat requires an understanding of lightning and a close study of the standards devised to minimize damage, deciding on the level of clamping is somewhat easier, since if the desired SPD is unavailable due to interface problems, immunity can be increased by creating another lightning protection zone.

For the most part, we are dependant on the manufacturer to supply us with this immunity information. We find this parameter in the technical specifications under EMC specifications, usually according to the EN 61000-4-5.

Table 1: Over-Voltage Classification according to EN 61000-4-5

Test level	Over-voltage
1	0.5kV
2	1kV
3	2kV
4	4kV

As defined by Table 1, the immunity of a device is classified by the EN standard with a number from 1-4. This value is our guide for choosing our Voltage Protection value (U_P).

When specifying our SPD, we will search for a device that will promise a U_P value lower than that specified by the immunity specifications.

3. What Type of Communication Are We Dealing With?

The question of application is most important in any engineering project, not least in selecting a device that will be interposed onto our communication line. As opposed to the working voltage on the terminals of the power supply, the working voltage on the communication input is carrying a signal; clamping the voltage, changing the waveform or frequency will compromise the signal. Since most SPDs are comprised of discrete electronic devices including coils, capacitors and resistors, together with varistors, diodes, and spark-gaps, the overall impedance must be taken into account when choosing an SPD.

In years past, the application of SPDs for VLV devices required a deep understanding of both the device being protected and the SPD. Today, however, there is little need for examining our device to such an extent, nor is an analysis of the SPD required as the industry leaders in lightning protection now market their products per application.

We are required to know only the basics regarding the device to be protected before turning to the catalogues of responsible manufacturers of SPDs.

After we have ascertained the type of surge we can expect and the relative immunity of our device, we must now focus on the interface itself. We will now define the communication parameters necessary to choose the correct SPD.

1. What type of cable is used?
 - ◇ Coax cable or multi conductor
 - ◇ What size of coax cable, and how many conductors in multi conductor
 - ◇ Are the conductors solid or multi strand
 - ◇ Is the cable shielded, and is the shielding of lightning quality (cat 7)
 - ◇ How many conductors are carrying signal and how many conductors are not in use (if any)
2. What connector is being used?
 - ◇ Coax cables can have BNC, 7/16, N or F type
 - ◇ Multi conductor cables can be equipped with RJ45, RJ11 or D-Pin to name but a few
3. What is the operating Peak to Peak voltage of the protocol?
 - ◇ A rated AC voltage listed as RMS will have a higher Peak to Peak Value
4. What is the operating frequency?
5. Is a DC component imposed on the line as a power source?
6. Is either of the signal carrying conductors grounded?

Equipped with answers to the above questions and the generic or trade name of the communication medium, we are ready to choose the best SPD for our VLV device.

4. An Example- Outdoor Surveillance Camera

For the purpose of example, few compare to the outdoor surveillance camera. This is a most common application for surge protection. It is also a good example of the complexity involved in application since the surveillance camera can have as many as three different cables connecting it to the distant base.

We shall take for example a video camera at number 4 in Figure 3. This camera is installed in an enclosure on a 4 meter mast. The distance to the building is 100 meters. The mast and enclosure are metallic, as is the connection between them. It is proper practice to ensure good galvanic connections between all elements on a mast, since any attempt to isolate the enclosure will not succeed and lead to catastrophic flash-over. The mast is equipped with high quality conducting wire with a cross section area of at least 8 mm^2 running from 0.5m above the mast down to a grounding electrode. It should be noted that the absence of this additional air termination does not affect our choice of SPD. Its inclusion will increase the efficiency of the overall protection solution.

STEP 1- From what are we protecting our device

The first step is to decide on the type of surge we are protecting against. The camera mounted inside the enclosure is subjected to surges from two directions; a direct strike into the mast and a direct strike into the building to which the camera is connected by cable.

Ironically, the direct strike into the mast creates less of a surge for the camera than a direct strike into the building 100 meters away. The camera is actually in an LPZ 1 while the enclosure is mounted in LPZ 0_B. From Figure 3 it is evident that the surge from this direction will be of type 8/20 as the lightning current goes to ground and induces an electromagnetic field that engulfs the grounded enclosure and camera. However, a cable grounded in the distant building is connected to the camera, and the camera is grounded locally. As such, we are susceptible to a surge of 10/350 due to a lightning strike into the distant building. An interesting conclusion deduced from this analysis is that an RF connection would be preferable for this application. This potential difference creating the 10/350 surge is to be dealt with at the building side where a cascaded protection will be installed.

STEP 2- To what level of voltage must we clamp

The second step is to ascertain the inherent immunity of the camera to the effects of over-voltage. Unfortunately, for this step we must depend on the declaration of the camera manufacturer in the camera specifications. This is not a problem when such specifications are evident. The problem arises when no specifications are evident. For the purpose of this paper we will assume that the manufacturer adhered to the CE standard for surge immunity, in which case we can assume immunity to 1500V. We require an SPD that will promise a U_p (Voltage Protection) of class 2 according to Table 1.

STEP 3- Defining the communication type

The third step entails classifying and defining the communication type. In our example we actually have three cables, each with its own parameters. The first, most obvious, is the video signal cable. This cable is most commonly coax, though in some instances multi conductor cable is used. The second cable is for controlling the pan\tilt \zoom of the camera. This control protocol is usually of the industrial standard RS-485, a shielded twisted pair of 1 mm² conductors. The third cable is optional, being the power supply cable. The power supply is often imposed on the signal cable negating the need for this third cable. In the case of a separate cable, a multi conductor cable with conductors of at least 1 mm² is used. In the event that the cable contains more than the necessary conductors, the extra conductors must be grounded at either end of the cable.

Once we are aware of the cables in use, we can settle on the cable interface. Most coax interface for video applications are of the BNC type. The control and optional power cables are usually supplied with bare ends for screw terminal connection.

Now that we visualize the cables and connections we can verify the voltages of the three cables. The video signal is usually no more than 1V peak to peak. The power supply is usually 24VDC. The RS-485 protocol works on a 5VDC differential balanced line.

We now fill out the picture with the frequencies of the three lines. The video signal frequency is usually no higher than 300Mhz. the power supply is DC and the RS-485

is a digital communication allowing a maximum rate of 10 Mb/s down to 100Kb/s at 100 meters.

The next parameter that must be examined is the possible grounding of one conductor in a transmission line. This must be taken into account when choosing the SPD device, though for the most part, when dealing with known protocols, the SPD is designed for this possibility. The shielding of an RS-485 transmission line is to be grounded at only one point. In our example it should be grounded at the building side, for reasons that will be made obvious shortly. The camera side should be grounded through a 90V gas tube arrestor. This will keep the shielding ungrounded at the camera end to ensure continuous communication yet will allow the shield to meet the ground when an over-voltage event occurs.

5. The Application-Putting it All Together

We shall begin with the camera side. We require 2 or 3 separate SPDs depending on if the power supply is to be imposed on the video line or not. Since manufacturers catalogues are organized by application, we have only search for each application in turn, and apply the requirements specific to our application.

- The RS-485 serial communication line- we will choose a recommended SPD with a screw terminal interface and an inherent gas tube between the shielding terminal and the ground. The choice of voltage and frequency is transparent when choosing a stock SPD for the defined communication type. We will choose a device that is capable of withstanding a 10/350 waveform.
- The power supply- we will choose a recommended SPD with a screw terminal interface and a continuous voltage rating (U_C) of 30 VDC. We will choose a device that is capable of withstanding a 10/350 waveform.
- The video signal- we will choose a recommended SPD with a BNC interface rated for the Peak to Peak voltage of the video signal or with a voltage rating of 30VDC to accommodate the DC power supply, if we have no separate power supply feed.

We will look for a rating of 10/350, yet we probably will not find one. This is because the manufacturers of SPDs have found that it is pointless to design a 10/350 device for a coax BNC interface since an energy wave of this intensity will usually vaporize the cable. There is a good chance that the SPD will also sacrifice itself, though the camera will not be damaged.

As discussed previously, the expected surge type induced by a local lightning strike will be of 8/20, the 10/350 waveform will endanger the camera only when lightning strikes the distant building to which the other end of the cable is attached. If we want to ensure continued video surveillance even after direct lightning strikes, we can not use a coax cable. We must use a lightning rated multi conductor cable (cat-7) and choose a recommended SPD with a screw terminal interface for installation in the camera. This requires an interface change between the BNC connector of the camera and our cat-7 exterior grade cable.

Our decision making process for applying the SPDs on the building side will be influenced by the decision taken on the camera side. If the client- a surveillance application, can live with the necessity to replace the cable end, or perhaps the whole cable if and when a direct lightning strike occurs, then we continue with the

application based on the use of a coax cable and BNC connector. If the client can not abide down time due to lightning strike, then we have a different application regarding the video cable. The video cable is now a shielded twisted pair of cat 7 rating.

From the building point of view, the major lightning threat is brought in by the cables arriving from the video camera. This threat is of 10/350 magnitude. If we stay with a coax cable, the cable will vaporize when the building or mast is hit by lightning, but we still have to deal with the other two cables.

We shall continue our application with the building side. The building side will have two SPDs for each application. The first will be of 10/350 capability for point of entry, the second will be of 8/20 at the input of our VLV device. A 10 meter length of cable should be realized between the SPDs to ensure impedance matching. This cascading approach to dealing with the 10/350 impulse current without sacrificing the cable or SPD requires that we digress from the simple catalogue application. We will search for a robust 10/350 SPD with a wide range of application to install at the point of entry. This SPD will usually be comprised of a robust gas tube arrester on each of the conductors, with nothing more. This SPD will be rated for 10/350 impulse and will be rated for a continuous operating voltage higher than our application.

- The RS-485 serial communication line- at the point of entry we will install a robust general purpose SPD with a screw terminal interface capable of handling a 10/350 impulse, rated for at least 6V continuous operating voltage, and capable of handling a frequency related to the 100Kb/s speed of digital communication expected on this line. We will ground the shielding directly into the earthing ring of the building at this point of entry. The cable length to our VLV device will be at least 10 meters. For installation at our VLV device input, we will choose a recommended SPD of 8/20 capability with a screw terminal interface and an inherent gas tube between the shielding terminal and the ground. The choice of voltage and frequency is transparent when choosing a stock SPD for the defined communication type.
- The power supply- at the point of entry we will install a robust general purpose SPD with a screw terminal interface capable of handling a 10/350 impulse, rated for at least 30 VDC continuous operating voltage. The cable length to our VLV device will be at least 10 meters. For installation at the VLV input, we will choose a recommended SPD of 8/20 capability with a screw terminal rated for 30 VDC.
- The video signal- at the point of entry we will install a robust general purpose SPD capable of handling a 10/350 impulse, rated for the Peak to Peak voltage of the video signal or with a voltage rating of 30VDC to accommodate the DC power supply, if we have no separate power supply feed. We will assume a cat7 shielded twisted pair, so we will choose an SPD with a screw mounted interface. At the device input we will choose a recommended SPD of 8/20 capacity rated for the appropriate voltage.

6. Conclusion

When lightning strikes the building, the potential difference will assert itself at the point of common coupling. The surge will affect both the building and the camera, though the propagation time to the camera is slower due to the mutual inductance of

the conductors in the cables. Consequently, the application of 10/350 SPDs at the building point of entry should take the brunt of the surge. The use of 10/350 on the camera side should offer enough energy dissipation to take down what does arrive. The use of 8/20 devices on our VLV device is to protect against induced voltages due to both direct strikes traveling through the building structure and distant strikes.

A direct strike into the mast will not raise the potential of the camera dangerously since the camera is part and parcel of the same potential. The primary danger is that of the voltage induced by the lightning flowing to ground centimeters from the camera enclosure. An 8/20 SPD would take care of this problem. A strike into the building will bring the potential difference to the camera, requiring some protection against 10/350 impulse.

We have seen that by applying the three step method for choosing the correct SPD we are equipping ourselves for the complicated process of dealing with the complete application.