A DETAILED REPORT on the BASIC, IN-LINE COAXIAL SURGE ARRESTOR

INTRODUCTION

The Surge Arrestors described in these notes are economy devices installed in series with a coaxial feed line to protect radio equipment from damage induced by lightning. There are many devices available ranging in sophistication, features, protection and cost. The two types studied here are basic, low cost, commonly used, and readily available products. These notes are the result of personal evaluations focused on gaining an understanding how these devices function and may be applied.

Two types of arrestors are examined; a Spark Gap device and a Gas Tube device.

A copper highway exists from the antenna system into the shack because of all the metallic wiring, such as coax, power, rotor cables, ground wires etc. Surge arrestors are intended to divert destructive lightning currents flowing in and on these wiring systems to earth so that damage to connected equipment, structures and injury to personnel is minimized.

In order for the arrestor to provide protection, the lightning currents must be kept OUTSIDE of the shack by diverting them to EARTH GROUND as DIRECTLY as possible through the use of these devices.

The coaxial lightning arrestors described can NOT guarantee protection against a direct strike.

However, when there is a direct strike to an object close by, there will still be significant induced voltages and currents in the antennas and cables, but at reduced levels depending on distance, improving the survival capability due to a well designed grounding and arrestor system. The observations presented in this article may help in the design and implementation of your own lightning protection system.

PART 1 – The A28 COAXIAL LIGHTNING ARRESTOR

Overview

Part 1 is focused on a ubiquitous in-line lightning arrestor. Typically, but not always, the part number contains the number sequence “A28”. These devices can be recognized by their characteristic appearance as shown in Figure 1.

Figure 1 - Typical A28 In-Line Coaxial Lightning Arrestor

Searching the internet and eBay will reveal a multitude of suppliers and prices of this device. The pricing of this A28 style arrestor was found to range from $1 to $24. The devices used in this study were purchased at $4.50 each from an Amateur Radio on-line dealer.

Vendors were contacted for technical information regards the performance of these devices. Those that replied did not have any information. Many did not reply at all. This raises questions as to what level of protection is offered.

Arrestor Construction

This arrestor is suitable for inserting into a coaxial cable transmission line. It does not lend itself for use on balanced feed lines or wiring. It consists of a cylindrical metal body which contains a spark chamber. There is a PL-259 male connector on one end and a SO-239 female connector on the other end. A center conductor runs through a metal body “casing” thus emulating coaxial cable construction.

The arrestor must be connected to an earth grounding system. A grounding screw with solder lug is provided so that a substantial grounding wire can be attached to the casing and be taken directly to the earth grounding system. This will divert current on the coax braid to earth.

The arrestor provides center conductor protection by introducing a small air gap between the center conductor and the grounded casing. When lighting strikes, a high voltage will be induced on and in the coaxial transmission line. The enclosed air gap will flash over between the center conductor and the grounded casing creating an arc that forms a low voltage conductive path, thus diverting damaging currents to earth. Hence the reference to “spark gap” arrestor.

The gap spacing will determine the flash-over voltage required to initiate an arc across the gap. The electrical breakdown voltage of air is about 30 kV / cm or 3 kV per mm[1]

The arrestors are made of brass with nickel plating. Connector insulating material is white, perhaps Teflon, but not confirmed.

Upon closer inspection, there are variations amongst the “A28” devices that impose significant performance differences, even though they appear outwardly similar. Three types have been identified. Type 0 has *no* screw gap adjustment, Type 1 has *one* screw gap adjustment, and Type 2 has *two* screw gap adjustments. All have a grounding screw.

The Type 2 appears to be obsolete as no supplier for this device has been found. The three on hand were purchased during the 70’s indicating that this general design has been available for decades. Performance results for the Type 2 are included in case others have such devices.

Figure 2 shows the three types. The grounding lug screw is not visible on Type 0 and Type 2 in this photo. Note that the grounding lug screw is NOT used as the spark gap screw.

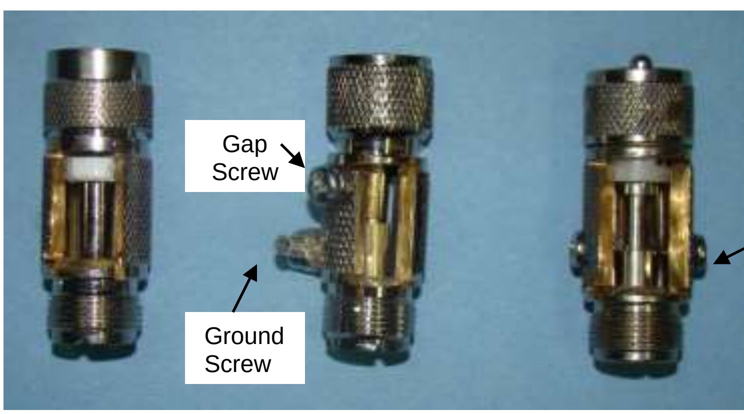

Figure 2 - Three Variants of the A28 Lightning Arrestor

1. The Paschen curve relates the breakdown voltage of various gases including air with respect to the gas pressure. At one atmosphere, for air, it is commonly taken to be 30 kV per cm

All the devices have been “opened up” so as to reveal the internal construction of the spark gap chamber. There are significant differences in this construction.

The Spark Chamber

General Description

Addendum 1 has fully dimensioned mechanical drawings of the spark chamber for all three arrestors.

The casing outer diameter, less the wall thickness, defines the diameter and length of this hollow chamber. Inside that is the center conductor joining the two coax connector pins. This structure forms a coaxial section that has an air dielectric. The space between the center conductor and the casing is where an arc is expected to be struck in an overvoltage situation. It will be noted that the spark chambers have quite different internal designs and implementations.

The Type 1 and 2 are equipped with adjustable spark gap screws so that the gap between the center conductor and the casing can be adjusted. This gap should be less than the intrinsic gap of the spark chamber structure. The exception to this is the Type 0 which is not equipped with a screw for adjusting a gap at all, and as such, the intrinsic spacing between the center conductor and casing wall *is* the gap.

The center conductor is insulated from the casing at both ends by the connector dielectric.

Type 0 – No Adjustable Gap

Figure 3 shows the exposed spark chamber and an end view of the female connector.

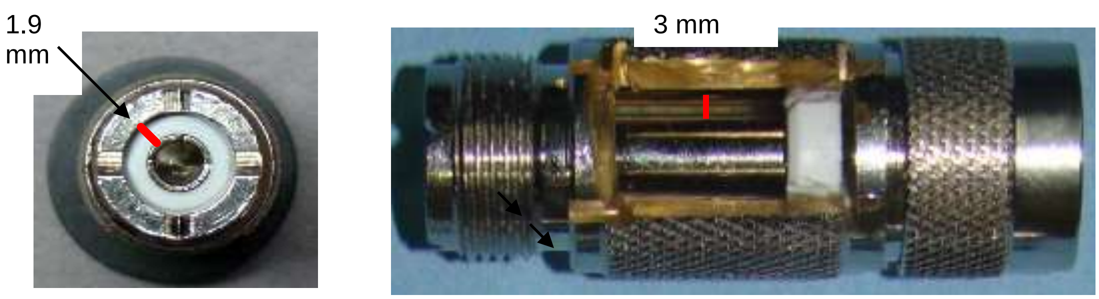

Figure 3
Type 0 with Exposed Spark Chamber – Non Adjustable Gap

The separation between the surface of center conductor and inside surface of the spark chamber is 3 mm for a theoretical breakdown voltage of 3kV/mm x 3 mm = 9 kV.

Examining the connectors for the length of their surface insulation path, the red line on the female connector is minimal at 1.9 mm. This provides for a theoretical breakdown voltage of 3kV/mm x 1.9 mm = 5.7 kV. Note that this is less than the chamber.

This will render the spark chamber ineffective as we would expect the flashover to first appear on the female connector instead of within the spark chamber.

Type 1 – Single Adjustable Spark Gap Screw

Figure 4 shows the exposed spark chamber and an end view of the female connector.

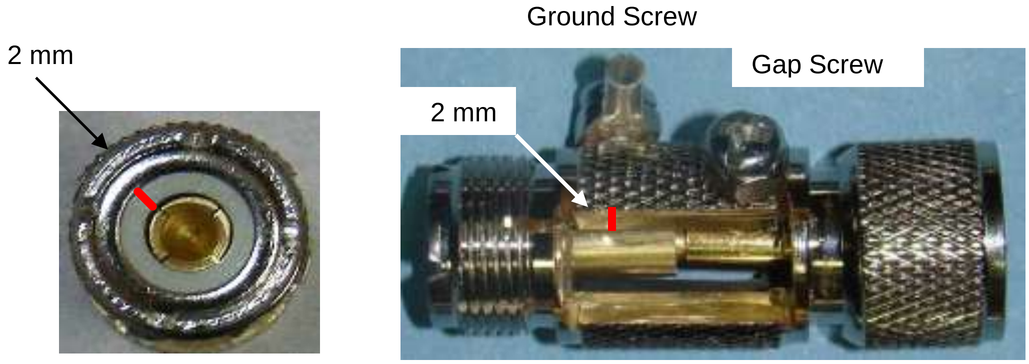

Figure 4
Type 1 with Exposed Spark Chamber & Single Screw Gap Adjustment
Misaligned Center Conductor
Female Connector End – Surface Path Length

This center conductor consists of three different diameter & length cylinders. It would seem that the left and right cylinders are each a part of their respective end connectors. The small cylinder in the middle may be a joiner.

One can clearly see that the cylinders are not well aligned or centered, being bent off axis. This raises doubt as to manufacturing tolerances and the resultant gap distance within the spark chamber.

As a result of this construction the smallest gap from the center conductor to the casing is 2mm for the larger diameter cylinder connected to the female end.

The red line on female connector between the center conductor and the outer shell of the connector has a 2 mm surface path length which is less than the male end and the same as the spark chamber. Since the chamber gap and female connector arc path dimensions are equal, one, either, or both will flash over at about the same time for a theoretical breakdown voltage of 3kV/mm x 2 mm = 6 kV.

However, there is a gap screw. The screw comes equipped with a nut. When this nut is tight against the screw head, and the combination is tightened down on the casing, the gap between the screw and the center conductor is governing at ~1.25 mm for a theoretical breakdown voltage of 3kV/mm x 1.25mm = 3.75 kV. This ensures that the gap breaks down before the connector.

Type 2 – Two Adjustable Spark Gap Screws

Figure 5 shows the exposed spark chamber and an end view of the male connector.

This design does have some interesting features which the newer ones do not exhibit.

Figure 5
Type 2 with Exposed Spark Chamber & Double Screw Gap Adjustment

This center conductor consists of a machined, stepped center conductor connecting the center pins of the two connectors.

The edge of sharp step down at the female end concentrates the electric field at that edge ensuring that flashover will occur at this point. The two gap screws are centered on that stepped edge further encouraging the flashover. As well, the screws have conical points for increasing the electric field and so flashover is guaranteed to occur at this precise location. The Type 0 and Type 1 have no equivalent feature.

The gap between the large diameter cylinder of the center conductor and the casing is 2.15 mm.

Inspecting the connectors for the length of the surface insulation path, the red line on male connector between the center conductor and the outer shell is 2.25 mm whereas the female end has a greater surface path length of 2.8 mm.

The gap adjusting screws will dominate with a lower gap distance. The two gap screws do not have a limiting nut as does the Type 1 and so when screwed down tight they will just about or will actually short to the center conductor, depending on tolerances. Careful screw adjustment is required to achieve something less than a 2mm gap. Refer to Table 4 as to how the gap can be adjusted.

Lightning Characterization

For 50% of strikes, the peak current in a cloud-ground lightning stroke will exceed 25,000 amperes (25 kA). The rise time to peak will take place in the order of microseconds. In 1% of instances, peak currents are in the order of 200 kA with rise times of up to 10 usec[2] .

In order to develop effective arrestors, specifications are needed to simulate lightning currents so that manufacturers can design devices to cope with these enormous values and users have confidence that they will be able to provide a defined level of protection.

Figure 6 illustrates one of a number of lightning waveforms that industry uses to simulate a strike. This example is the 8 x 20 usec waveform used for testing gas tubes and other transient suppression devices such as zeners & varistors.

[2] Lighting and Lightning Protection, Don White Consultants. 1979. Figures 3.5 , 3.6

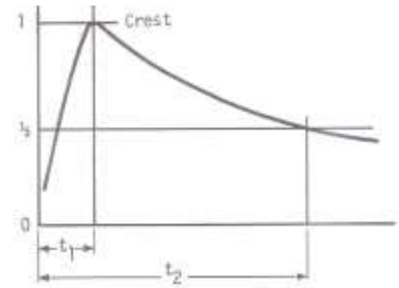

Figure 6 - Standard Lightning Waveform for Test Purposes

Time t1 is the rise time at 8 usec, time t2 is the fall time at 20 usec defined as one half the Crest value. The Crest value is typically 25,000 amperes. Other values will apply to other “standard” waveforms.

How to Test

At-home testing to the levels of current, and in compliance to rise and fall times, is beyond home style capability and so a simpler test has to suffice.

The objective is to observe the flashover of the suppressors given the various design configurations and troubling dimensions. This information might give some insight as to the protection likely to be achieved by the A28’s. It would also be interesting to observe the nature of the breakdown arc and its’ voltage behavior.

Test Methodology

Refer to Figure 7, the test arrangement.

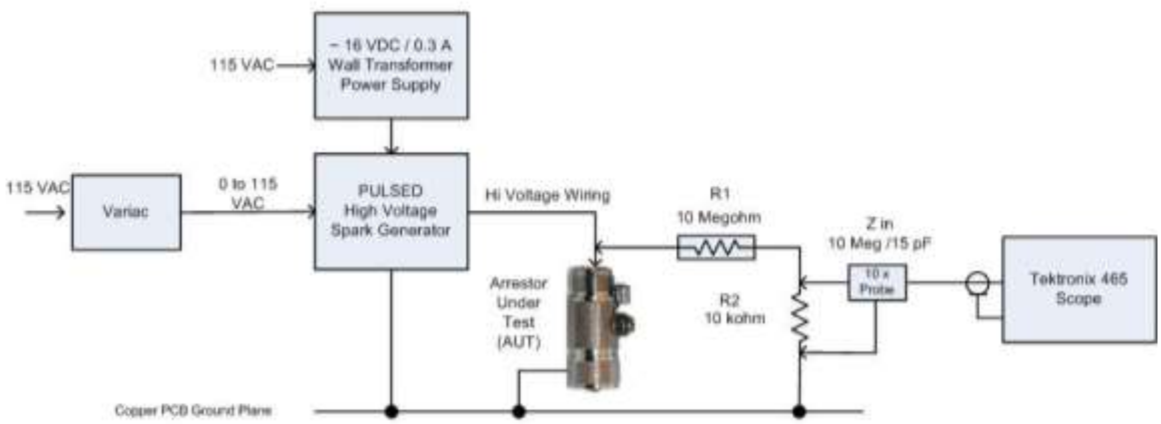

Figure 7 - Test Arrangement for HV Arcing

A pulsed high voltage spark generator was built using an old style, single, automotive spark coil to generate the high voltage (HV). The HV was applied to all Arrestors Under Test (AUT). A 10 megohm R1 and a 10 k ohm R2, form a 1000:1 voltage divider built to reduce the HV to a safe level for connecting to a Tektronix 465 ‘scope. 1 kV would read 1 volt. This set up would enable a dynamic measurement of the pulsed HV when applied to the AUT.

The HV can be varied from 0 to many kV by varying the 115 AC input voltage to the 12 VDC power supply that powers the primary of the spark coil. This was done using a Variac[3]

A built in pulse generator pulsed the primary of the coil about 3 times per second with an ON duration of about 50 milliseconds.

The HV was gradually turned up with the Variac until arcing was visually observed.

Test Fixture

A “holder” for the AUT was made for securing the device being tested. An SO-238 with the center removed was soldered to a small copper clad board. Figure 8 shows the set up. The red banana plugs are part of the HV arrangement – the one to the right goes to the spark coil and the one to the top goes to the HV 10 megohm resistive divider made up of 10, 1 megohm resistors + a 10k termination.

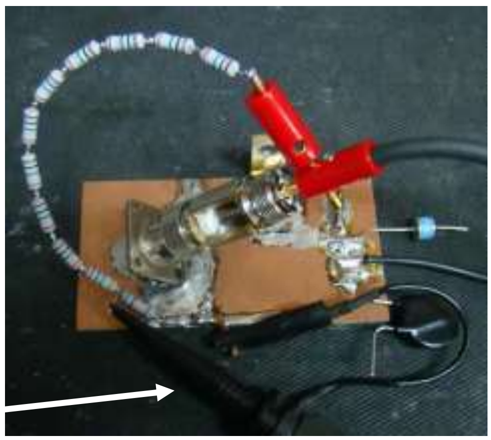

Figure 8 - Test Fixture

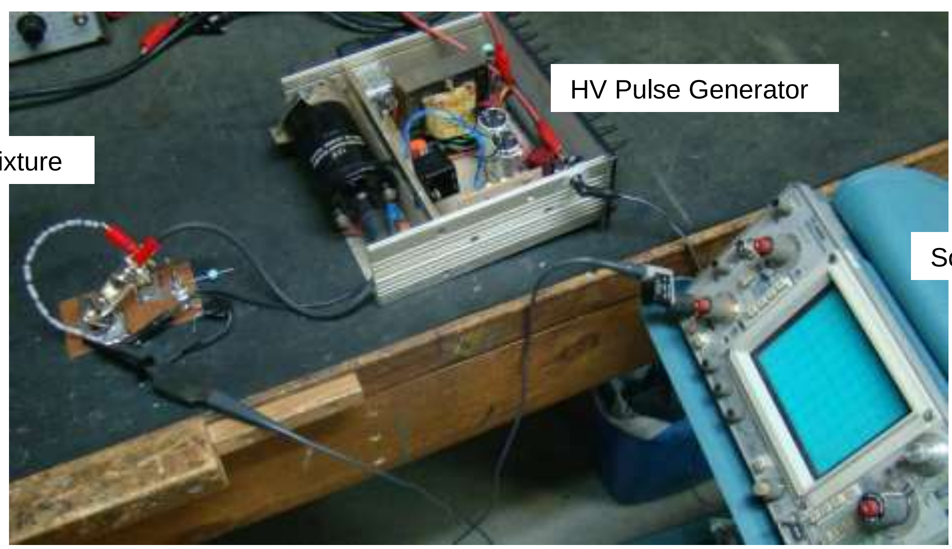

Figure 9 - Overview of Test Setup

3 A Variac is a a continuously adjustable auto-transformer that produces an AC output from 0 V to 140% of the input AC voltage by simply turning a large knob that moves a wiper across the transformer turns.

Flash Over Observations

Type 0 – No Adjustable Gap

- Flashover occurs on the female connector.
- Occasional activity is seen within the spark chamber.
- This is consistent with the 1.9 mm female connector insulation path vs the 3 mm spark gap chamber.
- The sharp edges on the female center receptacle concentrates the E field at the edges which flash over to the body.

Flashover

Figure 10 - Female Connector Flashover

Type 1 – Single Adjustable Spark Gap Screw

- Flashover occurs on the female connector.
- Occasional activity is seen within the spark chamber with factory set gap which measured 1mm with feeler gauges.
- This female connector insulation path is 2mm which is significantly more than the spark gap.
- However, it seems that the sharp edges on the female center receptacle concentrate the E field at the edge which flashes over to the body. Same effect as noticed on the Type 0

Flashover

Figure 11 - Female Connector Flashover

Type 2 – Two Adjustable Spark Gap Screws

- Being an old device with the screws having been fiddled with over the ages, the original factory settings have been lost. For the purposes of this test, both gaps were set to ~ 1 mm, (0.04”) using a feeler gauge.

- One of the gaps flashed over before the connector. One gap is always going to be marginally wider than the other and so the narrowest dominates and flashes over first.
- The female connector has a much longer insulation path, 2.8 mm, and looks better formed in all respects than the Type 0 and Type 1. The male connector has a shorter insulation path, 2.25 mm, but there are no sharp edges of the surfaces to produce concentrated E field.
- No connector flashover was observed with the gap screws in place.

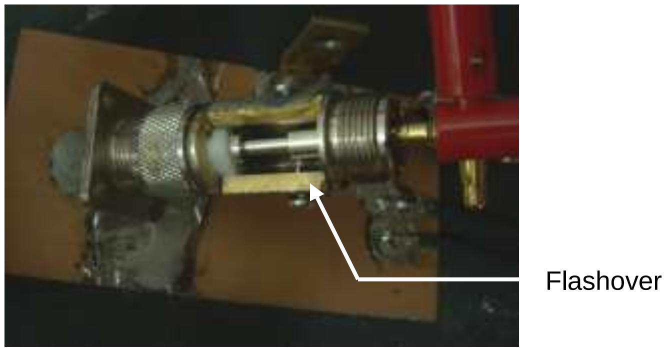

Figure 12 - Double Gapped Flashover

Waveforms

The waveforms were the same for all Types, 0, 1 and 2. Three waveforms were recorded, a) voltage before flashover, b) voltage at flashover as compared to (a), and c) an expanded view of the leading edge of the flashover voltage so as to get a better view of the voltage level characteristics and the flashover effect.

a) Voltage Across Device before Flashover

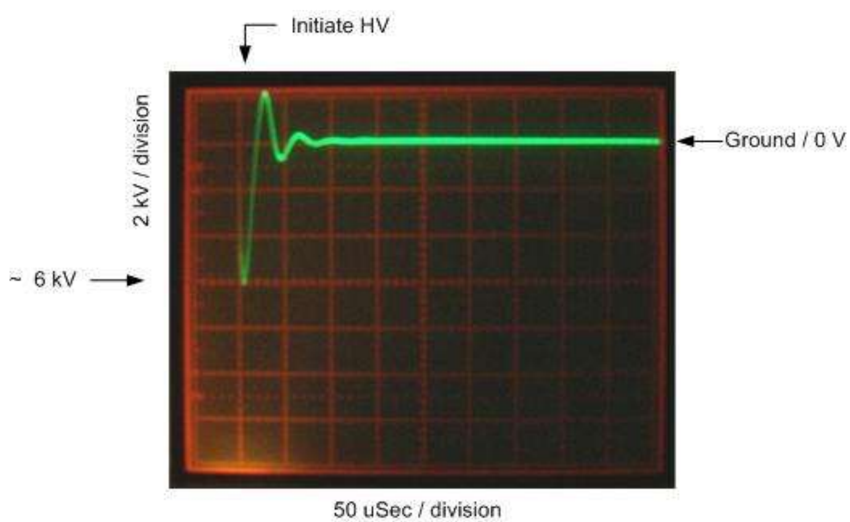

Figure 13 - Pre Flashover

The arc has NOT been struck. Peak voltage is ~ 6kV. A resonant oscillation is evident, dominating the waveform with a period of about 80 us / 12.5 kHz. This “ringing” is undoubtedly due to the stored energy in the spark coil being dissipated through the primary circuits of the spark generator as the secondary has not yet conducted (flashed over). Refer to Addendum 2.

b) Voltage at Flashover

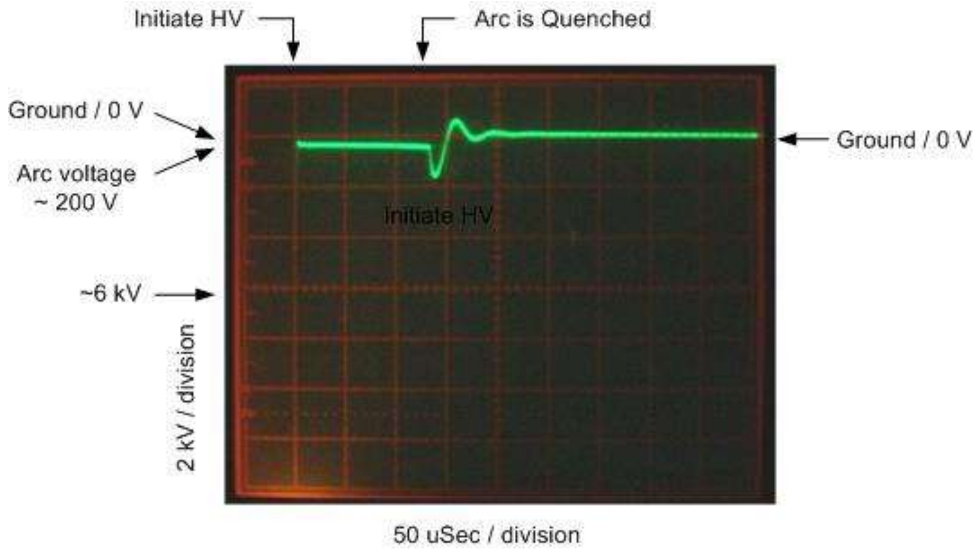

Figure 14 - Flashover

The applied HV is increased to just beyond 6 kV where visible flashover is initiated. The initiating 6kV+ spike cannot be seen as the arc is struck very quickly (See Fig 15). The arc voltage is evident on close inspection to be ~ 200V. The arc continues to conduct for ~ 160 usec when it is quenched, that is, the energy supplied by the spark coil is dissipated. The quenching is followed by a short lived, damped oscillatory waveform, or ringing, representing residual energy in the coil of an insufficient amount to sustain the arc, but not equal to zero.

c) Expanded View of Flashover

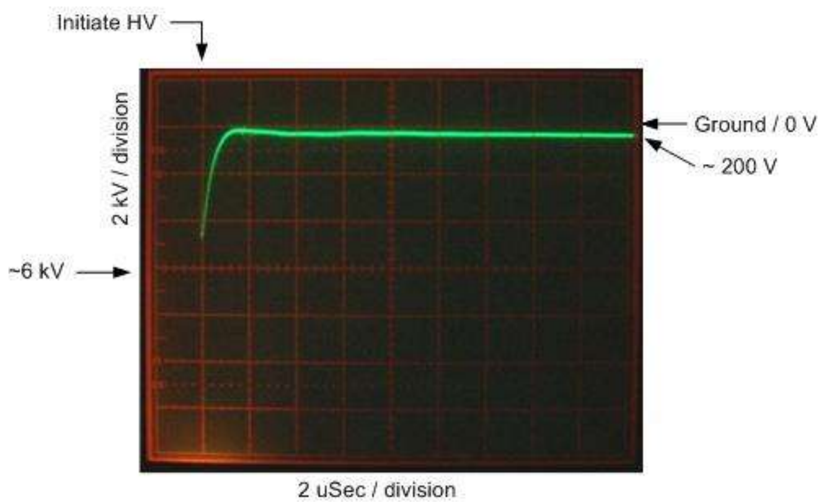

Figure 15 - Expanded View of Flashover

The rise time of the HV is extremely fast rising to the point of flashover which occurs at about 5.5kV. The time for the arc to be established is about 1 usec.

The arc does not initiate instantly as it takes time to invoke ionization of the air and induce the electron avalanche leading to the establishment of the arc[4]. However, this would appear to be a fraction of a microsecond.

PART 2 – IN LINE GAS TUBE LIGHTNING ARRESTOR

The Gas Tube Arrestor

Part 2 is focused on a simple, low cost, in-line, gas tube, surge arrestor. This $15US arrestor has a very detailed specification, Table 1. Every gas tube arrestor seen so far has some form of specification which is more than can be said for the A28's.

As can be seen in Figure 16, the (black) solid aluminum body accommodates a gas tube, a grounding screw and RF connectors on each end that thread in to the body. A center conductor passes centrally through a tubular cavity within the body. The top screw provides access to the gas tube which can be easily replaced. One terminal of the gas tube contacts the center conductor and the other terminal contacts the body. The bottom screw is the grounding lug.

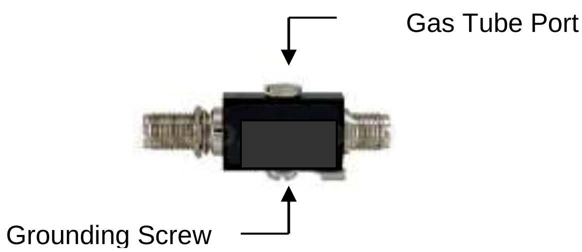

Figure 16 - Gas Tube Lightning Suppressor

Electrical Specifications	
Frequency Range	0 - 3 GHz
Protector Complies With	IEC / IEEE Standard
VSWR	1:1.3 Max (0 - 3 GHz)
Insertion Loss	0.4 dB Max (0 - 3GHz)
Impedance	50 Ohm
Standard Gas Tube Element: DC Breakdown Voltage Indicated	600 V 20%
Special Order Gas Tube Elements: DC Breakdown Voltages Indicated	90 V 20% 230 V 20% 350 V 20%
Gas Tube Impulse Breakdown Voltage	1000 V 20%
Gas Tube Insulation Resistance	10,000 MΩ
Maximum Withstand Current	5 KA

RF Power Rating - Standard 600 Volt Model

Model Suffix	Voltage Rating	DC – 30MHz		30500MHz		500MHz3GHz	
		PEP[1]	CW[2]	PEP[1]	CW[2]	PEP[1]	CW[2]
-4	600 Volt	2KW	1KW	800W	400W	320W	160W

Table 1 - Gas Tube Arrestor Specification

Five vendors supplying arrestors of this type were identified ranging in price from $15 to $50 and while commonly available, they often differ in their physical appearance compared to Figure 16. Devices costing more than $50 were not purchased or tested.

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4 http://enwikipedia.org/wiki/Electrical_breakdown

Arrestors of this type commonly have various options available with regards to connectors, such as PL. N, BNC etc, male of female, and gas tube breakdown voltages. They may also offer extended length female connectors suitable for bulkhead mounting on ground plates. This is highly desirable in terms of mounting to grounded towers and cable service entrances where ground connections should be present. A grounding screw is normally supplied with a ground lug to allow a ground wire to be utilized if no other ground mechanism is available.

These arrestors utilize a gas tube, which is basically a spark gap suppression technique that does not rely on uncontrolled air humidity, air pressure, or variation in spark gap length for breakdown as employed with the A28 spark gap arrestors.

Gas tubes are sealed devices with electrodes of fixed dimension and chambers filled with a controlled gas, all of which reliably determine the breakdown voltage. Tubes are rated to breakdown at various and specific voltages, as low as 90 V or as high as 1000 V. The tubes appear open circuit until they fire due to the presence of a voltage exceeding their breakdown rating.

In this particular product, a gas tube in the form of a pellet, Figure 17, is placed in a hole that enters the body of the arrestor. One contact of the tube presses against the center conductor joining the two connectors. The other contact is tight against the screw cap, which is screwed in to the body, and is the ground side of the arrestor. A spring washer ensures a constant contact pressure. The screw has an “O” ring washer to seal against water ingress.

Figure 17 - Gas Tube “ Pellet”

Gas tubes can be rated to divert currents ranging up to 25,000 amperes, Not all arrestors are equipped to handle that amount of surge current so check the vendors maximum withstand specifications..

Table 3 provides some typical performance parameters of gas tubes As previously seen in Figure 6, the spec quotes the 25,000 A, 8 x 20 us spec wave form. Only one strike is allowed at this level but at lower currents, survival can be extended to multiple hits. Note that the arc voltage clamps to a very low level, ~ 10 volts.

Impulse Discharge Current	25000 A, 8/20 μs***	1 operation minimum
	10000 A, 8/20 μs	>10 operations
	2500 A, 10/350 μs	2 operations
	500 A, 10/1000 μs	>400 operations
	100 A, 10/1000 μs or 10/700 μs	>1000 operations
Arc Voltage	> 1A	~10 V

Table 3 - Typical Gas Tube Characteristics

While these tubes can fail under severe over-current, they are easily replaced, provided the body survives. Typical cost, $5.

Test Fixture

The gas tube device is the black connectorized structure attached to the test jig bracket. The 1000:1 HV resistive voltage divider chain arches over the fixture. All other connections to the jig and the equipments are same as previous Figure 9.

Figure 18 - Gas Tube Test Fixture

Waveforms

The gas tube arrestor was tested under the same conditions as the spark gap arresters using the same equipment and test fixtures.

a) Voltage Across Device without a Gas Tube

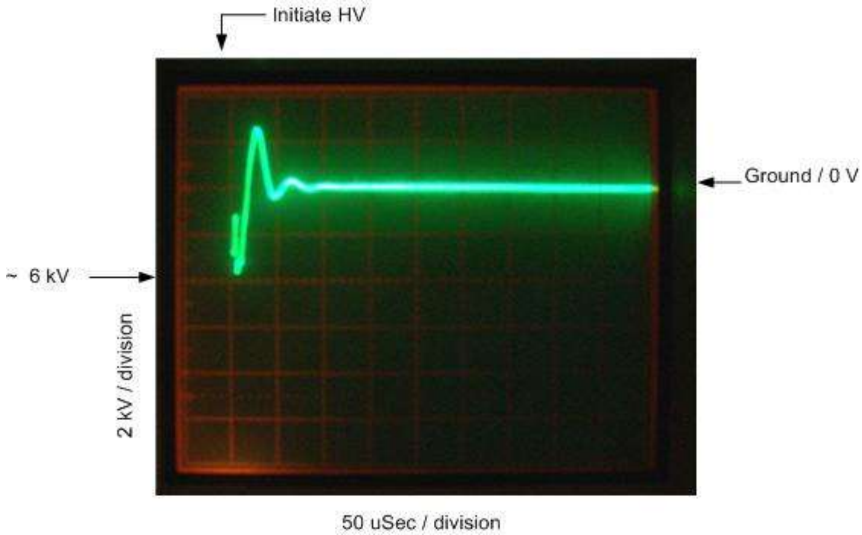


Figure 19 - Applied Waveform

The female connector was observed to flashover at just over 4 kV. The protector body does not have the gas tube installed and while this is the first flashover point, it is of little importance as the gas tube will suppress the HV at a much lower level when installed.

This waveform shows the same “ringing” characteristic of the spark coil self discharging.

b) Voltage across Arrestor with a 600 V Gas Tube Installed

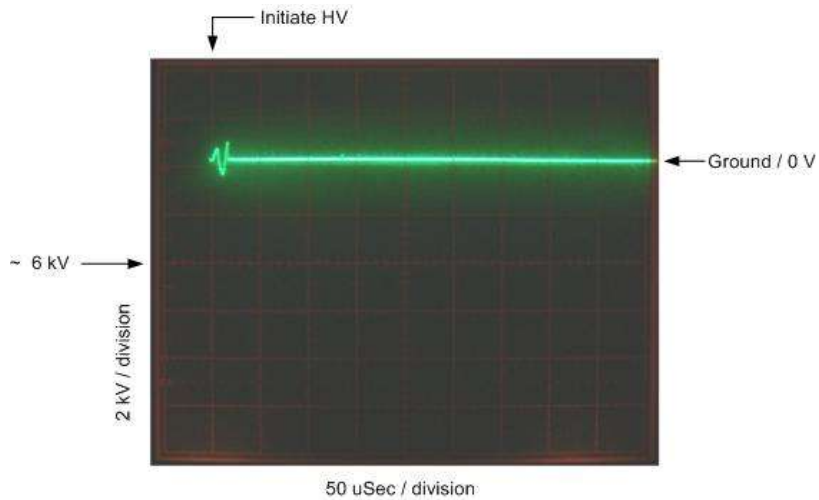


Figure 20 - Gas Tube Fired

The gas tube has fired and has suppressed the energy. There does not appear to be an initial overshoot. The arc voltage is clamped to an immeasurable level at this resolution, (spec'd at 10V). The oscillation of about +/- 200V is most likely akin to the residual quenched energy as seen in Fig 14.

c) Expanded View of the Gas Tube Firing

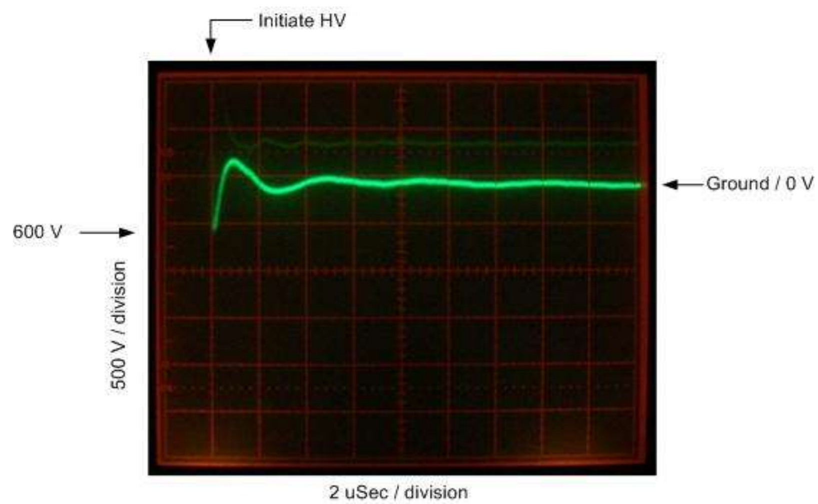


Figure 21 - Expanded View of Gas Tube

The gas tube appears to conduct as soon as the voltage rises to the ~ 600 V level. There is an oscillatory response as the tube continues to conduct and dissipate energy.

Other Arrestors

Referring to Figure 18, two other suppression devices were tested as the opportunity presented itself. On the right of the copper board is a (blue) axial leaded, 150v gas tube. This is simply a package variant of the gas tube pellets previously described. The black disk is a Varistor, not a disk ceramic capacitor. A varistor is a voltage dependent resistor. The resistance is normally > 10 megohm with no voltage applied. The resistance decreases rapidly above a rated threshold voltage, 100V in this case, and thereby shunts excess current to ground. Both items were tested and both can be used as stand alone suppressors for wired circuits such as rotor cables. They would be connected from each wire to a grounded terminal thus providing surge protection as do the coaxial arrestors. These devices are not the focus of this article but results are provided in Addendum 5.

Implementations

Photos are included in Addendum 6 illustrating the installation of the various arrestor devices presented in these notes. These are home made by the author.

Characteristic Impedance and Insertion Loss

Not to be forgotten is the disturbance to the coaxial transmission line when inserting these devices in to the line.

The A28's have no specification in this regard. The Gas Tube devices do have specifications.

The SWR performance of all types was measured using the AIM-4170 Vector Impedance Meter over the range 1 to 30 MHz and on to 150 MHz.

Refer to Addendum 4 for continuous plots from 1 to 150 MHz

TYPE	VSWR at 1 MHz	VSWR at 30 MHz	VSWR at 150 MHz
0	1:1	1.03:1	1.18:1
1	1:1	1.05:1	1.29:1
2	1:1	1:03:1	1.17:1
Gas Tube	1:1	1.01:1	1.05:1

Table 2 - SWR Performance

TYPE	I.L. at 30 MHz	I.L. at 150 MHz
0	< 0.05 dB	~ 0.05 dB
1	< 0.05 dB	~ 0.1 dB
2	< 0.05 dB	~ 0.05 dB
Gas Tube	< 0.05 dB	<0.05 dB

Table 3 - Insertion Loss

The Insertion Loss (I.L.) is negligible. They all perform well.

RF Power Ratings

The gas tube arrestors may be ordered with differing gas tube breakdown voltage levels. These breakdown voltages must be selected on the basis of transmitted RF power levels and frequency. VSWR should be taken in to account for anything higher than 1:1 (inevitable) as that will increase peak RF voltage levels at the various standing wave nodes along the coax. The RF voltage level for 1:1 can be calculated from $P = V^2 / R$ where P = transmit power, and R = characteristic impedance typically taken as 50 ohms. This voltage is the RMS value whereas it is the peak value that has to be considered, and so Vpeak = Vrms x 1.414. For instance, at 1500 W of RF, the peak voltage in the coax would be 312 V. If the SWR is 2:1, the peak voltage in the coax could be 624 V and so on. Again, see what the arrestor's manufacturer states for maximum power and frequency such as specified in Table 1 for instance.

PART 3 - CONCLUSIONS

General Impressions

<u>A28</u>

These designs are compromised with connector breakdown

Type 0 has no gap and so the connector arcs before any arc can be induced in the spark chamber. It is difficult to think that this is the intended mode of operation and so this design is rather bizarre.

Type 1 has an adjustable spark gap but has been observed to also arc at the connector.

Type 2, the obsolete design, is perhaps best of all but appears unavailable.

No weatherproofing is provided around the ground screws or gap screws leaving the chamber susceptible to weather. Same applies to the connectors. If contemplating use, wrap this device and the connectors fully in black electricians tape (Scotch Super 88) overlaid with a fusion tape to keep out the weather. A third layer of the same black tape is recommended for UV protection. This is easier said than done as the screws stick out making this awkward. Have the arrestor positioned such that water drains off the screw.

<u>Gas Tube</u>

The gas tube used herein performs as expected. The gas tube plug has a weather seal "O" ring and the ground screw does not penetrate the body into the center chamber. Still, it is recommended that this device be weather wrapped as well to protect the connectors and the device. Depending on the model chosen, this may be a problem with some devices that have a significantly protruding gas tube structure.

High Voltage Concerns on Coax

Refer to Addendum 3

The high voltage developed in the pre-ionization / pre-arc interval of the connected arrestor can easily exceed the insulation breakdown voltages of typical coaxial cable. It may be that the cable will be less than fatally damaged in terms of the dielectric being punched through in the pre-ionization phase due to constrained energy availability for the fractional microsecond or so before the protector fires. The coax may be compromised with pin-holes so developed, but perhaps with little consequence. An outright failure would likely constitute a carbonized, conductive path punched through the dielectric resulting in a large current flow causing destruction of the cable. Tests at RF power after the event would be in order. Instabilities in VSWR would indicate damage. To be certain, absolutely replace the coax after a very close or direct strike.

Which A28 to Use ?

Type 0 – Do not use.

Type 1 – Need to adjust the spark gap screw. Replace the supplied gap screw with a new 4 x 10 mm screw. Refer to screw adjustment section following.

Type 2 - It has the best arc inducing geometry but no source of supply has been identified. Should you find them, this will be the best device. The spark gap screws will need to be adjusted. Refer to screw adjustment section following.

Gap Screw Adjustment

The spark gap can not be set by direct measurement as the gap is inside the spark chamber. However, the gap can be set indirectly since the distance-per-turn of the screw is known. This works when starting from a known position, that is, against the center conductor. By backing off the screw, the gap can be set to a known distance, Table 4.

1. Discard the supplied gap screw. Save the nut or supply a new nut.
2. Use a 4 x 10 mm metric machine screw * to replace the supplied screw.
3. File, or grind with a Dremel © tool, a 4 sided point. A ~ 45 degree angle is good.
4. Thread the nut on the screw up to the head, just snug.
5. Thread this assembly into the vacated screw gap hole.
6. Connect an ohmmeter between the center conductor and the casing.
7. Screw the screw in until it shorts to the internal center conductor.
8. The “thread rate” on the 10 mm screw is about 0.7 mm per turn (1 revolution)
9. Back off the screw according to the Turns / Gap Table 4.
10. Lock the screw down by tightening the nut against the case. Careful not to disturb the setting.
11. Put some blue LOCTITE © on the joint to weather seal and hold the gap in place.

* recommend stainless steel as non-rusting.

TYPE	DEVICE	TURNS	~ GAP
1	Single Adjustable Gap	1 to 1-1/2	0.7 to 1.5 mm / ~ 0.028 to 0.06”
2	Double Adjustable Gap	1 to 2	0.5 to 1 mm / ~ 0.02 to 0.04”

Table 4
Turns / Gap Table

Note this procedure is not exact as gaps are small and there are production tolerance issues with the rigidity & centering of center conductor that could affect the actual the gap distance.

Ensure the gap is at least full 1 turn as possible shorts to the center conductor may develop due to thermal changes causing expansion and contraction of the internal parts. This may reduce the gap distance or short circuit the gap. The author has mounted 5 of the Type 1 suppressors using 1-1/2 turns, outdoors on two tower bases. The devices have been subjected to summer through winter conditions with temperature ranges of about -10 to +30 degrees C, under sun, rain and snow conditions, for over a year now at the time of this writing. The devices must be weather protected as previously described.

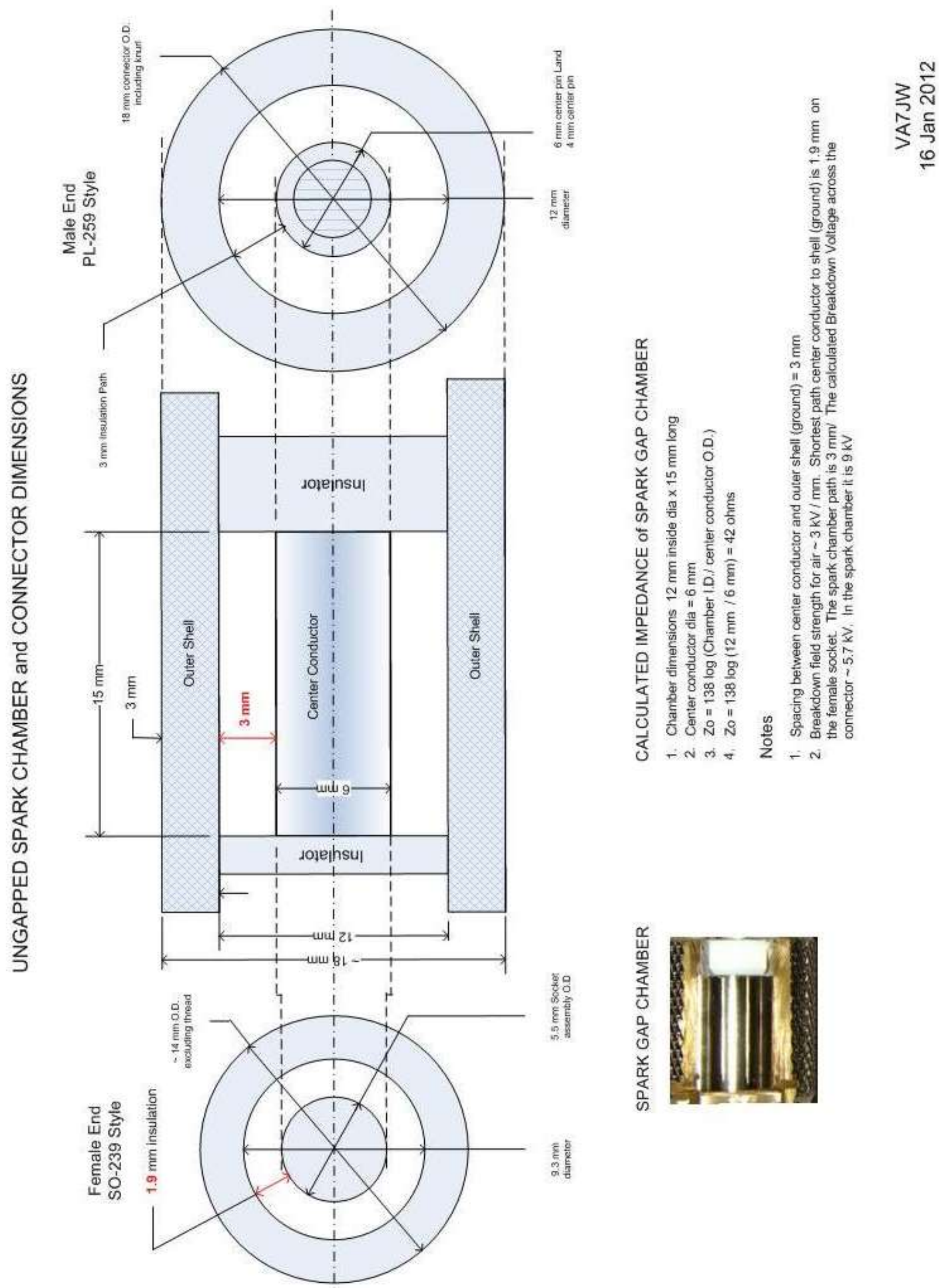
Check with ohmmeter to make sure there are no shorts after setting the gap and before use of the LOCTITE©. Watch for sudden VSWR changes at power which would indicate insufficient gap spacing and arcing.

Final Note

Hope this was helpful. Feedback would always be of interest on any aspect of this report.

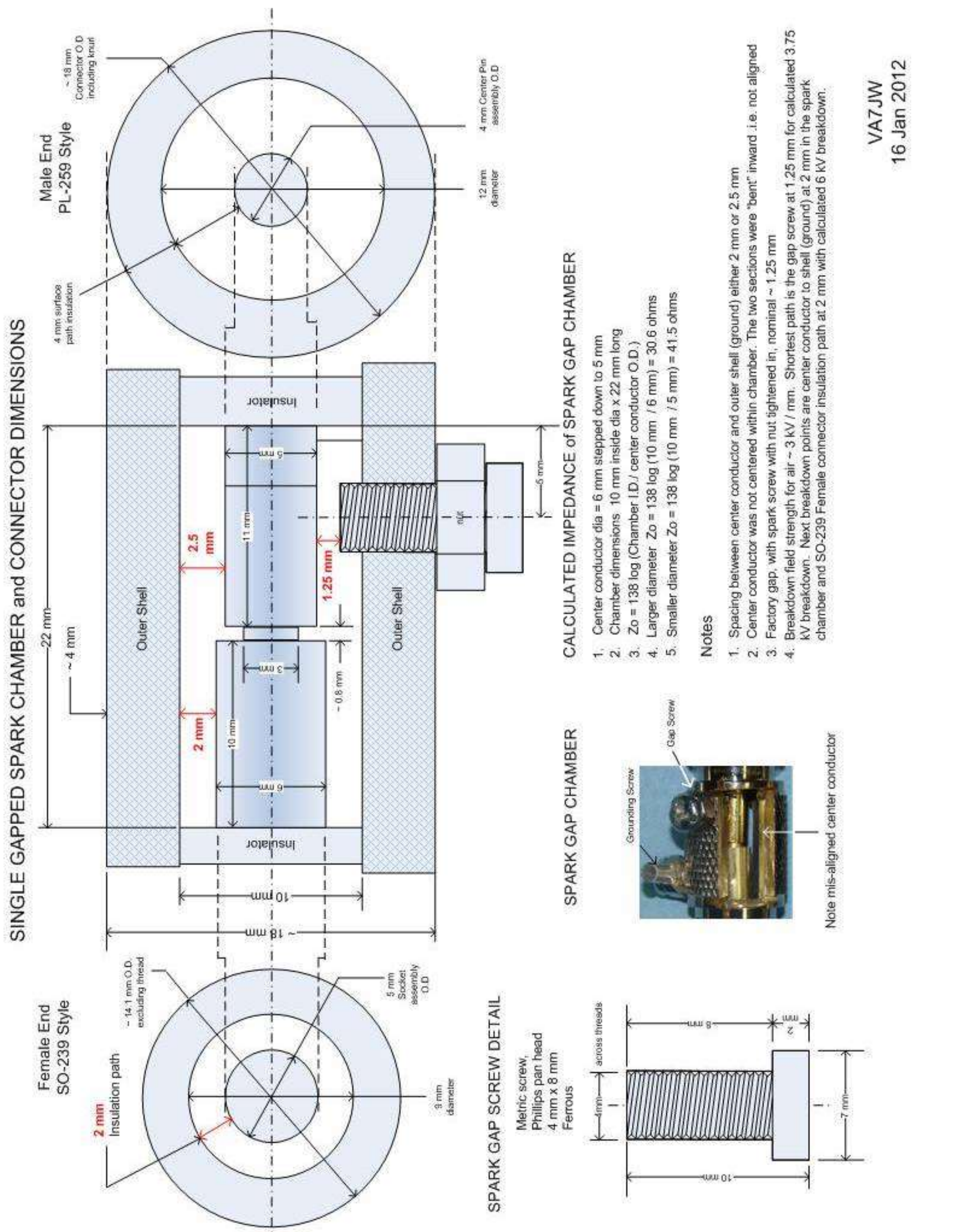
ADDENDUM 1A

TYPE- 0 NON ADJUSTABLE GAP - MECHANICAL DRAWING and DIMENSIONS



ADDENDUM 1B

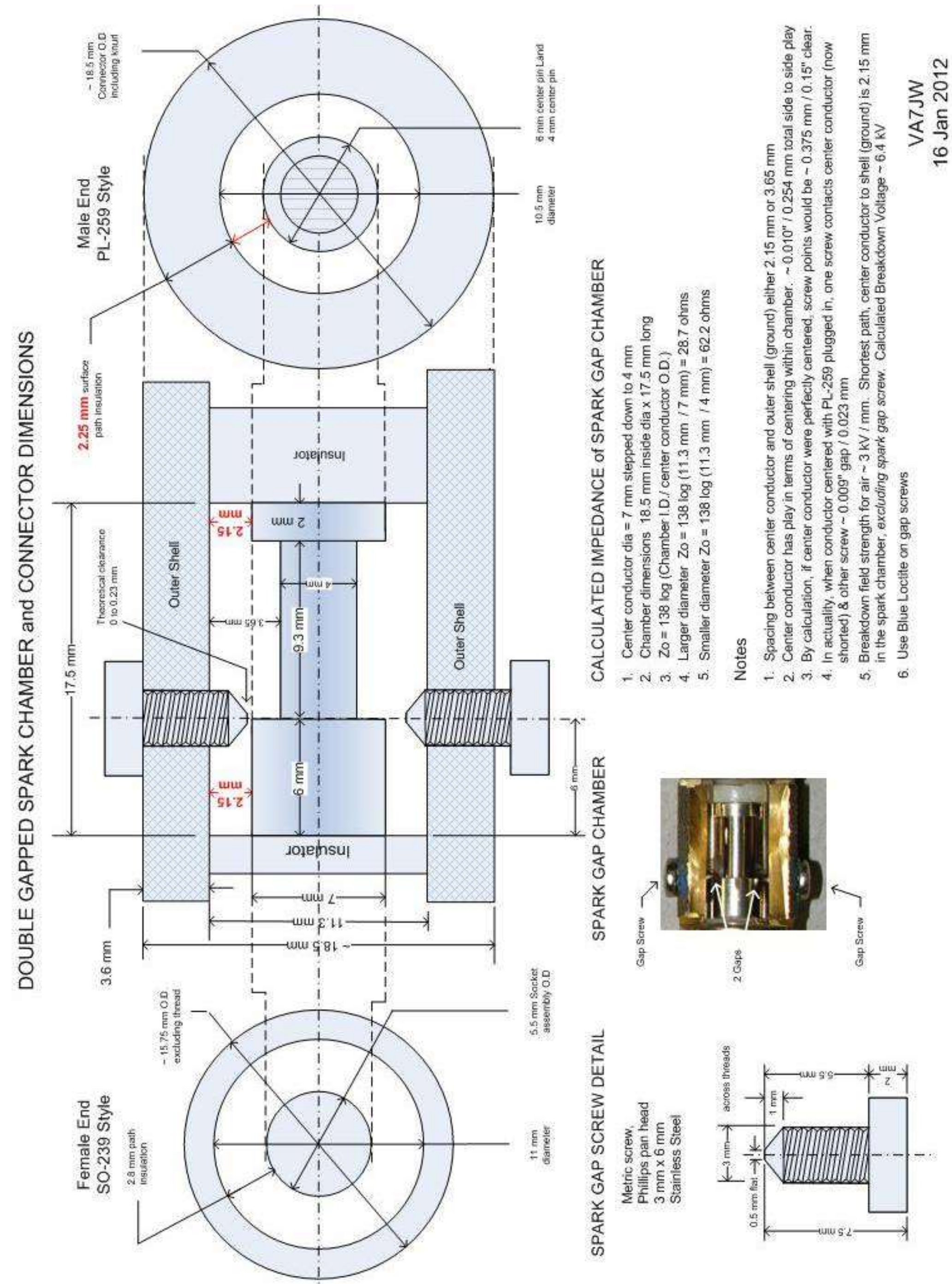
TYPE- 1 SINGLE ADJUSTABLE GAP - MECHANICAL DRAWING and DIMENSIONS



A DETAILED REPORT on the BASIC, IN-LINE COAXIAL SURGE ARRESTOR

ADDENDUM 1C

TYPE- 2 DOUBLE ADJUSTABLE GAP - MECHANICAL DRAWING and DIMENSIONS

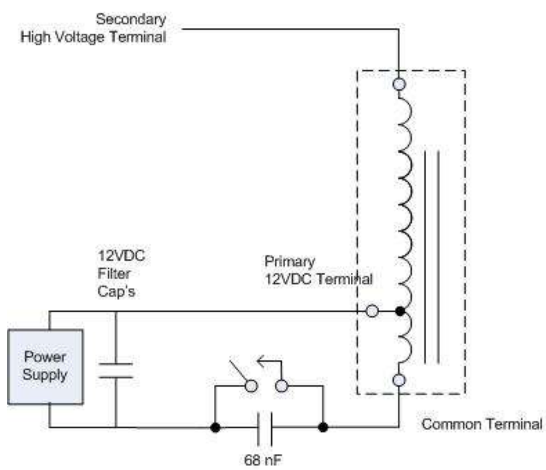


ADDENDUM 2

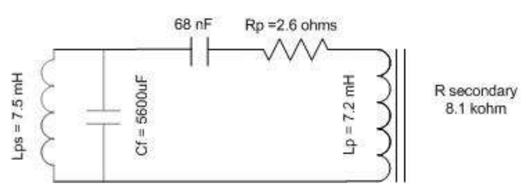
SPARK COIL PROPERTIES

When the primary (relay) goes open circuit, the energy stored in the inductance of the coil, measured at ~ 7mH, is transformed to a high voltage due to the fly-back effect generated by the collapsing of the magnetic field, and an open circuit on the secondary, which presents a very high voltage at the HV terminal. At the same time, a voltage also present at the primary terminal which is not actually open circuit. It is connected across the 68 nF commutating capacitor which is in series with the ~ 5600 uF posed by the DC filter caps in the 12 VDC supply. The 68 nF cap, being the much smaller capacitor governs as the resonating capacitor value in this circuit in so far as the characteristic waveforms that will be seen on the scope. The AC-DC power supply is across the primary as well and the inductance measured across the power transformer secondary is ~ 7.5 mH

AUTOMOTIVE SPARK PLUG COIL



EQUIVALENT CIRCUIT PARAMETERS



Simplistically, the natural ringing (resonant) frequency of this circuit is most likely determined by the 68 nF capacitor, the 7.2 mH of the coil as measured on the primary, and the 7.5 mH of the power transformer. Resonance is given by:

$$f = 1/ (2\pi\sqrt{LC}) = \sim 5 \text{ kHz}$$

This yields a Period of about 200 usec. The observed dominant ringing period is about 150 usec and so a discrepancy exists. Obviously there are unidentified circuit elements affecting the ringing frequency.

Given that the ringing frequency is an artifact of the spark generator and not a critical issue in the lightning study, this is only of passing interest in trying to account for all observations.

ADDENDUM 3

COAXIAL CABLE VOLTAGE RATINGS

Coaxial cables have published maximum voltage ratings. If the voltage rating is exceeded, then there is risk that the dielectric will fail and the center conductor and outer conductor (shield) will arc over to each other. This table provides published voltage ratings for commonly used coaxial cables.

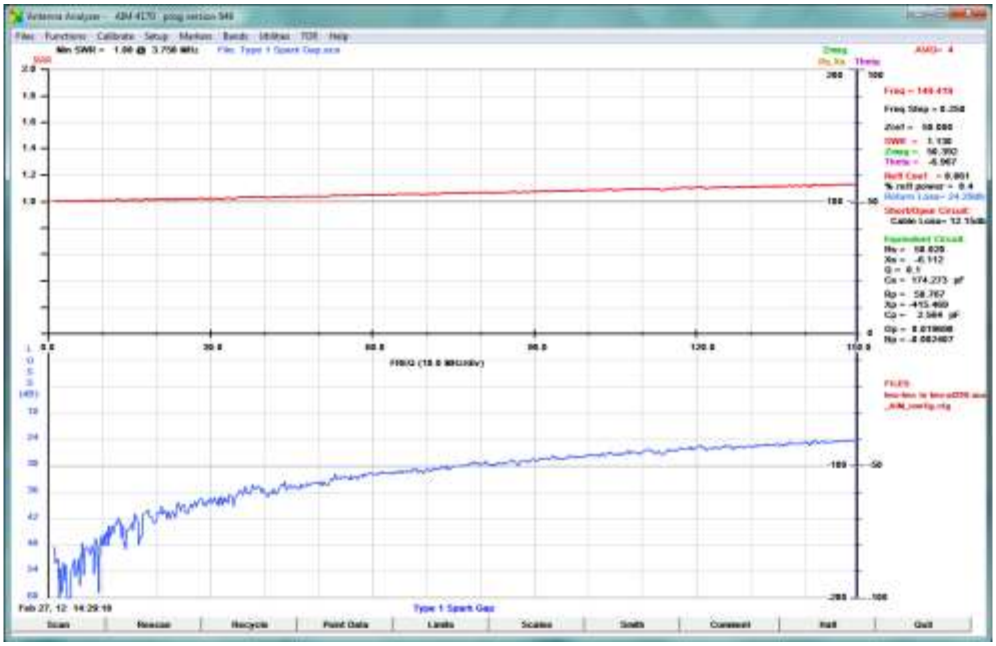
Maximum Operating Voltage Specifications of Commonly Used Coaxial Cable

50 Ohm COAX	Maximum RMS Voltage	Peak Voltage	DC Withstand	Jacket Spark *
RG 58/U (9201)	1900 v rms (non UL)	2687		
RG-8X	300 v rms (UL)	424		
LMR-240-UF			1500	5000
RG-8/U (8214)	600 v rms (non UL)	848		
RG-9/U (9913)	600 v rms (non UL)	848		
RG-213 (8267)	3700 v rms (non UL)	5232		
RG-214 (8268)	3700 v rms (non UL)	5232		
LMR-400-UF			2500	8000
LDF2-50 (3/8")			2500	5000
LDF4-50 (1/2")			4000	8000

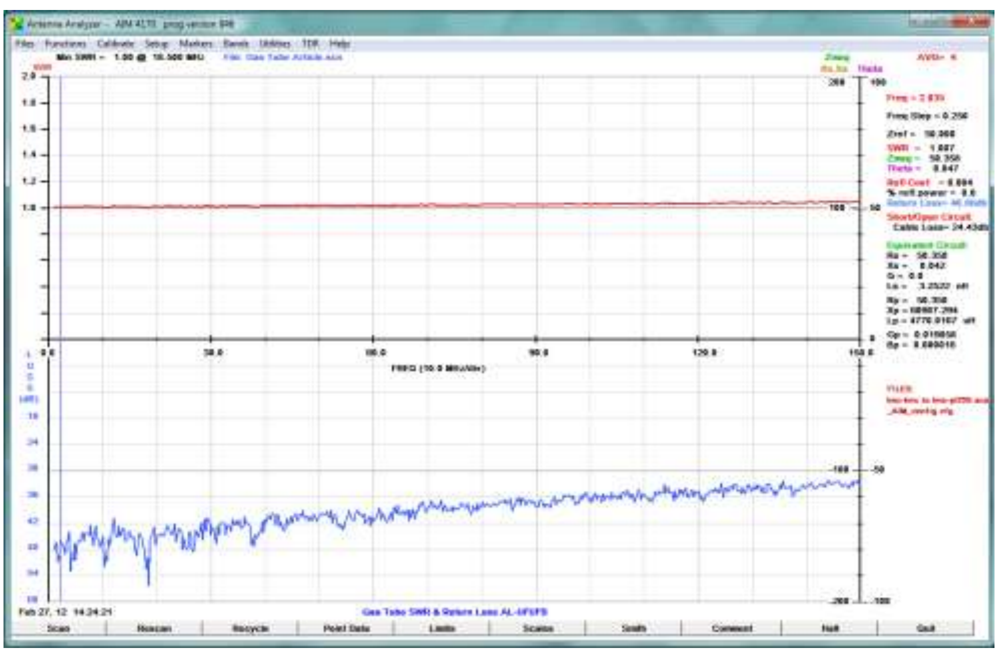
* Jacket Spark measures the insulation withstand between the jacket and outer conductor

ADDENDUM 4

VSWR PLOT TYPICAL of the A28 ARRESTOR



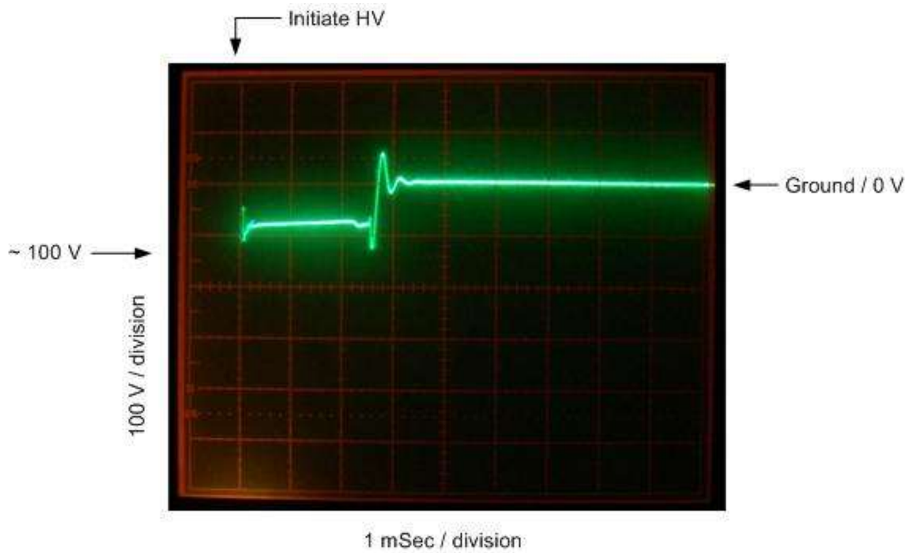
VSWR PLOT of the GAS TUBE ARRESTOR



Refer to Table 1 for numerical values at 1, 30 and 150 MHz

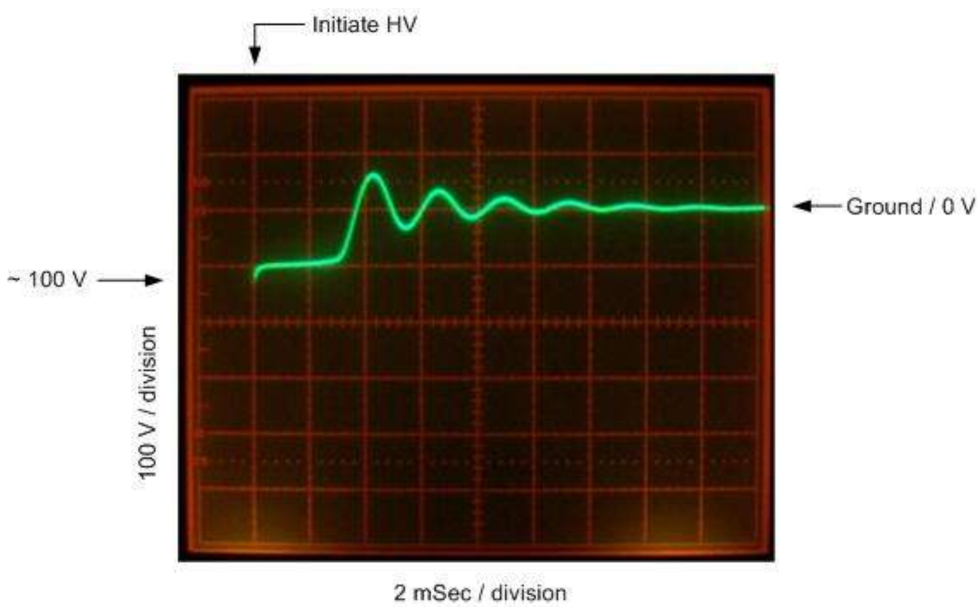
ADDENDUM 5

150V AXIAL LEADED GAS TUBE ARRESTOR



The gas tube is clamping at about 100V for ~ 2.5 msec after which the arc quenches with the characteristic ringing signature of the spark generator.

100V VARISTOR SUPPRESSOR



The 100 volt Varistor (Voltage Dependent Resistor) does not arc but rather lowers its resistance at higher voltages in order to shunt over-currents to ground. The varistor responds quickly to the HV and resistively dissipates energy. When the bulk of the energy is dissipated, about 2 msec, the voltage falls, the resistance increases and the residual energy ringing is supported for ~ 12 msec before totally gone.

ADDENDUM 6

IMPLEMENTATION EXAMPLES

Terminology

“Primary” protection refers to devices used at the tower location(s). Lighting currents are primarily diverted at this point (one hopes).

“Secondary” protection is implemented further “down the line” where the wire and coax leads enter the house. Again, arresting devices are employed to further divert currents and suppress voltages before entering the house and reaching the equipment.

Arrestor Ground Bar for Tower Mounting

This is an example of the use of the primary coaxial lightning arrestors for use on the tower. Material is ¼” x 2” x 2” Al angle. This home made assembly is bolted to the tower frame work at ground level. There are three Type 1 spark gap arrestors to the left and one Gas Tube arrestor on the right.

Gas Tube Arrestors for Wire Leads for Tower Mounting

This is a 12 wire, 150 V primary gas tube arrestor assembly, home made, built in to a 5” x 5” NEMA outdoor weather rated enclosure. These assemblies are installed at the base of the towers on aluminum panels.

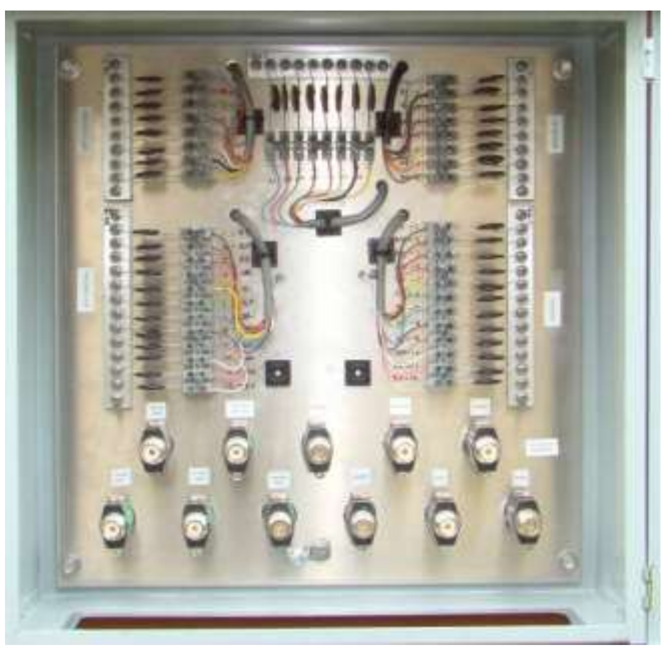
Lightning Panel at the Base of the HF Tower

The primary lightning panel at the tower base was under construction here and is used for mounting primary arrestors, being the spark gap bar ad the wire gas tubes. The bottom is chosen as this is the closest one can physically get closest to earth. This minimizes the potential difference between the voltage on the tower and earth ground. In turn, this will minimize the voltages and currents conducted along coax and other wires as they run to the shack.

Service Entrance Panel

This is the lightning protection & service entrance panel, again home made on the outside of the house providing a “thru wall” entrance to the ham shack. This panel provides the secondary suppression to the coax and wire leads before they reach the radio equipment.

The varistors are the black devices connected between the terminal boards and the aluminum grounding strips. The terminal boards connect the power, rotor and control wiring to the varistors. Gas tube arrestors for the coax cables are aligned across the bottom.



ADDENDUM 7

GROUNDING NOTES

Ground means EARTH

When using arrestors, divert the lightning currents on conducting cables as directly to earth as physically possible, and keep them OUTSIDE OF THE BUILDING. Lightning arrestors of any and all sort will be of little use if not directly earthed.

Lightning currents will find the lowest IMPEDANCE path to earth. Given the extremely fast rise time of lightning currents, measured in kA/usec, it is the impedance (R+X) of the grounding system that dominates, not the DC resistance. DC resistances may be 1 – 10 milliohms / foot, and so a 10 kA current would develop 10 to 100 V per foot of length. The inductance of the wire is much more significant. AWG # 6 copper, straight, has a self inductance of about 0.3 microhenries per foot. Given the inductance equation,

$$V = L \, di/dt$$

where di/dt is the rate of change of current over a specified time interval at 10 kA/usec, and L is the inductance. The calculated voltage potential along the length of line would be 3kV per foot. This is far greater than the resistance voltage gradient thus inviting flashover.

SHORT, STRAIGHT conductors are best as even a right angle turn in the wire increases inductance and therefore impedance, resulting in a local high voltage and possible flashover at that point.

In terms of current carrying capacity, the Canadian Electrical Code requires that grounding wire must be no smaller than #6 AWG stranded copper. From a lightning perspective, this size of wire will fuse, meaning it is on the verge of melting, if conducting 200 kA for ~ 1 msec [5]. This usually provides sufficient margin as the peak strike currents are of less duration and magnitude. Duration vs. Current specs for #6 as follows.

668 A / 10 sec	3.8kA / 1 sec	21 kA / 32 msec

Grounding within the station needs to be considered as well. All equipment should be bonded together, meaning the chassis's of all equipment are to be electrically connected together. This helps to ensure that dangerous electrical potentials will not develop between equipments when there is a strike. If not bonded, kV voltage differences may develop between equipment impedances which would be hazardous to the operator and damaging to the equipment.

For wire dipoles with coax feeding in to the house, an arrestor mounted on a metallic service entrance panel on the outside of the house would be a good start. The panel must be earthed by #6 AWG copper by the shortest possible, direct path to at least one 6 foot ground rod, if not more.

For tower mounted antennas, the tower must have a local ground rod system. All conductors must leave the tower at the bottom of the tower as close to earth as possible to ensure that the voltage difference between the conductors is minimal with respect to earth. Primary arrestors such as grounded spark gaps or gas tubes are installed on the tower at that point.

There are surge arrestor products for wire line control, power, rotors etc. They typically employ gas tubes and varistors as characterized in Addendum 5. Same earthing guidelines apply. An on-line search will list vendors of such products.

[5] Fig 3.49 Lightning and Lightning Protection Hart & Malone 1979. Published by Don White Consultants

Disclaimer

The suppressor discussed herein are not rated to survive a direct lightning hit to a tower or wire antenna nor save the cables or connected equipment, nor guarantee personal safety, but if the grounding methods used for the station have been installed with lightning in mind, they may minimize subsequent damage to house and equipment. These devices may save connected equipments from near field strikes that would otherwise induce destructive currents and voltages if left un-attenuated.

Consult ARRL and other Web based sources for additional information.

Prior to this work, a neighbor's 75 foot hemlock tree about 500 feet down the hill from the author, the top of which was well below my 65 foot tower, took a direct hit. The tree was demolished, mostly by the sap being instantly boiled by the current flowing within this conductive path, blowing off bark and branches. That got me thinking, and even though lighting is not rampant in greater Vancouver, my location is high and obviously vulnerable.

You may rightly ask, does any of this suppression stuff really work? I will only know if I survive a hit.

The author makes No Warranties or Guaranties on the content of this article

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Enquiries, comments, discussions, corrections, enlightenments as below,

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