Radio Frequency (RF) Surge Suppressor Ratings for Transmissions into Reactive Loads

Keep your RF surge suppressor from arcing over on transmitter power peaks.

Surge suppression devices in RF systems are typically mounted either at the base of an antenna or at the coaxial entry point at the radio site. They provide a direct path across the antenna terminals suppressor control short voltage spikes that should be grounded. One common surge suppressor is the Alpha Delta TT3G50UHP shown in Figure 1. The purpose of this technical note is to provide a methodology to calculate the peak voltage when the impedance and power are known. One software tool useful for the calculation is the Transmission Line for Windows (TLW) program provided by the ARRL. TLW is distributed in current editions of The ARRL Antenna Book.

Background

Surge protectors typically have coaxial terminals — Type N, BNC, or UHF connectors — and a removable/replaceable cartridge consisting of a ceramic, vacuum discharge tube. Grounding of the suppressor is provided by using a screw terminal. The surge protector use a removable cartridge — called an Arc-Plug™ by Alpha Delta — consisting of a metal threaded piece housing the vacuum discharge tube whose rating determines the power rating for the unit. The discharge tubes can also be changed out after a high energy surge event. The discharge tubes are considered a consumable device. Therefore, the end-user has an opportunity to tailor the part numbers depending on power capabilities of the surge device.

If an antenna is well matched at the connection point to the coaxial cable, the voltages presented across the connection are calculated using a variation of Ohm’s Law,

\[ V_{pk} = \sqrt{R \times 2 \times PWR} \]  

In 50 Ω impedance systems this is equal to

\[ V_{pk} = 10\sqrt{PWR} \] .

For example, with 1000 W at the antenna terminals and a 50 Ω match, the peak voltage equals 316 V. The surge suppressor must withstand this voltage without arcing over during normal transmissions.

The sporadic shutting down of my medium power amplifier during SSB operation first aroused my interest in the surge suppressor characterization. As my trouble shooting unfolded, I found what appeared to be voltage breakdown events within the antenna system. Although this could be attributed to a bad coax, connectors, antenna switches, antenna connections or the antenna itself, my final analysis lead me to the RF surge protection device. I discovered that the rating of the surge suppressor was too low for my peak transmitted power and SWR on the transmission line. At the time the voltage breakdown occurred, the amplifier would indicate a high SWR event on the line and automatically shut down, thus protecting its circuits.

In typical installations, the impedance of the antenna system is not well matched, and in fact, in many instances there are impedance matching devices that matches the radio to the coax and antenna system. The impedance is complex — it has both a resistive and reactive
components — and varies with frequency. This creates a peak voltage across the surge suppressor based on the RF frequency, the complex impedance, and transmitted power. The mismatched impedance creates standing waves on the transmission line that modifies the peak voltages present on the line and is characterized by the Standing Wave Ratio (SWR).

**Terminology**

During researching this topic, I noted that manufacturers used their own terminology to describe their products. Some of these terms are listed in Table 1. I will try to be careful to use their terminology when describing this technology.

**Surge Suppressors and Vacuum Discharge Tubes**

The Alpha Delta Model TT3G50 and the predecessor Transi-Trap model coaxial surge protectors use a replaceable vacuum discharge tube to provide protection across the transmission line. The discharge tubes are manufactured by several vendors, including EPCOS and Littelfuse. When the discharge tubes have outlived their service life, they should be removed and replaced with one of the same part number. After multiple strikes, the discharge tubes can become shorted and create a high SWR condition on the transmission line. A direct strike cannot be protected as the tubes would likely be destroyed. My station encountered a near strike while using the Transi-Trap surge protector. It did protect the front end of the transceiver. Other equipment like light dimmers, stereos, and TV’s did not do so well.

The EPCOS4 and Littelfuse⁵ discharge tubes can be delivered in a capsule or axial wire lead format. The axial leads must be carefully snipped leaving just the capsule for insertion into the Arc-Plug™ mechanical assembly. Insertion of the new tube and replacement of the screw cap must be done carefully, and hand tightened so as not to over-tightened the screw cap. Figure 2(a) shows an example of the axial lead device, and Figure 2(b) shows its schematic symbol. Replacement vacuum discharge tubes can be obtained from electronic distributors on the internet such as Digi-Key⁶ and Mouser Electronics⁷ for a few dollars ($US) each. This makes it very economical to provide replacements during maintenance, or to change the ratings of the RF surge protector assembly.

**Voltage Across an Impedance**

In a 50 Ω impedance system, the rms voltage across the load is

\[ V_{\text{rms}} = \sqrt{50 \times PWR} \]

where \( PWR \) is the RF power, W, and the characteristic impedance of the transmission line is 50 Ω. Multiply \( V_{\text{rms}} \) by the square root of 2 to obtain the peak voltage, as given by Eq (1).

When including the SWR on the line, the peak voltage becomes

\[ V_{pk} = \sqrt{100 \times PWR \times SWR} \]  (2)

This peak voltage must not break down the discharge tube protecting the transmission line from surges.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Manufacturer Model No</th>
<th>Power Capability (Vendor Data)</th>
<th>P/N</th>
<th>DC Voltage Breakdown</th>
<th>Impulse Spark-over @1 kV/µS Typ.</th>
<th>Single Pulse Discharge Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha Delta</td>
<td>TT3G50</td>
<td>200 W</td>
<td>EPCOS, EC350-00 O 350 VDC</td>
<td>&lt; 800 V 10 kA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpha Delta</td>
<td>TT3G50HP</td>
<td>2000 W</td>
<td>Littelfuse, CG2-1000 1000 VDC Typ.</td>
<td>&lt; 1600 V 10 kA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>500 W</td>
<td>EPCOS, EC-600 540 to 720 VDC Typ.</td>
<td>&lt; 1100 V 10 kA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>–</td>
<td>B88069X0780S102 600 Vdc nom.</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2**

RF surge protectors and discharge tubes.

**Figure 2(a)** — Axial lead format of EPCOS discharge tube.

**Figure 2(b)** — Discharge tube schematic symbol.
Using TLW Software

The Table 3 shows the peak voltage at various load impedance values and power levels. A very short length of RG-213 coaxial cable is assumed since anything longer would be more conservative if the surge protection device were mounted at the antenna. If surge protection device is mounted at the transmitter, the longer transmission line has the effect of reducing the actual SWR of the antenna due to the line loss at the operating frequency. The software program TLW is quite useful for calculating the SWR and impedance across the transmission lines. I used TLW to create the values in Table 3.

The TLW software program provides several screens, see Figure 3, that make it easy to input your antenna impedance, transmission line characteristics like type, impedance, and length, the RF power and the matching networks, see Figure 4.

The antenna impedance can be measured with a Vector Impedance Analyzer (VNA) — I used the Array Solutions AIM-4170C — but an RF noise bridge would also work. If these transmission parameters are not known, then use just the SWR. The value of using TLW is to understand the variation of the peak currents and peak voltages, see Figure 5, as you move along the transmission line, and to calculate other parameters such as additional loss due to SWR.

Other values of the peak voltage may be calculated directly using Eq (2). Note that the expression for peak voltage can also be rewritten so it expresses the power level and SWR that the discharge tube can withstand.

Thus, for a discharge tube rated at 1000 V and with an SWR of 10, the maximum power that could be applied is 1000 W, and for a vacuum discharge tube rated at 350 V and with SWR of 10, the maximum power would be 122 W.

I applied Eq (1) – (3) to the vendor data and listed my recommendations in Table 4.

Summary and Lessons Learned

With the help of Eq (2) and (3), the Amateur Radio operator can select the correct rating of surge suppressors discharge tube to use with RF surge protection devices.

Applying the formulas to the commercially available Alpha Delta TT3G50 and TT3G50HP surge suppressors indicate a maximum power at 5:1 SWR of 245 W and 2000 W, respectively. Using an alternate vacuum discharge tube device shows that the breakdown power can be increased and therefore tailored to the RF power requirements of your transmitter system.

Table 3 — Peak voltage across transmission line at various powers and load impedance values at 3.5 MHz.

| Power, W | RG-213, ft. | R load, Ω | X load, Ω | Z| load, Ω | Load SWR | Vpk (Eq 2) |
|---------|---------------|-----------|------------|-----------------|----------|-----------|
| 1       | 10            | 50        | 0          | 50              | 1        | 10        |
| 10      | 10            | 50        | 0          | 50              | 1        | 32        |
| 100     | 10            | 50        | 0          | 50              | 1        | 100       |
| 500     | 10            | 50        | 0          | 50              | 1        | 224       |
| 1000    | 10            | 50        | 0          | 50              | 1        | 316       |
| 5000    | 10            | 200       | 200        | 283             | 8.23     | 641       |
| 10000   | 10            | 200       | 200        | 283             | 8.23     | 907       |

Table 4 — Recommended RF surge protectors and vacuum discharge tubes.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model No.</th>
<th>Power Capability (Vendor Data)</th>
<th>Discharge Tube Manufacturer, P/N</th>
<th>Breakdown voltage, V</th>
<th>Working SWR</th>
<th>Max. Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha Delta</td>
<td>TT3G50</td>
<td>200 W</td>
<td>EPCOS, EC 350 00 O</td>
<td>350</td>
<td>2</td>
<td>613</td>
</tr>
<tr>
<td>Alpha Delta</td>
<td>TT3G50HP</td>
<td>2000 W</td>
<td>Littelfuse, CG2 1000</td>
<td>1000</td>
<td>2</td>
<td>123</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>500 W</td>
<td>EPCOS EC 600 B88069X0780S102</td>
<td>540 to 720</td>
<td>2</td>
<td>1458</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>500 W</td>
<td>EPCOS EC 600 B88069X0780S102</td>
<td>540 to 720</td>
<td>5</td>
<td>583</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>500 W</td>
<td>EPCOS EC 600 B88069X0780S102</td>
<td>540 to 720</td>
<td>10</td>
<td>291</td>
</tr>
</tbody>
</table>
Here is a summary of my lessons learned while studying RF surge suppressors with my transmission lines.

If the antenna system is matched to 50 Ω, such as a beam or dipole antenna used over a small bandwidth where the impedance does not vary considerably, the SWR will be low and stable across the band. Therefore, the surge protector at the transmitter would protect according to its rating.

If a wider multi-band antenna is being used such as a G5RV or Windom antenna, purchased, relatively inexpensively, that can replace the currently used tube. This discharge tube will protect against high voltage surges yet still allow transmissions to occur without breaking down.

It would be wise to have spare discharge tubes available to replace ones that fail during a high voltage surge event. These can be purchased directly from the manufacturer, vendor of the RF surge suppressor, or as a component from an electronic distributor.

Gene Hinkle’s, K5PA, father introduced his teenage son to amateur radio more than 50 years ago at the local MARS station on Randolph AFB near San Antonio, Texas. Gene began experimenting with the mysteries of radio, building transmitters, receivers and antennas that eventually led him to a solid career in RF engineering. He earned the MSEE from the University of Texas at Austin. He is an IEEE, Life Senior Member and a licensed (retired) Professional Engineer in Texas. Gene is a Life Member of the ARRL and serves as a Volunteer Examiner, assisting others to reach their goal of becoming Amateur Radio operators. He recently retired as a Systems Engineer from a radio communications technology company specializing in T/FDOA radio-geolocation.

His lovely wife, Carolyn, AD5HP, daughter, two sons-in-law, late father, sister, brother-in-law are also hams. His interests include working satellites, the International Space Station (ISS), low power digital modes, DX, State QSO Parties, ARRL Field Day, QRP to the field, and HF mobile. His favorite operating modes are Morse CW, low bandwidth digital modes and searching for DX. He and Carolyn enjoy participating in ARRL Field Day and the Texas QSO Party from Bed and Breakfast locations in the Texas Hill Country. Gene’s web page is [www.k5pa.com](http://www.k5pa.com).

---

**Notes**

3. The ARRL Antenna Book, 23rd Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL item no. 0390 (hardcover), 0444 (soft cover). Telephone 860-594-0355, or toll-free in the US 888-277-5289; [www.arrl.org/shop](http://www.arrl.org/shop); pubsales@arrl.org.
7. Digi-Key Electronics, [www.digikey.com](http://www.digikey.com).