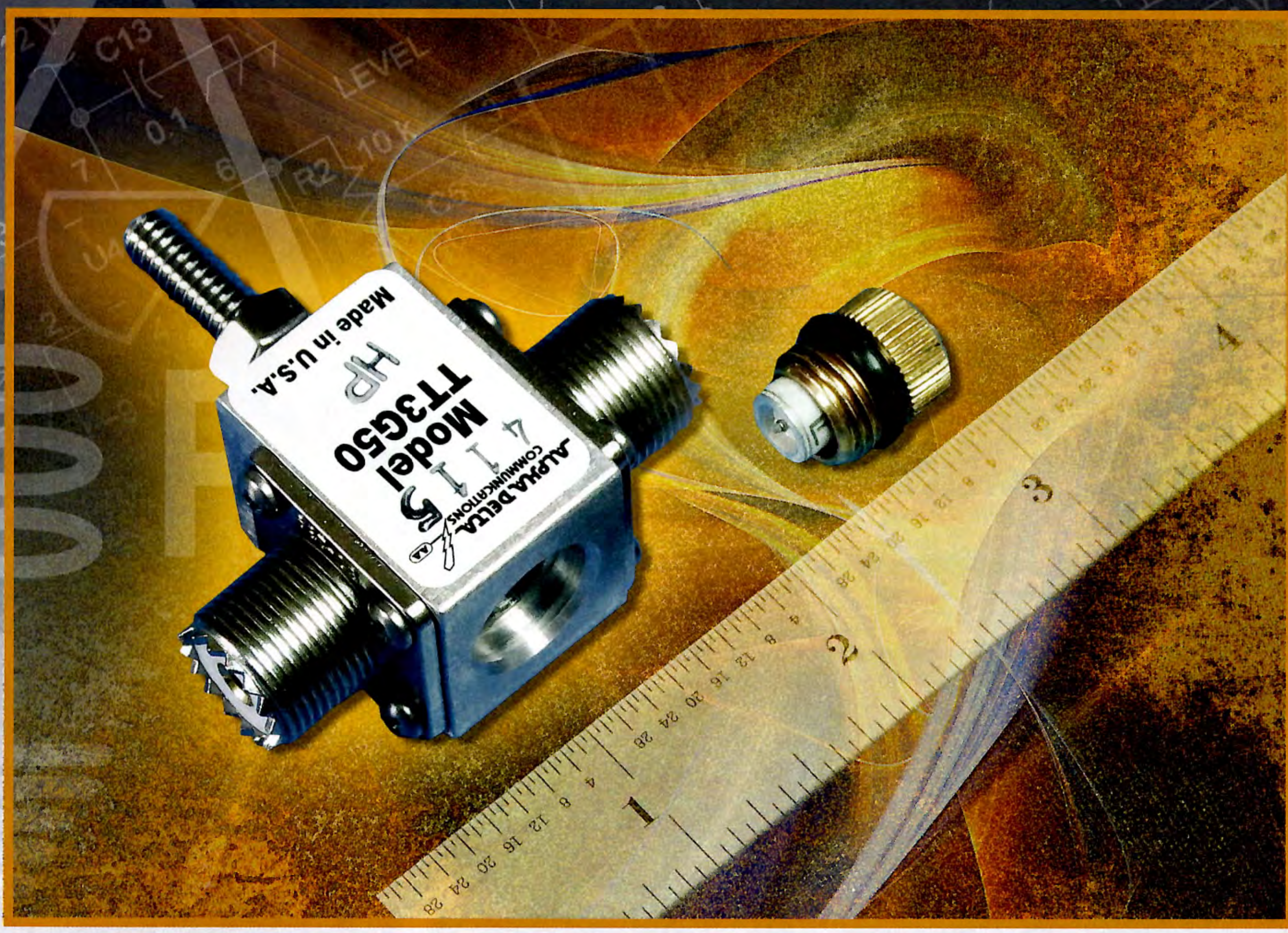
QEX
$5
July/August 2016
www.arrl.org

A Forum for Communications Experimenters

Issue No. 297



K5PA shows how to keep your RF surge supressor from arcing over on transmitter power peaks.

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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.[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.[2] *TLW* is distributed in current editions of *The ARRL Antenna Book*.[3]

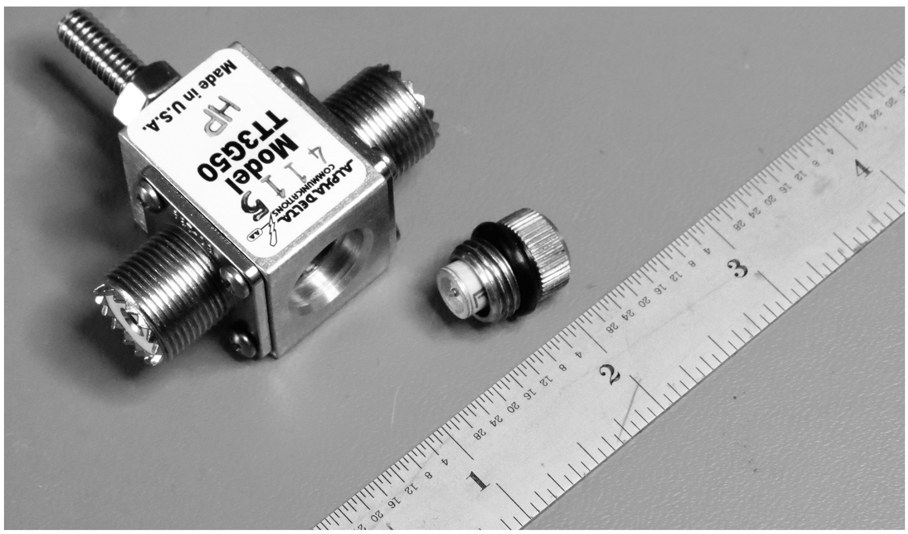


Figure 1 —The model TT3G50UHP surge protector from Alpha Delta.

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,

$$V_{pk} = \sqrt{R \times 2 \times PWR} \quad (1)$$

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 EPCOS[4] and Littelfuse[5] 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 distributers on the internet such as Digi-Key[6] and Mouser Electronics[7] 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.

Table 2 lists the RF surge protector models from Alpha Delta, along with the vacuum discharge tube installed, based on my inspection of the part numbers and the specification of the vacuum discharge tube.

Voltage Across an Impedance

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

$$V_{rms} = \sqrt{50 \times PWR}$$

where *PWR* is the RF power, W, and the characteristic impedance of the transmission line is 50 Ω. Multiply V_{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[8]

$$V_{pk} = \sqrt{100 \times PWR \times SWR} \qquad (2)$$

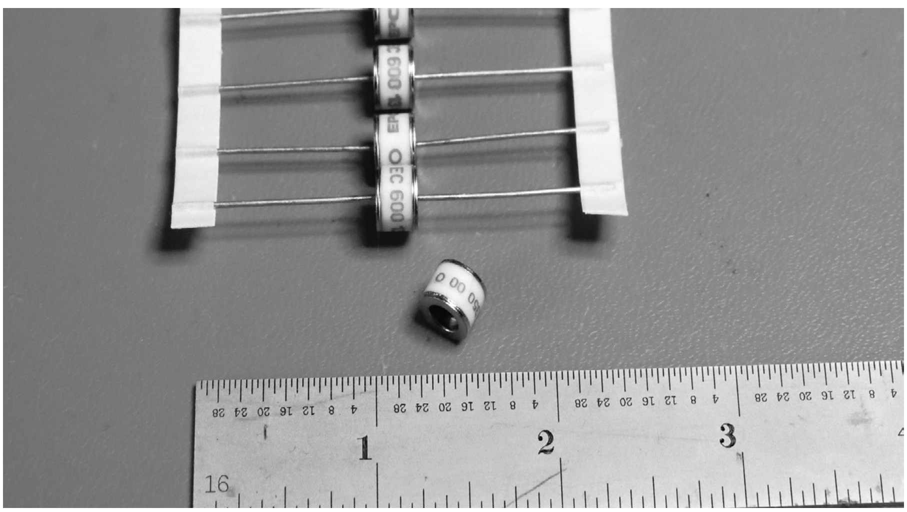
This peak voltage must not break down the discharge tube protecting the transmission line from surges.

Table 1
Terminology used by different manufacturers and vendors.

Company	*Terminology*	*Product Guide*
Alpha Delta	(1) Transi-Trap Surge Protector	See Note 1
	(2) Arc-PlugTM cartridge	See Note 1
EPCOS	Gas-filled surge arresters	See Note 4
Littelfuse	Gas Discharge Tube (GDT)	See Note 5

Table 2
RF surge protectors and discharge tubes.

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



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

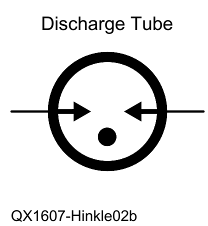


Figure 2(b) — Discharge tube schematic symbol.

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, the maximum power that can be safely applied, given the peak voltage rating of the discharge tube and SWR is

$$PWR_{\max} = \frac{V_{pk}^2}{100 \times SWR} . \qquad (3)$$

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.

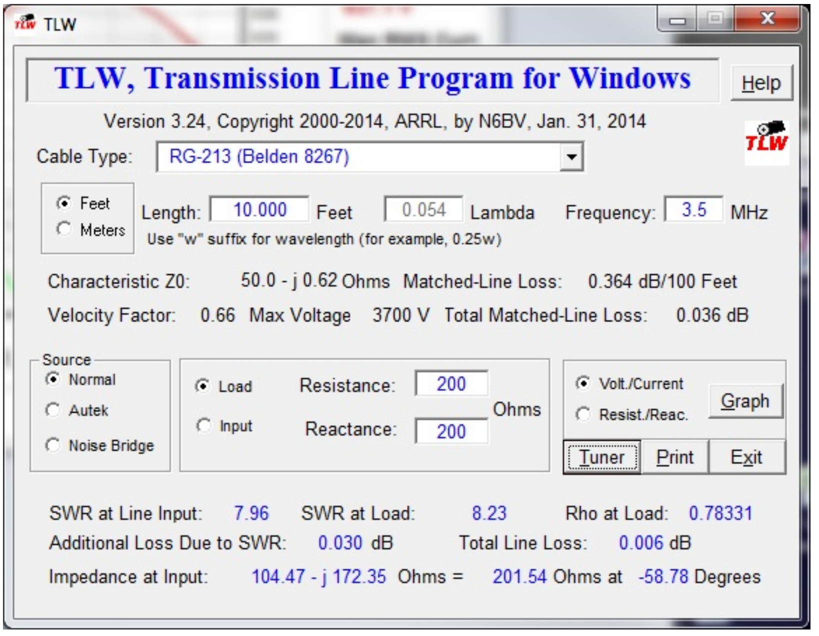


Figure 3 — Main screen of *TLW* software program Graphical User Interface (GUI).

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
500	10	200	200	283	8.23	641
1000	10	200	200	283	8.23	907

Table 4
Recommended RF surge protectors and vacuum discharge tubes.

Manufacturer	*Model No.*	*Power Capability (Vendor Data)*	*Discharge Tube Manufacturer, P/N*	*Breakdown voltage, V*	*Working SWR*	*Max. Power*
Alpha Delta	TT3G50	200 W	EPCOS, EC 350 00 O	350	2	613
				350	5	245
				350	10	123
Alpha Delta	TT3G50HP	2000 W	Littelfuse, CG2 1000	1000	2	5000
				1000	5	2000
				1000	10	1000
–	–	500 W	EPCOS EC 600 B88069X0780S102	540 to 720	2	1458
				540 to 720	5	583
				540 to 720	10	291

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, you must give attention to the SWR at the point where the RF surge protector is located. If it is located on the antenna side of an RF matching network, or at the antenna, the SWR may be high, and the peak voltage needs to be calculated based on this SWR. Otherwise, the discharge tube protection device will breakdown during peak-power transmissions, creating a high SWR and may possibly trigger a shut down of the amplifier or transmitter.

Alternate discharge tubes can be 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.

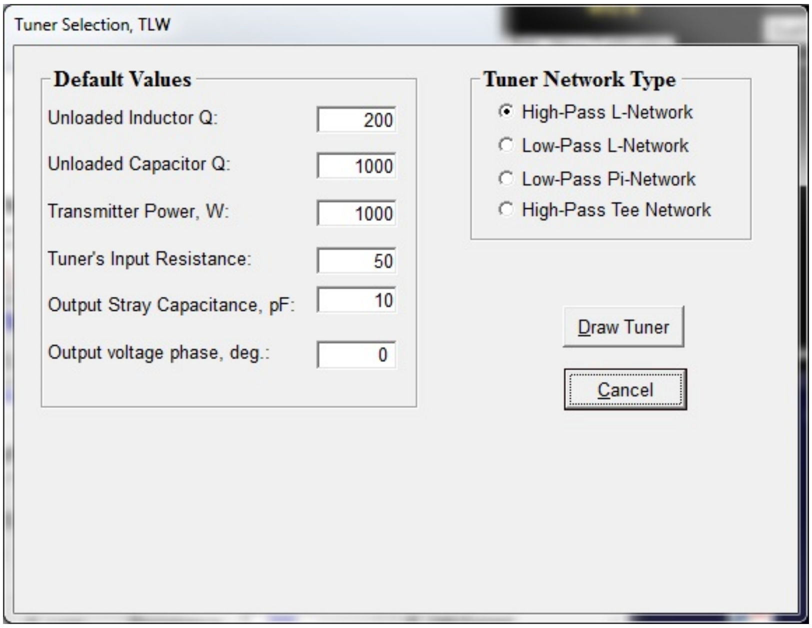


Figure 4 — Enter the transmitter power, 1000 W shown, on the Tuner selection *TLW* GUI.

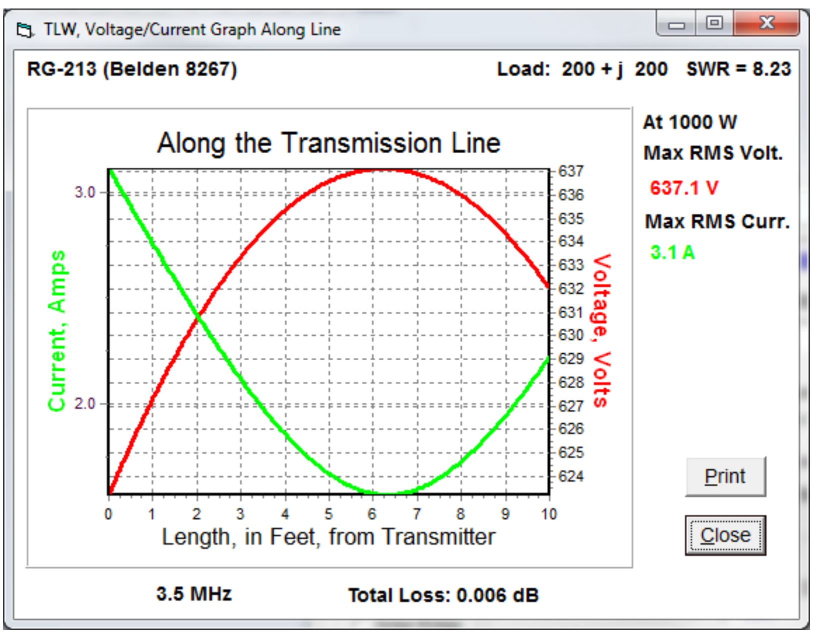


Figure 5 — The transmission line *TLW* GUI shows the rms voltage peak at 6.3 feet, and the rms current dips at 6.3 feet.

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****.*

Notes

[1]Alpha Delta, **https://www.alphadeltacom.com/pdf/TT3G50_instruction_sheets-6.pdf**.

[2]TLW User Manual, **www.arrl.org/files/file/Product%20Notes/Antenna%20Book/tlw.pdf**

[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**; **pubsales@arrl.org**.

[4]EPCO Technical Data, **en.tdk.eu/inf/100/ds/ec350x_x0810.pdf**.

[5]Littelfuse Technical Data, **www.littelfuse.com/products/gas-discharge-tubes/medium-to-high-surge-gdt.aspx**.

[6]Mouser Electronics, **www.mouser.com**.

[7]Digi-Key Electronics, **www.digikey.com**.

to fit your needs.

The latest updates on this project including firmware, source code, and PCB/enclosure ordering information can be found on my website, **https://ctr2.lynovation.com/**. I'll also be posting features and how-to videos to my YouTube channel. Search for Lynovation.

[Photos by the author].

ARRL member Lynn Hansen, KU7Q, was first licensed in 1971 as WN7QYG at the age of 14. He achieved the Amateur Extra class level and became KU7Q in 1981 while studying for his Commercial Radio Telephone license. His amateur radio experience, several Cleveland Institute of Electronics (CIE) home-study courses, and an innate desire to learn something new every day provided a career in electronics and communications as a utility communications technician, an engineering assistant, and finally as the operations manager over a large multi-state utility communications network. Now retired, he continues to learn and apply new technologies and has time to follow his passions. This project is one of many.

Errata

QEX Nov./Dec. 2021

In George R. Steber, WB9LVI, "*NanoSSB RX – An Ultra Low Cost SSB Multiband Receiver,*" *QEX* Nov./Dec. 2021, **Figure 3**, each of the two boxes to the right of the DSP should be labeled "DAC." Thanks to Wes Plouff, AC8JF, who spotted the error.

QEX Sep./Oct. 2021

In Luiz Duarte Lopes, CT1EOJ, "*Designing an Impedance Matching Network with a Drafting Ruler and Triangle,*" *QEX* Sep./Oct. 2021, the vector **BE** in **Figure 3** lags the vector **AD**, so it is an inductor. The vector **FD** should be **DF** with the arrow pointing to **F**. This component is a capacitor. In **Figure 2** reverse the position of the components *C* and *L*. In the *Final Calculations*,

$$X_L = V_a / I_L = 122.5 / 3.62 = 33.84$$

$$X_C = V_C / I_0 = 100 / 1.414 = 70.72$$

$$L = \frac{X_L}{2\pi f} = \frac{33.84}{2\pi \times 14.215} = 0.38\ \mu\text{H}$$

$$C = \frac{1}{2\pi f X_C} = \frac{10^6}{2\pi \times 14.215 \times 70.72} = 158\ \text{pF}.$$

Finally, delete **Figure 4** and delete the section *Confirmation* and everything under it, including **Table 1**, except the last paragraph. Thanks to Frank Fusari, W8KA, who called attention to the problem.

QEX Jan./Feb. 2021

In Eric P. Nichols, KL7AJ, "*Self-Paced Essays — #3 EE Math the Easy Way,*" *QEX* Sep./Oct. 2021, p. 19, we should have referred to Beverly Dudley as Mr. Dudley. We regret the error. Thanks to Richard Clark, WQ9T, who called attention to the problem.

QEX Jul./Aug. 2016

In Gene Hinkle, K5PA, "*Radio Frequency (RF) Surge Suppressor Ratings for Transmissions into Reactive Loads,*" *QEX* Jul./Aug. 2016, the missing reference is:

[8] *The Antenna Handbook*, 23rd Edition, pp. 23-13, [Eq. 18].

Thanks to Mike Zydiak, W2MJZ, for calling the omission to our attention.

Errata