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Antenna Feed Line Control Box

Add an extra switchable antenna port and provide backup protection for equipment with gas discharge tubes and bleeder resistors, and automatic feed line grounding when off the air.

Phil Salas, AD5X

My Elecraft KAT500 antenna tuner has three switched antenna ports. For most folks that would seem to be enough, but I needed one more — I wanted to be able to conveniently switch in my Ameritron ADL-2500 high-power dummy load without having to reach behind equipment to swap cables or reach under the operating table to manually set an antenna switch. My solution was to design a remotely switchable feed line control box built around inexpensive relays. The design is readily adaptable to other station configurations.

While this station accessory includes some additional static buildup and lightning impulse protection, it is not a primary lightning protection device, nor should it considered a "license" to operate with lightning in the vicinity. However, when you are off the air, all antenna feed lines routed through the box will be grounded ahead of your expensive station equipment. In addition, when you are either receiving or transmitting, blocking capacitors, gas discharge tubes, and bleeder resistors protect buildup on your antennas or possibly an impulse from a nearby lightning strike.[1]

First, I'll illustrate how the accessory fits into a station by describing my own installation. Then I'll discuss the design and its rationale, and how to adapt the accessory to your station. Finally, we'll look at construction details, and verify that station performance has not been degraded.

Station Installation and Operation

Figure 1 is a simplified block diagram of my station. The antenna feed line control box is located between the cable entrance panel and the Elecraft KAT500 antenna tuner. The physical location of the unit is under the operating table and close to the cable entrance panel (not visible) as shown in Figure 2. Individual ground wires connect each piece to the station single point ground on the cable entrance panel. The remote switch that operates the unit is conveniently located above the operating table as shown in the lower left of Figure 3.

When the switch S1 is set to LOAD, the KAT1 input to the box is connected to the dummy load. When the switch is set to ANTS, the KAT1 – KAT3 inputs are connected to the ANT1 – ANT3 outputs. These outputs pass through the cable entrance panel and lightning arrestors to connect to my 43-foot vertical antenna, 20 – 6 meter trapped dipole, and 6 meter beam antennas, respectively. And, when S1 is in the LOAD position, there will be no power supplied to the unit through the AFLCB POWER line, which will de-energize internal relays in

[1]Notes appear on page 44.

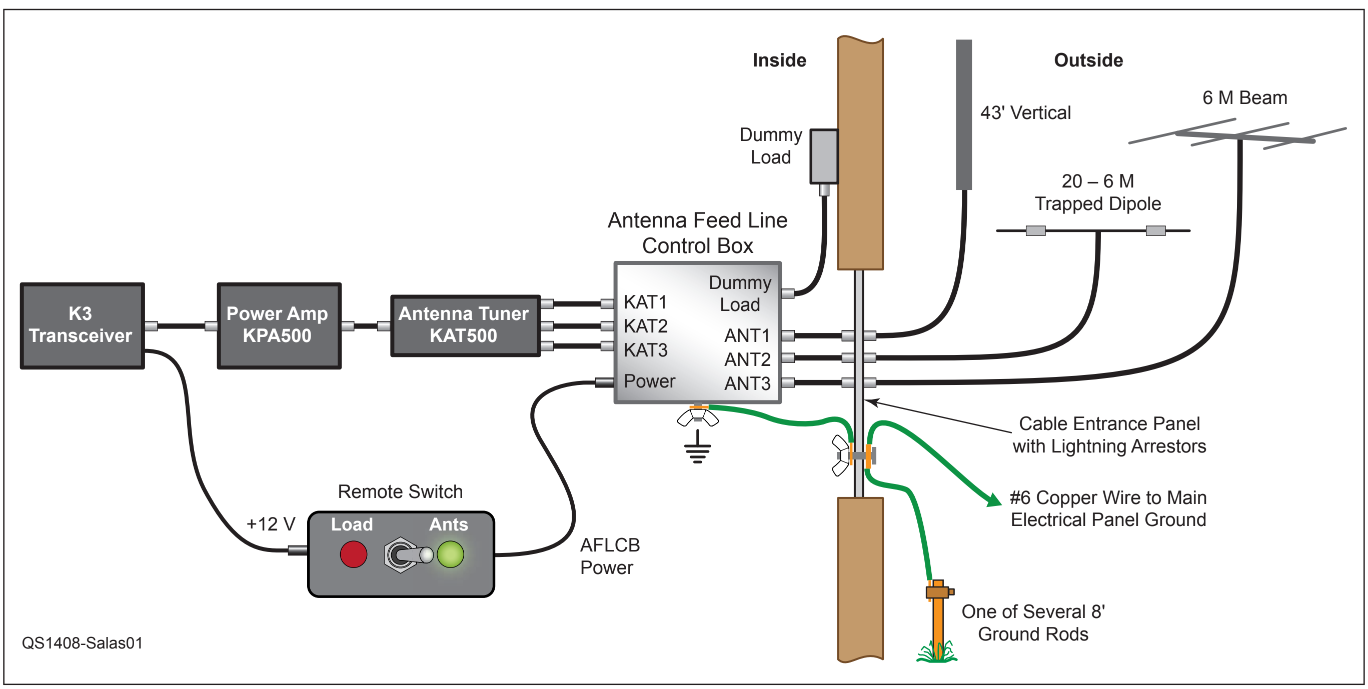

Figure 1 — Block diagram of station layout. The antenna feed line control box is placed near the cable entrance panel. When the station is off the air, all antenna feed lines are automatically grounded, providing an extra level of protection for expensive station equipment.

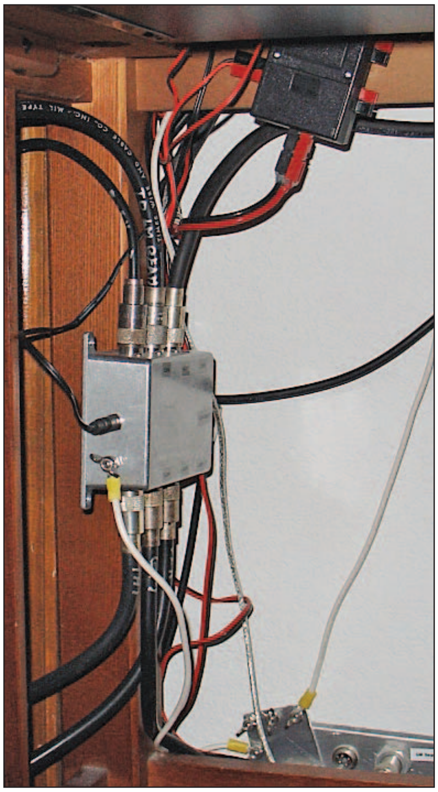

Figure 2 — The physical location of the unit is under the operating table and close to the cable entrance panel.

Figure 3 — The remote switch that operates the unit is conveniently located above the operating table, under a shelf that elevates the radio off the desktop.

the box, grounding ANT1, ANT2, and ANT3. This is also the nominal state when the station is off the air.

Design

Again, this design is not meant as protection against a direct lightning strike. While there are Amateur Radio stations every bit the equal of commercial stations in terms of design and engineering that are quite capable of weathering a direct lightning strike, a direct hit on a typical amateur station is potentially catastrophic.[2] So, it behooves us to understand this force of nature and take the greatest possible measures to mitigate its effect.[3, 4, 5, 6, 7]

Now we will consider the rationale behind the design, then discuss in detail the schematic shown in Figure 4, and finally look at how component values and ratings were calculated for this unit.

Rationale

While we can't contend with a direct strike, we can deal with voltage pulses caused by nearby lightning strikes and static buildup on antennas, both of which can damage equipment in the shack.

Static buildup (often termed *precipitation static*) on antennas can reach thousands of volts.[8] This can be prevented with bleeder resistors connected from the coax center conductor to ground.

As most of the energy in a lightning strike is concentrated well below 500 kHz,[9, 10] the high reactance of the blocking capacitors will attenuate much of this low frequency energy. This high reactance also allows the voltage to spike. Therefore gas discharge tubes will fire for impluse voltage greater than about 800 V, shunting that energy to ground.

Normally the blocking capacitors will simply serve to pass RF current from the unit's KAT inputs to the ANT outputs. Capacitors passing heavy current are subject to heating and will dissipate power P_d proportional to the product of the equivalent series resistance *ESR* and the square of the RF current I: $P_d = I^2 \times ESR$. This power dissipation can be minimized by choosing capacitors with a low dissipation factor *DF*. Because $ESR = DF \times X_c$ where X_c is the capacitor's reactance, the power dissipated by the capacitor can now be expressed as $P_d = I^2 \times DF \times X_c$. Stating X_c in terms of the frequency f and capacitance C yields $P_d = (I^2 \times DF) / (2\pi \times f \times C)$.

Capacitor heating can be further reduced by paralleling capacitors, which reduces the current through each capacitor. Assuming that the aggregate current remains the same, paralleling two equal-value capacitors will reduce the current through each by 2×. Because the power dissipated is proportional to the square of the current, the net effect will be to reduce the individual capacitor power dissipation by 4×.

Schematic

The schematic for the antenna feed line control box and its remote switch is shown in Figure 4. When remote switch S1 is set to LOAD, power is removed from SPDT relays K1 – K4. The disposition of the relay contacts shown in the schematic is for the power off condition, which is also the state of the unit when the station is off the air. In the power off state, relays K2 – K4 connect signals ANT1 – ANT3 (J5 – J7) to chassis ground, which in turn is connected to the station single point ground via a wing nut connection on the outside of the aluminum box. This prevents static charge buildup on the antennas and also provides a path to ground for pulses due to nearby lightning strikes. Additionally, when S1 is set to LOAD, relay K1 connects KAT1 to DUMMY LOAD through SO-239 connectors J1 and J4 respectively.

When remote switch S1 is set to ANTS, +12 V is supplied to the unit through POWER input J8, which in turn is connected to the coils of relays K1 – K4. Diode D1 suppresses the kickback voltage from the relay coils when power is removed and capacitors C8 and C9 bypass any RF voltage to ground.

In the power on state, the ground shunt connections made by relays K2 – K4 of signals ANT1 – ANT3 are removed along with the KAT1 connection to DUMMY LOAD through K1. Then, KAT1 is connected to ANT1 via K1

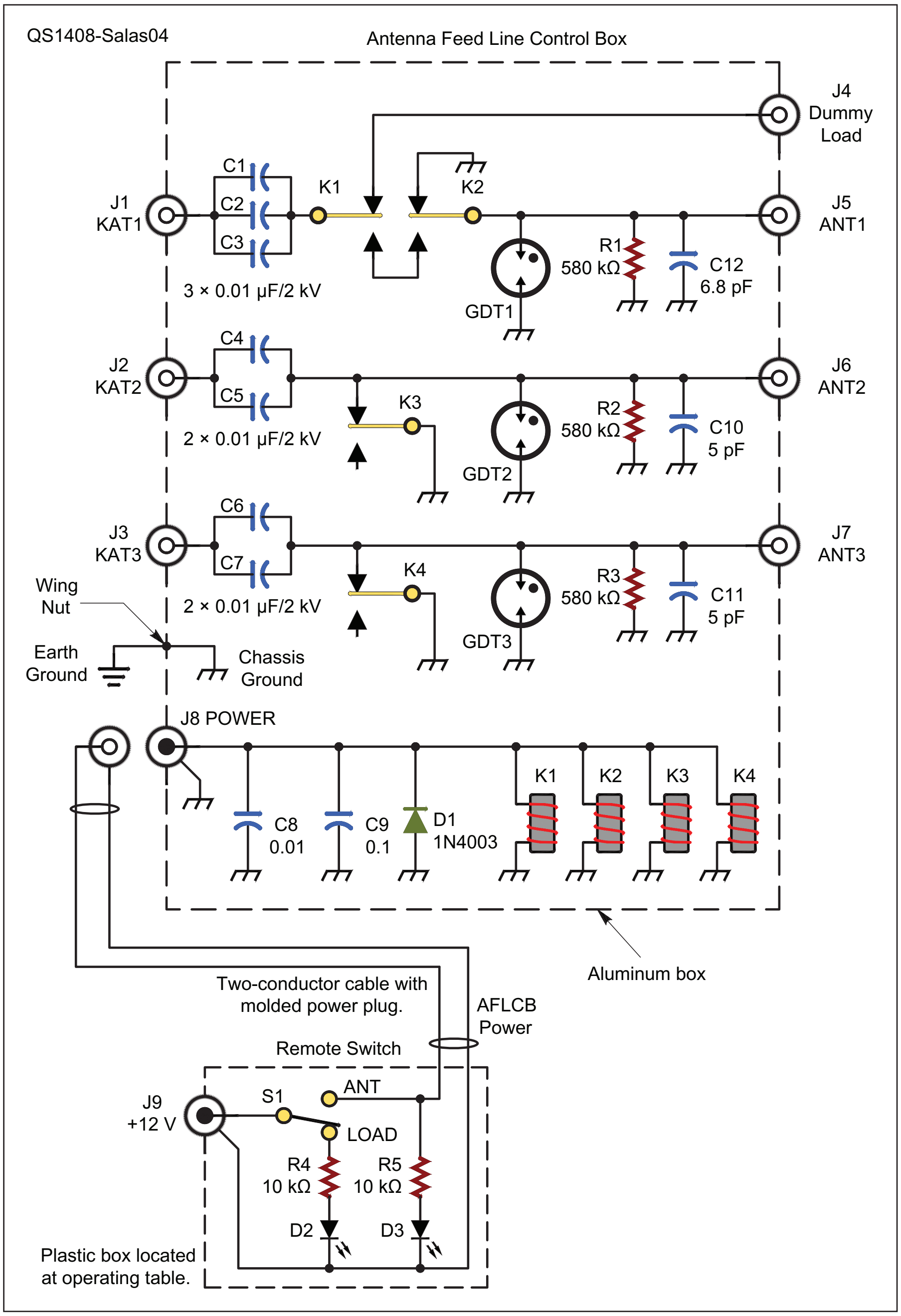

Figure 4 — Schematic diagram and parts list for the antenna feed line control box.
C1 – C7 — 0.01 µf 2 kV capacitor (Mouser 594-S103M69Z5UP63K7R).
C8 — 0.01 µf 100 V ceramic disc capacitor (Mouser 140-100Z5-103Z-RC).
C9 — 0.1 µf 50 V ceramic disc capacitor (Mouser 140-50U5-104M-RC).
C10, C11 — 5 pf 1 kV capacitor (Mouser 75-561R10TCCV50).
C12 — 6.8 pf 1 kV capacitor (Mouser 75-561R10TCCV68).
D1 — 1N4003 diode (Mouser 512-1N4003).
D2, D3 — Green LED (Mouser 941-C5SMFGJSCV14Q7S1).
GDT1 – GSD3 — Gas discharge tube 800 V (Mouser 652-2095-80-BLF).
R1 – R3 — 580 kΩ ½ W 3.5 kV resistor (Mouser 594-HVR3700005903FR5) [*Note: Typical resistors are only rated for a few hundred volts. — Ed.*].
R4 – R5 — 10 kΩ ¼ W resistor (Mouser 66-CMF1/41002FLFTR).
J1 – J7 — SO-239 connector (Mouser 601-25-7350).
J8, J9 — DC jack 2.1 × 5.5 mm (Mouser 163-1060-EX).
K1 – K4 — SPDT power relay (Mouser 655-RTB14012F).
S1 — SPDT toggle switch (Mouser 108-0009-EVX).
DC power cable (with compatible plug for J8) — 2.1 × 5.5 mm × 3 feet (Mouser 172-4204).
Plastic box — 1.38 × 1.38 × 0.79 inches (Mouser 546-1551MBK).
Aluminum box — 4.3 × 3.3 × 1.6 inches (Mouser 563-CU-5471).

and K2 and blocking capacitors C1 – C3. I paralleled three capacitors on this port because this is my only 160 meter connection.

The paths through the unit are similar, so we'll take the path from KAT2 (J2) to ANT2 (J6) as a representative case. Capacitors C4 and C5 are wired in parallel to share RF current in order to minimize heating due to their equivalent series resistance. In the power on state, since ANT1 – ANT3 are no longer grounded, the unit is vulnerable to pulses from nearby lightning strikes and to static charge buildup on the antennas.

In the event of a nearby lightning strike, the high reactance of C4 and C5 will block much of the energy from the pulse. And if the voltage spike should reach 800 V, gas discharge tube GDT2 will fire and the energy will be shunted to ground. While operating, static charge buildup is prevented by bleeder resistor R2 connected from the signal line to chassis ground.

The small-value capacitor C10 compensates for the impedance bump due to the unit's internal wiring. Without the capacitor the SWR of the unit degrades to about 1.3:1 on 6 meters when the unit is perfectly terminated. With the capacitor, the SWR is less than 1.03:1 (36 dB return loss) on 6 meters. Of course these capacitors are not really necessary as the management box follows the antenna tuner. However any impedance bump can degrade a less-than-perfect feed-line SWR enough to make the difference between bypassing the tuner and the need for the tuner to be in-line, especially at the higher frequencies.

Note that the voltage ratings of the components in this path are higher than typical: R2 is rated at 3.5 kV, where an ordinary resistor is only rated for a few hundred volts; blocking capacitors C4 and C5 are rated at 2 kV and C10 is rated at 1 kV. The relays, while inexpensive, work well through 6 meters, providing 1 kV RMS of isolation between contacts, 5 kV RMS of isolation between the coil and the contacts, and contacts rated at 12 A continuous current.

Design Formulas

This design is readily customizable to fit your own station's requirements. For stations running less than 500 W, the component values and ratings specified in the parts list are appropriate. In this context, *rating* refers to a components breakdown voltage

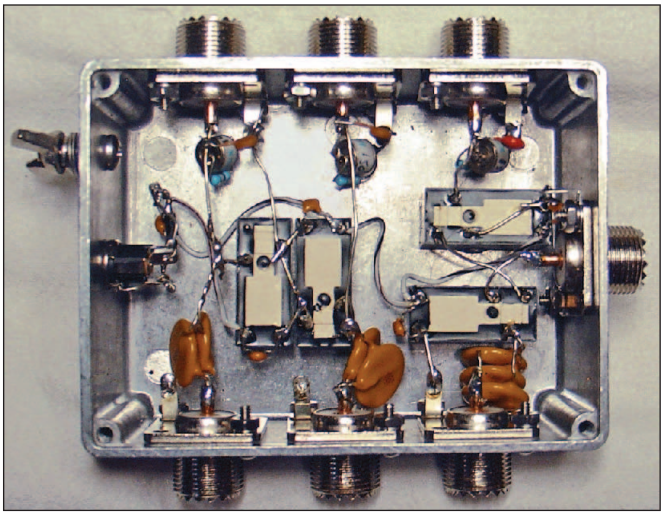

Figure 5 — View of parts placement inside the aluminum box housing the unit. The wing nut at the upper left connects the chassis ground of the unit to the station single-point ground at the cable entrance panel.

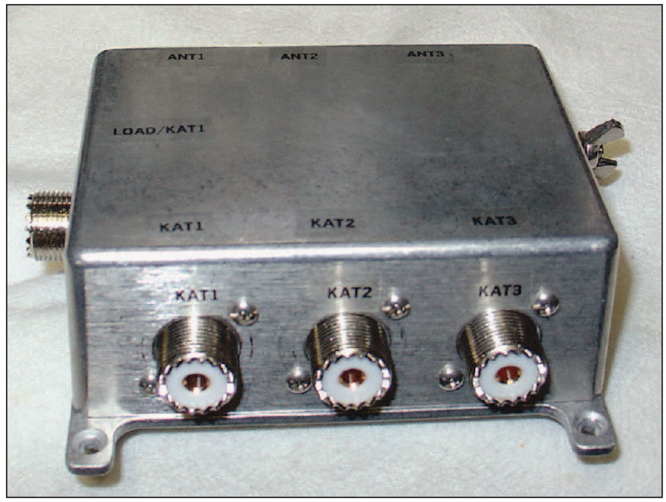

Figure 6 — Exterior view of the unit.

or its maximum power dissipation. However, for applications involving higher power, it is necessary to consider how the worst case component values and ratings were calculated.

Starting with one form of the equation for Ohm's Law ($E = I \times R$) and power ($P = E \times I$), and a few algebraic substitutions, we arrive at the equation for voltage ($E = (P \times R)^{0.5}$) in terms the power (P) and the resistance (R). In other words, voltage is the square root of the product of power and resistance.

Figure 7 — Remotely located housing for control switch S1.

This basic formula is also applicable to transmission lines if we consider the standing wave ratio or *SWR*. SWR is a dimensionless quantity equal to the greater of Z_0 / R or R / Z_0 where Z_0 is the characteristic impedance of the transmission line and R is the load at the end of the line. This mismatch could either be high impedance or low impedance. Both cases are important for our analysis because the high impedance load creates high voltages and the low impedance load creates high currents, even though the power in both cases is the same. To illustrate the computational procedure, we'll look at two examples, both involving the 10:1 SWR matching spec and 500 W limit of my KAT500 antenna tuner and coax feed line with a Z_0 of 50 Ω.

The first example considers a high impedance SWR of 10:1 and takes R to be 500 Ω since it's the high impedance case that we are going to investigate. Computing the voltage, given the power and resistance, $E = (P \times R)^{0.5}$, we obtain $(500 \times 500)^{0.5} = 500$ V. This is an RMS voltage; to find its peak value, multiply it by the square root of 2. The peak voltage is $500 \times 1.414 = 707$ V.

The relays used here have a 1000 V RMS limit between open contacts, so we are still within operating limits.

The conduction voltage of the gas discharge tube (GDT) is 800 V ± 20%. Here we need to ensure that the peak voltage on the line is less than the minimum conduction voltage for the gas discharge tube. The minimum conduction voltage for this GDT is $0.80 \times 800 = 640$ V. This would seem that for the worst case we are exceeding the GDT's specification. Therefore, we need to take a closer look at the actual data sheet.

The GDT is rated at 800 V breakdown at dc ± 20%, and a little higher for a pulse (100 V/µs = 1100 V, 1000 V/µs = 1200 V). A typical risetime for an RF signal is around 5 µs, so the RF transmitter's signal lies between the pulse specification and the dc breakdown specification. So if the GDT specification really is –20 %, the dc spark over voltage would actually be 640 V. However, this is probably normally not the case as this is worst case specification and there will be some extra margin as the RF signal is not quite dc.

The bleeder resistors' value and power dissipation must be chosen with regards to the worst case high voltage while transmitting. The 580 kΩ are special high-voltage resistors and have a breakdown voltage of 3.5 kV, so they can easily tolerate the 500 V RMS that could be caused an SWR of 10:1 at 500 W. Calculating their power dissipation as $P = E^2 / R$, we find that the power is $500^2 / 0.58 \times 10^6 = 0.43$ W.

The second example considers the low impedance 10:1 SWR case where high current can be an issue. Here we are concerned about exceeding the 12 A contact rating of the relays. With an SWR of 10:1 and a Z_0 of 50 Ω, we will take R as 5 Ω. Computing the voltage, given the power and resistance, $E = (P \times R)^{0.5}$, we obtain $(500 \times 5)^{0.5} =$

Table 1
Port-to-Port Isolation Measurements (10 meters / 6 meters)*

Ports x-y	KAT500 (dB)	Unit (dB)	Composite (dB)	Net Degradation (dB)
1-2	42/40	60/54	41.9/39.8	0.1/0.1
1-3	69/53	83/75	68.8/53	0.2/≈0
2-1	37/34	60/54	37/34	≈0
2-3	38/34	60/54	38/34	≈0
3-1	37/34	83/75	37/34	≈0
3-2	36/32	60/54	36/32	≈0

*Measurements to nearest 0.1 dB

50 V. As in the first example, $I = (P / R)^{0.5}$. The square root of (500 / 5) gives us a current of 10 A, which is within the 12 A rating for the relay contacts.

Construction

I built the unit into a cast aluminum box that has a mounting bracket that permits it to be rigidly mounted in place. Physical assembly details are shown in Figures 5 and 6. The relays (with pins up) are hot-glued to the aluminum box. A step-drill or ⅝-inch Greenlee punch works well for cutting the SO-239 connector holes. Note that there is also a ground stud consisting of a #8 stainless steel screw, nut, lock washer, and wing nut for connecting to your station's single-point ground. Figure 7 shows the remote switch control.

Performance

I measured the isolation between the different ports of the completed unit to ensure that there was no degradation of the KAT500 port-to-port isolation. The worst isolation was 54 dB on 6 meters and better than 60 dB on 10 meters between antenna ports 1 – 2 and ports 2 – 3. The best isolation was between ports 1 – 3, where the isolation was 75 dB on 6 meters and about 83 dB on 10 meters. Table 1 documents my isolation measurements and calculated composite isolations rounded to the nearest tenth of a dB. As you can see, the accessory box degrades the KAT500 port-to-port isolation by 0.2dB or less. Only the 10 and 6 meter isolation numbers are displayed as isolation gets much better as you go lower in frequency.

Conclusion

The antenna feed line control box provides automatic lightning and static protection for your station and adds a dummy load connection to your antenna switch if you are limited in switching ports. This unit can be modified to include more or fewer ports as needed.

Finally, once again, it must be stressed that this unit is not a primary lightning protection device nor a means to operate your station when lightning is in the vicinity — that first sound of thunder is nature's QST to get off the air!

Notes

[1]Bolt from the blue: **www.crh.noaa.gov/pub/ltg/crh_boltblue.php**.
[2]D. Park, KJ5QV, "Lightning Strike," Correspondence, *QST*, Jul 2006, P 25.
[3]R. Block, KB2UYT, "Lightning Protection for the Amateur Station," Part 1, *QST*, Jun 2002, pp 56 – 59.
[4]R. Block, KB2UYT, "Lightning Protection for the Amateur Station," Part 2, *QST*, Jul 2002, pp 48 – 52.
[5]R. Block, KB2UYT, "Lightning Protection for the Amateur Station," Part 3, *QST*, Aug 2002, pp 53 – 55.
[6]L. Scheff, W4QEJ, "Lightning: Understand It or Suffer the Consequences," Part 1, *QST*, Feb 2008, pp 40 – 44.
[7]L. Scheff, W4QEJ, "Lightning: Understand It or Suffer the Consequences," Part 2, *QST*, Feb 2008, pp 30 – 34.
[8]P. Husby, W0UC, "Wintertime Static on Antennas," Technical Correspondence, *QST*, Jul 1985, p 42.
[9]D. Le Vine, "Review of Measurements of the RF Spectrum of Radiation from Lightning," *NASA Technical Memorandum 87788*, Mar 1986.
[10]G. Kauffman, "Using commercial lightning protectors in defense applications," *RF Design*, Jun 2006, pp 16 – 21.

Photos by the author.

Amateur Extra class license holder and ARRL Life Member Phil Salas, AD5X, has been licensed since 1964. His early Amateur Radio interests led to BSEE and MSEE degrees from Virginia Tech and Southern Methodist University respectively, followed by a 33-year career in microwave and light wave telecom design and management. Now retired, Phil, a frequent *QST* contributor, is busier than ever, tinkering with electronics, playing with his grandsons, but mostly enjoying time with his wife Debbie, N5UPT, who is also his best friend. You can reach Phil at **ad5x@arrl.net**.

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