NVIS ANTENNA THEORY AND DESIGN
AAR6UK 20 FEB 2017

Requirements

A properly designed Near Vertical Incident Skywave (NVIS) antenna will have a directivity pattern that will maximize transmission and reception at high angles while rejecting low angle, long range noise. Further, this antenna must be tunable over at least an octave of frequency to track the local Critical Frequency (CF).
The required directivity pattern is shown in Figure 1.

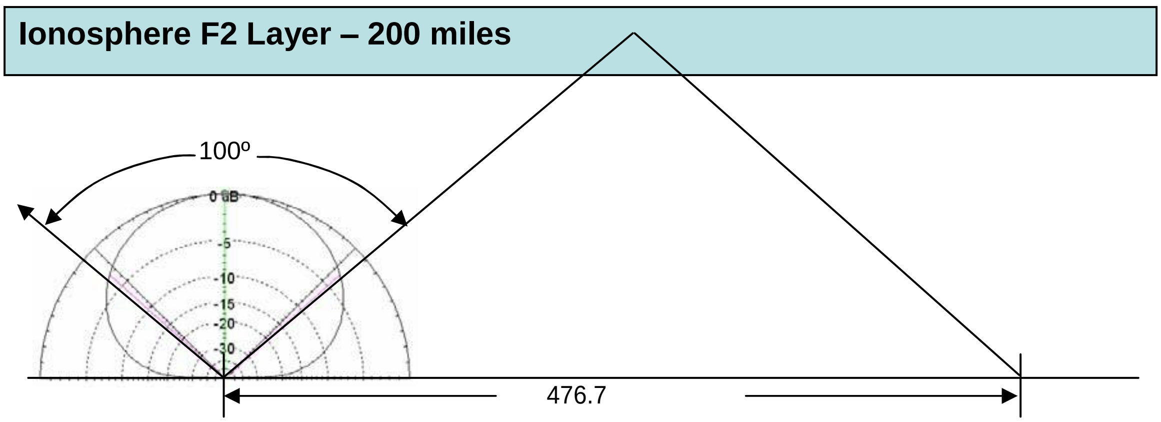


Figure 1: Required NVIS Antenna Vertical Directivity Pattern

The vertical or elevation directivity pattern should have a beam width (-3dB) of approximately 100º and the horizontal or azimuth directivity pattern should be omni-directional. The three-dimensional pattern should look like a toy balloon with the filler at the bottom.

Distant Noise Reduction

As we have all noticed, the most prevalent noise is long-range lightning from thunderstorm activity in the surrounding states. During summer evening nets, after D-layer absorption has dropped, thunderstorms, several states away can disturb Texas Army MARS nets. The "south-of-the-border" interference also falls into this category. There is little we can do about local thunderstorm noise, but a properly designed NVIS antenna can reduce the distant noise. An Australian scientist, C.J. Coleman, measured the noise directivity at both Alice Springs, Australia, and in South England (C.J. Coleman, The Directionality Of Atmospheric Noise And Its Impact Upon An HF Receiving System, HF Radio Systems and Techniques, Conference Publication No. 473 IEE 2000). The results of this study are shown in Figures 2 and 3. The horizontal direction, or azimuth, of the noise is displayed around the circle with North being towards the top of the page. The vertical angle or elevation, is depicted as the radial distance from the center with the center of the circle being 90º or overhead. Each doted-line circle represents 30º of elevation.

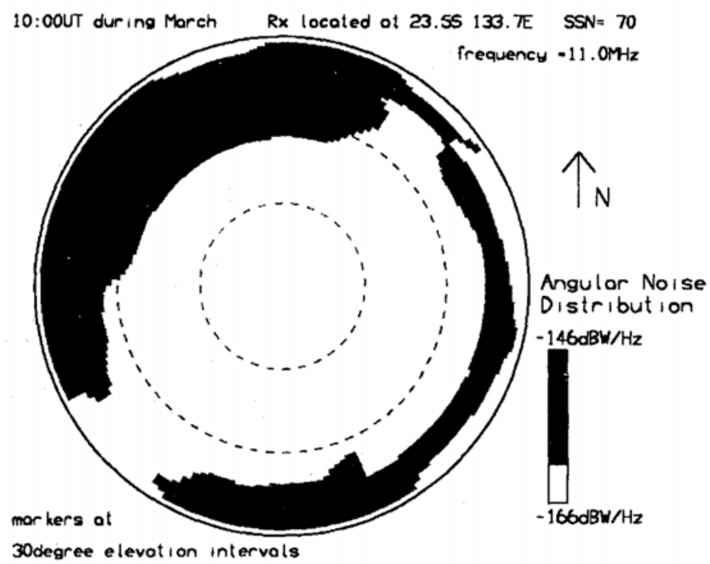


Figure 2: Vertical Angle of Arrival of Distant Noise – Alice Springs

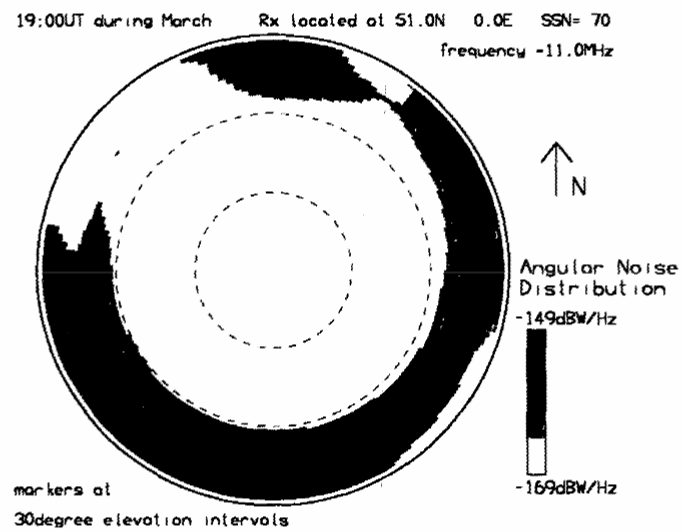


Figure 3: Vertical Angle of Arrival of Distant Noise – South England

In both figures, the noise arrived at vertical angles of less than 30º. These thunderstorms, just like ours, are more likely to occur at various long ranges than on top of us. If we can achieve the directivity shown in Figure 1, we can achieve from 5dB to 15 dB of attenuation against distant noise. A more advanced NVIS antenna design might do even better.

Generating the Correct Antenna Pattern – Optimum Height

The correct antenna pattern, shown in Figure 1, is surprisingly easy to generate. First let's look at the theory. Figure 4 shows a theoretical two-element yagi designed for 75m (3.8 MHz). The antenna consists of a half-wave dipole driven element and a passive reflector. The reflecting element is 5% longer than the driven element and is located 0.15 wavelengths behind the driven element. This is a very standard 2-element Yagi design. The resulting azimuth and elevation patterns can be seen in Figures 5 and 6.

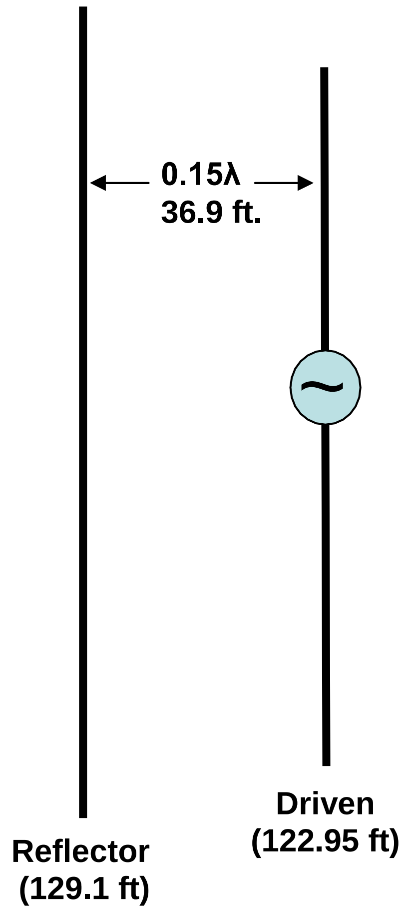


Figure 4: Theoretical 75m Yagi

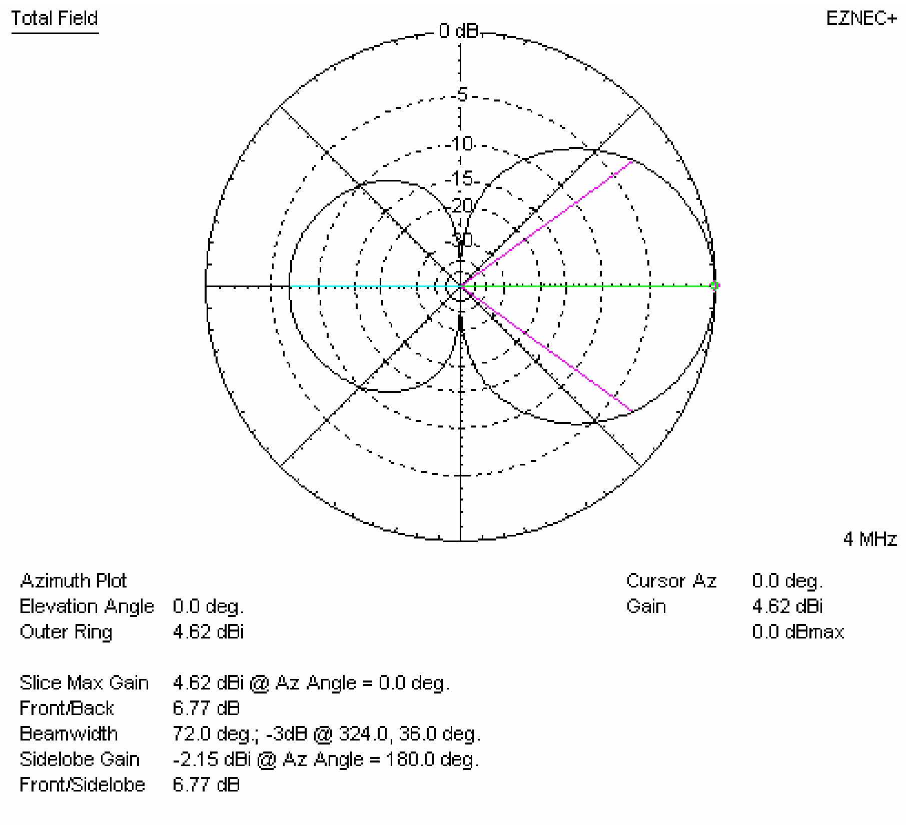


Figure 5: Azimuth Pattern for 2-element Yagi

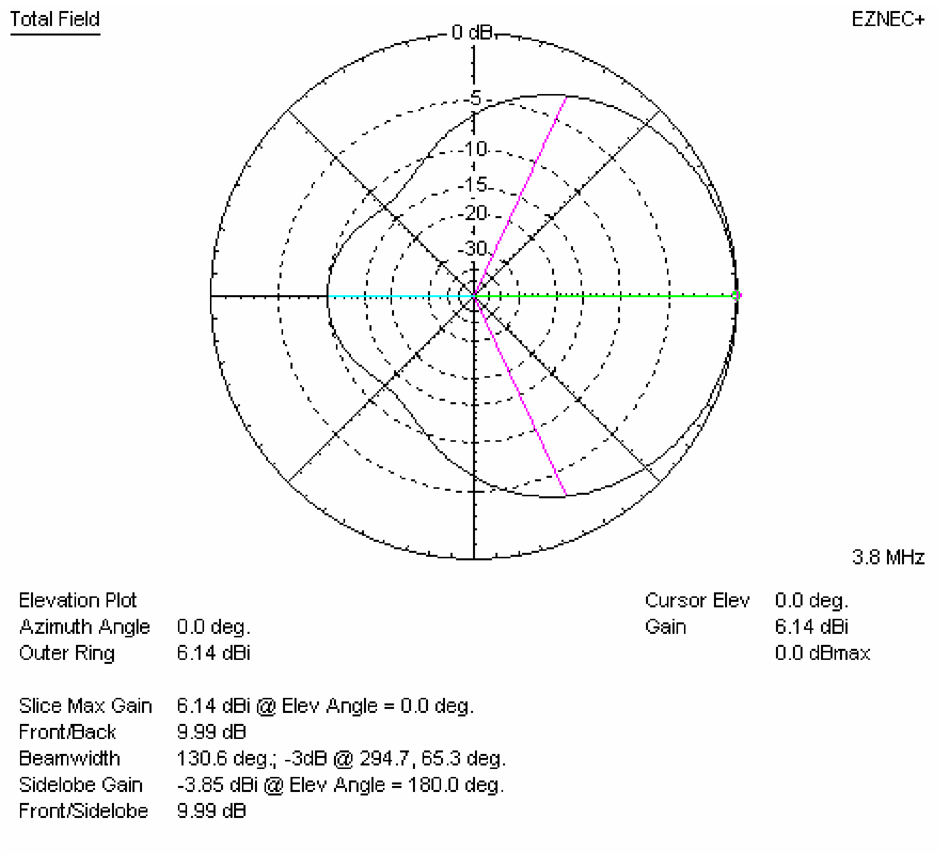
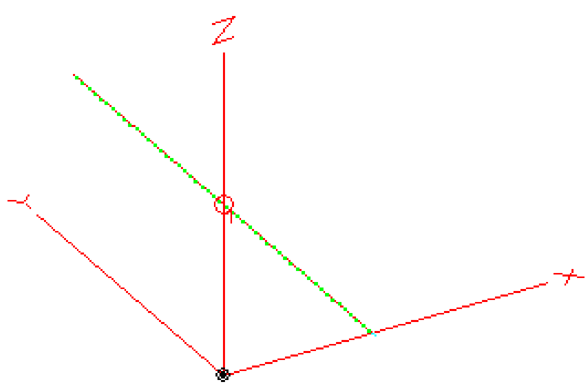


Figure 6: Elevation Pattern for 2-element Yagi

If this antenna were rotated 90° with the reflector toward the ground, the pattern would begin to resemble the required NVIS pattern. If the reflector is replaced by real (Sommerfeld-Norton, Average) ground and the 75m dipole placed at 0.15 wavelengths or 39 ft. above the ground, the elevation plot of Figure 7 results.



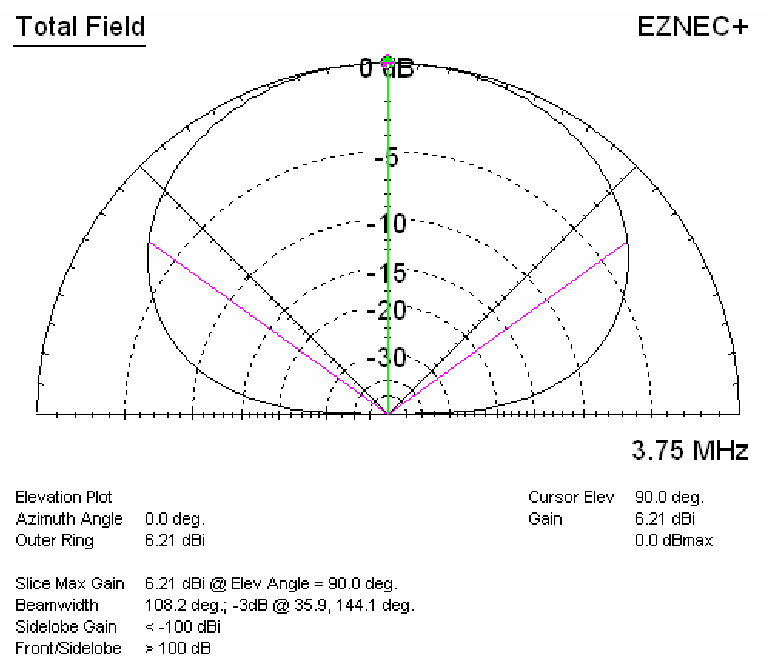


Figure 7: Elevation Pattern For a NVIS 75m Dipole

The azimuth plot is also almost circular as shown in Figure 8.

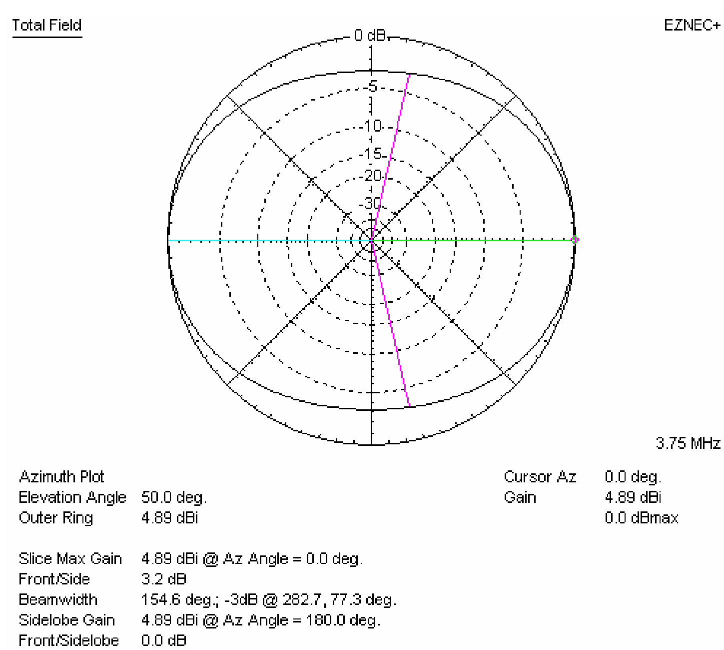


Figure 8: Azimuth Pattern For a NVIS 75m Dipole

Obviously, the ground is now acting as the reflector for this two element Yagi antenna. If this same dipole were placed at 0.5 wavelengths or 131 ft. height, then the “two” element Yagi has the classical DX elevation and azimuth patterns shown in Figures 9 and 10.

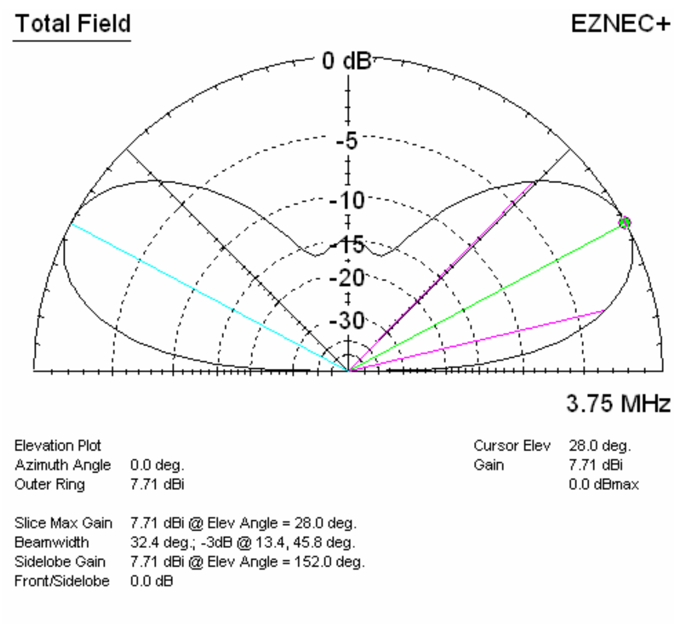


Figure 9: Elevation Plot of a 75m Dipole at ½ Wavelength Height

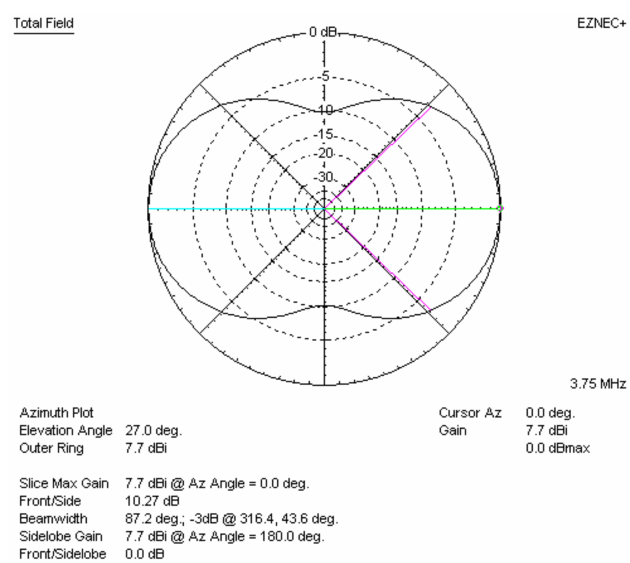


Figure 10: Elevation Plot of a 75m Dipole at ½ Wavelength Height

As can be seen when comparing Figures 7 and 8 with Figures 9 and 10, the 75m dipole goes from NVIS to DX by changing the height above ground from 0.15 to 0.5 wavelengths. Even the azimuth pattern becomes almost omni-directional as the antenna is lowered. The optimum NVIS height above ground can be seen in Figures 11 and 12 courteous of L.B. Cebik, W4RNL.

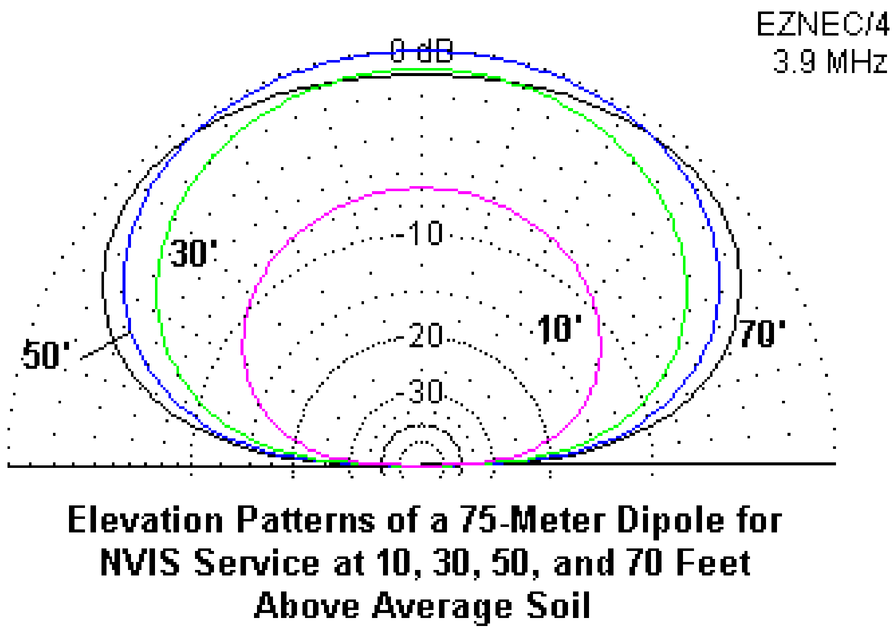


Figure 11: Gain and Elevation Plots of 75m NVIS dipole at Various Heights

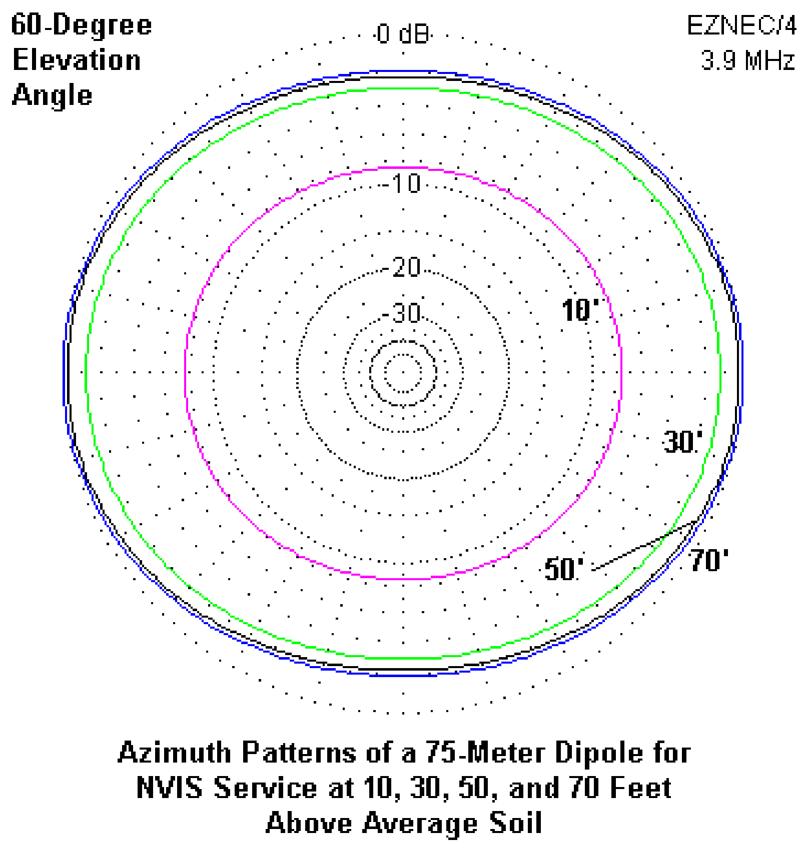


Figure 12: Gain and Azimuth Plots of 75m NVIS dipole at Various Heights

Note that the relative size of each plot, in different colors, represents the gain of the antenna at different heights. As can be seen in Figures 11 and 12, heights of between 30 and 50 ft. or 0.1 to 0.2 wavelengths worked quite well. Another way to plot this data, again courteous of L.B. Cebik W4RNL, is shown in Figure 13. As can be seen, heights from 0.1 to 0.3 wavelengths have the highest gain. This fact will be very important when optimizing a NVIS antenna to work over a wide range of frequencies. The wavelength heights from Figure 13 can be translated into any frequency where NVIS antenna performance is needed. For example, for 40m (7.2 MHz) operation, heights of 0.1 to 0.3 wavelengths, corresponding to heights of 13.6 ft. to 40 ft., have highest gain. For 75m (3.8 MHz) operation , a height of 40 ft. corresponds to 0.16 wavelengths height has good gain. Even for our lowest frequencies of 3.3 MHz and 2.2 MHz heights would be 0.14 wavelengths, and 0.11 wavelengths, respectively. Therefore a height between 40 ft. and 50 ft. would provide optimum performance over a frequency range of 2.2 to 7 MHz.

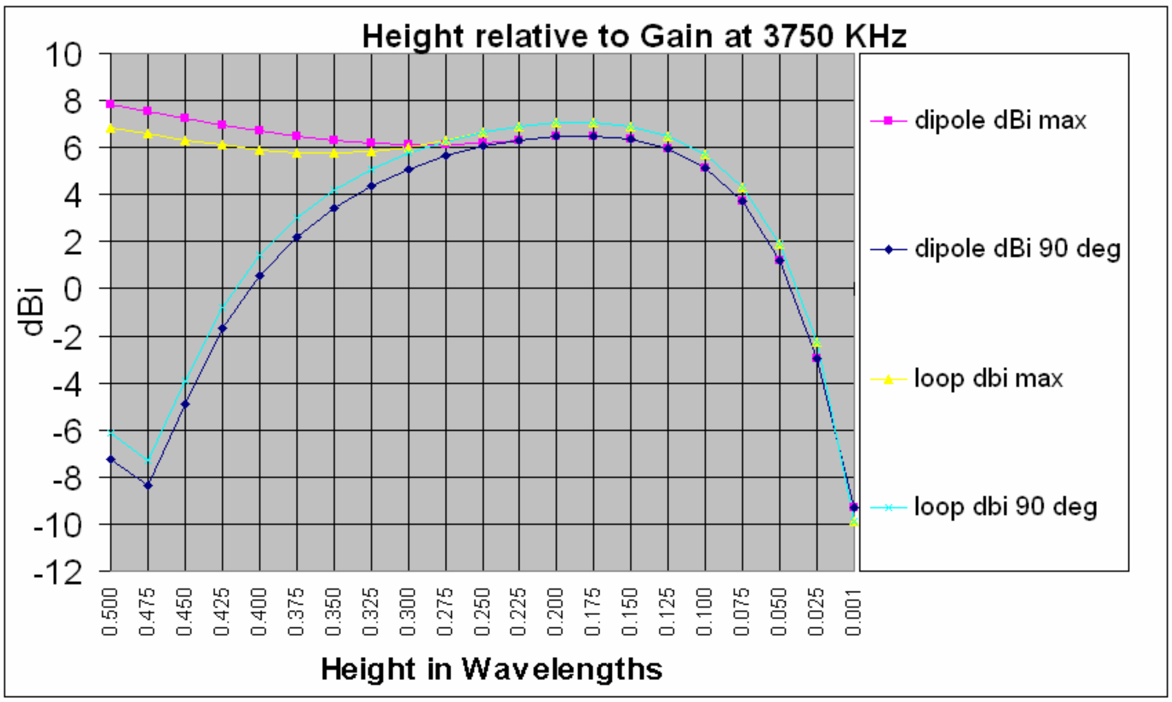


Figure 13: Height Versus Gain of a 75m NVIS Dipole

Generating the Correct Antenna Pattern – Optimum Length

A horizontal dipole that is significantly longer than one-half a wavelength will have an azimuth pattern that departs from omnidirectional as shown in Figure 14. For brevity, I have switched to a 3-dimensional plot for the following discussion. The azimuth plot is in the X-Y or horizontal plane. You can see a significant departure from a spherical pattern to that of an elongated ellipsoid (watermelon) shape.

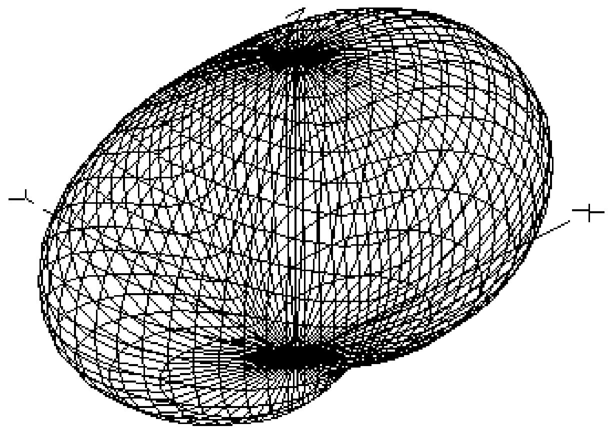


Figure 14: 75m NVIS Dipole Pattern at 40m

While this is still a useable NVIS pattern at twice its design frequency, attaching a 40m dipole to the driven point will significantly improve this pattern as shown in Figures 15 and 16. Antenna height is 39 ft.

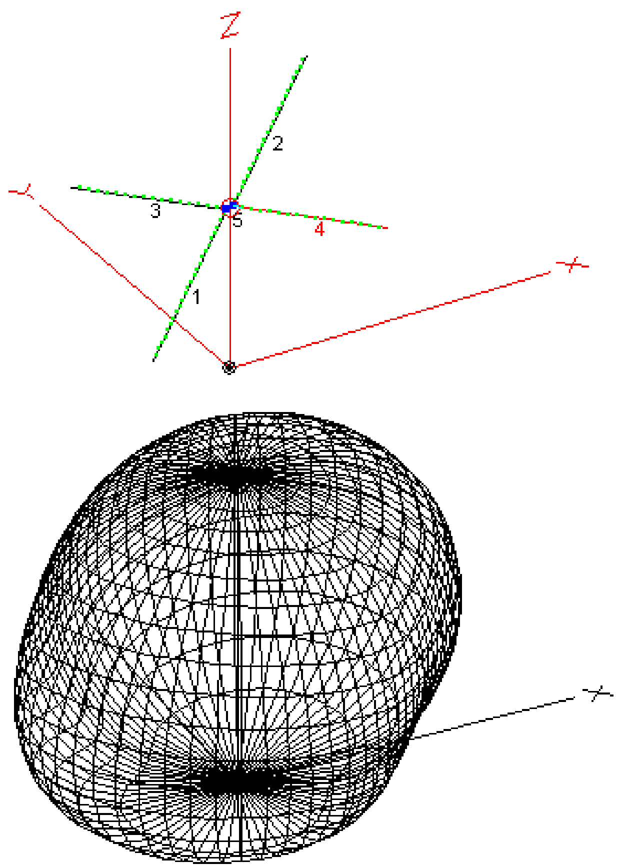


Figure 15: Cross-Dipole Antenna Pattern at 40m

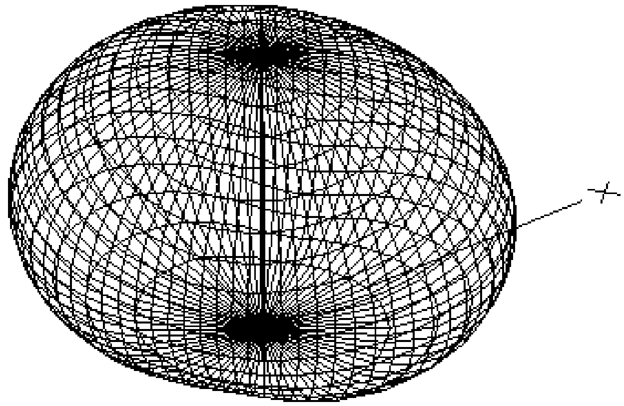


Figure 16: Cross-Dipole Antenna Pattern at 75m

A similar effect can be achieved by raising the apex of the 75m dipole to 50 ft. and slopping the legs down at 45º, creating the familiar 75m inverted-V antenna as seen in Figure 17. This will result in good NVIS patterns, shown in Figures 18 and 19, at frequencies between 3.75 MHz and 7.2 MHz but with a penalty of about 3 dB loss in gain at both frequencies when compared to the cross dipoles of Figure 15.

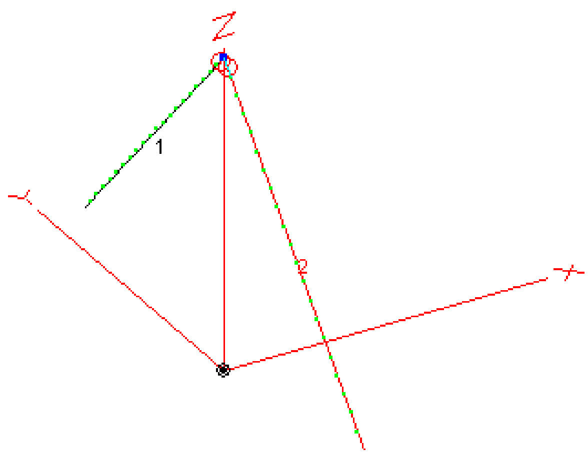


Figure 17: Inverted-V Dipole

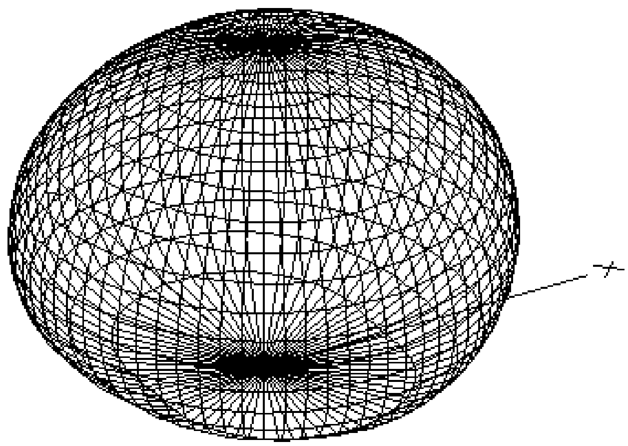


Figure 18: 75m Inverted-V NVIS Antenna at 3.75 MHz

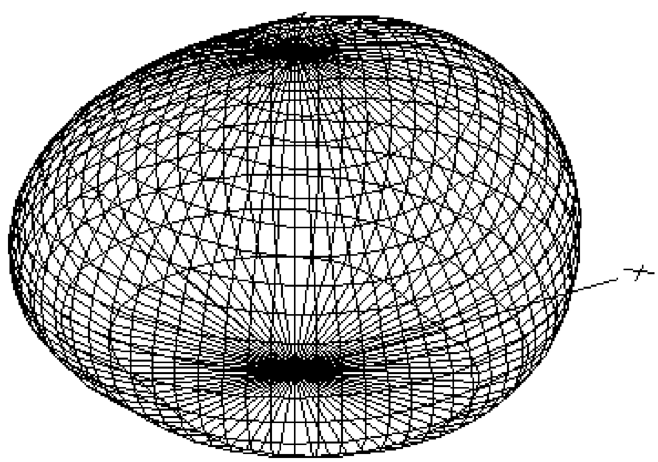


Figure 19: 75m Inverted-V NVIS Antenna at 7.2 MHz

The examples section of this document will discuss other solutions to the problem of maintaining proper NVIS directivity patterns over an octave of frequency.

Special Cases

A reflector "element" below the driven element is essential to generate the NVIS directivity pattern. While in most cases the earth can provide the required reflector, special cases, like very deep, dry sand, or a very high antenna mounting location, may require that an actual reflecting wire be provided as shown in Figure 20.

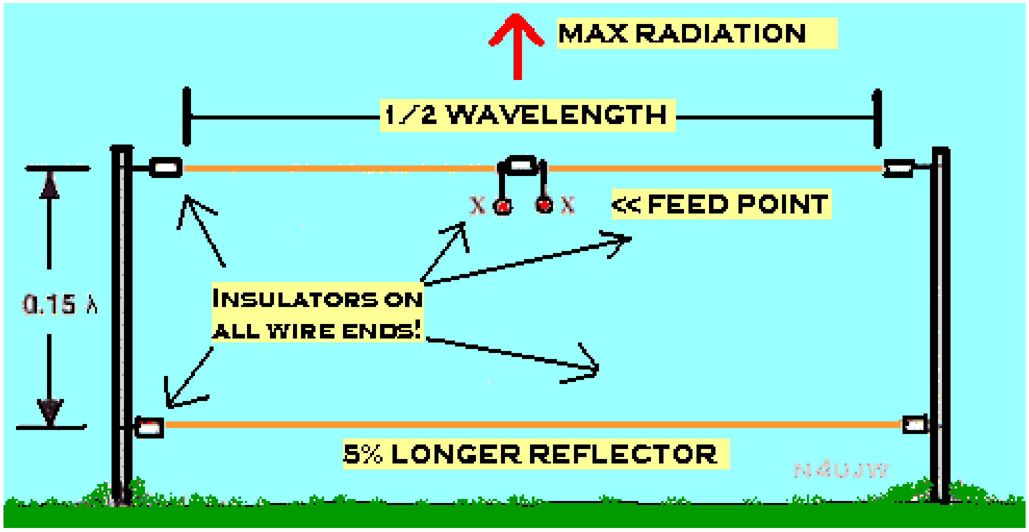


Figure 20: NVIS Configuration For Special Case of Low Earth Conductivity

Vertically Polarized Antennas

The vertically polarized antenna is not optimum for NVIS operation. For example, an idealized vehicle whip antenna and accompanying vertical directivity patterns can be seen in Figures 21 through 23.

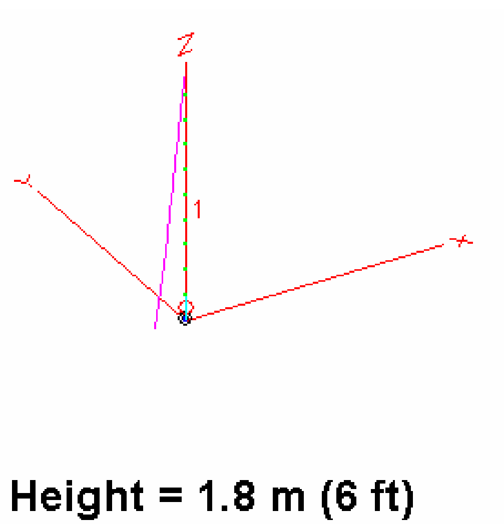


Figure 21: Vehicle HF Whip Antenna With Current Distribution

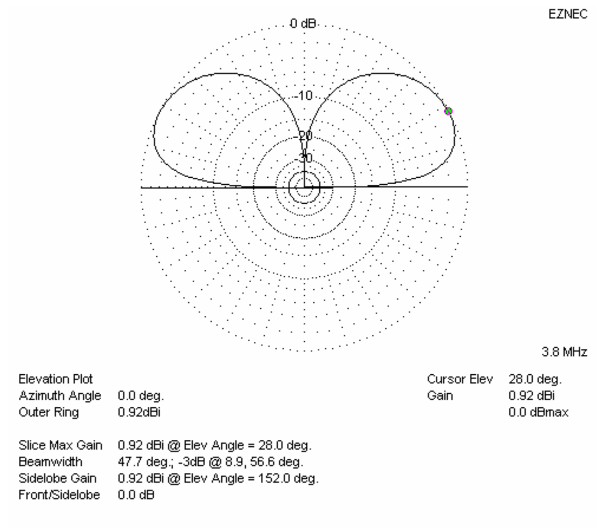


Figure 22: Elevation Pattern of Vehicle Whip At 75m (3.8 MHz)

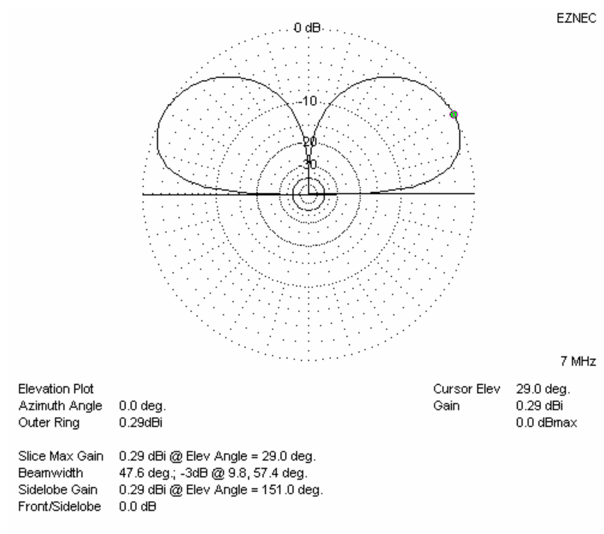


Figure 23: Elevation Pattern of Vehicle Whip At 40m (7 MHz)

These directivity patterns are certainly idealized and we know from experience that HF vertical antennas seem to perform better than expected. The military suggests moving a vertical HF antenna more horizontal for NVIS operation as shown in Figure 24.

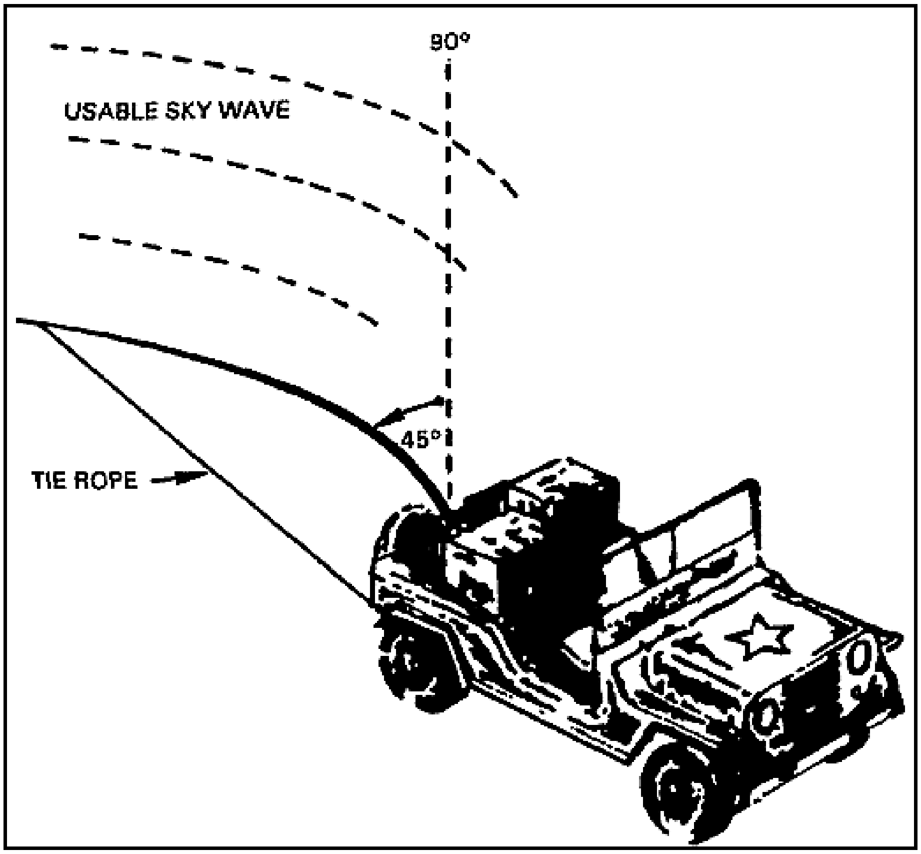


Figure 24: Improved NVIS Performance Of A HF Vertical Whip Antenna

Another option for limited space and mobile HF NVIS operation is the vertically oriented loop antenna as shown in Figures 25. The efficiencies are low for a small loop antenna, but typical NVIS signal levels exceed those from a vertical mobile whip.

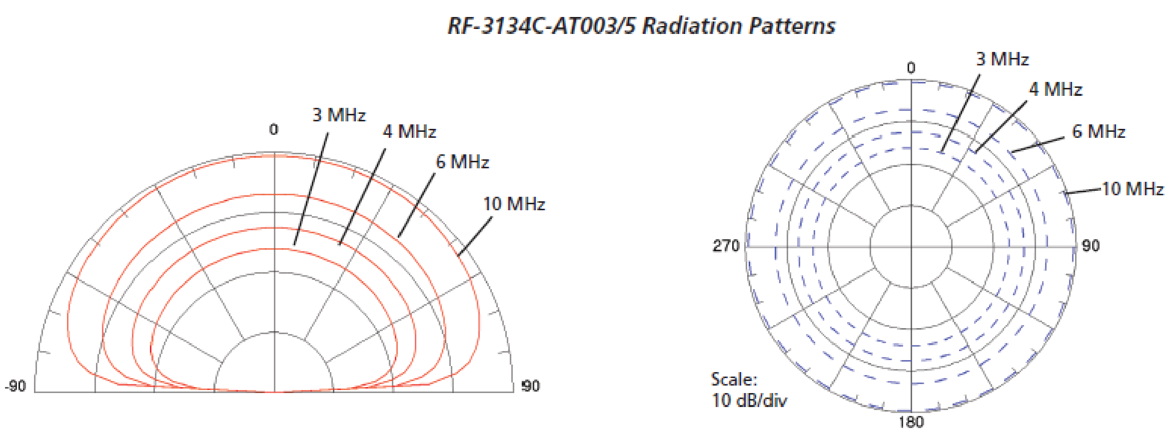


Figure 25: Harris NVIS Loop, RF-3134-AT003

Antenna Impedance Match

Once a NVIS antenna has been designed that can produce proper directivity patterns over the necessary MARS frequency range (2.2 MHz to 7 MHz), the task is only one-half complete. This wide-band antenna system must also provide an useable impedance (50 Ω) over this frequency range so it will accept RF power from the transmitter. The impedance matching problem can be seen in the standing wave (SWR) plots, shown in Figures 26 and 27 for both the 75m dipole and the cross-dipole antennas.

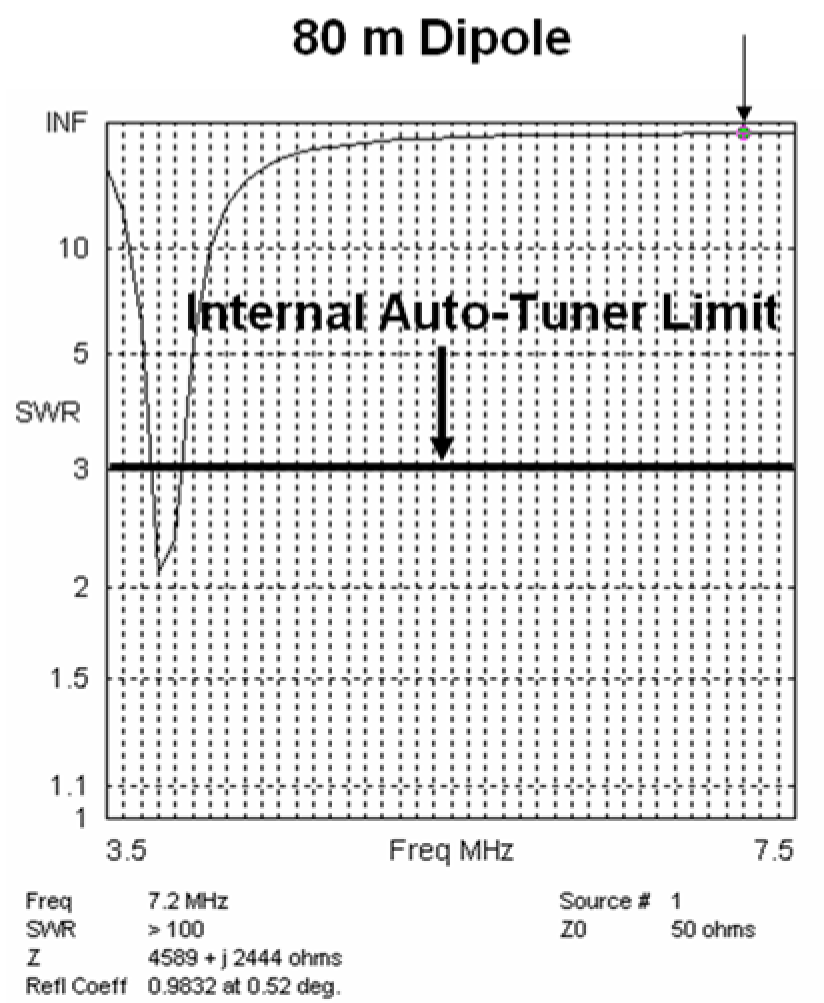


Figure 26: SWR Plot of 80m NVIS Antenna

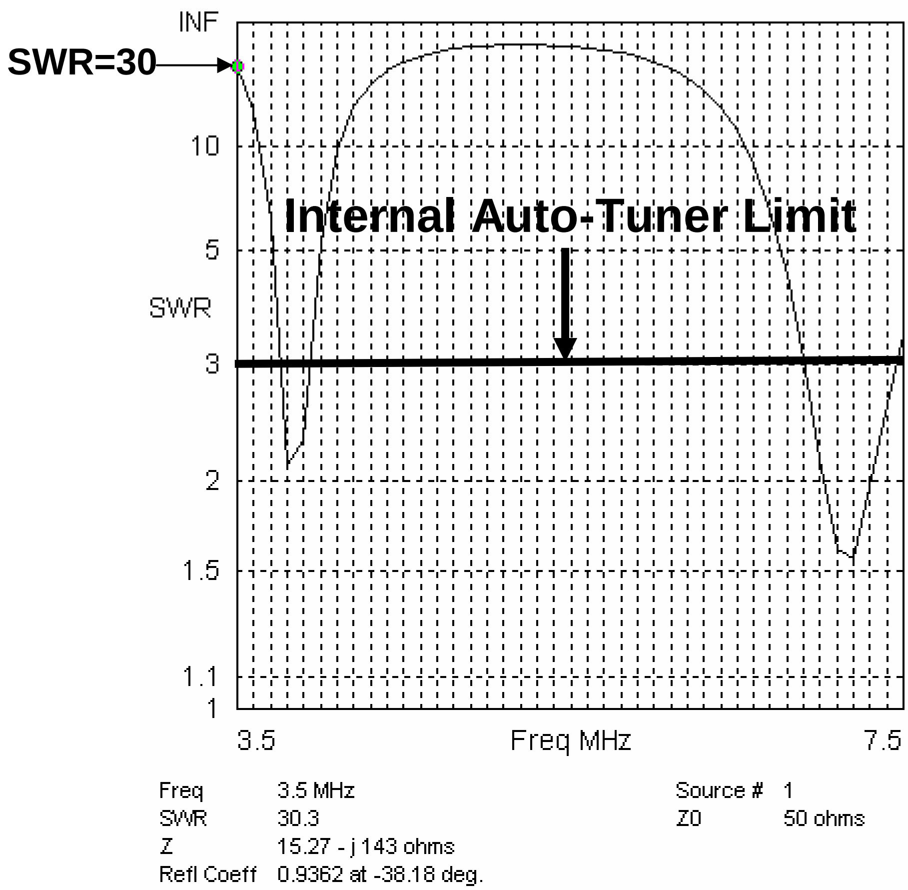


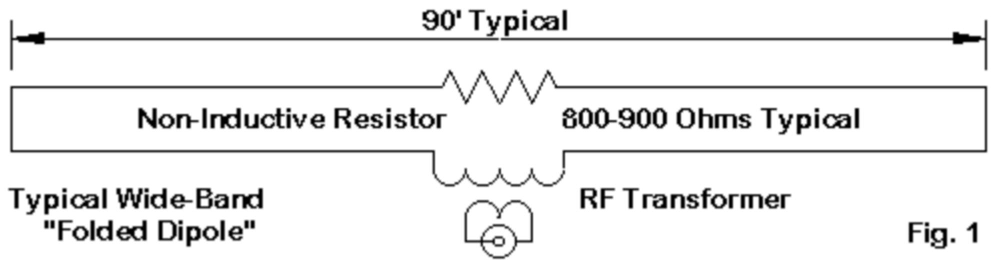
Figure 27: SWR Plot of Cross-Dipole NVIS Antenna

Also shown on each of these two plots is the typical internal auto-tuner limit of today's modern HF transceivers (3:1 SWR). Note that the typical required SWR tuning range for MARS frequencies can be greater than 100:1 for an 75m dipole and even for the cross-dipole antenna, as high as 30:1. To follow is a list of possible solutions to this problem:

A. Separate Tuned Wires For Each Frequency – A "fan-dipole" antenna with separate resonant ½ wavelength wires for each frequency can be constructed. This will require extensive measurement and trimming since there will be interaction between the separate dipoles. If this antenna is moved for portable operation, it will need to be re-tuned. To cover all Texas Army MARS NVIS frequencies, some 6 dipoles will need to be parallel connected and tuned. Some reduction in number might be possible for frequencies close together.

B. Terminated Folded Wide-Band Dipole – Several companies make special wide-band, folded dipoles with a termination load resistor and matching transformer as shown in Figure 28.

From: http://www.cebik.com/wire/wbfd.html



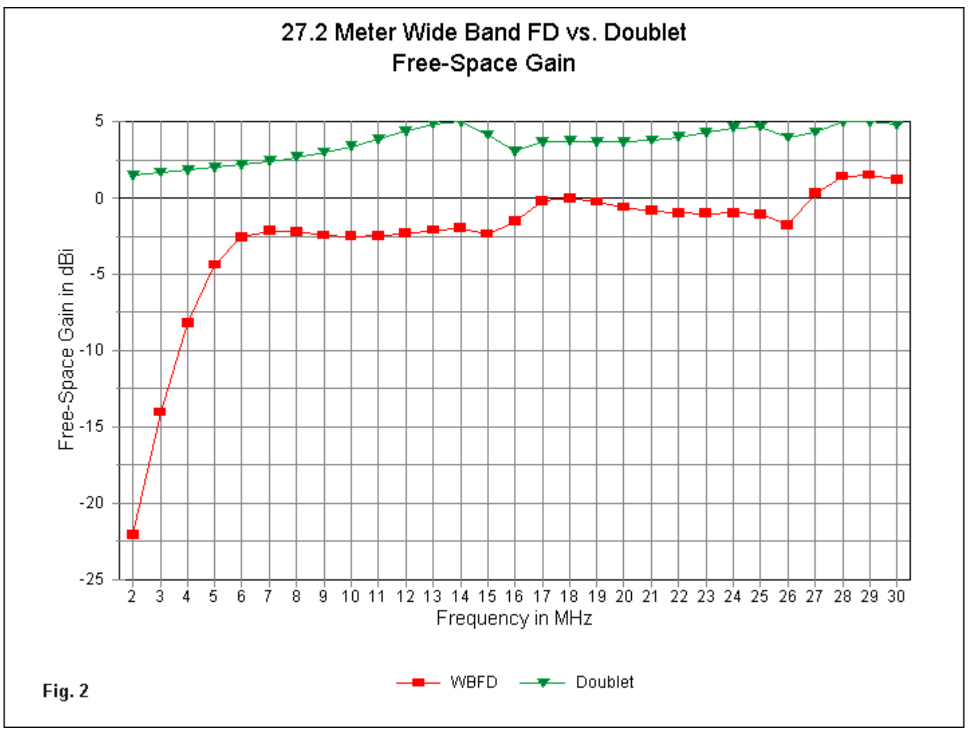


Figure 28: Terminated Folded Wide-Band Dipole Performance

These type of antennas have SWR that vary only about 2:1 over frequency ranges from 2 to 30 MHz. The problem is that they are considerably less efficient that the same length dipole (doublet) with optimized tuning. Figure 28 plots the gain of both a tuned dipole (doublet) and a B&W 90, folded, terminate dipole. The difference in gain (5-6 dB) translates into an efficiency loss of at least 50% when compared to the dipole of the same length.

C. Tuner Located at the Rig – The high SWR at most frequencies can cause significant losses in the transmission line if it is not extremely low loss. Figure 29 shows the additional loss in dB due to high SWR on a transmission line. For example, given that RG-8U has a loss of 0.55 dB/100 ft., then a SWR of 20 at the load would add an additional 2.5 dB/100 ft. for a total of 3.05 dB or one-half power.

The losses for SWR values of 100 would leave very little signal at the antenna. At this same frequency, the losses for 450 Ω ladder-line is not measurable.

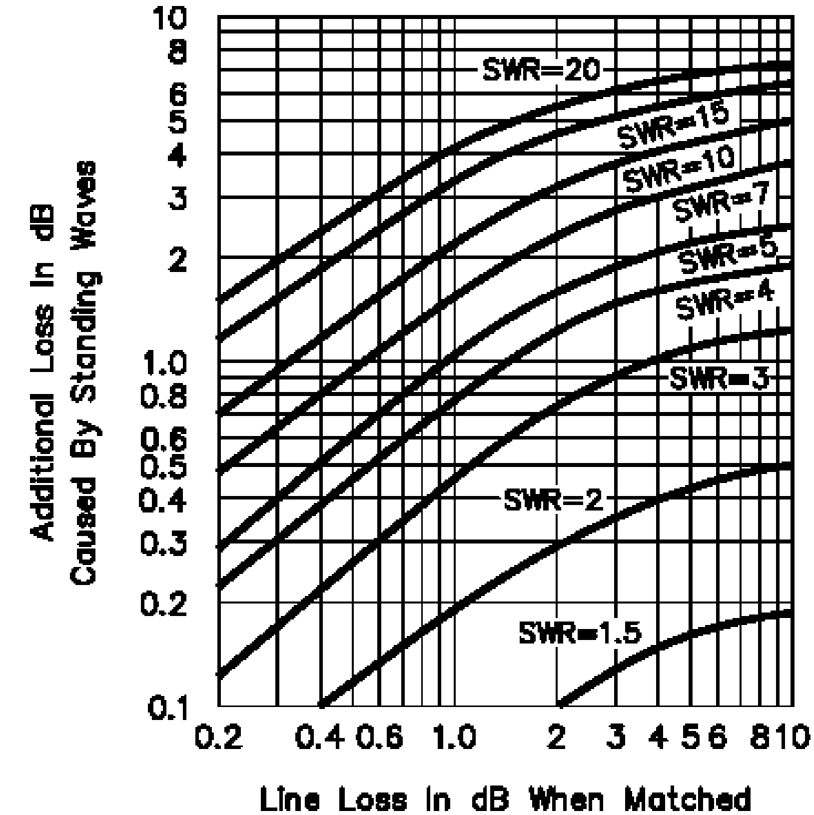
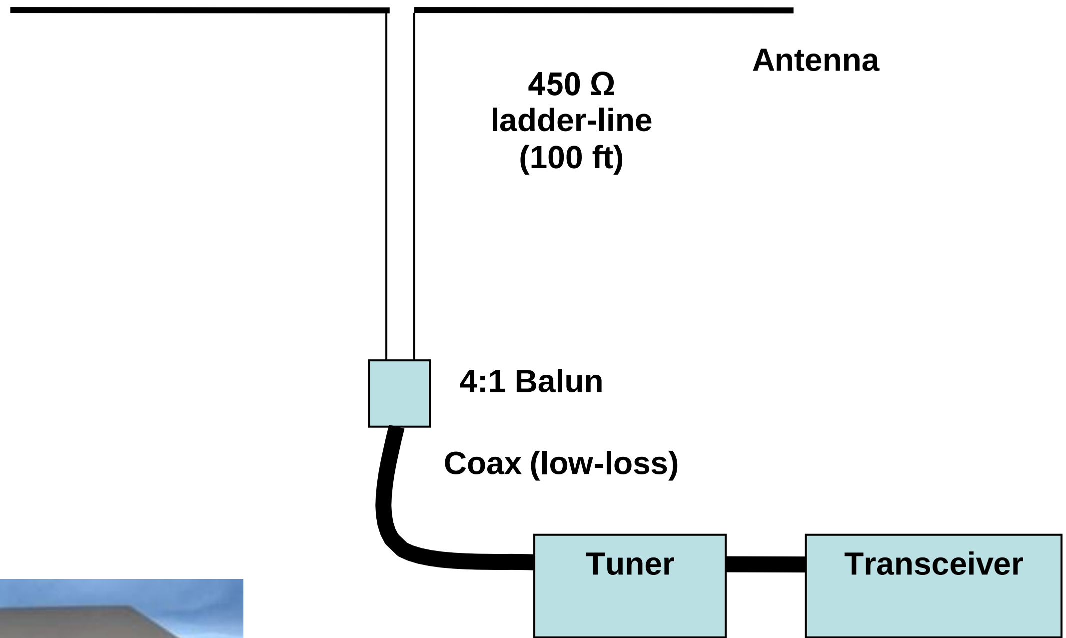


Figure 29: Additional Transmission Line Loss Due to High SWR

Figure 30 shows a typical arrangement for minimizing losses when a tuner is used at the rig location. Low loss 450 Ω Ladder-Line is used for the majority of the transmission line run. Near the entrance to the shack, a 4:1 balun and a short length of low-loss coax (RG-8 or Belden 9913 for example) are used to complete the connection between the antenna and the antenna tuner. If proper high-voltage bulkhead feed-throughs are available, the ladder-line can be connected directly to the antenna tuner, eliminating the losses in the balun and coaxial cable.



LDG-AT 200 Pro

MFJ – 949E

Figure 30: Wiring Arrangement For A Tuner Located At Rig

The antenna tuner must be able to handle 100 watts (or your actual power) at SWR ratios of at least 20:1. The impedance matching for a wide range antenna tuner is typically stated as 6 to 1000 Ω.

D. Tuner At The Antenna – The method favored by the military and marine antenna designers is to place an auto-tuner at the antenna as shown in Figure 31. These tuners can typically tune an antenna as short as 8 ft. from 3.5 MHz to 30 MHz. They require about 1 ampere at 13.5 VDC to provide power to the microcomputer located within the housing. The SGC and MFJ antenna tuners need only this DC power and about 10 watts of RF to allow the auto-tuner to match the antenna to the 50 Ω coaxial cable. DC can be transmitted up the coaxial cable and separated at the top and bottom using Bias-Tee's, available from both companies. The ICOM AH4 has both a coaxial cable and a 4 wire control cable and is designed to only operate with compatible ICOM HF transceivers (Ham and Marine). The three auto-tuners shown are water-tight but their plastic housing must be protected from the Texas sun. In addition, the sensitive electronics must be protected from EMP (Electromagnetic Pulse) damage from nearby lightning strikes. I am presently using a high-voltage relay, energized from the microcomputer DC line, to disconnect and short the tuner to ground when not in use. A schematic of this protective circuit can be seen in Figure 32. Additional external auto-tuner examples and construction hints can be found in Appendix 2.

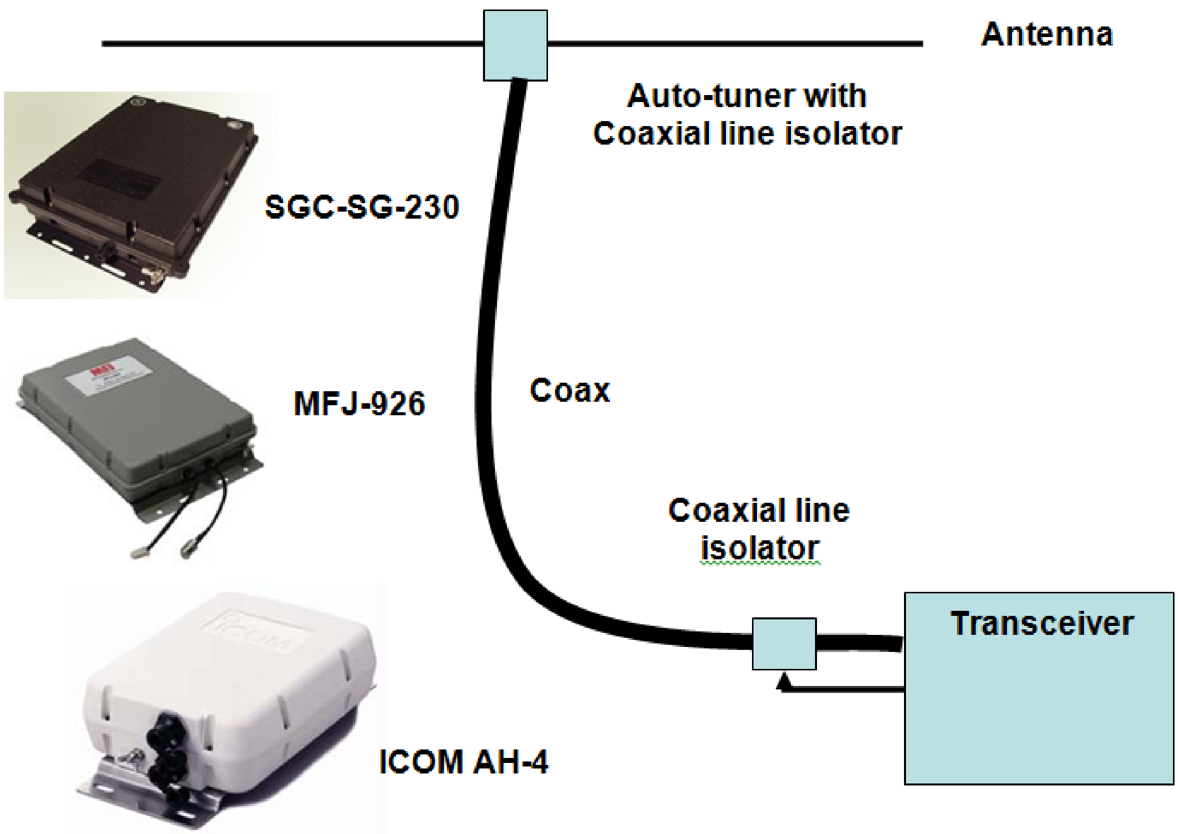


Figure 31: Tuner At The Antenna

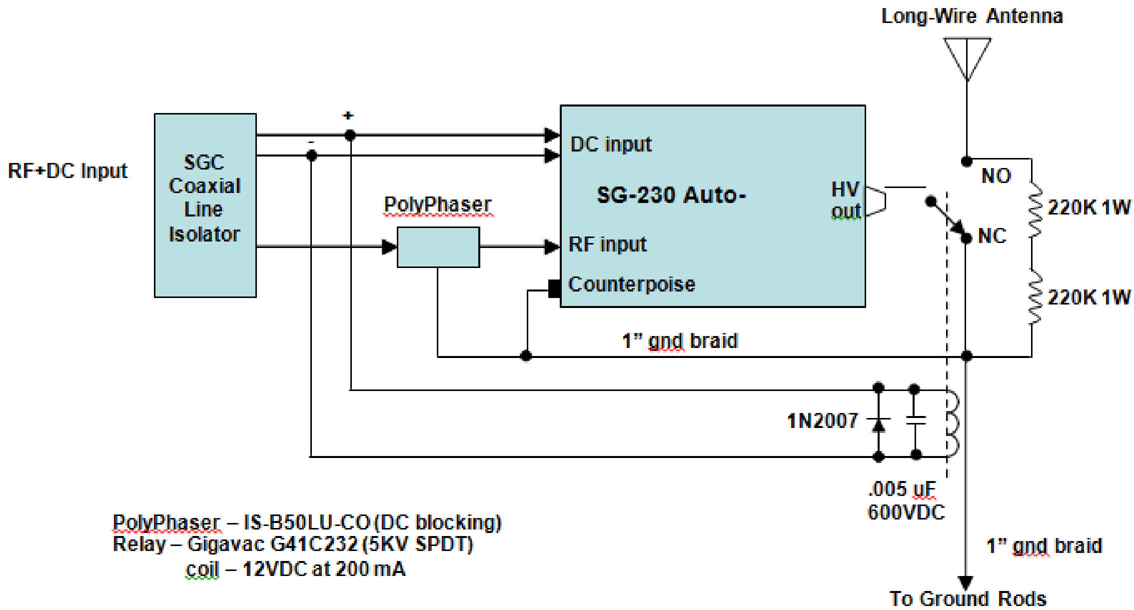


Figure 32: SGC Auto-Tuner Lightning Protection Circuitry

An example of an antenna mounted auto-tuner used for temporary portable operation can be seen in Figures 33 and 34. The housing is water-proof and if use is limited to portable operation, sun damage to the housing can be avoided.

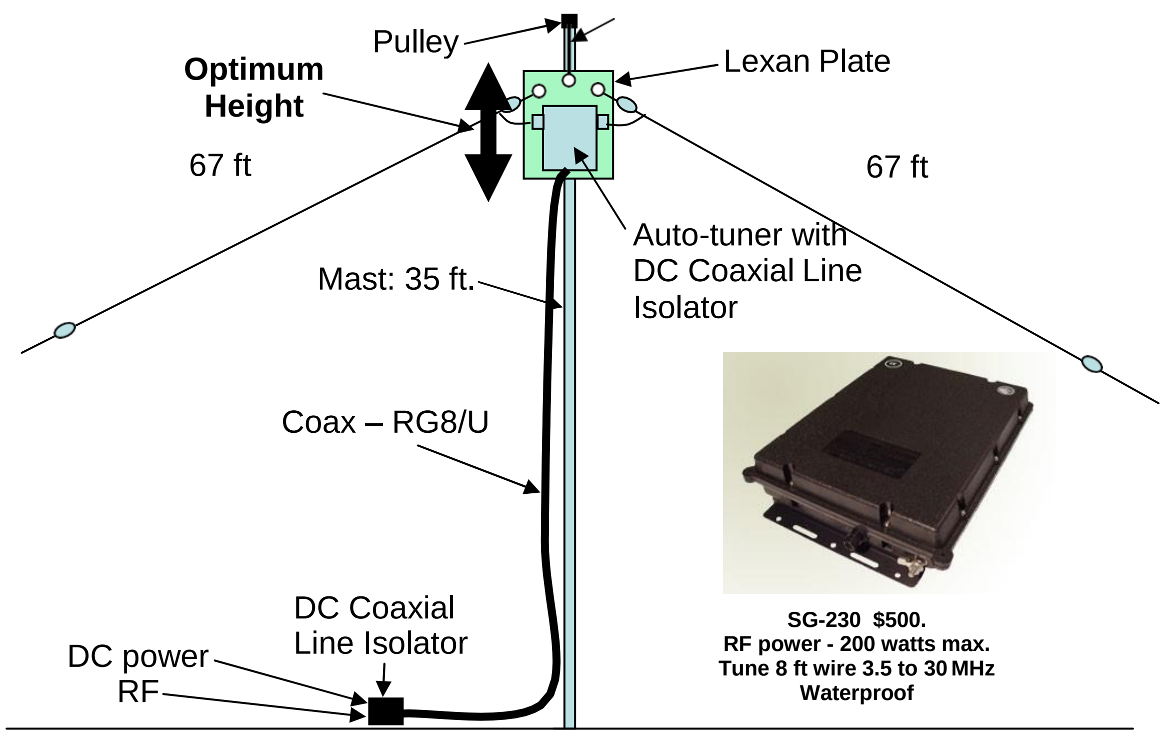


Figure 33: Auto-Tuner for Portable Operation

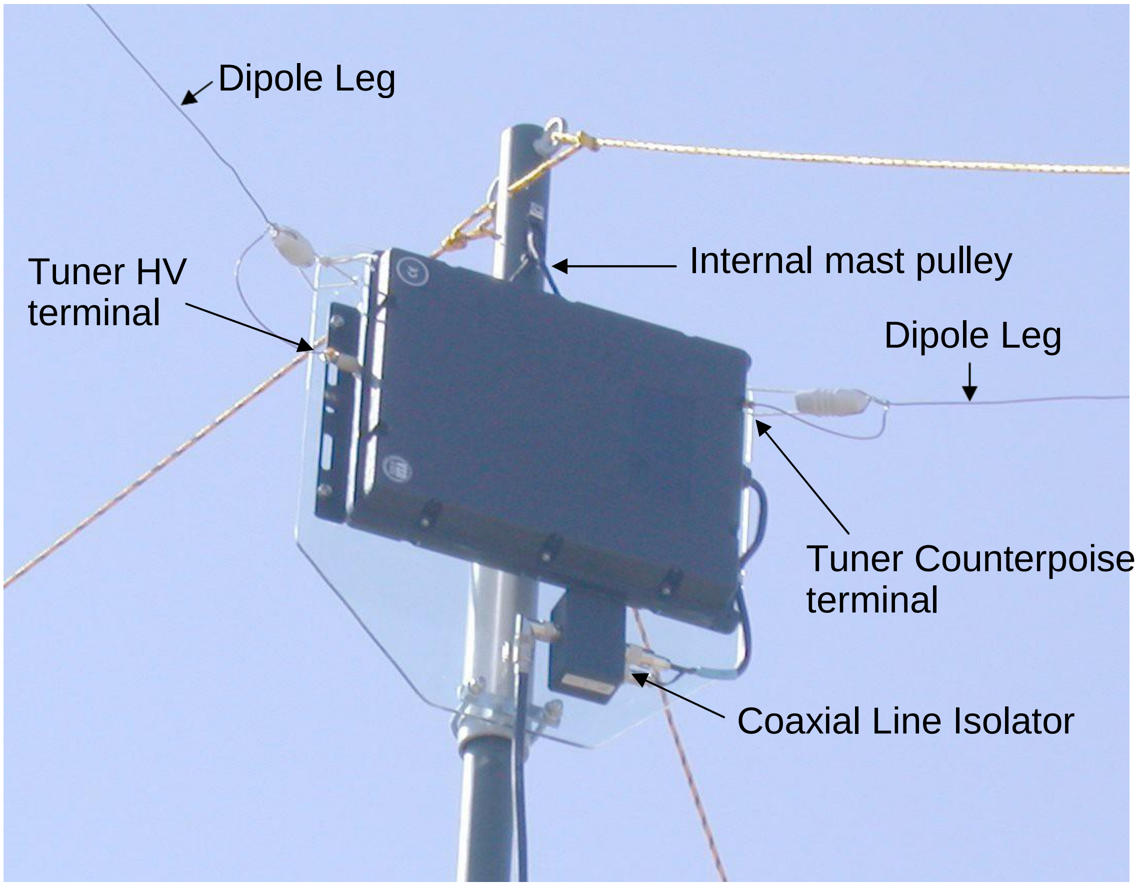


Figure 34: Portable Auto-Tuner Photograph

The SG-235 auto-tuner, mounted in a protective housing, is in use at the Texas Joint Force Headquarter, building 10 Camp Mabry, TSA San Antonio, and my personal QTH. More details can be found in Appendix 2.

Conclusions

The directivity pattern of a NVIS antenna should optimize transmission and reception from the ionosphere at high angles while rejecting distant, low angle noise. The accepted range definition of 400 to 500 miles for NVIS operations, will require an elevation beam width of approximately 100 º and an omnidirectional azimuth pattern. Significant frequency agility is required, since the NVIS operating frequency must be below the local critical frequency but as high as possible to minimizing daytime D-layer absorption losses. Maintaining proper antenna directivity and impedance matching over an octave of frequency requires special considerations. Single or multiple dipoles at heights in the vicinity of 40 to 50 ft. and feed with low loss transmission line can achieve the requirements for effective NVIS antenna performance.

APPENDIX 1
Antenna Examples

Many members of Texas Army MARS have excellent NVIS antennas systems. The examples below represent three different general approaches by the membership to achieve acceptable NVIS antenna performance.

Single Inverted-V with Rig-Located Tuner

This antenna system and its modeled SWR are shown in Figure A-1

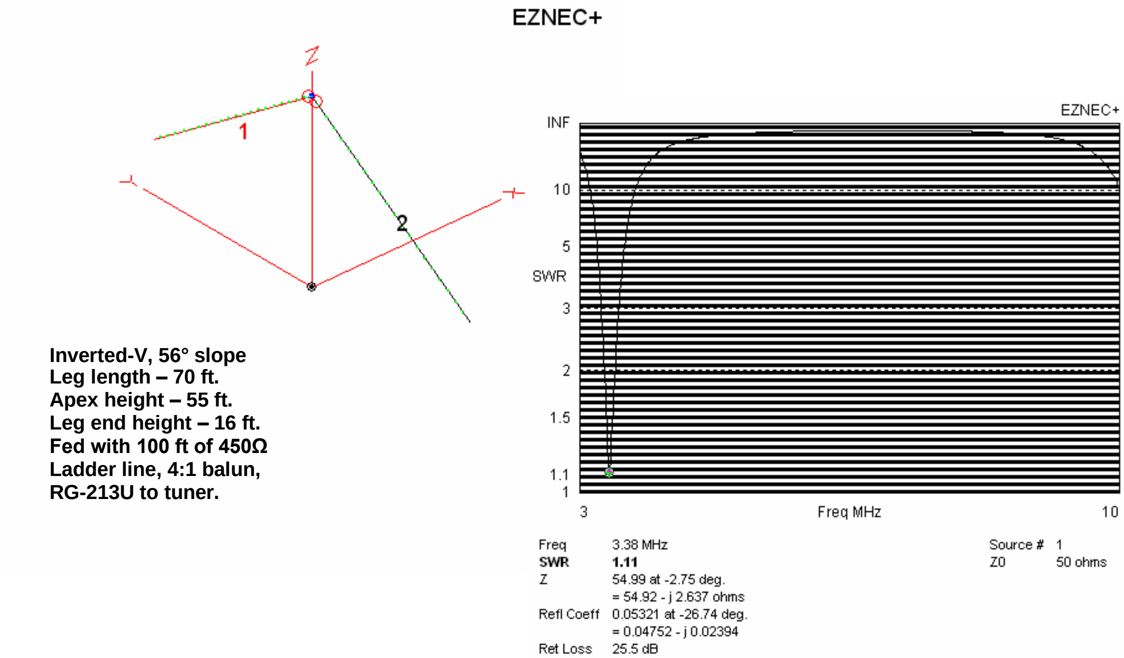


Figure A-1: Inverted-V NVIS Antenna

Antenna directivity patterns for a number of frequencies can be seen in Figures A-2 through A-6.

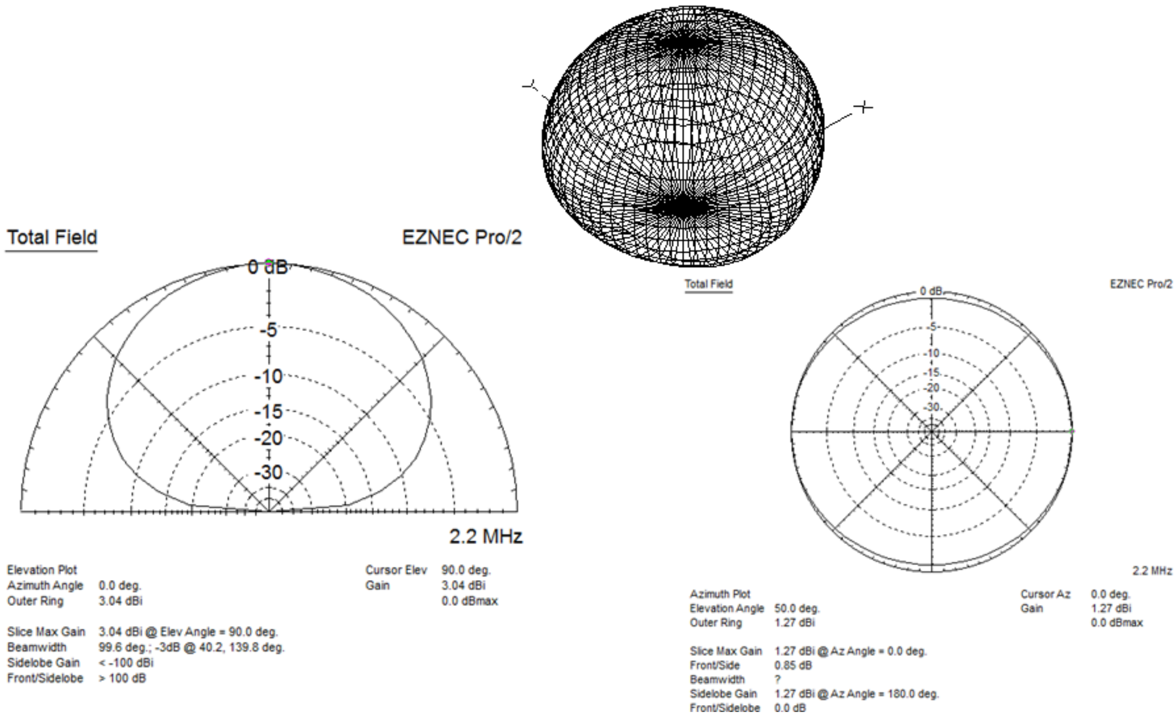


Figure A-2: Inverted-V Antenna Patterns at 2.2 MHz

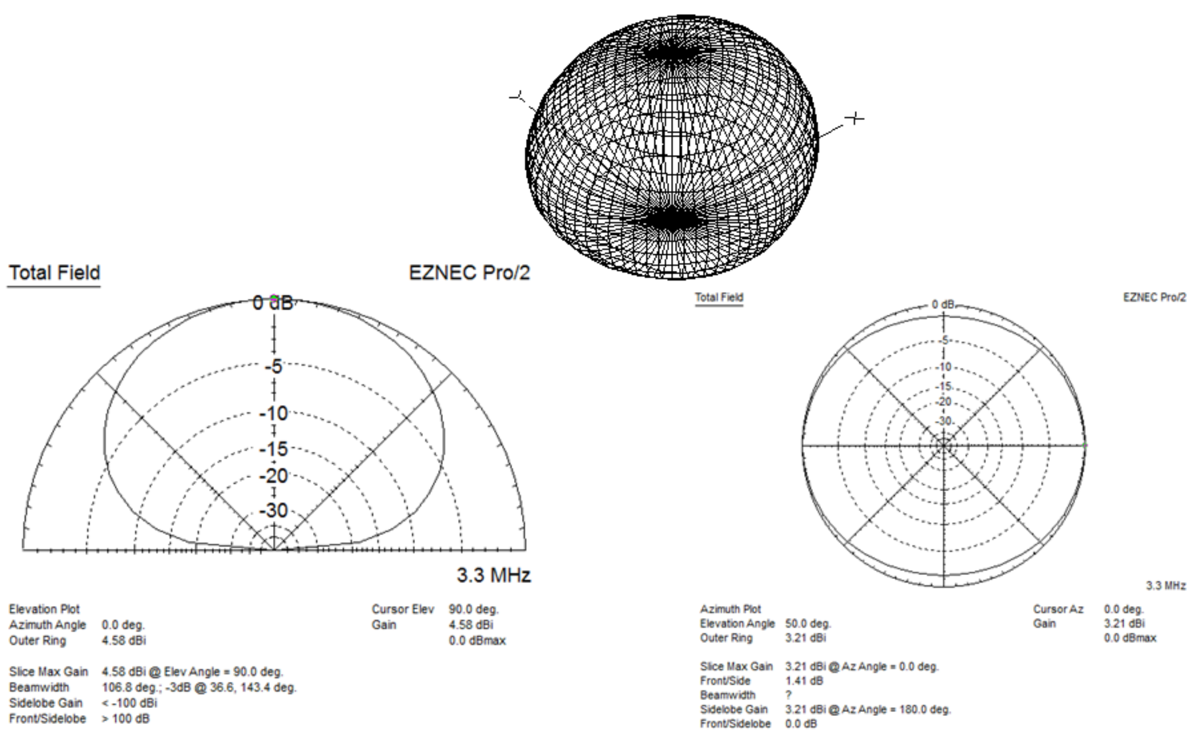


Figure A-3: Inverted-V Antenna Patterns at 3.3 MHz

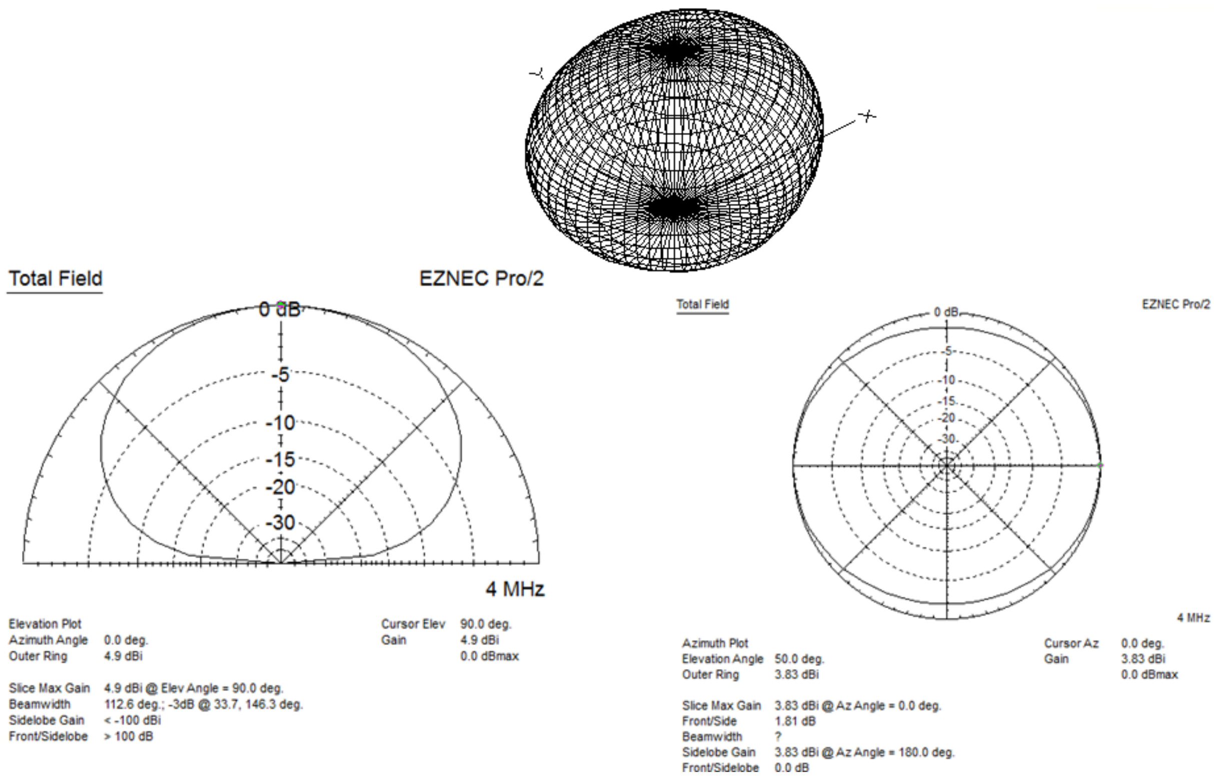


Figure A-4: Inverted-V Antenna Patterns at 4 MHz

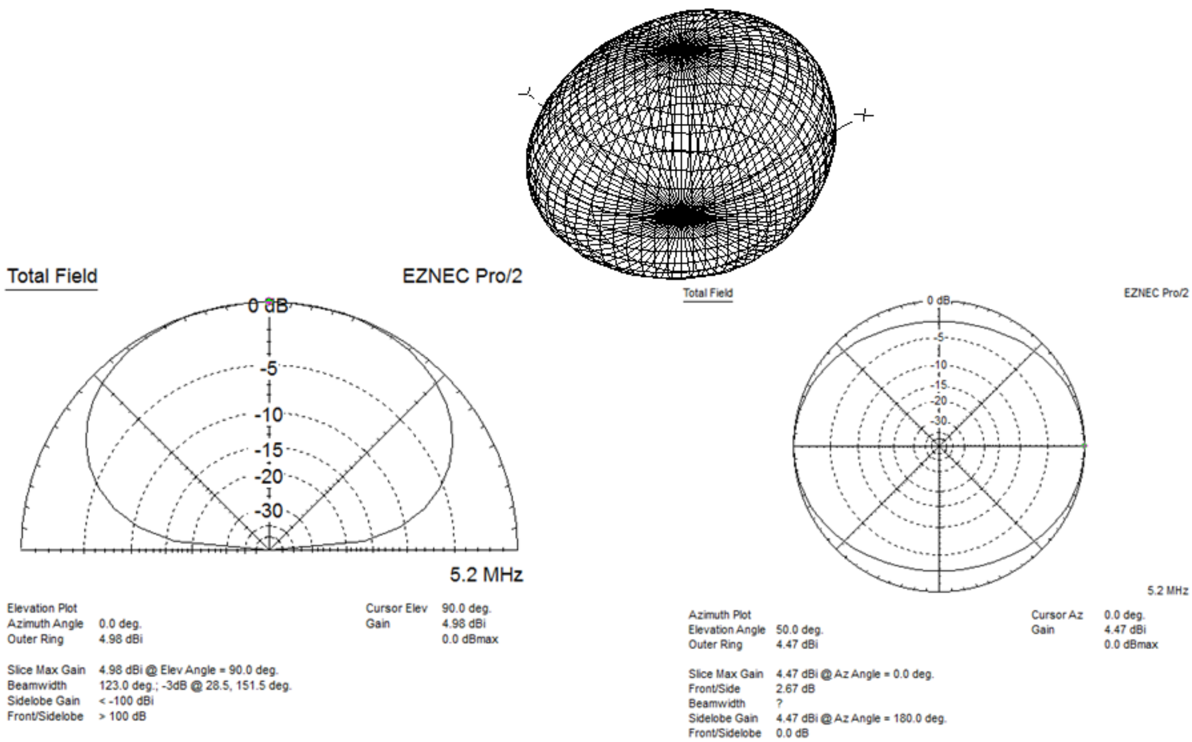


Figure A-5: Inverted-V Antenna Patterns at 5.2 MHz

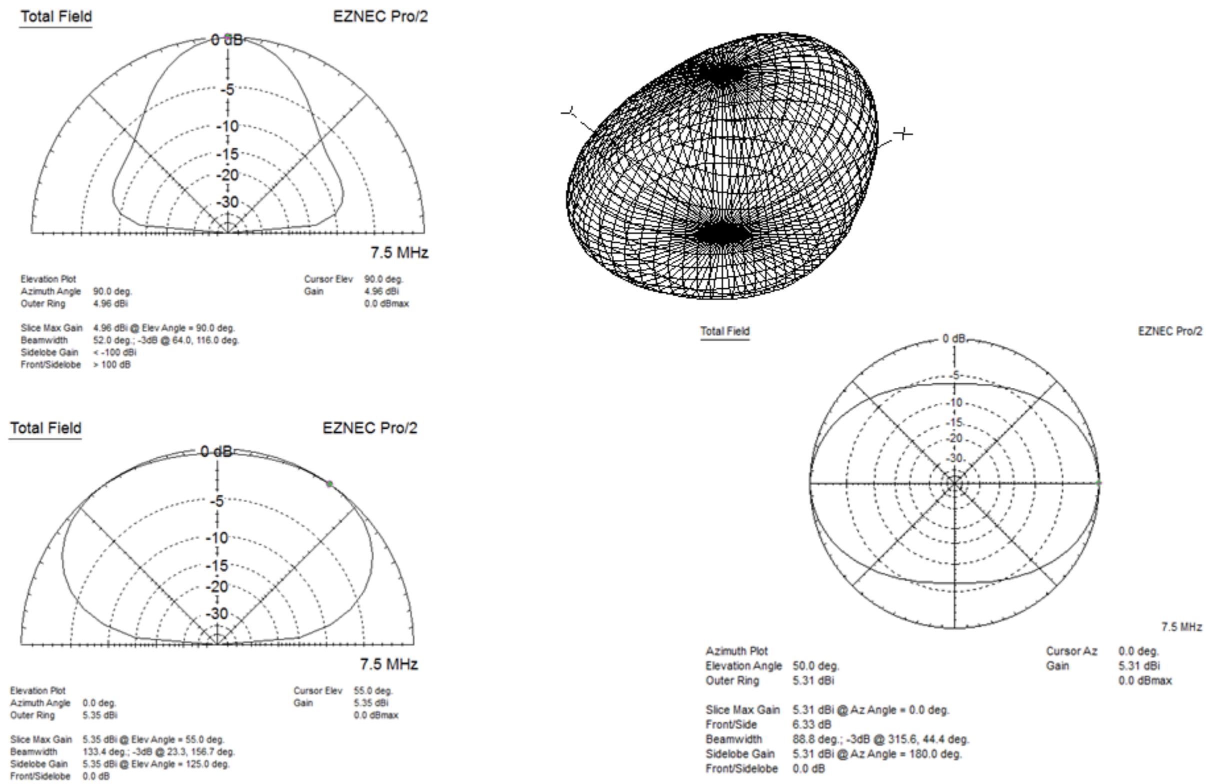


Figure A-6: Inverted-V Antenna Patterns at 7.5 MHz

Analysis –The average height of this single dipole is 35.5 ft., an ideal height for NVIS performance from 3 to 7 MHz. The length of the dipole legs are ideal for frequencies to 5 MHz, but as can be seen in Figures A-6, a little long for frequencies above 7 MHz. The use of ladder-line and minimal coax cable minimizes transmission line losses, allowing almost all the transmitter power to reach the antenna. The inverted-V configuration helps maintain directivity patterns but does reduces gain in comparison to the same antenna configured as a horizontal dipole.

Multiple or “Fan” dipoles

The antenna, see in Figure A-7 consists of three dipoles connected to a common driven point. The antenna systems exhibits multiple resonances based on the length of each dipole as seen in Figure A-8.

Height – 38 ft.
Legs 1, 2 – 76.5 ft.
Legs 4, 5 – 39.6 ft.
Legs 6, 7 – 50 ft.
Note that leg 3 is EZNEC connection
Requirement
End heights:
Leg 1 – 24.3 ft.
Leg 2 – 25.2 ft.
Leg 4 – 29 ft.
Leg 5 – 29.7 ft.
Leg 6 – 28 ft.
Leg 7 – 28.7 ft.

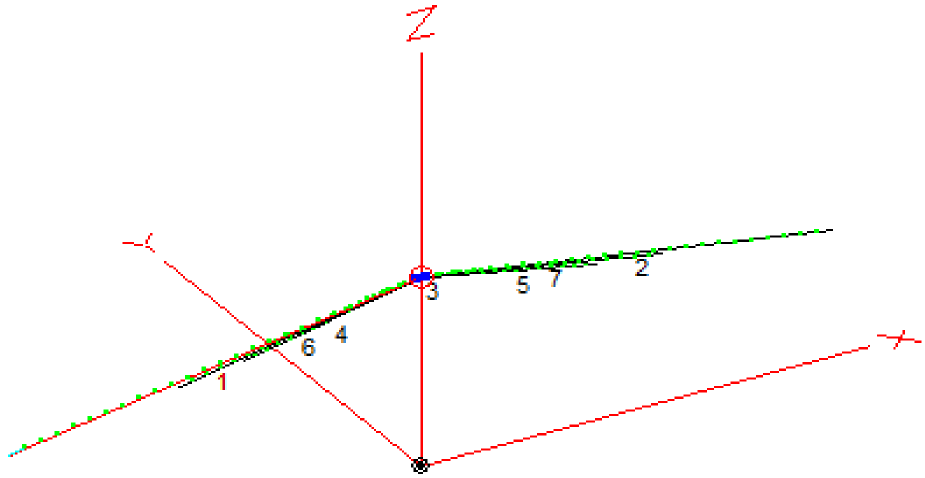


Figure A-7: Fan Dipole

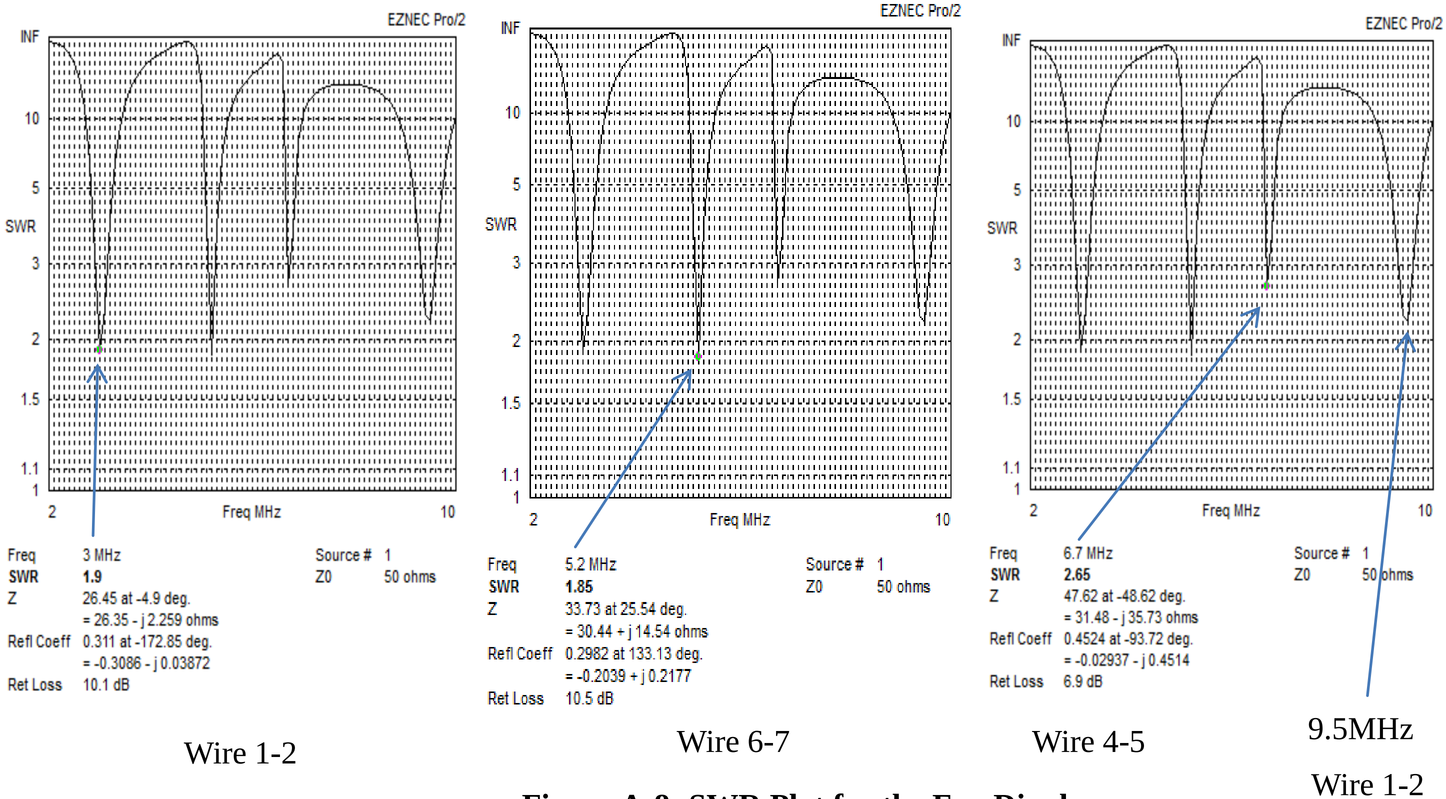


Figure A-8: SWR Plot for the Fan Dipole

Note that in between resonant frequencies, the SWR is still very high requiring wide-bandwidth tuning techniques previously discussed. The strength of this design is that the directivity patterns at different frequencies maintain reasonable directivity patterns while not compromising gain. Figure A-9 through A-13 shows the azimuth and elevation patterns for this antenna at different frequencies.

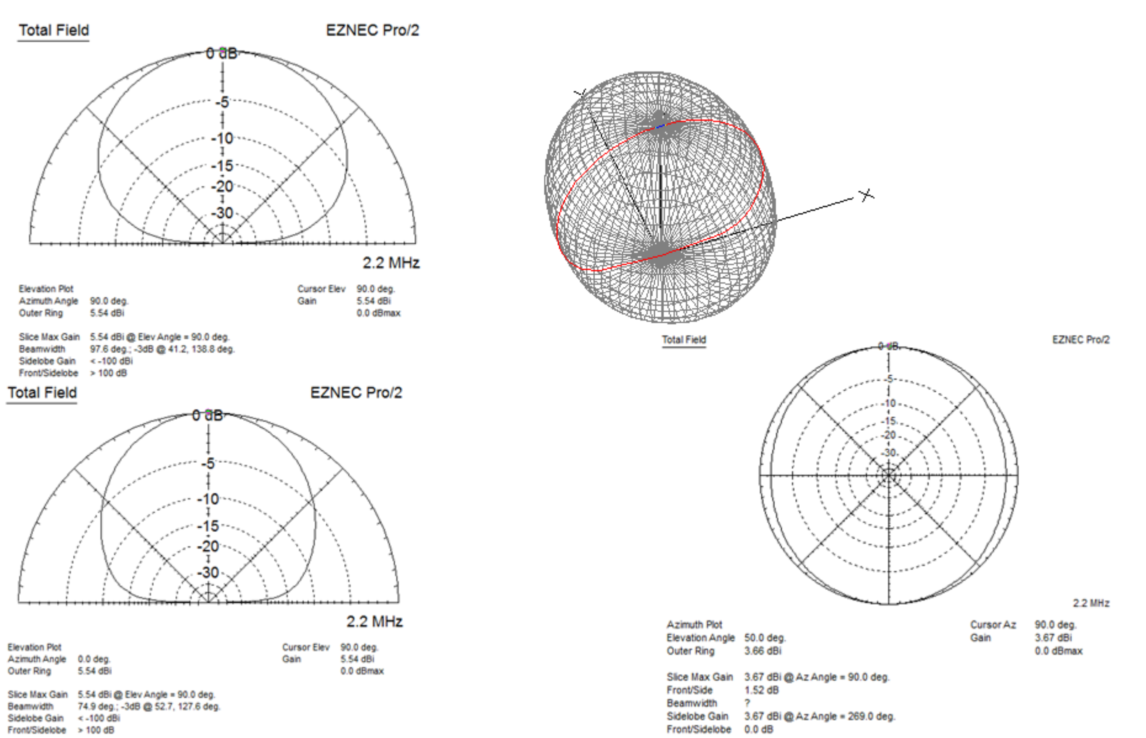


Figure A-9: Fan Dipole Antenna Patterns for 2.2 MHz

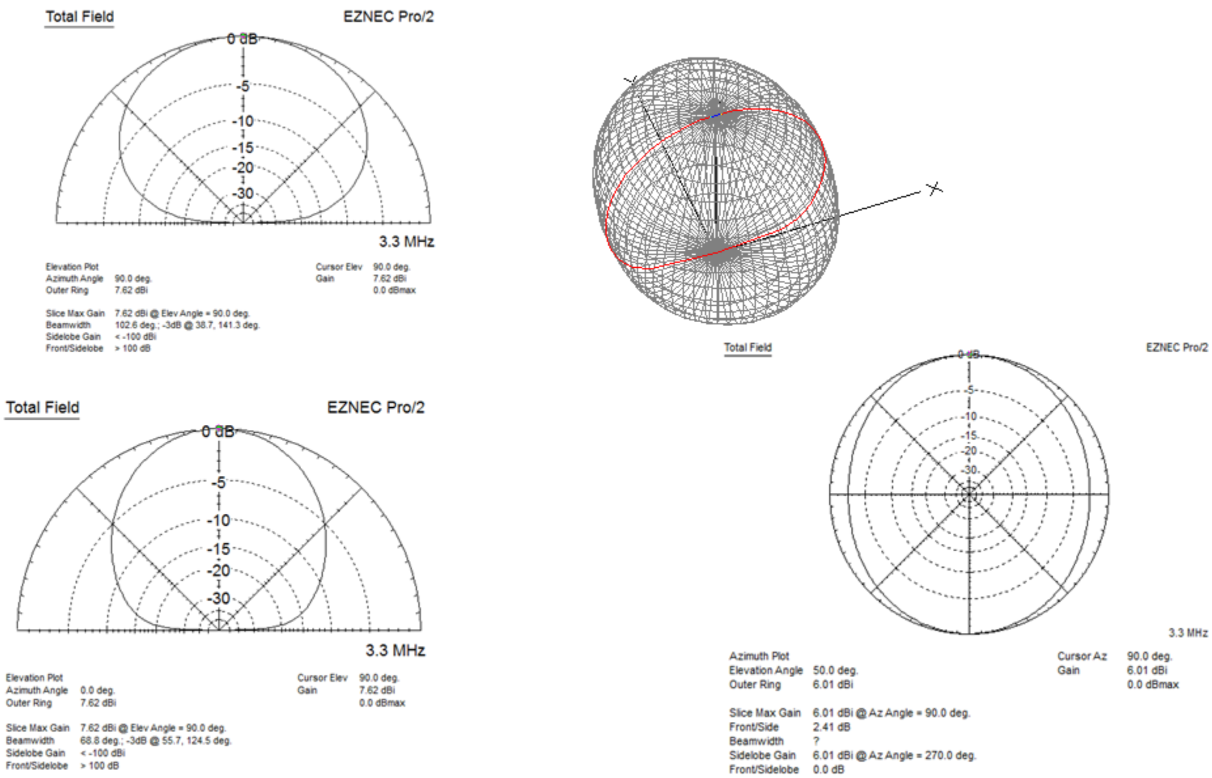


Figure A-10: Fan Dipole Antenna Patterns for 3.3 MHz

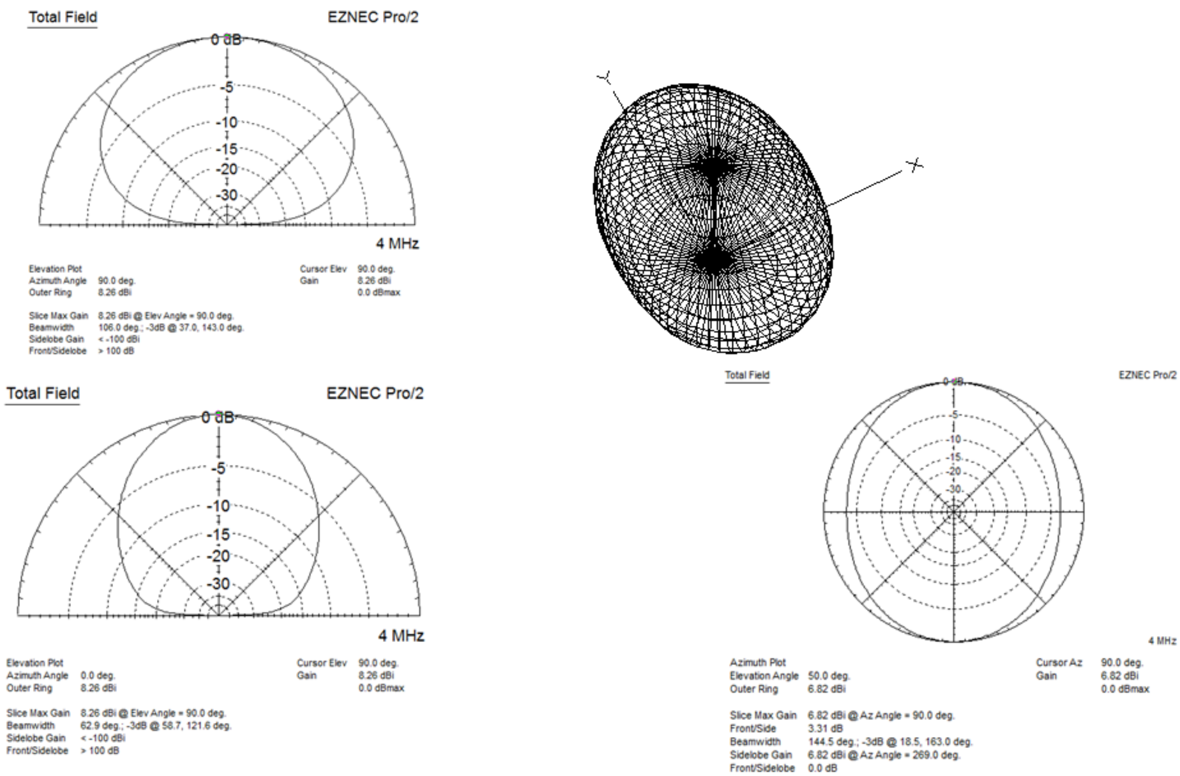


Figure A-11: Fan Dipole Antenna Patterns for 4 MHz

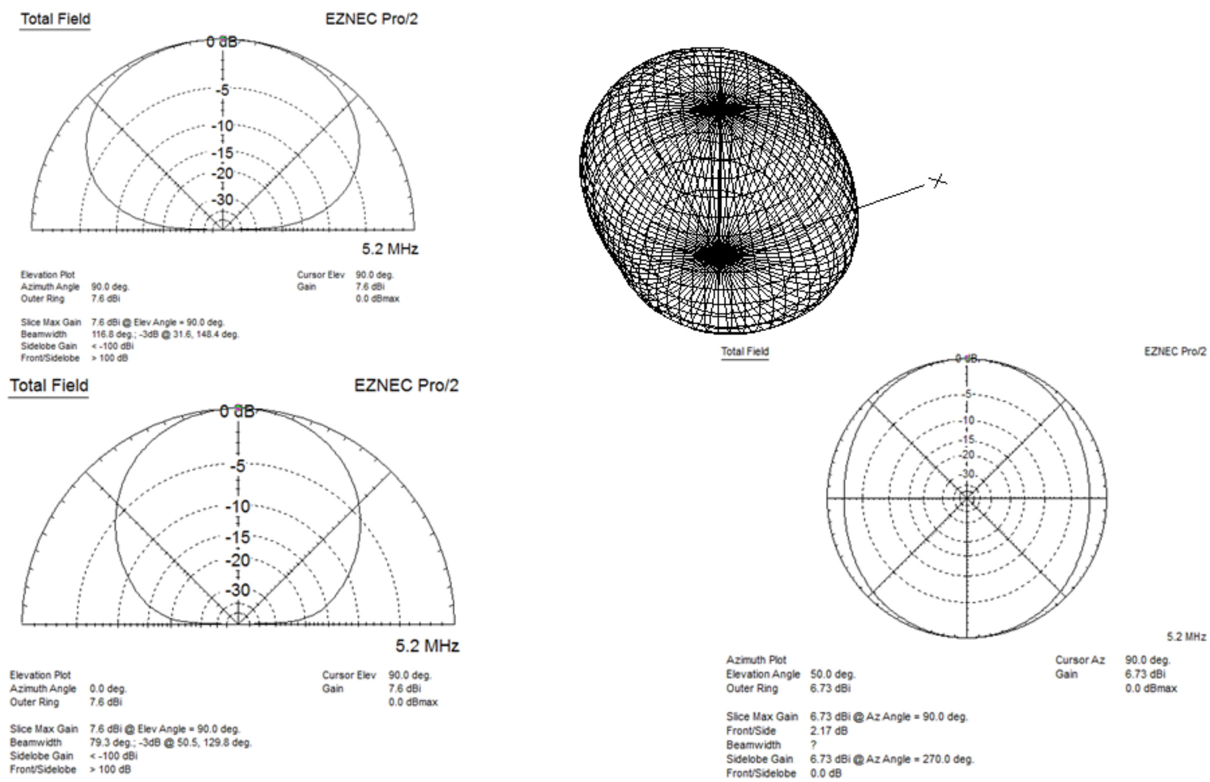
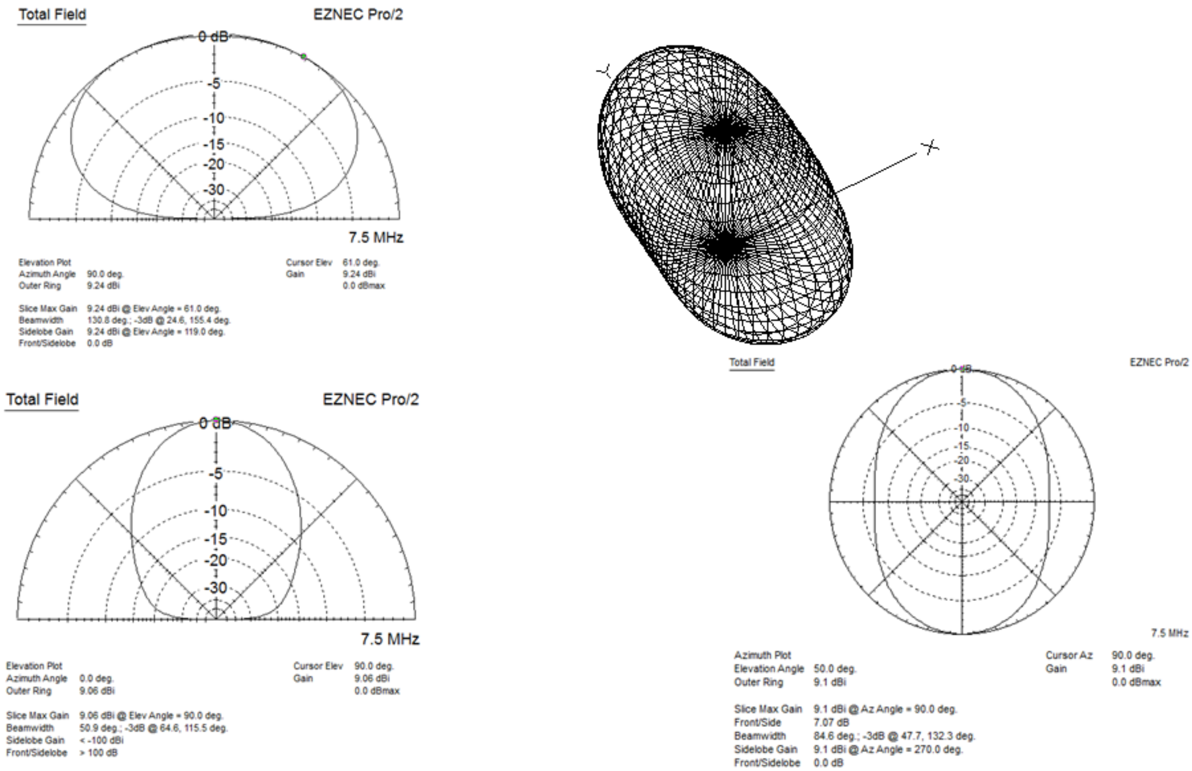


Figure A-12: Fan Dipole Antenna Patterns for 5.2 MHz



A-13: Fan Dipole Antenna Patterns for 7.5 MHz

Analysis – This antenna is a re-design of an early antenna that is now optimized for the lowest MARS HF frequencies. The impedance of each dipole is such that only around its resonance does it absorb and radiate power, therefore controlling the directivity pattern. The first three frequencies, 2.2 MHz, 3.2 MHz and 4 MHz use dipole 1-2. The 5 MHz frequency uses the middle length dipole 6-7 and the 7.5 MHz frequency uses the shortest dipole. This antenna was not designed to be resonant at all MARS frequencies, but rather to provide optimum directivity patterns with a minimum number of dipoles. Note that this antenna has approximately 3dBi more gain when compared with the Inverted-V example. To achieve reasonable directivity patterns, the Inverted-V antenna compromised gain. The Fan Dipole achieves similar reasonable patterns by using multiple dipoles.

Long-Wire Antenna

The long-wire antenna and its SWR Plot are shown in Figures A-14 and A-15.

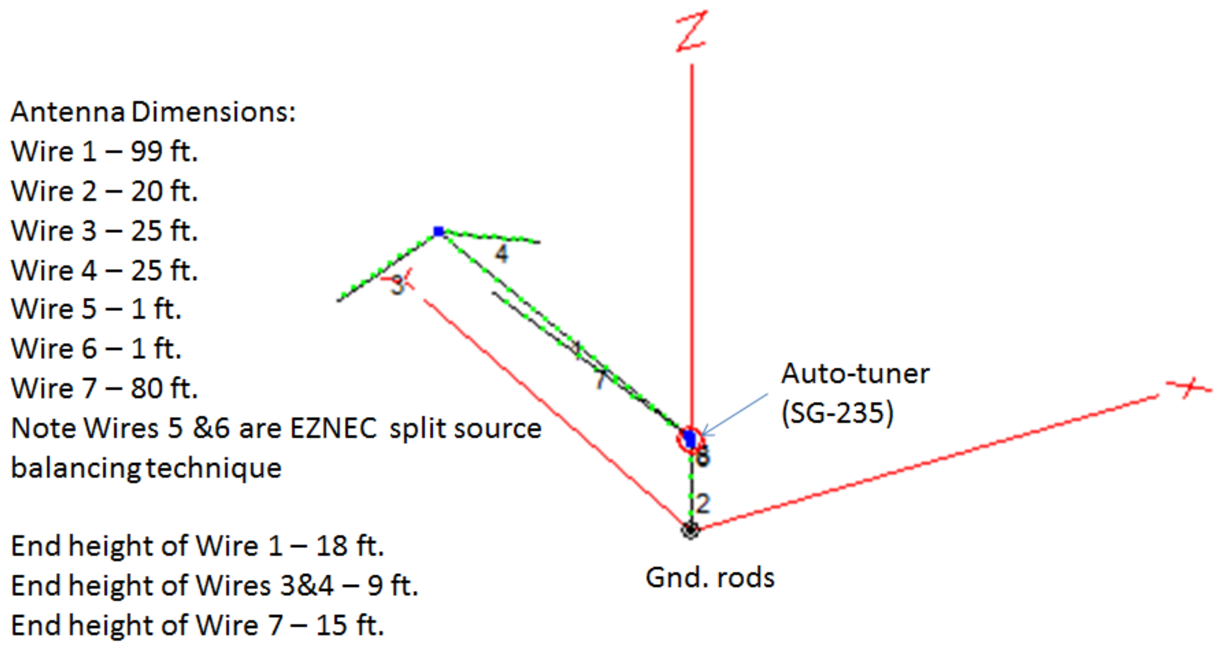


Figure A-14: Long-Wire NVIS Stealth Antenna

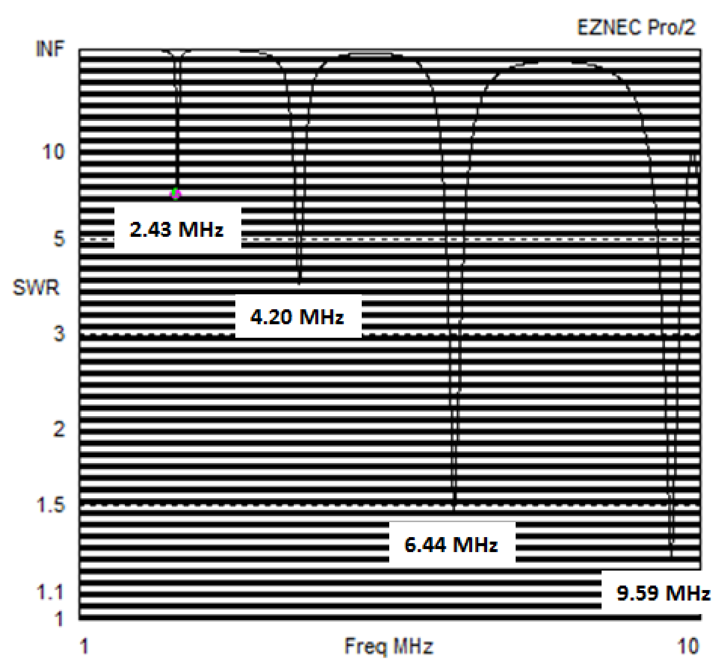


Figure A-15: Long-Wire SWR Plot

The dimensions of this antenna are limited by back yard dimensions (100 ft. x 80 ft.) and the need to be of low visibility and yet operate adequately at MARS frequencies. The antenna consists of a two long-wires (wire 1 & 7) connected to an auto-tuner with a grounded counterpoise (wire 2). Wires 3 & 4 act as “capacitor-hats” to extend tuning down to 2.2 MHz. Wires #1, 3 & 4 are the dominant radiators for 2.2 MHz. Wire #7 is the dominant radiator for 3.3MHz and 4 MHz. All the wires contribute to the radiation at 5.2 MHz, 6.8 MHz and 7.5 MHz. The horizontal wires are below the minimum recommended height of 0.1 wavelengths for frequencies below 5 MHz, yet performs adequately even down to 2.2 MHz. The AWG #14 copper wire is almost invisible from the side street next to the house at a range of 50 ft. The auto-tuner is mounted in a NMEA box on the back side of the house chimney and painted the same color as the house. Figures A-16 through A-22 show the azimuth and elevation patterns for this long-wire antenna.

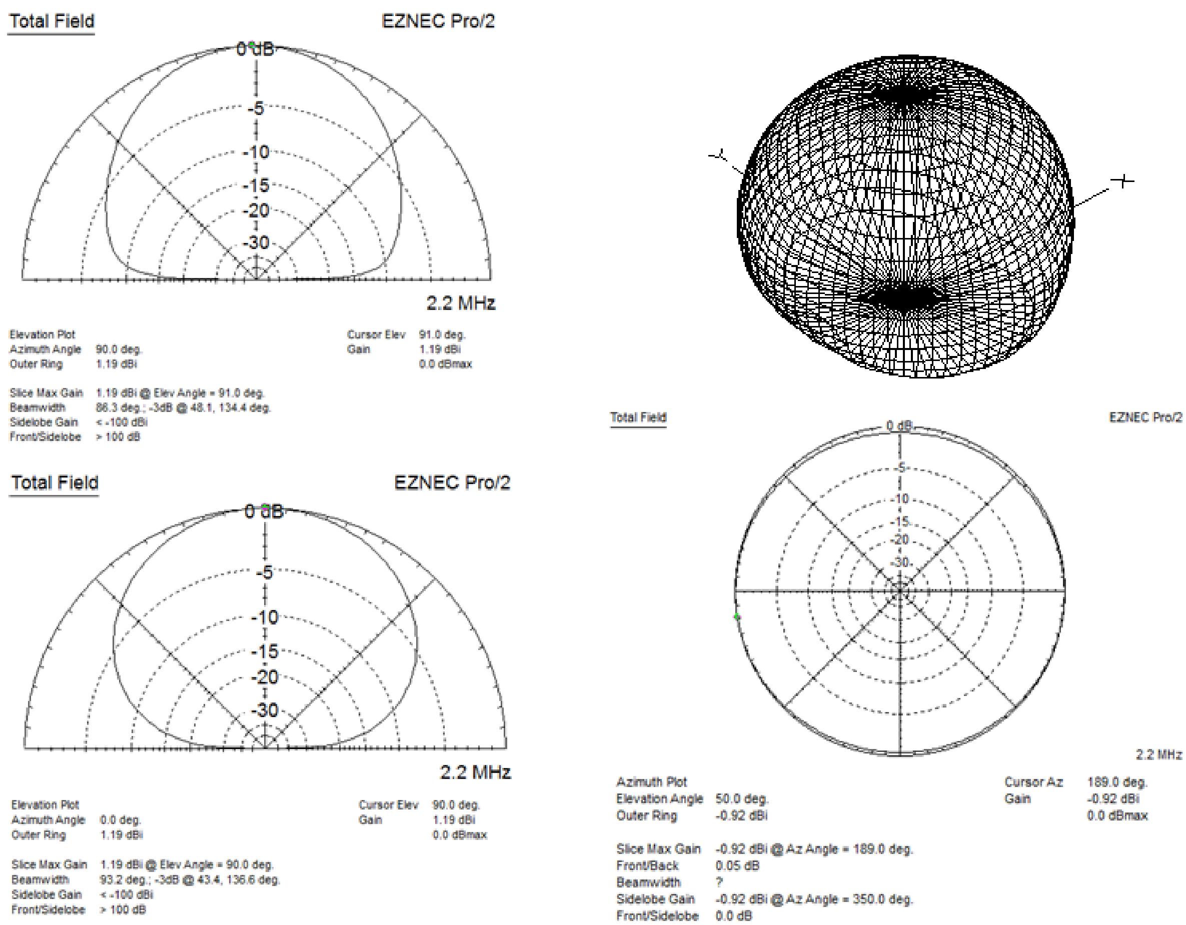
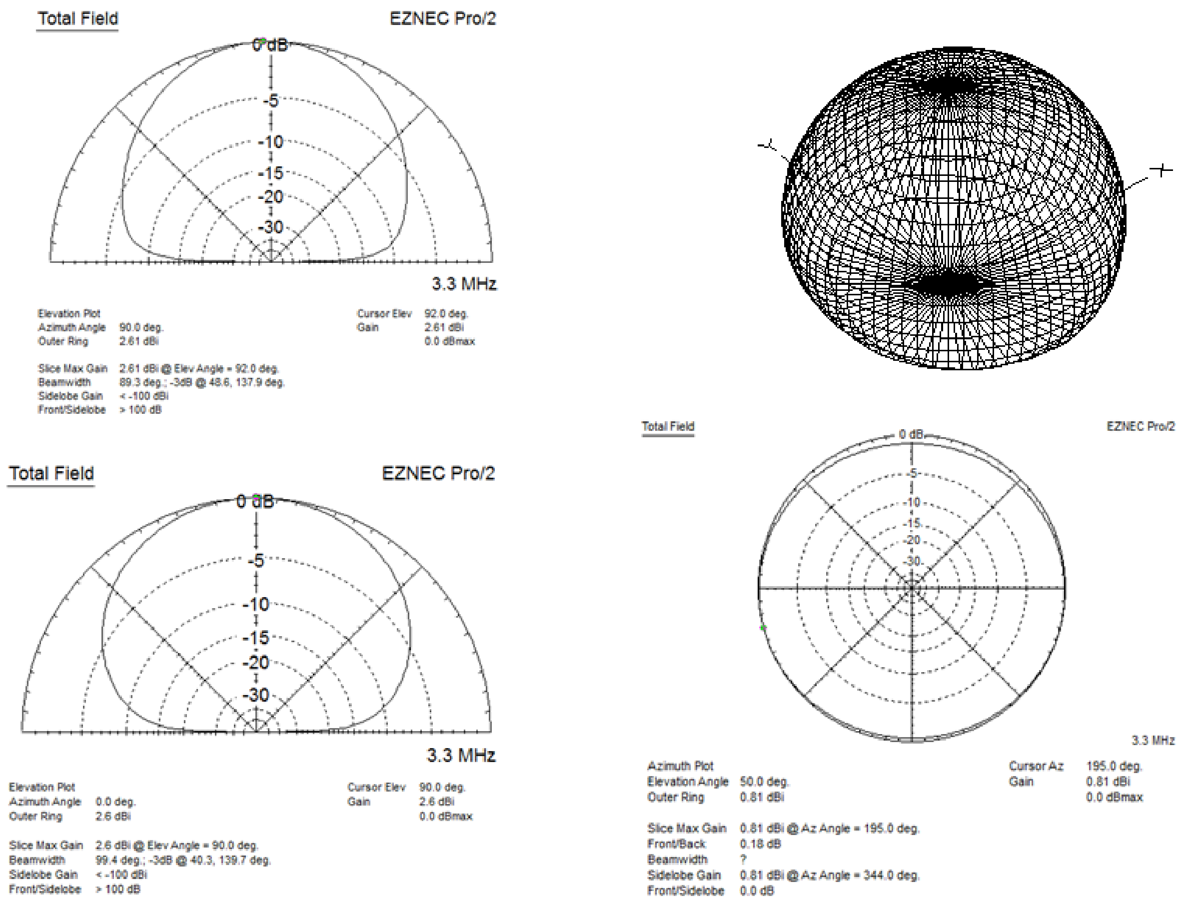
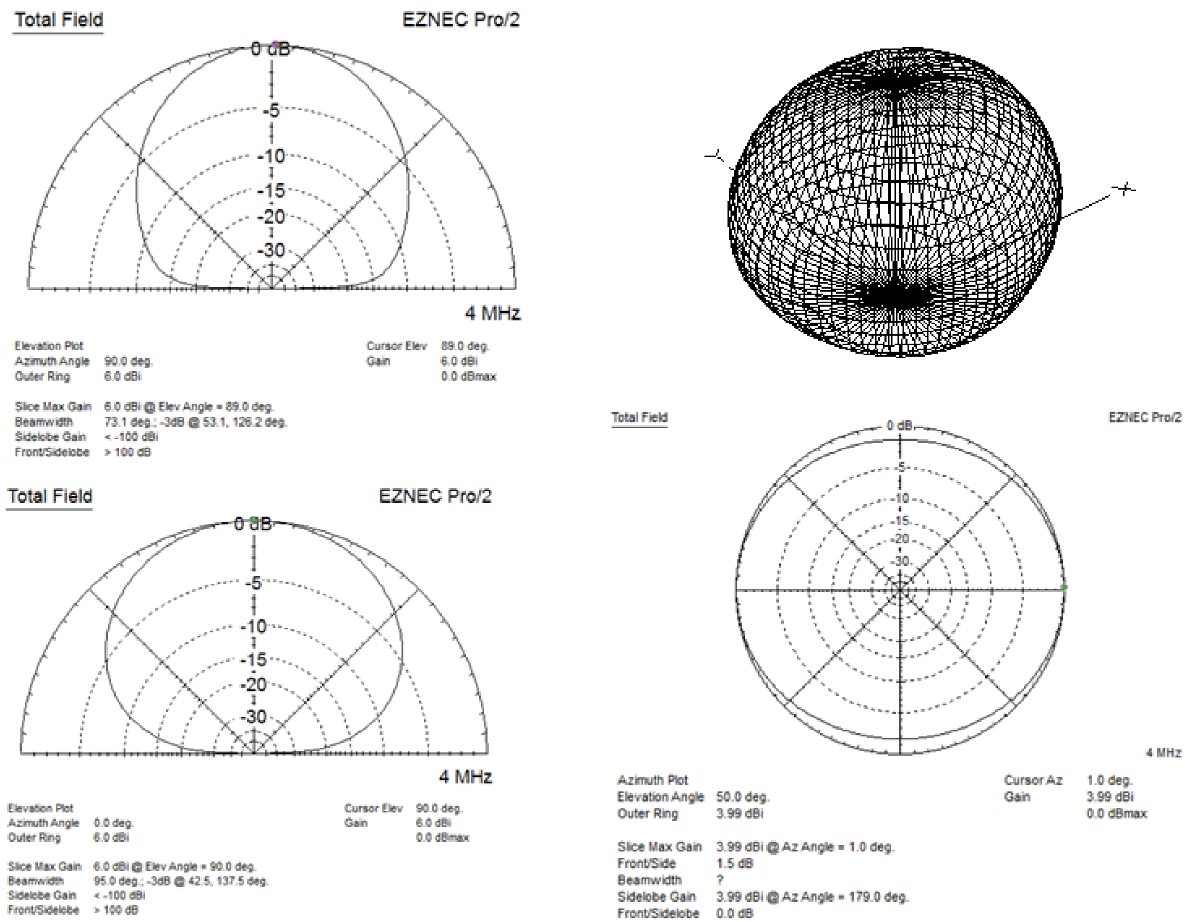


Figure A-16: Long-Wire Antenna Patterns at 2.2 MHz



A-17: Long-Wire Antenna Patterns at 3.3 MHz



A-18: Long-Wire Antenna Patterns at 4 MHz

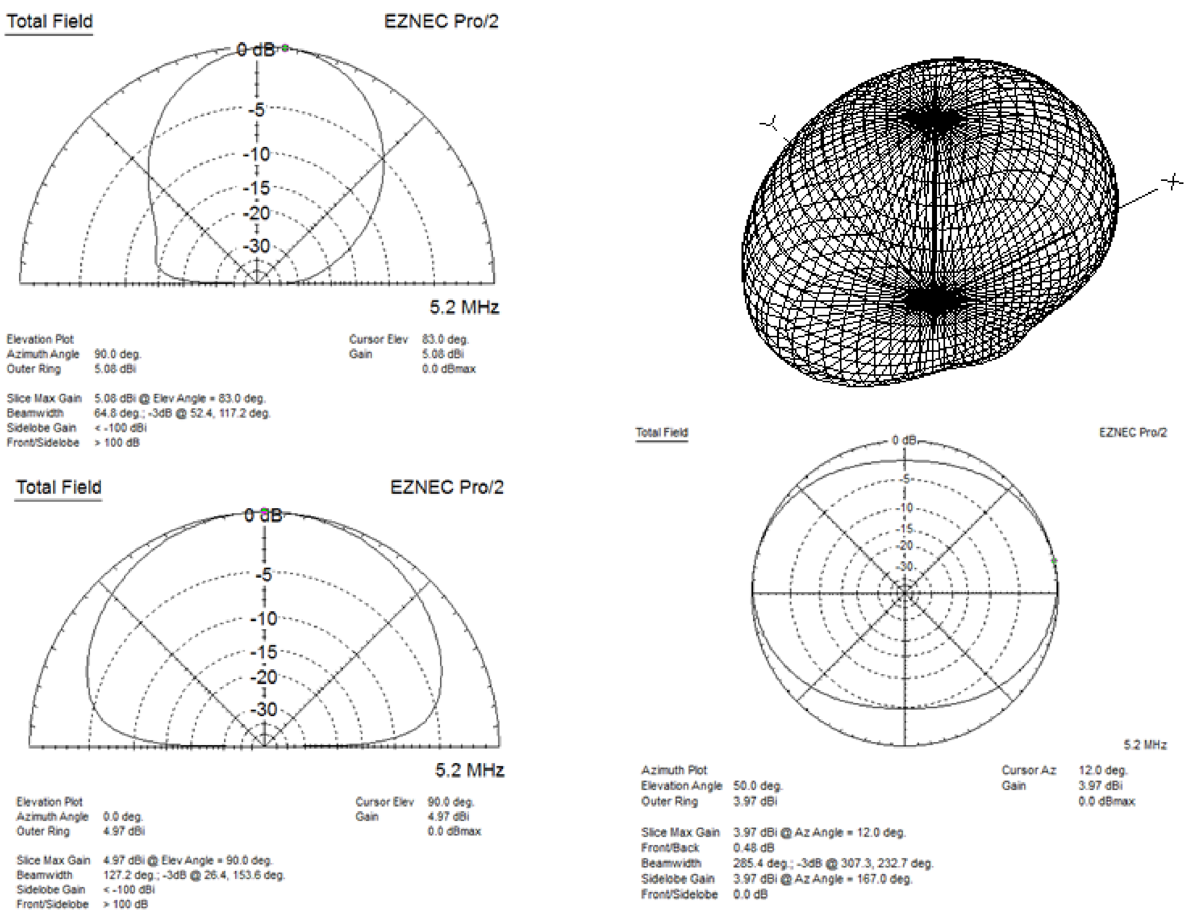


Figure A-19: Long-Wire Antenna Patterns at 5.2 MHz

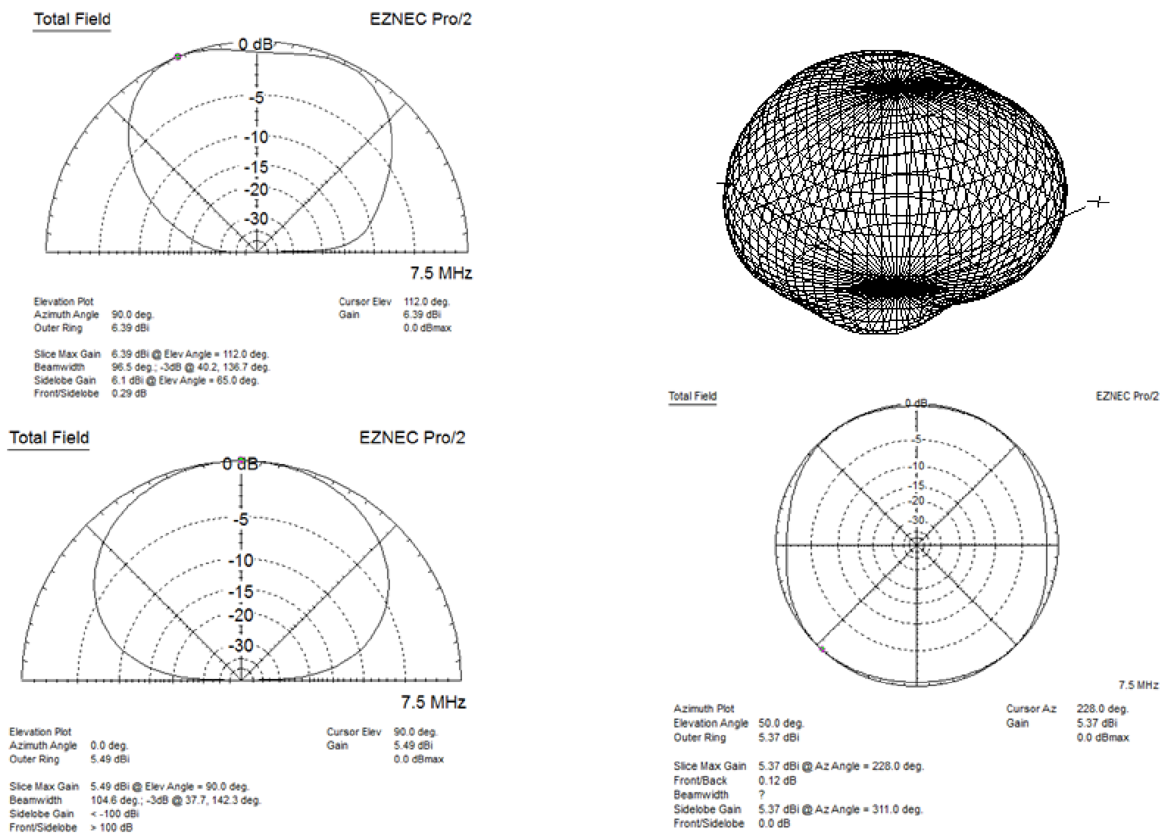


Figure A-20: Long-Wire Antenna Patterns at 7.5 MHz

Analysis – This long-wire antenna performs well at frequencies up to and including 8 MHz. At 9.3 MHz and above, the directivity pattern develops a high angle notch and most of the radiation is at low angles, good for long distance skip for stations oriented at right angles to the horizontal wires.

Example Conclusions

All three of these antennas have shown themselves to be good performers on Texas Army MARS nets. The inverted-V is simplest to implement but its efficiency is dependent on height and careful detail to minimize feed-line losses. The fan-dipole antenna is the best preforming antenna of these examples but again optimum height and minimizing feed line losses must be addressed. Finally, the long-wire antenna demonstrates that a low, stealthy wire antenna can perform well, if transmission line losses are minimized by locating the auto-tuner at the feed point.

Appendix 2
External Auto-tuner Examples

Background

The military and marine HF radio communities just like MARS have to operate over a wide range of HF frequencies. To minimize transmission line losses they typically locate an auto-tuner at or close to the antenna. The standard "green" radio for the U.S. Army is the Harris Falcon II. It has only a 20 watt output and a limited internal auto-tuner. For mobile and fixed site operation, the Falcon II is paired with either a 125 or 400 watt amplifier and a remotely located auto-tuner (RF-382 series). The amplifier can be located several hundred feet away from the auto-tuner and antenna. The auto-tuner series are water-proof and designed to be mounted with the antenna. The RF-382 can be seen in Figure 25, page 16, just under and connected to the Harris loop antenna.

Description of Function

All auto-tuners contain complex electronics that include a microprocessor , RF sampling electronics and wide range of inductors and capacitors. The typical auto-tuner, using RF from the transmitter, measures the antenna impedance and selects inductors and capacitors to transform the antenna impedance to 50 ohms real (no reactive component). It then "remembers" these component values for that frequency for future reference that will be used to speed up tuning the next time that frequency is encountered. This "memory tuning" capability is fast enough to allow ALE transmit scanning.

Vulnerabilities

The complexity of the an auto-tuner and its proximity to the antenna and possible remoteness from the operating area, makes it vulnerable to damage by either direct lightning strikes or Electromagnetic Pulse (EMP) damage. The manufacturer's cases of the auto-tuners are either not water-proof or can be damaged by UV radiation from the sun. Solutions to these issues and on-going testing will be discussed next.

Protective Enclosures

A number of companies make weather resistant, outdoor housing meeting the NEMA (National Electrical Manufacturers Association) standards. These housings come in a variety of sizes and materials and are reasonably priced. Both the steel and fiberglass housings listed below have demonstrated excellent resistance to precipitation and UV sun damage. One steel and five fiberglass housings have been in service without problems for 8 years. Two housings that can house either the SGC 230/235 series or the MFJ-994BRT and MFJ-998RT are listed below. The steel housing provides EMP protection (Faraday shield), but is much heavier and requires periodic paint touchup to prevent rusting.

Hammon Manufacturing EJ16146- steel (16" X 14" X 6" – 21 lbs.)
Allied Electronics, Inc. #70166780 - $120.14

Hammon Manufacturing PJ16148 – fiberglass (16.28" X 14.1" X 8.13" – 12 lbs.)

Allied Electronics, Inc.   #70166906 - $113.54

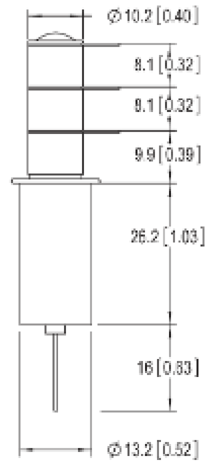
An internal mounting plate can be ordered for either box and will be needed to mount the SGC 230/235 tuners and the MFJ-994BRT.   Hammon Manufacturing makes a complete series of these two housing types in different sizes that can house a number of other auto-tuners.   For example, the SG239 and HV relay fit nicely in the PJ1086H.

<u>EMP and Limited Lightning Protection</u>

A high voltage relay shown in Figure A-21, is being used in a number of auto-tuner to switch the auto-tuner output from the antenna to tuner ground (counterpoise) when not in service. Schematic diagrams of this relay in use in two different auto-tuner designs can be seen in Figure A-23 and A-24. The cost of the Gigvac relay has increased dramatically in 2017. The “Ham” program in which a licensed amateur radio operator could purchase two relays a year for about $90 each has ended. The present price for the G41C232 is $270 each. A cheaper alternative is shown in Figure A-22. The Greenstone VHC-3 is available from Henry Radio for $79.95.   Alternative techniques using Gas Discharge Tubes are being explored. But the extreme sensitivity of the SGC design to EMP damage makes this option not favorable. The MFJ design appears to have less susceptibility to damage.

FEATURES

- RF efficient design offers high power handling in a small package
- Tungsten contacts improve hot load switching
- Contact GIGAVAC Applications Support for load capability
- Can be mounted in any position, any axis



PRODUCT SPECIFICATIONS

Contact & Relay Ratings	Units	G41
Contact Form		C
Contact Arrangement		SPDT
Voltage, Test Max., Contacts & to Base (15 µA Leakage Max., dc or 60Hz)	kV Peak	6
Voltage, Operating Max., Contacts & to Base (15 µA Leakage Max.)		
dc or 60 Hz	kV Peak	5
2.5 MHz	kV Peak	4.5
16 MHz	kV Peak	3.5
32 MHz	kV Peak	2.8
Current, Load Switching		Consult Factory
Current, Continuous Carry Max		
dc or 60 Hz	Amps	30*
2.5 MHz	Amps	24
16 MHz	Amps	16
32 MHz	Amps	12
Coil Hi-Pot (V RMS, 60 Hz)	V	500
Capacitance		
Across Open Contacts	pF	1.2
Contacts to Ground	pF	1.2
Resistance, Contact Max @ 1A, 28 Vdc	ohms	0.02
Operate Time	ms	10
Release Time	ms	10
Life, Mechanical	cycles	2 million
Weight, Nominal	g (oz)	28 (1)
Vibration, Operating, Sine (55-2000 Hz Peak)	G's	10
Shock, Operating, 1/2 Sine11ms (Peak)	G's	50
Temperature Ambient Operating	°C	-55 to +125

*Consult factory for load switching applications.

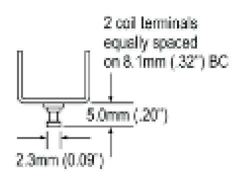
COIL RATINGS

Nominal, Volts dc	12	26.5	115
Pick-up, Volts dc, Max.	8	16	80
Drop-Out, Volts dc	.5 - 5	1 - 10	5 - 50
Coil Resistance (Ohms ±10%)	70	290	4700

PART NUMBER SYSTEM

G41C	3	3	4
Coil Voltage	**2** = 12 Vdc, Bus Wire **3** = 26.5 Vdc, Bus Wire **4** = 115 Vdc, Bus Wire **7** = 12 Vdc, Turret Terminal **8** = 26.5 Vdc, Turret Terminal **9** = 115 Vdc, Turret Terminal		
High Voltage Connections		**3** = Solder Connection	
Mounting			**2** = 3-hole Flange **4** = Std Flange

Turret Terminal



3-Hole Flange

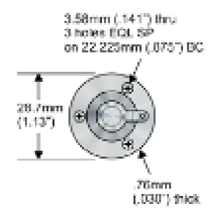


Figure A-21: High Voltage Relay - Gigvac

PRODUCT SPECIFICATIONS				
Contact & Relay Ratings		Units	VHC1	VHC3
Contact Form			C	C
Contact Arrangement			SPDT	SPDT
Test Voltage(KV Peak), Test Max., Contacts & to Base(15µA Leakage Max., dc or 60Hz)		KV Peak	5	5
Rated Operating Voltage, (KV Peak), Contacts & to Base (15µA Leakage Max.)	dc or 60Hz	KV Peak	3.5	3.5
	2.5MHz	KV Peak	2.5	-
	16MHz	KV Peak	2	-
	32MHz	KV Peak	1.5	-
Continuous Current, Carry Max.	dc or 60Hz	Amps	25	18
	2.5MHz	Amps	14	-
	16MHz	Amps	9	-
	32MHz	Amps	7	-
Coil Hi-Pot(V RMS，60Hz）		V	500	500
Capacitance	Across Open Contacts	pF	2	-
	Contacts to Ground	pF	2.5	-
Resistance, Contact Max@ 1A，28Vdc		ohms	0.01	0.02
Operate Time, Max.		ms	6	6
Release Time, Max.		ms	6	6
Mechanical Life		Cycles	2 million	2 million
Weight		g（oz）	28（1）	28（1）
Vibration, sine(10-2000Hz Peak)		G's	10	10
Shock, 1/2 sine 11ms(Peak)		G's	50	50
Operating Temperature Ambient		℃	-55~+125	-55~+125

COIL RATINGS			
Nominal, Volts dc	12	26.5	115
Pick-up, Volts dc, Max	8	16	80
Drop-out, Volts dc	0.5-5	1-10	5-50
Coil Resistance (Ω±10%)	80	335	6000
*Ratings listed are for 25℃, sea level conditions			

Figure A-22: High Voltage Relay – Greenstone VHC-3

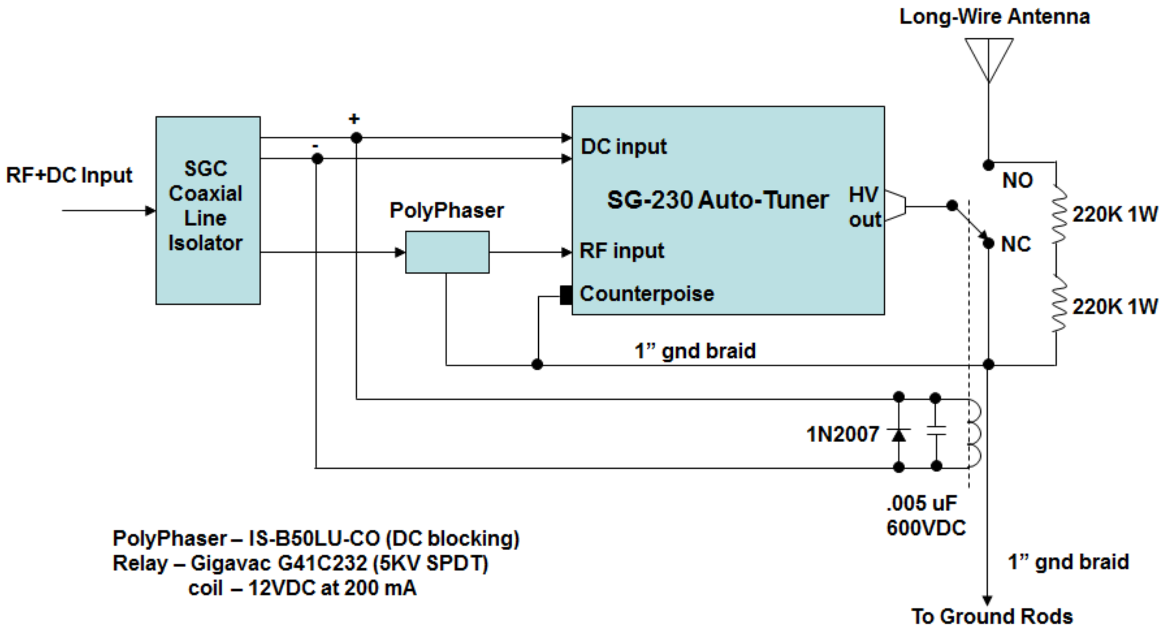


Figure A-23: SGC-230 with Single-ended Output

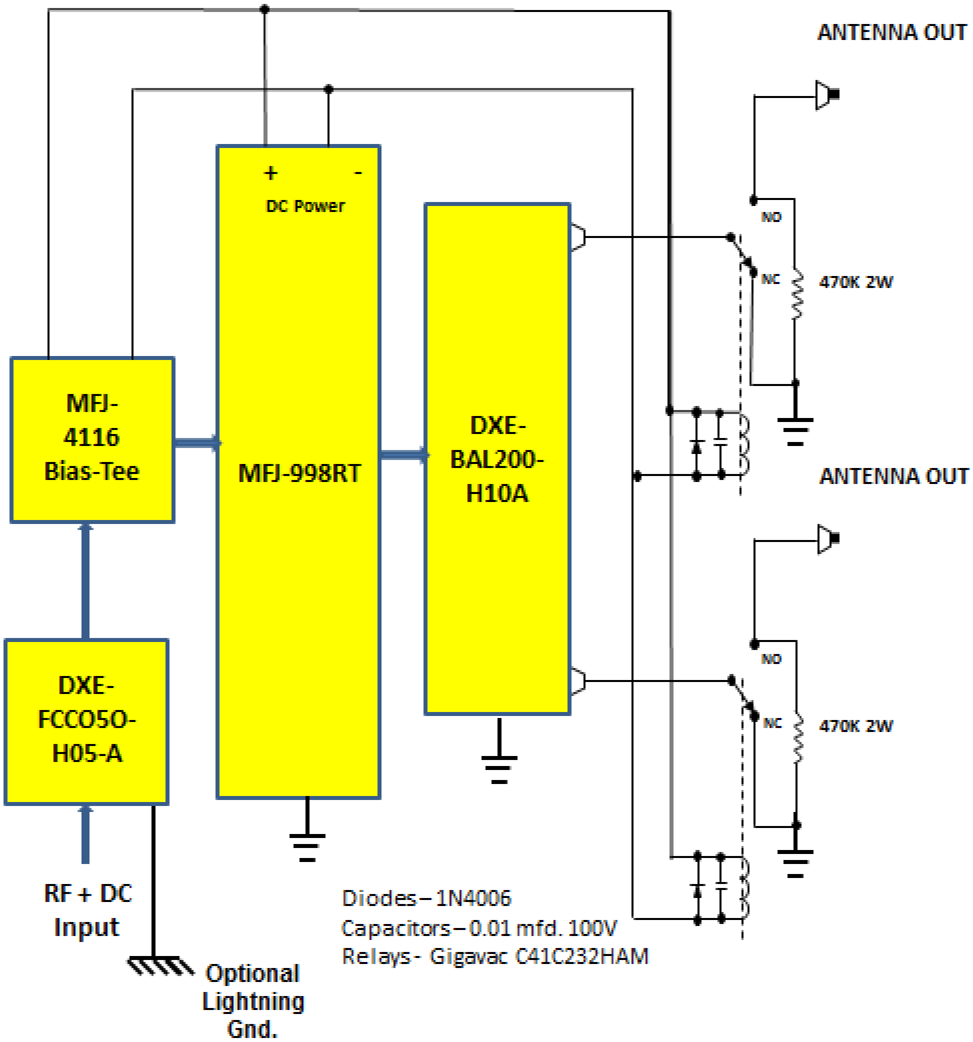


Figure A-24: MFJ-998RT with Balanced Output

For both examples, Figures A-23 and A-24, the resistors across the relay are used to drain the static electric charge on the antenna wire(s) when the auto-tuner is not connected to the antenna (NC position).

Another potential option, used by MFJ, is to place a Gas Discharge Tube across the output of the tuner. Unfortunately discussions with MFJ engineering about EMP damage to their tuners did not provide enough information to recommend their use instead of the relay technique shown in Figure A-24. Figure A-25 shows specifications for the Gas Discharge Tube type, used by MFJ in their 994BRT and 998RT auto-tuners. The model used is the CG3-2.5 a 2500 VDC breakdown tube.

Electrical Characteristics														
		Device Specifications (at 25°C)								Life Ratings				
Part Number	Device Dimension Type	DC Breakdown in Volts (@100V/s)			Impulse Break-down in Volts (@100V/µs)	Impulse Break-down In Volts (@1 Kv/µsec)	Insulation Resistance	Capaci-tance (@1MHz)	Arc Voltage (on state Voltage) @1Amp Min	Max Follow On Current[3]	Nominal AC Discharge Current (10x1sec @50-60Hz)	AC Discharge Current (1 x 50Hz 9 cycles)	Nominal Impulse Discharge Current[4] (@8/20µs)	Max Surge Current[5] (@8/20µs)
		MIN	TYP	MAX	MAX		MIN	MAX	TYP					
AC120[1]	A	230	285	340	500	550	10 GΩ (at 100V)	<1.5 pf	~ 25 V	200 Amps	5 A	65 A	10 shots 5kA	1 shot 10kA
AC240[1]	A	480	600	720	1100	1200								
CG3 1.0[1]	A	800	1000	1200	1400	1500	10 GΩ (at 100V)	<1.5 pf	~ 25 V	200 Amps	N/A	N/A	10 shots 5kA	1 shot 10kA
CG3 1.1[1]	A	880	1100	1320	1600	1700								
CG3 1.2[1]	A	960	1200	1440	1700	1800								
CG3 1.3[1]	A	1040	1300	1560	1800	1900								
CG3 1.5[1]	A	1200	1500	1800	1800	2000								
CG3 2.0[1]	A	1600	2000	2400	2500	2750								
CG3 2.5[1]	A	2000	2500	3000	3200	3500								
CG3 2.7[1]	A	2160	2700	3240	3600	4000								
CG3 3.0[1]	A	2400	3000	3600	4000	4200								
CG3 3.3[1]	A	2640	3300	3960	4600	4700								
CG3 4.0[2]	B	3200	4000	4800	5800	6000								
CG3 4.5[2]	B	3600	4500	5400	6150	6500								
CG3 5.0[2]	B	4000	5000	6000	7500	8000								
CG3 6.2[2,7]	B	4960	6200	7440	8100	9500								
CG3 6.5[2,7]	B	5200	6500	7800	9500	10000								
CG3 7.5[2,6,7]	B	6000	7500	9000	10000	10600								

Figure A-25: Gas Discharge Tubes – CG3 2.5 (2500V) used in MFJ Tuners

Tests by a member this spring during thunderstorm season may help to determine the effectiveness of this approach to preventing EMP damage in the MFJ 994BRT and MFJ 998RT. I do not believe that the Gas Discharge Tube approach will prevent damage to the SGC series tuners.

Providing DC power to External Auto-Tuners

The most convenient way to provide DC power to a remote, external tuner is to use a Bias-Tee (SGC- Coaxial Line Isolator). These devices, as shown in Figure A-26, combine RF and DC at the station location and then separate the DC and RF at the tuner location. MFJ tuner products like the 994BRT and the 998RT have a bias-Tee network built into the tuner and MFJ supplies a companion MFJ-4117 with these tuners for use at the station location. Because the remote auto-tuner provides a low SWR to the transmission line, and the tuner draws less than 1A at 13 VDC, lengths of RG-8 coax of 600 ft. have successfully been used between the station and remote auto-tuner.

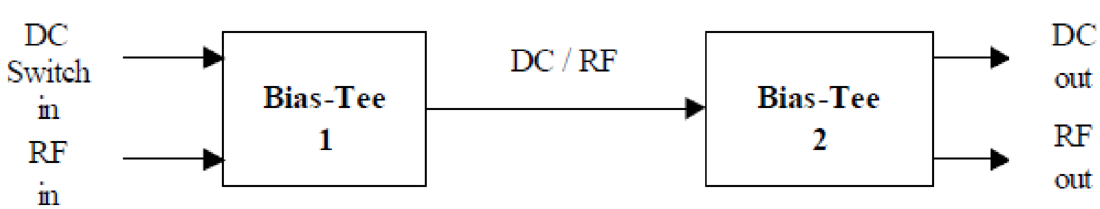


Figure A-26: Bias-Tee Operation

Physical Design Examples

To follow will be examples of auto-tuner assemblies built by AAR6UK for a variety of MARS and ARES members.   In all examples, the output ceramic feed-throughs used can be found at:

Surplus Sales of Nebraska – part Number – ICR-32201

General Electric, Silicone II sealant is used to seal all penetrations of enclosures.

Figure A-27 shows a SGC SG-230/235 single-ended tuner with a HV relay. This tuner is capable of driving a balanced dipole if a line isolator choke (MFJ-915 or DX Engineering FCC050-H05-A) is installed in the coaxial transmission line at the tuner input.

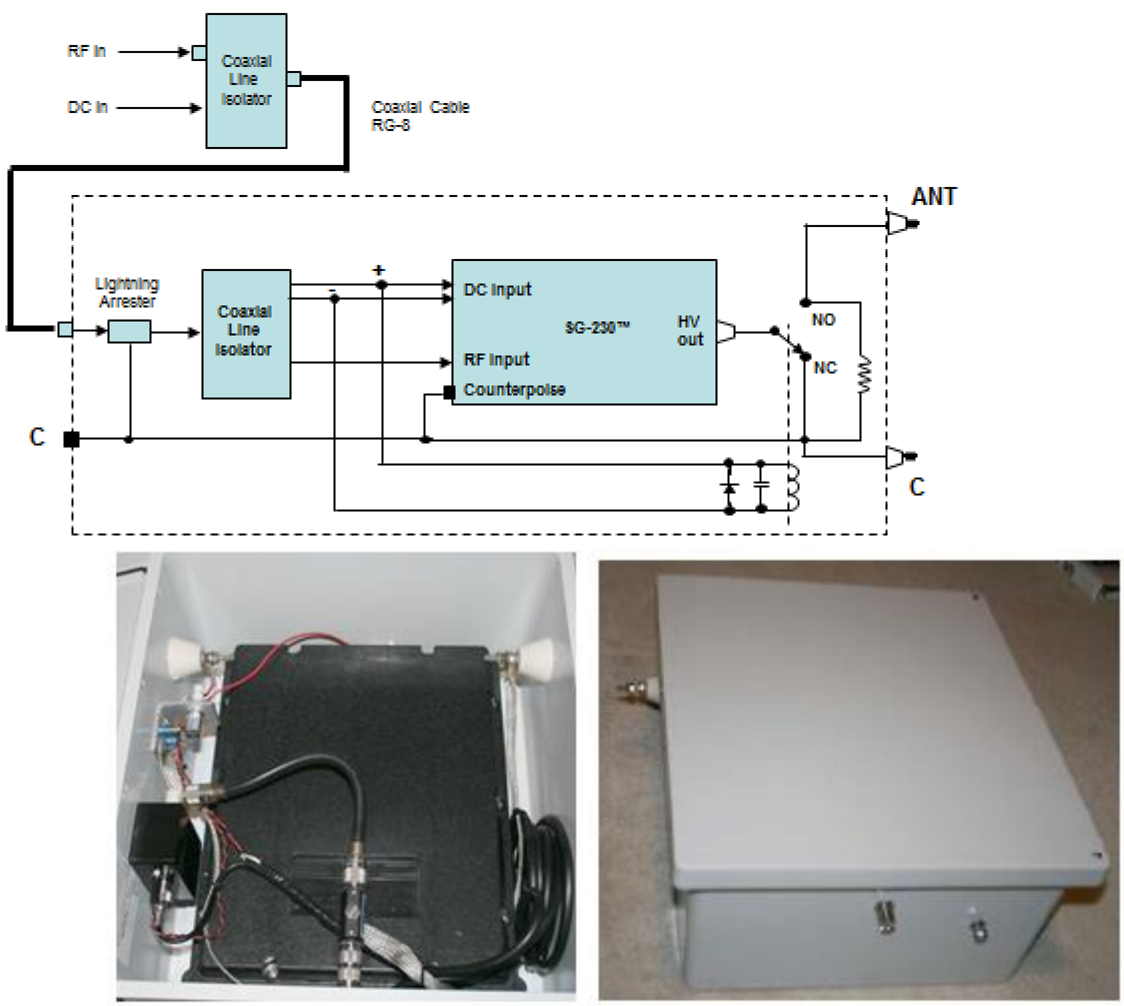


Figure A-27: Single-ended SG-230 Auto-Tuner

Figure A-28 shows a SGC SG-239 single-ended tuner with HV relay in a Hammon PJ-1086H housing.

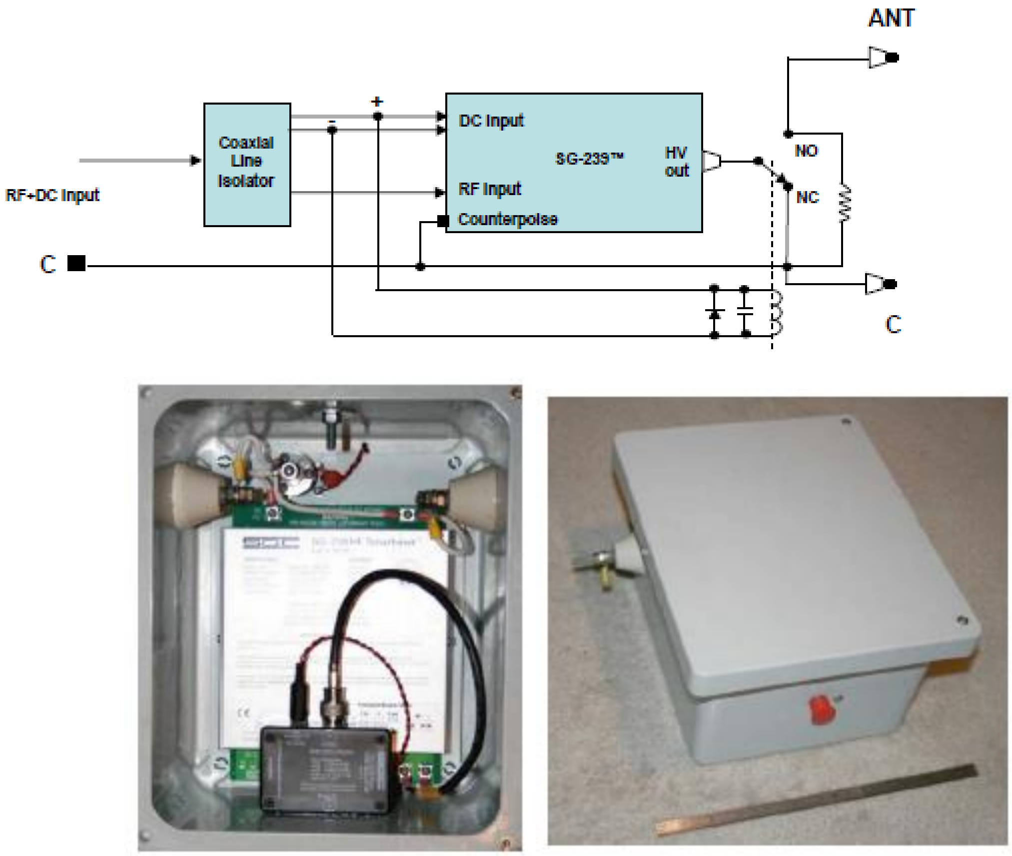


Figure A-28: SG-239 with HV relay

Figure A-29 shows a MFJ-998RT (1500W tuner) with balanced output and two HV relays. The schematic diagram can be in Figure A-24.

Figure A-29: MFJ-998RT Balanced output with HV relays

Figure A-30 shows the MFJ-998RT without relays and using the less expensive 4:1 balun from MFJ, the MFJ-912.   This tuner relies on a Gas Discharge Tube across the Tuner output for lightning EMP protection.

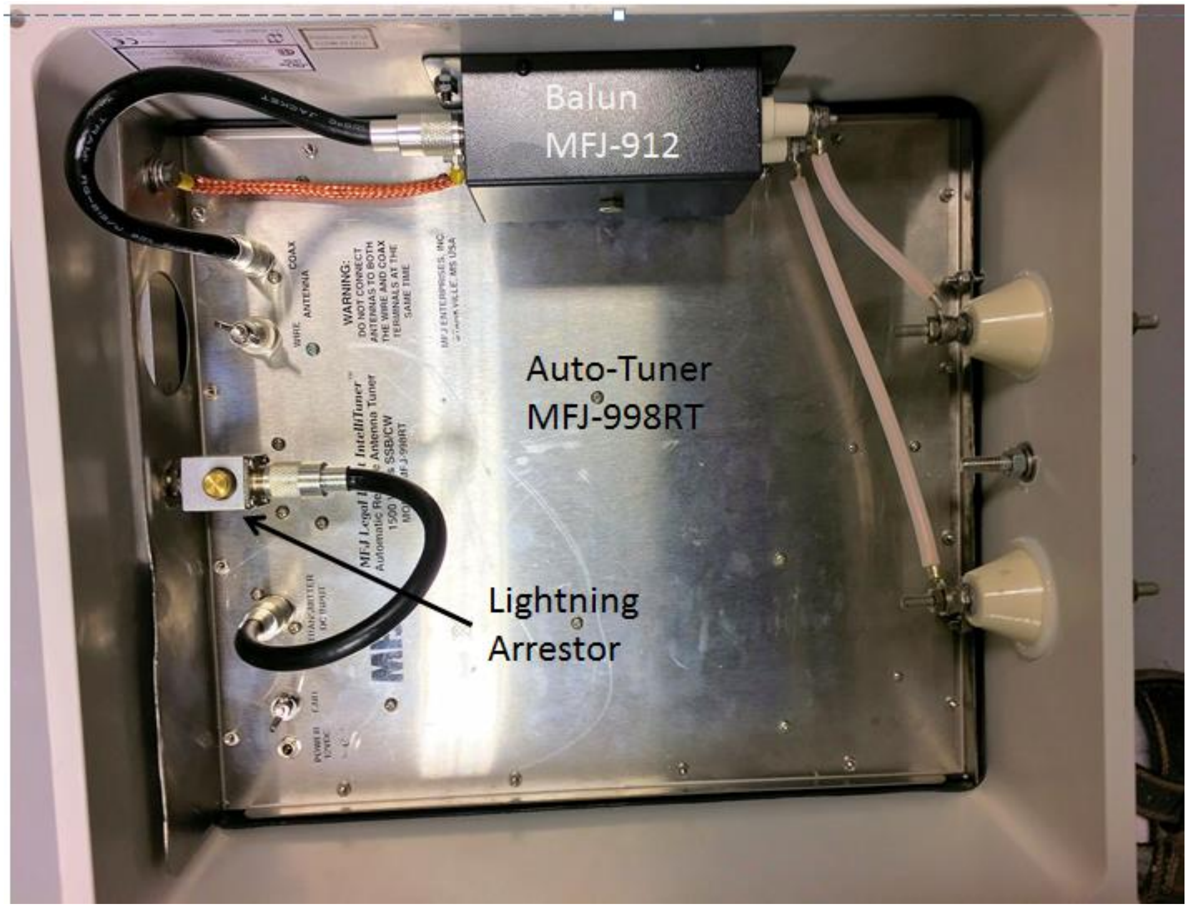


Figure A-30: MJF-998RT Balanced Output Without HV Relay

Figure A-31 shows the MFJ-998RT with relays (Greenstone VH3-C) and using the 4:1 balun from MFJ (MFJ-912). The DC input of the MFJ-998RT has been modified to provide DC power output for the relays. An internal diode in the MFJ-998RT was bypassed to allow power output rather than power input. The MFJ-998RT has an internal bias-Tee to separate the incoming DC/RF input.

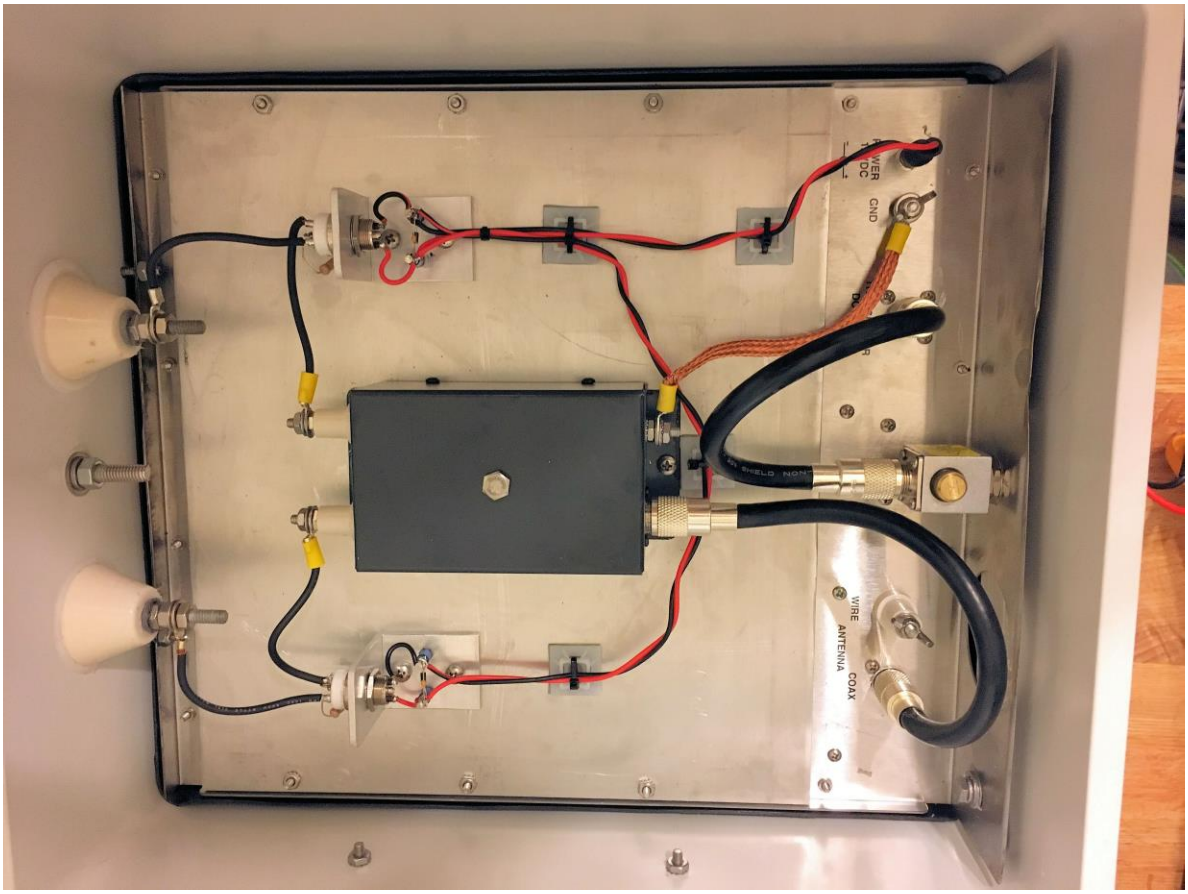


Figure A-31: MFJ-998RT With Greenstone VH3C Relays

Figure A-32 Shows the MFJ-994BRT (600 watts) auto-tuner without a HV relay.   It also relies on a Gas Discharge Tube across the tuner output for lightning protection. The MFJ-994BRT also has an internal bias-Tee to separate in input DC/RF. In a similar fashion, the MFJ-994BRT can be modified to include protective relays. Contact author for details.

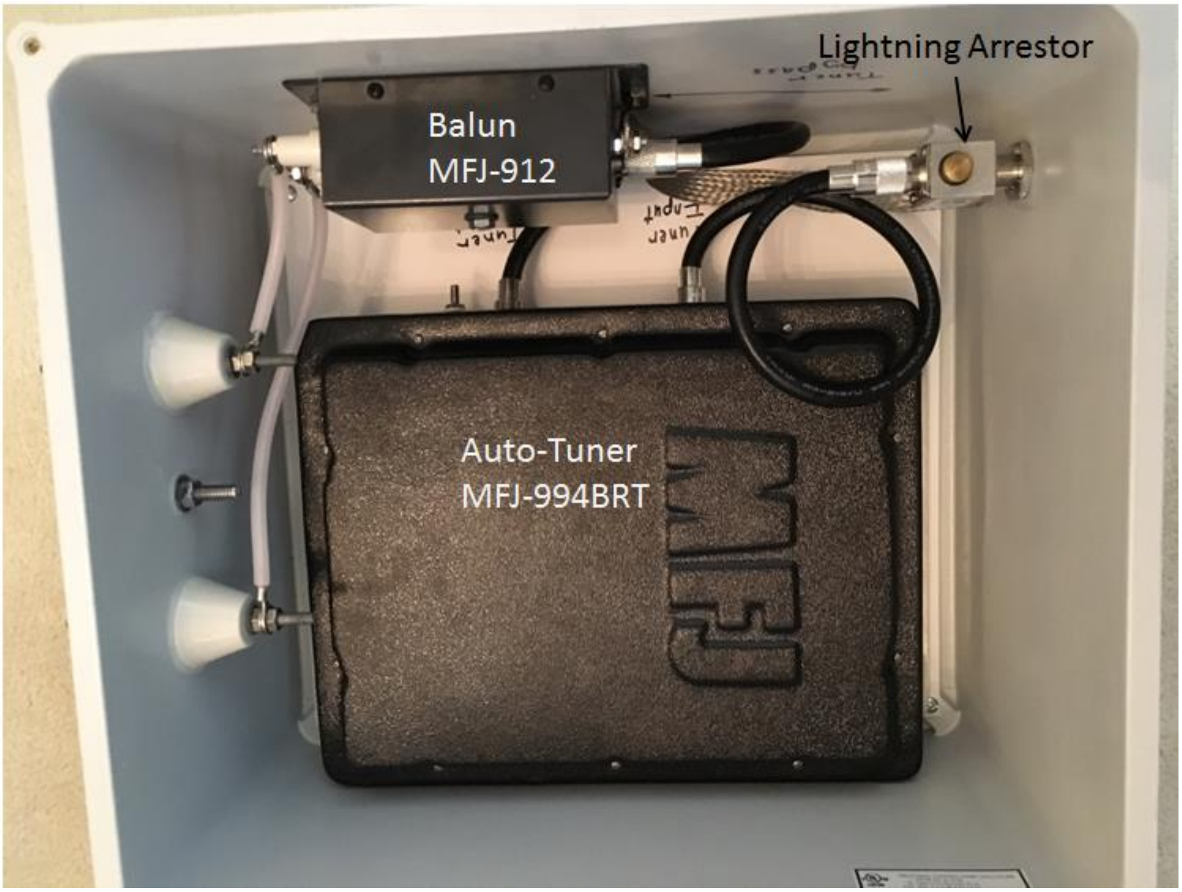


Figure A-32: MFJ 994BRT Without HV relays