Military NVIS Theory & Design Application Introduction

Ron P Milione AAR2JD/W2TAP

Ron.p.milione.ctr@us.army.mil

NVIS - **Near Vertical Incidence Skywave**, or **NVIS**, is a radio-wave propagation method that provides usable signals in the range between groundwave and skywave distances (usually 30 to 400 miles, or 50 to 650 km). It is used mainly for military and paramilitary communications and by radio amateurs. The radio waves travel upwards into the ionosphere, where they are refracted back down and can be received within a circular region up to 650 km from the transmitter. If the frequency is too high, refraction fails to occur and if it is too low absorption reduces the signal strength.

MILITARY NVIS ANTENNA THEORY AND DESIGN
Ron P Milione   AAR2JD/W2TAP

Introduction

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 one octave of frequency to track the local Critical Frequency (CF).

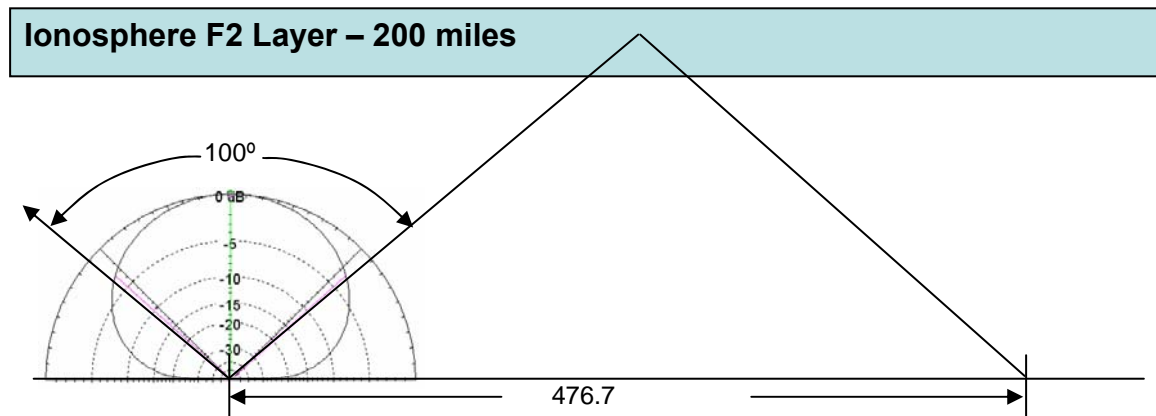The required directivity pattern is shown in Figure 1.

Figure 1: Required NVIS Antenna Vertical Directivity Pattern

The vertical or elevation directivity pattern should have a beam width (-3dB) of approximately 100° 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.

NVIS 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, azimuth, of the noise is displayed around the circle with North being towards the top of the page. The vertical angle, 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.
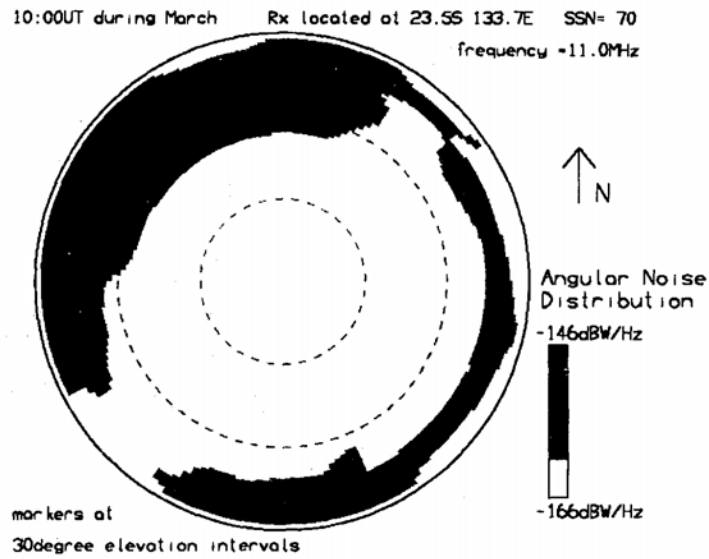
10:00UT during March   Rx located at 23.5S 133.7E   SSN= 70

frequency =11.0MHz

N

Angular Noise
Distribution

-146dBW/Hz

-166dBW/Hz

markers at
30degree elevation intervals

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

19:00UT during March   Rx located at 51.0N   0.0E   SSN= 70

frequency =11.0MHz

N

Angular Noise
Distribution

-149dBW/Hz

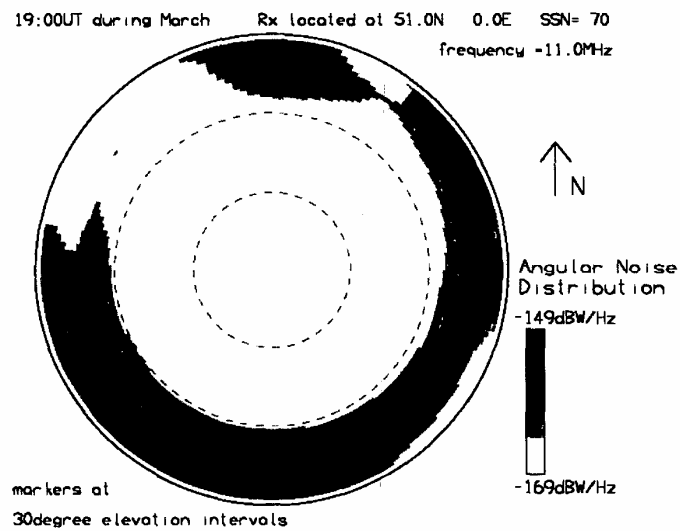-169dBW/Hz

markers at
30degree elevation intervals

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

Note that 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 somewhere from 5 to 15 dB of attenuation against distant noise. A more advanced 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-way 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.
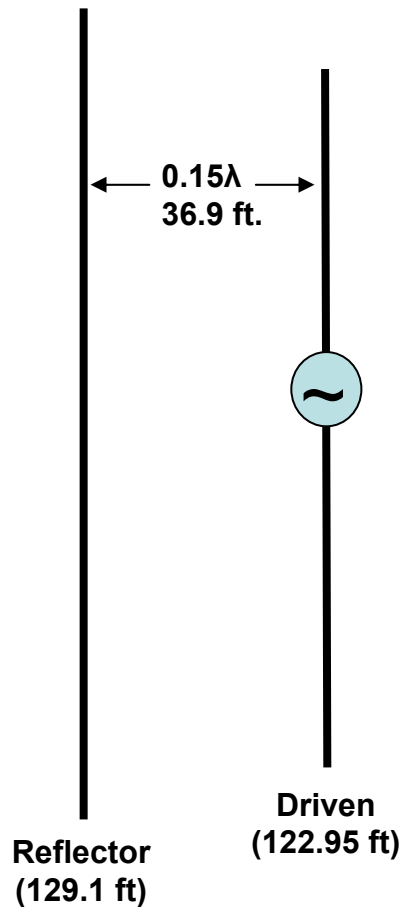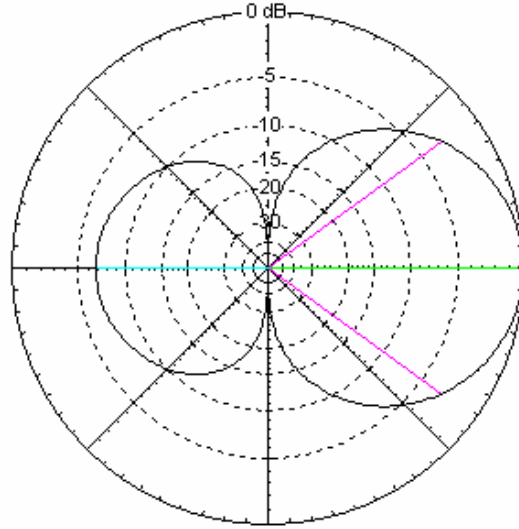

Figure 4: Theoretical 75m Yagi

Total Field   EZNEC+

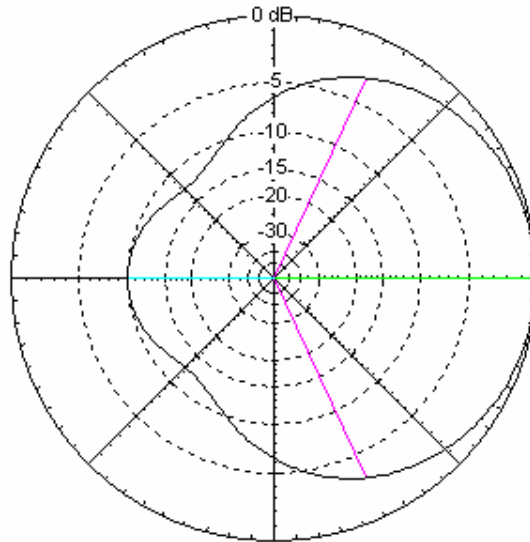   0 dB

                                                    4 MHz

Azimuth Plot   Cursor Az   0.0 deg.
Elevation Angle   0.0 deg.   Gain   4.62 dBi
Outer Ring   4.62 dBi   0.0 dBmax

Slice Max Gain   4.62 dBi @ Az Angle = 0.0 deg.
Front/Back   6.77 dB
Beamwidth   72.0 deg.; -3dB @ 324.0, 36.0 deg.
Sidelobe Gain   -2.15 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe   6.77 dB
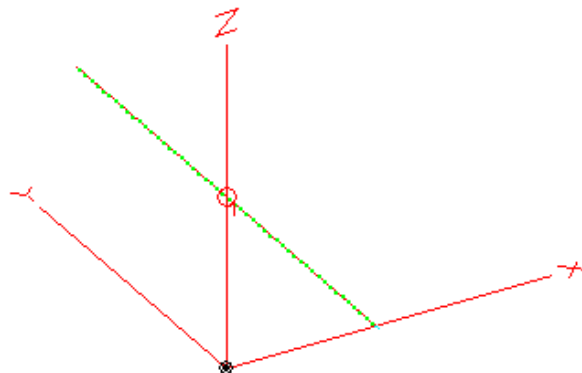
Figure 5: Azimuth Pattern for 2-element Yagi

3.8 MHz

Elevation Plot		Cursor Elev	0.0 deg.
Azimuth Angle	0.0 deg.	Gain	6.14 dBi
Outer Ring	6.14 dBi		0.0 dBmax

Slice Max Gain	6.14 dBi @ Elev Angle = 0.0 deg.
Front/Back	9.99 dB
Beamwidth	130.6 deg.; -3dB @ 294.7, 65.3 deg.
Sidelobe Gain	-3.85 dBi @ Elev Angle = 180.0 deg.
Front/Sidelobe	9.99 dB

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.
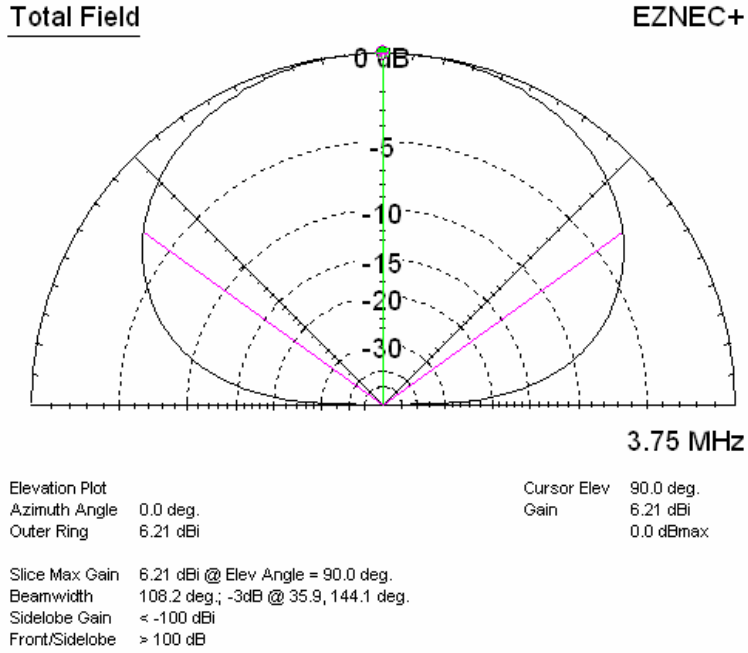

5

Total Field   EZNEC+

3.75 MHz

Elevation Plot   Cursor Elev   90.0 deg.
Azimuth Angle   0.0 deg.   Gain   6.21 dBi
Outer Ring   6.21 dBi   0.0 dBmax

Slice Max Gain   6.21 dBi @ Elev Angle = 90.0 deg.
Beamwidth   108.2 deg.; -3dB @ 35.9, 144.1 deg.
Sidelobe Gain   < -100 dBi
Front/Sidelobe   > 100 dB

Figure 7: Elevation Pattern of a NVIS 75m Dipole

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

Total Field   EZNEC+

3.75 MHz

Azimuth Plot   Cursor Az   0.0 deg.
Elevation Angle 50.0 deg.   Gain   4.89 dBi
Outer Ring   4.89 dBi   0.0 dBmax

Slice Max Gain   4.89 dBi @ Az Angle = 0.0 deg.
Front/Side   3.2 dB
Beamwidth   154.6 deg.; -3dB @ 282.7, 77.3 deg.
Sidelobe Gain   4.89 dBi @ Az Angle = 180.0 deg.
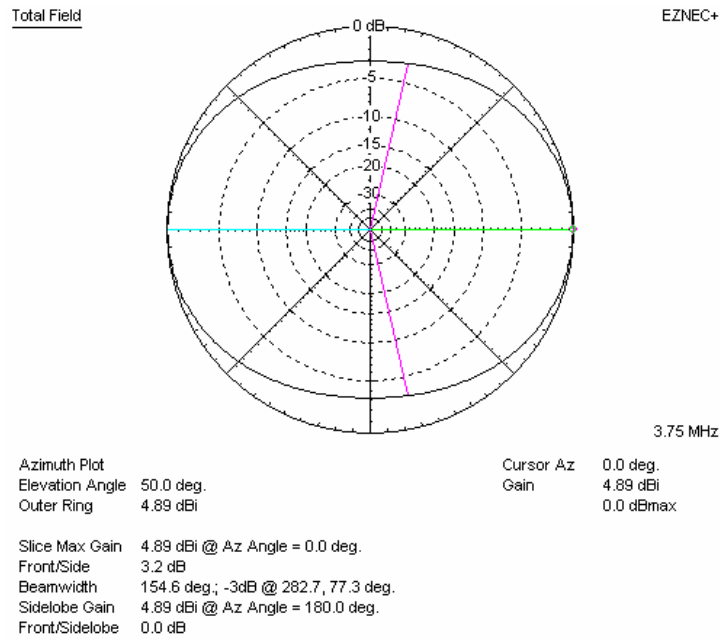Front/Sidelobe   0.0 dB

Figure 8: Azimuth Pattern 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.
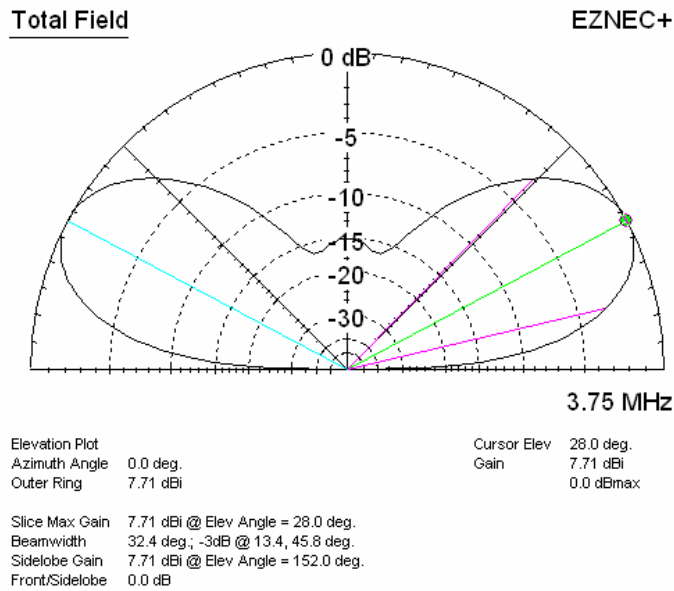

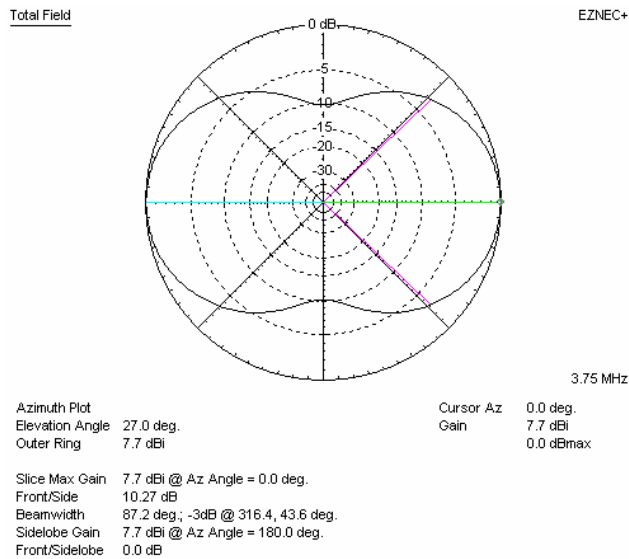**Figure 9: Elevation Plot of 75m Dipole at ½ Wavelength Height**

Figure 10: Elevation Plot 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 Devito, W2QHZ.
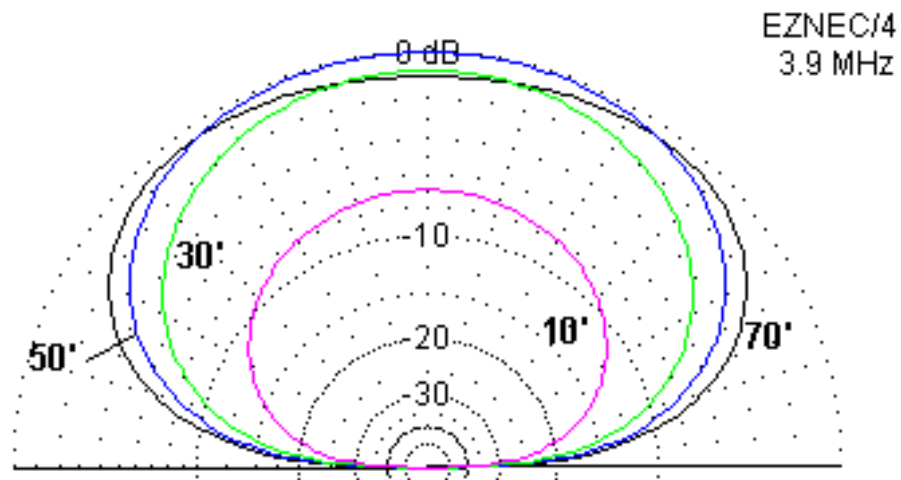
Figure 11: Gain and Elevation Plots of 75m NVIS dipole at Various Heights
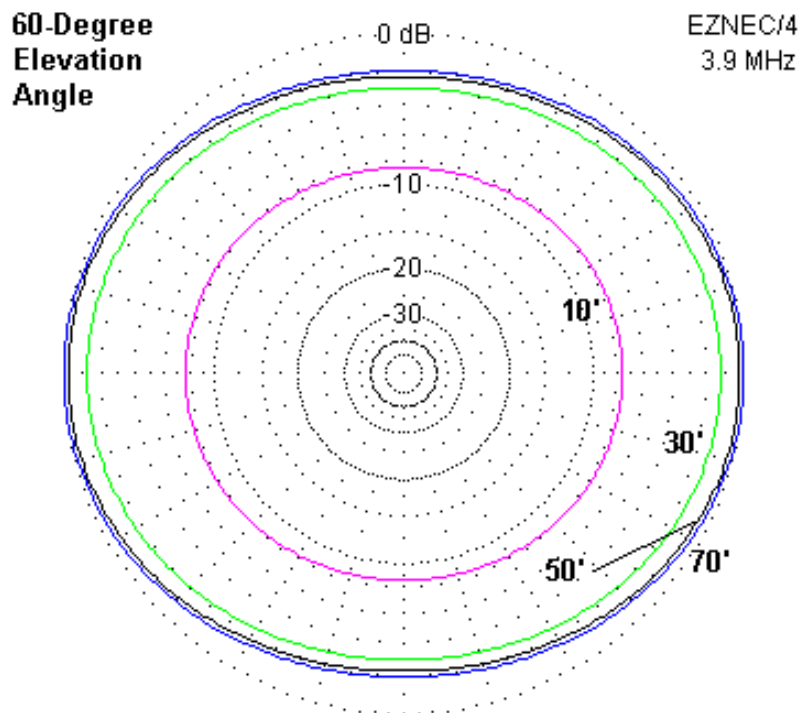
Figure 12: Gain and Azimuth Plots of 75m NVIS dipole at Various Heights

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 Devito, W2QHZ, 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 can be translated into any frequency where NVIS antenna performance is needed. For example moving all the way up to 40m (7.2 MHz), wavelengths of 0.1 to 0.3, correspond to heights of 13.6 ft. to 41 ft.   Note that 41 ft. would be an acceptable height for the 75m (3.8 MHz) NVIS dipole at 0.16 wavelengths height! So, one height of 40 ft would work from 3.75 MHz all the way to 7.2 MHz covering most all needed MARS NVIS frequencies. Even KBN would be 0.13 wavelengths, still a useable height.
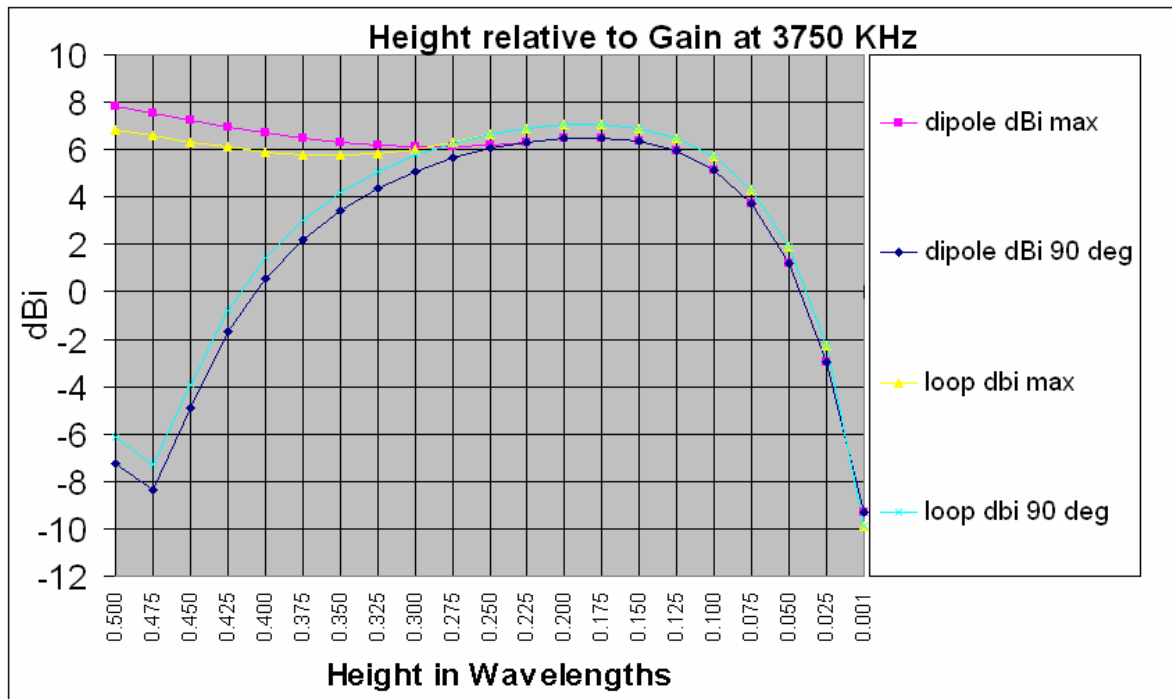

Figure 13: Height Versus Gain of a 75m NVIS Dipole

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 omni-directional 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.
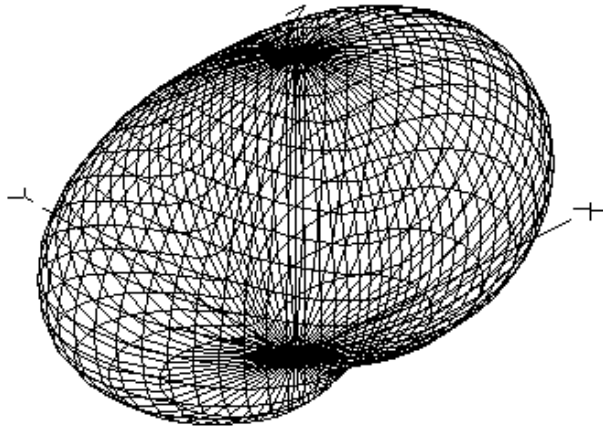
Figure 14: 75m NVIS Dipole Pattern at 40m

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 still 39 ft.
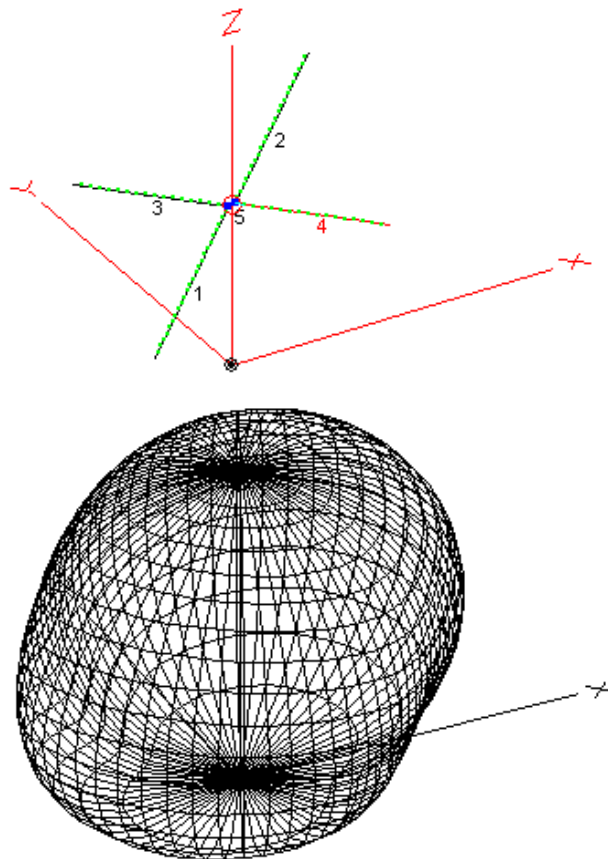

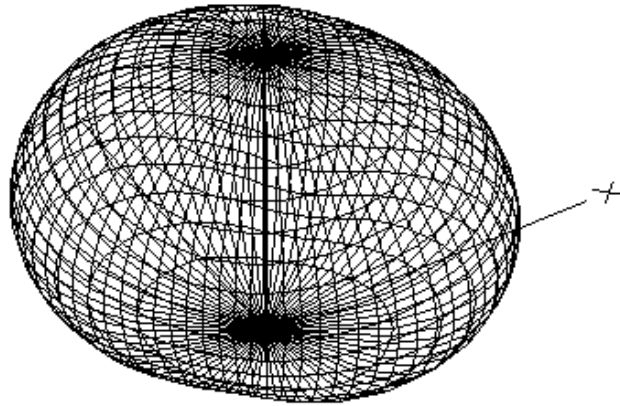**Figure 15: Cross-Dipole Antenna Pattern at 40m**

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. This will result in good NVIS patterns, shown in Figures 17 and 18, 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.
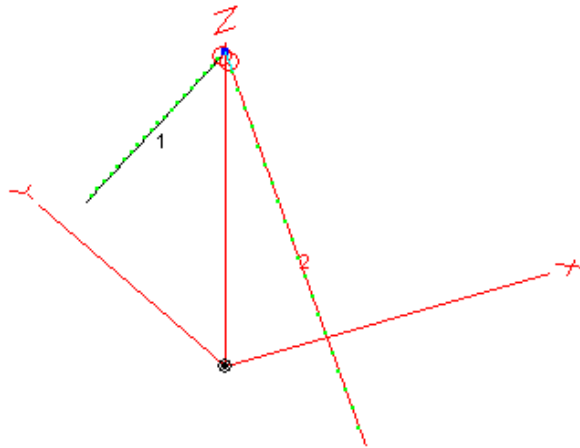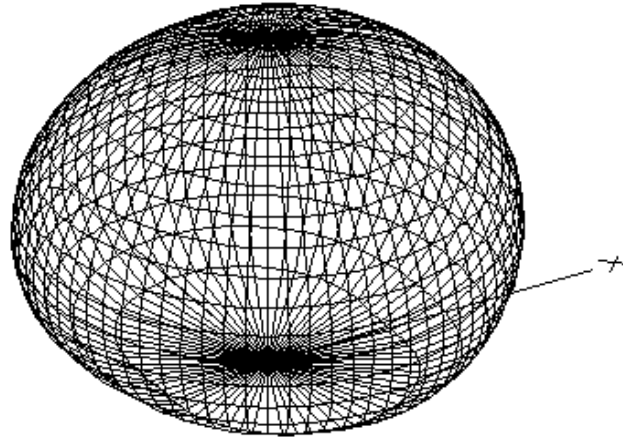
Figure 17: 75m Inverted-V NVIS Antenna at 3.75 MHz
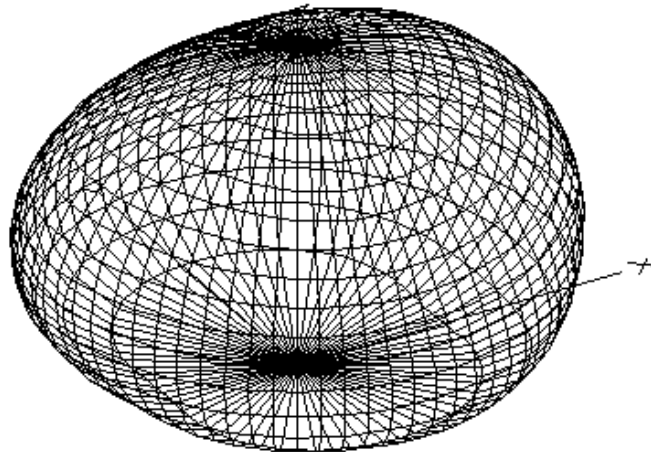
Figure 18: 75m Inverted-V NVIS Antenna at 7.2 MHz

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 reflecting "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 19.

Figure 19: NVIS Configuration for Special Cases of Low Earth Conductivity

Vehicle Whip Antennas
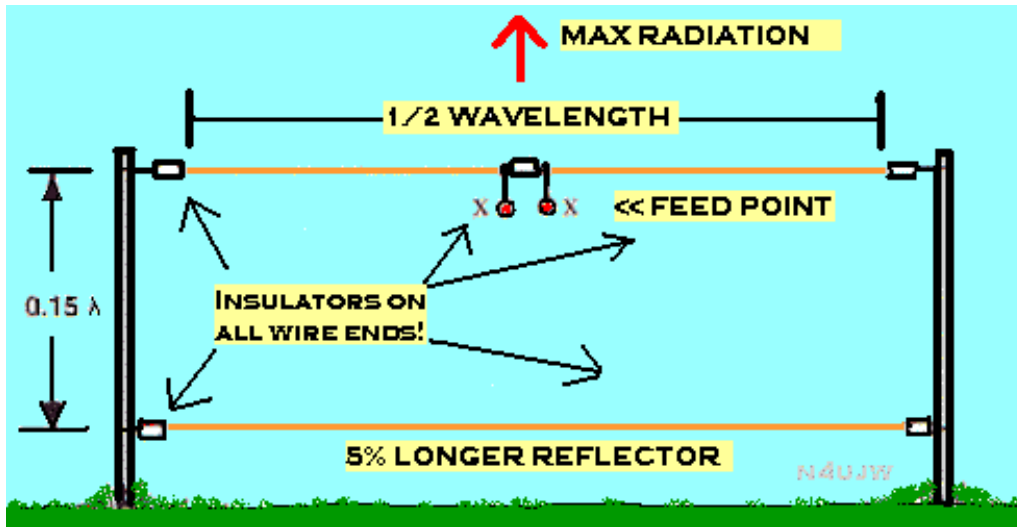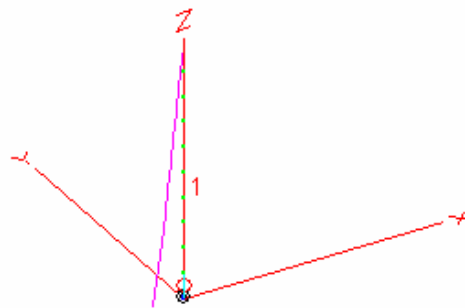The vertically polarized vehicle whip antenna is not optimum for NVIS operation. The idealized vehicle whip antenna and accompanying vertical directivity patterns can be seen in Figures 20 through 22.

Height = 1.8 m (6 ft)

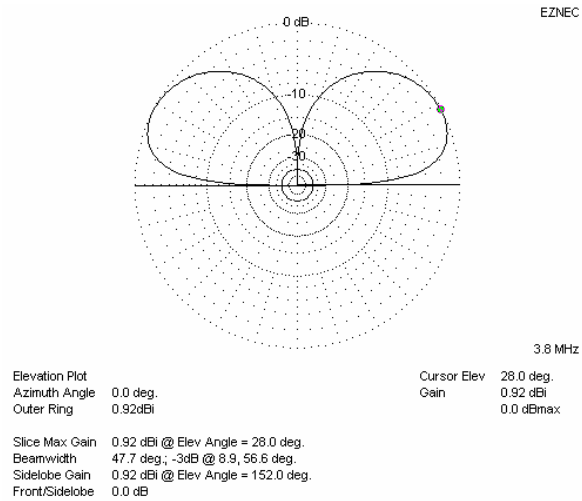**Figure 20: Vehicle HF Whip Antenna with Current Distribution**

Elevation Plot
Azimuth Angle   0.0 deg.   Cursor Elev   28.0 deg.
Outer Ring   0.92dBi   Gain   0.92 dBi
                                                                  0.0 dBmax

Slice Max Gain   0.92 dBi @ Elev Angle = 28.0 deg.
Beamwidth   47.7 deg.; -3dB @ 8.9, 56.6 deg.
Sidelobe Gain   0.92 dBi @ Elev Angle = 152.0 deg.
Front/Sidelobe   0.0 dB

Figure 21: Elevation Pattern of Vehicle Whip at 75m (3.8 MHz)

Elevation Plot
Azimuth Angle   0.0 deg.   Cursor Elev   29.0 deg.
Outer Ring   0.29dBi   Gain   0.29 dBi
                                                                  0.0 dBmax

Slice Max Gain   0.29 dBi @ Elev Angle = 29.0 deg.
Beamwidth   47.6 deg.; -3dB @ 9.8, 57.4 deg.
Sidelobe Gain   0.29 dBi @ Elev Angle = 151.0 deg.
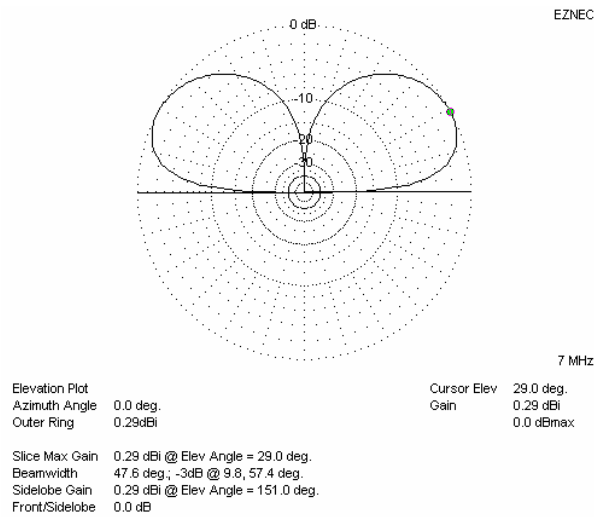Front/Sidelobe   0.0 dB

Figure 22: 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 23.
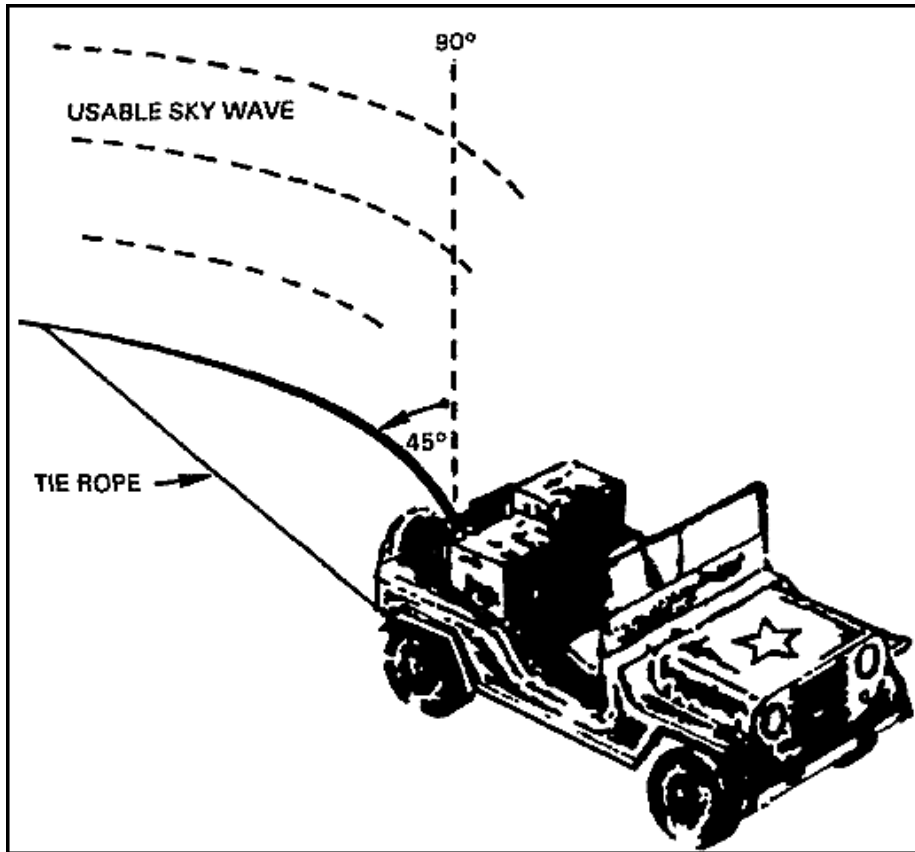
Figure 23: Improved NVIS Performance of a HF Vertical Whip Antenna

Other options for mobile HF NVIS operation include using vertically oriented loop antennas as shown in Figures 24 and 25.

Figure 24: Commercial (South Midlands Communications Ltd) NVIS Loop

Figure 25: Home-brew HF Mobile NVIS Loop Antenna

Antenna Impedance Match

Once you have designed a NVIS antenna that can produce proper directivity patterns over the necessary MARS frequency range (3.3 MHz to 7.4 MHz) the task is only one-half complete. This wide-band antenna system must also provide a useable impedance (50 Ω) over this frequency range so it will accept RF power from the transmitter. Standing wave plots (SWR) for both the 75m dipole and the cross-dipole antennas are shown in Figures 26 and 27.

80 m Dipole

SWR>100

INF

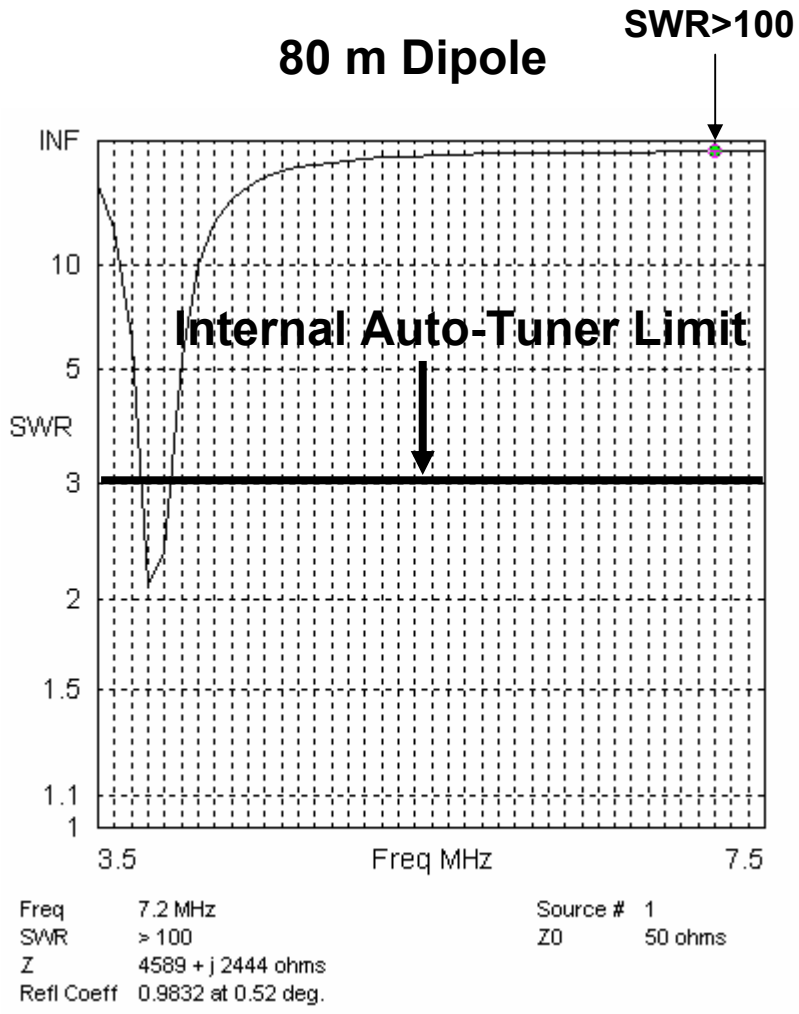Internal Auto-Tuner Limit

Freq	7.2 MHz		Source #	1
SWR	> 100		Z0	50 ohms
Z	4589 + j 2444 ohms			
Refl Coeff	0.9832 at 0.52 deg.			

Figure 26: SWR Plot of 75m NVIS Dipole

Cross-Dipoles

SWR=30

Internal Auto-Tuner Limit

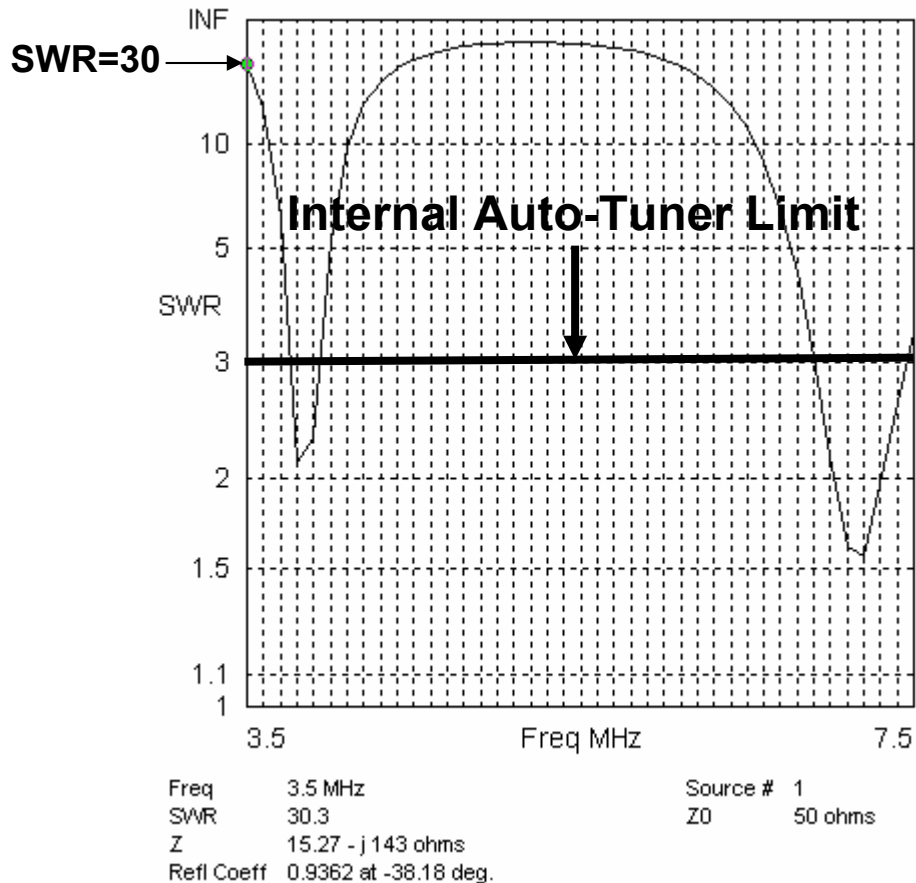| Freq | 3.5 MHz | | Source # | 1 |
SWR	30.3		Z0	50 ohms
Z	15.27 - j 143 ohms			
Refl Coeff	0.9362 at -38.18 deg.			

Figure 27: SWR Plot of Cross-Dipole NVIS Antenna

Also shown on each of these two plots is the typical 3:1 SWR internal auto-tuner limit of today's modern HF transceivers. 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 an incomplete 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 retuned. To cover all Texas Army MARS NVIS frequencies, some 8 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 (B&W series)** – Several companies make special wide-band folded dipoles with a termination load resistor and matching transformer as shown in Figure 28.
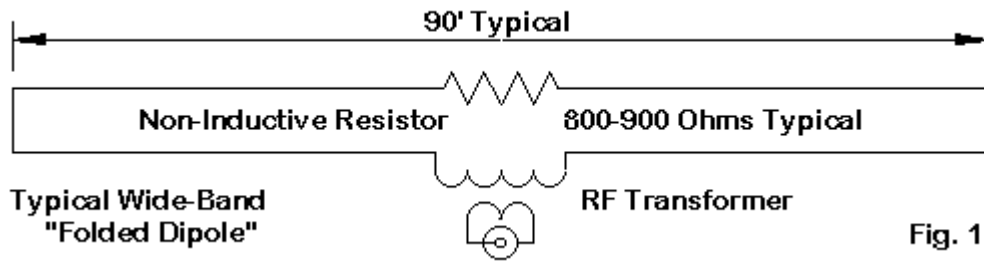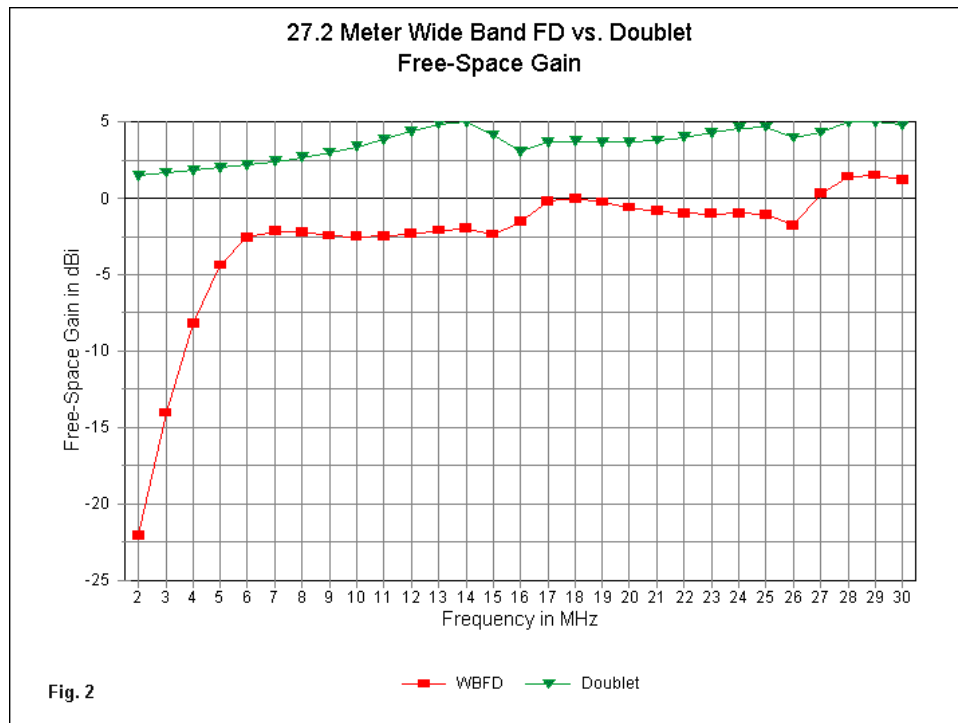
From: http://www.cebik.com/wire/wbfd.html

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) as shown in Figure 28.   The difference in gain (5-6 dB) translates into an efficiency difference of about 75% when compared to a 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 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.
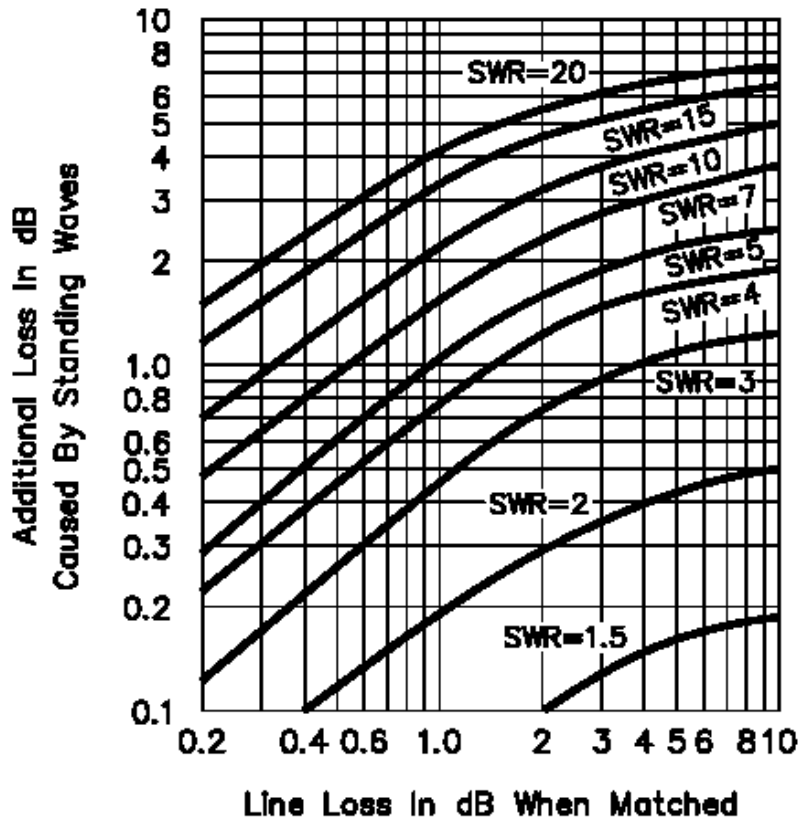

Figure 29: Additional Transmission Line Loss Due to High SWR

Figure 30 shows a typical arrangement for minimizing losses when a tuner is use 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.
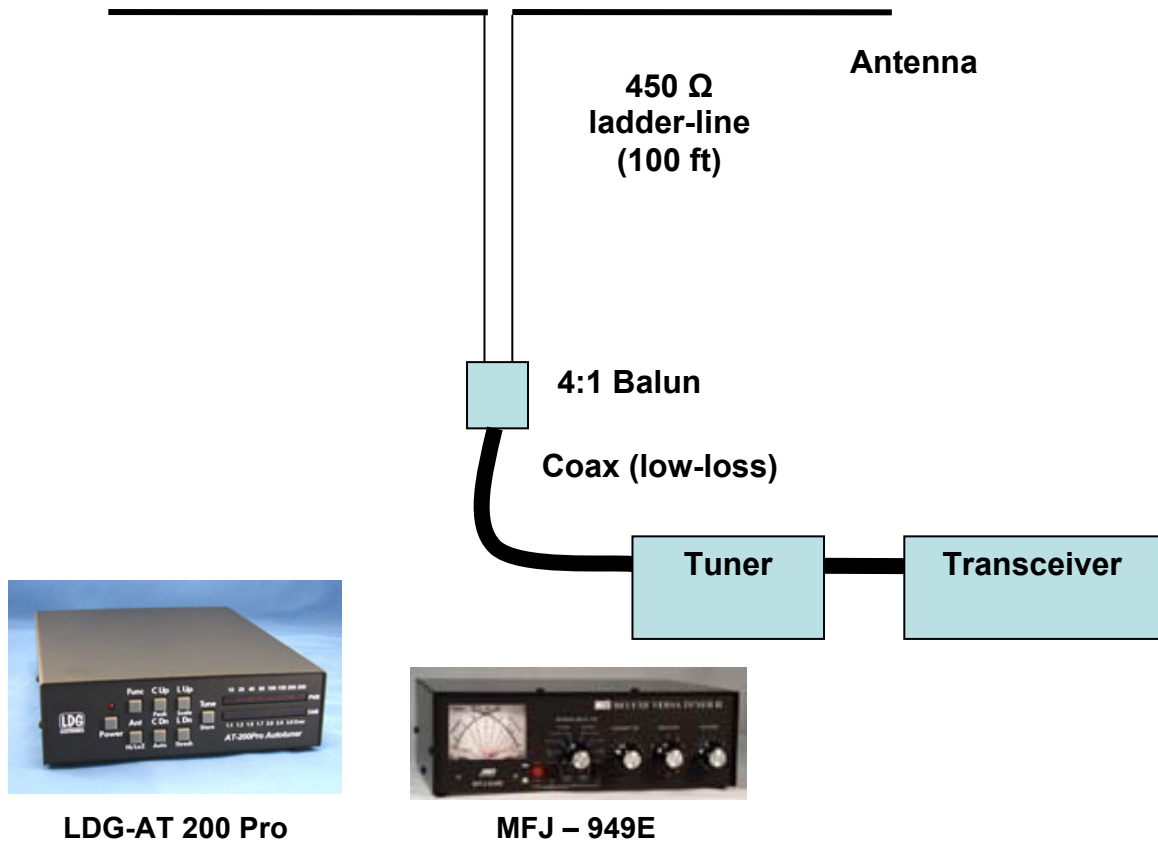
Antenna

**450 Ω
ladder-line
(100 ft)**

4:1 Balun

Coax (low-loss)

Tuner

Transceiver

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 coaxial line isolators, 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 shaded 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.
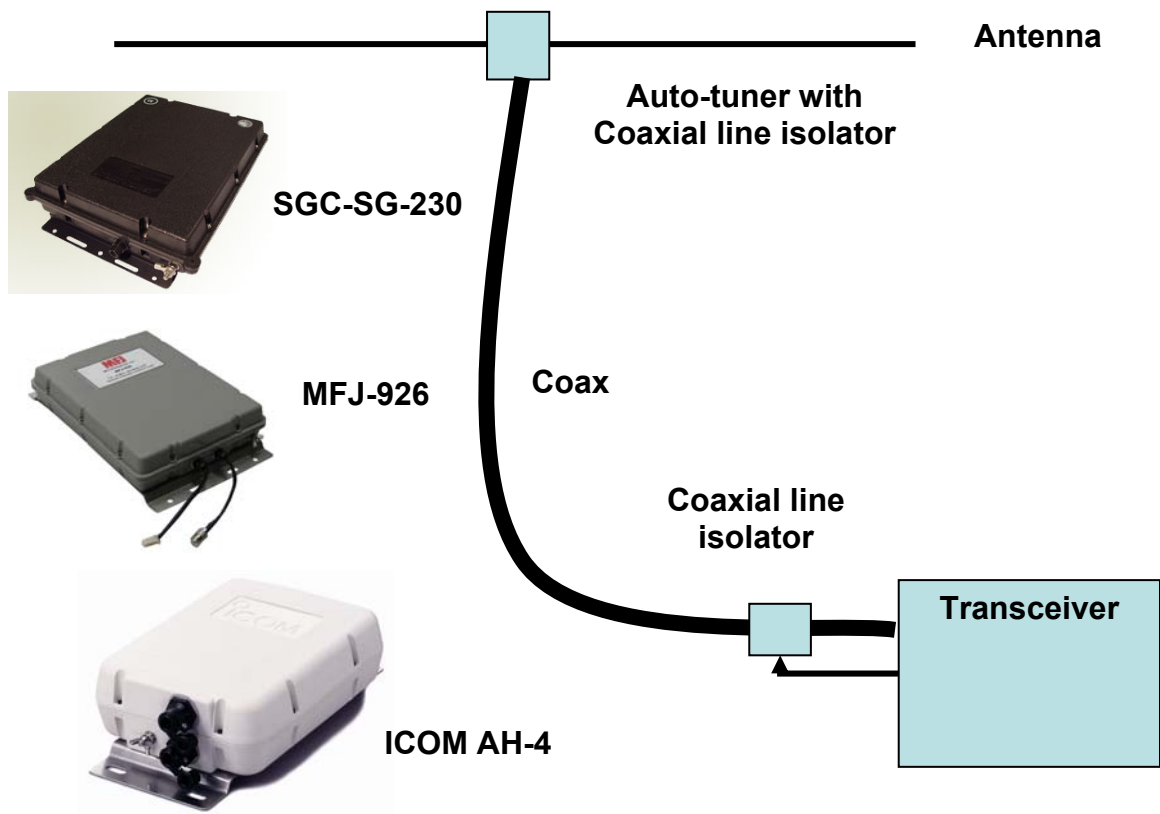
21

Figure 31: Tuner At The Antenna

PolyPhaser – IS-B50LU-CO (DC blocking)
Relay – Gigavac G41C232 (5KV SPDT)
coil – 12VDC at 200 mA
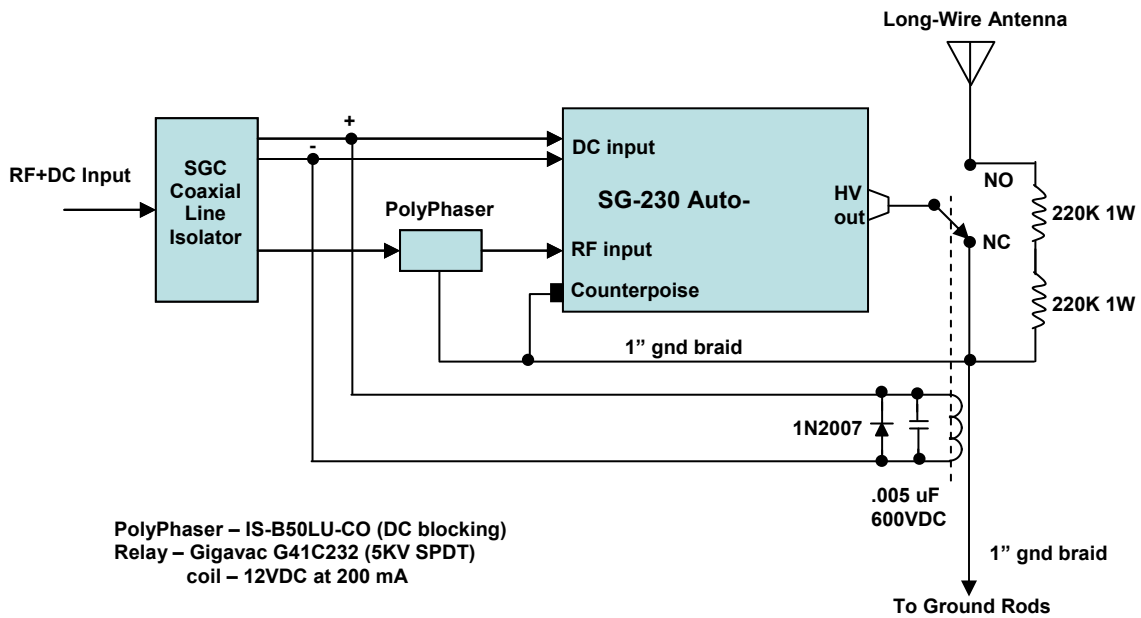
Figure 32: Auto-Tuner Lightning Protection Circuitry

An antenna mounted auto-tuner used for temporary portable operation does not need sun shielding as shown in Figures 33 and 34.

Pulley

Optimum
Height

Lexan Plate

67 ft

67 ft

Auto-tuner with
DC Coaxial Line
Isolator

Mast: 35 ft.

Coax – RG8/U

DC Coaxial
Line Isolator

DC power

RF

SG-230 $500.
RF power - 200 watts max.
Tune 8 ft wire 3.5 to 30 MHz
Waterproof

Figure 33: Auto-Tuner for Portable Operation

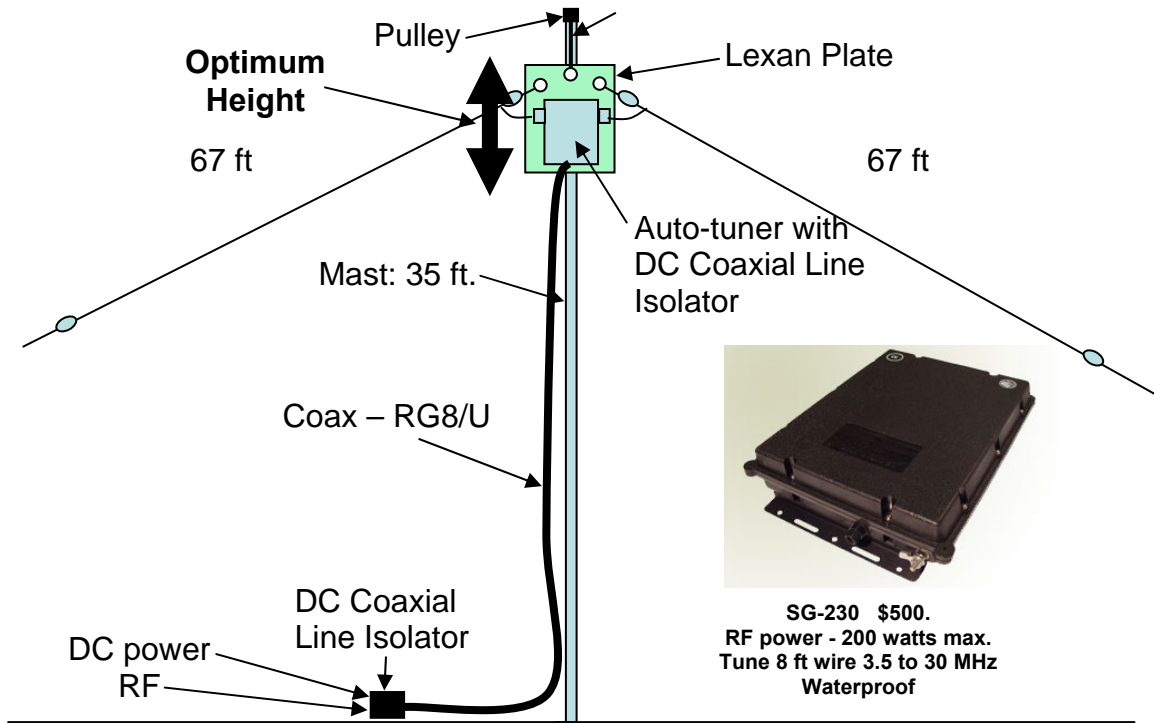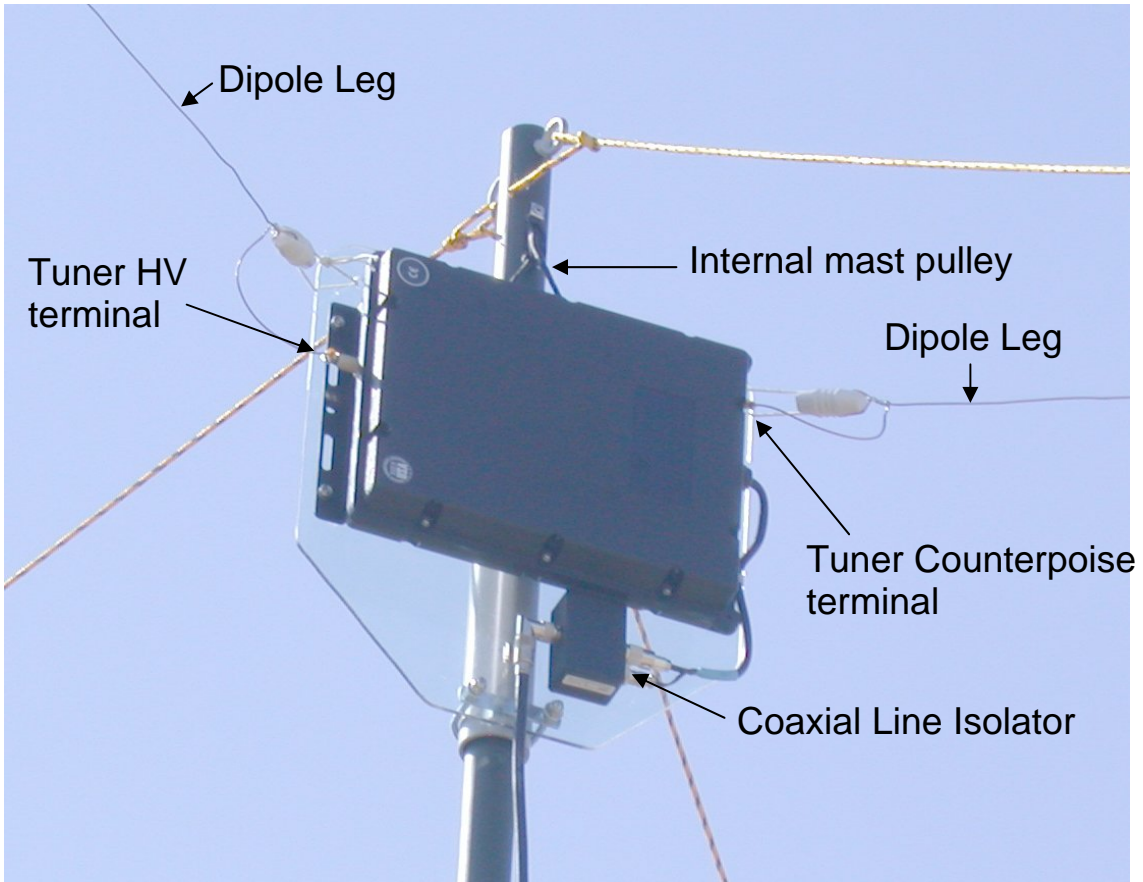**Figure 34: Portable Auto-Tuner Photograph**

This same type of tuner, mounted in a protective housing, is in operation at permanent locations at Texas State Guard, building 32 Camp Mabry, Figure 35, TSA San Antonio, Figure 36 and my personal QTH, figure 37.

UHF/VHF Vertical Antenna Mount

Side Arm Mount

Insulator

NVIS Dipole 70 ft

Auto-Tuner

50 ft tower next to 20 ft metal roofed building

House Bracket

Ground Level

Ground Rod 8 ft. depth

Concrete Filled hole Depth – 3 ft.
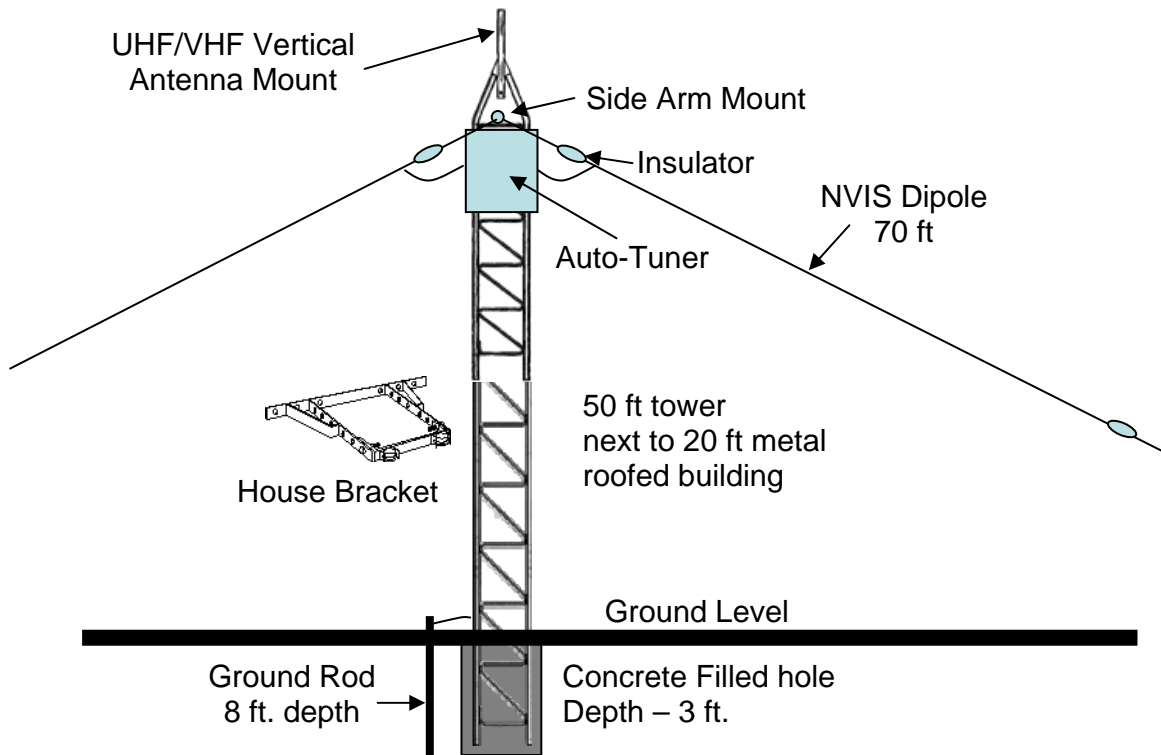
Figure 35: Auto-Tuned Dipole at TxSG Building 32, Camp Foster

Shakespeare
393 Antenna

PVC reinforced
Support pipe

Auto-Tuner

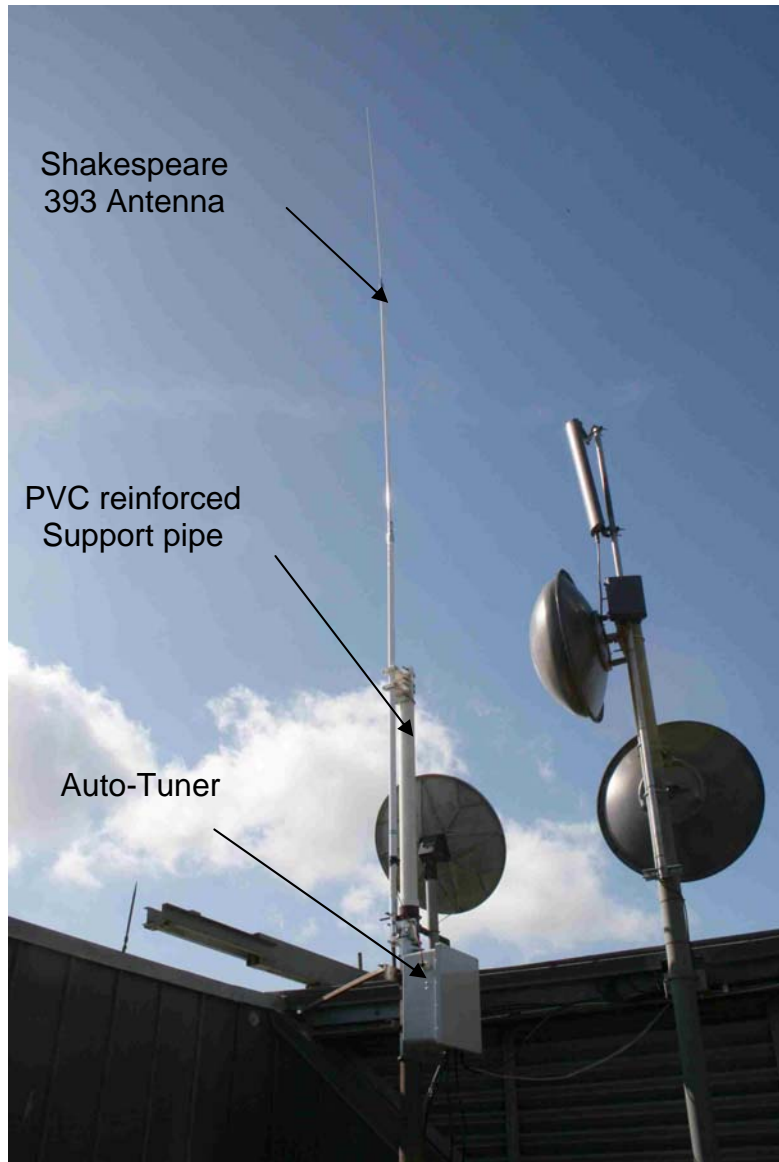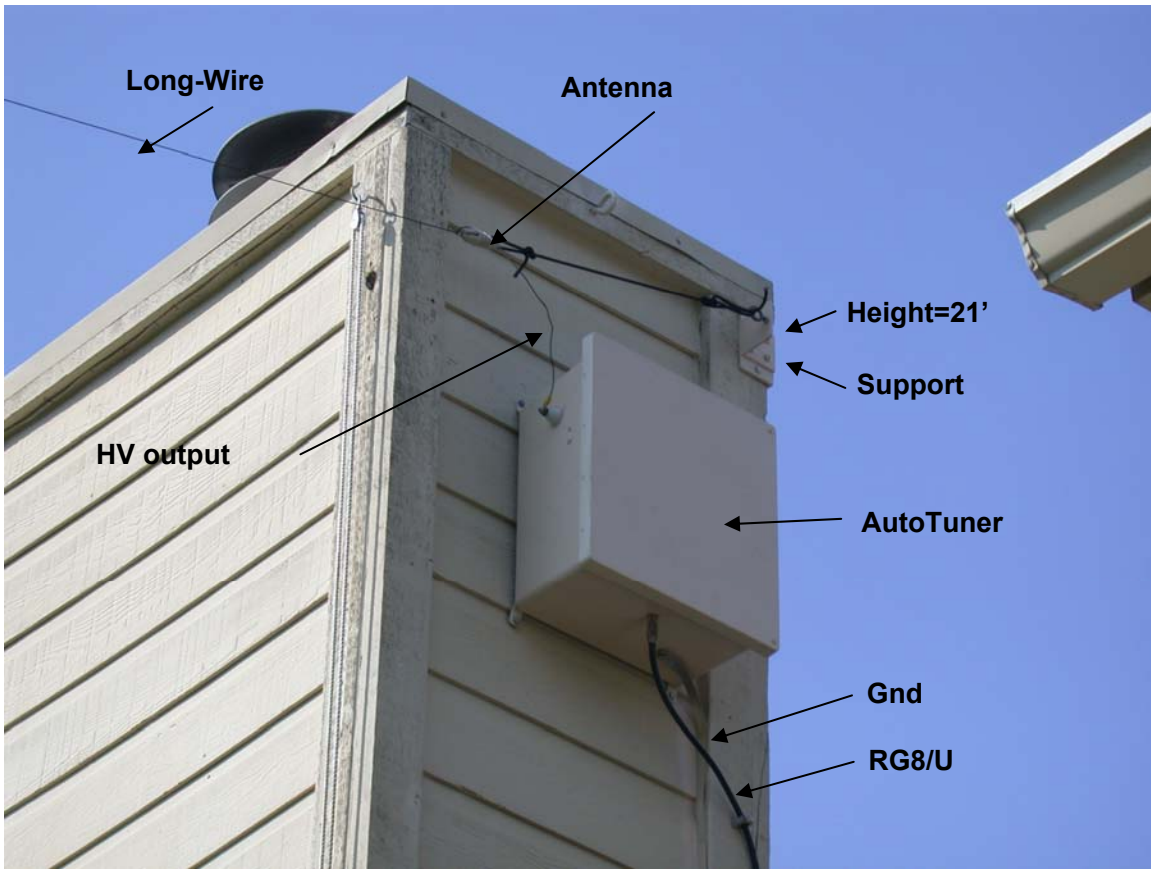**Figure 36: TSA, New York Auto-Tuned Antenna**

Figure 37: Auto-Tuned Long Wire at Home QTH (CC&R Restrictions)

All of these auto-tuners are identical in general wiring, with two connected to drive unbalanced antennas (vertical whip and long-wire) and one connected to drive a balanced dipole. The internal wiring can be seen in Figure 38. Complete construction details are available upon request.
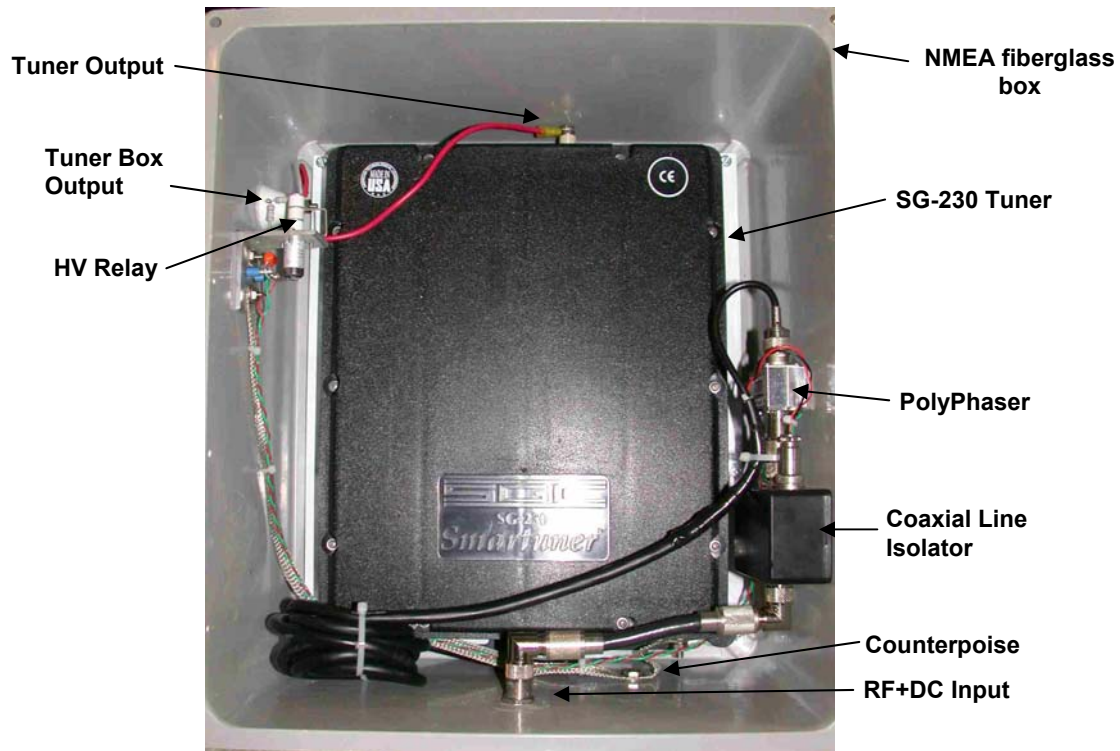
Figure 38: Internal View of Fix Location Auto-Tuner

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 result in requiring an elevation beam width of approximately 100 ° and an omni-directional azimuth pattern. Significant frequency agility is required, since NVIS operating frequencies must be below the local critical frequency but as high as possible to minimizing 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 feet and feed with low loss transmission line can achieve the requirements for effective NVIS antenna performance.

APPENDIX
Examples of New York Army MARS Member Antennas

The following section will discuss different approaches taken by several Texas Army MARS members in achieving reasonable NVIS directivity patterns and wide-bandwidth performance.   Many members of NY Army MARS have achieved similar results and these individual antenna systems are being discussed only because they represent three different general approaches to achieving acceptable NVIS antenna performance.

Single Inverted-V with Rig-Located Tuner – AAR2JD/W2TAP
This antenna system and its modeled SWR are shown in Figure A-1. Since this study was completed, this antenna has also demonstrated good performance on KAH.

EZNEC+

Inverted-V, 56° slope
Leg length – 70 ft.
Apex height – 55 ft.
Leg end height – 16 ft.
Fed with 100 ft of 450Ω
Ladder line, 4:1 balun,
RG-213U to tuner.

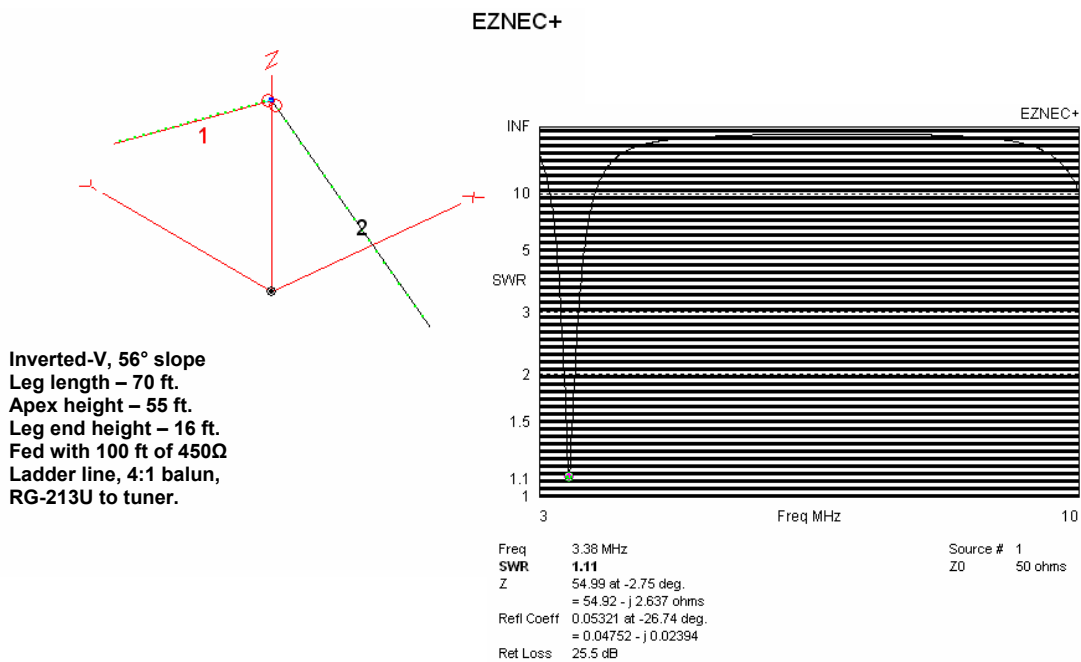|	
Freq	3.38 MHz
SWR	**1.11**
Z	54.99 at -2.75 deg.
	= 54.92 - j 2.637 ohms
Refl Coeff	0.05321 at -26.74 deg.
	= 0.04752 - j 0.02394
Ret Loss	25.5 dB

Source # 1
Z0   50 ohms

Figure A-1: NVIS Antenna of AAR2JD

Antenna directivity patterns for a number of frequencies can be seen in Figures A-2 through A-5.

EZNEC+

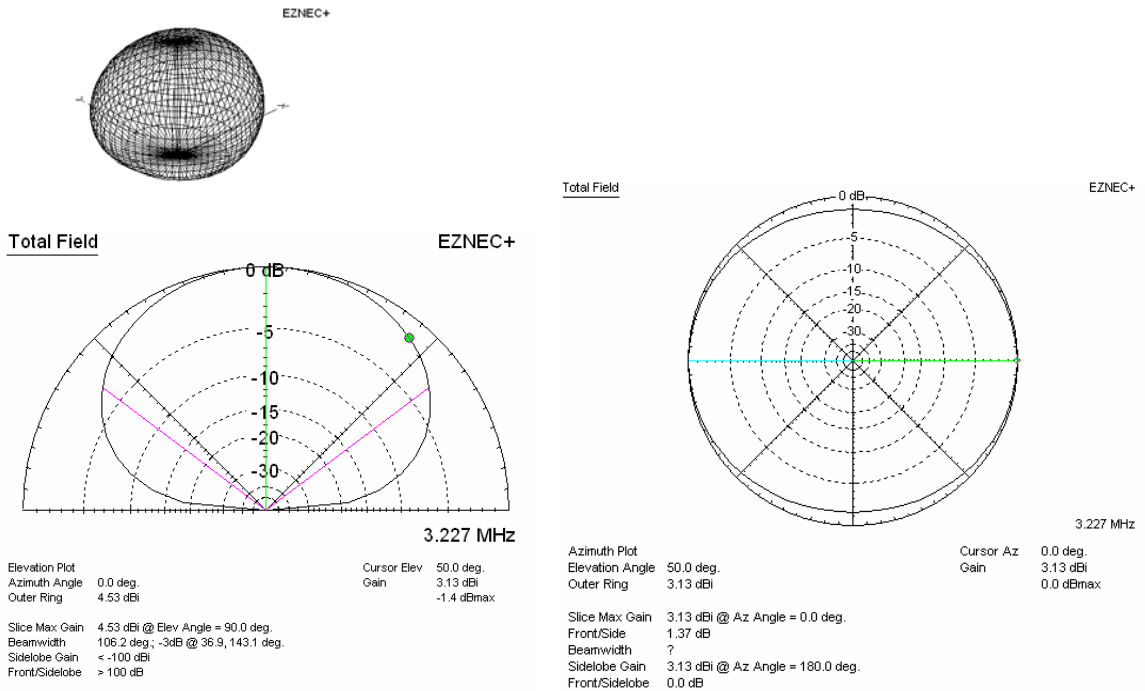Total Field   EZNEC+

0 dB

-5

-10

-15

-20

-30

3.227 MHz

Elevation Plot
Azimuth Angle   0.0 deg.
Outer Ring   4.53 dBi

Cursor Elev   50.0 deg.
Gain   3.13 dBi
               -1.4 dBmax

Slice Max Gain   4.53 dBi @ Elev Angle = 90.0 deg.
Beamwidth   106.2 deg.; -3dB @ 36.9, 143.1 deg.
Sidelobe Gain   < -100 dBi
Front/Sidelobe   > 100 dB

Total Field   EZNEC+

0 dB
-5
-10
-15
-20
-30

3.227 MHz

Azimuth Plot
Elevation Angle 50.0 deg.
Outer Ring   3.13 dBi

Cursor Az   0.0 deg.
Gain   3.13 dBi
             0.0 dBmax

Slice Max Gain   3.13 dBi @ Az Angle = 0.0 deg.
Front/Side   1.37 dB
Beamwidth   ?
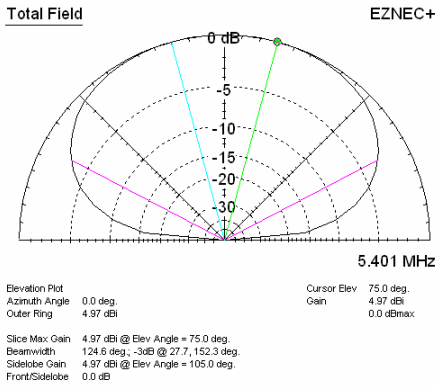Sidelobe Gain   3.13 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe   0.0 dB

Figure A-2: AAR2JD Antenna Patterns at 3.227 MHz

EZNEC+

Total Field   EZNEC+

0 dB

-5

-10

-15

-20

-30

4.0224 MHz

Elevation Plot
Azimuth Angle   0.0 deg.
Outer Ring   4.91 dBi

Cursor Elev   90.0 deg.
Gain   4.91 dBi
               0.0 dBmax

Slice Max Gain   4.91 dBi @ Elev Angle = 90.0 deg.
Beamwidth   112.8 deg.; -3dB @ 33.6, 146.4 deg.
Sidelobe Gain   < -100 dBi
Front/Sidelobe   > 100 dB

Total Field   EZNEC+

0 dB
-5
-10
-15
-20
-30

4.0224 MHz

Azimuth Plot
Elevation Angle 50.0 deg.
Outer Ring   3.84 dBi

Cursor Az   0.0 deg.
Gain   3.84 dBi
             0.0 dBmax

Slice Max Gain   3.84 dBi @ Az Angle = 0.0 deg.
Front/Side   1.82 dB
Beamwidth   ?
Sidelobe Gain   3.84 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe   0.0 dB

Figure A-3: AAR2JD Antenna Patterns at 4.0224 MHz

Total Field   EZNEC+

0 dB
-5
-10
-15
-20
-30

5.401 MHz

Elevation Plot   Cursor Elev   90.0 deg.
Azimuth Angle   90.0 deg.   Gain   4.97 dBi
Outer Ring   4.97 dBi   0.0 dBmax

Slice Max Gain   4.97 dBi @ Elev Angle = 90.0 deg.
Beamwidth   76.0 deg., -3dB @ 52.0, 128.0 deg.
Sidelobe Gain   < -100 dBi
Front/Sidelobe   > 100 dB

Total Field   EZNEC+

0 dB
-5
-10
-15
-20
-30

5.401 MHz

Elevation Plot   Cursor Elev   75.0 deg.
Azimuth Angle   0.0 deg.   Gain   4.97 dBi
Outer Ring   4.97 dBi   0.0 dBmax

Slice Max Gain   4.97 dBi @ Elev Angle = 75.0 deg.
Beamwidth   124.6 deg., -3dB @ 27.7, 152.3 deg.
Sidelobe Gain   4.97 dBi @ Elev Angle = 105.0 deg.
Front/Sidelobe   0.0 dB

Total Field   EZNEC+

0 dB
-5
-10
-15
-20
-30

5.401 MHz

Azimuth Plot   Cursor Az   0.0 deg.
Elevation Angle 50.0 deg.   Gain   4.55 dBi
Outer Ring   4.55 dBi   0.0 dBmax

Slice Max Gain   4.55 dBi @ Az Angle = 0.0 deg.
Front/Side   2.86 dB
Beamwidth   ?
Sidelobe Gain   4.55 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe   0.0 dB

Figure A-4: AAR2JD Antenna Patterns at 5.401 MHz

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Figure A-5: AAR2JD Antenna Patterns at 7.405 MHz

Analysis – The high performance of this station in the NYArmy MARS network is well known. The average height of the 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 Figure A-5, a little long for 7.4 MHz. The overall high gain of this antenna can compensate for the less than ideal horizontal directivity at 7 MHz. Note that the 6 dB variation in directivity at 7.4 MHz only amounts to 1 S-Unit. The use of ladder-line and minimal coax cable minimizes transmission line losses, allowing almost all the transmitter power to reach the antenna.

Multiple or "Fan" dipoles – AAR2JD/W2TAP
This antenna system is shown in Figure A-6. It is driven with low-loss coaxial cable leading to a rig located tuner.

Center Height = 25 ft.
Lengths:
   Wires 1 & 2 = 65 ft.
   Wires 3 & 4 = 46 ft.
   Wires 6 & 7 = 33 ft.
End Heights:
   Wire 1 = 12.5 ft
   Wire 2 = 11 ft.
   Wire 3 = 6.25 ft.
   Wire 4 = 6.25 ft.
   Wire 6 = 7 ft.
   Wire 7 = 6.67 ft.
Note: Wire 5 is a modeling
      trick to tie all wires to
      source.
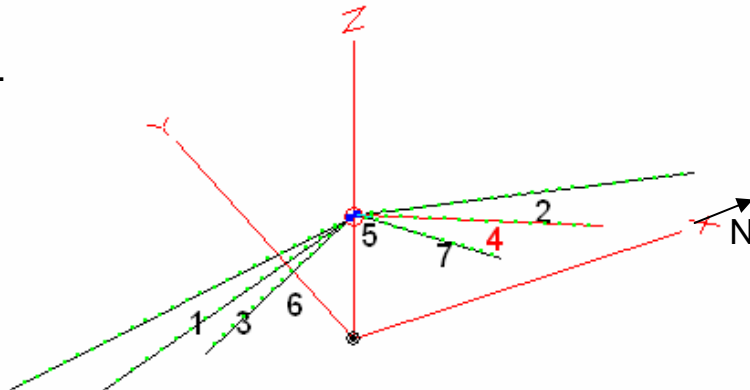
Figure A-6: Fan Dipole Configuration

The antenna 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-7.
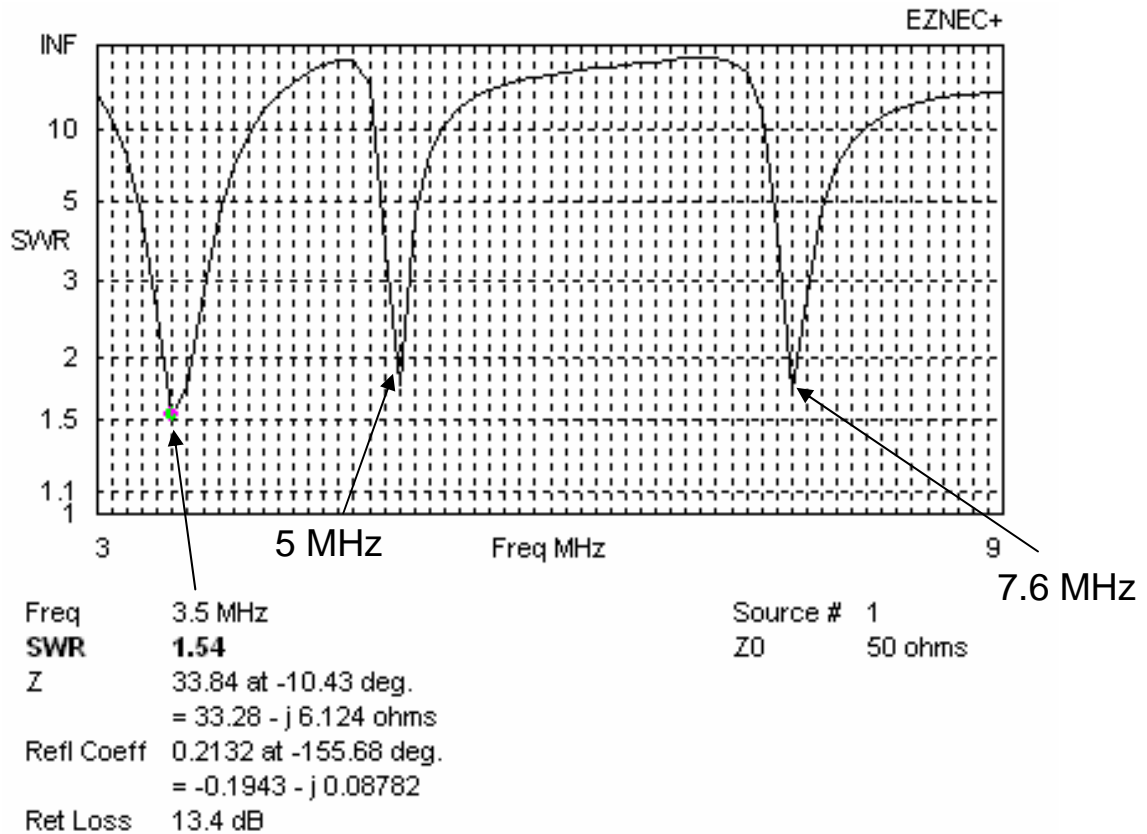
Figure A-7: SWR Plot for the Fan Dipole

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 almost ideal shape. Figure A-8 through A-11 shows the azimuth and elevation patterns for this antenna at different frequencies.
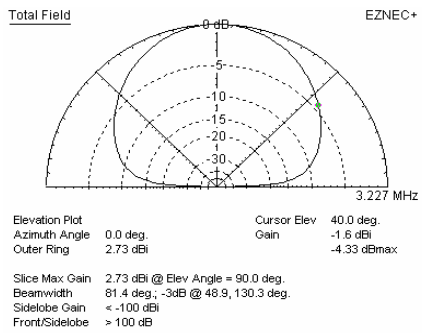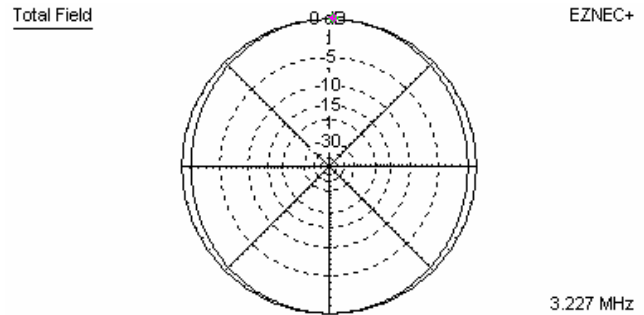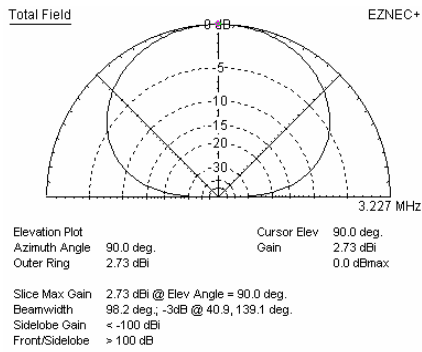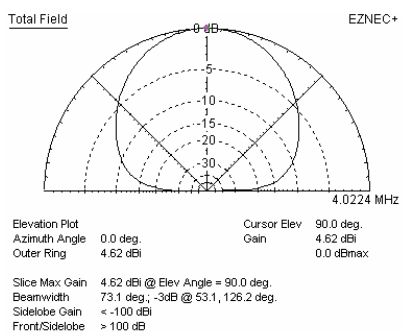
Figure A-8: Fan Dipole Antenna Patterns for 3.227 MHz
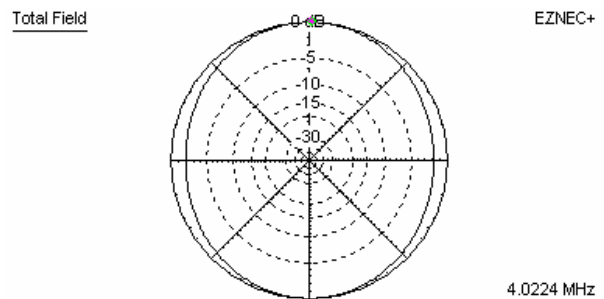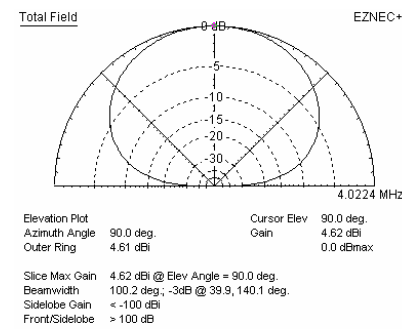
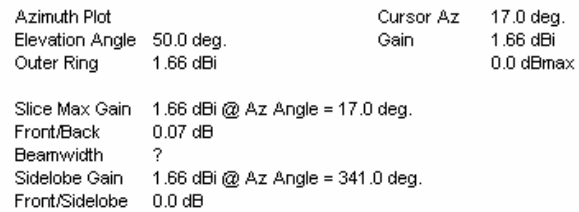**Figure A-9: Fan Dipole Antenna Patterns (AAR2JD/W2TAP) for 4.0224 MHz**

Total Field — EZNEC+ — 5.401 MHz (Elevation Plot)

Elevation Plot
Azimuth Angle 90.0 deg.
Outer Ring 4.41 dBi
Cursor Elev 90.0 deg.
Gain 4.42 dBi
0.0 dBmax

Slice Max Gain 4.42 dBi @ Elev Angle = 90.0 deg.
Beamwidth 103.2 deg.; -3dB @ 38.4, 141.6 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Total Field — EZNEC+ — 5.401 MHz (Elevation Plot)

Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 4.42 dBi
Cursor Elev 90.0 deg.
Gain 4.42 dBi
0.0 dBmax

Slice Max Gain 4.42 dBi @ Elev Angle = 90.0 deg.
Beamwidth 82.1 deg.; -3dB @ 48.9, 131.0 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Total Field — EZNEC+ — 5.401 MHz (Azimuth Plot)

Azimuth Plot
Elevation Angle 50.0 deg.
Outer Ring 2.83 dBi
Cursor Az 90.0 deg.
Gain 2.83 dBi
0.0 dBmax

Slice Max Gain 2.83 dBi @ Az Angle = 90.0 deg.
Front/Side 1.27 dB
Beamwidth ?
Sidelobe Gain 2.83 dBi @ Az Angle = 270.0 deg.
Front/Sidelobe 0.0 dB

A-10: Fan Dipole Antenna Patterns for 5.401 MHz

Total Field — EZNEC+ — 7.72 MHz (Elevation Plot)

Elevation Plot
Azimuth Angle 90.0 deg.
Outer Ring 2.42 dBi
Cursor Elev 90.0 deg.
Gain 2.42 dBi
0.0 dBmax

Slice Max Gain 2.42 dBi @ Elev Angle = 90.0 deg.
Beamwidth 110.6 deg.; -3dB @ 34.7, 145.3 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Total Field — EZNEC+ — 7.72 MHz (Elevation Plot)

Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 2.43 dBi
Cursor Elev 82.0 deg.
Gain 2.43 dBi
0.0 dBmax

Slice Max Gain 2.43 dBi @ Elev Angle = 82.0 deg.
Beamwidth 121.1 deg.; -3dB @ 29.0, 150.1 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Total Field — EZNEC+ — 7.72 MHz (Azimuth Plot)

Azimuth Plot
Elevation Angle 50.0 deg.
Outer Ring 1.66 dBi
Cursor Az 17.0 deg.
Gain 1.66 dBi
0.0 dBmax

Slice Max Gain 1.66 dBi @ Az Angle = 17.0 deg.
Front/Back 0.07 dB
Beamwidth ?
Sidelobe Gain 1.66 dBi @ Az Angle = 341.0 deg.
Front/Sidelobe 0.0 dB

A-11: Fan Dipole Antenna Patterns for 7.72 MHz

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Analysis – This antenna system produces excellent NVIS patterns over almost two octaves of frequency. 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 two frequencies, 3 MHz and 4 MHz use the longest dipole. The 5 MHz frequency uses the middle length dipole and the 7.7 MHz frequency uses the shortest dipole. A significant amount of modeling was used to optimize the dimensions of this antenna. This antenna was not designed to be resonant at each MARS frequency, but rather to provide optimum directivity patterns with a minimum number of dipoles. The efficiency of this antenna system would be increased by increasing the apex height to approximately 55 ft. as was done in the single dipole example (AAR2JD).

Long-Wire Stealth Antenna – AAR2JD
The long-wire antenna and its SWR Plot are shown in Figure A-12.

Long-Wire, slope 3.3°
Wire 1 – 105 ft.
Wire 2 – 21 ft.
End height – 15 ft.
Auto-tuner at junction
Of wires.
Wire 2 grounded at bottom
end.
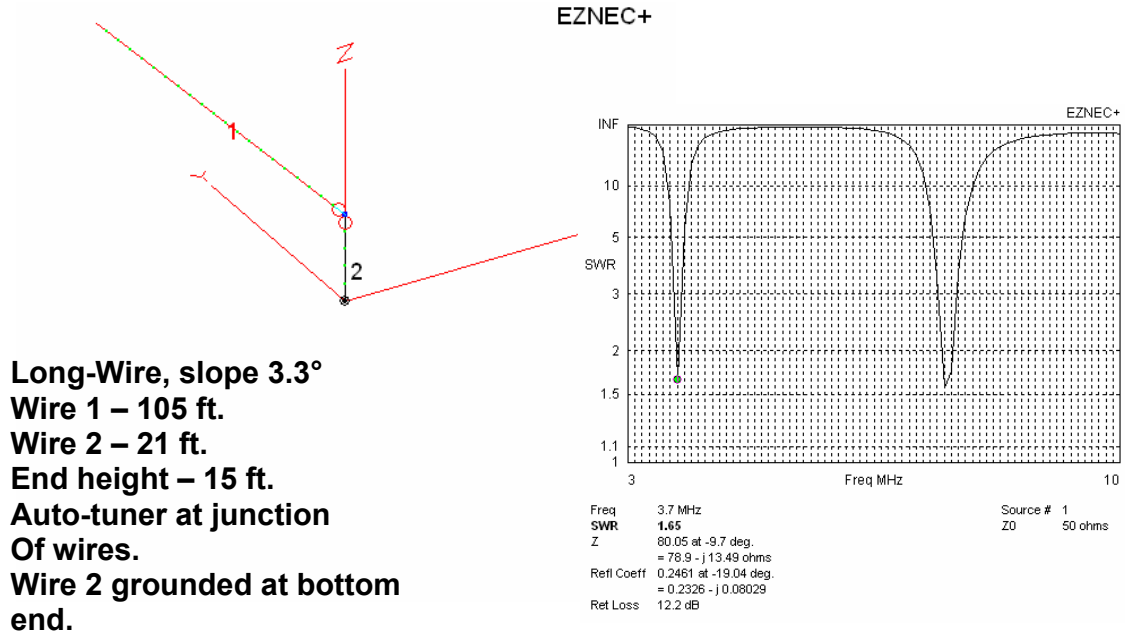
Figure A-12: Long-Wire NVIS Stealth Antenna

The antenna consists of a single long-wire (wire 1) connected to an auto-tuner, shown in Figure 37, and a grounded counterpoise (wire 2). Even using AWG #14 copper wire, this antenna is almost invisible from the side street next to the house (50 ft.). Observe that this wire is below the minimum recommended height of 0.1 wavelengths for frequencies below 5 MHz, yet performs adequately even down to KAH. Figures A-13 through A-16 show the azimuth and elevation patterns for this long-wire antenna.
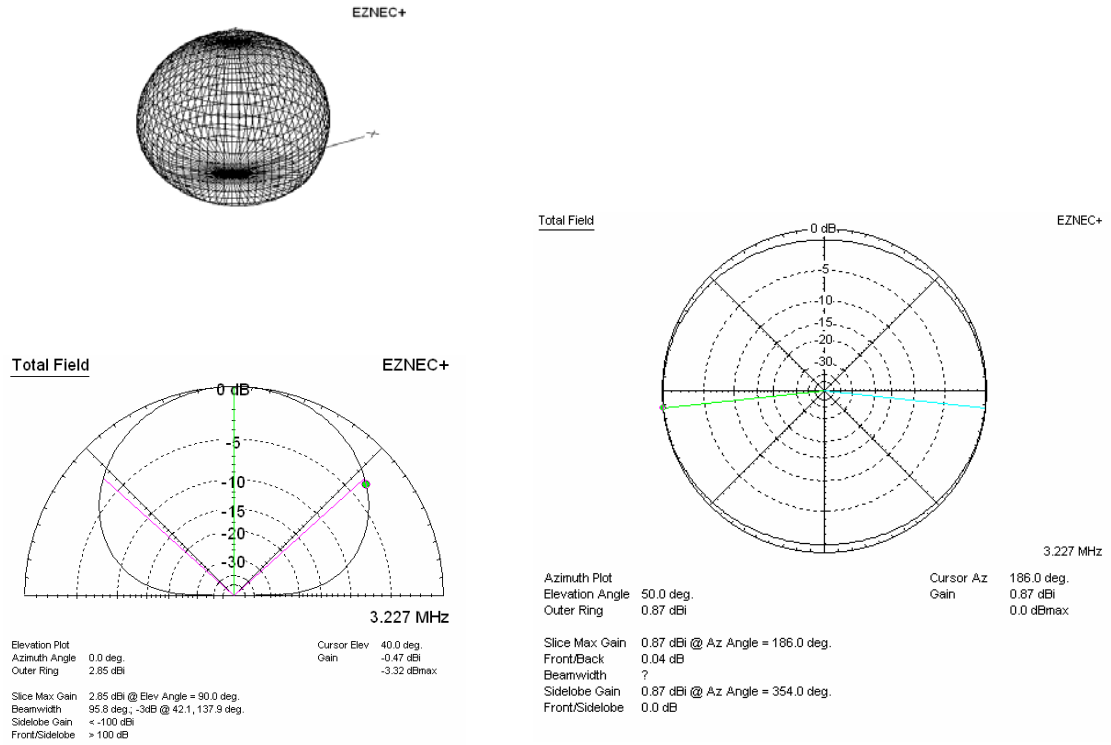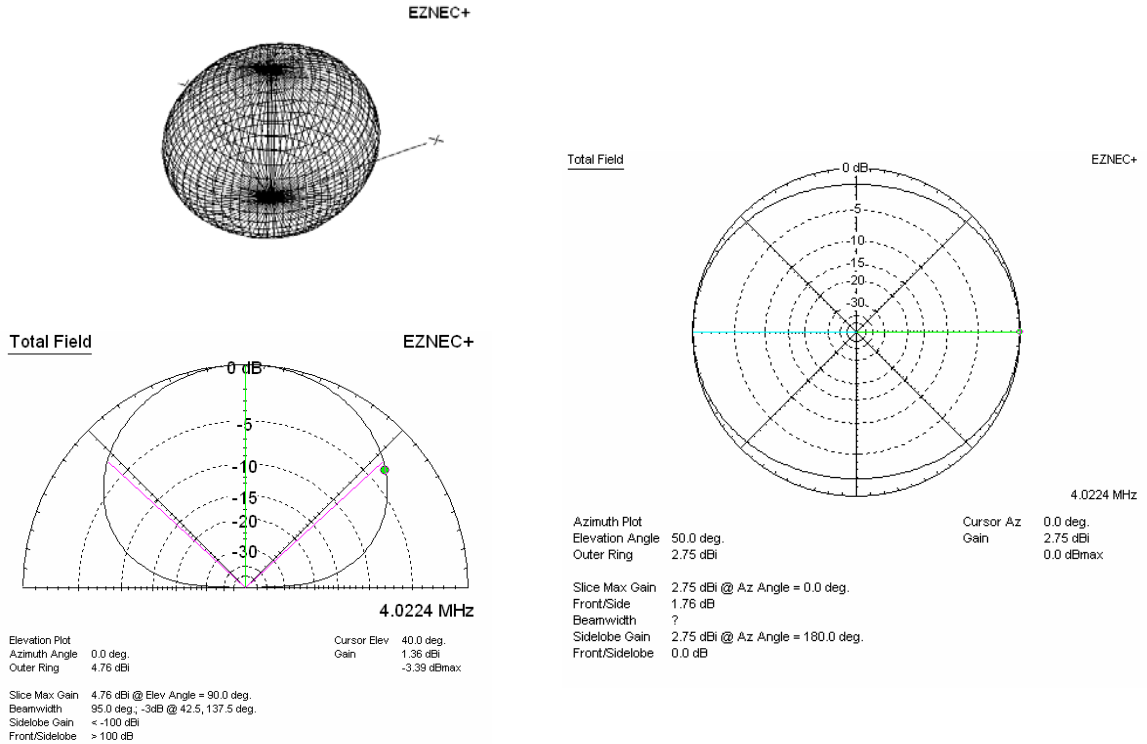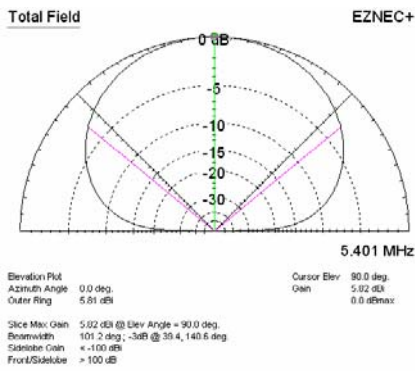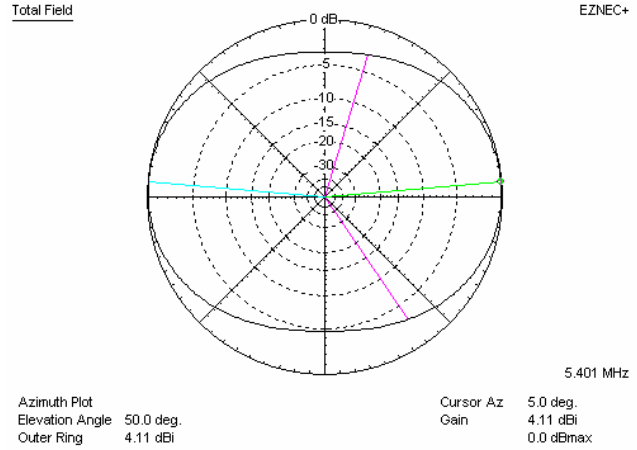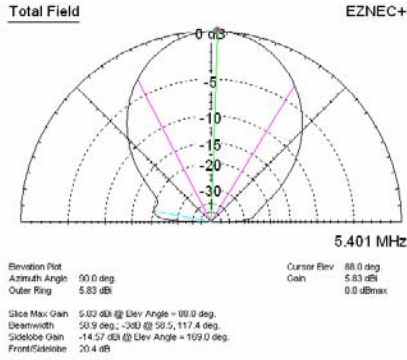
Figure A-13: Long-Wire Antenna Patterns at 3.227 MHz

A-14: Long-Wire Antenna Patterns at 4.0224 MHz

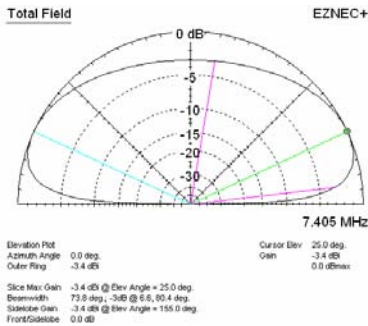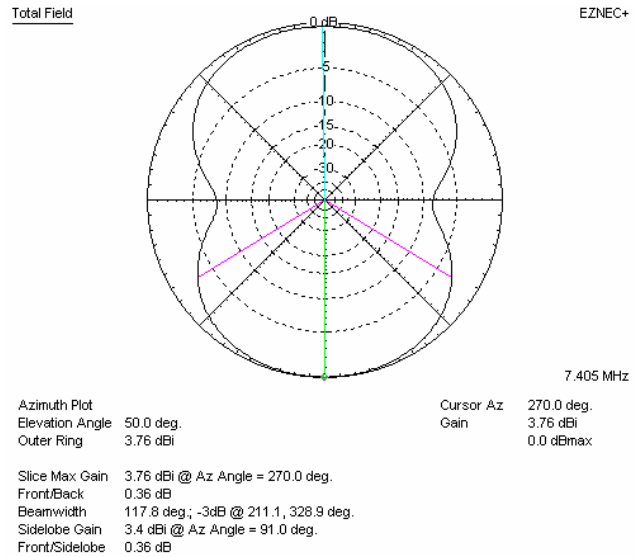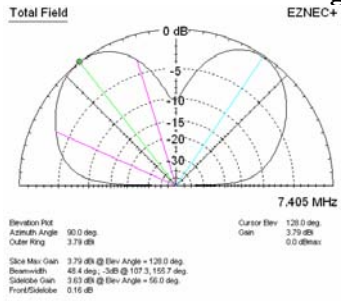**A-15: Long-Wire Antenna Patterns at 5.401 MHz**

Figure A-16: Long-Wire Antenna Patterns at 7.405 MHz

Analysis – This long-wire antenna performs well at frequencies at and below 5 MHz. But, the wire is some 0.79 wavelengths long at 7.4 MHz, generating significant directivity even close to the ground. Shortening the wire to 0.5 wavelengths or 66 ft., would result in a more useable NVIS pattern at 7.4 MHz at the expense of lower gain for the lower frequencies. Figure A-17 shows the azimuth and elevation patterns for the 66 ft long-wire antenna. The gain of this 66 ft. long-wire at 5.4 MHz is reduced by 0.8 dB, and 2 dB at 4.02 MHz and 3.227 MHz when compared to the 105 ft. version. When the sunspot cycle improves, moving the critical frequency variance up to 4 to 8 MHz, I will shorten the long-wire to 66 ft. to optimize performance at these higher frequencies.
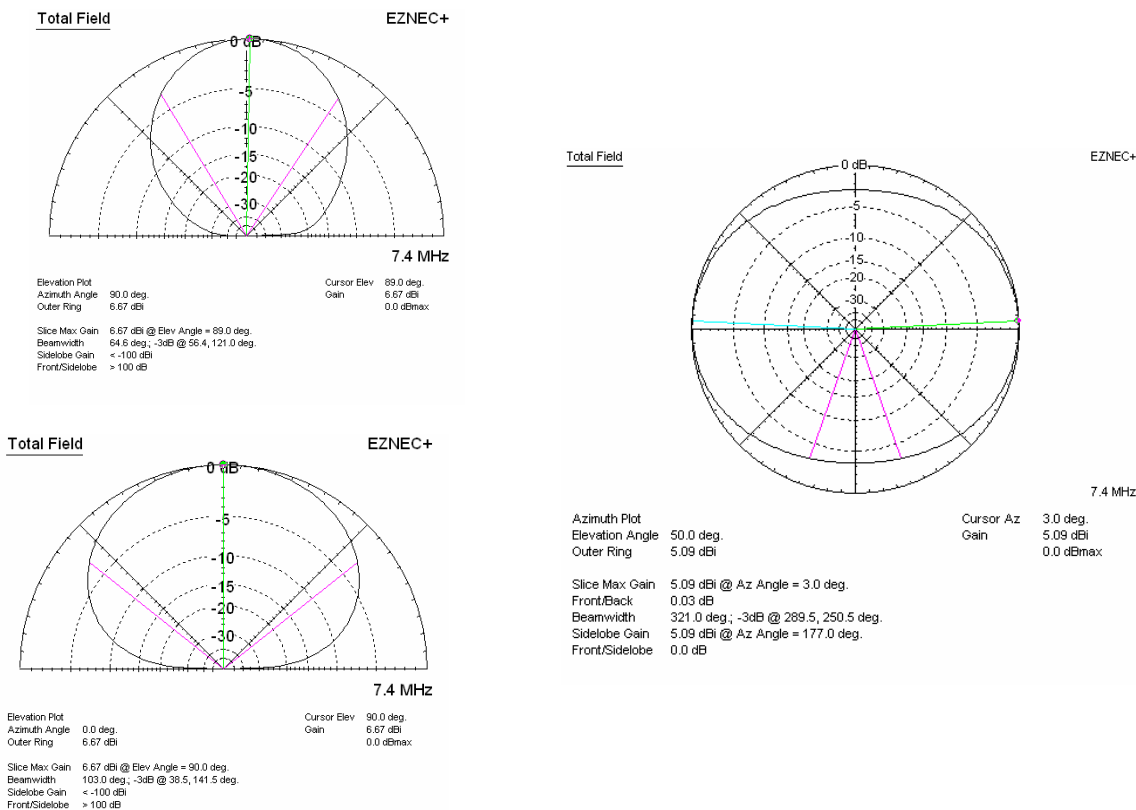

Figure A-17: Long-Wire Antenna Patterns at 7.4 MHz When Shortened to 66 ft.

Example Conclusions

All three of these antennas have shown themselves to be good performers on NY Army MARS nets. The inverted-V performs best due to its optimum height and careful detail to minimize feed-line losses. The fan-dipole antenna would perform even better if raised in height and feed with a lower-loss transmission line system (auto-tuner or ladder line). Finally, the long-wire antenna demonstrates that a low, stealthy single wire antenna can perform well, if transmission line losses are minimized.