LOFAR Low-range and Mid-range Dipoles

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INTRODUCTION:

I have carried out some observational tests and measurements on a few active dipoles and quite a large number of simulations on others. The limited number of tests that I have made suggest that the simulations are reasonably accurate so I have used the simulations to study some dipole configurations for the LOFAR low-range and mid-range dipoles. I find that both the ASTRON thin dipoles and my fat dipoles can be designed with sufficiently circular response patterns to permit good circular polarization when crossed dipoles are combined. Assuming that a receiver noise temperature ~100K can be achieved, the sensitivity of the ASTRON low-range dipole is adequate for sky noise dominated operation. It should produce sky noise temperatures of 1450K at 10 MHz and 1200K at 35 MHz. The sensitivity of the low-range fat dipole is considerably higher, producing sky noise temperatures of 3880K and 9960K at the same frequencies. The sensitivity of the ASTRON mid-range dipole is inadequate; it produces sky noise temperatures of only 74K, 476K, and 354K at 35 MHz, 90 MHz, and 120 MHz respectively. The fat dipole is significantly more sensitive but still not fully adequate, producing 251K, 1050K, and 368K at these frequencies.

BACKGROUND:

I had two goals in this study, one was to develop a better dipole for solar burst observations with the Bruny Island Radio Spectrometer (BIRS), the other was to develop active dipole configurations for LOFAR. I am presently using an active dipole (BIRS1) for 5.0 to 62.5 MHz solar scans, but I felt that its design could be improved in two respects. First, the present dipole is long enough and high enough that its response pattern deteriorates in the 60 MHz range and, second, it would be convenient to design a dipole that would be self-filtering, i.e. one that produces an essentially flat spectrum from the Galactic Background and automatically lowers the high background noise levels and strong RFI levels below 30 MHz. I presently do this with a rather complex filter after the active balun but this filter does not attenuate the 15 to 30 MHz band sufficiently while it has somewhat too much attenuation near 5 MHz. It would also be advantageous to lower the RFI levels before the signals reach the active balun with its possible intermodulation problems.

For all of this study I have used the simple and inexpensive EZNEC antenna simulation program. The use of more sophisticated programs and observational checks would be advisable to verify the EZNEC results.

BIRS DIPOLES:

Figure 1 illustrates the configuration of the two dipoles that I have built and tested for use with BIRS. Their specifications are as follows:

	BIRS1	BIRS2
Total arm length	3.20m	2.23m
Length of rectangular section	1.50m	1.01m
Length of triangular sections	0.87m	0.61m
Height at feed point	3.48m	2.00m
Gap at feed point	0.076m	0.076m
Droop angle	45°	45°
Conductor diameter	12.5mm (1/2 inch)	12.5mm
Balun impedance	150Ω	1200Ω

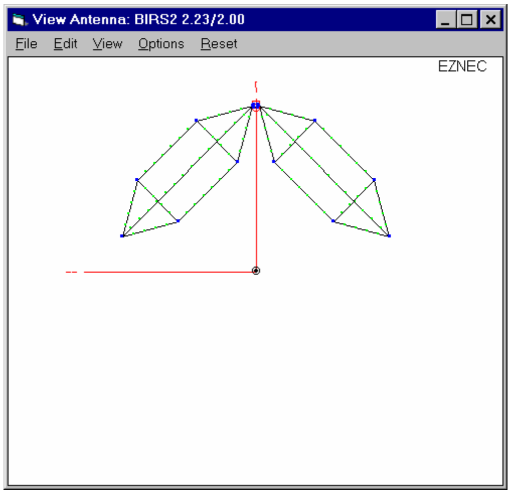


Figure 1. A diagram of the BIRS dipoles.

I have made rough measurements of the sky noise produced by BIRS1, and have also predicted the sky noise using EZNEC and Appendix A. I can only estimate the levels shown in Figure 2 to about 1 or 2 dB, but to that accuracy the measured and predicted antenna temperatures seem to agree reasonably well.

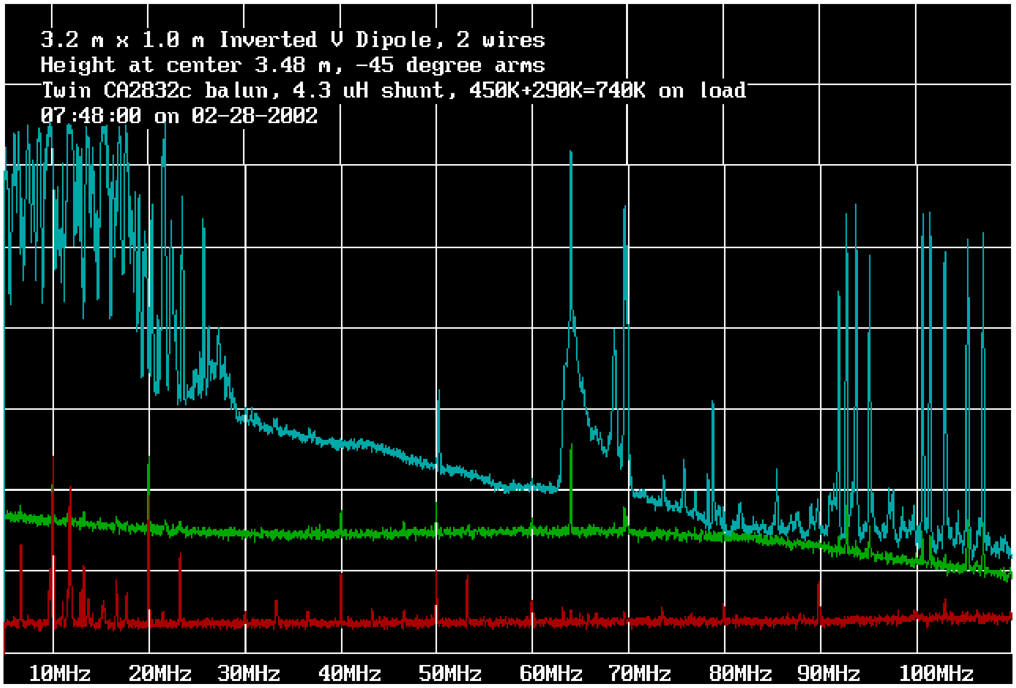


Figure 2. The spectrum produced by the BIRS1 dipole. Each box is 10 dB. The red trace is the spectrum analyzer noise level with the active balun switched off. The green trace is the noise level of the balun when terminated with a 300K load. The blue trace is sky noise as seen by the system.

Frequency	Measured Ta	Predicted Ta
20 MHz	23400K	24000K
30	11700	13300
40	9310	6720
50	4670	4272
60	2950	2860

At 10 MHz I cannot make a good measurement because of unresolved RFI; the lower envelope of the RFI spikes is ≈8 dB above the predicted sky noise level.

The measured impedance of the dipole compared well with the simulated impedance except at low frequencies (< 15 MHz) where the dipole's radiation resistance becomes very low. This suggests that the RF currents in the different parts of the dipole are being simulated correctly. Presumably, the radiation pattern produced by these currents should be correct, but I have no practical way on Bruny Island of measuring response patterns.

For BIRS2 I used a similar configuration to the original BIRS1 fat dipole. However, it is less fat, shorter, and closer to the ground. This configuration has only slightly better beamshape and efficiency properties than a dipole that consists of a rectangle and only a single triangle at the feed point. Although the BIRS1 and BIRS2 beamshapes become rather complex in the 60 MHz range, they remain simple enough for my solar observations over the full 5 MHz to 62.5 MHz range. They would not satisfy the more stringent LOFAR beamshape requirements.

As shown in Figure 3, the spectrum produced by BIRS2 is essentially flat while the spectrum from BIRS1 rises by about 12 dB from 60 MHz to 20 MHz. The data in Figure 3 were taken with the dipole over bare ground (no ground screen). I find that the measured sky noise levels are ½ to ¼ of that predicted for a perfect ground but they are a factor of 1.5 to 4 higher than those predicted for real ground. This discrepancy is most pronounced below 20 MHz where, because of RFI, it is obviously difficult to estimate sky noise levels.

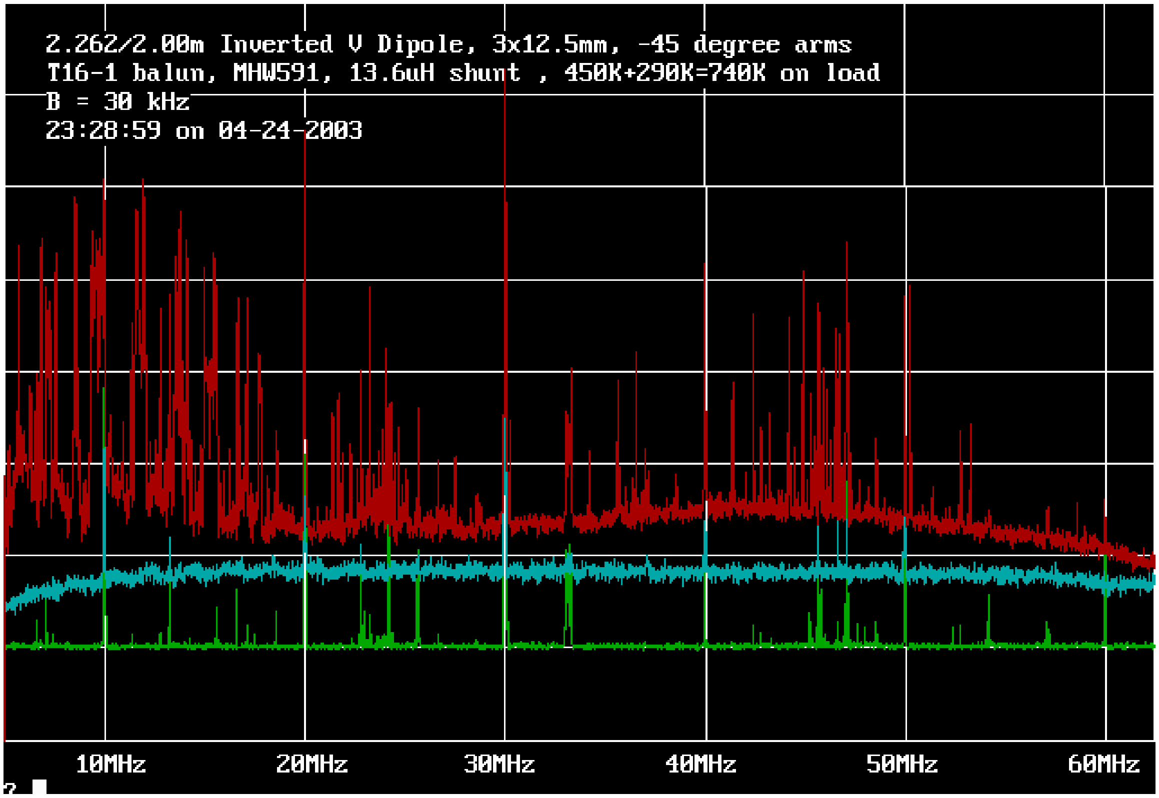


Figure 3. The spectrum produced by the BIRS2 dipole. Each box is 10 dB. The green trace is the spectrum analyzer noise level with the active balun switched off. The blue trace is the noise level of the balun when terminated with a 300K load. The red trace is sky noise as seen by the system. For convenience in testing, this dipole was erected next to the BIRS laboratory and the rather large amount of RFI above 30 MHz is caused by laboratory equipment.

The general agreement between predictions and observations is crude, but suggest that my simulations are reasonably accurate.

GENERAL CONSIDERATIONS REGARDING LOFAR DIPOLES:

The considerations for LOFAR are somewhat different from those for BIRS. In the case of LOFAR it is more important to have a large beamwidth for good sky coverage and to match the E and H plane responses to form circular polarization. It seems appropriate to design different dipoles for the 10 to 35 MHz and 35 to 120 MHz ranges because over the full frequency range of 10 to 120 MHz it is very difficult to optimize the response patterns and, also, the optimal spacings between dipoles would vary by a factor of twelve. By using two different dipoles we need to cope with only a 3.5/1.0 frequency ratio.

The effective collecting area of an active dipole requires some discussion. When incident radiation is collected by an ordinary, impedance-matched dipole, half of the collected power is delivered to the load at its terminals and the other half is reradiated. The effective collecting area is defined as the power delivered to the load divided by the power per unit area incident upon the dipole. An active dipole is normally mismatched and very little power is delivered to the load; almost all of the collected power is reradiated. With the above definition, the active dipole's effective collecting area can be very much less than that of a matched dipole (<1%). However, we can define a pseudo-collecting area, A_p, using the relation,

$$A_p = \lambda^2/\Omega \qquad (1)$$

Where Ω is the beam solid angle the dipole's response pattern. If the system noise is dominated by sky noise (Galactic Background noise), A_p can be used in system sensitivity calculations because the system noise falls in proportion to the mismatch losses. One note of caution, when using A_p in sensitivity calculations the system noise level must be taken to be equal to the sky noise temperature, not the actual system temperature. If the system is not sky noise dominated, then the actual collecting area, not the pseudo-collecting area, and the actual system noise level must be used to calculate sensitivities. The fact that the actual collecting area may be a tiny fraction of the pseudo-collecting area should be kept in mind when considering all applications of LOFAR. It might be important under some circumstances.

The impedance presented to the dipole by the active balun is important. A high impedance balun buffers the effects of the dipole's impedance variation with frequency and also buffers dipole impedance variations caused by mutual coupling between nearby dipoles. An impedance that is too high (>> 1 kΩ), however, results in very little power flow into the balun, making it impossible to maintain sky noise dominated operation. It appears to me that it also results in such weak excitation of the dipole that various stray currents become comparable to the dipole current, giving the system many undesirable properties. In practice, I have found that a balun impedance of about 300Ω to 1200Ω represents a good compromise. For the simulations in this report, I have adopted an constant impedance of 600Ω. The results are not very sensitive to this value. Since the active balun must accommodate strong RFI signals without intermodulation, a balanced, push-pull configuration of balun amplifiers is often advisable.

In any array of closely spaced elements, mutual coupling between the elements must be considered. The total impedance of an element is its self –impedance plus mutual coupling terms involving all of the other elements in the array. (In most cases, coupling to only the nearest few elements is important but I have run into situations where coupling to quite distant elements must be considered.) The sum of these coupling terms is often comparable to the self-impedance. If the array is fixed in phase, these coupling terms are constant and present no problem. However, as the phases of the elements are changed for beamsteering, these coupling terms vary in phase. In a matched system, the current that flows in an element depends upon its total impedance, thus the amplitudes and phases of the element currents vary in a non-uniform fashion across the array aperture and large sidelobes develop. In principle, it should be possible to calculate and compensate for these coupling terms but this has never proven to be practical. The standard way to mitigate this problem is to drive the element with a high source impedance, making the current in the element insensitive to its impedance. The LOFAR elements will be circularly polarized and this is a great advantage with regard to mutual coupling. The coupling between adjacent circularly polarized elements is intrinsically low because the induced currents are of the orthogonal polarization. However, it would be wise to drive the elements from high impedance sources to avoid any problems. I have not attempted to simulate the coupling terms but they should be simulated and measured at the NLTA or with a prototype array.

A large beamwidth, ~120°, is desirable for good sky coverage. This cannot be achieved across a wide bandwidth over a perfect ground screen because of the interaction between the dipole and its image. This interaction generally limits the beamwidth to about 90° except over very limited frequency ranges. Somewhat larger beamwidths, ~120°, can sometimes be obtained over real earth that is dielectric and conductive. Beamshapes are quite insensitive to the ground parameters; I have found that variations in earth dielectric constants from about 3 to 15 and conductivities from 0.003 to 0.01 siemens/meter cause only minor changes in simulated beamshapes. These earth parameters span the range to be expected in desert areas. Of course, ground losses lower the dipole efficiency and the power delivered by the dipole to the balun, making sky noise dominated operation more difficult to achieve. This effect makes ground screens imperative in many situations. The ground parameters will also change with moisture level but these effects will change slowly and should be simple to calibrate. Observational tests need to be made but I believe that it may be possible for the low-range dipoles to be operated without ground screens or with very rudimentary screens to increase the ground reflectivity at the lowest frequencies where the ground absorption is the most severe.

An important consideration in studying the dipole beamshape is to match the E and H-plane patterns as closely as possible because, in making circular polarization, the E-plane response of one dipole must be combined in quadrature with the H-plane response of the other crossed dipole. If these responses are poorly matched, elliptical polarization will result. At lower frequencies there are hundreds of turns of Faraday rotation in the ionosphere. This causes differential rotation of the major axis of the polarization ellipse across the passband, across the field of view, and across the LOFAR aperture. In theory, these effects can be calibrated but I seriously doubt that the signal-to-noise ratio will be adequate for accurate calibration after the data are sliced in several different directions. The conservative design approach is to match the E and H responses as well as possible to obtain circular dipole patterns.

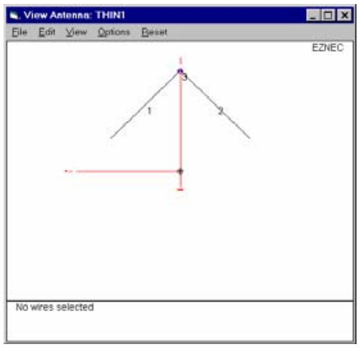
THE ASTRON DIPOLES – THIN DIPOLES:

The approach suggested by the ASTRON group is to use thin dipoles supported within small plastic pipes. This is a very appealing idea; it is cheap and simple. Thin dipoles have a much larger (~10 times) variation of impedance with frequency than fat dipoles and this puts more stringent constraints on the design of the active balun. This disadvantage must be weighed against the simplicity of thin dipoles.

I will use thin dipoles to illustrate several features common to all droopy dipoles, thin or fat. For this purpose I'll first use the 10-40 MHz dipole described by W. van Cappellen in LOFAR-ASTRON-ADD-009. Its specifications are:

THIN1

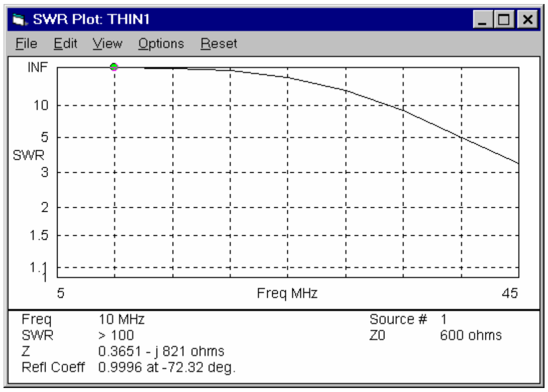
Arm length:	2.50m
Height at feed point	2.40m
Gap at feed point	0.10m (assumed)
Droop angle	45°
Conductor diameter	6.35mm (1/4 inch – assumed, not specified)
Balun impedance	600Ω (assumed)



No wires selected

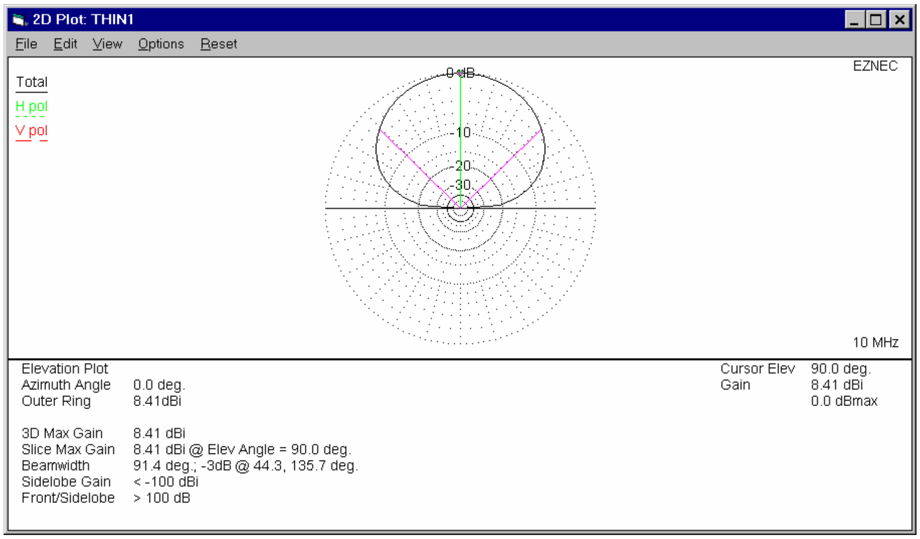
Figure 4. The thin dipole.

The properties of this dipole are simulated in Figures 5 to 13.



Freq 10 MHz
SWR > 100
Z 0.3651 - j 821 ohms
Refl Coeff 0.9996 at -72.32 deg.
Source # 1
Z0 600 ohms

Figure 5. SWR variation of THIN1 over a perfect ground.

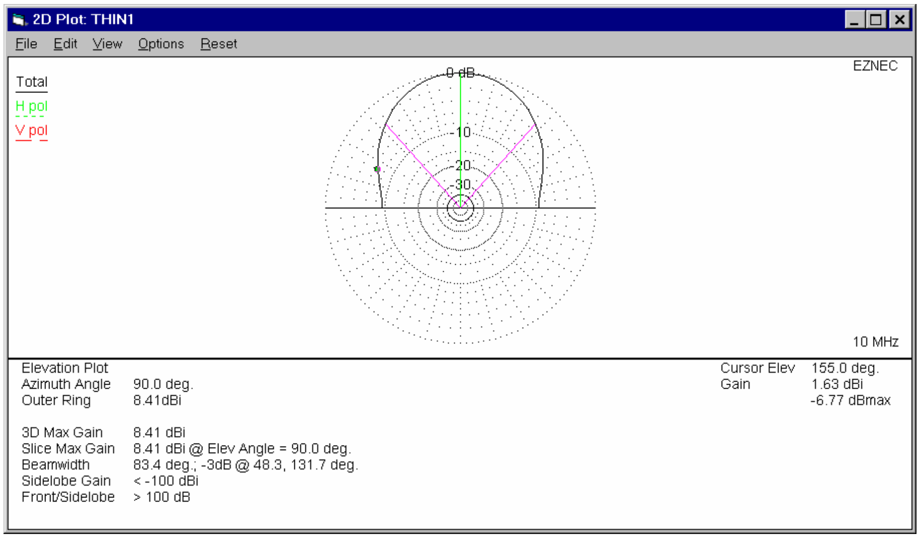


Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 8.41dBi

3D Max Gain 8.41 dBi
Slice Max Gain 8.41 dBi @ Elev Angle = 90.0 deg.
Beamwidth 91.4 deg.; -3dB @ 44.3, 135.7 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Cursor Elev 90.0 deg.
Gain 8.41 dBi
0.0 dBmax

Figure 6. H-plane elevation plot, 10 MHz.



Elevation Plot
Azimuth Angle 90.0 deg.
Outer Ring 8.41dBi

3D Max Gain 8.41 dBi
Slice Max Gain 8.41 dBi @ Elev Angle = 90.0 deg.
Beamwidth 83.4 deg.; -3dB @ 48.3, 131.7 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

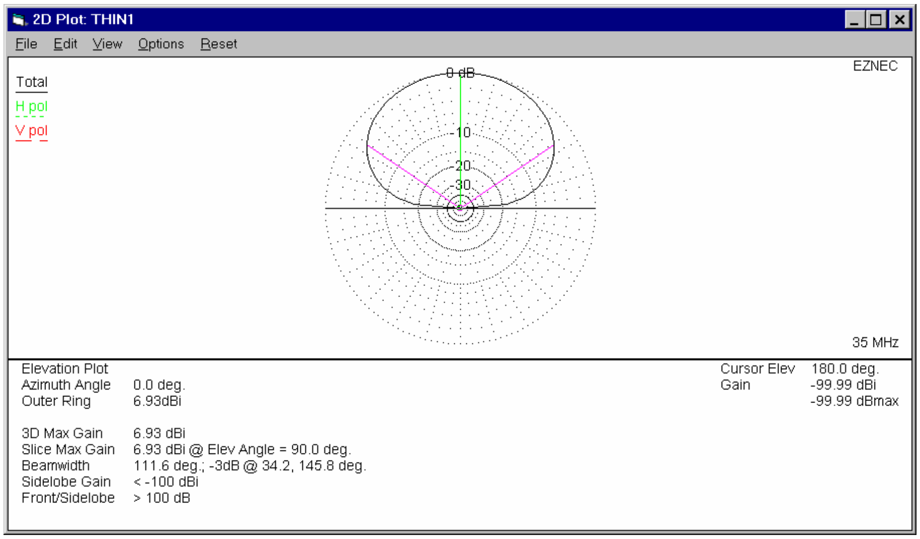
Cursor Elev 155.0 deg.
Gain 1.63 dBi
-6.77 dBmax

Figure 7. E-plane elevation plot, 10 MHz.

As given below, the patterns match well at 10 MHz. The zenith gain is 8.41dBi, the half-power beamwidths are 91.4° by 83.4°. It is essentially impossible to make the beamwidths any larger because they are set by the interaction of the dipole with its image, not by the dipole pattern itself. The dipole gain at various elevations with respect to the zenith gain is given below.

Pattern matching, 10 MHz.

Elevation (°)	H gain (dB)	E gain (dB)	Difference (dB)
75	-0.28	-0.39	+0.11
60	-1.19	-1.56	+0.37
45	-2.89	-3.47	+0.58
30	-5.83	-5.92	+0.09
15	-11.51	-8.30	-3.21



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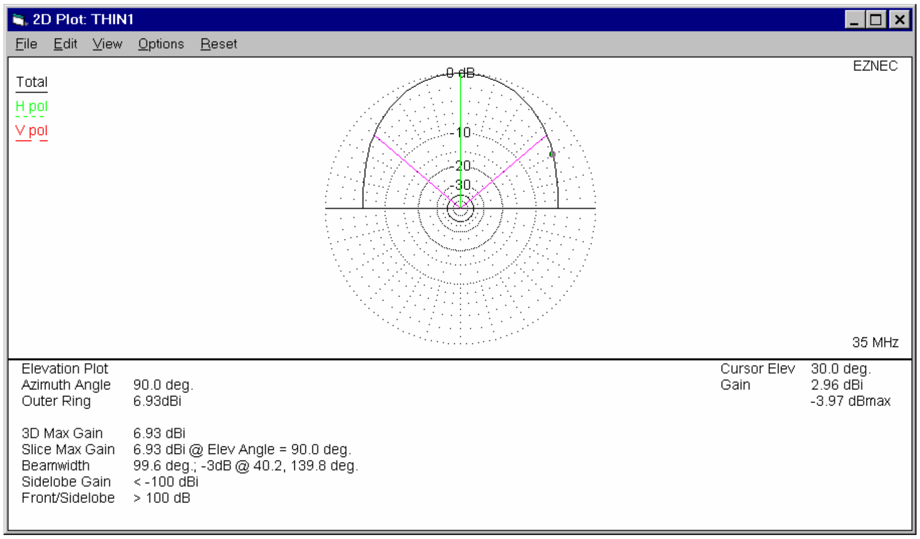
Elevation Plot                                   Cursor Elev  180.0 deg.
Azimuth Angle    0.0 deg.                        Gain         -99.99 dBi
Outer Ring       6.93dBi                                      -99.99 dBmax

3D Max Gain      6.93 dBi
Slice Max Gain   6.93 dBi @ Elev Angle = 90.0 deg.
Beamwidth        111.6 deg.; -3dB @ 34.2, 145.8 deg.
Sidelobe Gain    < -100 dBi
Front/Sidelobe   > 100 dB
```

Figure 8. H-plane elevation plot, 35 MHz.



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Elevation Plot                                   Cursor Elev  30.0 deg.
Azimuth Angle    90.0 deg.                       Gain         2.96 dBi
Outer Ring       6.93dBi                                      -3.97 dBmax

3D Max Gain      6.93 dBi
Slice Max Gain   6.93 dBi @ Elev Angle = 90.0 deg.
Beamwidth        99.6 deg.; -3dB @ 40.2, 139.8 deg.
Sidelobe Gain    < -100 dBi
Front/Sidelobe   > 100 dB
```

Figure 9. E-plane elevation plot, 35 MHz.

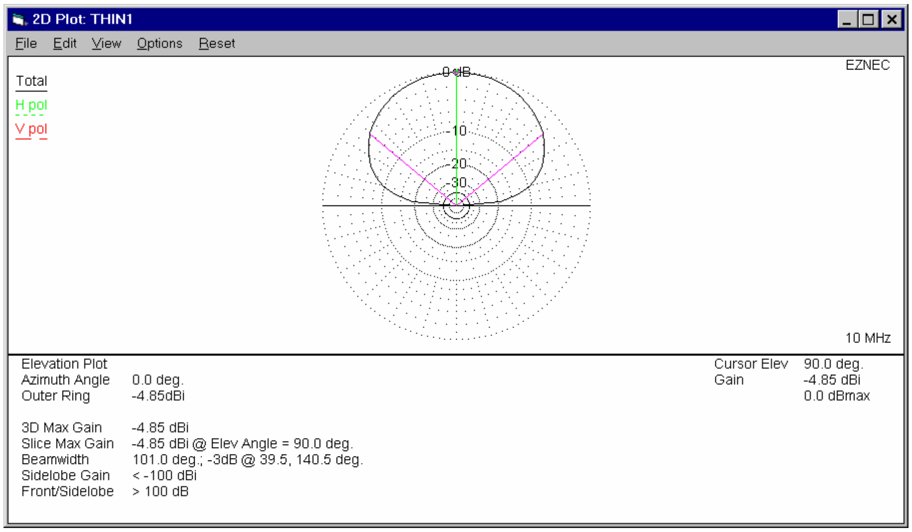
At 35 MHz, the patterns also match well. The zenith gain is 6.93dBi and the 3dB beamwidths are 111.6° by 99.6°

Elevation	H gain	E gain	Difference
75°	-0.10 dB	-0.31 dB	+0.22 dB
60	-0.49	-1.22	+0.73
45	-1.52	-2.54	+1.02
30	-3.81	-3.97	+0.16
15	-9.02	-5.09	-3.93

In general, the gains match well enough that it should be possible to produce good circular polarization and the dipole should be usable down to an elevation of about 20°, where its gain will be about 10dB below its zenith gain.

With a 600Ω balun the dipole reflection coefficient is 0.9996 at 10 MHz and its transmission coefficient is 0.005, resulting in sky noise antenna temperature of ~1450K (See Appendix A for a discussion of sky noise temperatures). I do not know how accurately my simple simulation program is able to determine these very large reflection coefficients. At 35 MHz its transmission is 0.74 and it produces an antenna temperature of 1200K. Sky noise dominated operation should be possible throughout the 10-35 MHz range.

It would greatly simplify the system if the use of a ground screen could be avoided, so I considered the same dipole over a real ground with a dielectric constant of 13 and a conductivity of 0.005 s/m, values typical of desert soils. In this case the E-plane pattern goes to zero on the horizon and the whole E-plane pattern is a bit narrower than the perfect ground case. Thus, the patterns do not match quite as well as in the case of a perfect ground. However, this problem can be corrected by increasing the droop angle from 45° to 60°. With a 60° droop I obtain the following parameters.

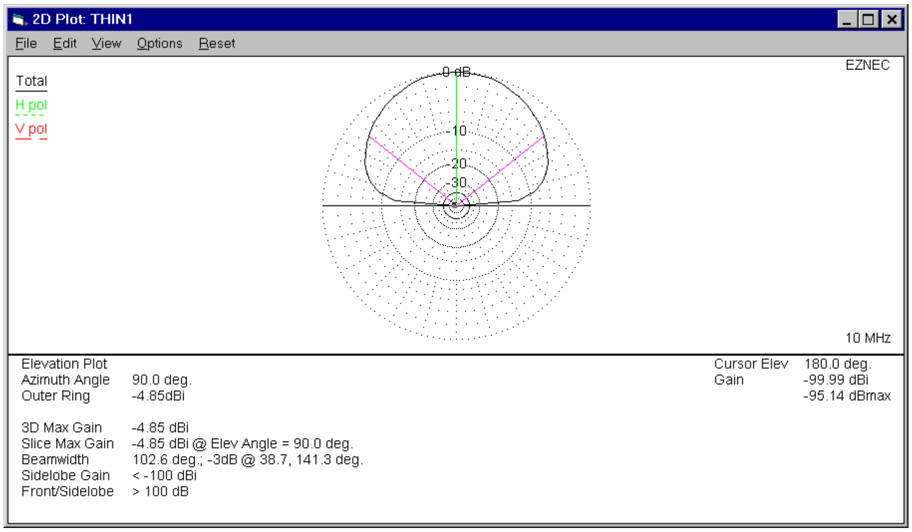


Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring -4.85dBi

3D Max Gain -4.85 dBi
Slice Max Gain -4.85 dBi @ Elev Angle = 90.0 deg.
Beamwidth 101.0 deg.; -3dB @ 39.5, 140.5 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Cursor Elev 90.0 deg.
Gain -4.85 dBi
0.0 dBmax

Figure 10. H-plane elevation plot, 10 MHz, 60° droop, no ground screen.

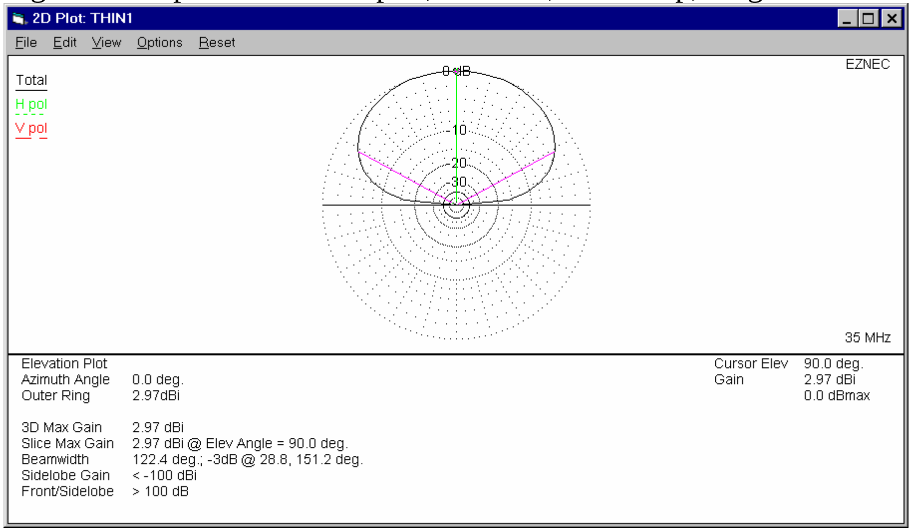


Elevation Plot
Azimuth Angle 90.0 deg.
Outer Ring -4.85dBi

3D Max Gain -4.85 dBi
Slice Max Gain -4.85 dBi @ Elev Angle = 90.0 deg.
Beamwidth 102.6 deg.; -3dB @ 38.7, 141.3 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Cursor Elev 180.0 deg.
Gain -99.99 dBi
-95.14 dBmax

Figure 11. E-plane elevation plot, 10 MHz, 60° droop, no ground screen.

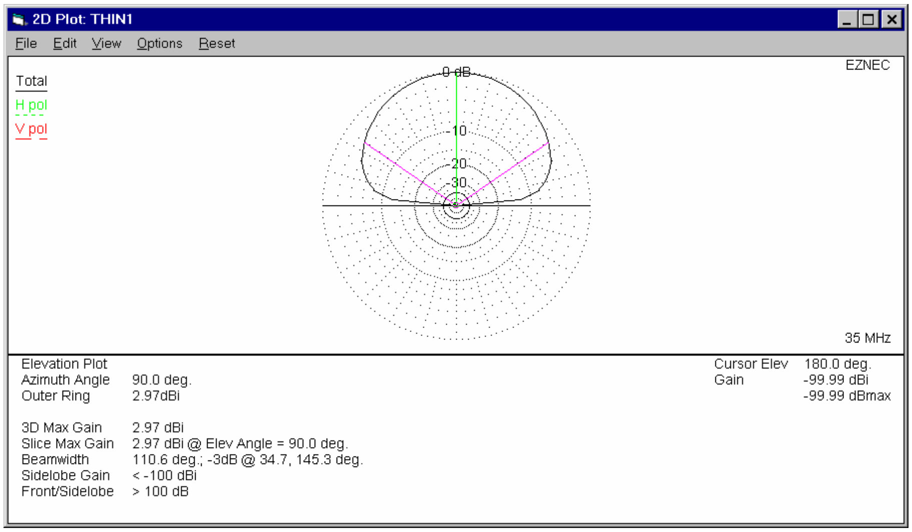


Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 2.97dBi

3D Max Gain 2.97 dBi
Slice Max Gain 2.97 dBi @ Elev Angle = 90.0 deg.
Beamwidth 122.4 deg.; -3dB @ 28.8, 151.2 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Cursor Elev 90.0 deg.
Gain 2.97 dBi
0.0 dBmax

Figure 12. H-plane elevation plot, 35 MHz, 60° droop, no ground screen.



Elevation Plot
Azimuth Angle 90.0 deg.
Outer Ring 2.97dBi

3D Max Gain 2.97 dBi
Slice Max Gain 2.97 dBi @ Elev Angle = 90.0 deg.
Beamwidth 110.6 deg.; -3dB @ 34.7, 145.3 deg.
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

Cursor Elev 180.0 deg.
Gain -99.99 dBi
-99.99 dBmax

Figure 13. E-plane elevation plot, 35 MHz, 60° droop, no ground screen.

The beamwidths are 101° by 103° at 10 MHz and 122° by 111° at 35 MHz.

The matching of the beamshapes is as shown below.

		10 MHz			35 MHz	
Elevation	H gain	E gain	Difference	H gain	E gain	Difference
75°	-0.21 dB	-0.27 dB	+0.07 dB	-0.03 dB	-0.23 dB	+0.20 dB
60	-0.90	-1.06	+0.16	-0.22	-0.91	+0.72
45	-2.25	-2.33	+0.08	-0.91	-2.00	+1.09
30	-4.75	-4.10	-0.65	-2.74	-3.56	+0.82
15	-9.90	-7.10	-2.80	-7.37	-6.45	-0.92

This element should be usable down to an elevation of 15°. (Note: Under good ionospheric conditions we found that we could successfully operate the Clark Lake system down to such elevations.) However, assuming that I am interpreting the simulations correctly, there is a serious problem involved with ground absorption if no ground screen is employed. At 10 MHz the ground loss is –11.8 dB. Although the reflection coefficient is a bit lower than in the perfect ground case, an antenna temperature of only 145K results. Assuming that it will not be possible to produce preamplifiers with less than ~100K excess noise, it would be almost impossible to achieve sky noise dominated operation under these conditions. This is a worse case scenario at the time of Galactic Pole transit; during most of the day the Galactic Plane is high in the sky and sky noise temperatures will be 3 to 5 times higher. Sky noise dominated operation may then be marginally possible. As shown below, the situation is less severe at higher frequencies.

Frequency	Sky noise temperature
10 MHz	145K
15	178
20	703
25	1103
30	1548
35	2740

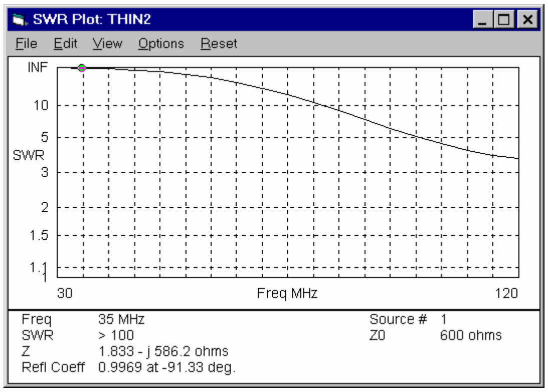
There are two possible solutions, we might decide to live with somewhat degraded operation below 20 MHz or we could install a minimal, very sparse grid of ground screen wires that would be reflective below 20 MHz but relatively transparent above that frequency. The low sensitivity at low frequencies would help to mitigate RFI problems and the lower E-plane gain of the dipole on the horizon is also useful in lowering RFI levels.

THIN2

The proposed mid-frequency ASTRO dipole has the following specifications:

Arm length:	1.00m
Height at feed point	1.20m
Gap at feed point	0.10m (assumed)
Droop angle	45°
Conductor diameter	6.35mm (1/4 inch – assumed, not specified)
Balun impedance	600Ω (assumed)

The SWR variation with frequency is shown below.



```
Freq        35 MHz                          Source #   1
SWR         > 100                           Z0         600 ohms
Z           1.833 - j 586.2 ohms
Refl Coeff  0.9969 at -91.33 deg.
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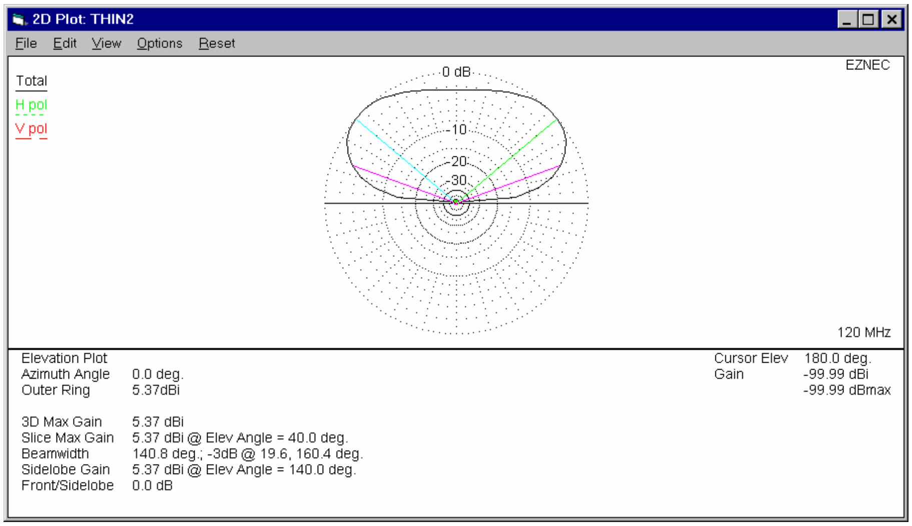
Figure 14. The SWR of the ASTRON mid-range dipole over a perfect ground.

At 35 MHz the beamwidths are 95° by 87°; the H and E-plane responses match well. At 90 MHz multilobing is starting to set in; but the beamwidths are 130° by 104° and, again, the patterns match well. Presumably, this dipole was designed for a maximum frequency of 90 MHz. At 120 MHz the situation is poor with an H-plane beamwidth of 141° and an unspecified E-Plane beamwidth because the maximum gain occurs on the horizon. I will illustrate this situation in Figures 15 and 16 in order to show the sorts of patterns that result when a dipole is operated somewhat above its design frequency.



```
Elevation Plot                                                Cursor Elev   180.0 deg.
Azimuth Angle    0.0 deg.                                     Gain          -99.99 dBi
Outer Ring       5.37dBi                                                    -99.99 dBmax

3D Max Gain      5.37 dBi
Slice Max Gain   5.37 dBi @ Elev Angle = 40.0 deg.
Beamwidth        140.8 deg.; -3dB @ 19.6, 160.4 deg.
Sidelobe Gain    5.37 dBi @ Elev Angle = 140.0 deg.
Front/Sidelobe   0.0 dB
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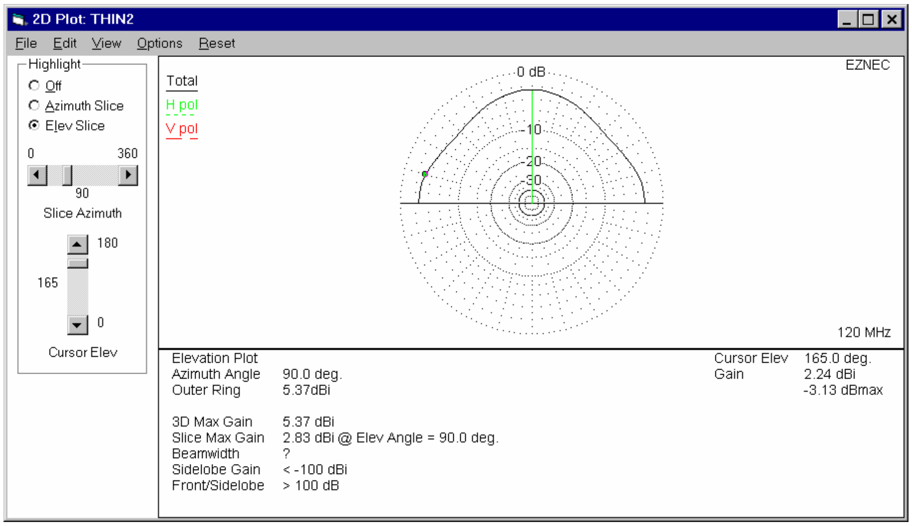
Figure 15. The H-plane pattern of THIN2 at 120 MHz.



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Elevation Plot                                                Cursor Elev   165.0 deg.
Azimuth Angle    90.0 deg.                                    Gain          2.24 dBi
Outer Ring       5.37dBi                                                    -3.13 dBmax

3D Max Gain      5.37 dBi
Slice Max Gain   2.83 dBi @ Elev Angle = 90.0 deg.
Beamwidth        ?
Sidelobe Gain    < -100 dBi
Front/Sidelobe   > 100 dB
```

Figure 16. The E-plane pattern of THIN2 at 120 MHz.

At 35 MHz a reflection coefficient of .9969 results in a transmission coefficient of 0.0062 and an antenna temperature of only 74K. Sky noise dominated operation would not be possible. At higher frequencies the transmission coefficient and antenna temperature rises so that an antenna temperature of 476K is predicted at 90 MHz. Because of the decrease in Galactic noise the antenna temperature then decreases to 354K at 120 MHz.

Therefore, with this dipole over a perfect ground plane its sensitivity is unacceptable in the lower part of the frequency range and its pattern is unacceptable in the upper portion of the range. Over a real ground, the patterns are somewhat better but the sensitivity is ~50% lower because of ground absorption. If my simulations are valid, this dipole design is unacceptable for LOFAR.

THE ERICKSON DIPOLES – FAT DIPOLES:

My initial opinion, based upon my experience with the BIRS dipoles and before I did any simulations, was that the large reactance of thin dipoles would limit their usefulness for LOFAR, i.e. that fat dipoles would be a better choice in spite of their somewhat greater complexity. I made a few observational tests on successively simpler structures, then Emil Polisenski and I simulated a number of them during June-July, 2002. We decided to build and test a configuration similar to that shown in Figure 17. These first ones became the present NLTA dipoles. The NLTA dipole design was a generic fat dipole for experience and test purposes. Its dimensions are intermediate between those appropriate for the low-range and the mid-range More recently I have simulated two similar designs developed specifically for low-range and mid-range LOFAR dipoles.

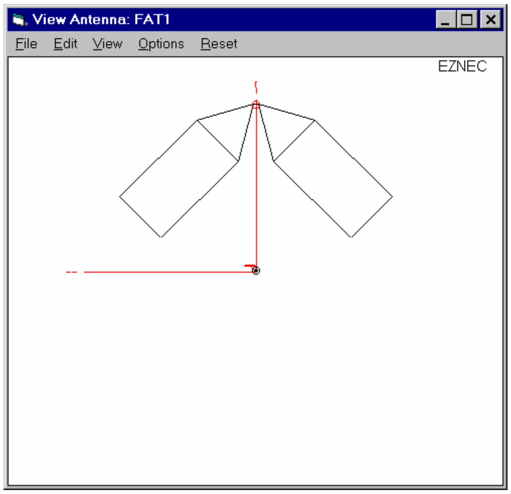
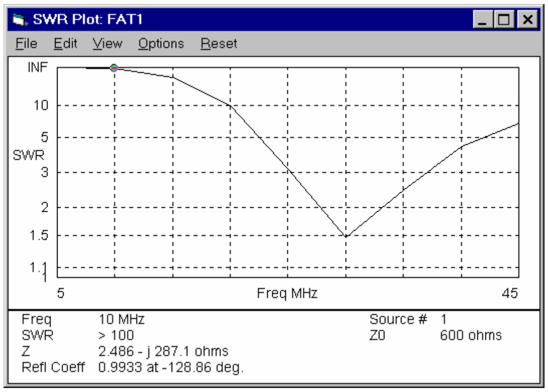


Figure15. A diagram of a FAT dipole.

FAT1 - A suggested design for a low-range dipole.

Overall arm length	3.44m
End triangle length	1.10m
Rectangle length	2.34m
Height at feed point	3.60m
Width of arm	1.26m
Gap at feed point	0.20m
Droop angle	45°
Conductor diameter	12.5mm (1/2 inch)
Balun impedance	600Ω



```
Freq        10 MHz                                  Source #   1
SWR         > 100                                   Z0         600 ohms
Z           2.486 - j 287.1 ohms
Refl Coeff  0.9933 at -128.86 deg.
```

Figure 16 The SWR variation for FAT1.

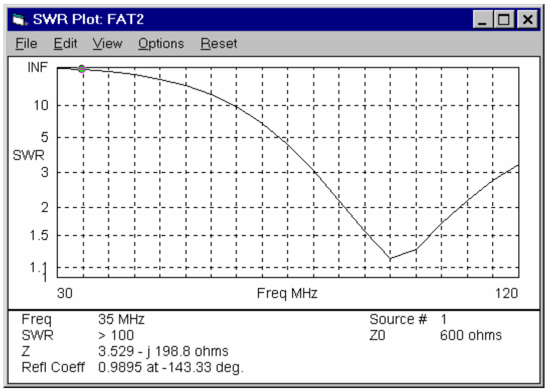
The H-plane and E-plane gain patterns are similar to those of Figures 6 through 9 except that the patterns do not match quite so well, the differences are as follows:

		10 MHz			35 MHz	
Elevation	H gain	E gain	Difference	H gain	E gain	Difference
75°	-0.26 dB	-0.41 dB	+0.15 dB	-0.06 dB	-0.73 dB	+0.67 dB
60	-1.11	-1.66	+0.55	-0.00	-2.15	+2.15
45	-2.73	-3.74	+1.01	-0.41	-3.25	+2.84
30	-5.60	-6.49	+0.89	-2.10	-2.89	-0.79
15	-11.21	-9.48	-1.93	-6.87	-1.62	-5.25

In comparing THIN1 and FAT1, it is important to note that the reflection coefficients for FAT1 are appreciably lower, 0.9933 at 10 MHz and 0.4123 at 35 MHz; the resulting sky noise antenna temperatures are three to eight times higher, 3870K and 9960K. With these values it should be quite simple to achieve the specified sky noise domination of 10 dB. It should also be feasible to operate FAT1 without a ground screen; the predicted sky noise temperatures are 3170K at 10 MHz and 5080K at 35 MHz. This would greatly simplify antenna construction.

FAT2 - A suggested design for a mid-range dipole.

Overall arm length	1.051m
End triangle length	0.336m
Rectangle length	0.715m
Height at feed point	1.100m
Width of arm	0.385m
Gap at feed point	0.100m
Droop angle	45°
Conductor diameter	9.25mm (3/8 inch)
Balun impedance	600Ω



```
Freq       35 MHz                         Source #   1
SWR        > 100                          Z0         600 ohms
Z          3.529 - j 198.8 ohms
Refl Coeff 0.9895 at -143.33 deg.
```

Figure 17. The SWR variation for FAT2.

The patterns are similar to those of the thin dipoles. The H-plane and E-plane patterns match well at the low end of the frequency range and become somewhat mismatched at the high end. The pattern match could be made better by shortening and lowering the dipole, but then the sensitivity becomes inadequate at low frequencies. As always, the above parameters represent a compromise.

At 35 MHz the beamwidths are 94° by 83°, at 90 MHz they are 120° by 106°, and at 120 MHz they are 130° by 66°. The pattern matching for FAT2 is obviously poor at 120 MHz but much better than THIN2. The gain differences between the H-plane and E-plane patterns are given below.

Elevation	35 MHz Difference	90 MHz Difference	120 MHz Difference
75°	+0.14 dB	+0.36 dB	+1.02 dB
60	+0.50	+1.15	+3.30
45	+0.85	+1.56	+4.48
30	+0.52	+0.32	+2.98
15	-2.61	-4.47	-0.58

The dipole gain at 15° is about 10 dB below the zenith gain; it should be useable to approximately that elevation.

The sensitivity of FAT2 over a perfect ground is tabulated below. I have also calculated a few representative values for the sensitivity over real ground; they are shown in parentheses.

Frequency	Reflection coefficient	Transmission coefficient	Ground Loss	Sky noise
35 MHz	.9895	.0209		251K
	(.9650)	(.0688)	(-6.66 dB)	(178K)
40 MHz	.9804	.0388		330K
45 MHz	.9663	.0663		417K
50 MHz	.9452	.1066		512K
	(.9090)	(.1737)	(-4.50 dB)	(296K)
70 MHz	.7348	.4601		920 K
90 MHz	.2173	.9528		1048K
	(.2953)	(.9172)	(-2.89 dB)	(516K)
100 MHz	.1334	.9822		820K
110 MHz	.3676	.8649		562K
120 MHz	.5402	.7082		368K
	(.4583)	(.7900)	(-3.28 dB)	(197K)

This table is useful for understanding the behavior of all active dipoles. The SWR and reflection coefficient decrease with frequency to 100 MHz. The consequent increase in transmission into the active balun is offset by the decrease in Galactic Background temperature with frequency (see Appendix A). Over a perfect ground the antenna temperature at 100 MHz due to sky noise essentially equals the Galactic Background temperature. Over a real ground there is significant absorption at all frequencies but it is highest at low frequencies where the dipole is closest to the ground in wavelengths and where the fields penetrate the farthest into the ground. I do not understand why the absorption appears to increase from 90 MHz to 120 MHz. Similar effects apply to the low-range dipoles.

CONCLUSIONS:

It must be remembered that my conclusions are based upon the very simple antenna simulation program, EZNEC. They need to be tested using a more sophisticated program and they also need to be verified observationally. My conclusions do seem to be sensible from an intuitive standpoint. From my observational tests I have found no reason to believe that my conclusions are grossly in error.

All four dipoles, THIN1, THIN2, FAT1, and FAT2 have sufficiently circular response patterns to form good circular polarization. It should be possible to correct for the residual polarization ellipticities in software. The thin dipole designs have slightly better polarization characteristics than the fat ones.

I assume a receiver temperature ~100K in all cases. Considering the low-range dipoles, THIN1 has adequate sensitivity for sky noise dominated operation when placed over a perfect ground; it produces sky noise antenna temperatures ranging from 1450K at 10 MHz to 1200K at 35 MHz. The efficiency and sensitivity of FAT1 is 4 to 8 dB higher than that of THIN1. FAT1 should produce 3870K at 10 MHz and 9960K at 35 MHz. In spite of ground absorption losses it should be practical to operate FAT1 over real ground, without any ground screen. In this case it should produce 3170K at 10 MHz and 5080K at 35 MHz. The simplicity of antenna construction without a ground screen would far outweigh the extra complexity of FAT1 compared with THIN1.

In the case of the mid-range dipoles, the sensitivity of THIN2 appears to be inadequate for use by LOFAR; it produces a sky noise temperature of only 74K at 35 MHz; at 90 MHz it produces 476K and at 120 MHz it produces 354K. FAT2 has marginal sensitivity, it produces 251K at 35 MHz, 1050K at 90 MHz, and 368K at 120 MHz. Above 100 MHz both dipoles become efficient and see, essentially, the Galactic Background temperature. I have a few ideas for increasing the sensitivity of the mid-range dipoles in the 35 MHz range, but I do not have time to explore them at this point. Matching circuitry that could deliver more power to the active balun might increase sensitivities. Any such circuits would have to be broadband and, in this case, we would need to carefully to evaluate possible mutual coupling effects. At this point it appears to me that FAT2 is the best choice for a mid-range dipole even though its sensitivity is not fully satisfactory.

APPENDIX A – The Polar Galactic background.

The Galactic Background in both polar regions has been well measured below 150 MHz. See H.V. Cane, 1979, (Mon. Not. R. astro Soc. 189, 465-478.) for a summary of approximately 150 such measurements by two dozen different observers. These data were modeled by Cane and she proposed a model involving a galactic component, an extra-galactic component, and local HII opacity. If ν is frequency in MHz and $\tau(\nu)$ is the opacity, then the polar brightness temperature becomes:

$$T(\nu) = T_{og}\,\nu^{-2.52}\,(1 - \exp(-\tau(\nu))/\tau(\nu) + T_{oeg}\nu^{-2.80}\exp(-\tau(\nu)) \qquad (2)$$

Where $T_{og} = 8.09 \times 10^7$ K is the galactic component, $T_{oeg} = 3.47 \times 10^7$ is the extra-galactic component, and $\tau(\nu) = 5.0 \times \nu^{-2.1}$ is the local HII opacity. $T(\nu)$ applies to both the North Galactic Pole (NGP) and the South Galactic Pole (SGP). The brightness temperature observed by a simple dipole antenna at a northern mid-latitude will be represented by (2) near NGP transit (≈13 hr LST) or at southern mid-latitudes near SGP transit (≈1 hr LST). Figure A1 is a graph of the function given in (2).

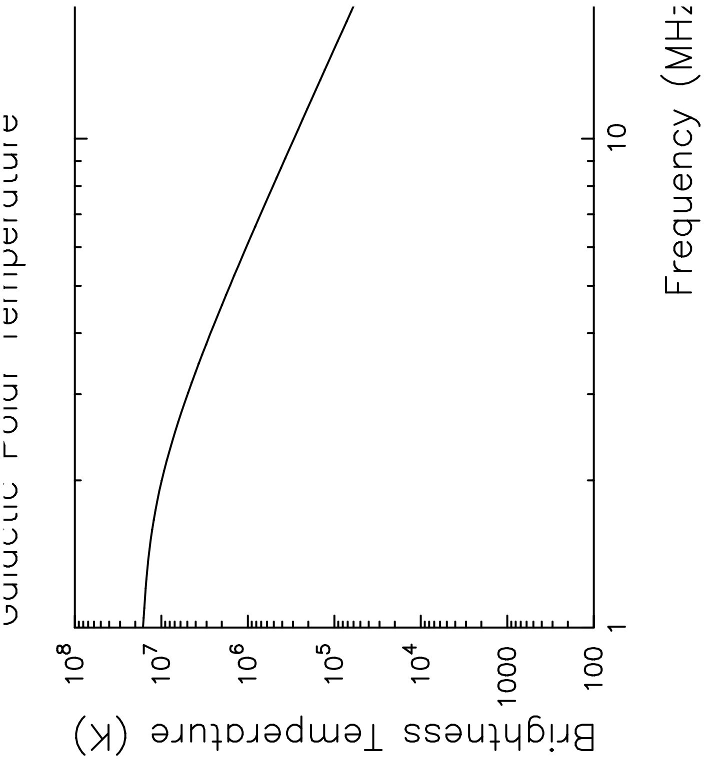


Figure A1. The galactic polar brightness temperature.

CCIR Reports 342-6, 258-5, 670-1 provide an approximation to this spectrum but for accurate antenna calibrations it is better to use the actual, observed spectrum. The CCIR reports also specify a fictitious “atmospheric noise” component that has not been seen by low frequency radio astronomers. For the past decade I, personally, have made daily observations of the galactic spectrum (day and night) and solar spectrum from 5.0 to 62.5 MHz without encountering this “atmospheric noise”.

APPENDIX B – The NLTA dipoles

For completeness I will include the specifications of the NLTA dipoles. They have the same configuration as FAT1 and FAT2. I have no impedance or calibrated antenna temperature measurements on these dipoles, so I can say little more about them.

Overall arm length	2.62m
End triangle length	0.79m
Rectangle length	0.1.83m
Height at feed point	3.45m
Width of arm	0.90m
Gap at feed point	0.100m
Droop angle	45°
Conductor diameter	12.5mm (1/2 inch)
Balun impedance	150Ω