May 22, 2006

Tests on Large Blade Dipoles

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1. Introduction

This is a description of the dipole tests that I made on Bruny Island from December 2005 to April 2006. I think that the data are sound and solid but I'm uncertain about some of my interpretations. This report may be rather long-winded but it is also for my personal use as documentation.

2. Dipoles and Mounting

Figure 1 shows the dipole and mount. This mount needs no central mast except for a temporary one during erection of the structure. It is easily transported as shown in the right panel of Figure 1. Larger diameter pipes are obviously needed to make the structure more rigid.

If mounts of this type were used for the LWA, the dipole systems could be built in a factory, nested together for transportation, and simply set out at the site. We had a ferocious windstorm in January with winds ~ 150 km/hr and severe damage in the area. (Power was off for about a day.) The dipole sat through the storm without movement or damage in spite of the fact that it was not tied down or secured in any way. It seems that the structures could be secured quite simply.

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Table 1. Dipole specifications

Specification	Value
Length – Triangular section	00.360 m
Length – Rectangular section	01.380 m
Width	00.420 m
Gap	00.100 m
Height	01.500 m
Angle (inverted Vee)	45.000°

Fig. 1.— Left, big blade dipole and mount. Right, easy transport!

The coordinates of the site are: S 43.367°, E 147.222°. However, in the area where the dipole is located the ground slopes 3.5° to the north and 2.5° to the west. $-2.5° \times \cos(\mathrm{lat}) = -1.82°$. Therefore, for the purpose of response pattern calculations, the "effective" geographic coordinates of the dipole are: S 39.867°, E 145.402°. The concept of "effective" geographic coordinates is worth mentioning explicitly. These are the coordinate of a point on the Earth where the vertical is parallel to the perpendicular of the local, sloped site. Since the distances to astronomical sources are effectively infinite, the response pattern of an antenna constructed on a sloping site is identical to that of one built on a horizontal site with effective coordinates such as these.

Note that the Galactic Center ($17^h45^m, -29°$) passes $\sim 11°$ north of the zenith while the South Galactic Pole ($0^h49^m, -27°$) passes $\sim 13°$ north.

3. Dipole Impedance

Figure 2 is a plot of the blade impedance as produced by EZNEC along with the measured points produced by my ham-type MJF SWR meter. The agreement seems to me to be quite decent. This suggests that the simulations of dipole properties should be reasonably reliable.

4. Output spectra

Using my BIRS spectral scanning system I compared the output of the two blades A and B with the outputs of the Hicks balun with its inputs matched. I also compared the outputs with and without a 3m$\times$ 4m ground screen under the structure. In Figure 3 the lower traces correspond to a temperature of 543K (balun noise plus room temperature)at the balun inputs. One can see the small slope in these traces caused by the coax (~ 130 m) attenuation. The upper traces show

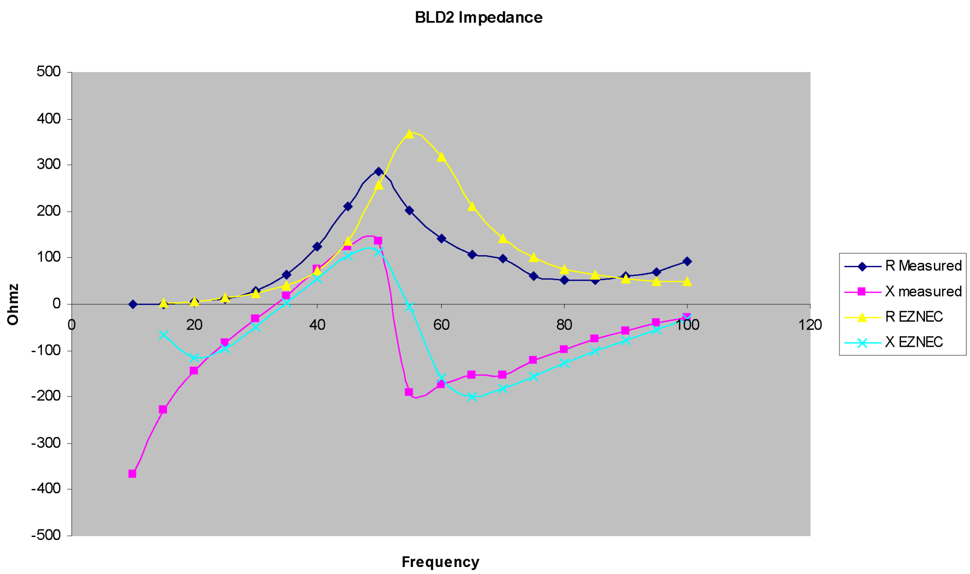

Fig. 2.— Impedance of big blade dipole, measured and simulated with EZNEC

that the sky + balun signal noise exceeds this 543K by > 6 dB from 20 to 60 MHz and by 4 dB to 6 dB up to 90 MHz, depending upon the presence or absence of the ground screen. A ground screen appears to raise the sensitivity of the system by about 2 dB above 60 MHz. These traces were taken between 18:00 LST and 18:30 LST, i.e. near the time of Galactic Center transit (nearly overhead); at the time of South Galactic Pole transit (also overhead) the sky noise is 4 to 5 dB lower. This fact must be kept in mind when comparing these traces with the sky noise drifts scans discussed below. The outputs of Blade B are essentially identical to those of Blade A. At the times of these scans the blades were oriented at ±45 ° azimuth.

The strong signals between 63 and 70 MHz are the local Channel 2 TV (Channel assignments in Tasmania differ from those in the USA).

Some of my experience with RFI may be useful in the design of the LWDA/LWA. Most of the spikes in Figure 3 above 25 MHz, except for the TV and the FM above 92 MHz, are internally generated and radiated by the PCs, A/Ds, and monitors housed in my unshielded wooden cottage. These radiations are mostly picked up by the dipole (130 m away) or by the last 30 m of the RG-213U coax that is unburied. The first 100 m of the coax is buried about 30 cm deep. If it is terminated where it comes up from underground, the spikes on the lower trace almost all disappear. If it is terminated at the end of the unburied section, many of them reappear. When the balun and dipole are connected they become stronger and more numerous. The spikes do not bother the measurements described below because these data were taken with my spectrometer in the RFI avoidance mode that I use for solar observations.

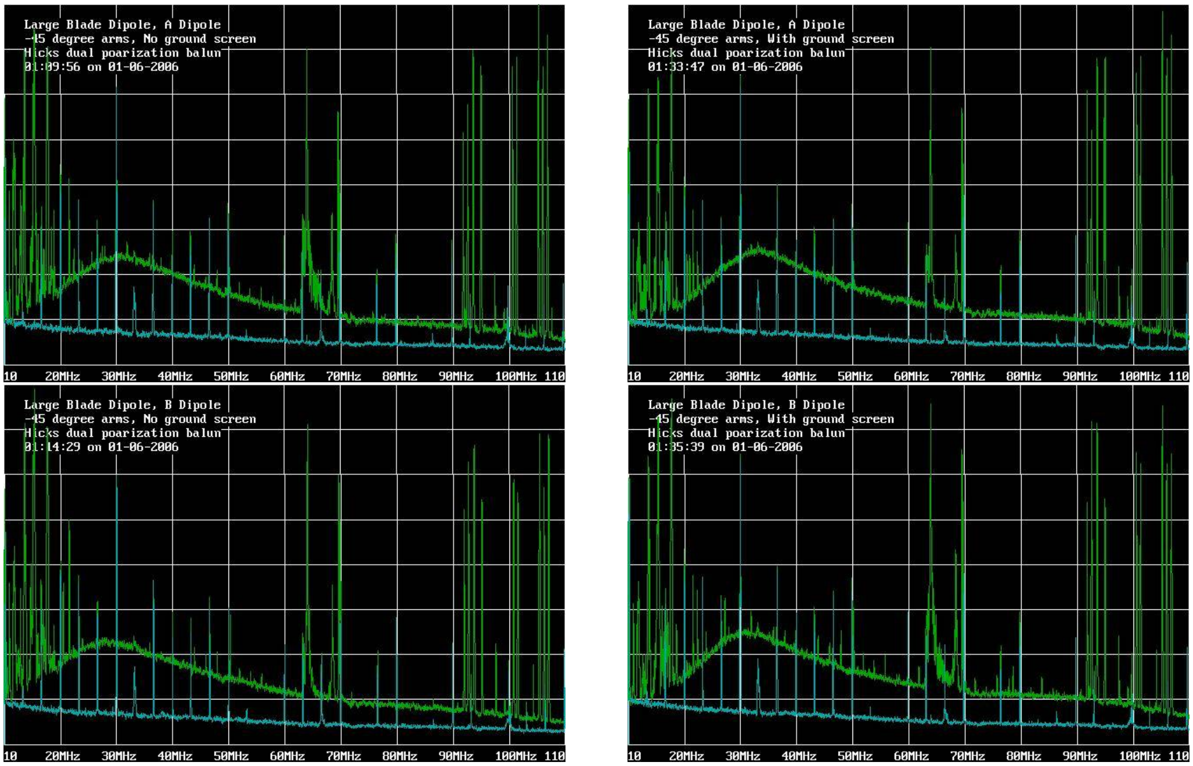

Fig. 3.— Sky and balun noise spectra.

5. Galactic background drift scans

I have generated many drift scans of the Galactic background a small selection of them are shown in Figures through 6. These data are at ten frequencies between 20 MHz and 106 MHz. Each scan combined data from five 30 kHz bands in the vicinity of the given frequency. 256 point scans were taken each minute and five of these scans were combined for each profile. Each of the five 30 kHz bands were chosen by the spectrometer to minimize RFI. Scans were taken with each of the two dipoles, with and without a ground screen. The ground screen was steel reinforcing mesh 4.8m N-S $\times$ 3.0m E-W. This mesh consisted of welded 50 mm squares of 3.5 mm galvanized steel wires.

In the twelve plots shown in Figures 4–6 the wiggly profiles are the data. The smooth profiles on some of the plots are Emil's simulations for this latitude. They do not agree very well with the data. This is odd because his simulation of the Green Bank data agreed well with the observations. In all of these plots the frequencies are listed at the lower right along with the offsets needed to match their minima. The colors of the profiles corresponding to the listed frequencies are black, red, green, blue, and cyan.

In these plots the 30 to 50 MHz profiles correspond to very high sky noise dominance as would

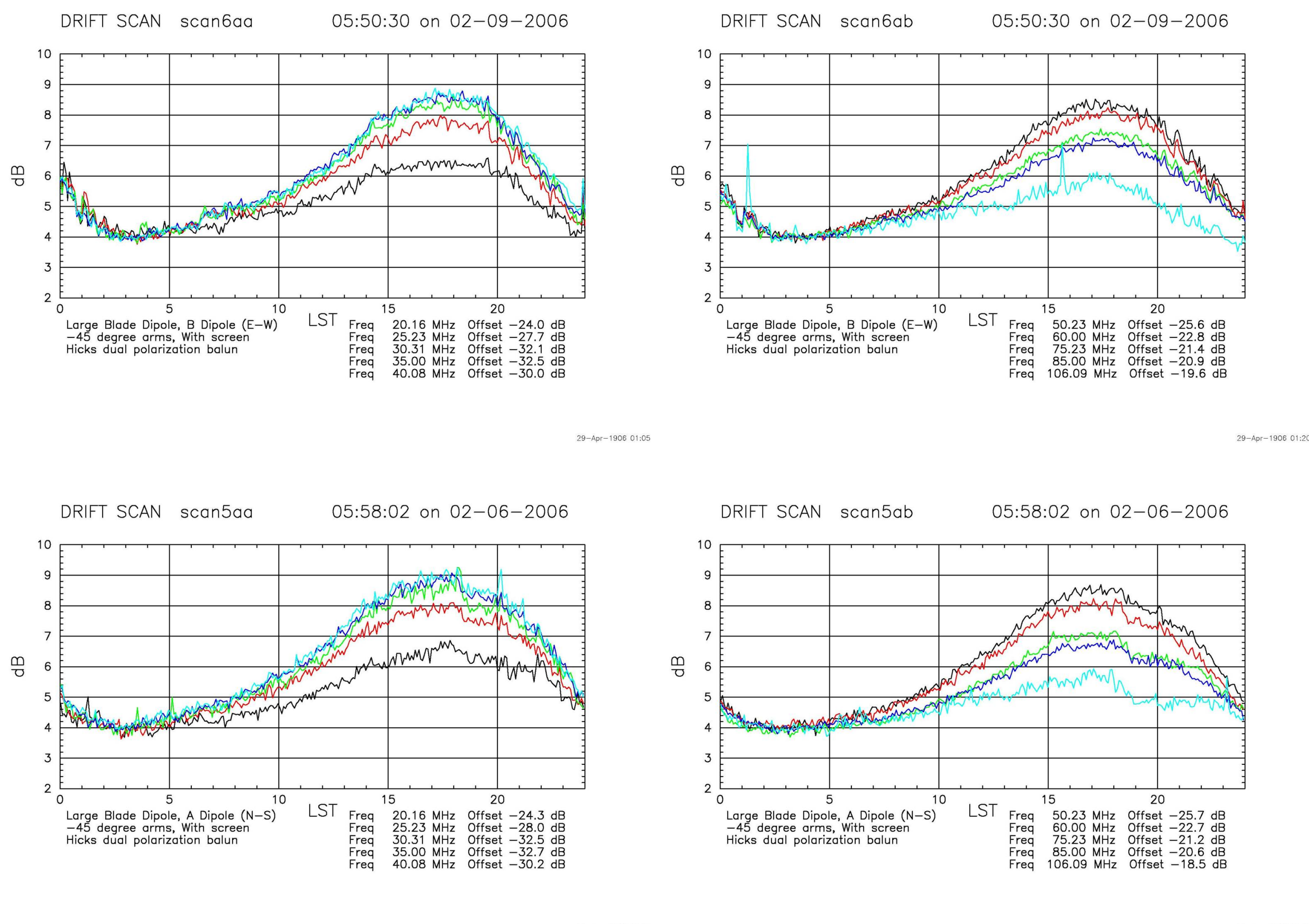

Fig. 4.— E-W & N-S dipoles, with ground screen, Hicks balun. (I suspect that the labels on the two dipoles in this figure were reversed.)

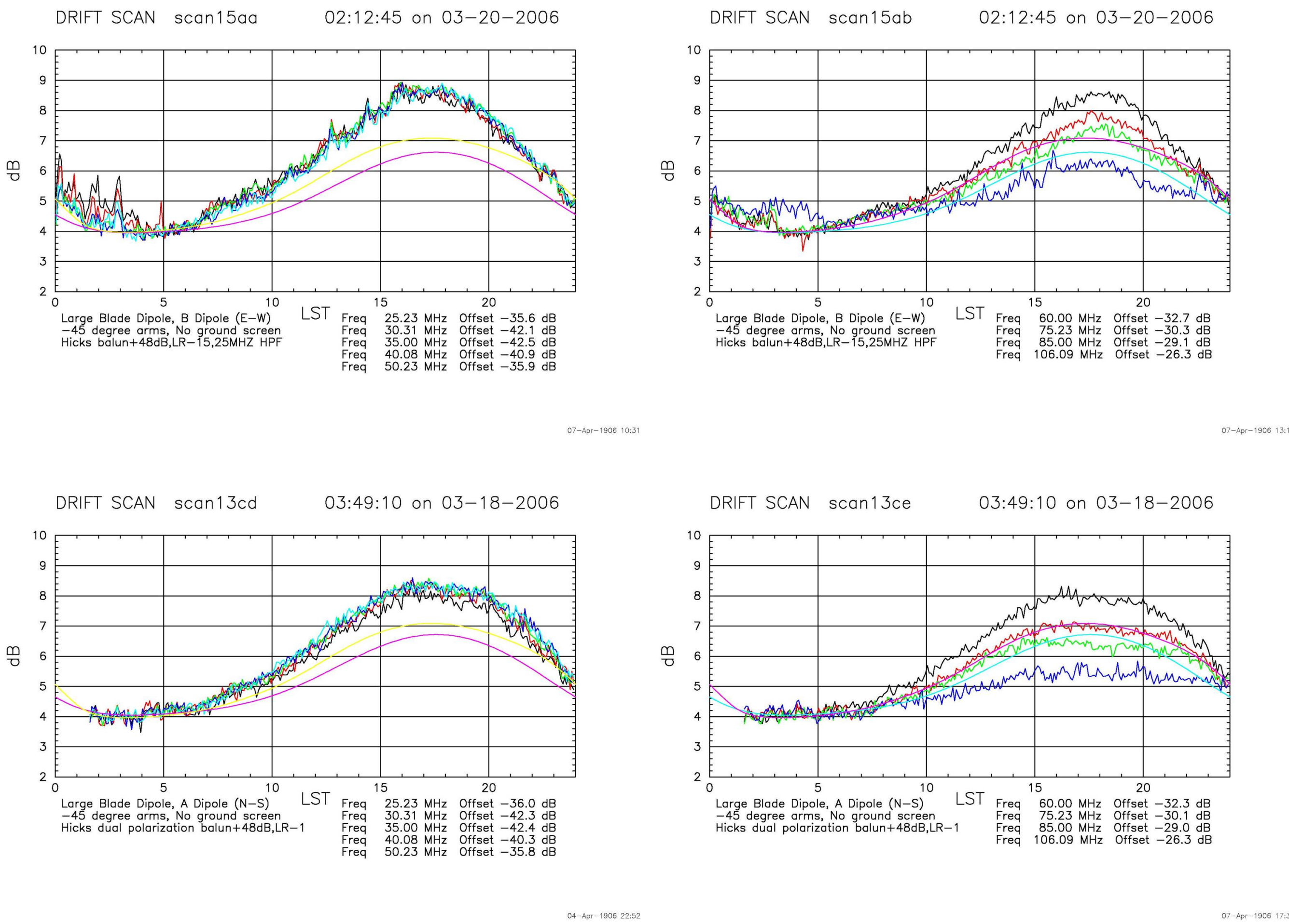

Fig. 5.— E-W & N-S dipoles, no ground screen, Hicks balun.

be expected from the sky and balun noise spectra shown above. The 20 and 25 MHz profiles and those above 50 MHz have appreciably lower maxima, presumably because the balun noise is appreciable compared with the sky noise. The similarity of the E-W and N-S profiles shows that the dipole response patterns must be azimuthally symmetrical; the Galactic center region rises and sets in completely different directions with respect to these dipoles. In particular, the large low elevation, E-plane sidelobe predicted by simulations for the dipole over a perfect ground screen must not exist.

The profiles taken without a ground screen are very similar to those with the screen. I had begun to have some problems with intermodulation in the spectrum analyzer caused by the very strong RFI below 25 MHz so I inserted a 25 MHz high pass filter in the amplifier chain and changed gain settings to reduce this problem. The offsets between scans in Figure 4 and Figure 5

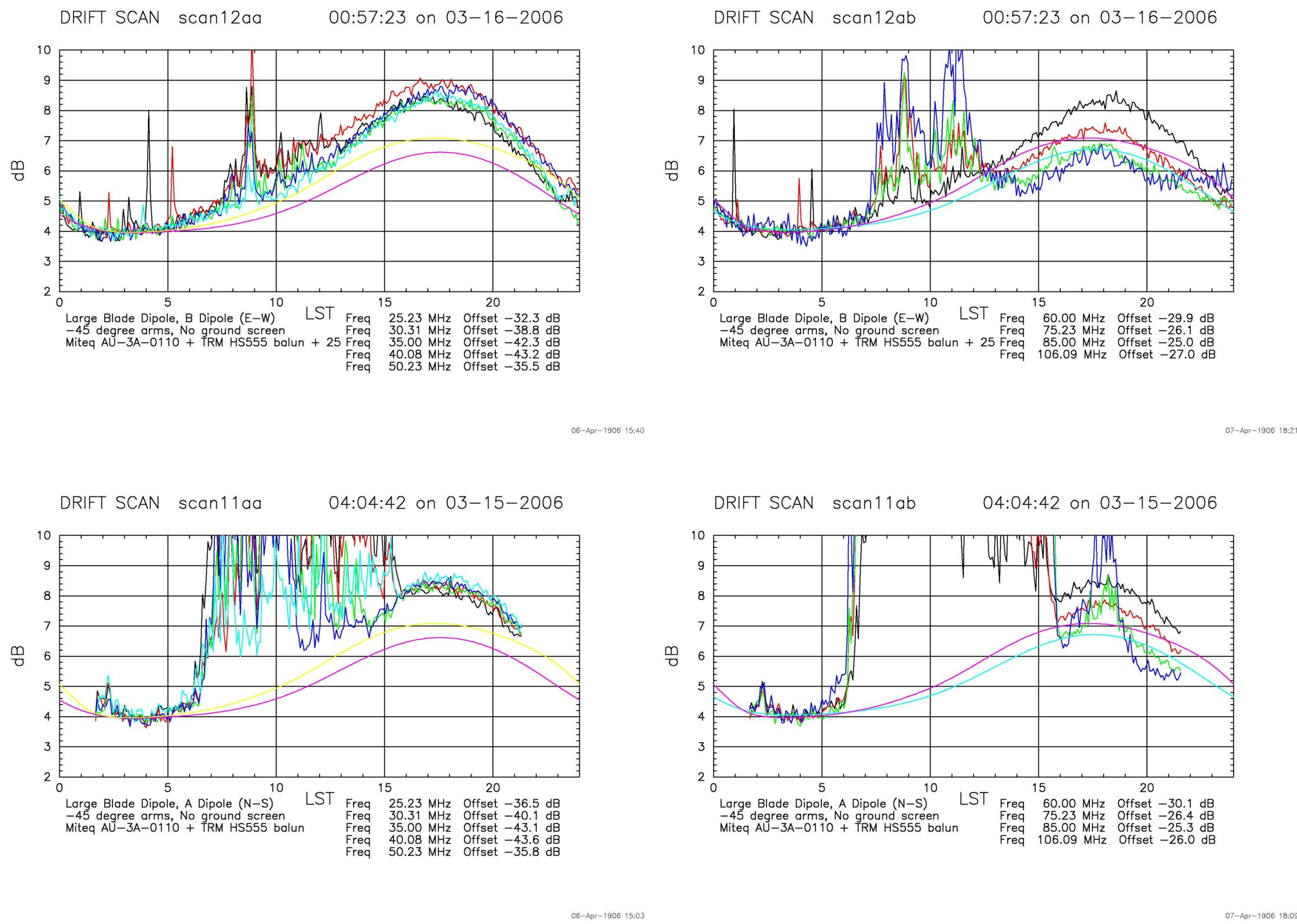

Fig. 6.— E-W & N-S dipoles, no ground screen, Miteq balun.

are uniformly about 10dB different but this value is arbitrary because of the different gain settings and, unfortunately, cannot be used to estimate ground absorption effects.

To check the influence of the ground screen one needs to compare the same dipoles with and without the screen, One sees that the maxima of the profiles with the ground screen appear to be about 0.3 dB higher than without the screen. From the frequency scans I would have expected a larger effect, especially ≥60 MHz.

The development of a balun with lower intrinsic noise than the Hicks balun is being planned. Since I had on hand a Miteq amplifier with a very low, 1.2 dB, noise figure, I decided to use it to fabricate a lower noise balun and study its effects on the drift scans and sky noise dominance. I fed the dipole with a TRM hybrid that has 0.28 dB loss (in addition to the 3.0 dB splitting loss). This setup is shown in the next figure. The excess noise of the amplifier is 98K and the hybrid loss

Fig. 7.— Setup of TRM hybrid and Miteq amplifier.

contributes another 19K resulting in an intrinsic noise level for this balun of 117K, less than half that of the 255K for the Hicks balun.

The profiles with the Miteq balun look very similar to those with the Hicks balun. The Miteq has much higher gain and caused quite a bit of spectrometer intermodulation late at night (roughly 6 to 16 hours LST) when the RFI levels below 25 MHz become intense. This happened in spite of a 25 MHz high pass filter that I inserted in the amplifier chain. Even with this lower noise balun the profiles at 75 and 85 MHz are much lower than the $\sim$35 MHz ones. I do not understand why the lower noise balun did not have a more beneficial effect.

I checked the logarithmic scale of my HP spectrum analyzer with many calibration runs at -10 dB, 0 dB, $+10$ dB, and $+20$ dB with respect to my adopted operating point. Over this 30 dB range these data agreed with each other amazingly well with a standard deviation of $< 0.5\%$.

The responses of the E-W dipole can be compared with those of the N-S dipole by comparing the appropriate profiles. In all cases the responses are nearly identical, as is expected since the dipole response patterns are designed to be nearly azimuthally symmetrical.

6. Sky noise dominance

The lower trace in Figure 3 certainly corresponds to 545K, the excess noise of the balun (255K) plus the noise from the room temperature load (290K). The upper trace corresponds to balun noise plus sky noise. Previously, we have used 255K as the balun noise when the Hicks balun is connected to the dipole, but I do not believe that this is correct because the balun noise should depend upon the impedance at its input. One simple way to see this is to consider that the balun presents a matched load to the dipole and thermal noise will flow from this load into the dipole. When the dipole is well matched, this thermal noise is radiated off into space but when it is mismatched with a reflection coefficient, Γ, a fraction of this noise, Γ^2, will be reflected back into the balun, raising its noise temperature. Rich Bradley has studied this problem in detail but he does not have the parameters for the GALI-74 used in the Hicks balun in order to apply his results. In the meantime, I have adopted a simple approach. The balun presents a well matched load at its input. By looking at the balun input with another amplifier I find that it appears to be a load at essentially room temperature, 290K. Also, I have measured the output level of the balun with a matched load at its input, a short, and an open circuit. The output levels under these three input impedances are all fairly equal. This suggests that when the input is shorted or open, noise is reflected back into the input at essentially the same level as that generated by a matched load at room temperature and suggests that a reasonable estimate of the balun noise when attached to a dipole with a reflection coefficient Γ is

$$T_b = T_e + \Gamma^2 T_o$$

Where T_b is the effective balun noise, T_e is the excess of the balun, and T_o = 290K

I have measured the dipole impedance at various frequencies and found that EZNEC predicts these impedances quite accurately so I've used these impedances to derive Γ. Using a similar method for the Miteq balun I get the following balun noise temperatures (Table 2). In order to lower the noise contribution of the balun it will be necessary to both improve the dipole matching and the intrinsic noise level of the balun.

There is another basic, but inaccurate method of determining sky noise dominance directly from the drift curves. It is similar to a Y-factor determination of noise figure. Consider the drift curves presented above.

Let,

N = the frequency independent balun noise contribution to the drift curve,

S_1 = the sky noise contribution at the maximum of the drift curve,

S_2 = the sky noise contribution at the minimum of the drift curve,

$S_1 + N$ = the level at maximum,

$S_2 + N$ = the level at minimum,

$D = S_2/N$, is the sky noise dominance at minimum,

$R_0 = S_1/S_2$, is basically an unknown but can be estimated,

$R = (S_1 + N)/(S_2 + N)$, is the measured ratio between the maximum and minimum of the drift curve.

Then, dividing the numerator and denominator by S_2,

$$R = \frac{(S_1/S_2 + N/S_2)}{(1 + N/S_2)} = \frac{(R_0 + 1/D)}{(1 + 1/D)} \tag{1}$$

A bit of algebra leads to,

$$D = \frac{(R-1)}{(R_0 - R)} \tag{2}$$

R can be measured but the main problem lies in estimating R_0. I can think of two ways. If one had reliable drift curve simulations, the ratio of their maxima to minima should be R_0. Alternatively, if we can take R_0 to be essentially frequency independent, then the ratio of maximum to minimum at frequencies where the sky noise clearly dominates by a large factor, like 35 to 50 MHz, should provide an estimate of R_0. Until better simulations are made, I have tried to use this method to estimate R_0.

Another problem arises because D is the ratio of two differences, $(R-1)$ and $(R_0 - R)$, each of which is inaccurately determined, especially when $R \sim R_0$.

This method of determining D is basically a ”good” or ”poor” method. If R is essentially equal to R_0, the sky noise dominance is good; whenever R is appreciably below R_0 the dominance is poor, well below 6 dB.

Once we have D we can easily estimate the ratio of the time required to obtain a given sensitivity with the real system to the time required by an ideal, completely sky noise dominated system.

$$t/t_0 = (1 + 1/D)^2 \tag{3}$$

I have estimated the values of R as shown in Table 3, which lead to the estimates for sky noise dominance shown in Table 4. These estimates are very crude, but suggest that the sky noise dominance is quite low at $\geq$60 MHz.

On the other hand, in the last few days (as of May 19, 2005) Emil Polisensky has made some new simulations of the sky noise that should received by the dipole at the various frequencies that are plotted above. These simulations indicate that the system responses should follow the observed drift curves quite well and that R_0 should decline $\geq$60 MHz such that $R_0 \sim R$. If these simulations are verified by further work they would indicate that the sky noise dominance is good at all frequencies. This would explain the similarity of the drift curves with and without the ground screen, and with the Hicks and Miteq baluns since, in all these cases, the drift curves would reflect only the Galactic background distributions convolved with the dipole patterns, not sky noise dominance.

I also tried a different approach. By substitution of a thermionic noise source for the dipole, I calibrated the sky noise temperatures seen by the balun at the various frequencies. These measurements were made in a hurry just before I left Tasmania. I also simulated these data using EZNEC

Table 2. Excess noise of Hicks and Miteq baluns.

Freq (MHz)	Γ	$\Gamma \times T_0$ (K)	Hicks (+255K) (K)	Miteq (+117K) (K)
20	.90	262	517	379
25	.75	217	472	335
30	.47	137	392	254
40	.12	34	289	151
50	.27	78	333	195
60	.36	106	361	223
75	.38	109	364	226
85	.32	92	347	209
105	.12	34	289	151

Table 3. Estimates of R, the ratio of maximum to minimum of the drift profiles.

Scan	6a	5a	13a	15a	11a	12a
Balun	Hicks	Hicks	Hicks	Hicks	Miteq	Miteq
Screen	Yes	Yes	No	No	No	No
Dipole	N-S	E-W	N-S	E-W	N-S	E-W
HPF	No	No	Yes	Yes	Yes	Yes
Freq (MHz)	R (dB)	R (dB)	R (dB)	R (dB)	R (dB)	R (dB)
20	2.4	2.4	-	-	-	-
25	3.8	3.8	3.9	4.5	4.2	4.2
30	4.3	4.4	4.3	4.6	4.3	4.8?
35	4.7	4.8	4.3	4.6	4.3	4.4
40	4.7	4.8	4.3	4.6	4.4	4.7
50	4.4	4.4	4.3	4.6	4.5	4.2
60	4.0	4.0	3.9	4.4	4.3	4.3
75	3.3	3.0	3.0	3.7	3.6	3.3
85	3.0	2.5	2.3	3.3	2.8	2.7
106	1.9	1.6	1.5	2.2	2.5	2.3

Table 4. Sky noise dominance estimates.

Scan	6a	5a	13a	15a	11a	12a
Balun	Hicks	Hicks	Hicks	Hicks	Miteq	Miteq
Screen	Yes	Yes	No	No	No	No
Dipole	N-S	E-W	N-S	E-W	N-S	E-W
HPF	No	No	Yes	Yes	Yes	Yes
Freq (MHz)	D (dB)	D (dB)	D (dB)	D (dB)	D (dB)	D (dB)
20	-2.2	-2.4	-	-	-	-
25	4.0	3.5	7.9	>10	9.2	7.1
30	8.4	8.2	>10	>10	>10	?
35	>10	>10	>10	>10	>10	9.5
40	>10	>10	>10	>10	>10	>10
50	9.6	8.2	>10	>10	>10	7.1
60	5.4	4.1	7.9	>10	>10	8.4
75	1.5	-0.1	1.6	4.0	3.9	1.5
85	0.2	-2.0	-1.5	1.8	0.0	-1.0
106	-4.1	-5.5	-4.9	-2.7	-1.3	-2.5

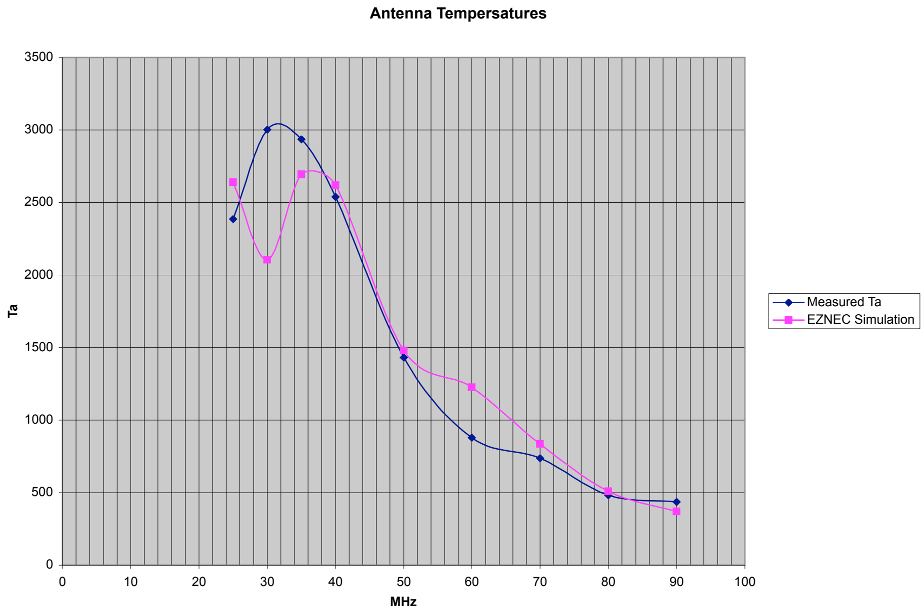

Fig. 8.— Sky noise temperatures

(including coupling losses and ground losses). The results are shown in Figure 8. Translating these data into estimates of sky noise dominance, I obtain the results shown in Figure 9.

7. Discussion

The first point is that the large blade dipoles do seem to work to some extent over the whole 10 to 90 MHz range. I have obtained good records of solar bursts throughout this range.

It is important to have definitive simulations of the drift curves in order to make more reliable estimates of R_0 and D using the drift scan method. The most recent simulations suggest that the sky noise dominance exceeds the 6 dB goal throughout the 25 to 85 MHz range, but this requires confirmation. If confirmed, this would indicate that the present Hicks balun and large blade combination satisfies our specifications without the use of ground screens or lower noise amplifiers. It would also provide the simplest explanation of the similarity of the different drift curves, with and without screens, and with the Miteq balun, since they would all be sky noise dominated.

On the other hand, my antenna temperature measurements combined with my estimate of the balun noise (with its mismatched input) give independent estimates of sky noise dominance. They suggest dominances at 75 MHz and 85 MHz of only 2.5 dB and 1.3 dB. Our goal of 6 dB dominance results in required integration times a factor of 1.56 longer than needed with infinite dominance. These integration time factors would be increased to 2.4 and 2.7 at 75 MHz and 85 MHz and

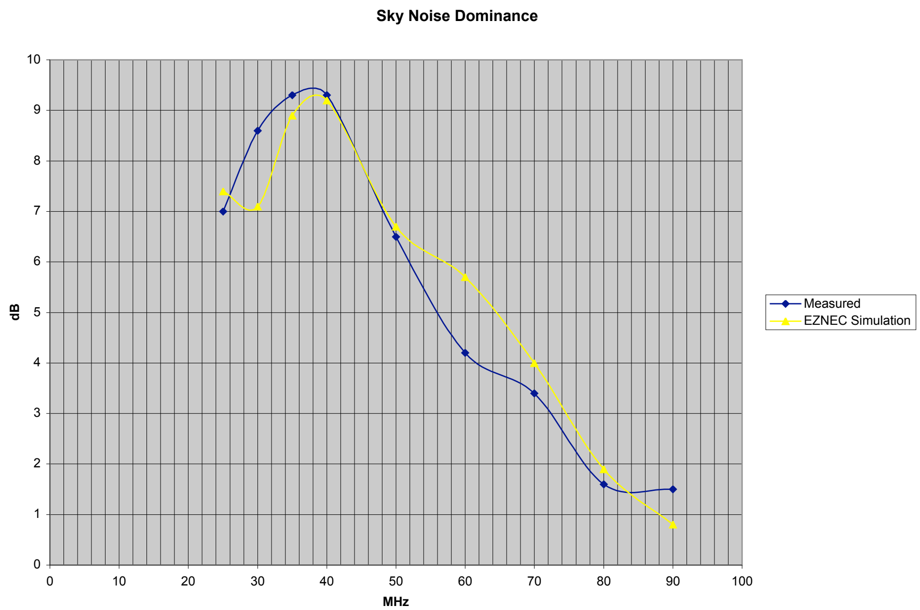

Fig. 9.— Sky noise dominance estimates.

Galactic Pole transit. This is not disastrous, but if these low estimates are confirmed by further work, we should attempt to obtain better dipole matching and lower balun noise temperatures in order to reduce these factors. This appears to me to be quite feasible but, hopefully, it will be unnecessary.

A. Raw spectra from large blades

I decided to plot out and superimpose some of the raw spectra from the data that I have taken (Figures 10 and 11). They each show about 3 seconds of data taken on each dipole near their maxima close to Center transit (1745 LST) and near their minima near (0315 LST). I've collected $>$ 200 hours of such spectra.

In order to keep the plot scale reasonable, I've clipped a few of the RFI peaks. Notable features of these plots include:

- The curves are well separated ($\sim$ 3.5 dB) at 32 MHz; the separation decreases at higher frequencies ($\sim$ 1.5 dB at 80 MHz). This could be caused by poor sky noise dominance with the balun noise becoming relatively more important at the higher frequencies or by the variation of beam pattern with frequency.
- All of the curves are essentially identical on the E-W and N-S dipole. This proves to me that the dipole patterns are very symmetrical in azimuth. The Galactic Center rises in the SE, transits 15 degrees N of the zenith, and sets in the SW. The tracks through the dipole patterns are quite perpendicular for the two dipoles. About the only way for them to give identical responses is for the E-plane and H-plane patterns to be the same.

You may find other things of interest in these data.

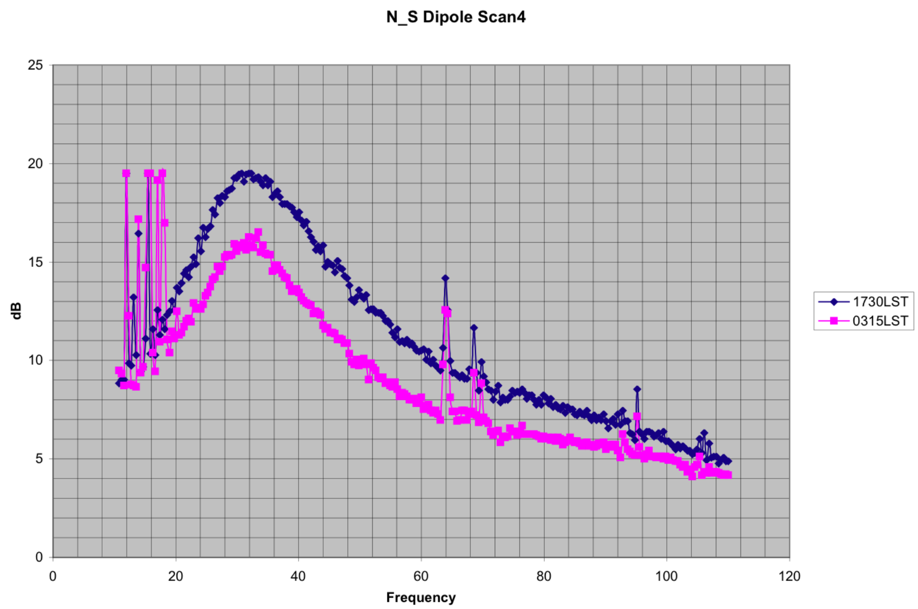

Fig. 10.— Variation in spectra for the N-S dipole.

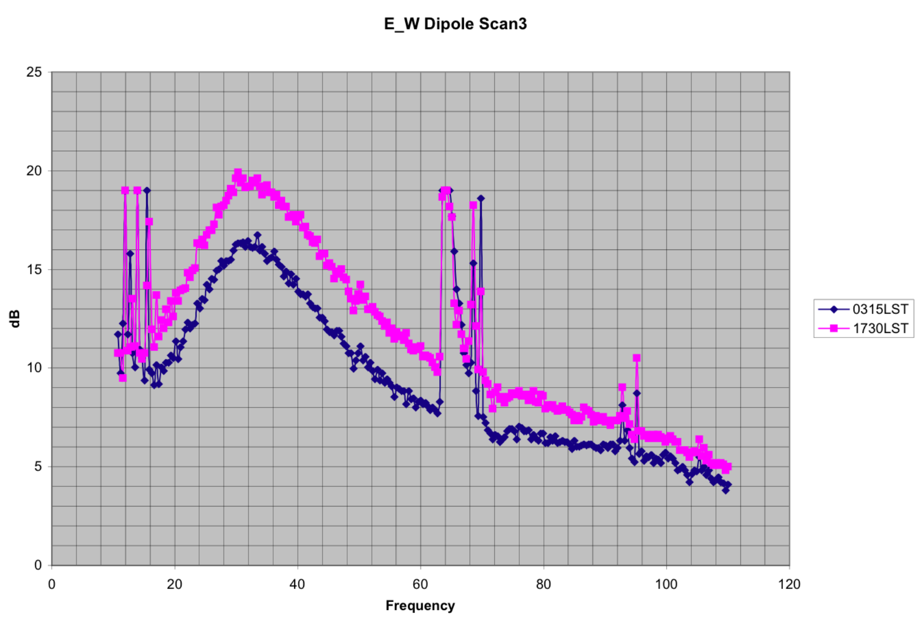

Fig. 11.— Variation in spectra for the E-W dipole.