An EVLA compact configuration with optimized side lobes.

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Abstract

The EVLA compact configuration using the central part of the VLA D-configuration has been designed. The size of the array is approximately 300meters. Twelve existing antenna pads are used. The positions of the rest 15 antennas are optimized minimizing side lobes. The configuration requires 350 m of new rail roads. The side lobes inside of the primary beam are minimized to 7%. For comparison the VLA D-configuration has the side lobes > 50%. The array gives the advantage in observation time 2.6 times in comparison with VLA-D, tapered to the same resolution. The designed configuration can not be considered as a final design. If the brightness sensitivity considers as a main criterion than the size of the array can be decreased to get the better sensitivity.

1 Introduction

The most compact configuration will be the part of the Expanded Very Large Array (EVLA) project. Continuing the letter abbreviation this configuration can be called as E-configuration. One of the main goal of the E-configuration is to achieve the highest surface brightness sensitivity. Mark Holdaway designed ([1]) two compact configurations for EVLA without an optimization except reducing the grating side lobes at one of the configurations.

2 The array

At this memo we describe the E-configuration located near the VLA center. The size of the array is approximately 300meters. Twelve existing antenna pads are used. The positions of the rest 15 antennas are optimized minimizing side lobes inside of the primary beam of the 25 meter dish. The AIPS task CONFI used for the side lobe optimization. To simplify the optimization the mask file included the prohibited area for the new antennas was created. The prohibited area includes the area at the proximity of the existing rail roads of the existing antennas and of the conduit of the waveguides. the maximum positive side lobe is 7%. The found configuration together with the mask file is shown at the figure 1. The coordinates of the configuration relatively the bottom left corner (BLC) of the mask are given at the table 1.

Table 1: The coordinates of the configuration relatively the bottom left corner (BLC) of the mask.

N	X, m	Y, m	N	X, m	Y, m
1	200.000	200.850	15	225.925	77.750
2	200.000	254.890	16	265.343	79.981
3	200.000	294.870	17	153.169	335.721
4	200.000	334.870	18	147.980	268.291
5	160.762	178.255	19	146.175	233.332
6	121.341	156.409	20	116.558	214.435
7	71.117	128.577	21	56.092	201.088
8	200.000	161.000	22	87.499	252.723
9	200.000	121.000	23	251.393	232.354
10	238.833	177.580	24	262.463	323.326
11	277.864	155.045	25	281.013	271.430
12	327.591	126.335	26	292.339	222.126
13	135.735	74.072	27	316.138	196.415
14	174.053	80.792			

The two dimensional beam at zenith and the two slices of this beam at the RA and DEC directions are shown at the figures 2, 3, and 4. The RA slice of the VLA-D beam tapered to the design array beam is shown at the figures 5. The side lobes are $\sim$ 60% in comparison with 7% at the design array. The distribution of the baseline density at UV plane is shown at the figure 6. All previous plots were given for the snapshot observation. Including the Earth rotation tracks improves UV coverage and the beam shape. The maximum positive side lobe goes down to 3%. The UV coverage for the 8 hours observations centered at zero hour angle is shown at the figure 7.

3 Surface brightness sensitivity

Mark Holdaway wrote at his memo ([1]):
"A common rule of thumb is that the surface brightness sensitivity of an array is proportional to the filling factor of antenna dishes over the area which the array covers". The expressions for the surface brightness sensitivity of an array including tapering are given at the Appendix. I repeat them here.

$$\sigma T_b = 2.14\,\alpha\,T\,\frac{1}{\sqrt{\Delta f \tau}}\,FILFAC \tag{1}$$

where T is the antenna receiver noise temperature
Δf is the bandwidth
τ is the time of averaging
$\alpha = 1 - 2$ stands for the nose increasing because digitizing of signals

The filling factor FILFAC is determined by the following expression:

$$FILFAC = \left(\frac{D_{eff}}{D_{ant}}\right)^2 \tag{2}$$

where $D_{eff} = 1.04\,\frac{\lambda}{\theta_{0.5}}$ is the diameter of the equivalent circular dish with the table illumination which has the given beam width at the level 0.5
$\theta_{0.5}$ is the full(double) width of the array beam at the level 0.5

$D_{ant} = D\sqrt{\eta N}$ is the diameter of the equivalent circular dish with the table illumination which has the geometric area equaled to the effective area of all antennas of the array
D is diameter of the array antenna
η is the antenna efficiency

For the absolute compact configuration $D_{ant} = D_{eff}$ and therefore FILFAC=1. For an actual array $FILFAC > 1$ and the less FILFAC is the better the surface brightness sensitivity. If we compare different configuration of the same number of identical antennas then FILFAC is the only parameter which determines the surface brightness sensitivity.
The expression for the FILFAC when UV data are tapered is following:

$$FILFAC_{tap} = FILFAC \, \frac{(beamx * beamy)_{notap}}{(beamx * beamy)_{tap}} \, SENS \tag{3}$$

where $(beamx * beamy)_{notap}$ is the no tapered beam size
$(beamx * beamy)_{tap}$ is the tapered beam size
$SENS > 1$ is the loosing of sensitivity because of the tapering

Based on these expressions the table 2 gives comparison of 'this' paper configuration E3 with VLA-D and the two configurations designed by M. Holdaway (M.H.E1 and M.H.E2) and GBT. All parameters are given for for f=1.4GHz. This table emphasizes the expected advantage of the smaller size configurations.

Table 2: Comparison of 'this' configuration E3 with VLA-D and the two configurations designed by M. Holdaway ([1]).

Array	Size, m	Beam, "	D_{ant}, m	D_{eff}, m	FILFAC
VLA-D	1100	54.1	100	834	69.6
M.H.E1	500	90.0	100	500	25
This.E3	300	147.6	100	305	9.3
M.H.E2	250	180.0	100	250	6.25
GBT	100	514.0	80	89	1.23

Tapering UV coverage of VLA-D we can increase the beam width and therefore decrease the fill factor. At the same time the sensitivity loosing because of the tapering is not so high for VLA-D because of the big central condense of the VLA-D configuration. So the fare comparison of VLA-D configuration with a new configuration has to be carried out at the same beam size tapering VLA-D. We used the AIPS task UVCON to simulate VLA-D snapshot observation and the AIPS task IMAGR to get the information about the tapered beam size and loosing the sensitivity because of the tapering. The equation (3) is used to calculate the tapered filling factor. The table 3 gives the comparison of the three compact arrays with VLA-D tapered to the beam width of the relevant array.

It is seen from the table 3 that the E1, E2, and E3 array are faster than relevantly tapered VLA-D at 1.5, 3.4, and 2.6 times respectively.

4 Shadowing

In order to estimate the sensitivity which is lost because shadowing, I followed the M. Holdaway memo ([1]). So I took the square root of the fraction of the baselines which have not been lost to shadowing for hour angles ranging from -4 to 4 hours. The result for the design compact array is given at the table 4 for the declinations ranging from -30 to 80 degrees. A value of 1.00 indicates that no sensitivity has been lost. As seen from the table 4 the the array is affected by shadowing only at the extreme hour angles

Table 3: Comparison of the three compact arrays with VLA-D tapered to the beam width of the relevant array. The column GAIN means the gain in FILFAC in comparison with the tapered VLA-D. The column SPEED is the square of GAIN and mean the gain in time in comparison with the tapered VLA-D.

Array	Beam, "	FILFAC	GAIN	SPEED
E1	90.0	25	1.22	1.5
VLA-D tapered to E1	89.3	30.6		
E3	147.6	9.3	1.6	2.56
VLA-D tapered to E3	151.0	14.8		
E2	180.0	6.25	1.85	3.42
VLA-D tapered to E2	180.7	11.6		

($|HA| \geq 4$) and declinations ($\delta \leq -20°$). This conclusion coincides with conclusion of M. Holdaway ([1]) for VLA-D configuration and the two configurations given at the memo ([1]).

Table 4: Sensitivity Considering Shadowing

	Hour Angle, hours								
Decl., deg	-4.	-3.	-2.	-1.	0.	1.	2.	3.	4.
80.	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
70.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
60.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96
50.	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96
40.	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30.	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20.	0.92	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92
10.	0.81	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.81
0.	0.58	0.96	1.00	1.00	1.00	1.00	1.00	0.96	0.70
-10.	0.51	0.85	0.96	1.00	1.00	1.00	0.96	0.81	0.51
-20.	0.32	0.66	0.85	0.77	0.81	0.81	0.85	0.74	0.32
-30.	0.28	0.36	0.58	0.62	0.74	0.74	0.55	0.36	0.17

5 Conclusion

The compact E-VLA configuration described at this memo uses 12 existing pads of VLA-D configuration and requires 350 m of new rail roads. The side lobes inside of the primary beam are minimized to 7%. The array gives the advantage in observation time 2.6 times in comparison with VLA-D, tapered to the same resolution. The design configuration can not be considered as a final design. If the brightness sensitivity considers as a main criterion than the size of the array can be decreased to get the better sensitivity.

References

[1] M. Holdaway, Evaluating various options for a VLA E array, EVLA memo No 6, 1996.

Appendix

Lets derive the general equation for the surface brightness sensitivity to simplify comparison of different arrays. The sensitivity of the array with N identical antennas to the flux density is described by the following equation:

$$\frac{1}{2}\sigma F\, A\, N_{int} = \alpha\,\sqrt{N_{int}}\,\frac{kT}{\sqrt{\Delta f \tau}} \tag{1}$$

where the left part of the equation is the power of the received signal
the right part of the equation is rms of the noise
σF is the flux density created the signal equaled rms of the noise
A is effective area of the antenna
$N_{int} = \frac{N\,(N-1)}{2}$ is the number of interferometers
Δf is the bandwidth
τ is the time of averaging
$\alpha = 1 - 2$ stands for the nose increasing because digitizing of signals

the surface brightness sensitivity σT_b is related with σF- flux density created the signal equaled rms of the noise by the following equation:

$$\sigma F = \frac{2k\,\sigma T_b}{\lambda^2}\Omega \tag{2}$$

where λ is the wavelength
Ω is the solid angle of the array beam

Combining the equations (1) and (2) we obtain the following expression for the surface brightness sensitivity:

$$\sigma T_b = T\,\frac{\lambda^2}{\Omega\, A}\,\frac{\alpha}{\sqrt{N_{int}}\sqrt{\Delta f \tau}} \tag{3}$$

The solid angle of the array beam Ω can be found as a solid angle of the equivalent circular dish of diameter D_{eff}.

$$\Omega = \pi\,\left(\frac{\theta_{0.5}}{2}\right)^2 = \pi\,\left(0.52\,\frac{\lambda}{D_{eff}}\right)^2 = 0.84\,\left(\frac{\lambda}{D_{eff}}\right)^2 \tag{4}$$

where $\theta_{0.5}$ is the double width at the level 0.5 of the equivalent dish beam with the table illumination.

Substituting equation 4 into equation 3 and taking ino account that $\sqrt{N_{int}} \sim \frac{N}{\sqrt{2}}$ we obtain the final expression for the surface brightness sensitivity:

$$\sigma T_b = 2.14\,\alpha\,T\,\frac{1}{\sqrt{\Delta f \tau}}\,FILFAC \tag{5}$$

$$FILFAC = \left(\frac{D_{eff}}{D_{ant}}\right)^2 \tag{6}$$

$$D_{eff} = 1.04\,\frac{\lambda}{\theta_{0.5}} \tag{7}$$

$$D_{ant} = D\,\sqrt{\eta N} \tag{8}$$

where $\theta_{0.5}$ is the double width at the level 0.5 of the equivalent dish beam with the table illumination.
D_{eff} is the diameter of the equivalent circular dish with the table illumination
which has the given beam width at the level 0.5
D_{ant} is the diameter of the circular dish with the table illumination
which has the geometric area equaled to the effective area of all antennas of the array
D is diameter of the array antenna
η is the antenna efficiency

The parameter D_{eff} is roughly equal to the array size, as the parameter D_{ant} is the diameter of the equivalent dish with area equaled the summarized effective area of the array antennas. For the absolute compact configuration $D_{ant} = D_{eff}$ and therefore FILFAC=1. For an actual array $FILFAC > 1$ and the less FILFAC is the better the surface brightness sensitivity. If we compare different configuration of the same number of identical antennas then FILFAC is the only parameter which determines the surface brightness sensitivity.

Tapering UV data we can increase the beam size and therefore decrease D_{eff} but the sensitivity will be aggravated because of the tapering. So tapering can increase or decrease the FILFAC depending on the distribution of the density of the baselines at the UV plane.

The expression for the FILFAC when UV data are tapered is following:

$$FILFAC_{tap} = FILFAC \, \frac{(beamx * beamy)_{notap}}{(beamx * beamy)_{tap}} \, SENS \tag{9}$$

where $(beamx * beamy)_{notap}$ is the no tapered beam size
$(beamx * beamy)_{tap}$ is the tapered beam size
$SENS > 1$ is the loosing of sensitivity because of the tapering

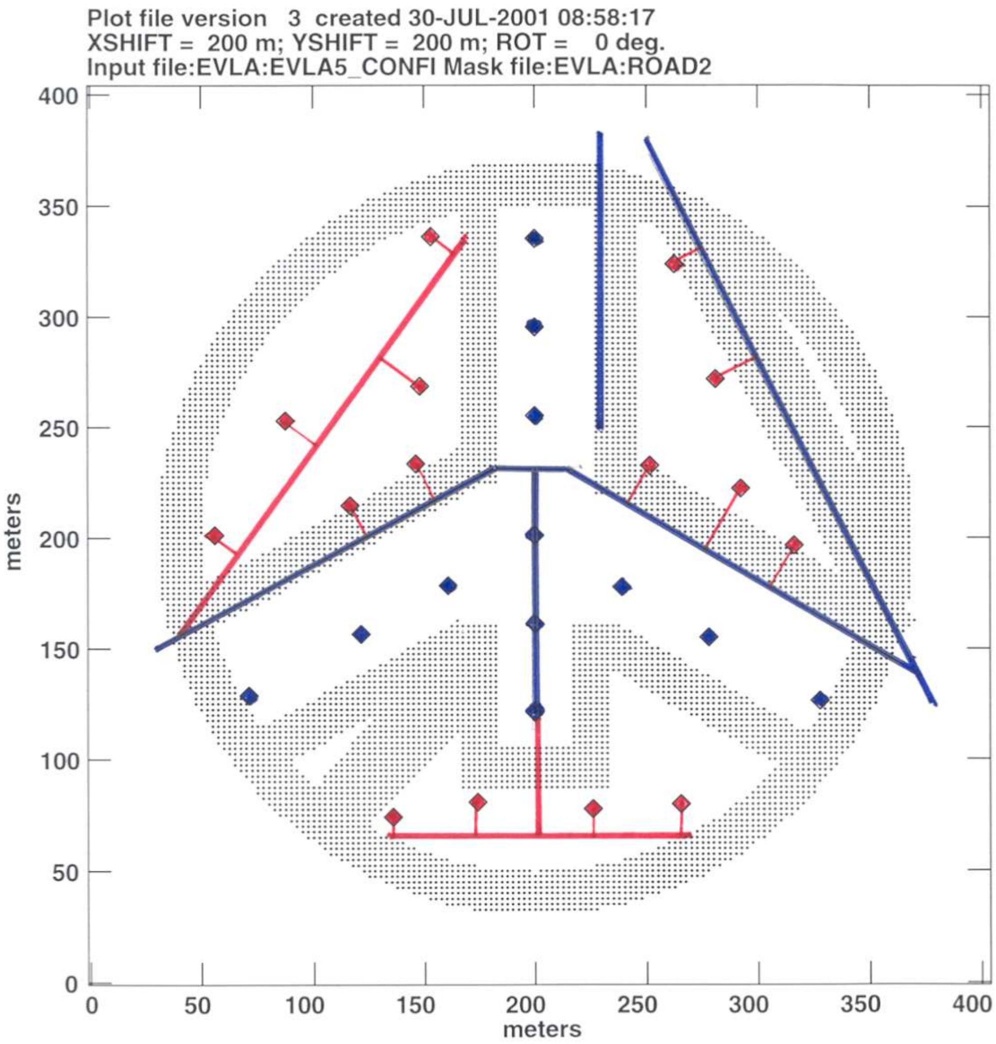

Figure 1: The configuration together with the prohibited area. The red lines and diamonds are the new rail roads and the new antenna pads. The blue lines and diamonds are the existing rail roads and the existing antenna pads. The side lobes are optimized inside of the primary beam (maximum side lobes $\sim 7\%$)

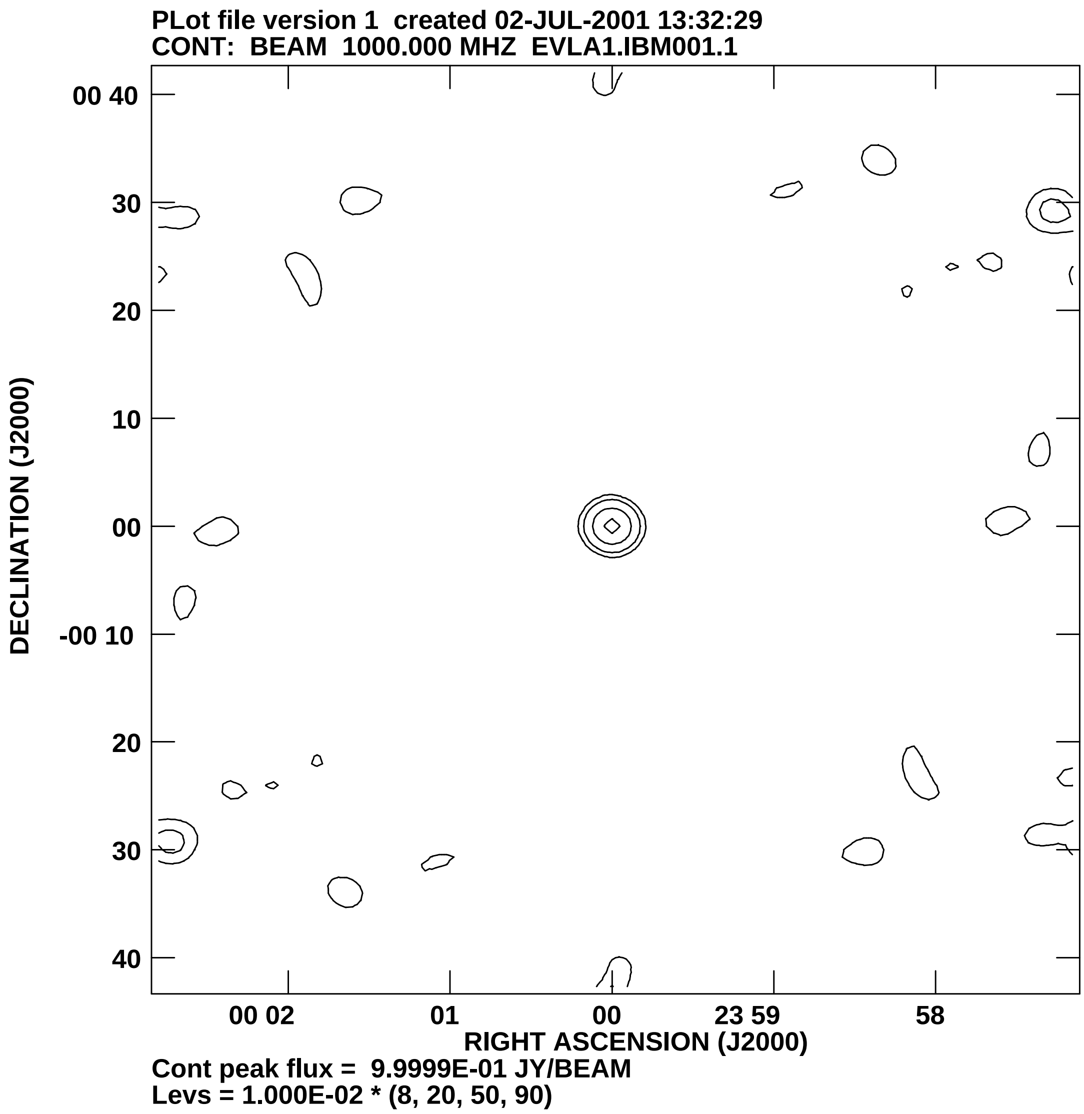

Figure 2: The two dimensional beam at zenith.

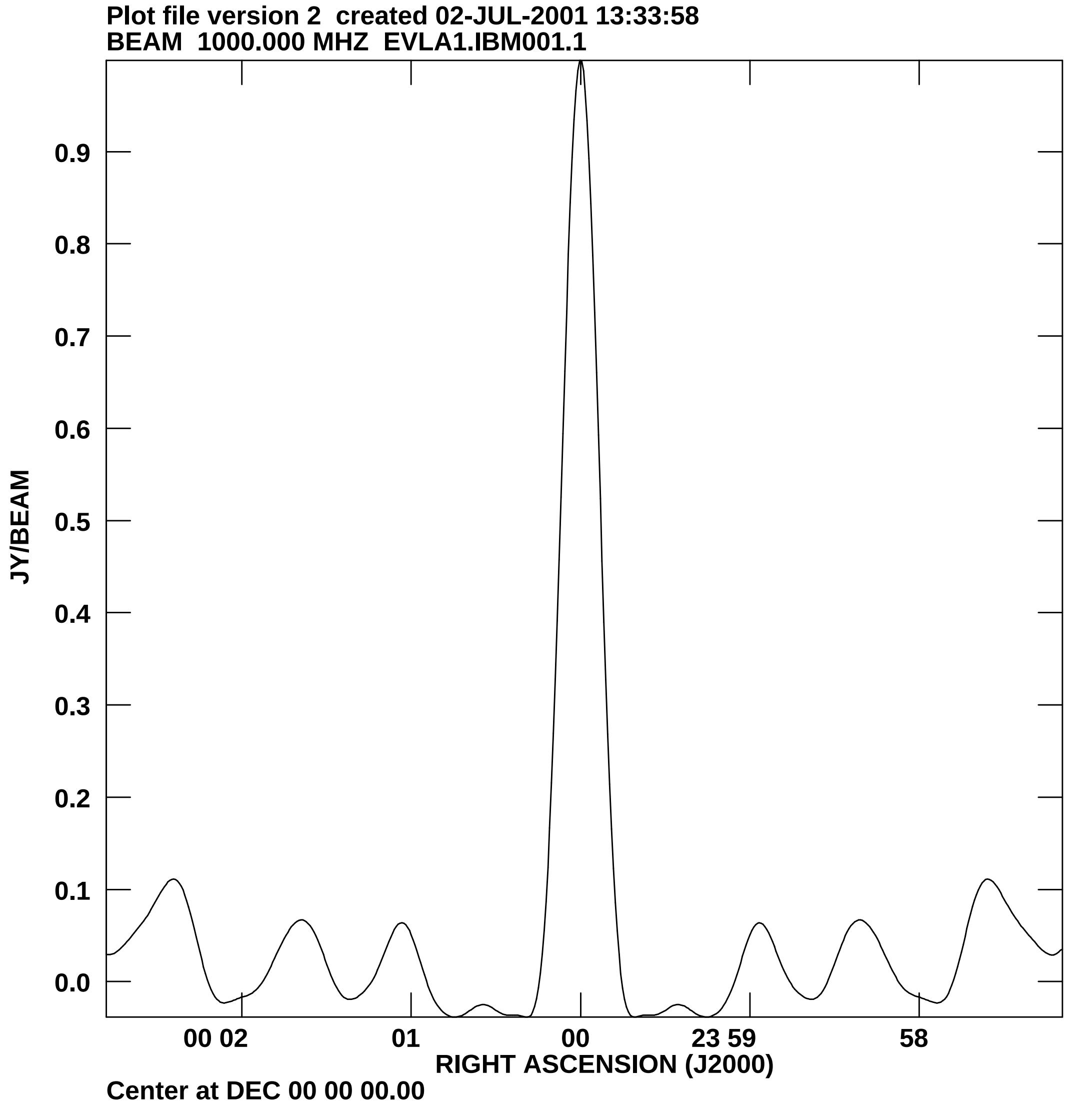

Figure 3: The RA slice of the two dimensional beam at zenith.

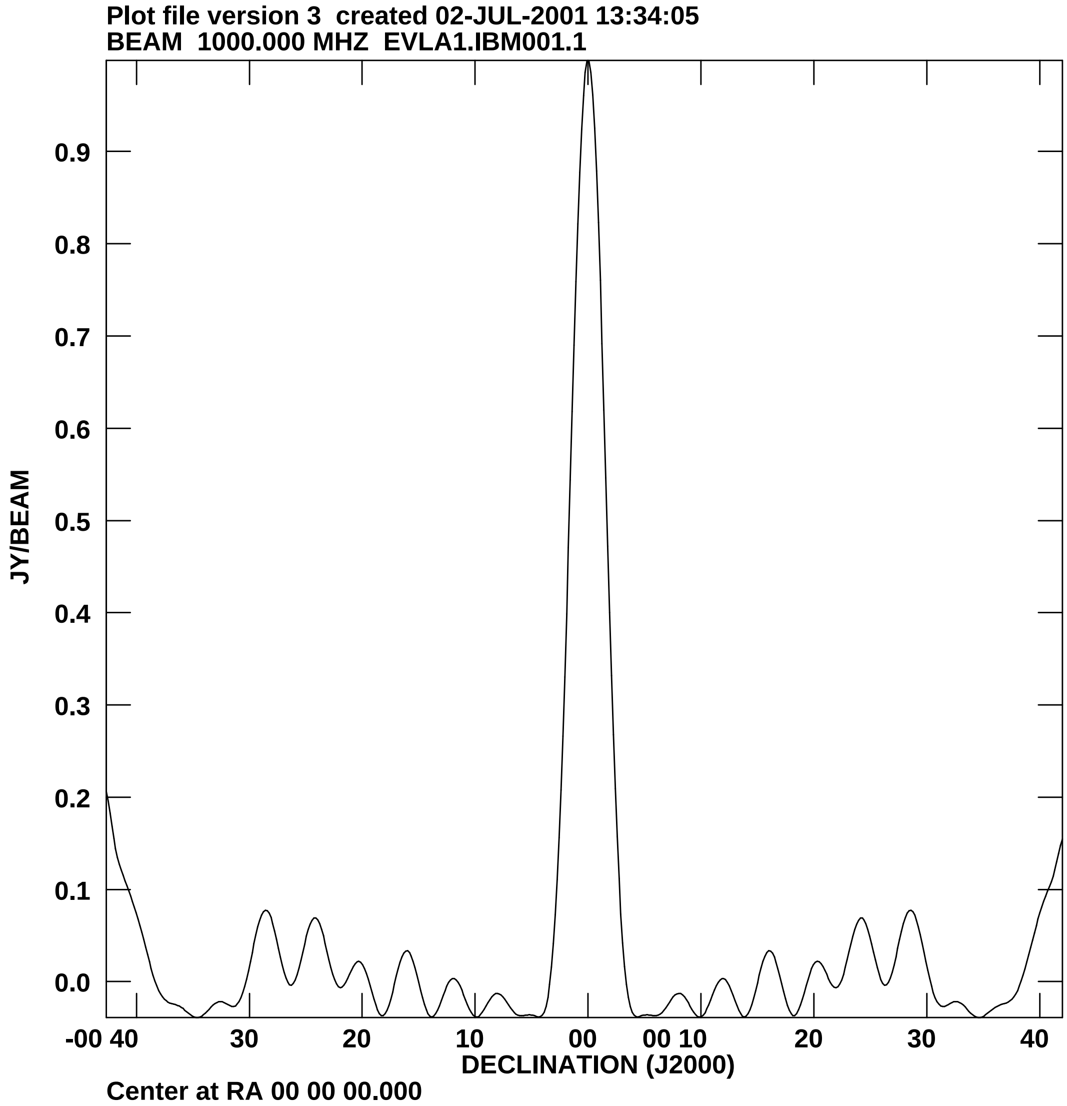

Figure 4: The DEC slice of the two dimensional beam at zenith.

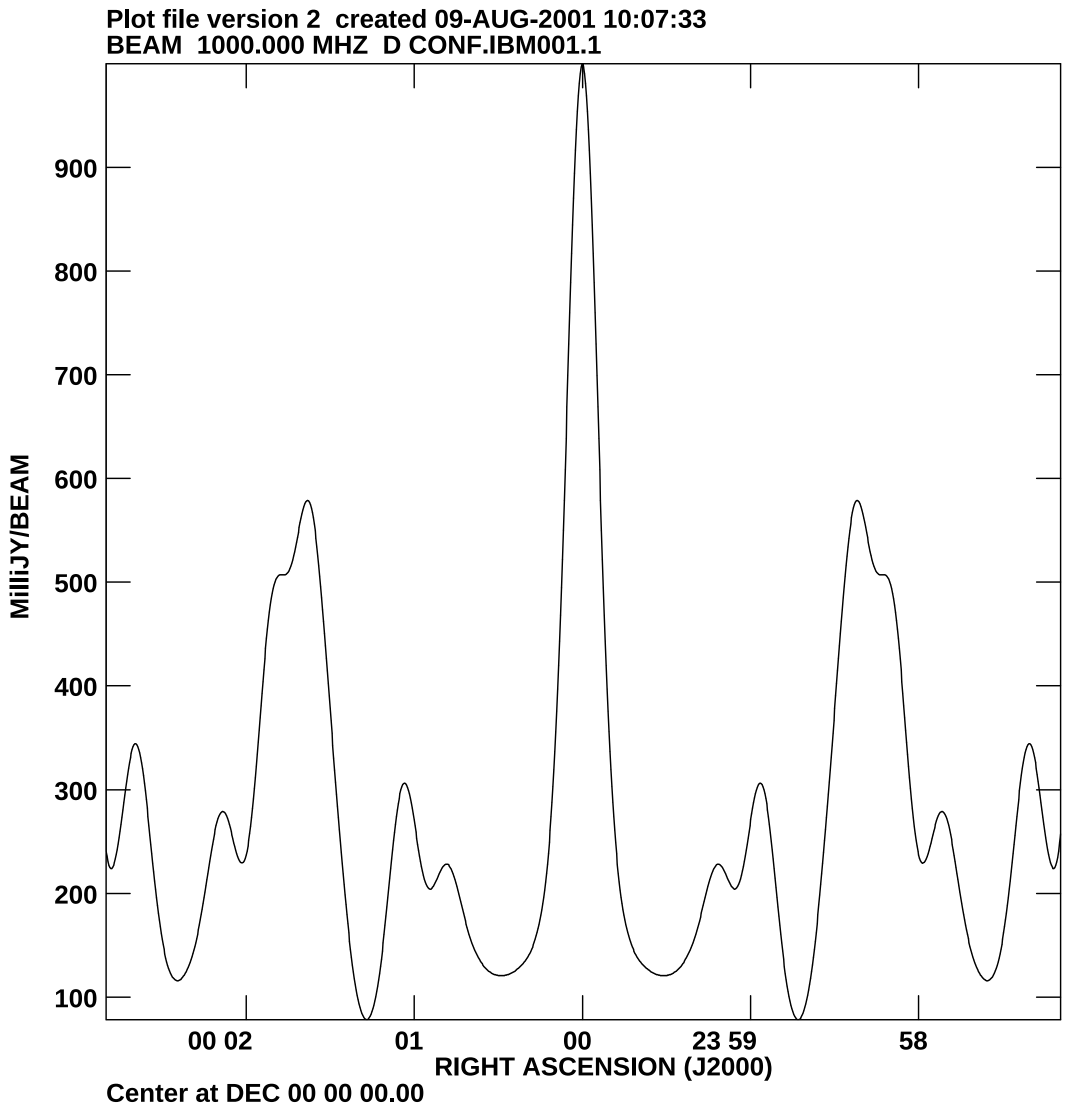

Figure 5: The RA slice of the two dimensional beam of the VLA-D configuration tapered to the designed array beam.

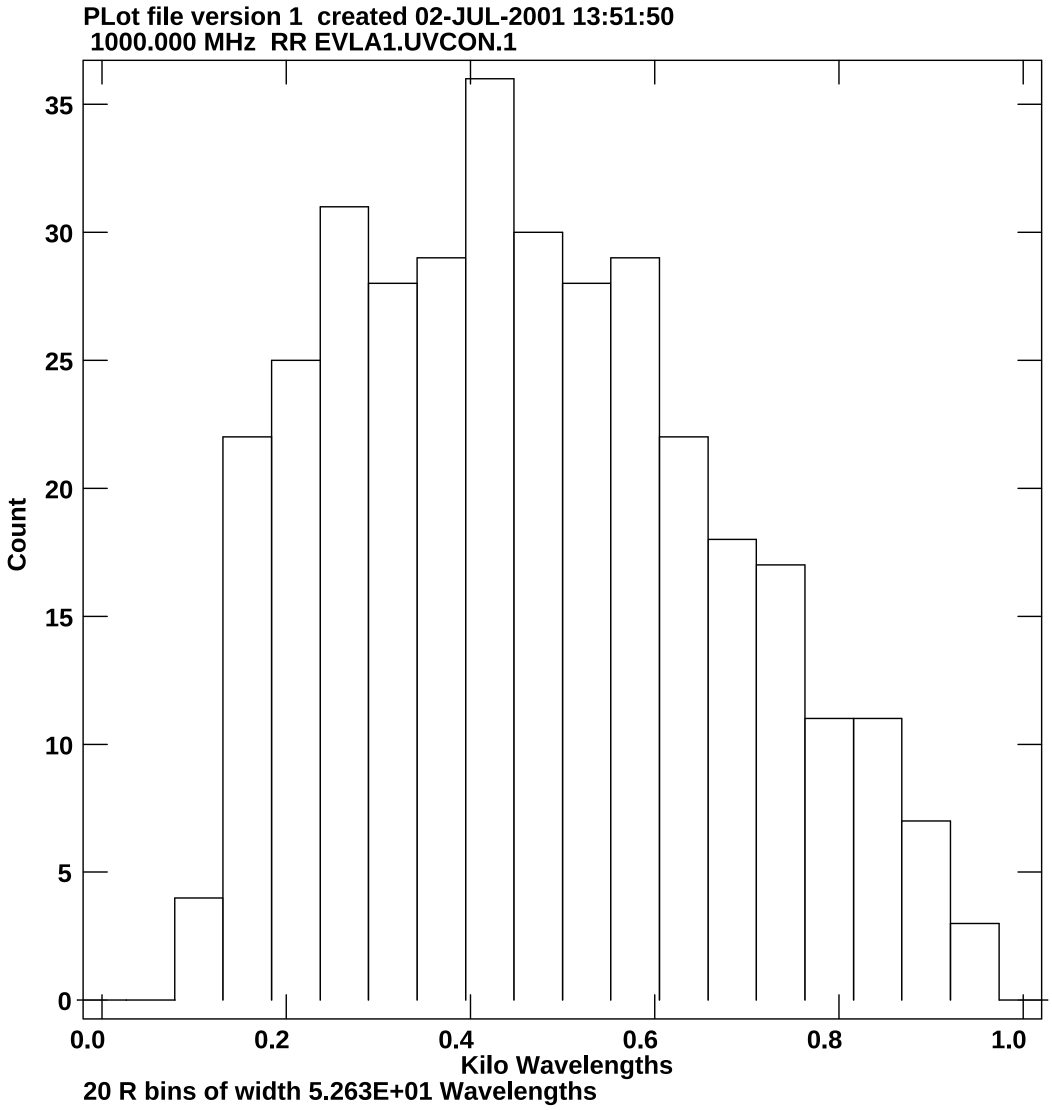

Figure 6: The distribution of the baseline density as a function of UV distance.

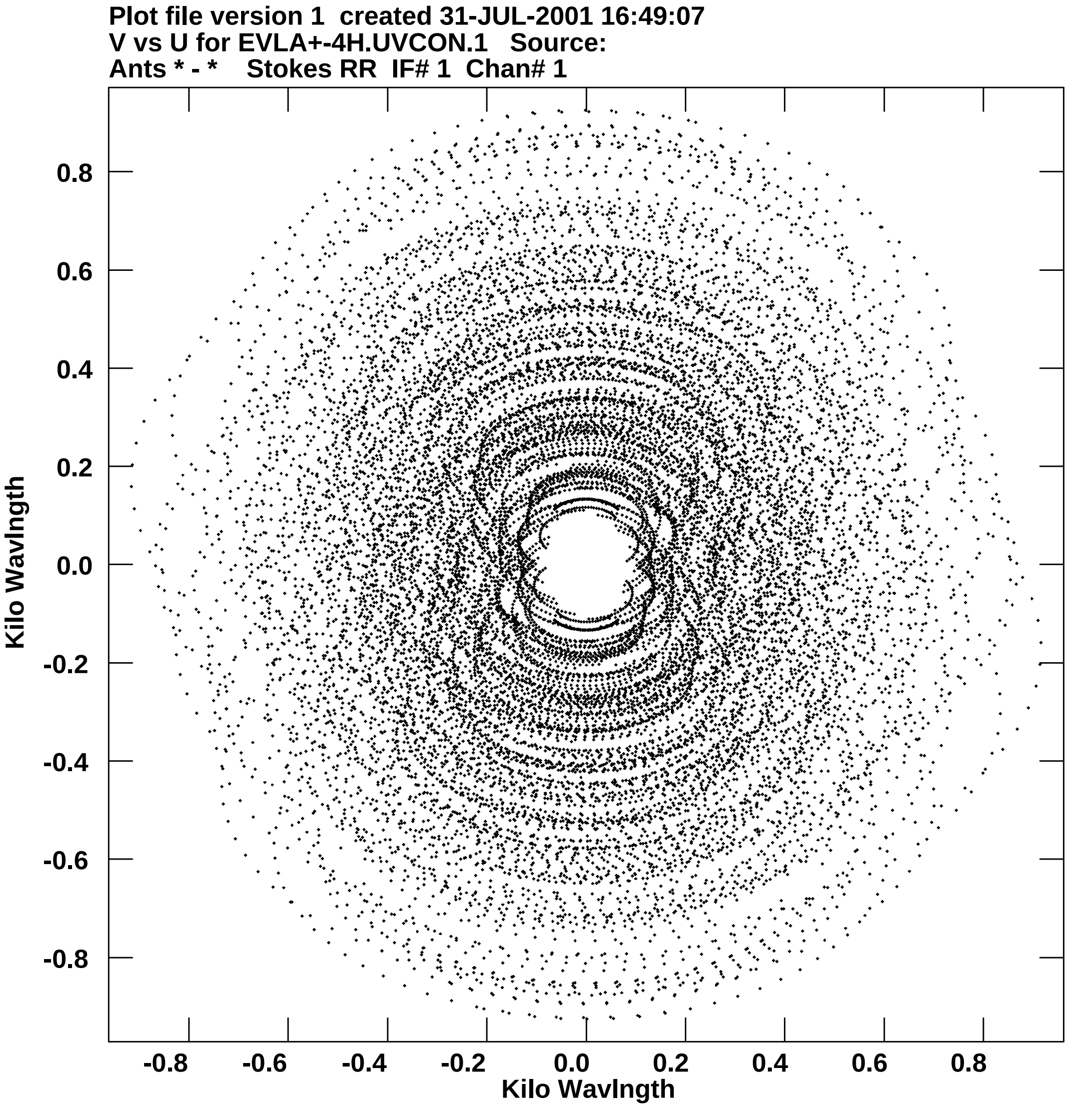

Figure 7: The UV coverage for the 8 hours observations centered at zero hour angle. Each tenth point is plotted to diminish the file size.