National Radio Astronomy Observatory
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VLA TEST MEMO. 167

NOISE PERFORMANCE OF THE UPGRADED L-BAND SYSTEM

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INTRODUCTION

For VLA L-band sky survey some tests were made during last D-array using new default center frequencies of 1464.9 and 1385.1 MHz with bandwidths of 50 MHz. It has been reported that the resulting images at 1385 MHz had 30% higher noise than those at 1465 MHz. Also there have been reports of increased incidence of external rfi by many VLA L-band users during recent past. Further three quarters of the antennas have now been outfitted with new VLBA design receivers to improve its noise performance. To see (1) whether there is any obivious cause of the higher noise in 1385±25 MHz band compared to 1465±25 MHz band, and (2) noise performance of the upgraded system and compare it with the old one, we decided to measure the system sensitivity over 1360 to 1560 MHz. This memo describes the results of the test measurements.

SYSTEM SENSITIVITY

We measured increase in the system temperature on Virgo-A (3C274) with respect to directions 5° on east and west of it, as a function of frequency for all the antennas in the array. Table 1 gives the average increase in system temperature values on Virgo-A for all the 27 antennas for each of the four IFs (IFs: A, B, C, and D) at various frequencies. Measurements were made with 12.5 MHz backend bandwidth on 1992Dec28, and used backend synchroneous detector values. The data show: (1) pre-dawn measurements (starred), made at elevation of about 68° give about 10% higher G/T than those made between 8:18 and 8:42 MST (unstarred) at elevation of about 55° on the monday morning after X-mas weekend, (2) system G/T variation looks smooth with frequency, and peaks at about 1400 MHz, (3) from 1400 MHz to 1553 MHz Virgo-A flux density decreases by about 9 % but the G/T drops by about 20 %, i.e. $(G/T)_{1400MHz}/(G/T)_{1550MHz} \approx 1.11$, and (4) average System Equivalent Flux Density (SEFD)= $214/(0.594 * 1.02) = 353$ Jy at 1400 MHz for all 27 antennas (antennas #2 to 28) in the direction of Virgo-A. Lower G/T values for post-dawn measurements may be due to (1) lower elevation (55° instead of 68°) and increased atmospheric contribution due to increse in atmospheric water vapor–observation log comments possible rain in area, (2) Sun in far sidelobes of the antennas, (3) increased rfi — but that has to be present all over the observation frequency range of 1360 to 1560 MHz.

Observations were repeated at night time on 1993Feb01 on Crab and also tipping curves were performed at the same time. Table 2 gives system temperature measurements on Crab for the four IFs averaged over all the 27 antennas. Table 3 gives the average of tipping measurements (azimuth= 0°) at system default frequency settings (center frequencies 1385 and 1465 MHz and bandwidth=50 MHz) for all the 27 antennas, and average of all four IFs are plotted against secent zenith angle (sec z) in Fig. 1. These measurements lead to basically the same results as those from measurements on 1992Dec28 on Virgo-A. The average SEFD =368 Jy at 1400 MHz is about 15 Jy higher than that for Virgo-A direction, which is consistant with the increased galactic background for the direction of Crab compared to that of the Virgo-A. From table 3 we see that system temperature increases by about 6% at 55° elevation compared with that at 70° elevation. About 10 % increase in the system temperatureat 55° elevation compared with that at 68° elevation on 1992Dec28 may have been due to (some) variations in weather between the two sets of measuremets (pre-dawn and post-dawn) on a day when there was bad weather (the two sets of measurements were seperated in time by more than 2 hours).

Data of table 2 are seperated for antennas with upgraded receivers and those with old receivers in tables 4 and 5 respectively. Results of table 4 show that increase in system temperature on Crab with frequency for upgraded antennas is present but it is much more prominant for unupgraded antennas. For upgraded antennas SEFD at 1400 MHz is about 330 Jy in the direction of Crab compared with 590 Jy for the unupgraded antennas.

Table 6 gives tipping measurements for 21 upgraded antennas at the system default settings for azimuth= 0°. Average results for all the four IFs are plotted against sec z in Fig. 2. From the tipping results we see that the average T_{sys} value increase by about 44% at elevation of 30° compared to zenith, and more than doubles at elevation of 10° elevation. for good antennas (probably those with low receiver temperatures) the increase is as much as 55% at 30° elevation. From opacity/transperency curves by Schwab and Hogg (MMA Memo. #58, 1989) we see that for the VLA one would expect zenith atmospheric contribution of about 2° K during good weather, and $\leq$ 3° K during fairly poor weather (1.5 cm water). It means the antenna spillover is caussing the increase in the T_{sys} values with increasing zenith angle. A quick look at the measured feed patterns suggest that a part of this may very well be accountable by the feed far sidelobes. A rough estimate of the contribution from scattering by the quadrupode legs (based on Landeker et al., 1990–Preprint) gives an increase of only about 4-8° K. Remainder of the increase in the T_{sys} for zenith angles of 20° to 70° is probably due to feed sidelobes.

Atleast about half of the antennas with upgraded receivers have more than 6 Volts synchoneous detector output signal value, which is high. This is due to high injected noise calibration signal which contributes to the system temperature. We should reduce the T_{cal} values to give about 4-5 Volts in the backend Synchoneous detectors and about 3 volts in the frontend synchroneous detectors. This may reduce the average T_{sys} by a few percent.

NOISE IN IMAGES

To further pursue the problem of increased map noise seen by J. Condon in his snapshots made during the last D-array configuration, I made observations of a field at declination of 88° to have roughly same fringe rates as typical of the D-array. The observations were made in spectral line using all four IFs (VLA observing mode 4) with backend filters of 12.5 MHz over 1360 to 1560 MHz. The data (antenna gains and bandpasses) were calibrated using observations on 3C286. Channel 0 images for both Stokes parameters I and V of size 256X256 were made using HORUS. The peak maximum and minimum in these maps given by HORUS, and number of visibilities used for making the images are listed in table 7 for both I and V maps at various frequencies. The total intensity (I) maps were cleaned using APCLN with number of iterations

(NITER) =1000. The rms noise in the cleaned I and V maps are measured using IMSTAT as listed in table 7. The expected rms image noise is calculated using $S_{rms} = 1.234T_{sys}(Jy)/\sqrt{NtB}$ is also given in the table. The factor 1.234 is due to two bit three level correlator efficiency, $T_{sys}(Jy)$ is system temperature expressed in Jy (assumed =1.25*353 Jy, here 1.25 is due to the increase in the system temperature at 35° elevation compared with that at 70 ° elevation measured for Virgo-A to be 353 Jy —average value for all antennas), N is product of visibilities and polarizations (i.e. rcp and lcp), t is the integration period (=10s), and B is the bandwidth (=9.3 MHz). In these data there is no clear difference between noise over 1385 ±25 MHz band compared to 1465 ±25 MHz band at more than a few % level.

Peak noise in individual 1.5 MHz channel maps (using HORUS) is shown in Fig. 3. There are rfi spikes at 1364.5, 1400, and 1486.4 MHz. Channels in frequency range of 1529.5 to 1544.8 MHz are seriously affected due to external rfi but there is no indication of substantially increased noise in 1385±25 MHz band compared with those in 1465±25 MHz band. From these results (Table 7 and Fig. 3) it seems that at about 0.3 mJy rms noise level in images (for signal bandwidth of 9 MHz) we donot see much difference ($\leq$ 10 – 15%) in sensitivity obtained over any 50 MHz bandwidth in the frequency range of 1360 to 1520 MHz.

For one of the frequency settings (AC: 1396.3±6.25 MHz, BD: 1446.3±6.25 MHz) we split out the channel 0 data for durations of 30 sec, and 2 min from a total of 8 min data. We made images of 30 sec data, 2 min data, and 8 min data using HORUS for both Stokes I and V. The peaks in the images given by HORUS, along with number of visibilities used in making the images, are given in table 8. We cleaned the images using APCLN with NITER=1000. The resulting residuals given by APCLN for the images are given in table 8. Also rms noise the cleaned I and v images measured using IMSTAT are given in the table. Note that 1396.3 MHz channel 0 image contains 1400 MHz frequency where interference is observed. The peak and rms noise for 30 sec, 2 min, and 8 min images go down more rapidly than square root of integration for 1396.3 MHz images but slower than square root of integration period for the 1446.3 MHz images. This is probably due to the fact that narrow band interference for short integrations is likely to reduce more like linearly with the integration, and the 1396.3 MHz images have 1400 MHz birdie. This is probably also the explaination for the higher noise in 1385±25 MHz (which contains 1365 and 1400 MHz birdies) snapshots compared with 1465±25 MHz snapshots made by Condon.

CONCLUSIONS

Upgraded VLA antennas have average SEFD of about 310 Jy at zenith for cold galactic background, and when the system is finally (well) tuned up it may go down somewhat below 300 Jy. Unlike the old system the upgraded system has essentially flat G/T and noise performance (except when the map noise is dominated by rfi) over 1360 to 1560 MHz frequency range. The system temperature increases rapidly with increasing zenith angle (probably due to the feed sidelobes). For finally upgraded (and tuned up) system the increase in the system temperature is likely to be 50% at elevation of 30°, and double at 15° elevation. For short snapshot maps over a frequency band containing rfi the map noise is (probably) dominated by the interference especially for field with low fringe rates (very high declinations) even for A-array.

93JAN05 T_{sys} increase on VIRGO-A at L-band (92Dec28 data)

Average over Antennas # 2 to 28

VIRGO S_ν (Jy)	FREQ (ν) MHz	IF A	IF B	IF C	IF D
		(BW = 12.5 MHz)			
218.3	1366	1.589 *	1.554	1.597 *	1.567
	1378	1.597 *	1.548	1.598 *	1.561
214 Jy	1391	1.622 *	1.569	1.621 *	1.578
	1404	1.614 *	1.564	1.615 *	1.574
	1416	1.559	1.562 *	1.558	1.600 *
	1428	1.534	1.584 *	1.538	1.610 *
	1440	1.556	1.525 *	1.552	1.608 *
	1453	1.546	1.580 *	1.549	1.595 *
	1466	1.561 *	1.515	1.572 *	1.534
	1478	1.567 *	1.523	1.590 *	1.546
	1491	1.560 *	1.523	1.572 *	1.533
	1503	1.543 *	1.493	1.557 *	1.515
	1516	1.491	1.526 *	1.516	1.548 *
	1528	1.493	1.532 *	1.486	1.550 *
	1541	1.487	1.527 *	1.459	1.53 *
195.6	1553	1.469	1.509 *	1.464	1.519 *

1.598
1.592 → T_{sys}(Jy) ~ 353

$$T_{sys}(Jy) = \frac{214 \times 1}{.595 \times 1.02} = 353$$

Unstarred measurements between 8:18 to 8:42 MST el ~ 55°
* MEASUREMENTS BETWEEN 5:48 to 6:15 " el ~ 68°

Table 1

93 FEBØ1

INCREASE IN T_{sys} ON CRAB (EL ~ 70°) for VLA antennas at 20 cm — ALL 27 antennas

Freq ν (MHz)	A	B	C	D	$\frac{A+B+C+D}{4} = R$
1366	3.494	3.480	3.460	3.571	3.501
1378	3.494	3.424	3.516	3.475	3.477
1391	3.558	3.507	3.565	3.587	3.554
1404	3.605	3.507	3.601	3.578	3.573
1416	3.488	3.413	3.505	3.476	3.471
1428	3.441	3.414	3.460	3.463	3.444
1440	3.531	3.484	3.554	3.578	3.536
1453	3.528	3.488	3.510	3.572	3.525
1466	3.436	3.392	3.443	3.46	3.432
1478	3.512	3.446	3.561	3.561	3.520
1491	3.501	3.409	3.504	3.492	3.477
1503	3.401	3.351	3.431	3.471	3.414
1516	3.388	3.344	3.44	3.443	3.404
1524	3.409	3.366	3.439	3.439	3.413
1541	3.244	3.321	3.297	3.331	3.298
1553	3.346	3.286	3.349	3.301	3.321

T_{sys} (Jy) at 1480 MHz $= \frac{940}{2.56} \sim 368$ Jy

Table 2

93FEB01 INCREASE IN Tsys of 21 upgraded L-band Antennas AT 20 cm ON CRAB (El ~ 70°)

S_ν (Jy)	Freq ν (MHz)	A	B	C	D	(A+B+C+D)/4
950	1366	3.779	3.749	3.724	3.852	3.776
	1378	3.776	3.681	3.795	3.750	3.75
	1391	3.847	3.78	3.845	3.867	3.835
	1404	3.883	3.751	3.89	3.868	3.848
	1416	3.742	3.649	3.783	3.750	3.732
	1428	3.70	3.659	3.746	3.745	3.713
	1440	3.797	3.729	3.850	3.881	3.814
	1453	3.791	3.730	3.795	3.862	3.795
	1466	3.688	3.625	3.72	3.736	3.692
	1478	3.787	3.701	3.861	3.862	3.803
	1491	3.781	3.665	3.808	3.791	3.761
	1503	3.691	3.616	3.723	3.764	3.699
	1516	3.669	3.604	3.747	3.752	3.701
	1528	3.698	3.631	3.739	3.734	3.701
	1541	3.500	3.581	3.573	3.605	3.565
914	1553	3.62	3.572	3.638	3.597	3.609

Ave SEFD ~ 330 Jy

Table 3

93FEB01 INCREASE IN Tsys on 6 **NOT** upgraded L-Band Antennas AT 20 cm ON CRAB — (Ant # 2, 6, 9, 12, 16, 17) (El ~ 70°)

Freq ν (MHz)	A	B	C	D	R = (A+B+C+D)/4
1366	2.498	2.538	2.535	2.585	2.539
1378	2.507	2.525	2.543	2.513	2.522
1391	2.546	2.553	2.589	2.607	2.574
1404	2.633	2.653	2.589	2.564	2.61
1416	2.596	2.586	2.529	2.514	2.556
1428	2.536	2.556	2.461	2.473	2.51
1440	2.603	2.625	2.518	2.518	2.566
1453	2.606	2.642	2.512	2.555	2.579
1466	2.555	2.579	2.474	2.494	2.526
1478	2.550	2.552	2.513	2.505	2.53
1491	2.521	2.512	2.439	2.444	2.479
1503	2.388	2.423	2.409	2.444	2.416
1516	2.406	2.433	2.364	2.362	2.391
1528	2.395	2.439	2.391	2.402	2.407
1541	2.349	2.411	2.332	2.370	2.366
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Table 4

T_{sys} (Jy) at 1400 $= \frac{940}{1.58} \sim 590$ J[illegible]

$$\frac{R_{1400}}{R_{1550}} \sim \frac{2.61-1}{2.32-1}$$

$$\frac{(G/T)_{1400}}{(G/T)_{1550}} \sim \frac{1.22}{1.03}$$

93FEBØ1 TIPPING Data
02:57 IAT
LOOKING NORTH
AMB TEMP · 2·2 °C
DEW PT 0·1 °C

AC : 1385 MHz /50
BD : 1465 /50

EL	A	B	C	D	(A+B+C+D)/4	SEC Z
90	1·0	1·0	1·0	1·0	1·0	1·0
70	1·019	1·014	1·022	1·013	1·017	1·064
65	1·028	1·020	1·031	1·021	1·025	1·103
60	1·045	1·039	1·05	1·039	1·043	1·155
55	1·073	1·067	1·078	1·064	1·071	1·221
50	1·109	1·102	1·115	1·10	1·107	1·305
40	1·22	1·218	1·225	1·214	1·219	1·556
30	1·391	1·395	1·403	1·395	1·396	2·0
20	1·603	1·624	1·62	1·628	1·619	2·924
15	1·754	1·783	1·771	1·792	1·775	3·864
12	1·868	1·903	1·885	1·905	1·890	4·81
10	1·963	1·998	1·984	2·003	1·987	5·759
8	2·061	2·094	2·085	2·104	2·086	7·185

Table 5

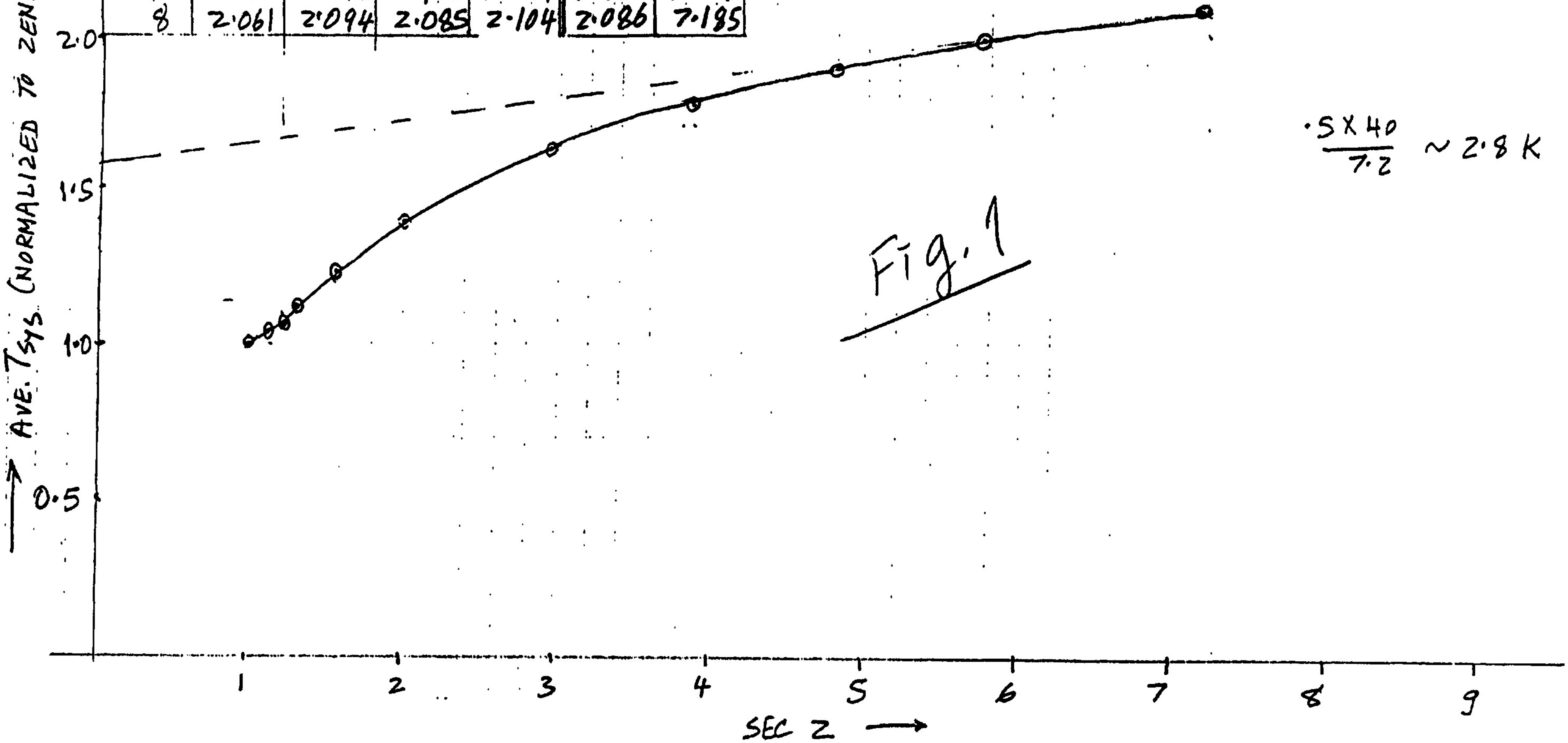

Fig. 1

930209

Tipping curves at 20 cm on 21 L-band upgraded antennas —

93 FEB 01 data 02:57 IAT
Tipping AZ = 0 (NORTH)
AMB-TEMP. = 2.2°C
DEW PT = 0.1C.
DEFULT FREQ/BW AC 1385/50 MHz
BD 1465/50

EL	A	B	C	D	(A+B+C+D)/4	sec Z
90°	1.0	1.0	1.0	1.0	1.0	1.0
70	1.021	1.016	1.020	1.016	1.018	1.064
65	1.031	1.023	1.031	1.024	1.027	1.103
60	1.051	1.044	1.053	1.044	1.048	1.155
55	1.083	1.075	1.085	1.073	1.079	1.221
50	1.123	1.116	1.126	1.112	1.119	1.305
40	1.247	1.246	1.253	1.239	1.246	1.556
30	1.439	1.444	1.453	1.442	1.444	2.0
20	1.675	1.701	1.696	1.702	1.694	2.924
15	1.842	1.88	1.867	1.886	1.869	3.864
12	1.97	2.014	1.994	2.012	1.997	4.81
10	2.076	2.121	2.105	2.122	2.106	5.759
8	2.185	2.229	2.218	2.236	2.217	7.185

Table 6

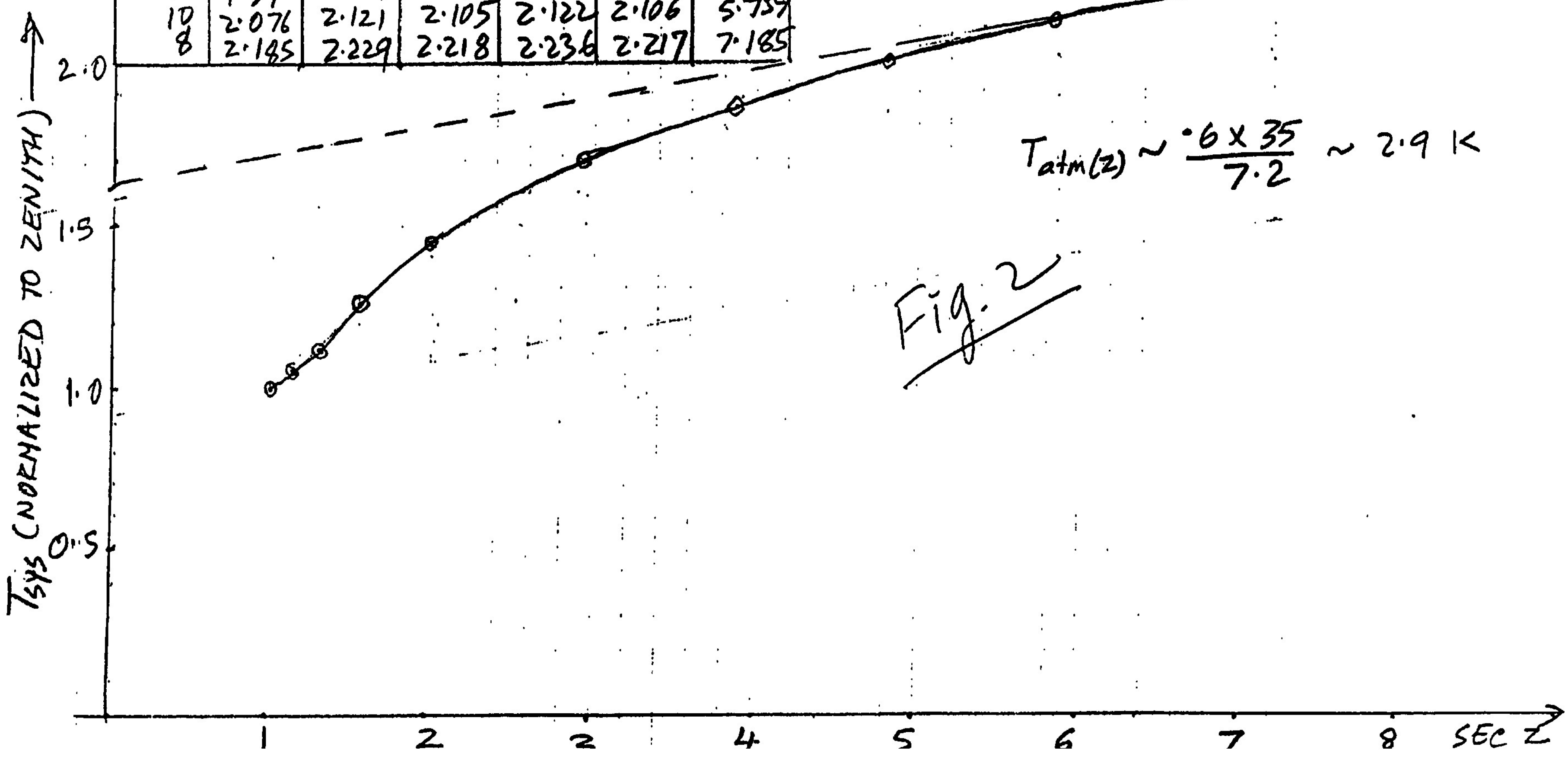

Fig. 2

FREQUENCY (MHz) CH0: BW=9.3	IFs	# OF VISIBILIT.	I MAP HORUS MIN (mJy)	I MAP HORUS MAX (mJy)	I MAP RMS (*1) (μJy)	V MAP HORUS MIN. (mJy)	V MAP HORUS MAX (mJy)	V MAP RMS (*2) (μJy)	EXPECTED RMS (μJy)
1366·3	AC	15444	-1·6	2·6	338	-1·4	1·4	310	312
1376·3	AC	17199	-1·5	1·1	274	-1·0	1·2	260	296
1386·3	AC	17199	-1·6	1·6	345	-1·2	1·2	310	296
1396·3	AC	17199	-1·5	1·9	306	-1·7	1·8	438	296
1406·3	AC	17199	-1·4	1·4	268	-1·2	1·0	268	296
1416·3	BD	15444	-1·9	1·6	355	-1·3	1·4	308	312
1426·3	BD	17199	-1·5	1·7	286	-1·1	1·2	272	296
1436·3	BD	17199	-1·2	1·5	286	-1·1	1·2	258	296
1446·3	BD	17199	-1·3	1·5	258	-1·1	1·2	261	296
1456·3	BD	17199	-1·5	1·2	260	-1·2	1·2	274	296
1466·3	AC	12636	-1·8	1·6	319	-1·3	1·4	299	345
1476·3	AC	17199	-1·3	1·2	260	-1·2	1·1	255	296
1486·3	AC	17199	-1·7	1·3	338	-1·4	1·3	336	296
1496·3	AC	16497	-1·5	2·0	262	-1·2	1·3	268	302
1506·3	AC	17199	-1·9	1·4	254	-1·8	1·4	282	296
1516·3	BD	12636	-1·6	1·6	299	-1·3	1·5	323	345
1526·3	BD	17199	-6·8	6·8	1517	-6·1	6·6	1710	296
1536·3	BD	17199	-11·2	7·5	2382	-11·2	8·6	2638	296
1546·3	BD	16497	-4·8	5·1	1161	-3·1	3·7	830	302
1556·3	BD	17199	-1·4	1·2	256	-1·5	1·2	282	296

*1 = RMS USING IMSTAT OVER CLEANED MAP USING APCLN (NITER=1000)
*2 = RMS USING IMSTAT OVER V-MAPS

TABLE 7 (Revised 930224PM)

INTEGRATION DURATION	FREQ/BW (MHz)	# OF VISIBILITIES.	I MAP HORUS PEAK MIN. (mJy)	I MAP HORUS PEAK MAX (mJy)	I MAP APCLN PEAK RES (μJy)	I MAP RMS (IMSTAT) (μJy)	V MAP HORUS PEAK MIN (mJy)	V MAP HORUS PEAK MAX (mJy)	V MAP APCLN PEAK RES (μJy)	V MAP RMS (IMSTAT) (μJy)
30 SEC	1396.3/9.3	1053	-8.8	11.7	1947	1769	-8.9	8.5	1895	2279
	1446.3/9.3	1053	-5.9	4.9	996	912	-6.1	4.5	935	1107
2 MIN	1396.3/9.3	4212	-4.9	4.4	857	819	-4.2	3.8	848	989
	1446.3/9.3	4212	-2.8	2.8	514	479	-2.0	1.9	471	508
8 MIN	1396.3/9.3	17199	-1.6	1.9	388	306	-1.7	1.8	429	438
	1446.3/9.3	17199	-1.4	1.5	308	262	-1.1	1.2	284	268

Table 8 -

2

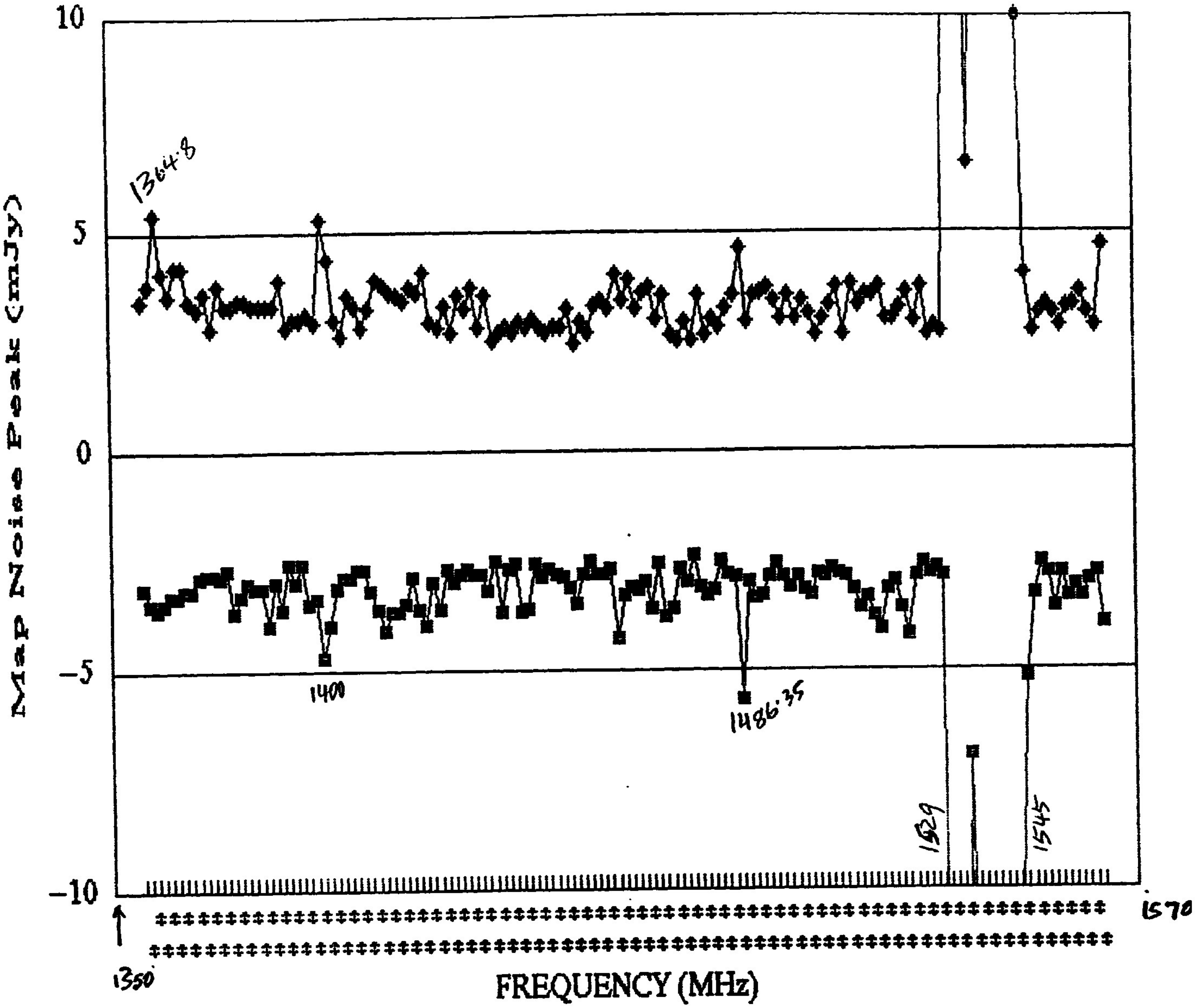
10
5
0
−5
−10
Map Noise Peak (mJy)
1364.8
1400
1486.35
1529
1545
1350
1570
FREQUENCY (MHz)

FIG. 3