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Continuum- and Polarisation Mapping Performance of the 8.35 GHz SFK-Receiver

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Abstract: We give the results of test observations of the recently installed improved 8.35 GHz SFK receiver at the Effelsberg 100-m telescope in September and November 2001. This report describes its performance for radio continuum and polarisation mapping observations. The most unexpected result is that during the entire test phase the full bandwidth of 1.1 GHz was usable. Only a few percent of time was lost due to interference, although the band is not protected. We also tested the receivers performance at 100 MHz and 200 MHz bandwidth.

The sensitivity for total intensities at 8.35 GHz and 1.1 GHz bandwidth (broad band = BB) for typical mapping observations observations and clear sky is between 1.8 and 2.2 mJy/b.a. sec. With scattered thin clouds the total intensity sensitivity drops by more than 50% as expected for a single feed system. For Stokes U,Q a sensitivity of 0.4 mJy/b.a. sec is measured nearly independent from sky conditions. The total intensity sensitivity for the simultaneous observed narrow band at 8.00 GHz and 200 MHz bandwidth (small band = SB) is just marginally worse compared to that of the BB despite the bandwidth difference. The SB sensitivity is about 2.2 mJy/b.a. sec with some variations.

The beam is a nearly circular Gaussian with a HPBW of 81.9" BB (84.5" SB at 8 GHz). An aperture efficiency of 47% (56% at 8 GHz) was calculated based on the previously measured calibration signal. The instrumental polarisation (BB) is about 0.5% or below for SB. However, towards the band limits the instrumental polarisation increases to about 1%

The single beam receiver requires a perfectly clear sky for sensitive continuum observations, while polarisation measurements suffer much less from weather effects. Sensitive polarisation observations require the BB receiver, while total intensity sensitivities are not much different for BB and SB observations.

The receiver concept: 8.35 GHz (X-band) is a standard VLBI frequency. The Effelsberg telescope has an S/X receiving system installed in its secondary focus cabin (SFK) allowing simultaneous observations at these two frequencies. The previous 8.35 GHz receiver had just one polarisation channel and was recently replaced by a dual-channel system with enhanced sensitivity. 8.35 GHz also is a VLA frequency and there is strong interest to combine Effelsberg and VLA continuum and polarisation data to obtain maps with complete information on all spatial scales. Polarisation data at a frequency between 4.85 GHz and 10.55 GHz are of importance to solve for rotation measures. Sometimes a higher sensitivity is required than achievable with the 10.55 GHz receiver.

The technical data of the receiving system have been listed in the report from O. G. Lochner, which we attach to this memo. In brief, the receiver is technically rather similar to the 4.85 GHz and the 10.55 GHz systems. Its system temperature was measured to about 25 K in zenith. The system is a two channel (RHC, LHC) total power receiver with an attached polarimeter to observe simultaneously Stokes U and Q. The full bandwidth of the receiver centred at 8.35 GHz is 1.1 GHz (BB). Alternatively a narrow band (SB) of up to 200 MHz can be selected. Parallel to BB observations SB data are simultaneously recorded in RHC, LHC, U and Q but centred at 8.00 GHz. This set-up is recommended to use as long as no significant interference shows up.

Test observations: First tests of the system were made on September, 12. under unfavourable weather conditions including rain for some time, but showing the system to work as expected. More tests have been made on November, 15., 17./ 18. and 19./20. Except for the last night with a mostly cloudy sky, the weather was fine with periods of clear sky or thin high altitude clouds. Fog shows up in the early morning with little influence.

We mapped several polarised and unpolarised calibration sources and made deep observations of the antenna pattern. We made numerous small maps on a weak quasar of a few mJy to find the systems sensitivity. Maps of Tycho´s supernova remnant were made to study the effect of stability on a moderately strong extended source, which can be compared with Effelsberg 10.55 GHz data. Repeated scans or stripes with lengths of up to 2° were observed with varying scan velocity to study the total power stability.

Beam shape and aperture efficiency: The beam shape as found from mapping 23 strong calibration sources was found to be a nearly circular Gaussian with a HPBW of 82.7" x 81.1" (BB) and 85.3" x 83.7" (SB with 200 MHz centred at 8.00 GHz). The range of elevations where the observations were made was between 26° and 71°.

From the average of five observations of 3C286 (elevations between 34° and 66°) we measure T_A/S [K/Jy] = 1.35 (BB) and 1.59 (SB at 8 GHz). We calculate a main beam solid angle for BB (SB) measurements of $\Omega_{mb} = 1.78\ 10^{-7}$ ($1.90\ 10^{-7}$) sr. These data depend on the accuracy of the internal calibration signal as measured by O. G. Lochner to be 2.5 K (see attached report). We found an aperture efficiency of 47 (56) %. This discrepancy is likely due to a slight increase of the calibration signal with frequency across the full bandwidth (O. Lochner, private communication), which could not be taken into account. The full beam solid angle is $\Omega_0 = 3.46\ 10^{-7}$ ($3.20\ 10^{-7}$) sr. A beam efficiency of 51 (59) % is calculated from the observed Ω_{mb}. We obtain a rather large conversion factor for main beam temperature and flux density of T_b/S [K/Jy] = 2.62 (2.68).

Antenna pattern and instrumental polarisation: We have observed two antenna pattern in orthogonal directions centred on 3C273 and on 3C84. These measurements were made without the S-band mirror mounted. A later additional observation with the S-band mirror mounted show no differences in the characteristics. 3C273 is the stronger source and sidelobe structures down to a level of –36 dB are clearly seen. However, the source is polarised at about 5.8% and thus less suited for determining the polarisation characteristics. We used the unpolarised source 3C84 for this purpose, while its total intensity data were somewhat affected by weather effects. We note just marginal differences between the BB and SB pattern in I. However, the instrumental polarisation for BB with a peak at about 0.4% is below that for the SB, where a peak of 0.9% is seen. The BB pattern as obtained for I (30´x30´) and PI (20´x20´) are shown in Fig. 1.

We derived the beam squint from the 3C84 BB measurements by subtracting the LHC and the RHC pattern after correcting for the scaling difference of 2.3% between the LHC and the RHC channel. We found maximum positive/negative amplitudes of +/- 4.3% at a distance of +/- 0.7′ from the pointing direction at a position angle of ~45°. The beam squint is smaller than that at 6 cm (~7%), but larger than that at 2.8 cm (~2.2%).

Calibration sources: We refer to 3C286 as the main calibrator. Its assumed flux density was obtained from interpolation between 4.85 GHz and 10.55 GHz data. Its percentage polarisation was adopted as measured with the VLA to be 11.7% at a polarisation angle of 33°. We found the injection angle of the calibration signal to differ from the expected 45° by 1.8° (being corrected within the standard reduction process).

We give the measured flux densities and polarisation data for a number of sources in Table 1 (BB) and Table 2 (SB), where we also include data from the literature for comparison. Both flux densities measurements agree quite well. Here we simply averaged the LHC and RHC signals. We note a scaling difference: CH1 x 1.023 = CH2 (RHC < LHC) for BB observations at 8.35 GHz and CH1 x 0.982 = CH2 (RHC > LHC) for SB at 8.00 GHz.

Table 1: Calibration data for BB observations (8.35 GHz/1.1 GHz)

Source	S [Jy]	Ott et al. S[Jy]	Pol. [%]	VLA Perc.[%]	Angle[°]	VLA Angle[°]
3C286	5.16	5.22	11.7	11.7	33	33
3C48	3.20	3.35	5.6	5.3	115	114
3C138	2.43	2.45	11.4	11.9	168	169
3C295	3.40	3.47	1.2	—	—	—
3C380*	3.86	—	1.7	—	—	—
NGC7027	5.90	5.87	0.4	—	—	—
3C84	18.2	Variable	0.4	—	—	—
3C273	25.5	Variable	5.8	—	145	—
3C345*	11.2	Variable	0.8	—	—	—

* from a single measurement

Table 2: Calibration data for SB observations (8.00 GHz/ 200 MHz)

Source	S [Jy]	Ott et al. S[Jy]	Pol. [%]	VLA Perc.[%]	Angle[°]	VLA Angle[°]
3C286	5.33	5.38	11.7	11.7	33	33
3C48	3.35	3.50	5.9	5.3	115	114
3C138	2.52	2.50	10.6	11.9	168	169
3C380*	3.97	—	2.1	—	—	—
NGC7027	5.88	5.83	0.7	—	—	—
3C84	18.0	Variable	0.9	—	—	—
3C273	26.0	Variable	5.0	—	146	—
3C345*	11.3	Variable	1.4	—	—	—

* from a single measurement

100 MHz narrow band observations were carried out for 3C286 and NGC7027 to study the performance of the system across the 1.1 GHz bandwidth. The variation of the system parameters are listed in Table 3. Calibration is frequency dependent and must be measured for each selected frequency separately. Because of the unexpected low level of interference for the BB observations just a few narrow band measurements were made.

Table 3: 3C286 and NGC7027 as observed with 100 MHz bandwidth

ν[GHz]	Source	PC	PA	Source	PC	HPBW" max	HPBW" min
7.95	3C286	10.5	33.7	N7027	1.0	86	83
8.05	3C286	10.8	33.7	N7027	0.8	85.5	84
8.15	3C286	10.8	33.8	N7027	1.1	85.5	82.5
8.25	3C286	11.5	35.0	N7027	0.2	84.5	81.5
8.35	3C286	11.9	35.3	N7027	0.2	83.5	81
8.45	3C286	11.6	34.2	N7027	0.5	83	79.5
8.55				N7027	1.1	84	80
8.66				N7027	1.6	82	79

Deep integration and sensitivities for mapping observations:

We have made a series of observations of a **7′x7′** field centred on the weak mJy quasar **J1053-0016** (z=4.3). The mapping parameters were V=30′/min and SINT=30". The field was observed alternatively in orthogonal directions. 9 coverages were made on November, 15 with BB, but no SB data. The total intensity map (τ=9 sec/pixel) with a fitted peak flux density of 5.85 mJy is shown in Fig. 2. The same procedure was repeated on November, 20. with 18 coverages and BB as well as SB data, but less favourable weather conditions. A confusion limit of 150 μJy (interpolated from 4.85 GHz and 10.55 GHz data) was assumed to correct the rms noise for total intensity data. Both observations reveal no polarised emission from the source exceeding the limit set by noise to about 2%.

The following rms noise (mJy/sec) was measured :

Date	I (BB)	U,Q (BB)	I (SB)	U,Q (SB)
15.11.01	2.2	0.4	—	—
20.11.01	2.7	0.4	2.8	1.5

We also observed the core of **M31 (10′x10′)**. We show the broad band data from November 15. for I and PI in Fig. 3, measured under clear sky conditions. The observations were repeated under cloudy conditions on November 17. We measured the following noise (mJy / sec integration time):

Date	I (BB)	U,Q (BB)	I (SB)	U,Q (SB)
15.11.01	2.2	0.4	—	—
17.11.01	3.9	0.4	3.4	2.0

We also mapped a **16′x 16′** field around **Tycho′s SNR**, which is a fairly strong and extended source. From two orthogonal coverages at better sky conditions than the M31 observations made immediately before we obtain the following rms-noise data (mJy/sec) :

Date	I (BB)	U,Q (BB)	I (SB)	U,Q (SB)
17.11.01	1.8	0.4	2.2	1.8

We show the Tycho BB and SB map in Fig. 5 and Fig. 6. Note the unexpected small differences in the BB and SB properties of the system for total intensity measurements.

During the 27h of test observations we lost less than about 20 minutes of time due to clearly visible strong interference. These favourable conditions will unlikely last for ever in view of the unprotected frequency band. Therefore observations with the BB system are recommended to be done immediately.

With a single beam system no atmospheric emission can be cancelled and in particular total intensity observations require a rather clear sky. Polarisation is much less effected. A blower is attached to the feed so that observations can be quickly resumed after rain fall. During unstable weather higher telescope velocities (1°/min or 1.5°/min) and more coverages are recommended. Improvement of moderately effected data can be achieved by using the unsharp masking (PRESSE) software or the PLAIT (Fourier) destriping technique, which requires orthogonal mapping.

System stability: We tested the stability of the system by repeating long scans or small stripes across weak but extended sources.

2x10 scans of **40′ length** were made across the ring structure of **M31** about 25′ north of the centre. The integration time was 1 sec/30" pixel. We arranged the ten scans from each observation into a map and measured the rms noise of the original data, after a linear and a second order fit along the scans. Only BB data were observed on November, 15. When the observations were made The rms noise (mJy/sec) for both scans are:

Scan	#1107				#1109			
	Ch1	Ch2	Ch3	Ch4	Ch1	Ch2	Ch3	Ch4
Original	4.5	5.8	0.52	0.48	4.8	6.2	0.57	0.57
1. Order	3.8	4.8	0.44	0.44	4.0	5.0	0.47	0.46
2. Order	3.6	4.6	0.42	0.43	3.9	4.8	0.48	0.48

Obviously a first order fit improves the baseline quality significantly, higher order fitting gives little improvement and should be avoided when mapping extended structure. The system drift stability is quite good and comparable to that at 4.85 GHz and 10.55 GHz, although different types of HEMT amplifiers are used for the 8.35 GHz system. CH2 (LHC) shows always higher noise than CH1 (RHC). The ratio is not changed by polynomial fitting. This indicates high frequency noise.

We have averaged all data for 20 sec of integration time per 30" pixel. The scans are shown in Fig. 4 with the signals from the ring of M31 in I, U and Q as expected from previous observations. We find the rms noise (mJy/beam) to be nearly independent from previous fitting of individual scans. Outside of visible structures we measure 0.86 mJy (I), 85 μJy (U) and 110 μJy (Q), while we expect 0.5 mJy (I) and 90 μJy for U and Q.

1°50′ long stripes were observed across the HII region complex **W5** with scanning velocities of 45′/min, 60′/min and 90′/min. Although the integration times per 30" pixel were 0.33, 0.5 and 0.66 sec, respectively, the measured noise was rather similar varying between 1.4 and 1.7 mJy/sec for I and 0.3 to 0.4 mJy/sec for U,Q. The sky was clear at that time on November, 15. The measurements were repeated three times on November 17., where also SB measurements were made. The integration time for all stripes was 0.5 sec/pixel and the BB rms noise per sec varied between 1.6 and 1.8 mJy/sec for I and was always at 0.4 mJy/sec for U, Q. For the simultaneous SB measurements we find variations between 2.1 to 2.2 mJy for I and always about 1.6 mJy for U, Q. We show the individual total intensity maps separately for CH1 (LHC) and CH2 (RHC) in Fig. 7. Weak weather effects show-up as common distortions in both channels, while the system stabilities are independent for each receiver and slightly higher in CH2. However, from these tests it is clear that the system stability is high enough to allow reliable observation of weak sources extending up to 2° or may be even more. There are indications that higher scanning velocities (exceeding 45′/min) result in a slightly higher sensitivity per sec than data observed with lower scanning speeds. The stability of the 3.6 cm total power receivers are comparable with those being used at 6 cm and 2.8 cm.

The 3.6cm RX in comparison: Available receivers for continuum and polarisation mapping observations at the Effelsberg 100-m telescope (December 2001)

Frequency [GHz]	Bandwidth [MHz]	Feeds	HPBW [']	Tb/S [K/Jy]	RX	Rms* I [mJy]	rms* U,Q [mJy]
0.86	10	1	14.5	1.9	2	100	-
1.40	20	1	9.3	2.1	2	10	4
4.85	500	1	2.4	2.5	2	1.4	0.4
4.85	500	2	2.4	2.5	4	1.3	0.3
8.00	**200**	**1**	**1.4**	**2.6**	**2**	**2.2**	**1.6**
8.35	**1100**	**1**	**1.4**	**2.6**	**2**	**1.8**	**0.4**
10.55	300	1	1.15	2.2	2	2.4	1.4
10.55	300	4	1.15	2.2	8	2.3	0.7
32.0(II)	2000	3	0.45	1.8	6	4	-
32.0(I)	2000	3	0.45	1.8	6	12	2.4

* 1 sec integration time

In the BB mode the 3.6 cm RX provides equivalent sensitivity to the 6 cm receiver and is significantly more sensitive when compared with the 2.8 cm RX even when using all its four feeds. The total intensity sensitivity is more equivalent to the 2.8 cm system rather the 6 cm receiver. The small sensitivity difference between BB and SB total intensity observations is remarkable and needs explanation. The situation is similar to that noted for the 9 mm receiver, where the total power sensitivity 32.0(I) is about a factor of 3 below that of the correlation receiver 32.0(II).

Observing files: Set-up files are stored at [observer.kont.36], where also cross-scan files and files to map calibration sources and mapping examples are found. Type: @obsein.pro, to define a number of useful symbols for observations. The set-up file is for standard BB observations with simultaneous SB data at 8.00 GHz. Another SB frequency is not possible with combined BB observations. The bandwidth of the SB data needs to be selected at the filter unit attached to the narrow band polarimeter. To selected a specific narrow band within the receivers bandwidth (7.8 GHz to 8.9 GHz) the operator has to start the "single" rather the "general" receiver set-up. For SB frequencies other than 8.00 GHz the BB data are lost. The operator also has the command to set the frequency requested by the observer (e.g. frqrx 8.35 f sb) and knows about the polarimeter adjustment integrated within the 2.8 cm rack, which must be phase corrected for each frequency. The command cont36 switches back to BB observations. Any change of the set-up requires to measure a calibration source.

Reduction software: The data from the 3.6 cm system are stored in 12 channels. Channels 1-4 have the SB data and 5-8 the BB data (for technical reasons channels 9-12 are duplicates of channels 5-8). The sequence for both BB and SB data is RHC, LHC, U and Q signals. Data reduction procedures for both the BB and the SB data are available from /local/nod/master for cross-scans (ed36bbros, ed36sbros), calibration source mapping including Gaussian fitting (ed36bbcal, ed36sbcal) and mapping observations (ed36bbmap, ed36sbmap).

The polarimeter files para0.dat are available too. By the command copy36 all relevant files are transferred from /local/nod/master into the actual directory where subdirectories for BB and SB data will be created. The software may be subject of changes or improvements. Before starting observations it is recommended to contact P. Reich for the actual status of the software and also to report any problems to her.

Summary: The new 3.6 cm RX is quite an interesting addition to the existing 6 cm and 2.8 cm systems for continuum mapping observations at the 100 m telescope. This holds in particular for polarisation observations with the full band width of 1.1 GHz. Total intensity measurements require a clear sky. The actual situation with nearly no interference across the band should be used for deep integrations unless the situation changes.

Acknowledgement: We are very grateful to O. G. Lochner for the up-grade of the 3.6 cm receiver and his help with the technical preparations of the test measurements.

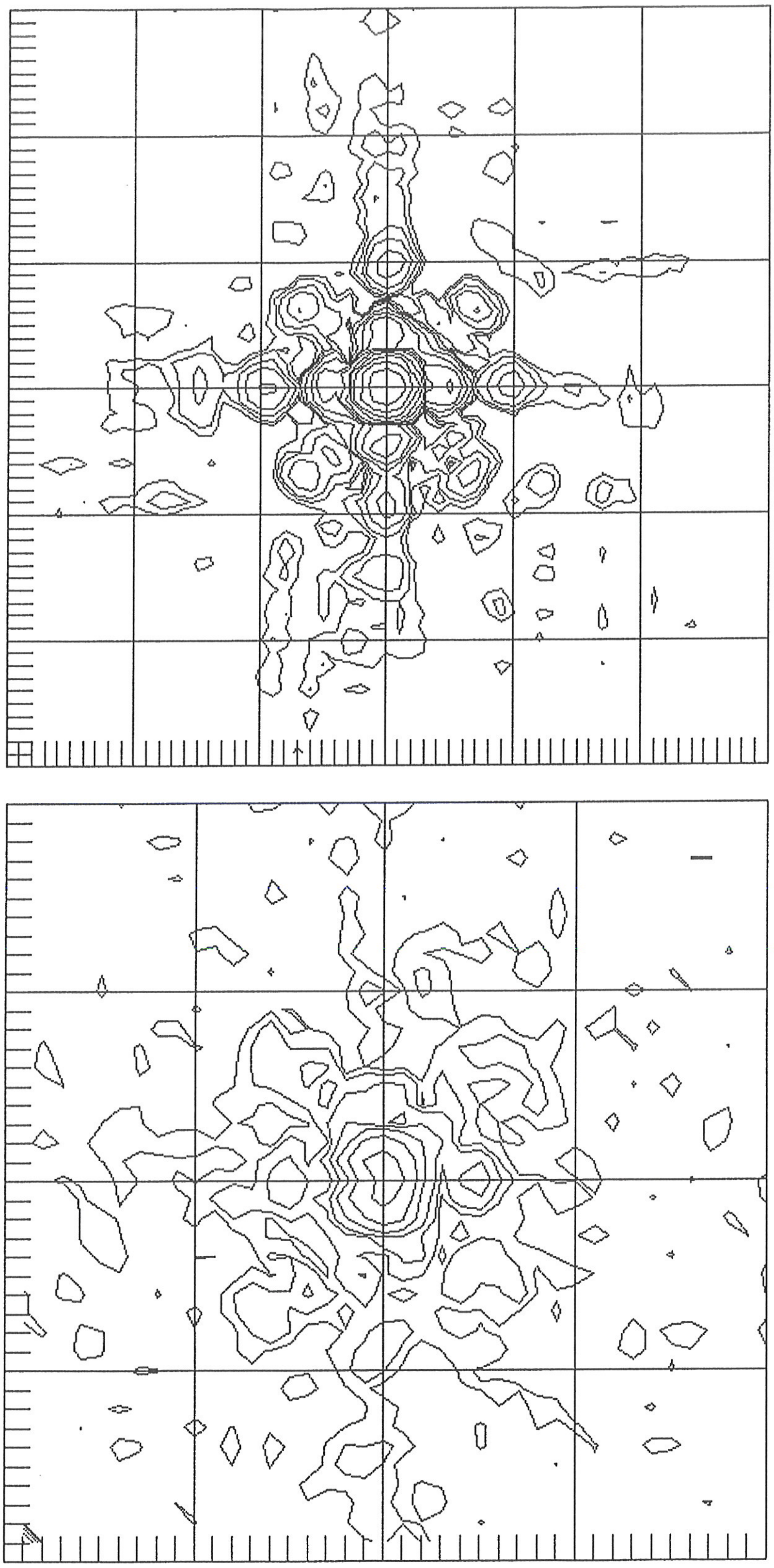


Fig. 1. BB antenna pattern. Stokes I (3C273, top) for 30'x30' in steps of -3db down to -36dB. PI (3C84, bottom) for 20'x20'. The maximum is at -24.2dB of the I maximum. Contours run in steps of -3dB down to -45dB.

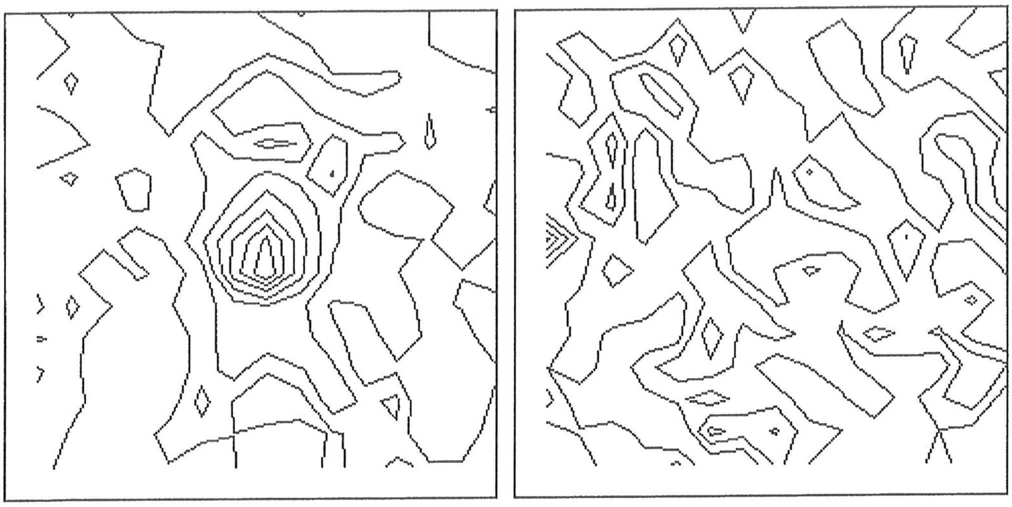


Fig. 2. Nine coverages with BB of a 7'x7' field centred on QSO J1053-0016. Contour steps are 1 mJy/b.a. for I (left) and 0.1 mJy/b.a. for PI (right)

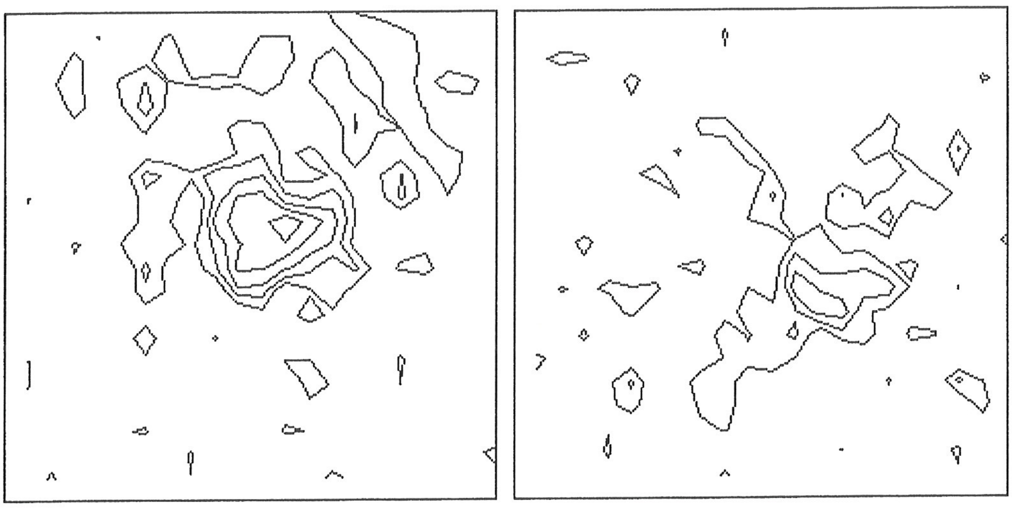


Fig. 3. 10'x10' core of M31 from two BB coverages. Contour steps are 2 mJy/b.a. for I (left) and 0.3 mJy/b.a. for PI (right). The offset of the polarised emission from the total intensity is already known.

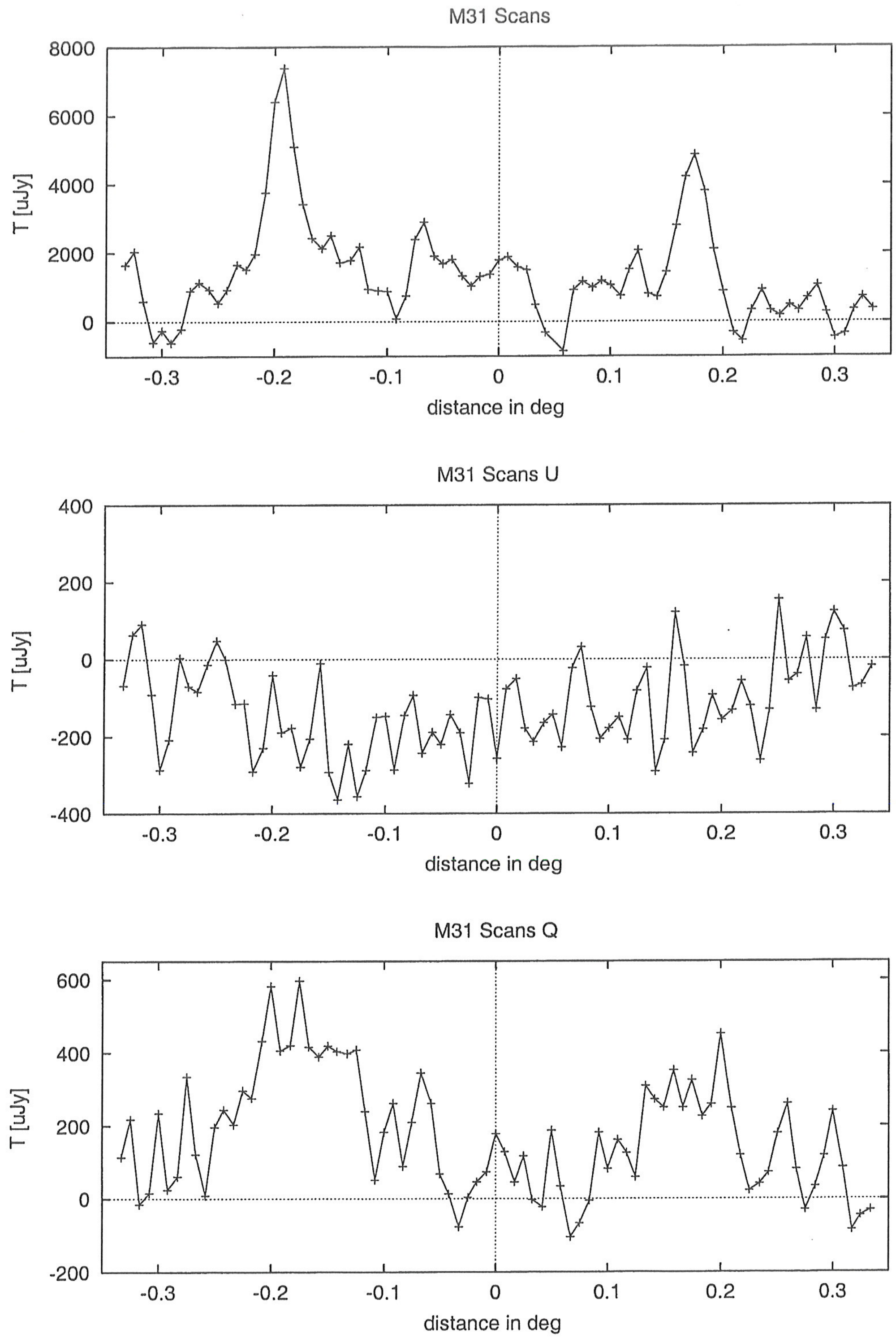
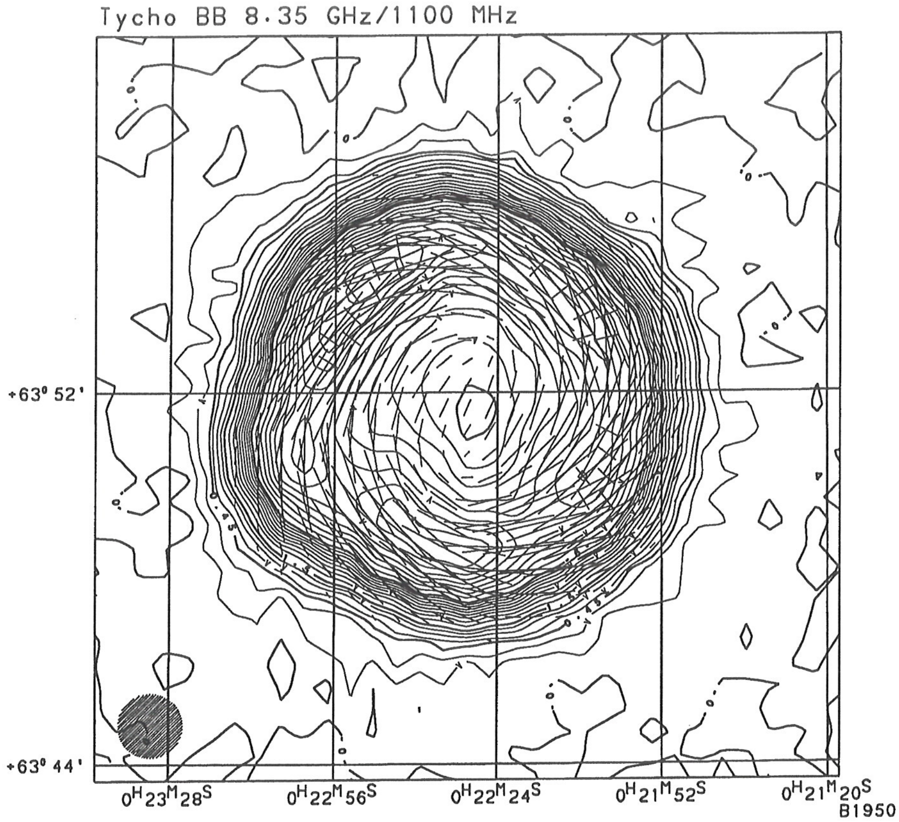


Fig. 4. Average from 20 scans (20 sec/pixel) across the ring of M31. Polarisation is clearly detected with the magnetic field running along the ring as expected.



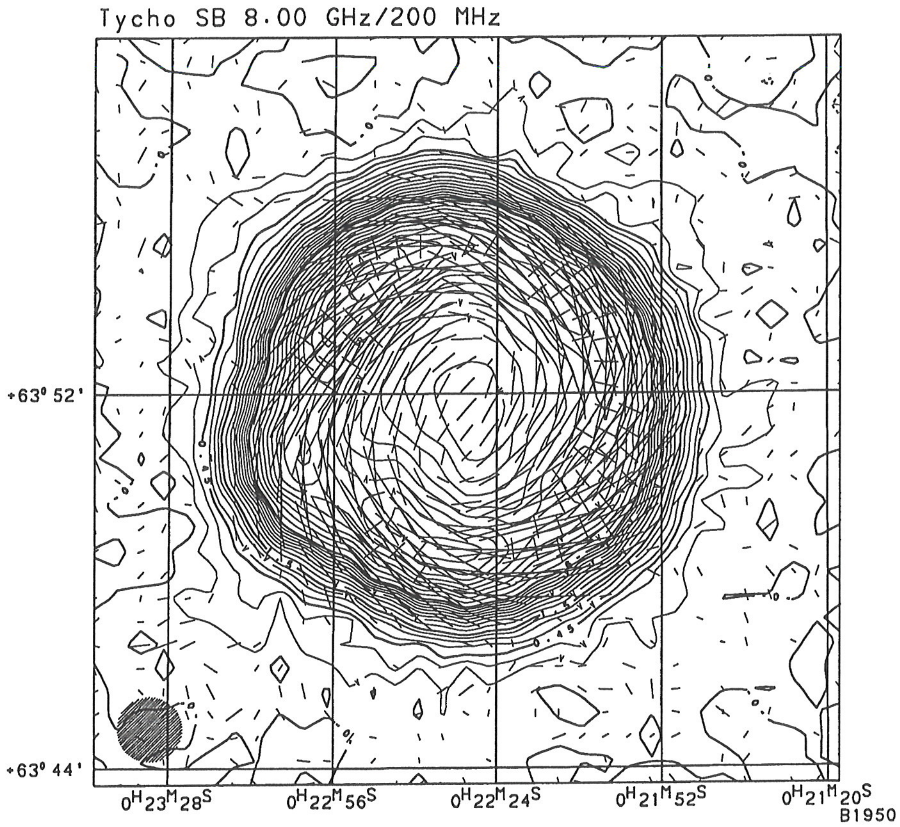
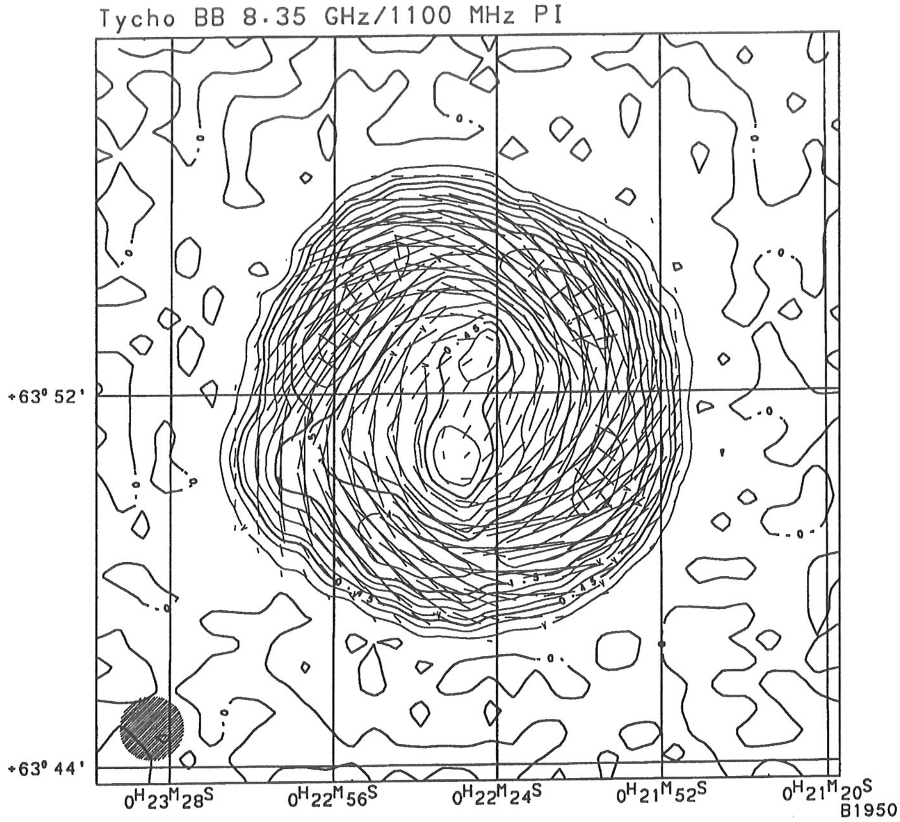


Fig. 5. BB and SB maps of Tycho's SNR with polarisation vectors in E-direction superimposed



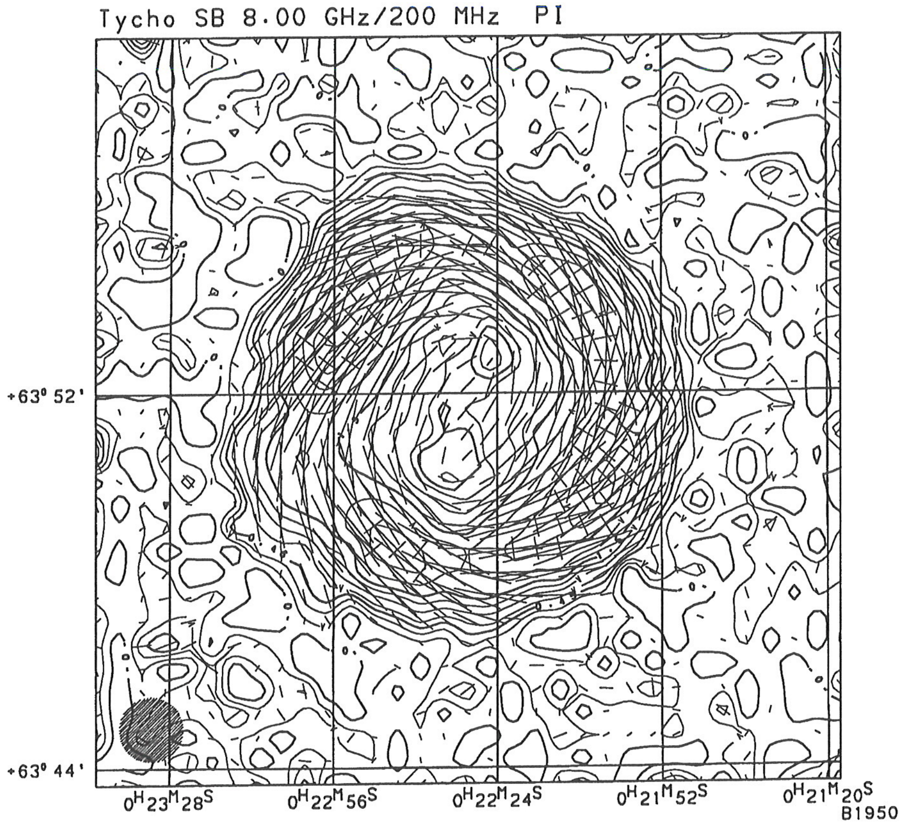


Fig. 6. BB and SB maps of polarised emission from Tycho's SNR. Polarisation vectors are in E-direction

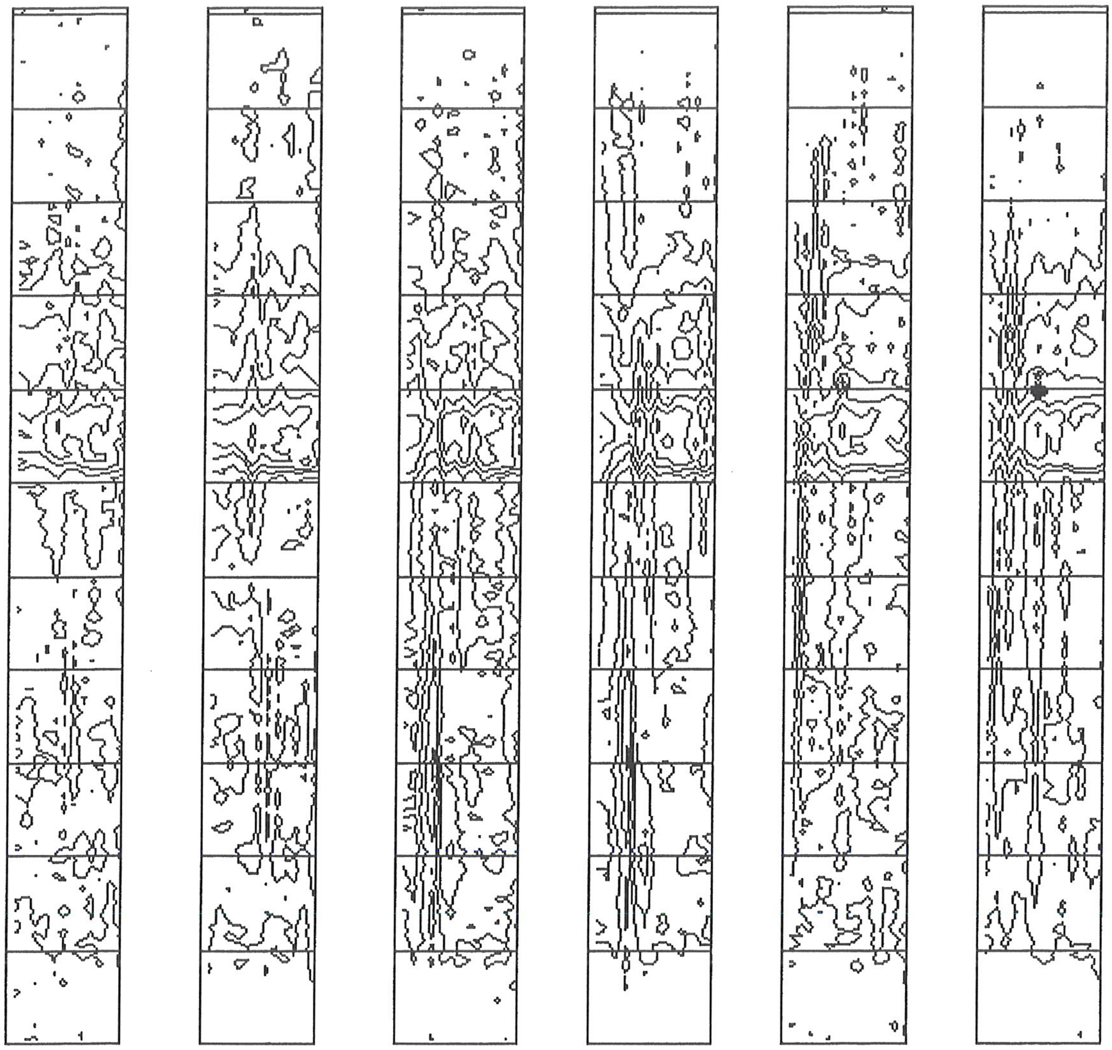


Fig. 7. Three repeated BB measurements of a 110' long scan across W5. CH1 (RHC) and CH2 (LHC) are shown separately illustrating the common influence of weather effects and differences in the system stability (see text).

Kurzbeschreibung 3.6 cm NEU

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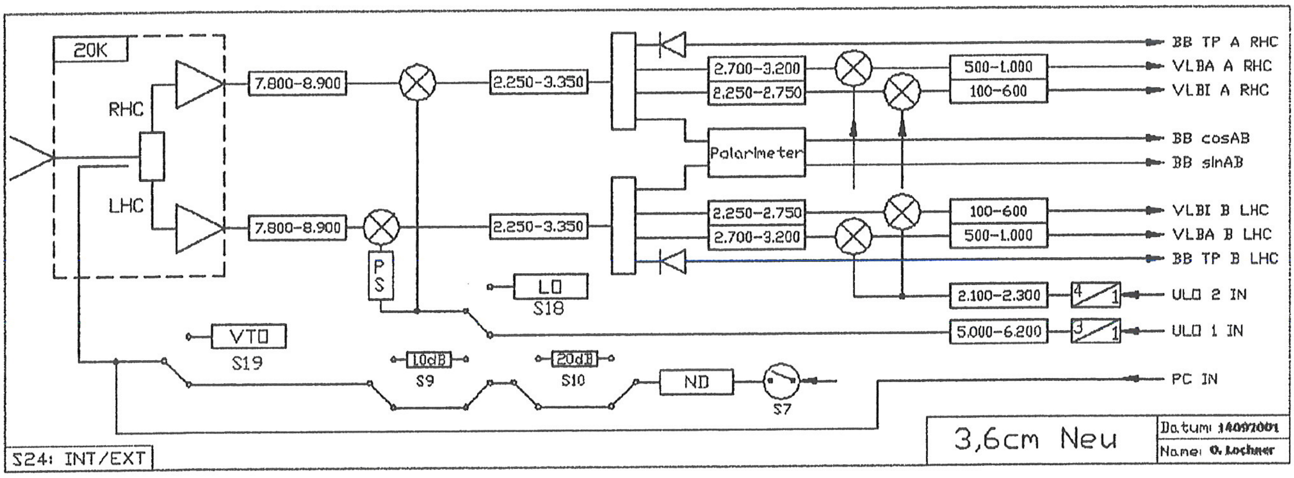
Dieses System ersetzt den 1988 eingebauten Empfänger. Der Einbauort wurde exakt beibehalten. Systemtemperatur, Bandpaßverhalten, Kalibrationsverhalten, Polarisationseigenschaften und Verstärkungsstabilität wurden wesentlich verbessert. Zusätzlich wurde ein Breitbandpolarimeter eingebaut.



1 Betriebsarten

VLBA: Summen LO 7800 MHz
VLBA: Summen LO 8100 MHz

VLBI: Summen LO 8260 MHz
VLBI : Summen LO 8110 MHz (Geodäsie)

Kontinuum: Breitband 1100 MHz Bandbreite
Kontinuum: Schmalband, 150 MHz Zwischenfrequenz, 7800 MHz - 8700 MHz

Pulsar: Breitband 1100 MHz Bandbreite
Pulsar: Schmalband, 150 MHz Zwischenfrequenz, 750 MHz Zwischenfrequenz

2 Frequenzaufbereitung:

Breitband Kontinuum

$$f_{sky} = 6 \times f_{ULO1} + IF_1$$

IF_1 = 2800 MHz
f_{ULO1} = 925 MHz

Schmalband 500 - 1000 MHz

$$f_{sky} = 6 \times f_{ULO1} + 4 \times f_{ULO2} + IF_2$$

IF_2 = 750 MHz
f_{ULO1} = 833 MHz - 1033 MHz
f_{ULO2} = 550 MHz

Schmalband 100 - 600 MHz

$$f_{sky} = 6 \times f_{ULO1} + 4 \times f_{ULO2} + IF_2$$

IF_2 = 150 MHz
f_{ULO1} = 891 MHz - 1042 MHz
f_{ULO2} = 575 MHz

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2 Technische Daten:

RF- Bereich	7800 - 8900 MHz
IF1-Bereich	2250 - 3350 MHz
IF2-Bereich VLBA	500 - 1000 MHz
IF2-Bereich VLBI	100 - 600 MHz
Breitband Kontinuum	einfache Überlagerung
Alle anderen Betriebsarten	doppelte Überlagerung
Seitenbandlage alle Betriebsarten	oberes Seitenband
Polarisation Empfänger Ausgang	
Breitband Kanal A	RHC
Breitband Kanal B	LHC
VLBA Kanal A	RHC
VLBA Kanal B	LHC
VLBI Kanal A	RHC
VLBI Kanal B	LHC
Hornanpassung	> 28 dB PRL
Isolation LHC I RCH	> 25 dB
Elliptizität 7800 - 8900 MHz	< 1.5 dB
Elliptizität 8200 - 8600 MHz	< 0.05 dB
Kalibration S9 = 0; S10 = 0	23,2 K
Kalibration S9 = 1; S10 = 0	2,5 K
Kalibration S9 = 0; S10 = 1	0,27 K
Kalibration S9 = 1; S10 = 1	29 mK
Kalibration Gleichlaufabweichung LHC I RHC	< 0.2 dB
Kalibration Frequenzgang 7800 - 8900 MHz	< 1 dB
Kalibration Welligkeit	< 0.4 dB
Systemtemperatur (100m RTE, Elv = 90°; keine Bewölkung, 1100 MHz Bandbreite)	**25 K**

14092001 Lochner

3C84 8.35GHz mit dB-Konturen (3db)