VLBA TEST MEMO NO. 53

VT006 — MkIV Test Results at the VLBA Correlator

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Contents

1 Introduction

The VLBI experiment designated VT006 was one in a series of experiments designed to test the use of various telescopes around the world in conjunction with the VLBA correlator. VT006 was the first of these experiments in which a significant number of telescopes recorded data with the MkIV VLBI system, including the new MkIV formatter. Leonid Gurvits and Huib van Langevelde acted as the principal investigators for the experiment. This document reports the results of VT006 as viewed from the perspective of the VLBA correlator.

2 Experiment Description

VT006 included a total of 8 participating telescopes observing at a wavelength of 6 cm.[1] The experiment took place on 14 December 1996, from 0600 to 1209 UTC. In the U.S., the telescopes were the VLBA antennas at Fort Davis (FD), Hancock (HN), and Saint Croix (SC). In Europe, the telescopes were the 25-m telescope at Onsala (ON), the 32-m telescope at Torun (TR), the 26-m Mark 2 telescope at Jodrell Bank (JB), a single 25-m telescope at Westerbork (WB), and the 100-m telescope at Effelsberg (EF). The three VLBA antennas and TR used VLBA Data Acquisition Systems, while the remaining four telescopes in Europe all used MkIV Data Acquisition Systems.

Although it was not intended, VT006 was accidentally carried out using two subarrays. A schedule update was sent to the VLBA, but inadvertently not transferred to the operations system, resulting in the three VLBA telescopes observing a different schedule than the five European telescopes. Although the different schedules used the same observing modes and many of the same sources, they also differed by 2 MHz in sky frequency. Coincidentally, EF accidentally observed with a 2-MHz error in sky frequency, so that its frequencies were identical to those at the VLBA telescopes. Therefore, we were left with two subarrays. Subarray 1 consisted of FD, HN, SC, and EF; these telescopes observed with similar schedules, but EF occasionally observed different sources from those observed with the VLBA antennas. Subarray 2 consisted of JB, ON, TR, and WB; these telescopes observed with identical schedules.

Five different observing modes were used, all with data rates of 128 Megabit/s, and all recorded on 16 tape tracks simultaneously, at a rate of 8 Megabit/s per track. These modes are listed in Table 1. The three telescopes in the U.S. recorded at high density on thin tapes, while the five telescopes in Europe recorded at low density on thick tapes.

Table 1: Observing Modes in VT006

Fan-out	Channels	Channel BW	Sample Bits	BBCs	Sideband	Comments
1:1	16	4 MHz	1	8	USB & LSB	
1:1	[illegible]	4 [illegible]Hz	2	8	USB	
1:2	8	8 MHz	1	8	USB	
1:4	2	16 MHz	2	2	USB	VSOP Mode
1:4	4	16 MHz	1	4	USB	

[1] A companion experiment at 1.3 cm, using a different set of antennas, was cancelled.

3 Data Delivery

A deadline of 1 week was set for the delivery of the required log files and GPS files. VLBA files arrive in real time, while the data files from Europe are placed on the regional server in Bologna. Since the experiment took place on 14 December, the deadline was 21 December. All logs from Europe arrived by 16 December, with the exception of the TR log, which arrived by 18 December. All GPS files were present by 18 December. One set of files that never arrived was from Medicina. That telescope did not participate, and failed to post a dummy log to communicate that fact.

A deadline of 2 weeks was set for receipt of tapes at the VLBA correlator in Socorro. All tapes arrived before that deadline. The dates on which the tapes were received at Socorro, and the method of shipment, are given in Table 2. NRAO has an automatic accounting system set up with Federal Express which can help expedite tape shipment from external observatories. WB is the only observatory participating in VT006 that shipped tapes using that system. In fact, the tapes from WB were inadvertently separated in shipment; after the first tape arrived alone, Federal Express was notified and quickly located the second tape, which arrived the next day. All tapes except those from TR arrived within five days of the experiment.

Table 2: Tape Arrival Dates in Socorro

Station	Arrival Date	Shipping Method
FD	17 December	FedEx, NRAO system
HN	18 December	FedEx, NRAO system
SC	17 December	FedEx, NRAO system
EF	18 December	UPS
JB	17 December	FedEx
ON	18 December	FedEx
TR	23 December	FedEx
WB	18, 19 December	FedEx, NRAO system

4 Results of Data Correlation

4.1 Description of Correlation

Data correlation was done on the VLBA correlator in Socorro. Only data in the time range between 0600 and 0930 were correlated, since this range (corresponding to the first of two thick tapes for stations in Europe) contained all five observing modes and had sufficient information to perform all required tests. All correlation was done with no preliminary clock searches, under the assumption that one purpose of the experiment was to test the methods of routine processing, in which accurate clocks should be derivable from the GPS files. For Subarray 1, a single correlation was sufficient. However, three different attempts at correlation were necessary for Subarray 2. In the first attempt, several station locations were incorrect. Recently, the responsibility for loading MkIV logs was transferred to VLBA Operations, and the mechanism for identifying the participating antennas at multiple-telescope observatories broke down when the responsibility for loading logs was transferred. In addition, VT006 contained a situation that had not been encountered previously, that of a single antenna observing at Westerbork. In the second attempt, fringes to ON were found in a delay sidelobe or were missing in some modes because the GPS file had a sign opposite to that of the VLBA convention, which was described in [1]. Finally, after the sign was reversed for the ON clock and clock rate, parts of the experiment were correlated for a third time. In this third correlation, only portions of 3 of the

5 observing modes were processed, which was sufficient to check the hypothesis that the *a priori* ON clock had previously had the wrong sign.

Correlation for Subarray 1, and the first two correlations for Subarray 2, were done with 2-second correlator integrations and 256 spectral points per channel. The third correlation for Subarray 2 was done with 1024 spectral points per channel, in order to prevent false fringes from being found in delay sidelobes. In this mode, only two channels can be correlated in a single pass, so only a fraction of the observed channels was processed.

4.2 Recording Quality

For the most part, the recording quality of the tapes was acceptable. The major exception is JB, where recording was very poor, and playback gave very low weights and missing tracks. This could not be fixed at the correlator, although attempts were made to read the data using several different playback drives. During some of the time ranges checked for fringes, there was no usable data from JB. This was later found to be caused by a hardware problem at JB.

4.3 Fringe-Fitting

Fringe-fitting on small sections of data was done in AIPS, using the program FRING. Typically, solution times of about 1 minute were used. Longer integrations often were not feasible because of the large number of spectral channels present in the data. The relatively short solution times were adequate to give good fringes once the correct station locations and clocks were used. No attempt was made to line up the IF channels; instead, fitting was done in each channel separately. Final fringe-fitting results discussed below were obtained for one of two sources, either 1803+784 or 3C 273.

Delays and delay rates found from the fringe-fitting are given in Table 3 for Subarray 1, and in Table 4 for Subarray 2. The fitted delays and rates have been averaged over the different IF channels. The tables contain results using FD and TR as reference antennas for their respective subarrays. In each case, the residual delays and rates are the residuals *after* the listed clock values from the GPS files have been applied as part of the correlator model.

The ON GPS clock value given in Table 4 is the value used as the *a priori* offset in the third round of correlation, and has a sign opposite to that supplied in the GPS file. Also note that the residual fringe rates relative to the reference antenna cluster near -11 mHz. Since the TR clock rate in the GPS file corresponded to a fringe rate of -5.4 mHz, it is probable that the TR GPS file also had a sign convention opposite to the VLBA convention. In fact, it seems likely that all stations in Subarray 2 had GPS clock files with sign conventions opposite to the VLBA convention (see page 8 of [2]).

Table 3: Fringe-Fitting Results for Subarray 1

Station	GPS (0800 UTC) (μsec)	Resid. Delay (μsec)	Total Clock (μsec)	Resid. Rate (mHz)	Comments
FD	+2.66	$\equiv 0.00$	+2.66	$\equiv 0$	Reference antenna
HN	-0.41	0.04	-0.37	0	
SC	+2.06	0.00	+2.06	0	
EF	+2.67	-2.42	+0.25	0	

Table 4: Fringe-Fitting Results for Subarray 2

Station	GPS (0800 UTC) (μsec)	Resid. Delay (μsec)	Total Clock (μsec)	Resid. Rate (mHz)	Comments
TR	−2.81	$\equiv 0.00$	−2.81	$\equiv 0$	Reference; GPS sign incorrect
JB	−0.58	+6.31	+5.73	−9	Sign of GPS file?
ON	+14.42	−6.97	+7.45	−11	GPS sign changed from file
WB	−0.51	−6.71	−7.22	−12	Sign of GPS file?

It is also of interest to compare the results found in Socorro with the results found at the Bonn correlator for an experiment using the MkIV EVN telescopes on the same day. Since EF was not in Subarray 2 for the experiment processed in Socorro, this comparison is restricted to JB, ON, and WB. Results from the Bonn correlator have been taken from [3], while results for the Socorro correlator are taken from Table 4, except with the signs of all the clocks reversed relative to the GPS files. The clock comparisons, with WB defined to be the reference antenna, are shown in Table 5. The difference between WB and ON is essentially identical for Socorro and Bonn (after taking the opposite sign convention of the two correlators into account), but there is a large clock difference between the two correlators for JB. This difference is currently unexplained.

Table 5: Comparison of Socorro and Bonn Clock Results

Station	Socorro Clock (μsec)	Socorro Rate (mHz)	Bonn Clock (μsec)	Bonn Rate (mHz)	Comments
WB	$\equiv 0.00$	$\equiv 0$	$\equiv 0.00$	$\equiv 0.0$	Reference antenna
JB	+12.88	+3	+1.51	−1.5	
ON	+14.67	+1	−14.70	−1.7	

4.4 Bandpass Plots

Bandpass shapes for all five different modes were checked by plotting both total power and cross-power using the AIPS Task POSSM. Total-power plots of the bandpasses are provided in Figures 1 through 6.[2] In general, the MkIV and VLBA bandpasses are designed to look different. The total-power plots show clearly that the MkIV and VLBA bandpasses look much more different at 8-MHz and 16-MHz channel bandwidths than at the narrower bandwidths. Specifically, the MkIV bandpasses begin a gradual downslope at roughly 6 MHz within each channel. For 16-MHz channel bandpasses, the total power near 14 MHz is typically only about 40% of the total power near 4 MHz.

In addition to the bandpass shapes, the phase-calibration amplitudes sometimes vary substantially across the bands, and there are a number of spikes in the bandpasses. Finally, in the single 1:2 fan-out mode that was observed, IF channel 5 shows a bizarre shape for all MkIV systems. This is seen at ON, WB, and EF (the recording from JB was not readable). The appearance is that of a 4-MHz low-pass filter inserted in the 8-MHz channel, although the MkIV logs clearly report 8-MHz widths for each channel.

Sample cross-power plots, after fringe-fitting and application of the fits, are shown in Figures 7 to 12. These plots only include two IF channels for Subarray 2, since the use of 1024 spectral points in the final correlation permitted the correlation of only two channels in a single correlator pass.

[2]Note that Effelsberg is denoted by "EB" in all plots.

5 Problems in VT006

This section briefly identifies the main problems that were discovered in VT006. Recommendations for addressing those problems are given in Section 6.

5.1 Communications and Socorro Operations

There were two areas in which operational communications between Europe and Socorro, or within Socorro, caused significant problems in VT006. The first is with the schedule changes that were made less than two weeks before the experiment. Several different groups or individuals in Socorro were notified that a new set of card files had been deposited on the appropriate computer in Socorro. However, each assumed that someone else would make sure the schedule was updated in the VLBA operations area, so the update was not done.

The second area of communication difficulties was in the identity of the telescopes taking part in the experiment. As discussed in Section 4.1, the transfer of MkIV log-loading to operations broke the previous mechanism for identifying which antennas had observed at multiple-telescope observatories. Therefore, the first correlation of Subarray 2 was made with incorrect positions for 3 of the 4 telescopes. In addition, as mentioned in Section 3, Medicina failed to post a dummy log that would have notified VLBA personnel that they had not observed.

5.2 Observing Schedule

EF accidentally observed with a sky frequency 2 MHz different from that commanded in the schedule. In this regard, it was fortuitous that the VLBA telescopes observed with an old schedule that also had the 2-MHz difference from the "final" schedule. The combination of these two problems actually permitted correlation of EF against the VLBA antennas for large portions of the observing run; otherwise, no cross-correlation information would have been available for EF.

5.3 Recording

Despite attempts to use several different playback drives, many of the tracks from the JB tape were unreadable. It was fortunate that enough data could be recovered to get any information about the performance of JB. Recent information indicates that this was caused by a hardware problem that was fixed the week after VT006.

5.4 Clocks

Most EVN stations (see [2]) appear to be using a sign convention in their GPS files that is opposite to the VLBA sign convention described in [1]. Although this information was apparently known in Europe, it was not communicated to the VLBA. Since ON had a large *a priori* clock offset that was applied with the wrong sign, fringes to ON were found initially only in the narrow channel bandwidths. In fact, the first ON fringes would not have been found at all if the initial correlation had used 128 or fewer spectral channels per IF

channel. The second correlation for Subarray 2 still was not sufficient, because the ON clock error remained even after the identities of the other observing telescopes had been corrected.

The other clock problem found was the large difference in the JB clock between the VLBA correlator and the Bonn correlator, for data taken on the same day. This is still unexplained.

5.5 Bandpasses

The *a priori* shape expected for the MkIV bandpasses in production versions of the Data Acquisition System was not known at the VLBA correlator; only data recorded with a prototype system had been processed previously. An investigation of the VLBA correlator software was made to attempt to identify bugs that might have resulted in the different bandpass shapes, but no such errors were found. It now seems likely that the MkIV bandpasses, particularly the 8- and 16-MHz channels, have quite different shapes from the VLBA bandpasses; this should be checked by means of local measurements.

A few of the IF channels showed strong spikes in their total-power spectra. Some of these spikes appeared to be caused by anomalously strong phase-calibration tones (see WB in Figure 2), while the origin of others is unknown (see ON in Figure 2). In general, EF seemed to be better-behaved than ON and WB, while it is difficult to characterize JB because of the poor recording.

In the mode with 1:2 fanout, all MkIV stations showed anomalous shapes in channel 5 (see Figures 3 and 4). This shape is not shared by the stations operating with VLBA systems. The most likely explanation appears to be that there is some problem with the MkIV system and that the filter bandwidth is incorrect.

6 Conclusions and Recommendations

VT006 was quite successful in the sense that it proved the capability of a number of European telescopes and the VLBA correlator to work together, so that we can say confidently that MkIV data can now be processed in Socorro. However, this success was achieved only with a substantial time investment by a number of people, and several re-correlations, due to a number of problems in the operational systems and a general lack of complete information transfer. The success could never have been achieved in a routine operations scenario. With that in mind, a number of recommendations can be made:

1. Operational procedures must be tightened up in Socorro to make certain that schedule updates and telescope identities are properly communicated and entered into the operational system. (This has already occurred to some degree.)
2. Some means should be developed for effective communication to Socorro of the identity of telescopes that participated in a experiment, from sites having multiple telescopes. (Comments buried in an FS9 log are not sufficient.)
3. All recorders in the field must be checked out regularly, particularly before long experiment sessions, so that the recording problems seen for JB are not common.
4. There should be a plan to change the conventions for GPS clock files in a coordinated fashion, in order to have all stations use the VLBA sign convention. A good target would be to have all stations conform to the VLBA convention before VT009, which is expected to take place in mid-February.

5. The clock offset for JB between the Bonn and Socorro correlators should be investigated and accounted for.
6. Bandpass plots of the MkIV systems at several observatories should be made in conjunction with the next test observation in the series (VT008), so that they can be compared to the results obtained at the VLBA correlator. Preferably, these plots would be faxed to Socorro or made available as PostScript files.
7. The anomalous shape of the MkIV bandpasses in IF channel 5 for the 1:2 fanout mode must be explained.
8. Anomalous phase-calibration strengths and other spikes in the MkIV systems should be explained and eliminated.

7 Acknowledgments

The VT006 experiment and correlation were collaborative efforts of a large number of individuals, both those in Europe who conducted the observations and supplied extra information to the author, and those in Socorro who participated in various aspects of the correlation and troubleshooting. Leonid Gurvits and Huib van Langevelde acted as the principal investigators for VT006. In Socorro, I would particularly like to thank Steve Blachman, Barry Clark, Mark Claussen, Phil Diamond, Ron Heald, Craig Lewis, Dave Medcalf, Peggy Perley, Jon Romney, and Steve Thompson. Elsewhere in the U.S. and in Europe, I acknowledge John Conway, Tony Foley, Dave Graham, Ed Himwich, and Dan Smythe.

References

[1] van Langevelde, H. 1996, "GPS Clocks in the EVN; Toward Blind Correlation," EVN document #65, version 2.01, 3 January 1996.

[2] Sanghera, H., Rioja, M., Aaron, S., Alef, W., & Graham, D. 1996, "3/96 — Calibration observations October 1996 Session," November 1996.

[3] Graham, D. 1997, e-mail message, 2 January 1997.

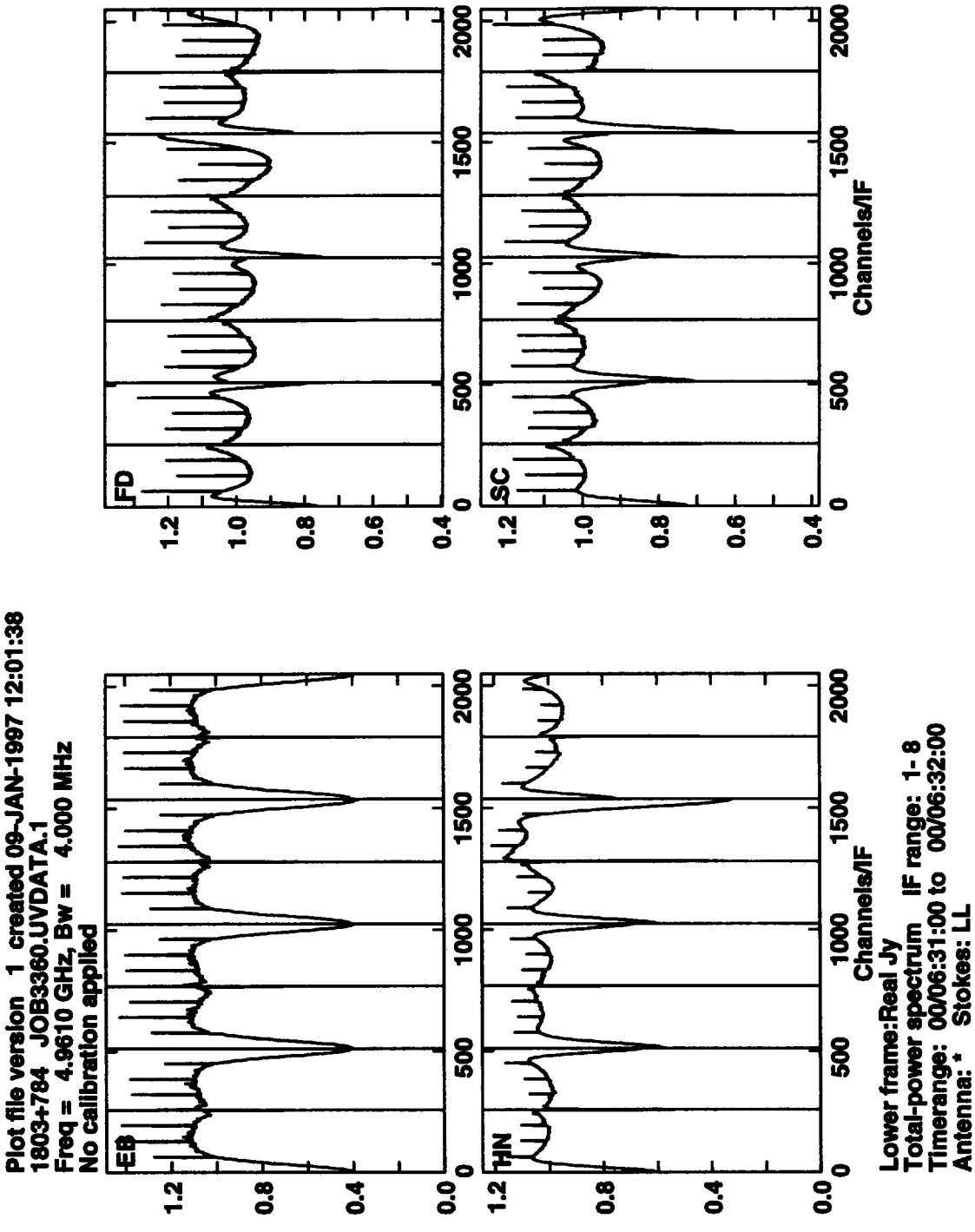

Figure 1: Total power plots for 1:1 mode, Subarray 1

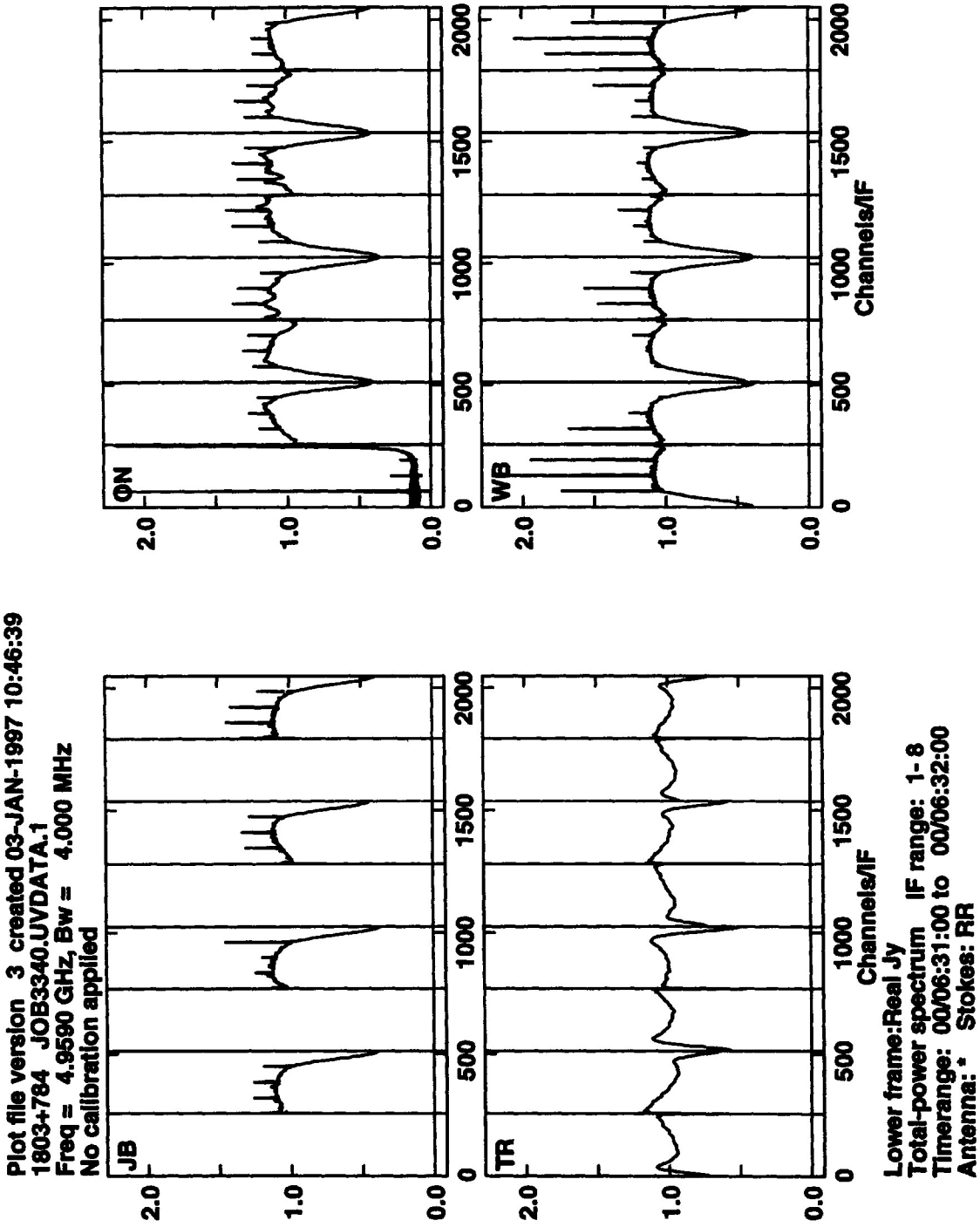

Figure 2: Total power plots for 1:1 mode, Subarray 2

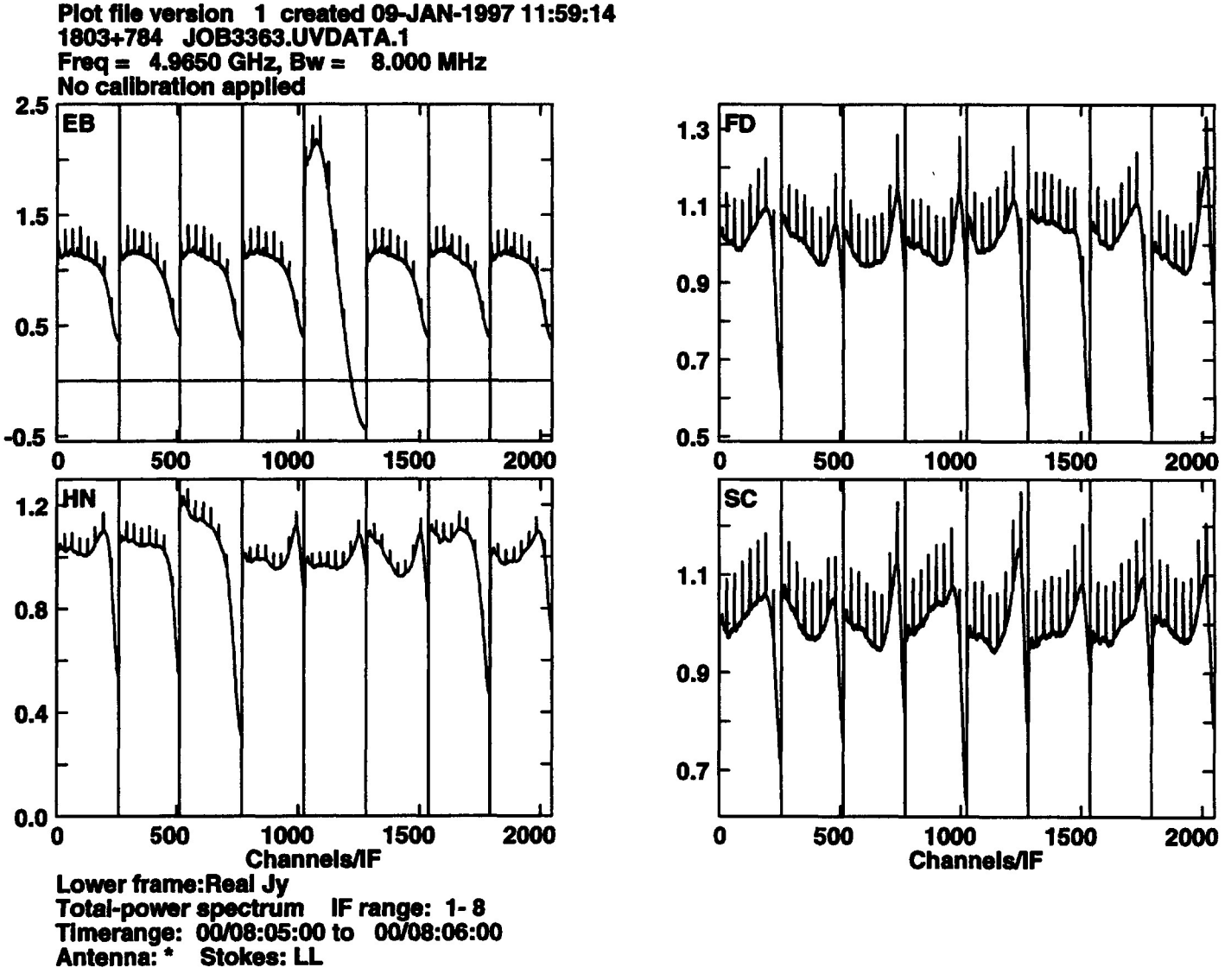

Figure 3: Total power plots for 1:2 mode, Subarray 1

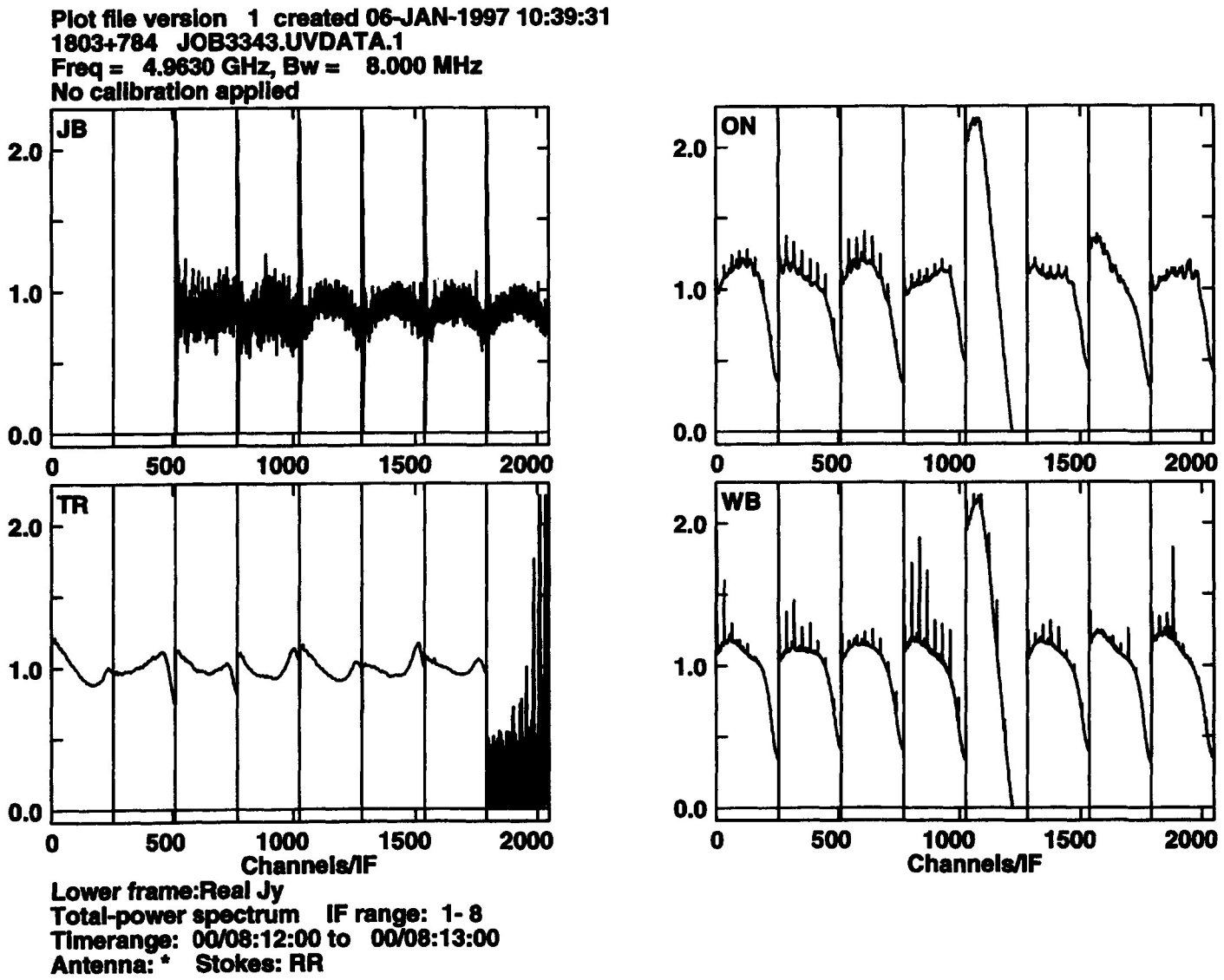

Figure 4: Total power plots for 1:2 mode, Subarray 2

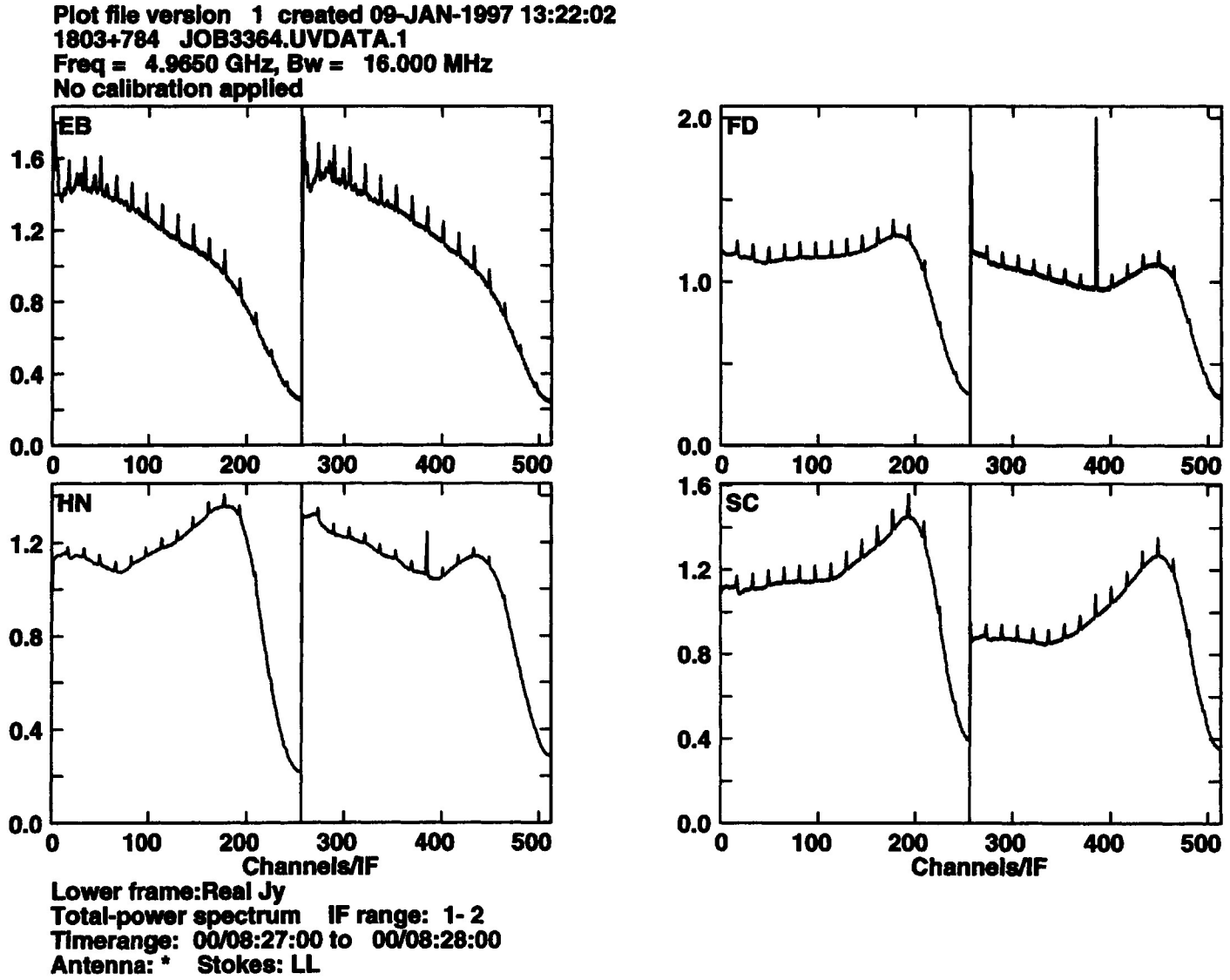

Figure 5: Total power plots for 1:4 mode, Subarray 1

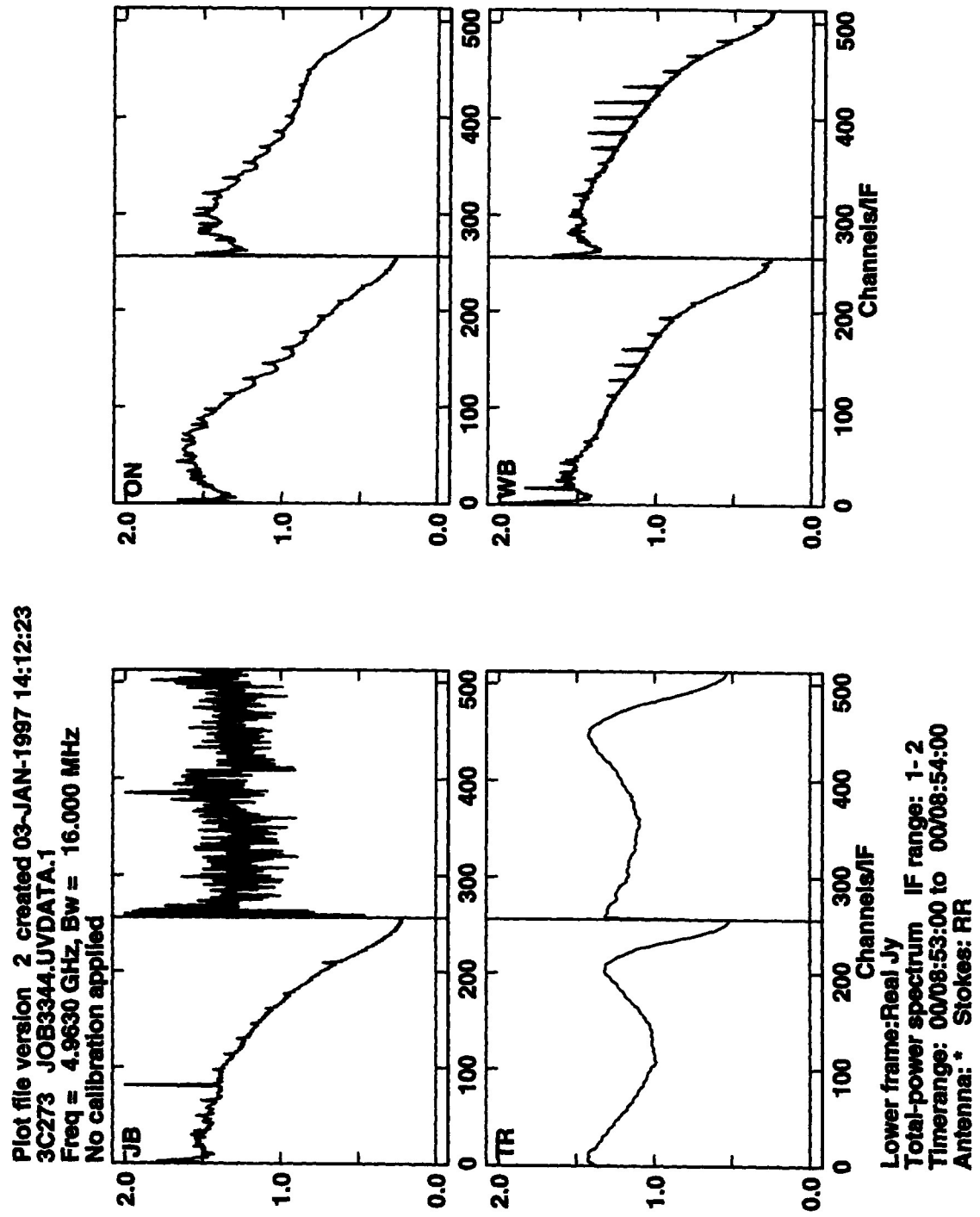

Figure 6: Total power plots for 1:4 mode, Subarray 2

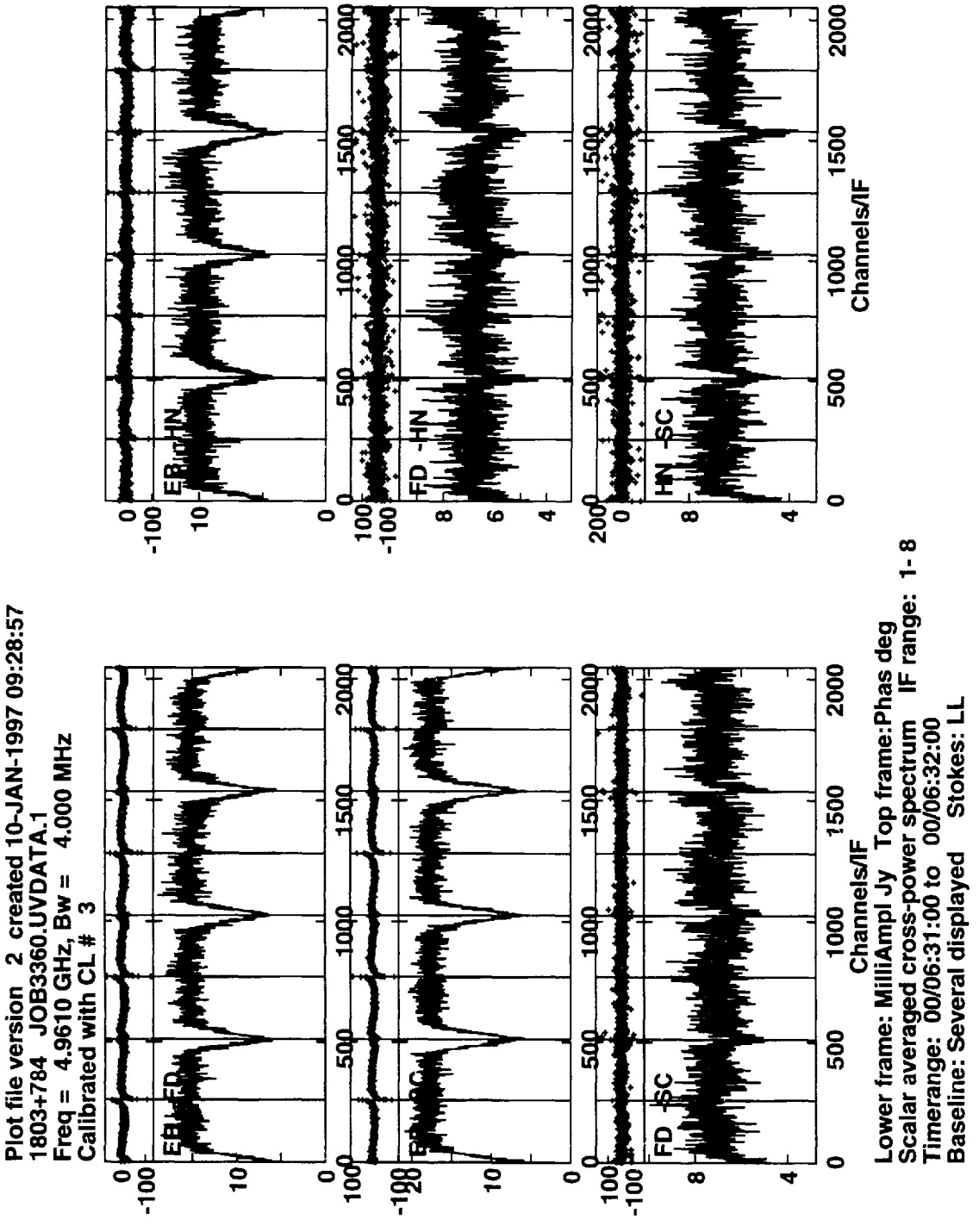

Figure 7: Cross-power plots for 1:1 mode, Subarray 1

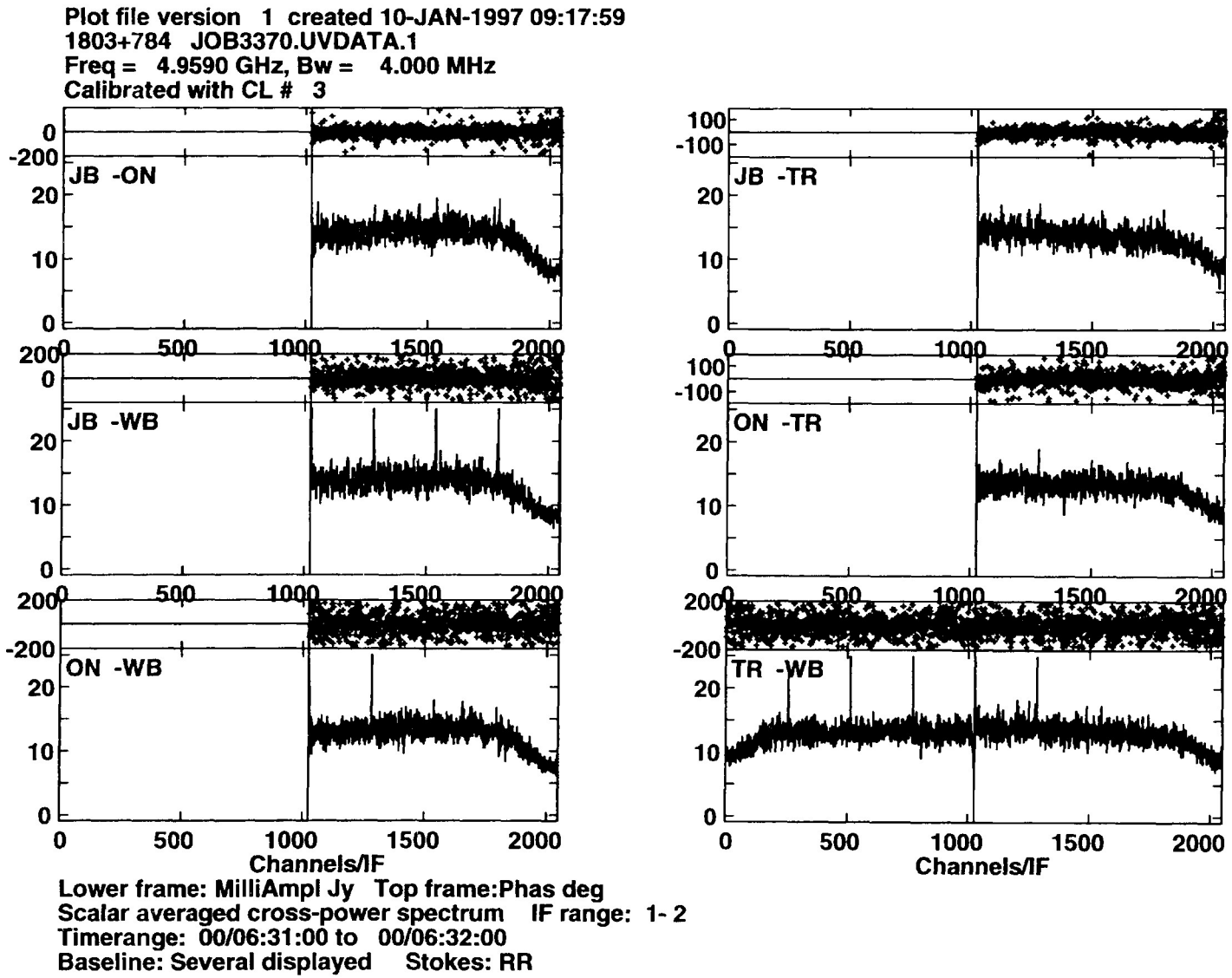

Figure 8: Cross-power plots for 1:1 mode, Subarray 2

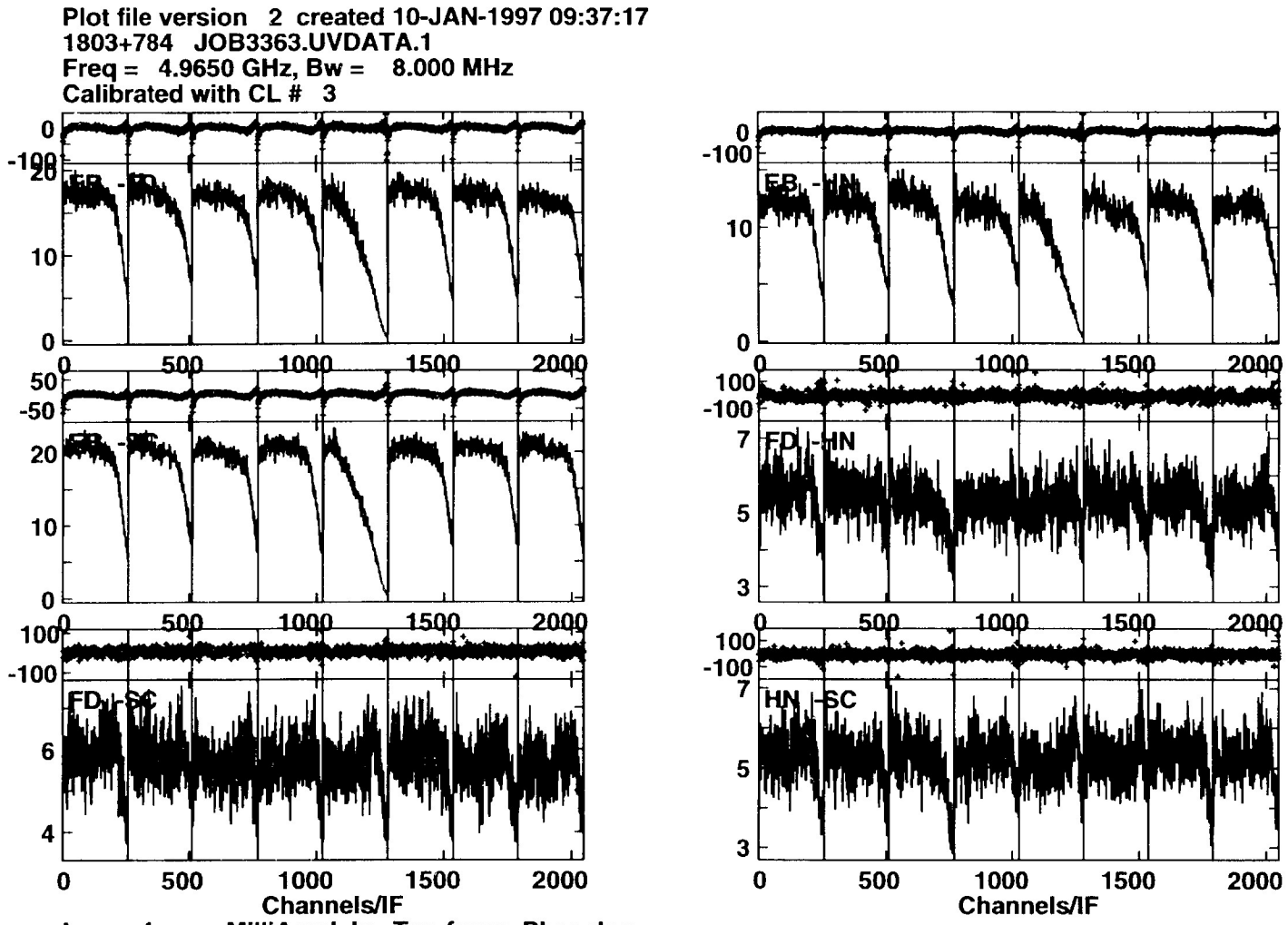

Figure 9: Cross-power plots for 1:2 mode, Subarray 1

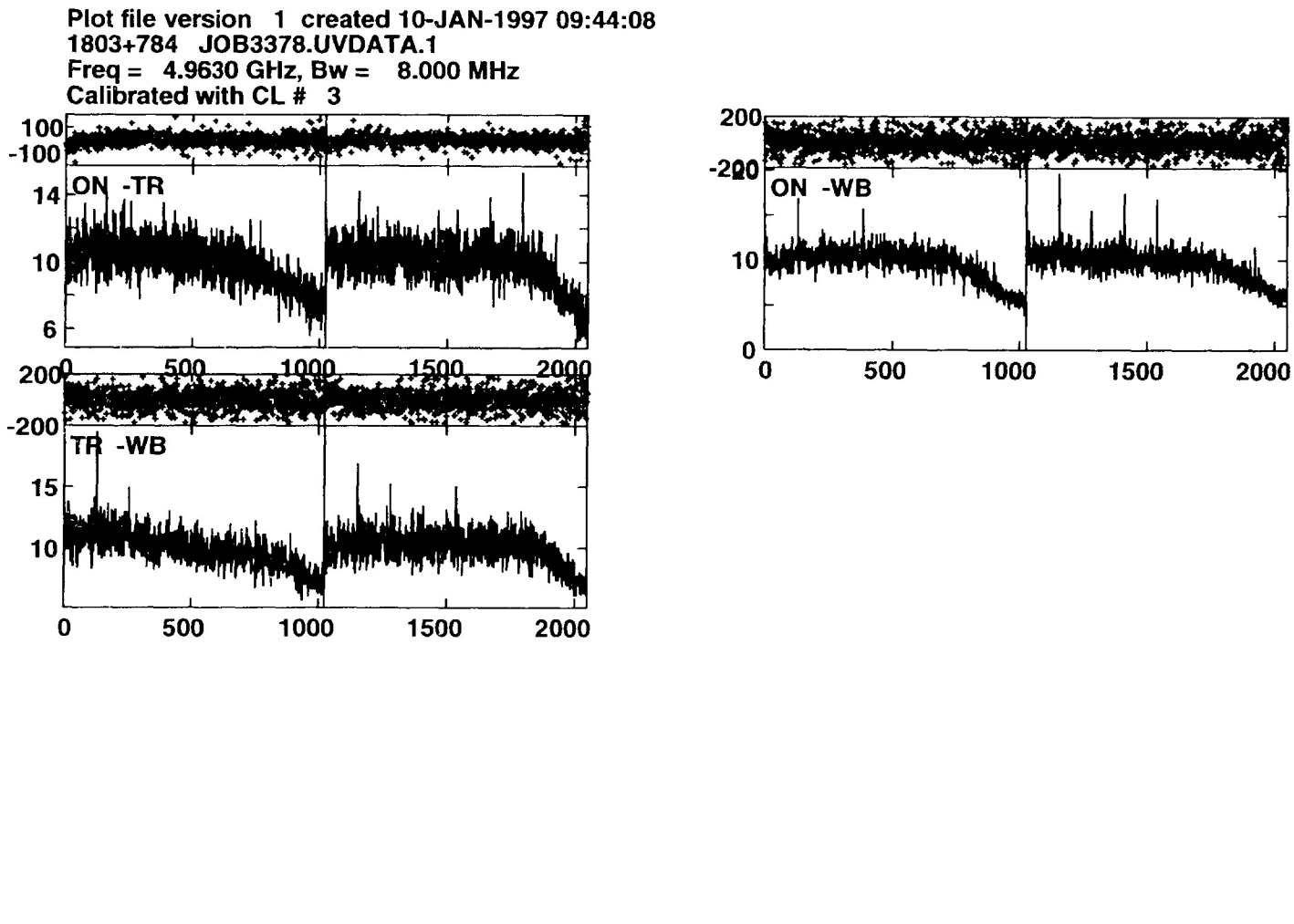

Figure 10: Cross-power plots for 1:2 mode. Subarray 2

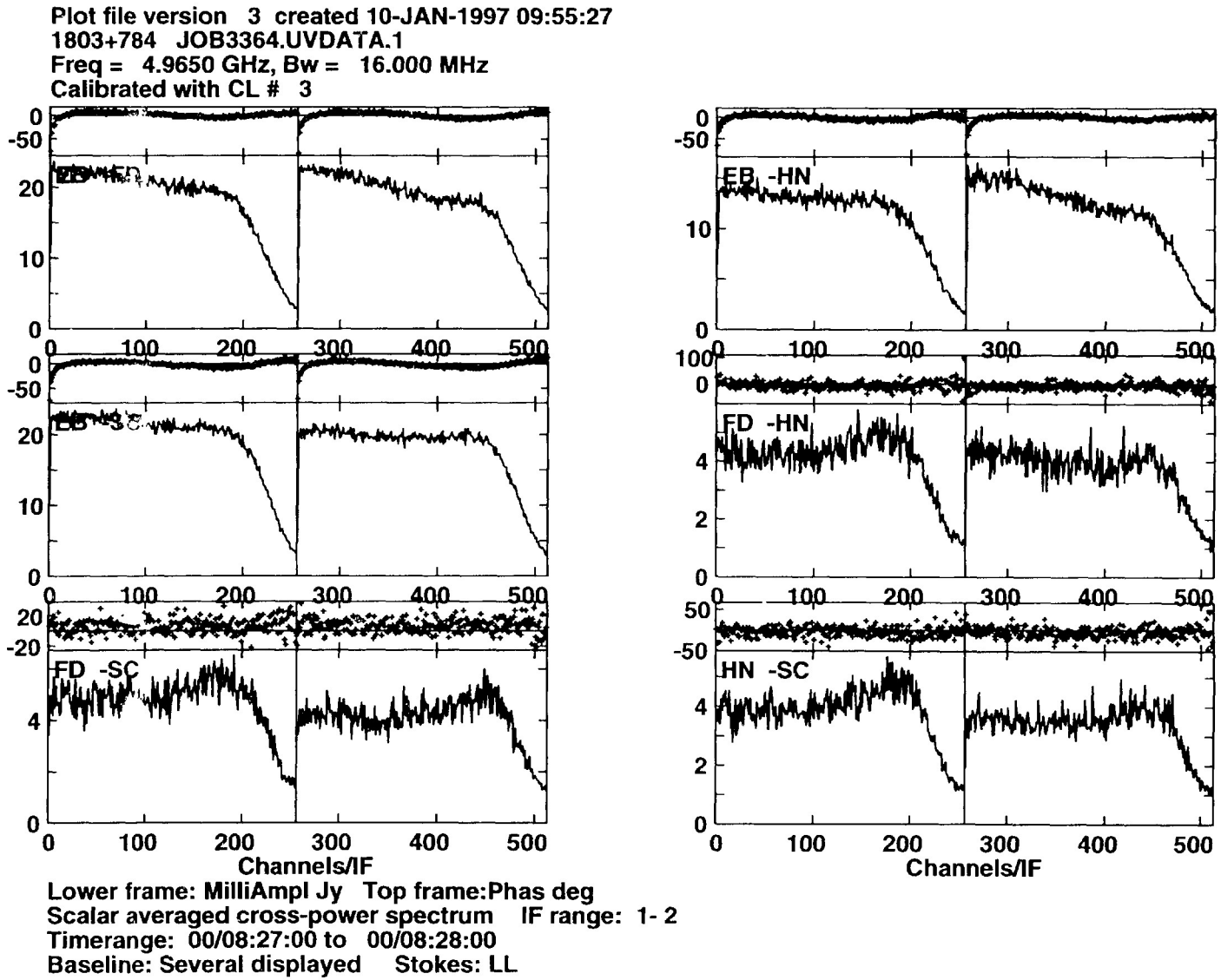

Figure 11: Cross-power plots for 1:4 mode. Subarray 1

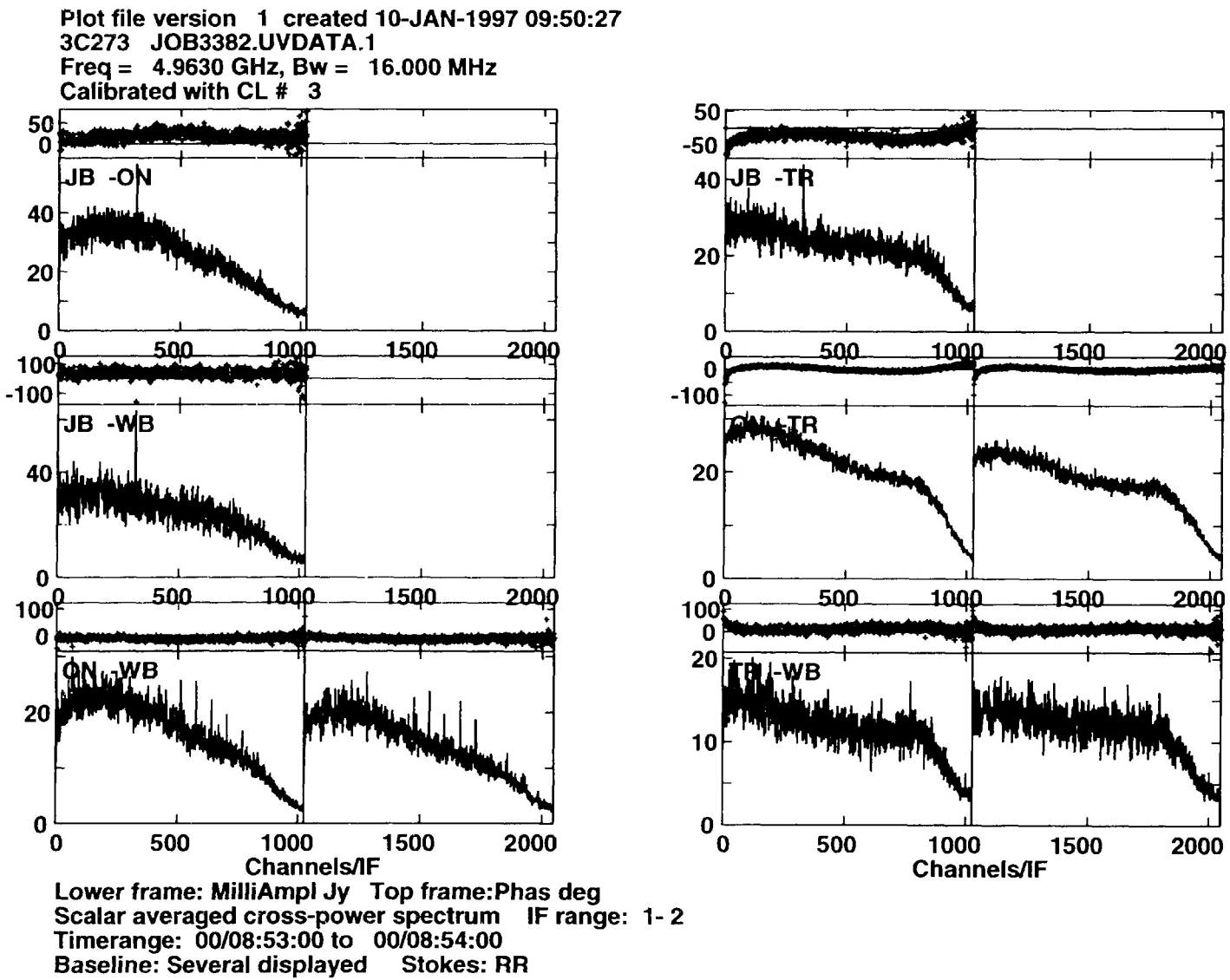

Figure 12: Cross-power plots for 1:4 mode. Subarray 2