VLBA TEST MEMO NO. 52

Mark 4 Format Test

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INTRODUCTION

An interoperability test between the Mark 4 formatter and the VLBA correlator was performed on 1996 March 8. This test had the dual purposes of confirming that the Mark 4 formatter could generate various fan-out and 2-bit modes correctly, and that the VLBA correlator could reproduce the Mark 4 tape frame. Central to the test was the prototype Mark 4 formatter, operating at the Westford (WF) antenna. Three VLBA stations, and two geodetic stations equipped with VLBA Data Acquisition Systems under control of the Mark 4 Field System, also participated.

Analysis of a subset of this array using the Mark 3 correlator at Haystack Observatory began immediately following the observations. Those results will be presented elsewhere.

This report describes the analysis performed subsequently on the VLBA correlator at the NRAO Array Operations Center. To simplify the process and obtain a rapid evaluation of the test, we correlated a different subset of the 6-station array, including only the Westford antenna and the three VLBA stations. The necessary tapes were received at the AOC on 96/4/10, and successfully correlated 96/4/17-20.

OBSERVATIONS

The test observation consisted of two repetitions of the following sequence of modes:

Table 1.
Modes Observed

Mode Name	Format	Chnls	Chnl BW[MHz]	Bits/ Smpl	Fan- Out	Tracks	Mbps/ Track
X1	M4/VLBA	8	8	1	1:4	32	4
X2	M4/VLBA	16	4	1	1:2	32	4
X3	M4/VLBA	4	16	2	1:4	32	8
X4	M4/VLBA	8	8	2	1:2	32	8
X5	M4/VLBA	4	8	2	1:4	32	4
X6	M4/VLBA	16	2	2	1:1	32	4
XB	Mark 3	16(14)	4	1	1:1	16	8

All modes were observed in right circular polarization near 8.4 MHz, in upper/ lower sideband channel pairs with a fixed 16-MHz spacing between the center frequencies of successive pairs, regardless of bandwidth. The format designation "M4/VLBA" means that Westford recorded in Mark 4 format, while the VLBA stations used VLBA format. Because the Mark 4 formatter was not yet ready to exercise the barrel-roll function, all stations observed without this feature.

Each mode was recorded in a single 390-second scan, followed by a 210-second pause, except that two such scans were recorded in mode XB (Mark 3 Mode B), to use all 32 tracks. The entire sequence was then repeated. Two headstack index positions were left blank between the first occurrences of modes X6 and XB, as an extra guard band to protect against possible confusion in the VLBA correlator's playback interface (Since the second occurrence of X1, immediately following the first pair of XBs, was correlated without incident, this precaution appears to have been unnecessary.)

The compact source 2145+067 was observed for the entire 2.6-hour session.

WEATHER

Weather impacted the analysis significantly. A heavy snowstorm began at the VLBA Hancock (HN) station before the run, and continued throughout. Although the Hancock system temperature was only slightly higher than normal at the beginning, it had more than doubled by the end of the session. The same storm appeared to affect the nearby Westford site as well, although not monotonically. The Westford system temperatures fell by about 15% during the first half of the run, and then rose again. To best accommodate these effects, only the earliest usable occurrence of each mode was selected for analysis: the first scans in modes X2 through XB, and the second mode X1 scan (the first having started too late at Westford), spanning a total interval of 1.2 hours.

(Originally only two VLBA stations had been scheduled; a third, added thanks to quick action by VLBA Operations when the snowstorm at Hancock was noticed, proved an invaluable asset in the analysis of this test.)

CORRELATION

Correlator control scripts ("jobs") were generated following our standard procedures, except that the Westford Field System log could not be used directly. Although we have already loaded Field System Version 9 logs into our database successfully, the Field System at Westford was in an intermediate state and its log did not include certain critical entries, specifically, the track assignments. Since the observing schedules used at Westford and the VLBA stations had been identical, we chose to generate the correlator jobs using the "shadowing" technique, assuming log entries for Westford identical to those logged at another (in this case, any other) station. The correct tape serial number and a few other parameters were then inserted manually. This scheme is known to be variably successful, but appeared to produce adequate performance in this case.

The VLBA's normal GPS clock values were used for the three VLBA stations. A Westford clock provided in a message accompanying the tape was used (with the well-known sign reversal) and found eventually to agree quite accurately with the VLBA's values.

Specially modified software had been prepared in advance for this test, but was not initially successful due to some minor misunderstandings among the engineers and programmers involved. A second iteration also failed, because we had not been aware that modulation of the data field, which (we understand) will be a normal feature of the Mark 4 format, had not been implemented yet. Our third attempt successfully yielded fringes. Most of the selected time interval was correlated on 96/4/17, a week after receiving the last tapes. The second X1 scan was not done until 4/20.

The special software modifications were built within the current development version, which at that time contained a bug which introduced phase glitches at each of the 2-minute wavefront model updates. To eliminate any effect of these glitches on the results, the data reduction procedure was restricted to a single 2-minute time interval for each mode, as described below.

Please note that the VLBA correlator cannot accept Mark 4 format at present for ANY routine correlation. The special-purpose software used for this test has been dismantled, so that other new features can be developed. With the insights gained from this test, it should be relatively straightforward to implement Mark 4 format for routine processing once the necessary infrastructure has been established in the VLBA database, job control scripts, and internal tables. We anticipate that this capability will be available by the time the first production Mark 4 formatters are put in service at the end of this summer.

REDUCTION

The correlated data were loaded into AIPS without incident. The relevant options were selected to enable proper normalization, and subsequent correction for decorrelation due to residual delay errors. Fringe fits were performed, on the last complete interval between even 2-minute UTC points, i.e., x4:00 - x6:00, to avoid corruption of the fit by the wavefront model glitches. The fit results were applied to flatten the bandpass phase characteristic and to stop the residual phase rotation. Inspection of plots showing these phase dependencies verified that the model glitches described above had left no significant overall phase rotation. The plots are appended to this report.

The fringe fit solutions for Westford exhibited significantly larger variations in residual delay among the modes (and, to a lesser degree, among baseband channels) than did the results from the VLBA stations. And as had been expected from the comments accompanying the Westford tape, some scans yielded corrupted signals in the two channels from VC3.

To avoid these problem channels, and to obtain a commensurate set of results, amplitudes were averaged over the entire passbands of the first -- or only -- four channels, and over the last complete interval between even 2-minute UTC points, i.e., x4:00 - x6:00. These results formed the basis for subsequent analysis.

At this point, the bandpass amplitude characteristic was examined as well. All appeared quite normal. There was no indication of the pronounced central dip or other passband distortions which we have come to associate with scrambled track assignments (or out-of-phase barrel rolls, something not relevant in this case). The 16-MHz filters at Westford exhibited rather rounded shoulders, something possibly of interest but also not relevant to this test.

ANALYSIS

Although the results to this point had been sufficient to declare success already, we attempted to determine whether the amplitudes measured on the the six baselines in each mode were consistent. This effort was limited by the severe effects of weather at the two closely-spaced stations in the Northeast, but inclusion of both the North Liberty and Fort Davis VLBA stations allowed useful conclusions to be drawn.

In the following table, the five baselines involving HN and/or WF are normalized to the amplitude in each mode on the FD-NL baseline, the only one not affected by weather.

Table 2.
Amplitudes Relative to FD-NL

Mode	Time	FD-HN / FD-NL	FD-NL / FD-NL	FD-WF / FD-NL	HN-NL / FD-NL	HN-WF / FD-NL	NL-WF / FD-NL
X2	18:14-16	0.37	1	0.26	0.35	0.106	0.26
X3	18:24-26	0.32	1	0.27	0.32	0.101	0.27
X4	18:34-36	0.28	1	0.29	0.29	0.093	0.30
X5	18:44-46	0.29	1	0.36	0.28	0.109	0.36
X6	18:54-56	0.23	1	0.43	0.23	0.110	0.43
XB	19:04-06	0.23	1	0.42	0.23	0.106	0.41
X1	19:24-26	0.21	1	0.43	0.20	0.101	0.41

The modes are listed in chronological order of the observing scans used, and showing the two-minute time intervals in which the amplitudes were measured. The reduction in sensitivity at HN, relative to the two other VLBA stations, is striking, and the similarity of variations on the two (FD,NL)-HN baselines, and on the two (FD,NL)-WF baselines, is apparent. The latter trends are as would be expected from the oppositely-varying system temperatures at HN and WF, respectively; the negligible variation on the short HN-WF baseline presumably is a fortuitous combination of these effects.

As a final step, various closure amplitudes are tabulated in the next table:

Table 3.
Closure Amplitudes

	FD-HN * NL-WF / FD-NL * HN-WF	FD-NL * HN-WF / FD-WF * HN-NL	FD-WF * HN-NL / FD-NL * HN-WF	FD-HN * NL-WF / FD-WF * HN-NL
X1	0.85	1.18	0.84	1.00
X2	0.91	1.15	0.87	1.04
X3	0.86	1.17	0.85	1.01
X4	0.91	1.10	0.91	1.00
X5	0.94	1.07	0.93	1.00
X6	0.90	1.11	0.90	1.00
XB	0.91	1.10	0.91	1.01

In this case, the modes are listed in the normal sequence of Table 1, since no time variations are apparent. (All these closure amplitudes necessarily include each of the northeastern stations in each part of the fraction.) Although the weather effects have been cancelled out, some evidence of extended structure in 2145+067 appears, with the closure amplitudes averaging about 11% below or 13% above unity, respectively, when the very short HN-WF baseline is in the denominator or the numerator of the fraction. The single closure amplitude not involving this short baseline has a mean and standard deviation of 1.0086 +/- 0.0136.

CONCLUSION

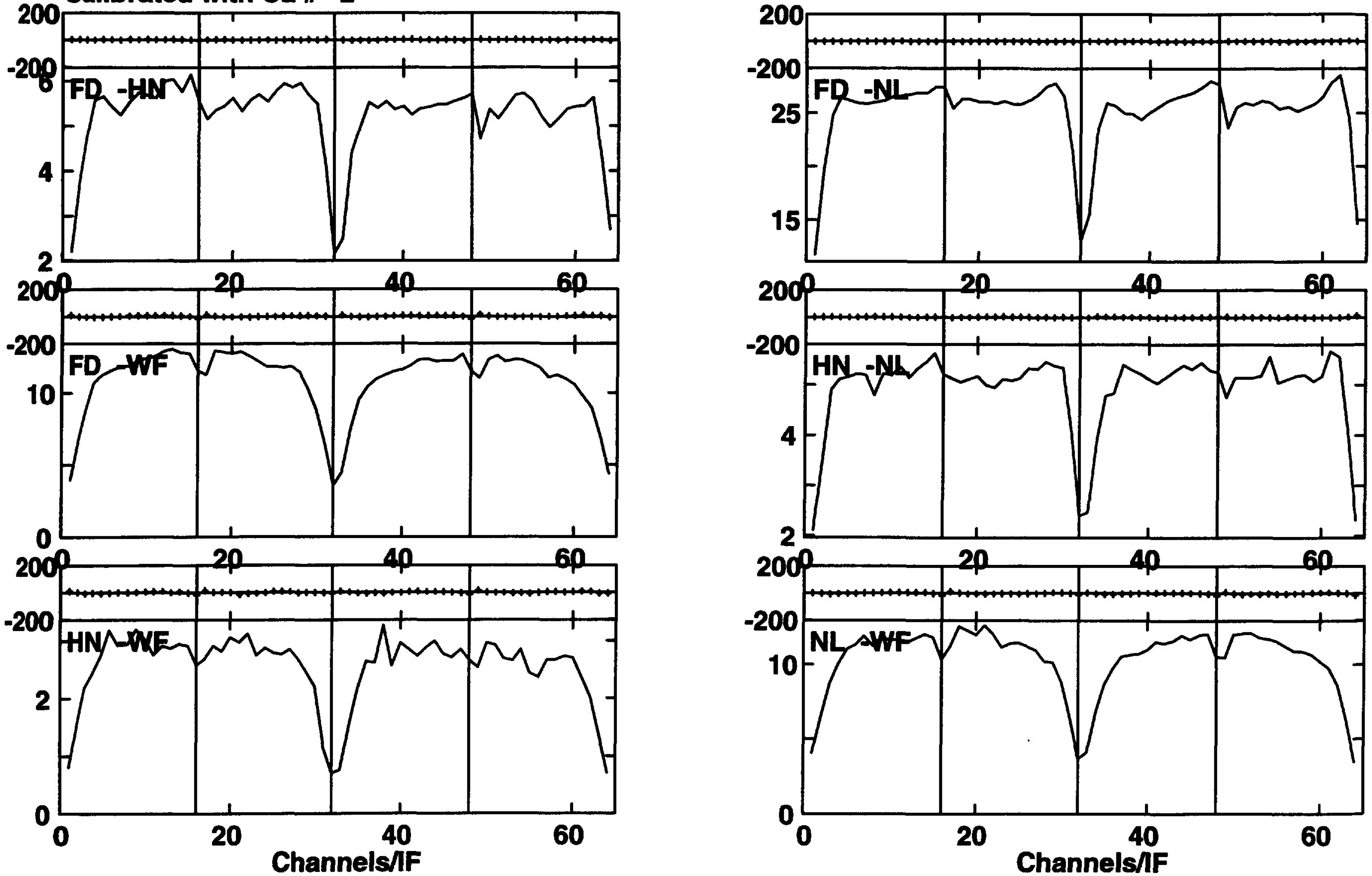
Both the prototype Mark 4 formatter and the VLBA correlator performed exactly as specified for the modes tested. Although weakened by the variations due to the snowstorm in the Northeast, and by apparent extended structure around 2145+067, the available results appear entirely sufficient to establish this conclusion.

ACKNOWLEDGEMENTS

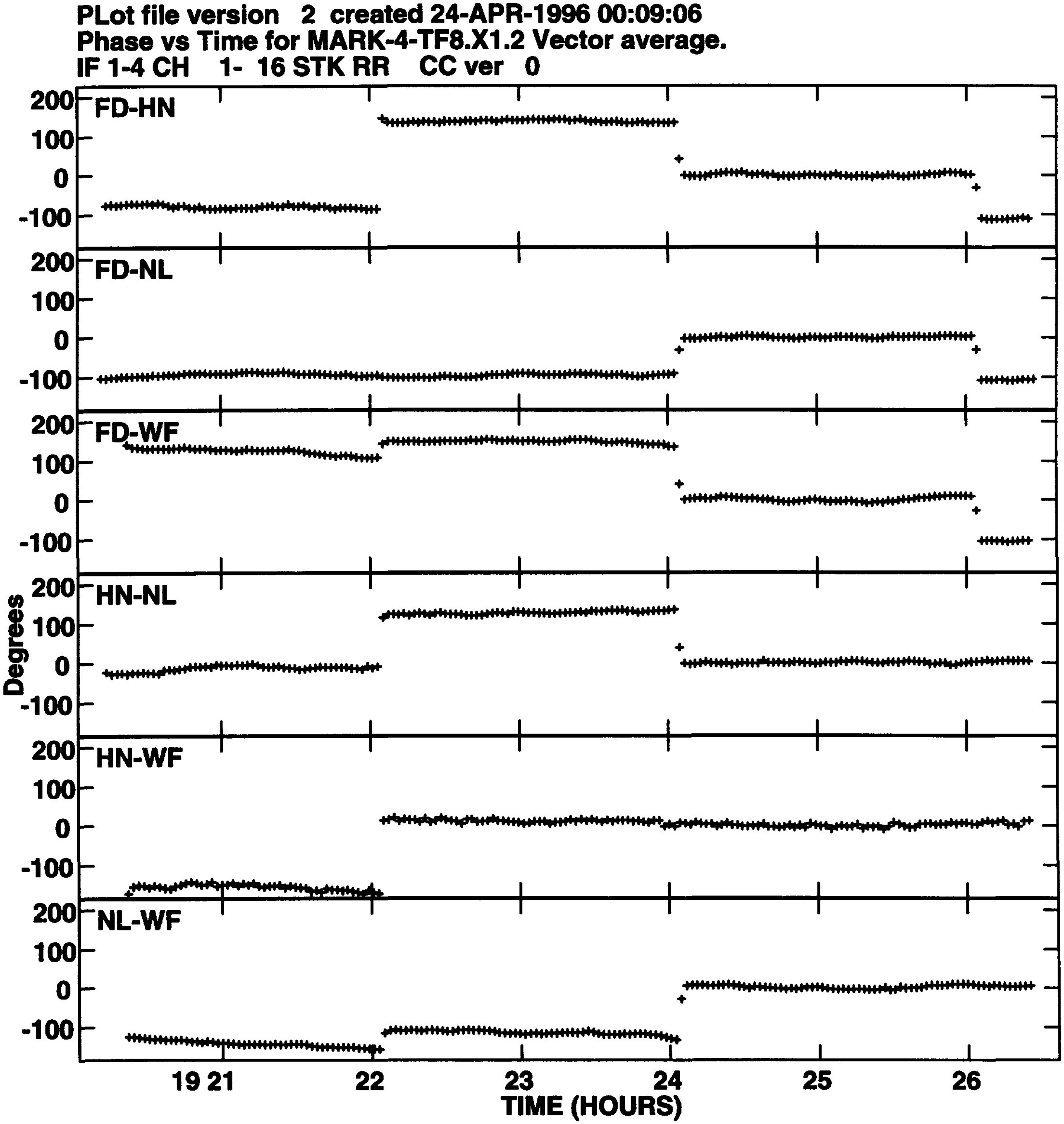
A large number of participants should be credited with bringing this result out as quickly as has been possible. Alan Whitney and I first discussed a much simpler version of this test last September. Scheduling of the observations was started by Craig Walker, and completed by Nancy Vandenberg, Dan Smythe, and myself. Mike Titus and Dan Smythe provided valuable information about the recording at Westford. The third station was added to the VLBA subarray on the initiative of Peggy Perley. Steve Blachman and Chuck Broadwell prepared the specialized VLBA correlator software. The undersigned organized the test correlations at the AOC and undertook the post-correlation reduction and analysis.

J. D. Romney

Plot file version 1 created 21-APR-1996 18:32:46
MARK-4-TF8.X1.2
Freq = 8.3930 GHz, Bw = 8.000 MHz
Calibrated with CL # 2



Lower frame: MilliAmpl Jy Top frame:Phas deg
Vector averaged cross-power spectrum IF range: 1- 4
Timerange: 00/19:24:00 to 00/19:26:00
Baseline: Several displayed Stokes: RR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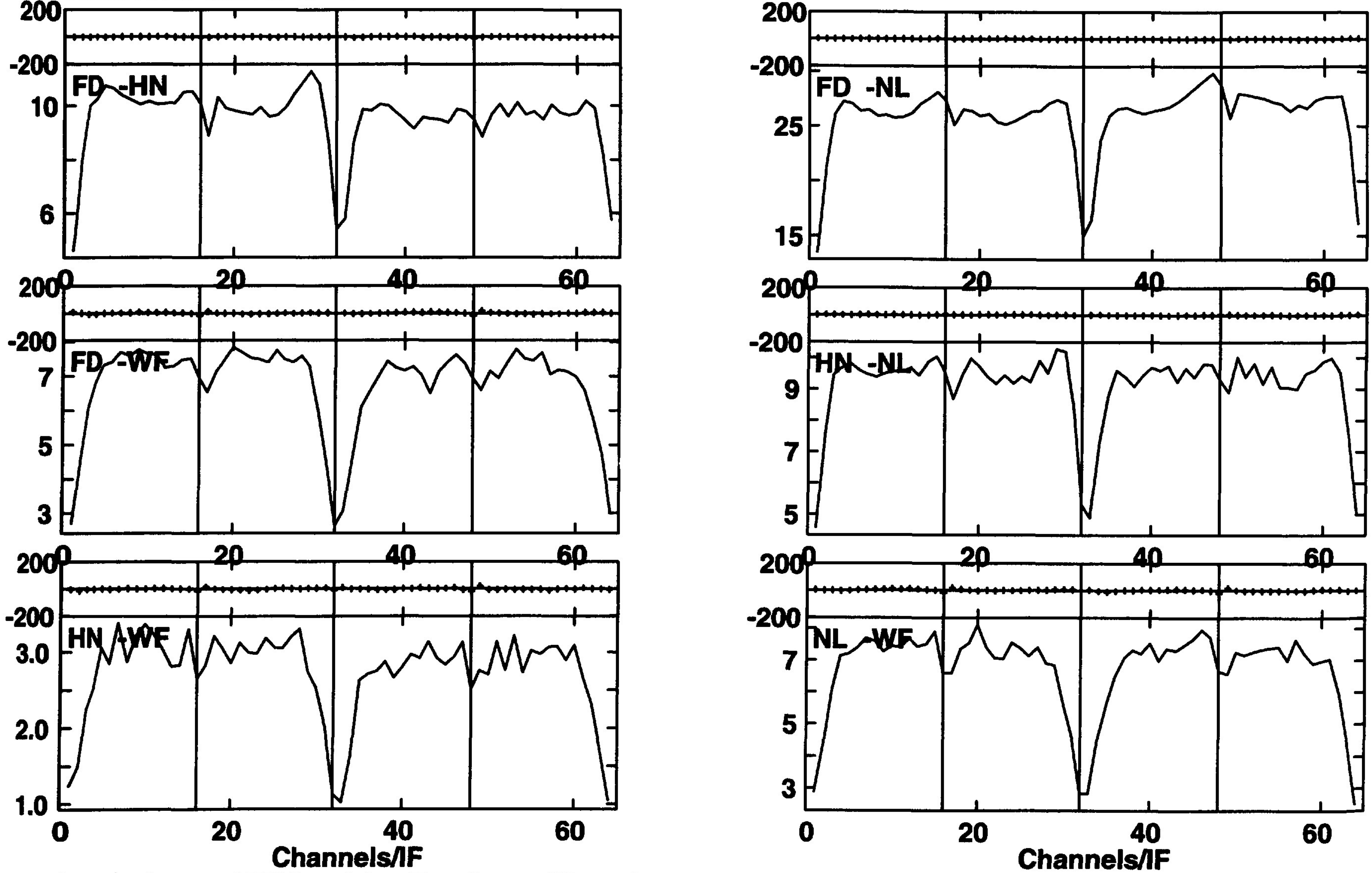
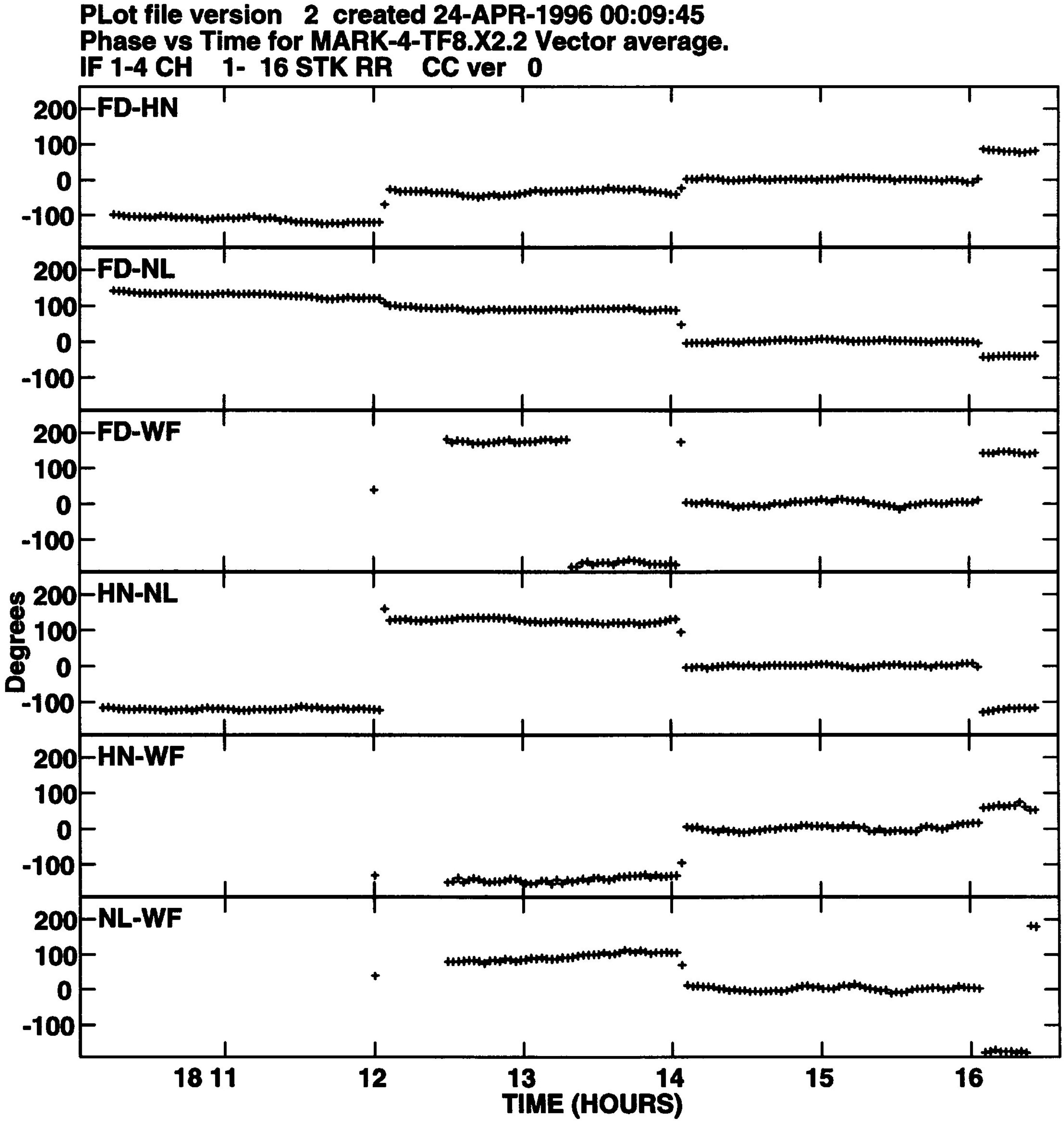
Phase vs Time for MARK-4-TF8.X1.2 Vector average.
IF 1-4 CH 1- 16 STK RR CC ver 0
FD-HN
FD-NL
FD-WF
HN-NL
HN-WF
NL-WF
Degrees
200
100
0
-100
19 21
22
23
24
25
26
TIME (HOURS)

Plot file version 1 created 21-APR-1996 18:32:53
MARK-4-TF8.X2.2
Freq = 8.3970 GHz, Bw = 4.000 MHz
Calibrated with CL # 2



Lower frame: MilliAmpl Jy Top frame:Phas deg
Vector averaged cross-power spectrum IF range: 1- 4
Timerange: 00/18:14:00 to 00/18:16:00
Baseline: Several displayed Stokes: RR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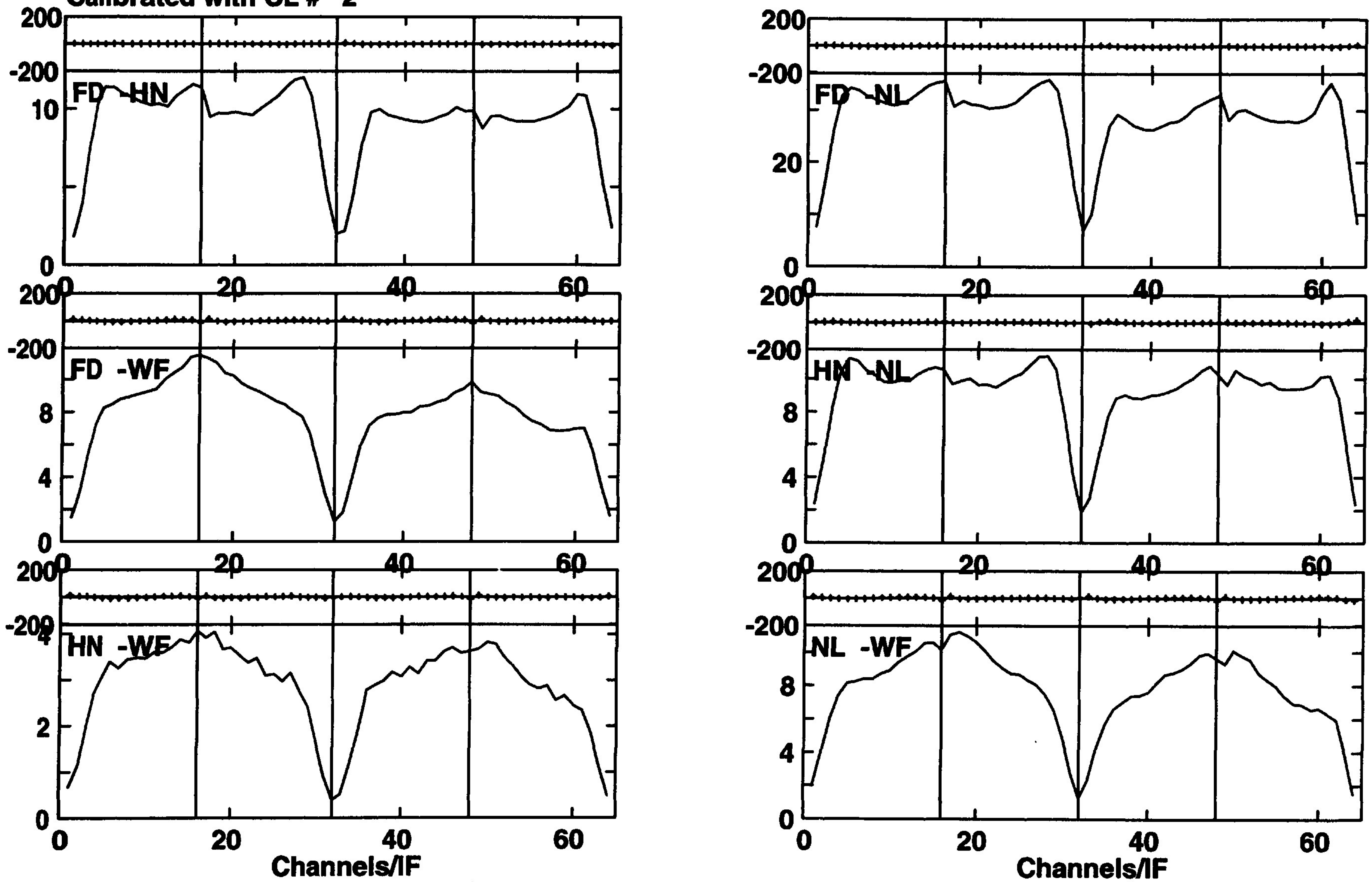
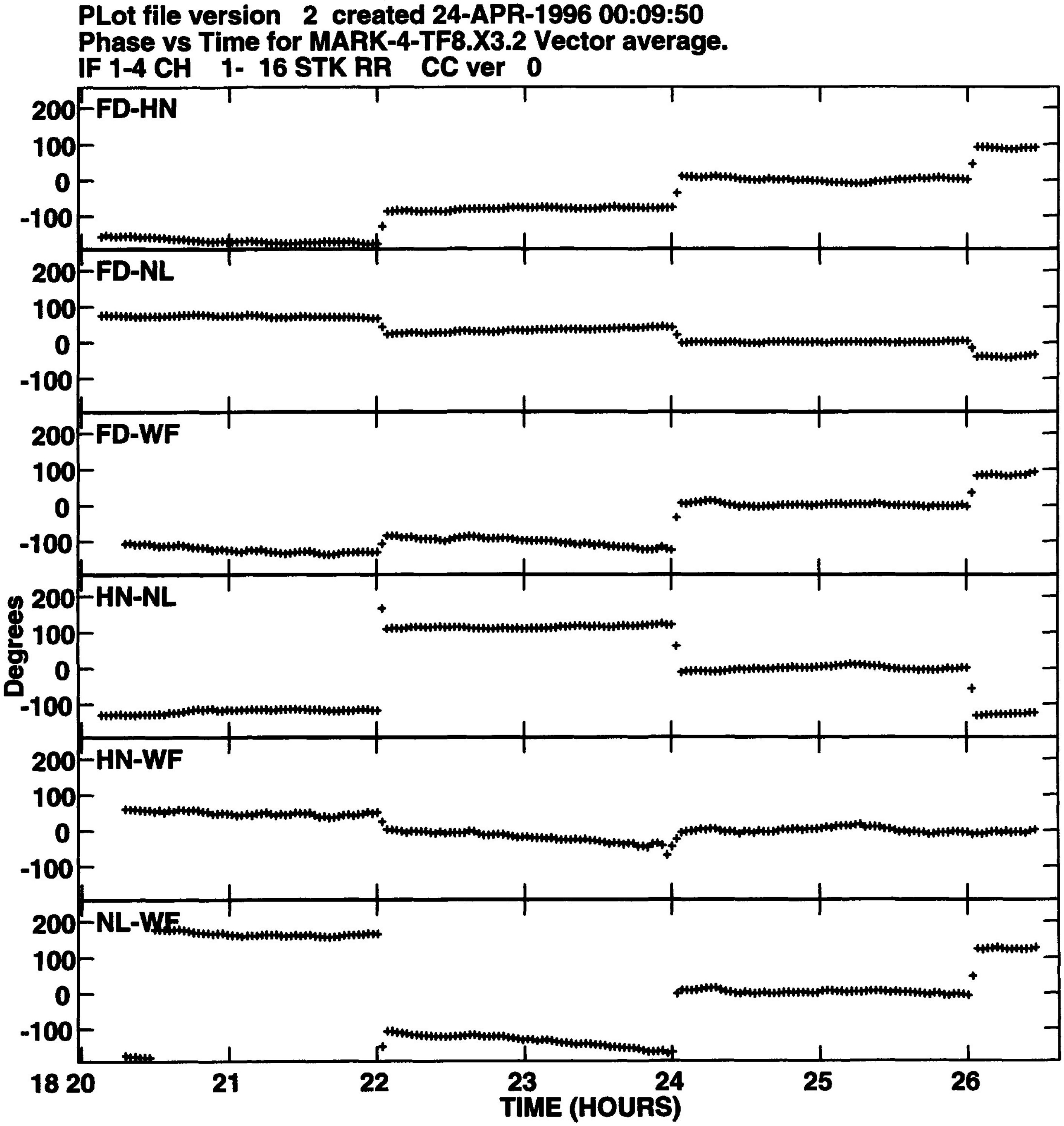
Phase vs Time for MARK-4-TF8.X2.2 Vector average.
IF 1-4 CH 1- 16 STK RR CC ver 0
FD-HN
FD-NL
FD-WF
HN-NL
HN-WF
NL-WF
Degrees
200
100
0
-100
18 11
12
13
14
15
16
TIME (HOURS)

Plot file version 1 created 21-APR-1996 18:33:00
MARK-4-TF8.X3.2
Freq = 8.3850 GHz, Bw = 16.000 MHz
Calibrated with CL # 2



Lower frame: MilliAmpl Jy Top frame:Phas deg
Vector averaged cross-power spectrum IF range: 1- 4
Timerange: 00/18:24:00 to 00/18:26:00
Baseline: Several displayed Stokes: RR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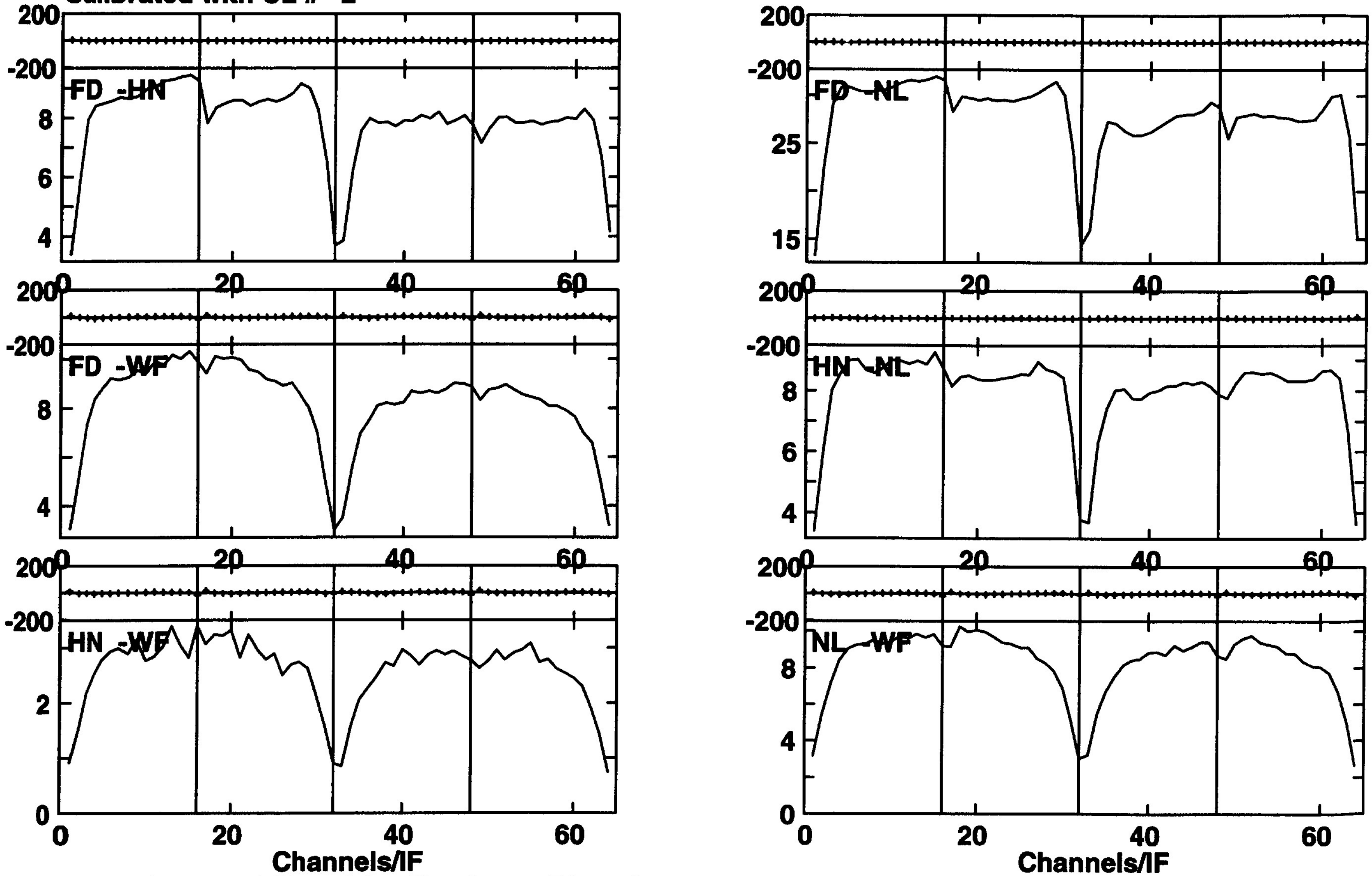
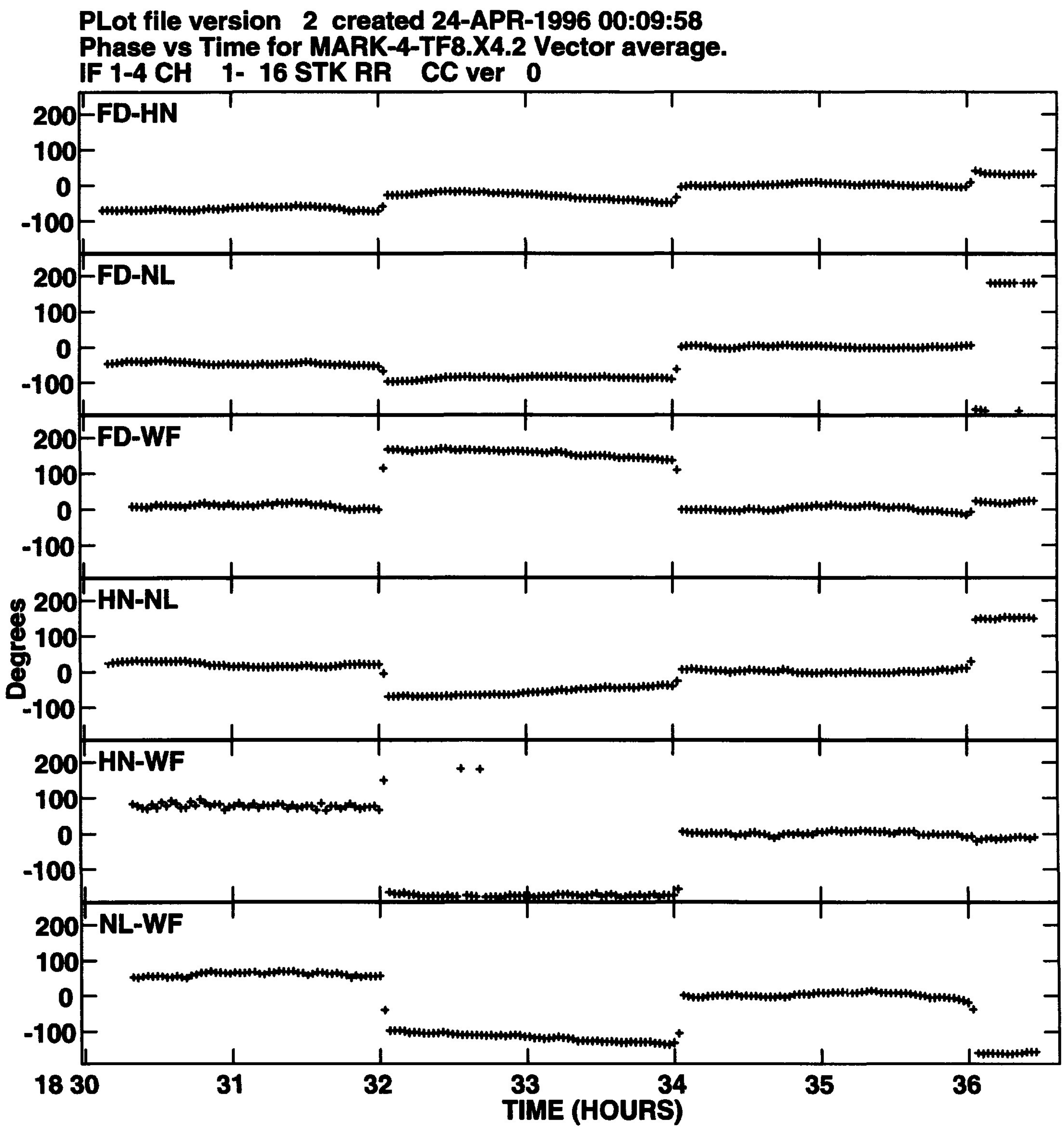
Phase vs Time for MARK-4-TF8.X3.2 Vector average.
IF 1-4 CH 1- 16 STK RR CC ver 0
FD-HN
FD-NL
FD-WF
HN-NL
HN-WF
NL-WF
Degrees
200
100
0
-100
18 20
21
22
23
24
25
26
TIME (HOURS)

Plot file version 1 created 21-APR-1996 18:33:18
MARK-4-TF8.X4.2
Freq = 8.3930 GHz, Bw = 8.000 MHz
Calibrated with CL # 2

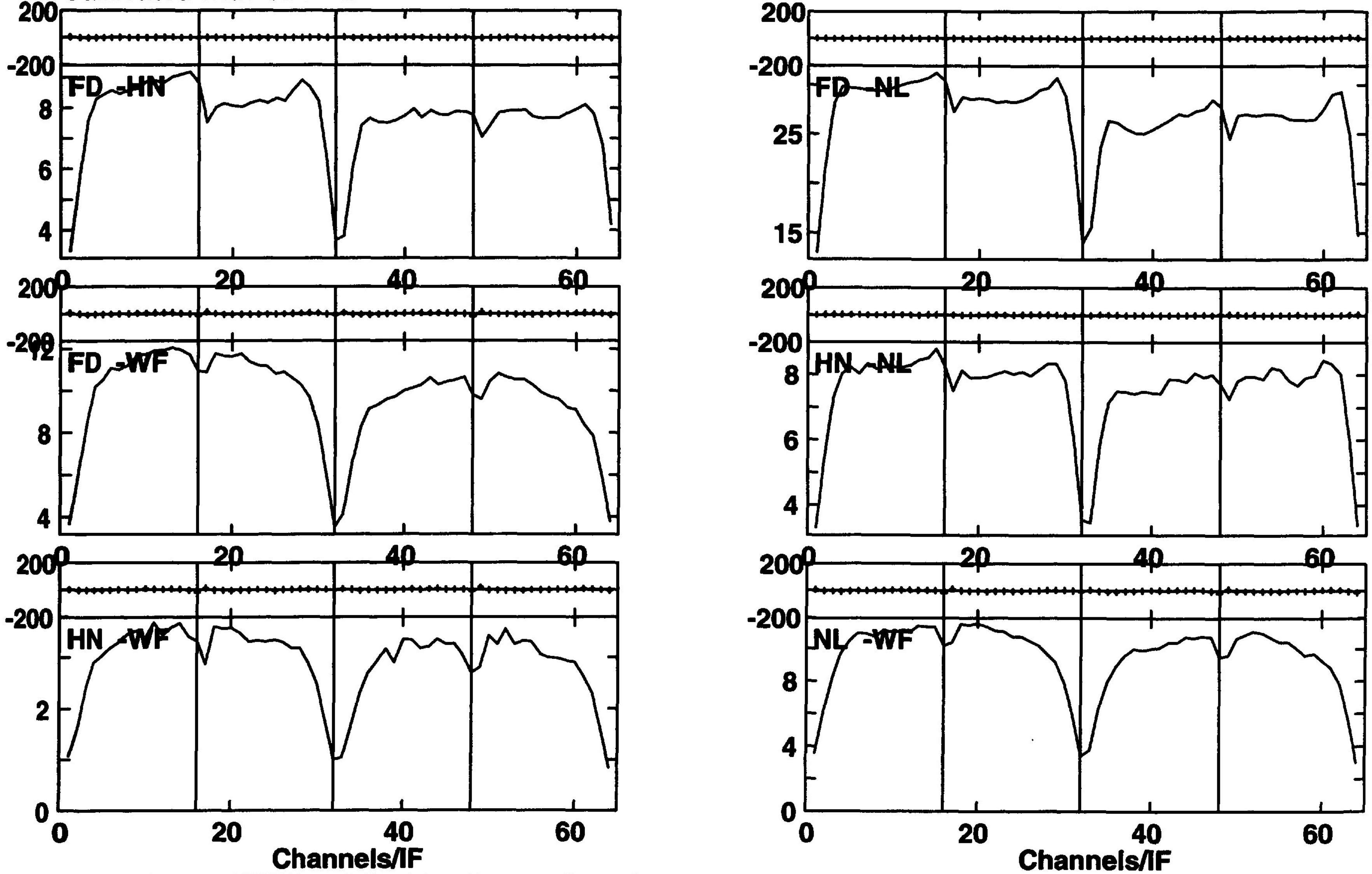


Lower frame: MilliAmpl Jy Top frame:Phas deg
Vector averaged cross-power spectrum IF range: 1- 4
Timerange: 00/18:34:00 to 00/18:36:00
Baseline: Several displayed Stokes: RR

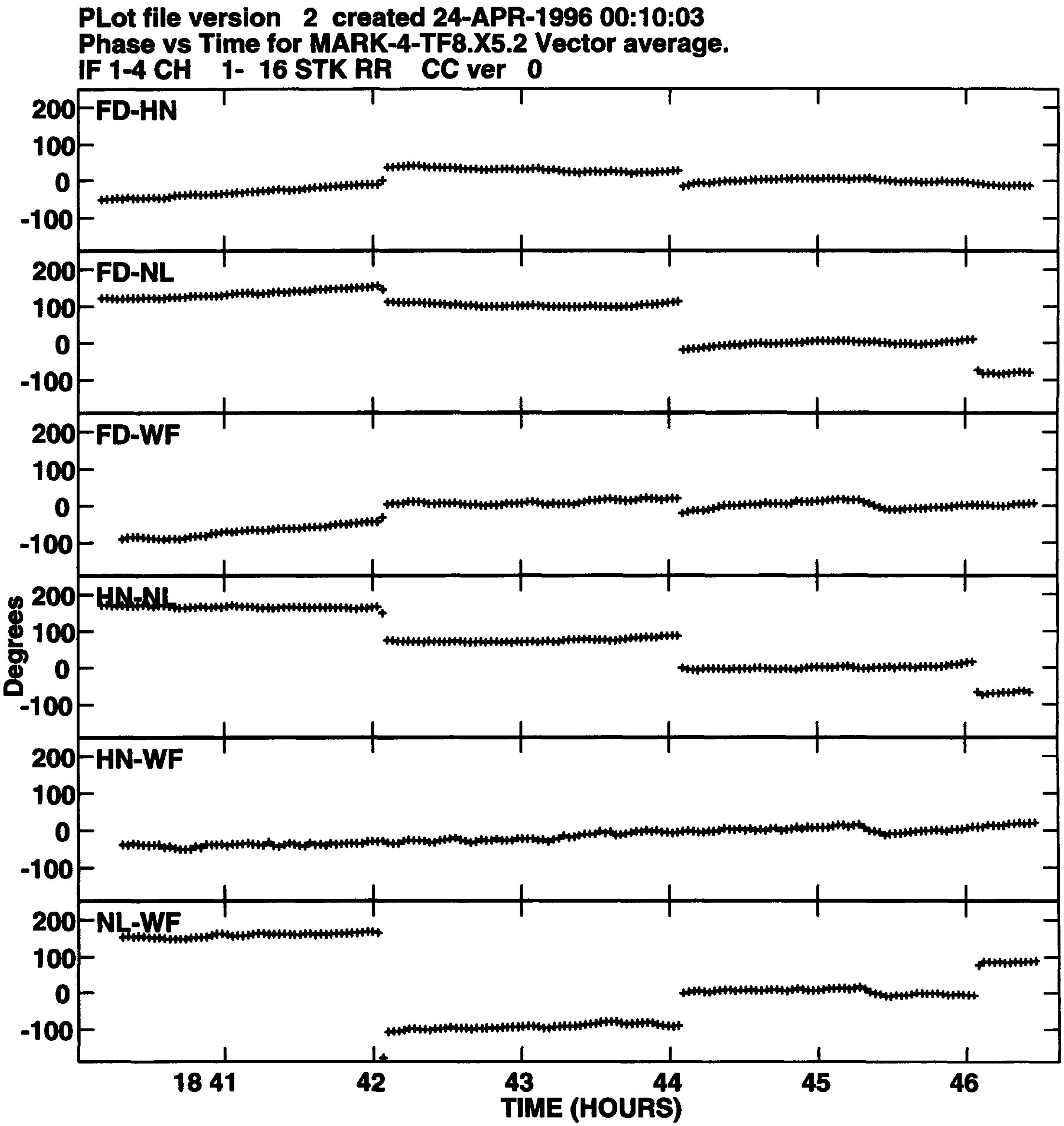


PLot file version 2 created 24-APR-1996 00:09:58
Phase vs Time for MARK-4-TF8.X4.2 Vector average.
IF 1-4 CH 1- 16 STK RR CC ver 0
FD-HN
FD-NL
FD-WF
HN-NL
HN-WF
NL-WF
Degrees
200
100
0
-100
18 30
31
32
33
34
35
36
TIME (HOURS)

Plot file version 1 created 21-APR-1996 18:33:35
MARK-4-TF8.X5.2
Freq = 8.3930 GHz, Bw = 8.000 MHz
Calibrated with CL # 2



Lower frame: MilliAmpl Jy Top frame:Phas deg
Vector averaged cross-power spectrum IF range: 1- 4
Timerange: 00/18:44:00 to 00/18:46:00
Baseline: Several displayed Stokes: RR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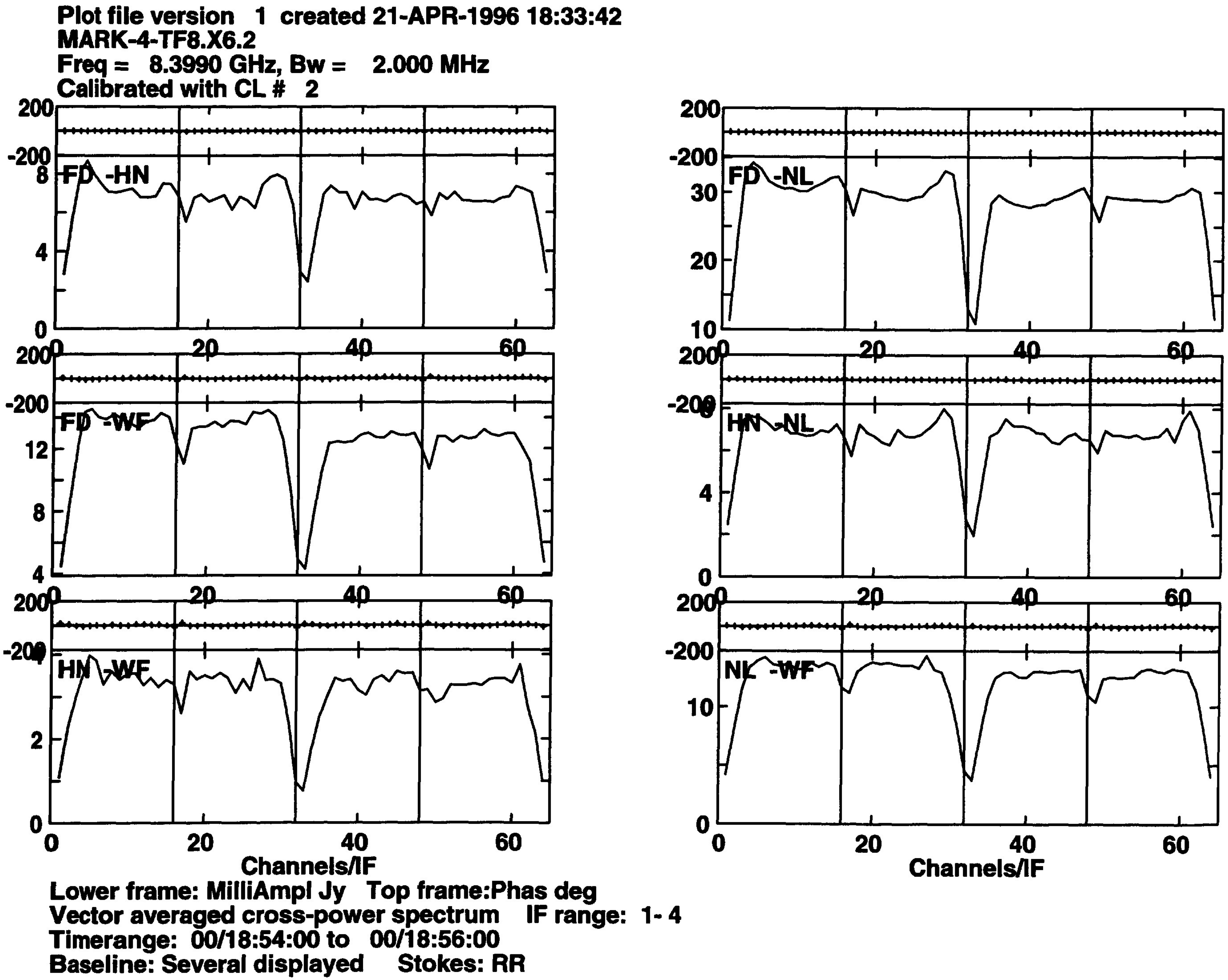
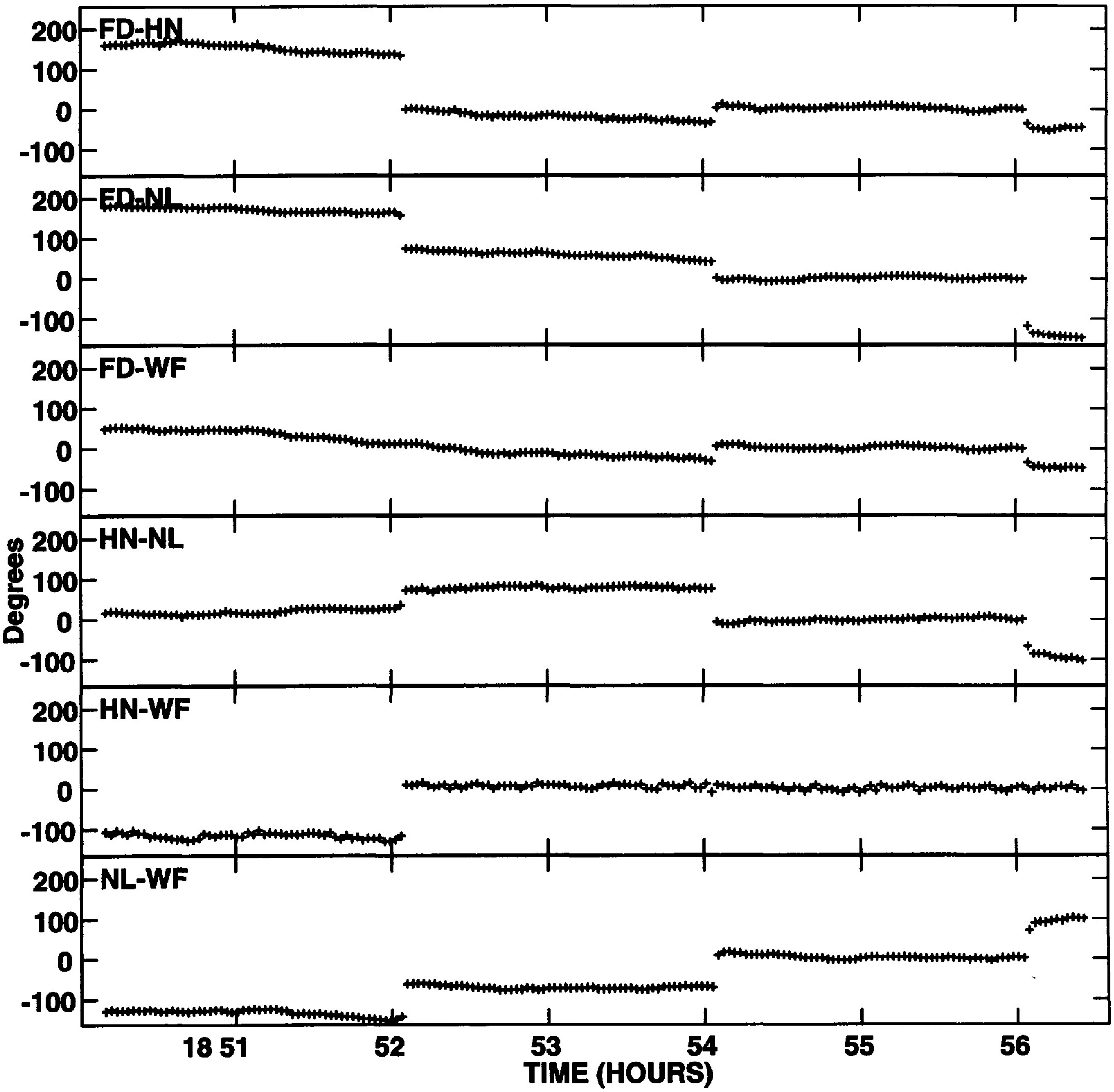
Phase vs Time for MARK-4-TF8.X5.2 Vector average.
IF 1-4 CH 1- 16 STK RR CC ver 0
FD-HN
FD-NL
FD-WF
HN-NL
HN-WF
NL-WF
Degrees
200
100
0
-100
18 41
42
43
44
45
46
TIME (HOURS)


Plot file version 1 created 21-APR-1996 18:33:42
MARK-4-TF8.X6.2
Freq = 8.3990 GHz, Bw = 2.000 MHz
Calibrated with CL # 2
FD -HN
FD -NL
FD -WF
HN -NL
HN -WF
NL -WF
Channels/IF
Channels/IF
Lower frame: MilliAmpl Jy Top frame:Phas deg
Vector averaged cross-power spectrum IF range: 1- 4
Timerange: 00/18:54:00 to 00/18:56:00
Baseline: Several displayed Stokes: RR

PLot file version 2 created 24-APR-1996 00:10:10
Phase vs Time for MARK-4-TF8.X6.2 Vector average.
IF 1-4 CH 1- 16 STK RR CC ver 0



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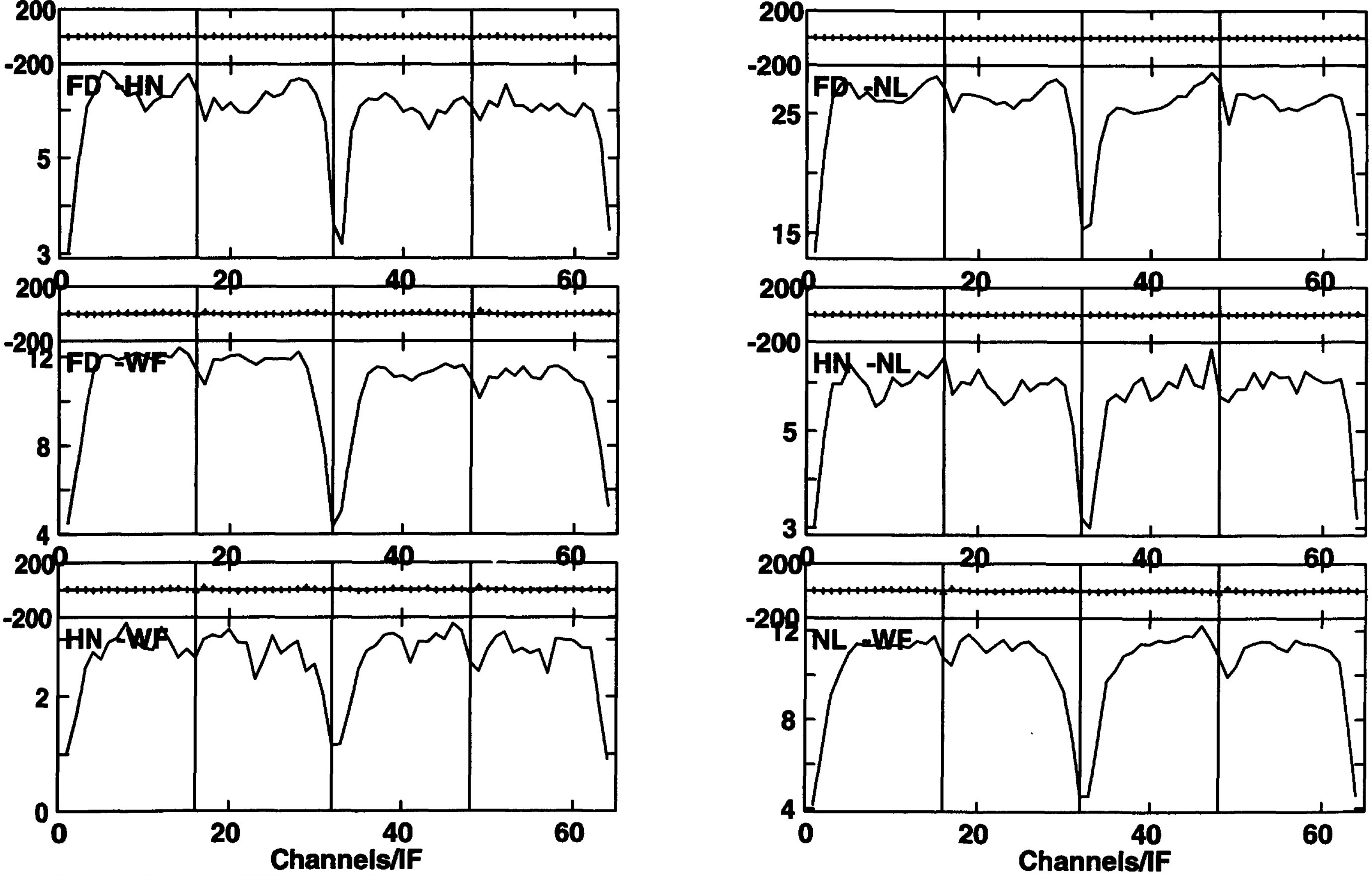
Calibrated with CL # 2



Lower frame: MilliAmpl Jy Top frame:Phas deg
Vector averaged cross-power spectrum IF range: 1- 4
Timerange: 00/19:04:00 to 00/19:06:00
Baseline: Several displayed Stokes: RR

PLot file version 2 created 24-APR-1996 00:10:17
Phase vs Time for MARK-4-TF8.XB.2 Vector average.
IF 1-4 CH 1- 16 STK RR CC ver 0