March 20, 1995

To: Distribution
From: Ed Knight/RDC and Tim Zukowski/Swales

Subject: TAC POLARIZATION DATA ANALYSIS

Summary

We have received the SBRC polarization data and processed it on the GSFC TAC. This report summarizes what we have done and identifies items that would be useful to do in the future.

Familiarity with the Polarization Test Procedure (E152973) and the reduction algorithms (SBRC Doc. #151868) is assumed.

Data Summary

We have processed all the delivered data on the TAC. We covered all detectors in the bands identified by SBRC as "good" for each collect. These included: Set 1: Bands 1-4, 8 at -45, 0, 35, and 45 degrees; Set 2: Band 1 at 45 degrees; Set 3: Bands 3-4, 8, 13, 14 at 45 degrees; and Set 4: Bands 3-4,8 at 45 degrees. The first three sets were collected in January with different gains. Set 4 was collected in March after several changes were made to the electronics. Set 4 is divided into 4a and 4b; different spectral shaping filters were used in the PSA for these cases.

Attached is a Summary Table covering this data. As can be seen, in-band variations can be up to about 1%. Also, applying a curve fit to minimize the effects of noise reduces the polarization factor about 0.5%. There are no consistent biases between mirror sides. It is clear the Set 2 is out of line with the other sets; further examination of this set shows it to be suspect data; with noise of either a few hundred counts or zero counts. Band 4 in Set 4a is also zero--apparently the spectral shaping filters cut off this wavelength. A detailed examination of the Summary Table will show some anomalies, such as the high value in Band 2 at 35 degrees. Several of these will be addressed in following sections.

Following the Summary Table are five figures of Polarization Factor as a function of Scan Angle. These cover the middle and end detectors for each of the bands in Set 1 and include both mirror sides.

Since several data sets were collected at an incident angle of 45 degrees, we decided to compare these results. Figures 6 and 7 presents this comparison.

One advantage of the TAC software is that all data is now available in tab-delemetered ASCII tables for further analysis. Parties wishing to examine this data should contact Tim Zukowski (572-1292).

Observed Characteristics

Figures 8-12 show samples of the plots we created. We looked at detector-to-detector variation for all bands and have plots available. Where the summary data looked unusual, we went back and plotted the raw data.

We observed that detector to detector variations could be large, up to 1.3 percent. There was a consistent "banana shape" to the plots of polarization factor vs. channel in sets 1-3 with the high numbered detectors having higher polarization than the others. An example is given in Figure 8. This was not as pronounced in Set 4 (Collect 149), but still present.

In some cases, a dip was observed about 1/3 the way down the track direction (also observed in Figure 8). This appeared to be a real feature as the data were not discernibly invalid; it appeared to be similar to the remaining channels (Figures 9 and 10 show one channel in the dip and one outside it).

There were several instances where the raw polarization factor (PF_Meas) varies with channel, but the fit does not. It appears that the slope of DN vs. Angle changes with channel (Figure 11).

Curve Fit variations

We did convergence checks on the curve fit data. While SBRC sometimes used 20 iterations, we found things converged generally after 4 iterations (1-3 was too few, we used 10 to reduce processing time). The observed failures to fit the data were due to either pathological data or poor starting conditions. In other words, it may have converged on the wrong value, but it got there fast.

In a few data sets, the curve fit resulted in a negative polarization factor for some detectors. We took the absolute value of these to be the actual value. These data sets are Band 2 sides 1 and 2 at 45 degrees (shown in Figure 11), Band 3 sides 1 and 2 at 35 degrees and Band 4 side 1 at 45 degrees. In collect 89, Band 4 sides 1 and 2, Band 14 sides 1 and 2, and Band 3 side 1 have negative values. For Band 2 side 2 and Band 4 side 1, this appears to be due to a failure of the curve fit.

In many cases, the fit failed to represent the data, apparently due to poor signal to noise (a cosine squared variation is only barely detectable). For

example, the fit for Detector 10, Band 2, Scan Angle 35 degrees, mirror side 2 also failed, resulting in an anomalously low polarization factor.

The slope term in the curve fit was consistently negative. The only exceptions in the data examined were Bands 3 and 4 in collect 149 (Set 4), where the raw data looked like cosines, instead of cosine squared. Figure 12 shows a sample of these unexplained phenomena.

There appear to be some problems, not yet investigated, in the calculation of the measured value of the polarization factor. In some cases (for example, Band 3 side 2 at -45 degrees) the standard deviation of the measured data was given to be zero when the average was not an integer. This is physically not possible.

The high value for Band 2, 35 degrees, side 1 is due to a single anomalous detector reading. This detector had a signal 500 counts high for one scan out of the 5 collected. The detector behaved properly at all other scan angles and on the other mirror side. We are considering this a glitch, possibly due to the electronics problems present at the time, and believe this value can be ignored.

Data for Bands 13 and 14 at 35 degrees were included in the templates. Computed polarization factors are minimal. This appears to be due to poor signal to noise in the measurements.

Useful Unperformed Analysis

The following are analyses we believe would be useful but have not had time to do. We do not anticipate returning to polarization soon, so include this list as a reference for possible later use.

Check all cases for DN vs. angle to do comprehensive quality assessment of the fit--e.g., when the data is good, when the fit is good, and when it is appropriate to report the fit value of polarization factor.

Since the curve fit failed several times, try a different routine or other fits. Doublecheck the ability to avoid local minima.

Assess the validity of the current curve fit--perform Chi squared or other tests for QA, check the covariance matrix for the uncertainty of the coefficients of the fit.

The phase term in the fit should be consistent for all detectors and bands. Examine the variation in this fit term. Determine if the phase term variation is appearing in the raw data or is a result of the curve fit. Alternatively,

ignore the phase and take the absolute value of the amplitude (which would solve the negative value problem).

Pull apart the DNA routine and determine why sigmas were occasionally zero, when the average was not an integer DN value.

Pull apart the DNA routine to determine if averaging just the center frame is appropriate; examine the option of averaging several center frames. Also look for consistent spatial variations in the raw data.

Determine the amount of mismatch between 0 and 360 in Set 4 for all detectors.

Test Procedure Recommendations

The following are recommendations of changes to the test procedures for Protoflight.

Make sure the gains and electronics are correct before beginning. The noise is having a larger effect on the results of the polarization tests than desired.

One difficulty in data sets 1-3 is the lack of a repeat value at 0 and 360 degrees. This data should be collected to confirm that these two points match. When this was done for set 4, no match was observed in the subset we examined.

When Set 1 was collected, it was taken from 0 to 180 degrees, then -30 to -150 degrees. It will be valuable in identifying problems to collect some data without this reversal of direction--i.e., one set from 180 to -180 and then another set from -180 to 180 degrees without any reversal of direction in the middle. This may help identify whether the failure of the endpoints to match is due to drift or alignment.

Characterize the spatial uniformity of the PSA. Verify its alignment in the track direction.

Take more time during testing and better optimize the reduction routines so that intra-band variations and "bad fits" may be identified immediately and appropriate steps taken.

Test Data Reduction Change Recommendations

Because of the volume of data, SBRC chose to examine the center pixel of each band and leave the worries about intraband variation until later. We chose to process all detectors in a given band as part of a single TAC run, which made intraband variations much more easy to identify. By modifying the Polarization Routine to do Min/Max/# above Threshold for all values in

the summary file, it will be possible to even more quickly identify problems in the future. SBRC may wish to consider other simple statistics that can be used immediately to identify outliers or spreads in computed values that are larger than expected.

For Collect 149, SBRC added user comments to the UAID.INFO file. This is very useful and we believe that SBRC should continue or expand this practice as a means of generating and/or distributing metadata.

Conclusion

As is well known to all by now, the polarization test data were not collected under optimum circumstances. Many of the problems with this data--too few bands, too few angles, excess noise due to electronics problems, etc., are obvious.

The GSFC analysis has identified several other areas where the data is not optimal. We have tried to focus on only the major anomalies and variations. The curve fit fails too frequently, and can make the difference between being in and out of specification (up to 0.5% variation out of a 2% spec.). The within band variation is also significant (up to 1%) and needs to be understood or eliminated on Protoflight. We have made several recommendations for improving the data collection and analysis for the Protoflight Model.

Finally, we have been asked about our opinion of the quality of this data. It is our opinion that this data shows that we are in the right range for the expected polarization. However there is too little of it (in terms of bands, angles, low noise, etc.) and what there is has sufficient problems (curve fits, intra-band variations, etc.) that we are unable to draw conclusions about the instrument's overall polarization specification compliance. As for conclusions on the test methodology, we believe that there are several concerns in the collection and analysis, (failures of fits, uniformity of PSA, etc.), that will have to be addressed before Protoflight Model testing. We are optimistic that SBRC will be able to collect good polarization data then.

Distribution:

Ken Anderson/421
John Barker/925
Bill Barnes/970
Gerry Godden/925
Bruce Guenther/925
Harry Montgomery/925

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Mike Roberto/421
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Dick Weber/421

ENGINEERING MODEL
POLARIZATION RESULTS SUMMARY

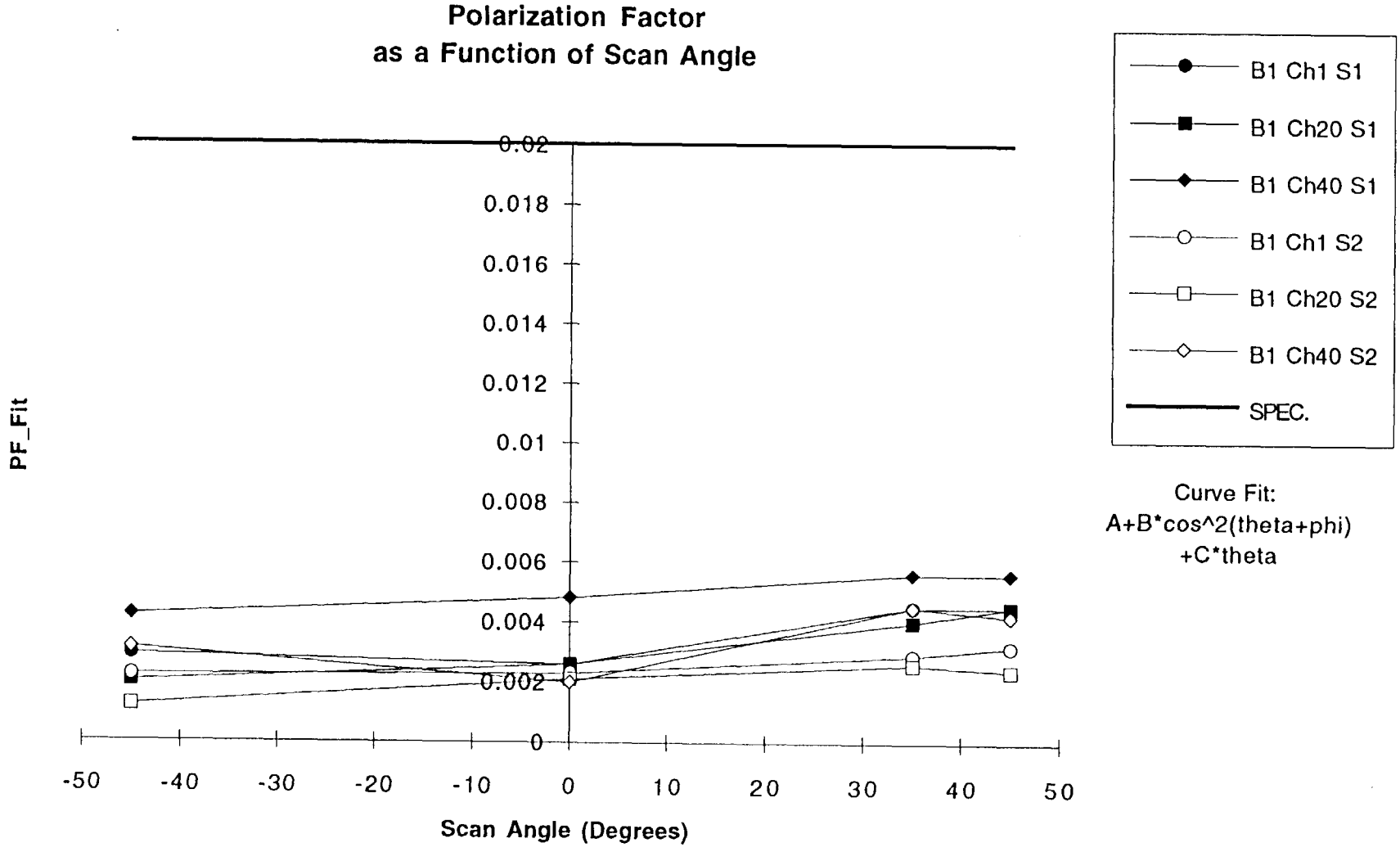
	EM Polarization Measurement Results				All Detectors			
PF Measured is the Polarization Factor with no curve fit					Range is over all detectors in the band			
PF 3-Term Fit assumes the expected A+B*cos^2(theta+phi) response					#above 2% is the number of detectors above 2%			
PF 4-Term Fit uses the SBRC A+B*cos^2(theta+phi)+C*theta fit								
SET 1 (0,35,45,m45)			PF Measured	PF Measured	PF 3-Term Fit	PF 3-Term Fit	4-Term Fit	4-Term Fit
BAND	SCAN ANGLE	MIRROR SIDE	Range (%)	# above 2%	Range	# above 2%	Range (%)	#above 2%
1 (858 nm)	0	1	0.30-0.64	0	0.23-0.45	0	0.24-0.49	0
1 (858 nm)	0	2	0.26-0.54	0			0.20-0.44	0
1 (858 nm)	35	1	0.37-0.70	0			0.34-0.61	0
1 (858 nm)	35	2	0.32-0.54	0			0.24-0.45	0
1 (858 nm)	45	1	0.44-0.72	0			0.40-0.67	0
1 (858 nm)	45	2	0.33-0.58	0			0.21-0.52	0
1 (858 nm)	-45	1	0.24-0.76	0			0.19-0.55	0
1 (858 nm)	-45	2	0.18-0.54	0			0.12-0.42	0
2 (645 nm)	0	1	1.60-2.17	5	1.11-1.51	0	1.18-1.53	0
2 (645 nm)	0	2	1.70-2.10	6			1.30-1.61	0
2 (645 nm)	35	1	1.45-20.92	1			0.52-6.49	1
2 (645 nm)	35	2	1.45-2.27	9			0.19-0.92	0
2 (645 nm)	45	1	1.45-2.32	13			0.04-0.57	0
2 (645 nm)	45	2	1.47-2.22	12			0.09-0.68	0
2 (645 nm)	-45	1	2.00-2.52	19			1.66-2.01	1
2 (645 nm)	-45	2	1.97-2.60	19			1.53-2.06	1
3	0	1	1.11-2.37	3	0.90-1.49	0	1.04-1.82	0
3	0	2	1.47-2.37	6			1.13-1.70	0
3	35	1	0.81-1.51	0			0.01-0.86	0
3	35	2	0.74-1.80	0			0.02-1.04	0
3	45	1	1.05-1.97	0			0.19-0.87	0
3	45	2	0.71-1.78	0			0.15-0.71	0
3	-45	1	2.17-3.18	20			1.80-2.55	17
3	-45	2	2.20-3.21	20			1.92-2.51	18

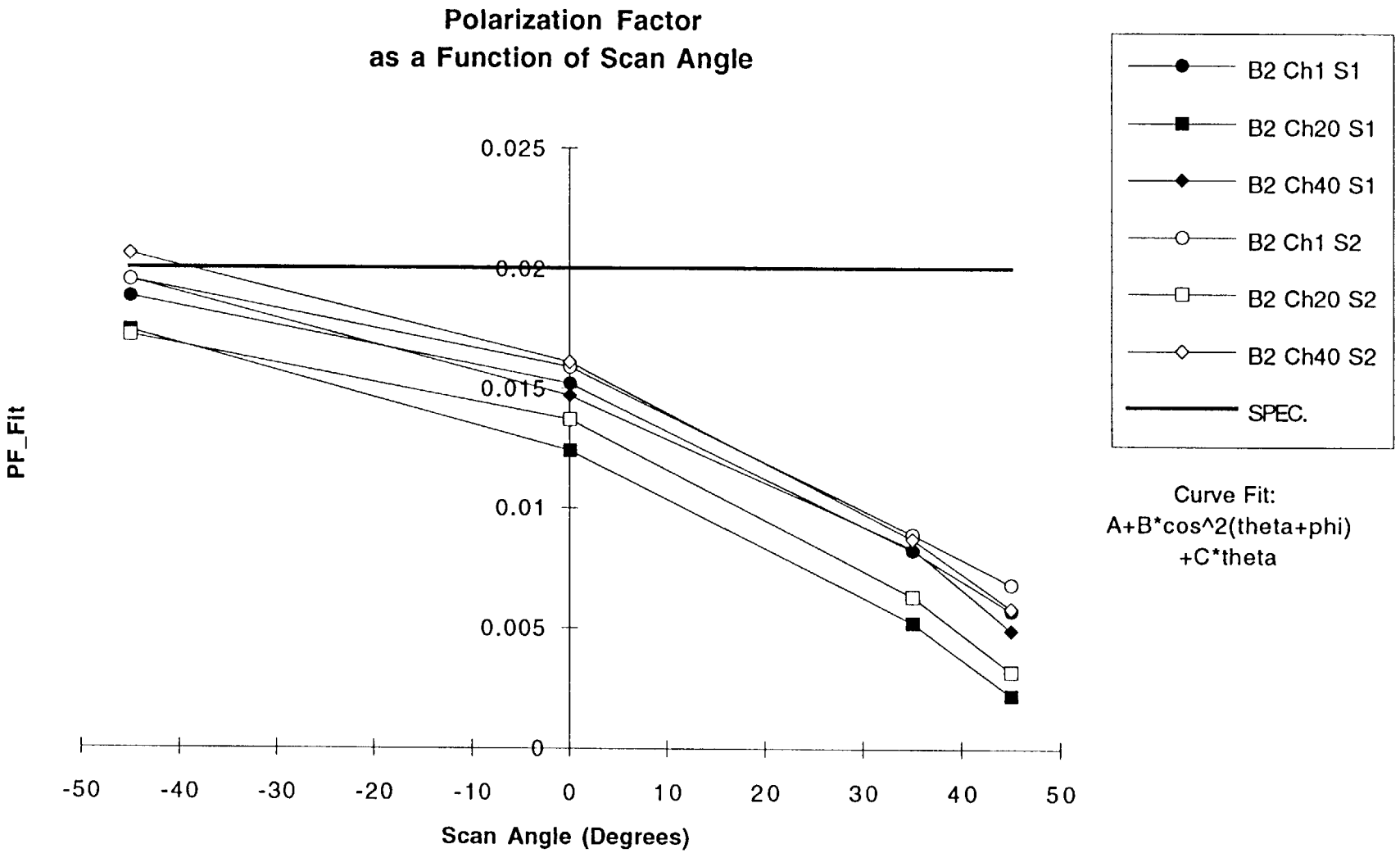
ENGINEERING MODEL
POLARIZATION RESULTS SUMMARY

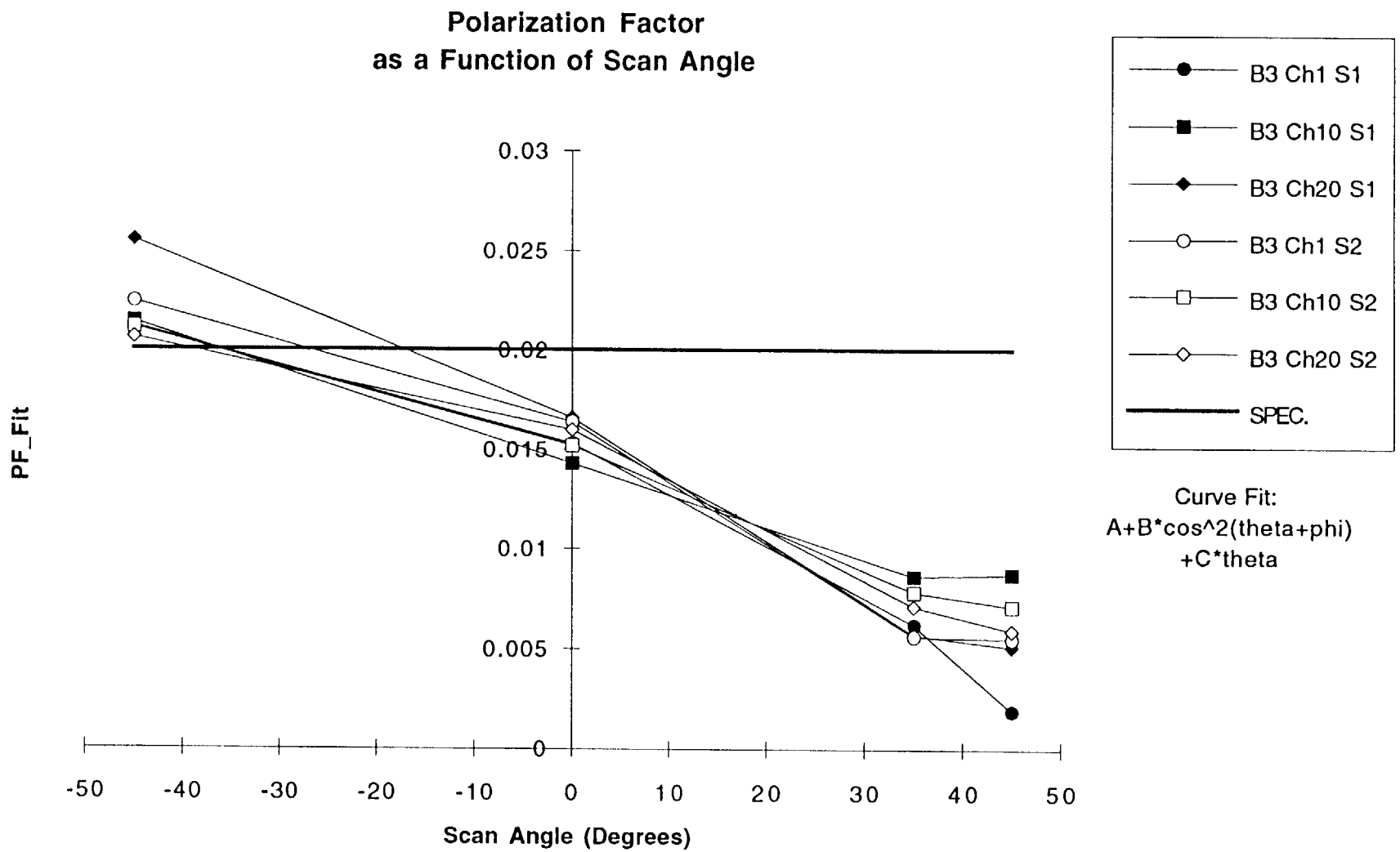
	EM Polarization Measurement Results				**All Detectors**			
PF Measured is the Polarization Factor with no curve fit					Range is over all detectors in the band			
PF 3-Term Fit assumes the expected A+B*cos^2(theta+phi) response					#above 2% is the number of detectors above 2%			
PF 4-Term Fit uses the SBRC A+B*cos^2(theta+phi)+C*theta fit					NOTE: BAND 8 NOT COVERED BY SPEC.			
SET 1 (0,35,45,m45)			PF Measured	PF Measured	PF 3-Term Fit	PF 3-Term Fit	4-Term Fit	4-Term Fit
BAND	SCAN ANGLE	MIRROR SIDE	Range (%)	#above 2%	Range	#above 2%	Range (%)	#above 2%
4	0	1	1.71-2.10	7	1.17-1.57	0	1.33-1.78	0
4	0	2	1.72-2.21	9			1.40-1.86	0
4	35	1	1.22-1.88	0			0.31-0.88	0
4	35	2	1.22-1.58	0			0.55-0.98	0
4	45	1	1.39-1.80	0			0.01-0.33	0
4	45	2	1.30-1.64	0			0.11-0.58	0
4	-45	1	2.24-2.86	20			1.93-2.41	16
4	-45	2	2.32-2.82	20			1.92-2.37	17
8	0	1	1.33-1.79	0	0.32-0.67	0	0.69-1.07	0
8	0	2	1.50-1.96	0			0.97-1.31	0
8	35	1	1.30-2.38	4			0.90-1.26	0
8	35	2	1.10-1.98	0			0.49-0.84	0
8	45	1	2.08-2.80	10			1.24-1.64	0
8	45	2	1.55-2.30	5			0.52-0.97	0
8	-45	1	2.07-3.01	10			1.83-2.22	5
8	-45	2	2.18-2.96	10			0.26-2.32	2
SET 2 (UAID 90)								
1	45	1	0.18-21.82	29			0.09-18.02	29
1	45	2	0.18-21.82	29			0.09-16.64	28

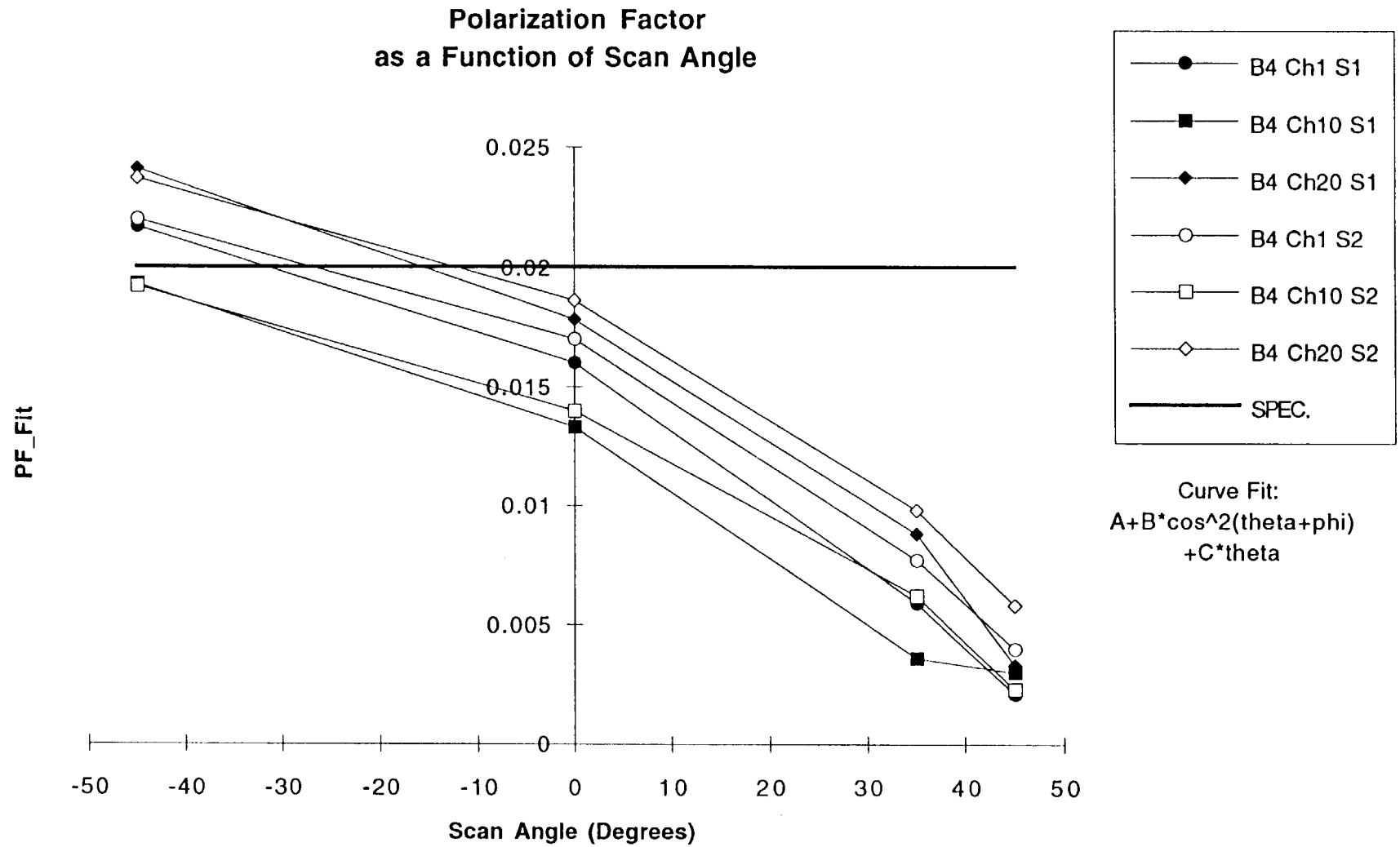
ENGINEERING MODEL
POLARIZATION RESULTS SUMMARY

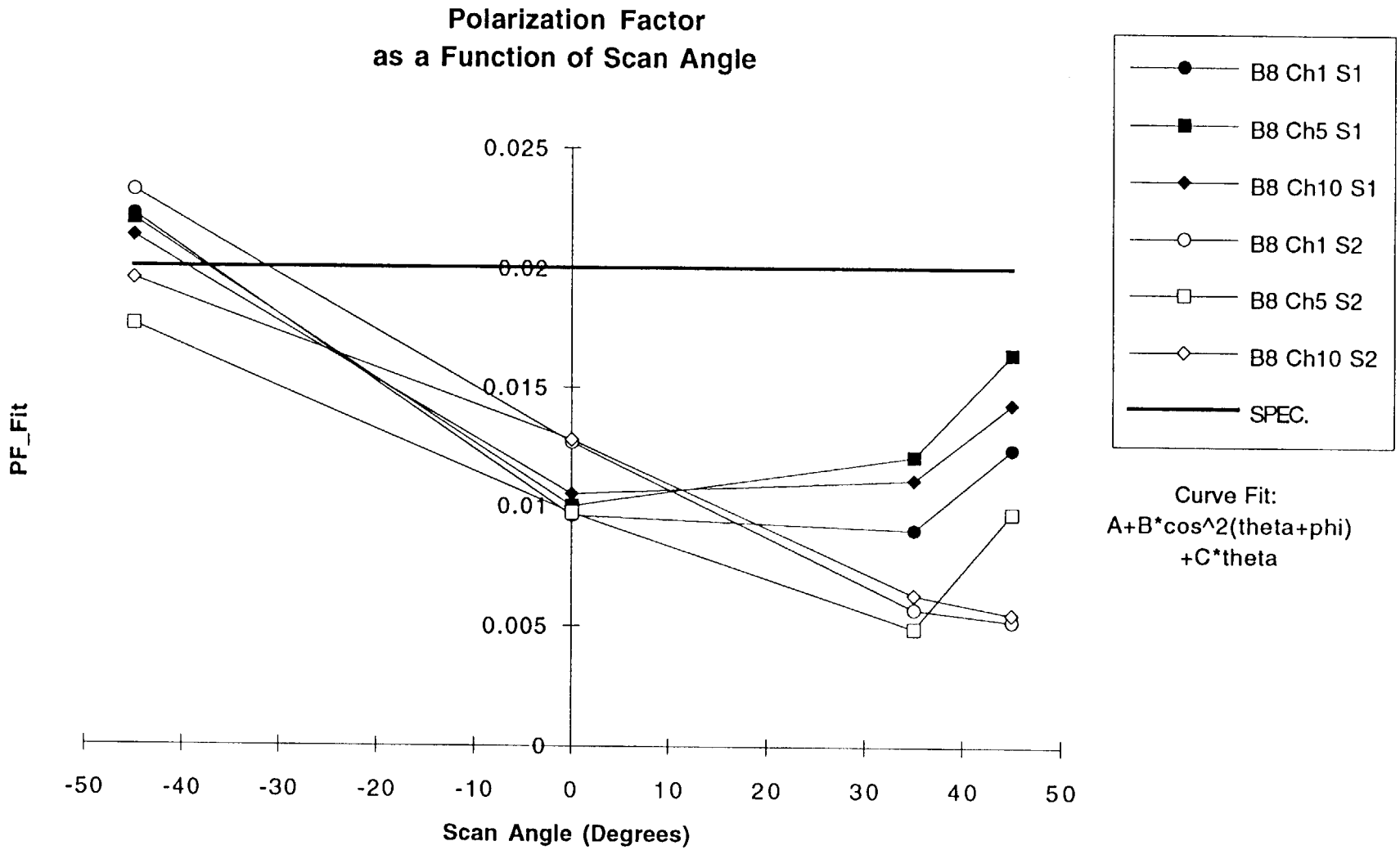
	EM Polarization Measurement Results				**All Detectors**			
PF Measured is the Polarization Factor with no curve fit					Range is over all detectors in the band			
PF 3-Term Fit assumes the expected A+B*cos^2(theta+phi) response					#above 2% is the number of detectors above 2%			
PF 4-Term Fit uses the SBRC A+B*cos^2(theta+phi)+C*theta fit					NOTE: BAND 8 NOT COVERED BY SPEC.			
SET 3 (UAID 89)			PF Measured	PF Measured	PF 3-Term Fit	PF 3-Term Fit	4-Term Fit	4-Term Fit
BAND	SCAN ANGLE	MIRROR SIDE	Range (%)	#above 2%	Range	#above 2%	Range (%)	#above 2%
3	45	1	1.02-2.78	4			0.16-0.69	0
3	45	2	0.76-2.38	3			0.08-0.79	0
4	45	1	0.82-3.12	8			0.03-1.34	0
4	45	2	0.82-2.70	6			0.05-0.70	0
8	45	1	2.20-3.04	10			1.16-1.75	0
8	45	2	1.79-2.49	7			0.29-0.88	0
13	45	1	1.84-2.79	9			0.78-1.23	0
13	45	2	1.56-2.71	8			0.45-1.09	0
14	45	1	1.49-1.79	0			0.05-0.44	0
14	45	2	1.39-1.73	0			0.01-0.48	0
SET 4a(UAID 149)								
3	45	1	1.06-1.40	0			0.04-0.27	0
3	45	2	1.08-1.35	0			0.04-0.44	0
4	45	1	0.03-0.06	0			0-0.03	0
4	45	2	0.03-0.06	0			0-0.03	0
8	45	1	1.70-2.29	5			1.02-1.45	0
8	45	2	1.48-2.01	1			0.89-1.32	0
SET 4b(UAID 149)								
3	45	1	0.56-1.08	0			0.09-0.40	0
3	45	2	0.56-1.11	0			0.05-0.39	0
4	45	1	0.45-1.27	0			0.12-0.73	0
4	45	2	0.49-1.27	0			0.07-0.46	0
8	45	1	1.76-2.42	5			1.36-1.86	0
8	45	2	1.48-2.42	3			1.24-1.69	0


Polarization Factor
as a Function of Scan Angle
PF_Fit
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Scan Angle (Degrees)
B1 Ch1 S1
B1 Ch20 S1
B1 Ch40 S1
B1 Ch1 S2
B1 Ch20 S2
B1 Ch40 S2
SPEC.
Curve Fit:
A+B*cos^2(theta+phi)
+C*theta

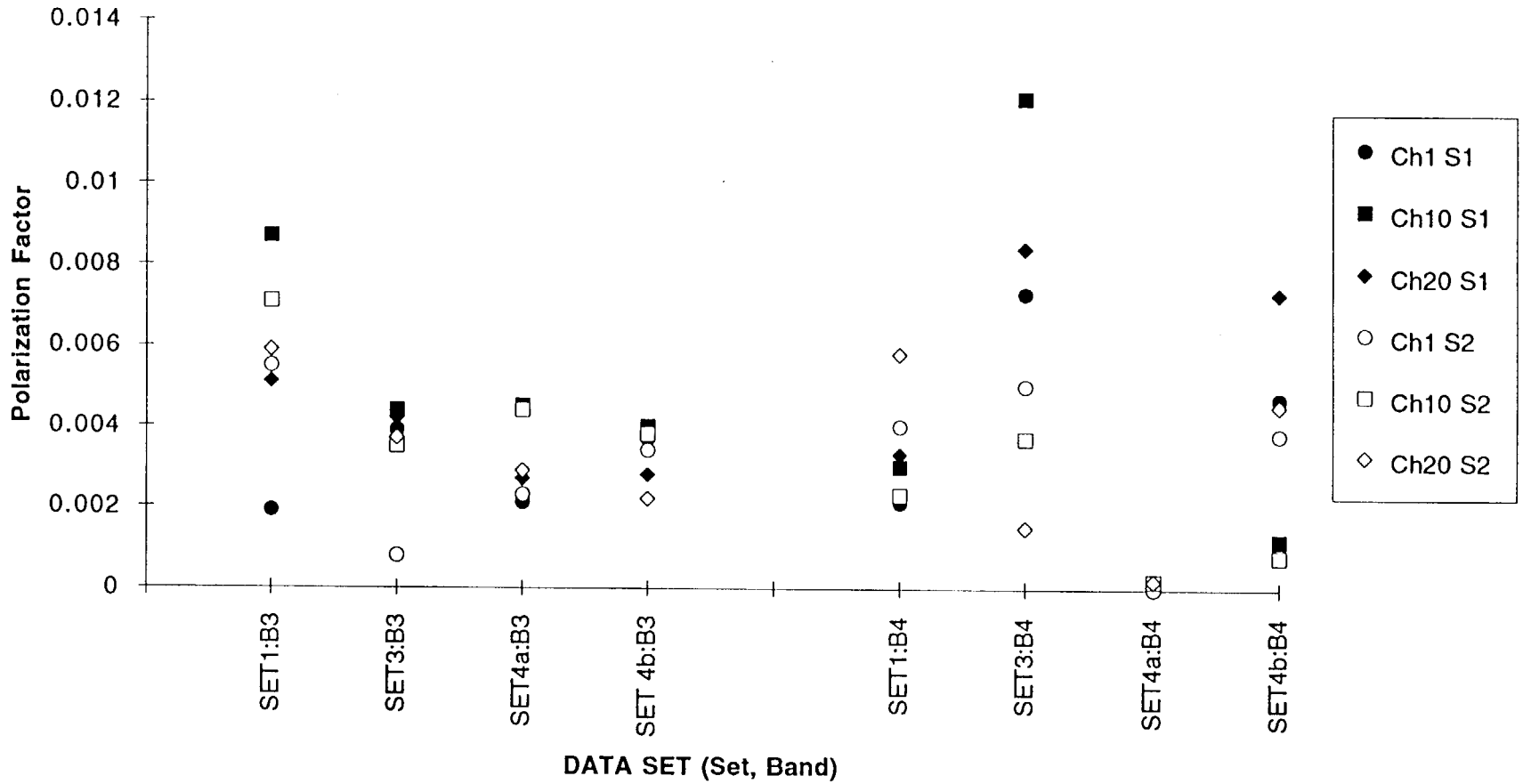

Polarization Factor
as a Function of Scan Angle
PF_Fit
0.025
0.02
0.015
0.01
0.005
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Scan Angle (Degrees)
B2 Ch1 S1
B2 Ch20 S1
B2 Ch40 S1
B2 Ch1 S2
B2 Ch20 S2
B2 Ch40 S2
SPEC.
Curve Fit:
A+B*cos^2(theta+phi)
+C*theta


Polarization Factor
as a Function of Scan Angle
PF_Fit
0.03
0.025
0.02
0.015
0.01
0.005
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Scan Angle (Degrees)
B3 Ch1 S1
B3 Ch10 S1
B3 Ch20 S1
B3 Ch1 S2
B3 Ch10 S2
B3 Ch20 S2
SPEC.
Curve Fit:
A+B*cos^2(theta+phi)
+C*theta

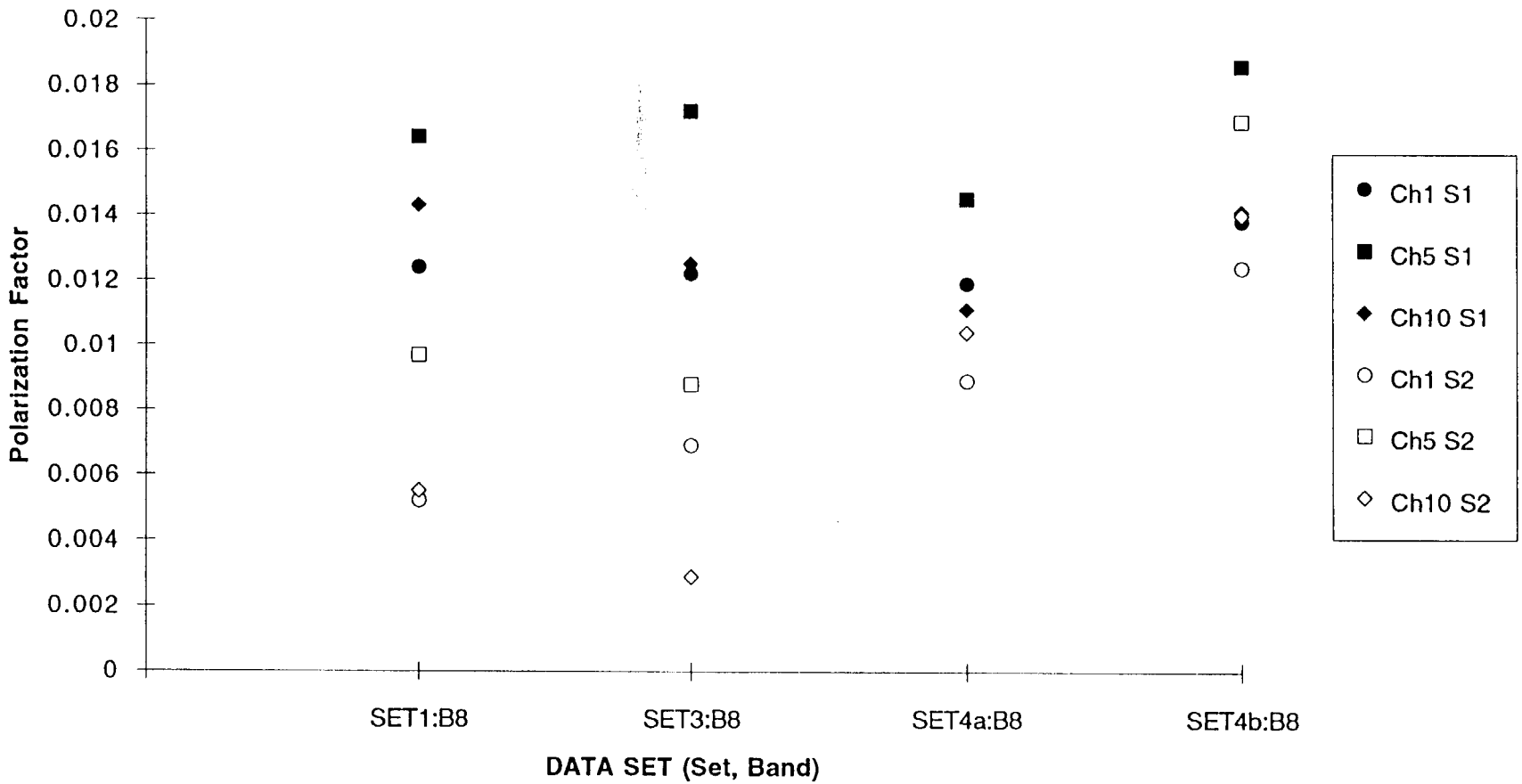

Polarization Factor
as a Function of Scan Angle
PF_Fit
0.025
0.02
0.015
0.01
0.005
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Scan Angle (Degrees)
B4 Ch1 S1
B4 Ch10 S1
B4 Ch20 S1
B4 Ch1 S2
B4 Ch10 S2
B4 Ch20 S2
SPEC.
Curve Fit:
A+B*cos^2(theta+phi)
+C*theta


Polarization Factor
as a Function of Scan Angle
PF_Fit
0.025
0.02
0.015
0.01
0.005
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Scan Angle (Degrees)
B8 Ch1 S1
B8 Ch5 S1
B8 Ch10 S1
B8 Ch1 S2
B8 Ch5 S2
B8 Ch10 S2
SPEC.
Curve Fit:
A+B*cos^2(theta+phi)
+C*theta

COMPARISON OF DATA SETS 1, 3, and 4 for SCAN ANGLE 45 DEGREES BAND 3 an BAND 4



COMPARISON OF DATA SETS 1, 3, and 4 for SCAN ANGLE 45 DEGREES BAND 8



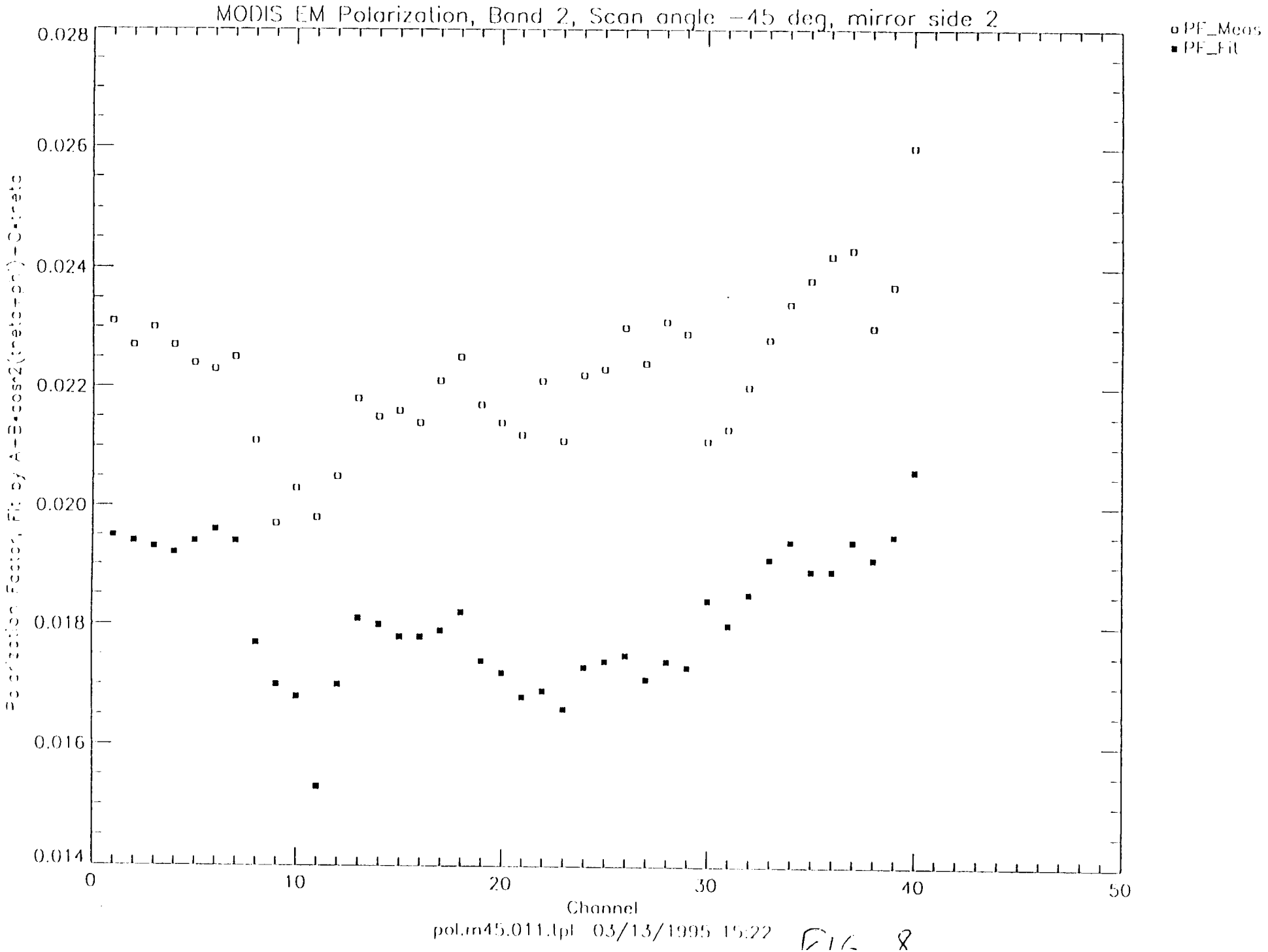
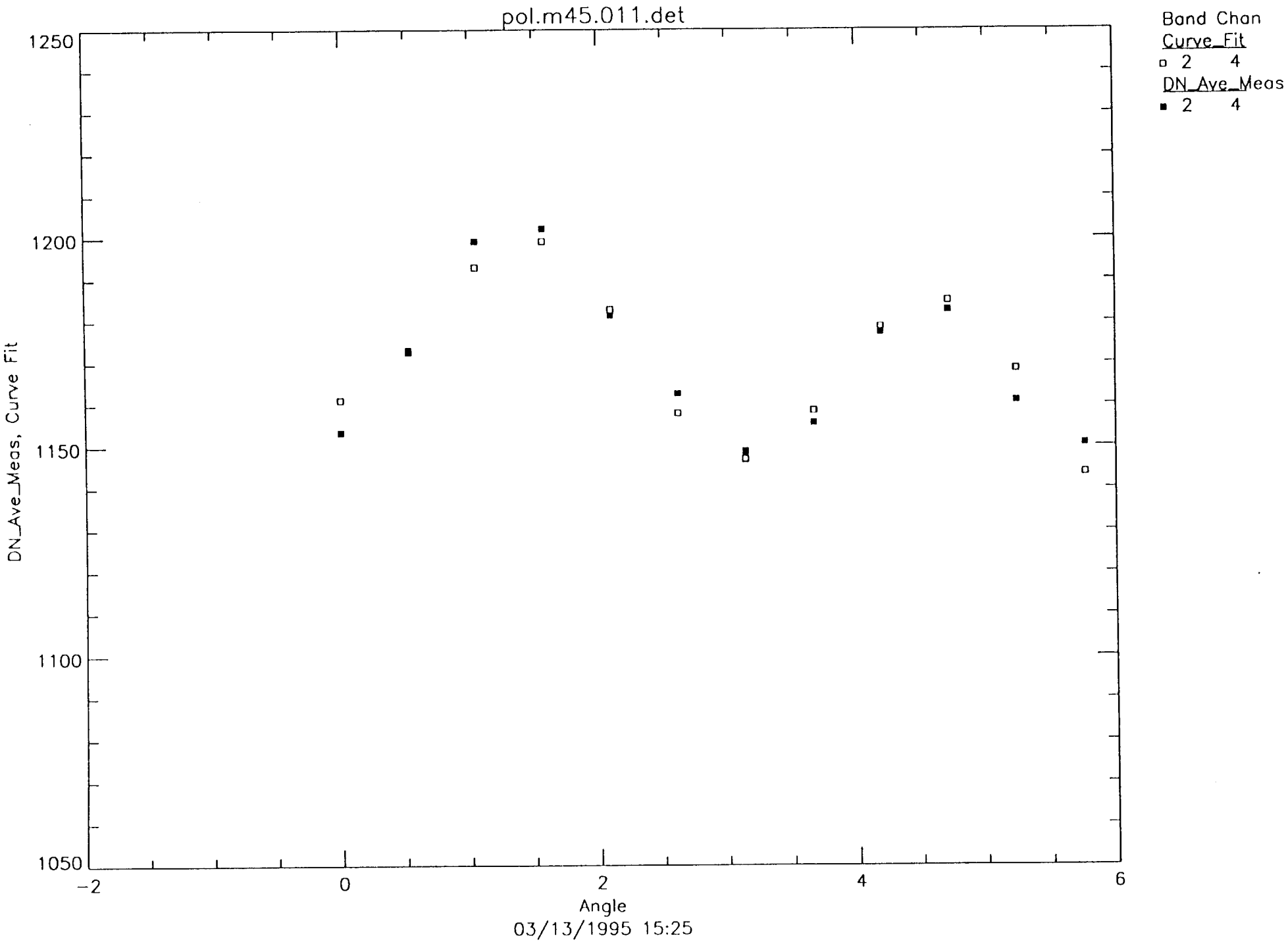

MODIS EM Polarization, Band 2, Scan angle −45 deg, mirror side 2
PF_Meas
PF_Fit
Polarization Factor, Fit by A−Bcos2(theta−phi) − Corrected
0.028
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0
10
20
30
40
50
Channel
pol.m45.011.lpl 03/13/1995 15:22

FIG 8


pol.m45.011.det
Band Chan
Curve_Fit
2 4
DN_Ave_Meas
2 4
1250
1200
1150
1100
1050
DN_Ave_Meas, Curve Fit
−2
0
2
4
6
Angle
03/13/1995 15:25

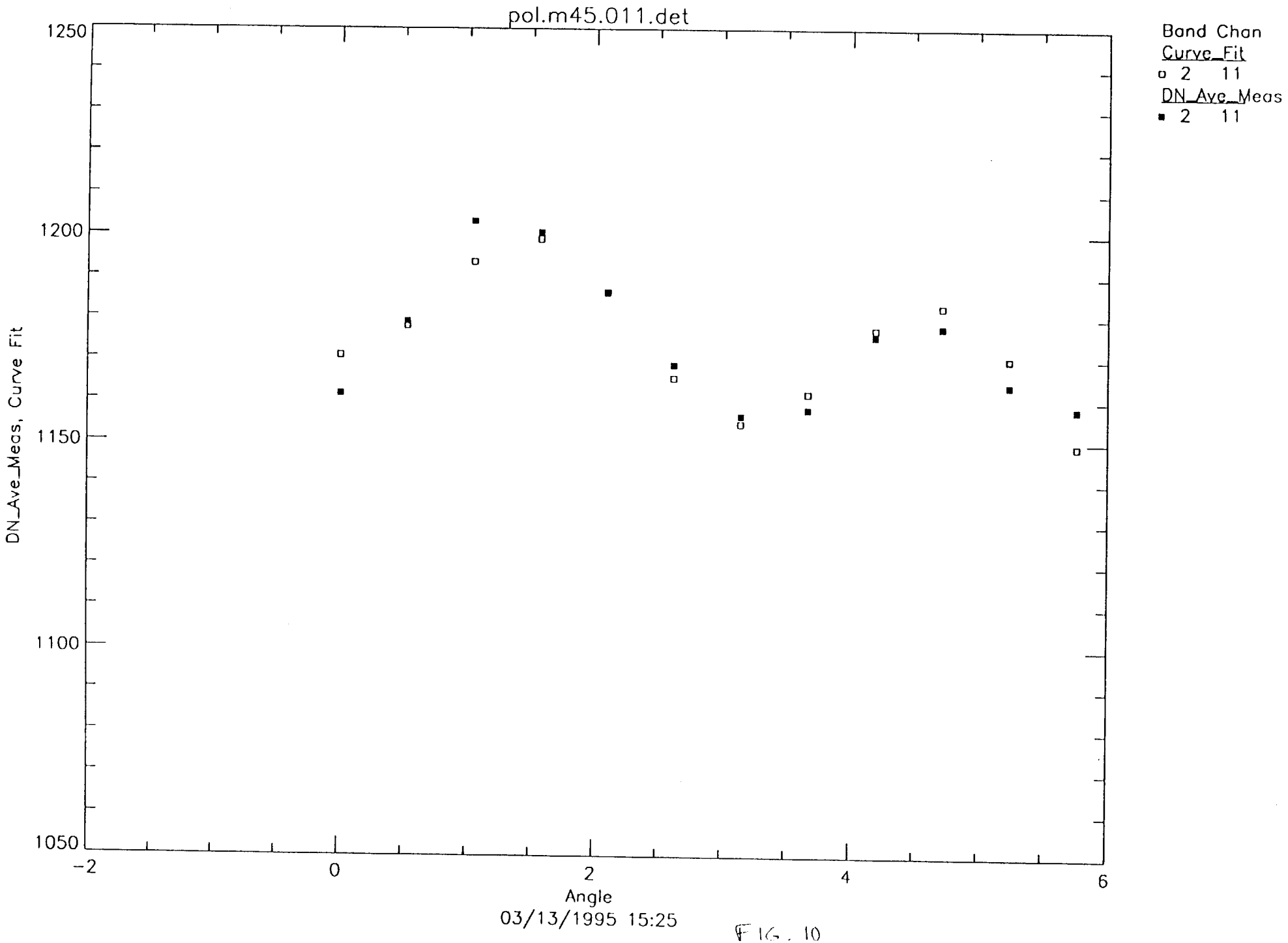

pol.m45.011.det
Band Chan
Curve_Fit
2 11
DN_Ave_Meas
2 11
DN_Ave_Meas, Curve Fit
1250
1200
1150
1100
1050
-2
0
2
4
6
Angle
03/13/1995 15:25

FIG. 10

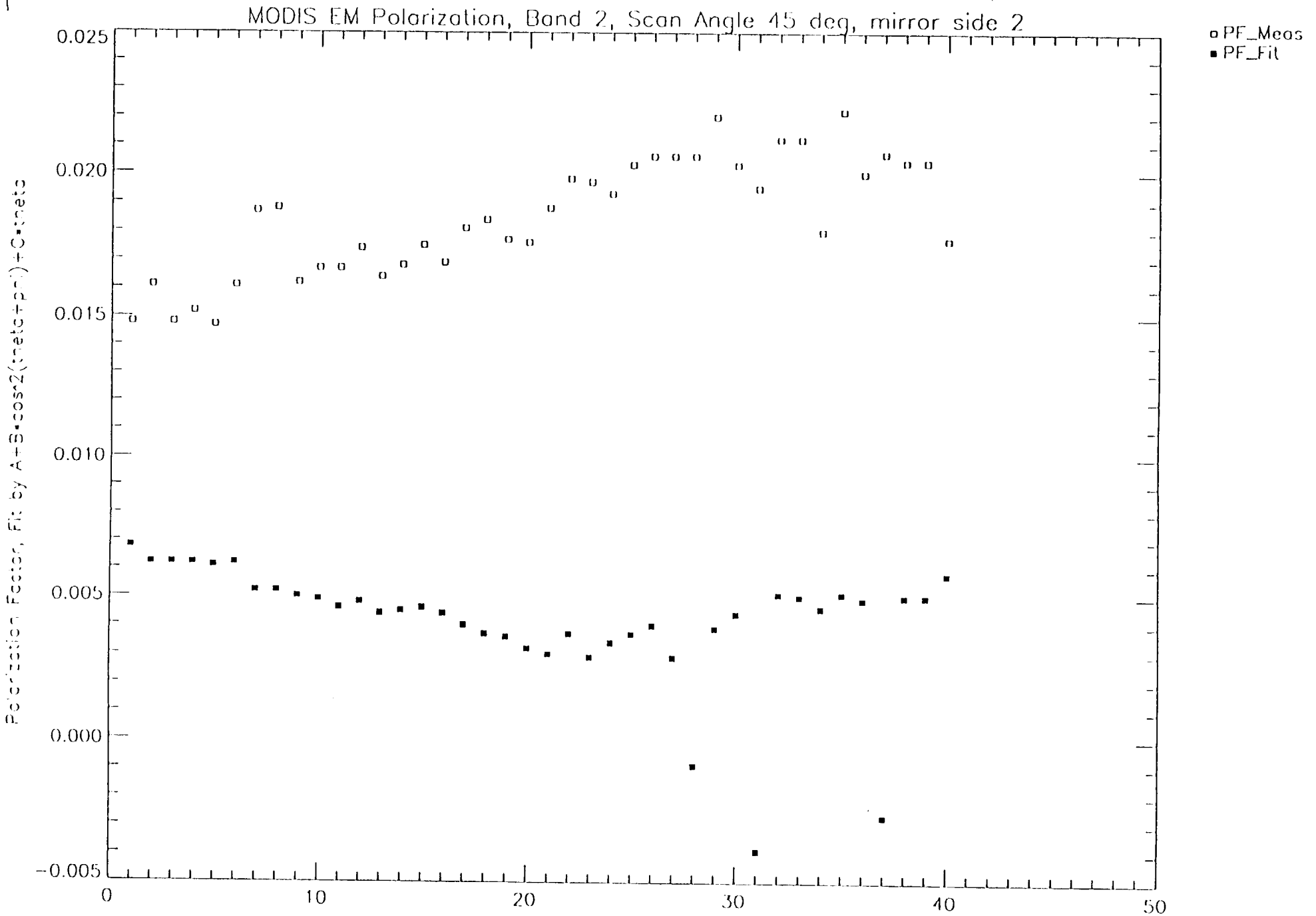
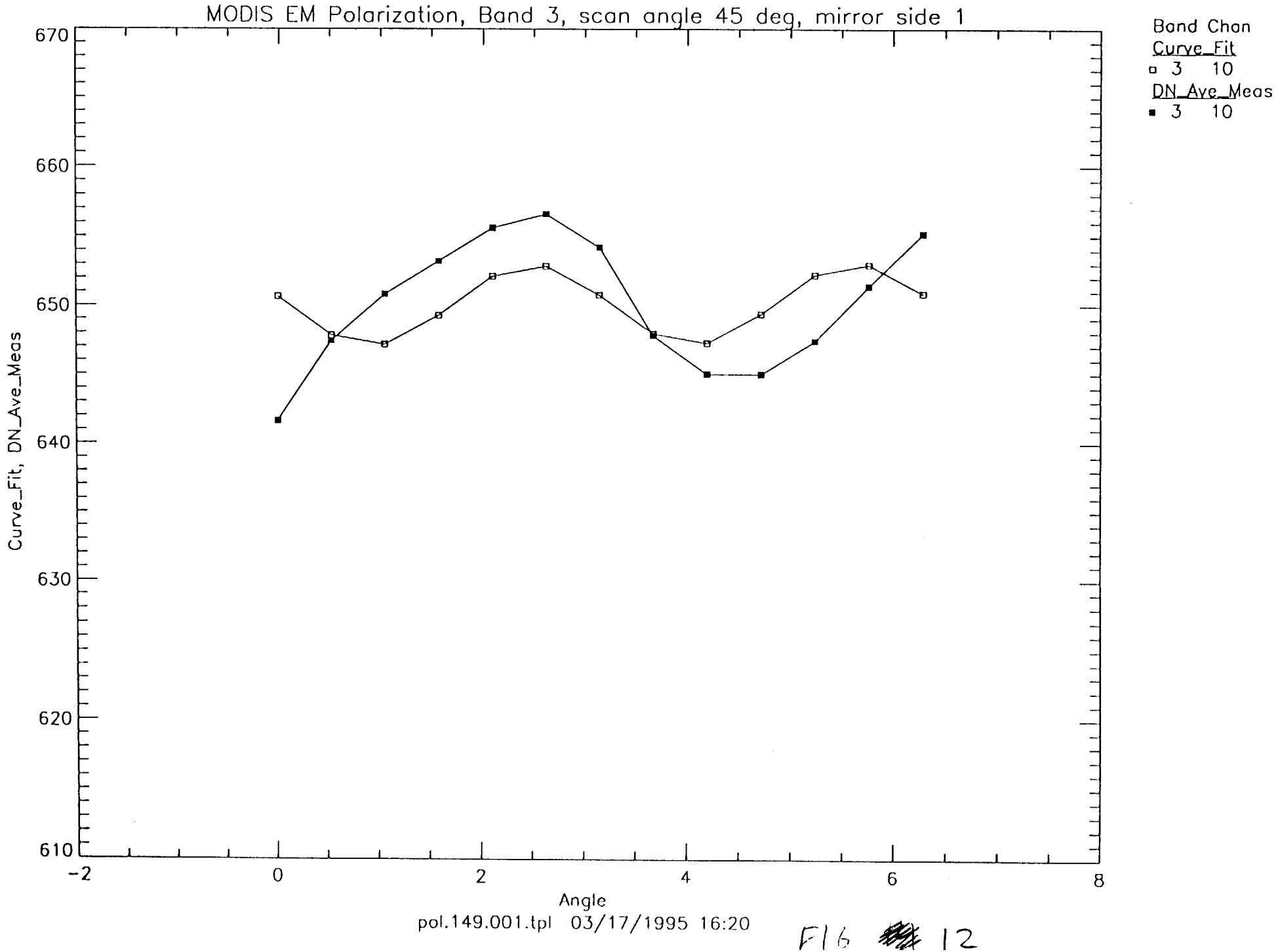

MODIS EM Polarization, Band 2, Scan Angle 45 deg, mirror side 2
PF_Meas
PF_Fit
Polarization Factor, Fit by A+B•cos2(theta+phi)+Cxtheta
0.025
0.020
0.015
0.010
0.005
0.000
-0.005
0
10
20
30
40
50
Channel
pol.45.011.tpl 03/13/1995 13:47

Fig 11



F16 [redacted] 12