# GBES Antenna Pointing Offsets

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## Overview

This document describes the measurement of OVLBI GBES antenna pointing corrections. The pointing offset function is described and previous measurements of the coefficients listed. The process of gathering offset measurement data, fitting the data to measure the offsets, and the process of fitting the offsets to a model are described. An Appendix describes the `c` programs `pat2Off`, `off2point` and `peakRatio` used to calculate the pointing coefficients.

## Introduction

Bright compact radio sources were observed with the GBES antenna on 94 April 7, 12, 15, 21, 29 and 94 August 5, 7 and 8. The offsets between the known source location (in azimuth, elevation) and encoder readings of at location of signal maximum were recorded.

The antenna pointing error model described in GBES Memo 31 (Murphy and D'Addario) was used to measure the antenna pointing offsets. The pointing model assumed, where the offsets from the nominal azimuth and elevation were fit to equations below:

$$\Delta el = C_1 + C_2 \cos(az) + C_3 \sin(az) + C_4 \cos(el)$$

and

$$\Delta az \ \cos(el) = C_5 \cos(el) + C_6 \cos(az) \sin(el) + C_7 \sin(az) \sin(el) + C_8 \sin(el) + C_9$$

The coefficients are interpreted as follows:

$C_1, C_5$ Elevation encoder and collimation.

$C_2, C_7$ Elevation axis error.

$C_3, C_6$ Azimuth axis error.

$C_4$ Gravitational sag of the antenna.

$C_8$ Represents the non-perpendicularity of the axes.

$C_9$ Represents the non-perpendicularity of the beam and elevation axis.

In memo 31, the fitted pointing coefficients are listed. In table 1, the last few measurements are recorded, along with the latest measurements, using a new method. The newest measurements were taken under rather poor observing conditions. Also the 94 April 7-12, measurements are *not* corrected for refraction. However these measurements were taken at elevation > 30 degrees and refraction is a small addition to the pointing offsets.

Table 1: Measurements of the GBES pointing coefficients. The 1992 measurements 31, the 1994 April 12 to 21 measurements are without the FFS and ellipsoidal mirror. All measurements after 94 April 25 are made with the FFS and ellipsoidal mirror. After 1994 April 21, the relationships between the coefficients were enforced: $C[2] \equiv C[7]$ and $C[3] \equiv -C[6]$.

| | 920711 | 920713 | 920716 | 940412 | 940415 | 940421 | 940429 | 940807 |
|---|---|---|---|---|---|---|---|---|
| C[1] | 9.19 | 9.08 | 9.36 | 8.66±0.25 | -1.52 | 2.62±0.31 | -5.87±0.27 | -7.08±0.25 |
| C[2] | -5.81 | -5.99 | -6.12 | 4.73±0.14 | -5.20 | 4.69±0.12 | 5.28±0.10 | 4.98±0.13 |
| C[3] | 8.22 | 8.55 | 8.58 | -6.00±0.10 | -5.11 | -6.37±0.10 | -6.61±0.12 | -6.48±0.13 |
| C[4] | 1.80 | 1.92 | 1.45 | -0.08±0.36 | -2.17 | -1.88±0.41 | -1.82±0.33 | -1.22±0.34 |
| C[5] | 13.92 | 13.76 | 12.45 | 18.74±1.32 | 14.16 | 8.95±1.08 | 14.20±1.05 | 13.95±0.99 |
| C[6] | 8.88 | 8.74 | 8.77 | 5.99±0.19 | 5.11 | 6.20±0.17 | 6.61±0.12 | 6.48±0.13 |
| C[7] | 5.99 | 6.33 | 6.14 | 6.39±0.15 | 5.20 | 4.52±0.16 | 5.28±0.10 | 4.98±0.13 |
| C[8] | -1.17 | -0.81 | -2.18 | 2.97±1.34 | -0.53 | -3.03±0.90 | -1.05±0.83 | -1.82±0.96 |
| C[9] | -9.40 | -9.49 | -7.74 | -7.13±1.77 | 0.81 | 4.98±1.32 | -4.11±1.26 | -2.89±1.27 |

The measurements after 94 April 15 are corrected for refraction effects, and include a first order correction for the sky effects on the baseline data. Between April 15 and April 21, a number of adjustments to the focus, rotation and tilt of the sub-reflector were make. These adjustments were known to effect these pointing coefficients.

On 94 April 25, the subreflector was rotated 180 degrees and the ellipsoidal mirror installed. The optical path to the Ku band feed, then included a reflection off the Frequency Selective Surface (FSS) to the ellipsoidal mirror and then to the Ku Band feed. The subreflector rotation was set to 4.95 volts, and the subreflector focus was set to 1.24 volts.

On 94 August 7, the antenna pointing was again measured. During these measurements, both the X and Ku band Front End electronics were installed. The pointing coefficients were calculated based on measurements with the X-band feed LCP polarization. Figures 1 - 9 show the measured data and a comparison of measurements and the model fit for the 94 August 7 observations. The discrepancies in the model and fit are mostly due to errors in a few points from the fainter radio sources.

## Beam Squint

Observations of beam squint were made on 94 August 7 in 'reasonable' weather (partly cloudy) with the GBES 45ft antenna. The observations consisted of "X" + "+" cross scans on a small set of bright radio sources, observing in both X band (synthesizer set to 8.9 GHz) and Ku band (synthesizer set to 13.4 GHz). The each observation consisted of a total of 1 minute to execute the scan pattern. Because of the high signal to noise ratio needed for these measurements, only observations of Cas A and Taurus A where retained.

After data editing, a total of 82 good observations were retained. The offset of the peak source intensity relative to the predicted intensity was fit for each polarization and band (a total of 4 channels). The fitting was done with the C program `pat2Off`. The results of these fits were recorded in a output file.

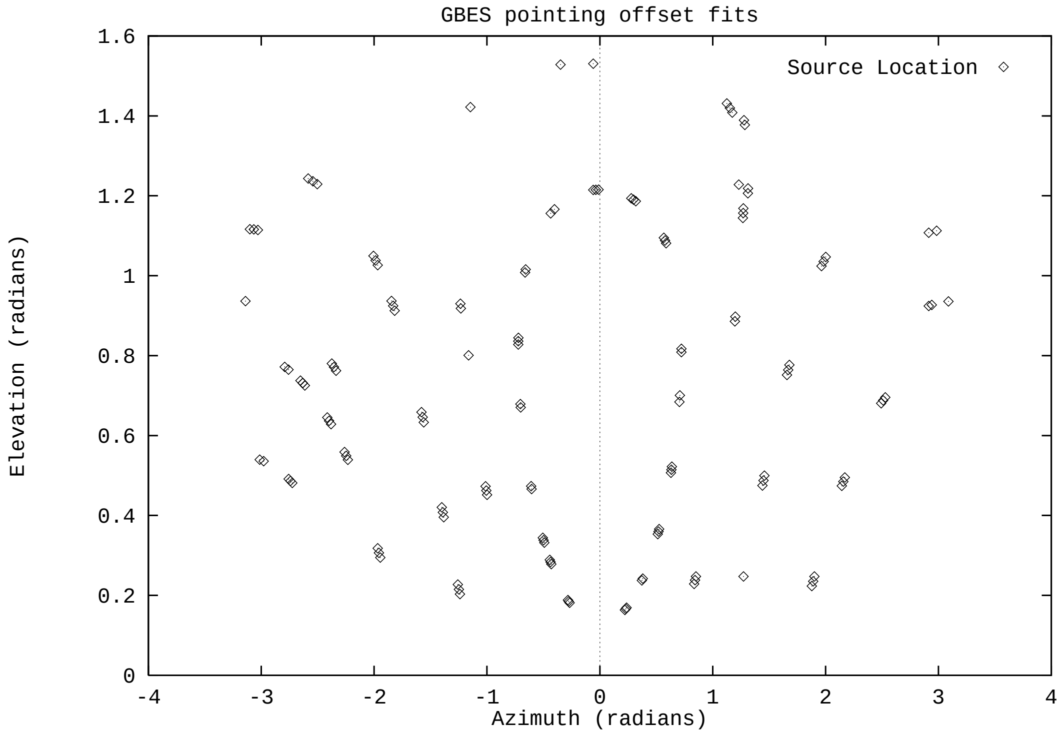


Figure 1: Plot of the Azimuth and Elevation (radians) locations of the radio sources when pointing offset measurements were taken on 1994 August 7.

The program `offsetCalc` was used to read in the fit offsets and using X band polarization channel B (RCP) as the reference, the difference in offset positions were calculated. The program `offsetCalc` is described in the appendix. This step left only the difference between where the channels were pointed on the sky. The Ku Band A channel (LCP) down-converter failed early in the observations giving only 24 useful measurements in this channel.

The average and RMS values for these offsets were calculated and are summarized below. The RMS values are the "average" deviation from the mean. The uncertainty in the measured value of the offsets are calculated to be the RMS value divided by the square root of the number of measurements.

The output of the program `offsetCalc` is given below, based on the output from the `pat2Off` program.

| Channel Offsets | D Az (arc min) | D El (arc min) | N measure | Az RMS (arc min) | El RMS (arc min) |
|---|---|---|---|---|---|
| XL - XR | -0.001 +/-0.02 | -0.27 +/-0.02 | 79 | 0.17 | 0.19 |
| KL - KR | -0.08 +/-0.02 | -0.87 +/-0.05 | 24 | 0.14 | 0.23 |
| KR - XR | -0.19 +/-0.02 | 0.18 +/-0.03 | 81 | 0.18 | 0.22 |

These measurements indicate that the beam squint between Ku LCP and Ku RCP is small but detectable. The Ku band RCP and X band RCP beams are well aligned on the sky.

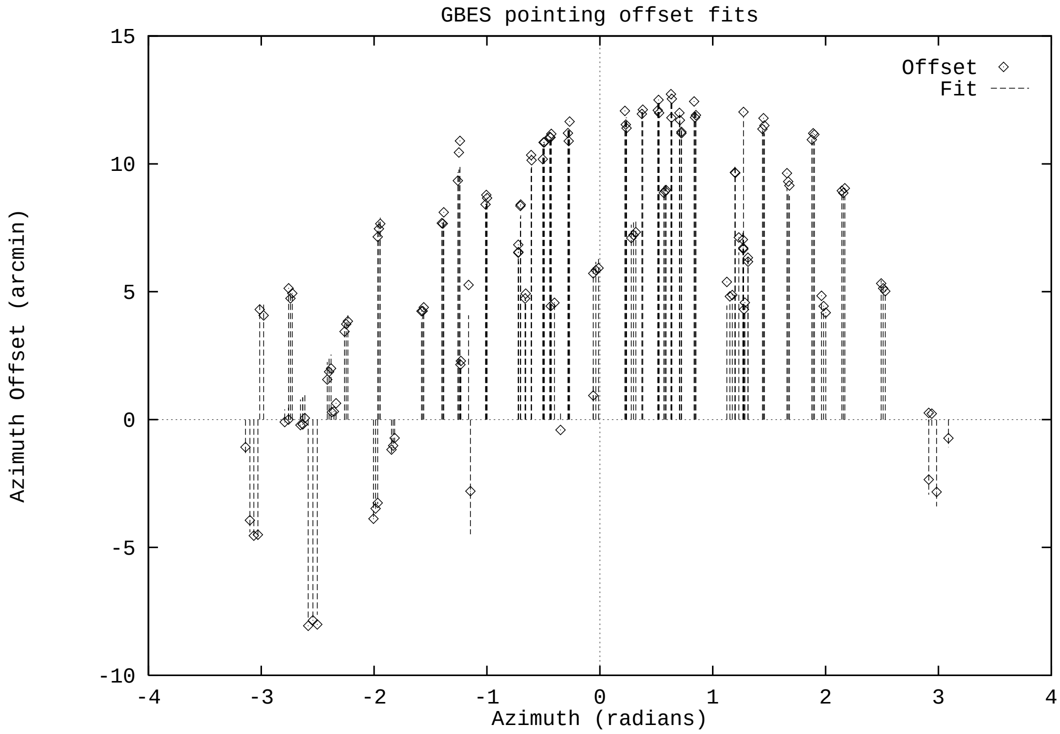


Figure 2: Plot of the Azimuth offsets (arc minutes) as a function of Azimuth (radians) of the radio sources. The measured points are marked by diamonds ($\diamond$), and the model values are shown by dashed lines.

(Ku band LCP must therefore be miss-aligned with X band LCP).

## Conclusions

The method for calculating the GBES pointing coefficients produces a fit with small residual errors. The RMS of the residuals after compensating for pointing errors is less than 1 arc-minute, sufficiently small to allow accurate tracking of satellites at 15 GHz.

The beam squint between the LCP and RCP polarizations at both X and Ku band is small compared to the Full Width of Half Maximum beam widths. The angular offset on the sky between the X and Ku beams is small and allows simultaneous tracking of satellites at X and Ku band.

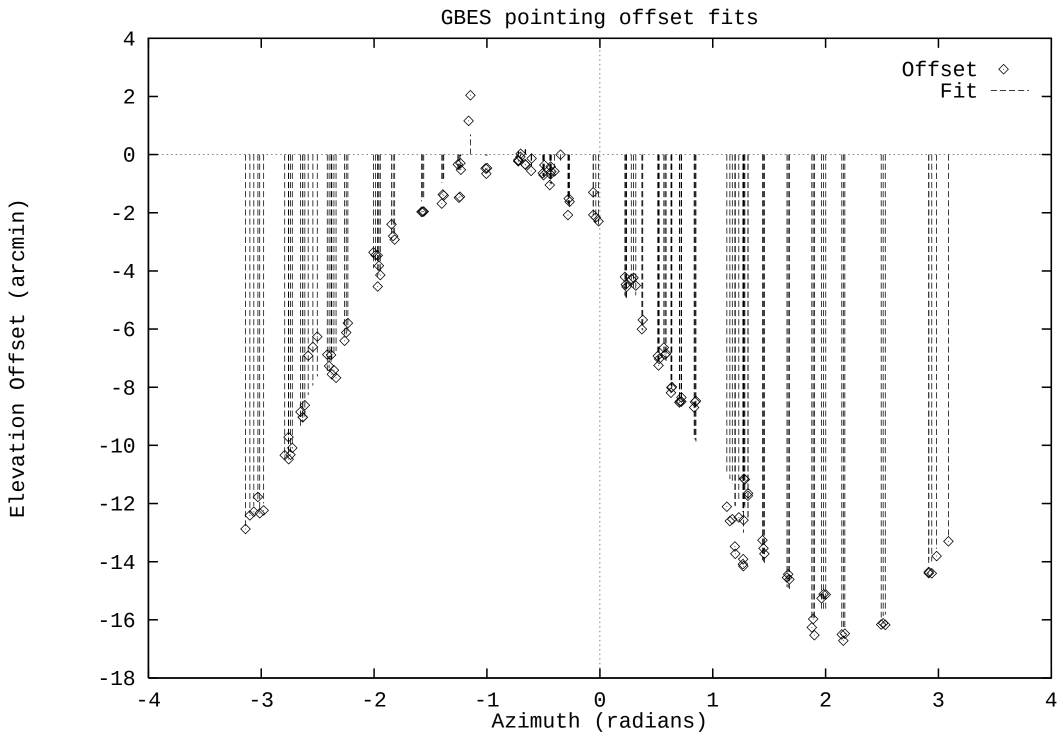


Figure 3: Plot of the Elevation offsets (arc minutes) as a function of Azimuth (radians) of the radio sources.

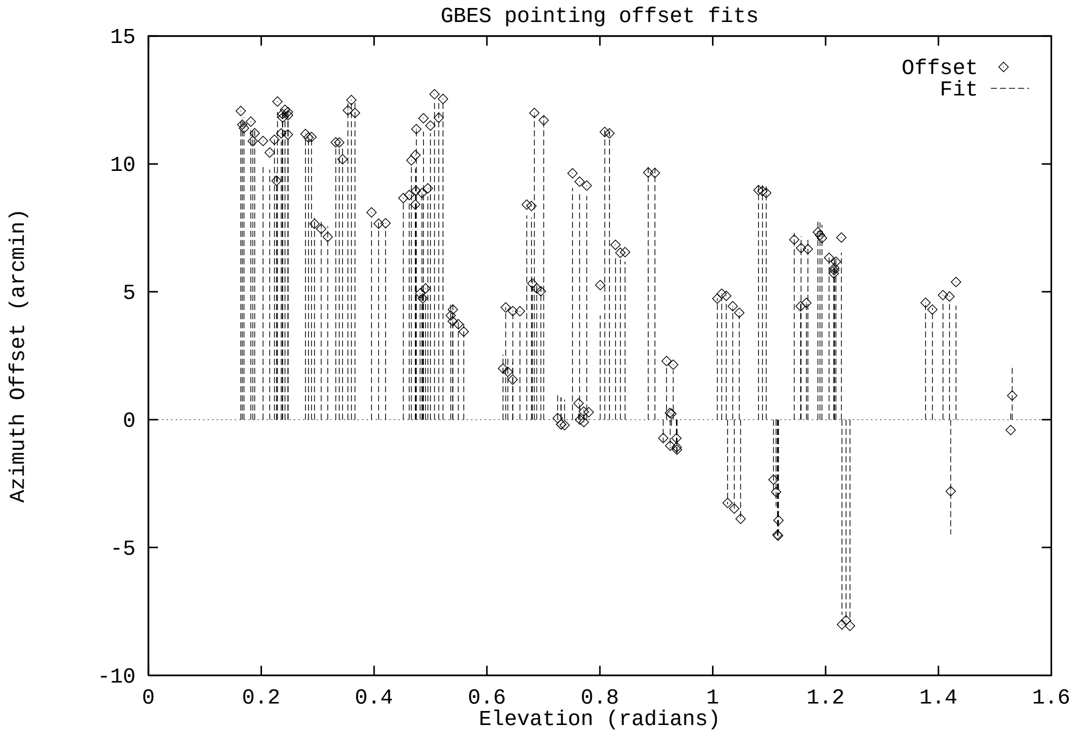


Figure 4: Plot of the Azimuth offsets (arc minutes) as a function of Elevation (radians) of the radio sources.

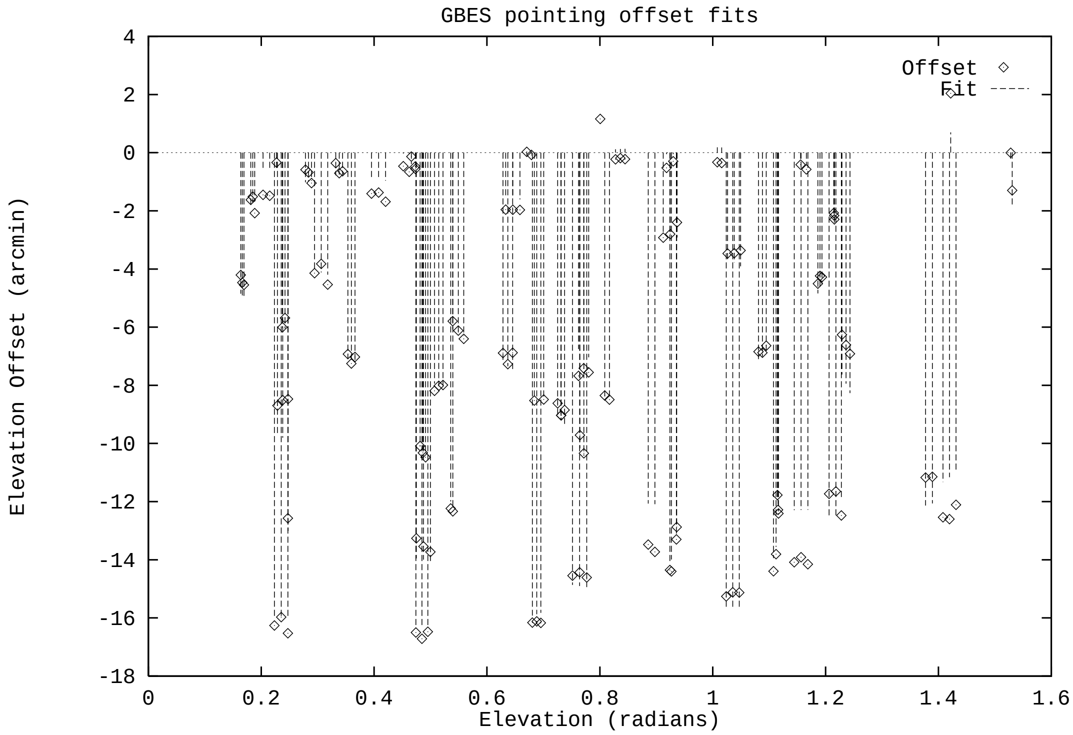


Figure 5: Plot of the Elevation offsets (arc minutes) as a function of Elevation (radians) of the radio sources.

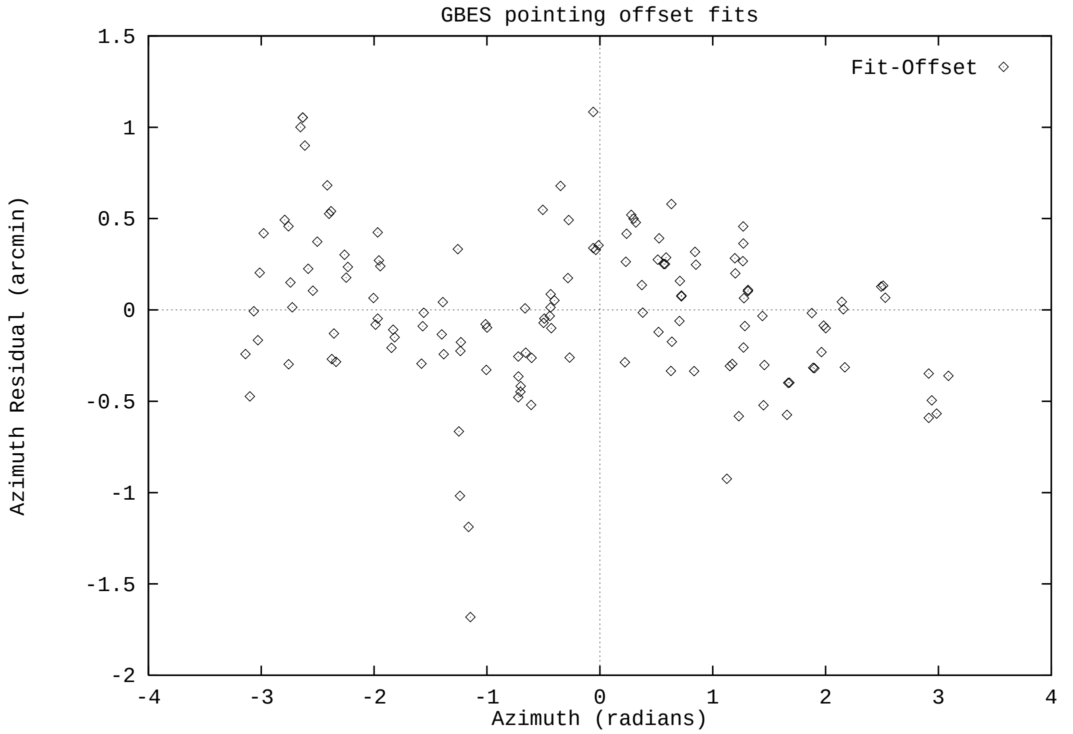


Figure 6: Plot of the Residual of the Azimuth Fit - Measured Azimuth Offsets (arc minutes) as a function of Azimuth (radians) of the radio sources.

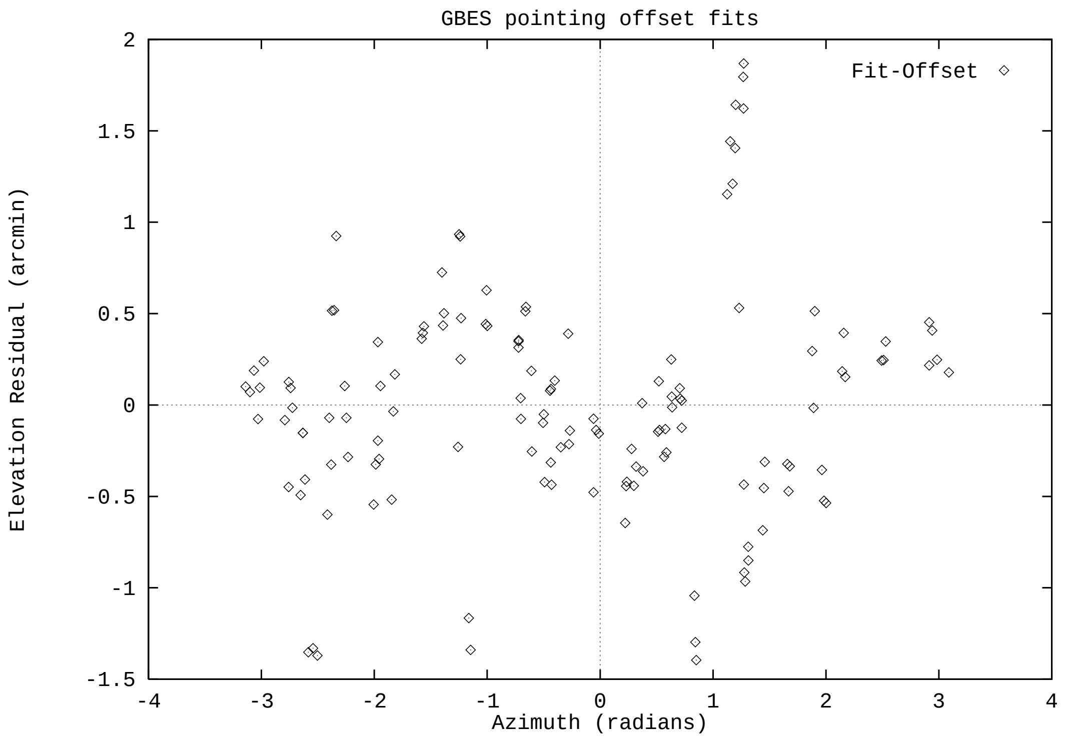


Figure 7: Plot of the Residual of the Elevation Fit - Measured Elevation Offsets (arc minutes) as a function of Azimuth (radians) of the radio sources.

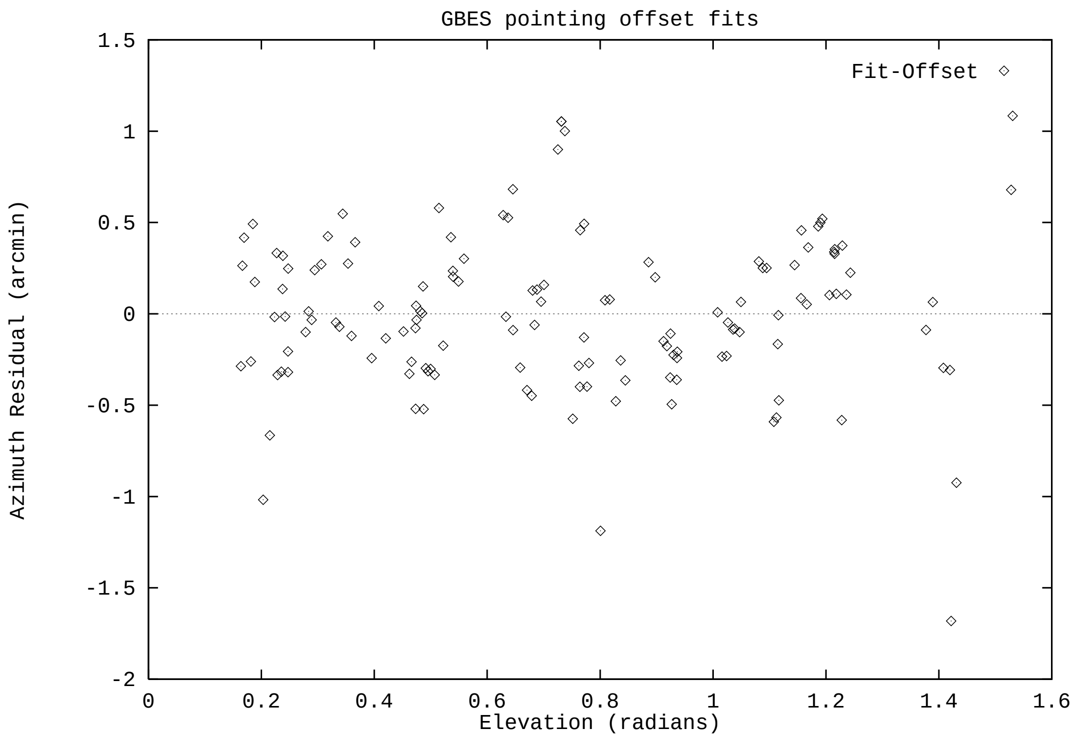


Figure 8: Plot of the Residual of the Azimuth Fit - Measured Azimuth Offsets (arc minutes) as a function of Elevation (radians) of the radio sources.

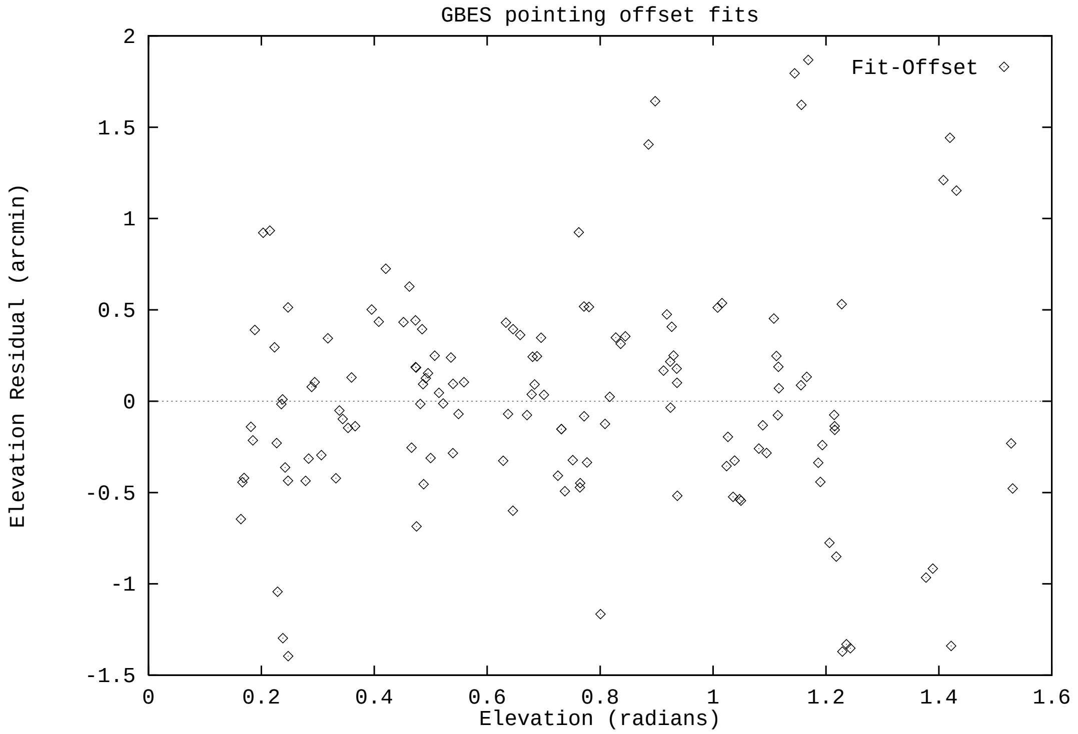


Figure 9: Plot of the Residual of the Elevation Fit - Measured Elevation Offsets (arc minutes) as a function of Elevation (radians) of the radio sources.

## Appendix: Programs used in Pointing Calculations

The process of measuring the pointing offsets and recording them, consists of several steps.

DISPATCH: The GBES real-time DISPATCH commands are used to repeatedly measure the brightness and location of maximum intensity of a set of bright radio sources. The DISPATCH command PEAKUP is used to perform an X + "+" pattern centered on the predicted location of the source. The measurements are recorded in a `PATTERN.DAT` file.

`pat2Off`: Offline, after all measurements are made, the pattern file `PATTERN.DAT` is read and a Gaussian is fit to each pattern. From this fit, the offset between the antenna encoder values and the predicted azimuth and elevation of the source is determined. These FITS are recorded in a `FIT` file. `pat2Off` is also produces an offset file containing the source offsets for each of the four frequency - polarization data sets.

`off2point`: After all patterns are measured, the `FIT` file is input to the pointing offset fit program. This program determines the pointing coefficients.

`offsetCalc`: Takes the offset output of `pat2Off` and calculates the average offsets between the separate beaks. `offsetCalc` calculates the average offsets of the X and Ku beams and the beam squint between the two pairs of LCP and RCP measurements.

`peakRatio`: The relative system gain is determined using the program `peakRatio`. This program reads an output file from `pat2Off` and calculates the ratio of the LCP and RCP gains at both X and Ku band.

<u>DISPATCH</u>

The DISPATCH commands used to point the antenna at radio sources are placed in several files. The first file contains a command to initialize antenna motion and the repetition of an `INCLUDE` command to make one series of observations of compact sources bright at 15 GHz. The file, called `point.cmds` is listed below:

```
STARTUP
BRAKEOFF

DEFINE PEAKUNIT=4CM
DEFINE PEAKPOL=A
DEFINE PEAKRAD=20'
INCLUDE /s3/ovlbi/in/pointlist.cmds
INCLUDE /s3/ovlbi/in/pointlist.cmds
INCLUDE /s3/ovlbi/in/pointlist.cmds
...
INCLUDE /s3/ovlbi/in/pointlist.cmds
STOW
```

The DISPATCH command file `point.cmds` contains five types of records

*1)* `STARTUP:` Initializes the antenna control unit and places the antenna under computer control.

*2)* `BRAKEOFF:` Releases the antenna breaks, allowing movement.

*3)* `DEFINE:` Assign names to command argument values. The arguments for the `PEAKUP` command are `DEFINE`d here. The arguments are `PEAKUNIT` are the receiver to use for locating the maximum source intensity, `PEAKPOL` the receiver polarization channel to be used for locating the peak intensity, and `PEAKRAD` the angular radius from the nominal source position to search for the source maximum.

*4)* `INCLUDE:` Includes other DISPATCH commands files for execution.

*5)* `STOW:` Directs the antenna to move to the stow position and set the antenna break.

These commands are described in detail in the "Dispatch Design Document". The file included by the DISPATCH pointing command file is `pointlist.cmds`, which contains a list of the coordinates of bright second radio sources and commands to search for the maximum intensity in the region near these sources. The contents of this file are listed below:

```
INCLUDE /s3/ovlbi/in/LATESTPOINTING

TRACK RADEC=350.8533d,58.8164d (CASA)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD

TRACK RADEC=83.6329d,22.0144d  (CRAB=TAURUS A, S=1000Jy)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD

TRACK RADEC=83.8187d,-5.3894d  (ORION A)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD

TRACK RADEC=49.9058d,41.5117d  (3C 84.0=0319+4130, S=43Jy)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD

TRACK RADEC=187.2784d,2.0516d  (3C273.0=1229+0203, S=34Jy)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD

TRACK RADEC=187.7057d,12.3909d   (3C274.0=VIRGO A, S=28Jy)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
```

```
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD

TRACK RADEC=272.3504d,-20.3169d  (W31)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD

TRACK RADEC=309.7550d,42.3292d    (DR21=HII S=20Jy)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD

TRACK RADEC=299.8678d,40.7337d    (CYGA)
PEAKUP TESTSEARCH=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
PEAKUP POINTING=60 UNIT=PEAKUNIT POLAR=PEAKPOL RADIUS=PEAKRAD
```

The point source command file `pointlist.cmds` contains three types of records:

*1)* `INCLUDE:` Includes other DISPATCH command files for execution, in this case a file initializing the pointing error model, based on previous pointing measurements.

*2)* `TRACK:` Directs the antenna to move towards a J2000 Right Ascension and Declination. (Other `TRACK` modes are supported, by not used for pointing measurements.)

*3)* `PEAKUP:` Directs to move in positions offset from the nominal tracking positions. During these "X" and "+" motions over the nominal positions, the system temperature is recorded.

The `PEAKUP` command arguments described below are used only for antenna pointing measurements and are not used in normal satellite tracking. The `PEAKUP` commands in `pointlist.cmds` cause DISPATCH to perform several consistency checks of the commanded Azimuth and Elevation before starting measurements. If the source being tracked lies below the horizon, the `PEAKUP` command exits immediately. In this way, it is possible to skip immediately to sources which are visible. If the source is above the horizon, the `PEAKUP` command causes the control system to wait for the antenna to arrive at its commanded location before beginning to gather data. It is not necessary to synchronize the pointing commands before taking measurements. With these command files, `DISPATCH` moves as rapidly as possible to the visible sources, making observations in rotation.

When `PEAKUP` is commanded with argument `TESTSEARCH=60`, the motion has a total duration of 60 seconds and a maximum in the system temperature is searched for, but not recorded. If the maximum satisfies some consistency checks, the location of the source maximum is used to calculate a constant pointing offset for azimuth and elevation. These pointing correction constants are added to all following pointing commands.

When `PEAKUP` is commanded with argument `BIGSEARCH=60`, the motion has a total duration of 60 seconds and a maximum in the system temperature is searched for, and the entire set of measurements are recorded in a file named PATTERN.DAT. The output file contains all pointing measurements in ASCII format, concatenated together, and separated by two lines describing the date and center coordinate of the observations. The output measurements are the difference between the antenna encoder values and the commanded azimuth and elevation. Since refraction is weather dependent (not an antenna constant), the output values *are* corrected for refraction effects. The pattern data are median filtered to remove variations in sky brightness before fitting.

A third file, containing the pointing coefficients is included by pointlist.cmds. This file, called LATESTPOINTING is listed below:

```
POINTCOR -5.87, 5.28,-6.61,-1.82,14.20, 6.61, 5.28,-1.05,-4.11
```

This DISPATCH command initializes the GBES pointing model with the input coefficients. The PEAKUP pointing offsets are also reset to zero.

## Pointing Model Calculations

The c program pat2Off is used to read in the measured data pattern (in PATTERN.DAT) and fit a four component Gaussian model to the data. The four components are *1)* height (kelvins), *2), 3)* X-offset, Y-offset (arc minutes) and *4)* FWHM size of the Gaussian (arc minutes). The fitting technique uses a non-linear least squares fit to the data with data weighted by the height of the point above the background level. Four fits are performed, one for each of the four bands of data gathered by dispatch.

After fitting the data to a model, the model is subtracted from the data. If the RMS noise in the subtracted pattern did not decrease, the pattern is rejected as not containing a valid measurement. Also, if the width of the Gaussian model exceeds 20 arc-minutes, the fit is rejected.

The program pat2Off produces a help message when executed without command line arguments. This message is shown below:

```
% pat2Off
pat2Off usage: pat2Off <Pattern.file> <date>
       where <Pattern.file> is a PeakUp pattern
       and   <date>         is the extension added to output files
 outputs: pat2Off.<date>    file of fits to measurements
          offSets.<date>    file of coordinate offsets for all bands
          peaks.<date>      file of peaks for all bands
```

The three output files are inputs to other offline processing files and may also be used as gnuplot input files for plotting.

The accepted offset fits to the data are logged in a file.

### off2point

The c program off2point is used to take the measured offsets and calculate the pointing equation fit, using a non-linear least squares solution to the pointing equation. The initial guess for the pointing fit is that of the last fit determined by Murphy and D'Addario, as described in GBES Memo 31. The calculating program `off2point` conforms to the convention of giving helpful messages if no command line arguments are given, as is shown below:

```
% off2point
off2point usage: off2point <fit.file> <fitType> <residFile>
       where <fit.file>     is an input list of fits
       where <fitType>      is an integer fit type
       where <residFile>    is an output residuals file
ie: off2point pat2off.aug7 10 resid
FitTypes -1: Linear Least Squares
FitTypes  0: No-fit, calculate residuals (from coded model)
FitTypes  1: 1 free parameter Non-Linear Least Squares
FitTypes  2: 2 free parameter Non-Linear Least Squares
FitTypes  3: 3 free parameter Non-Linear Least Squares
FitTypes  6: Fit azimuth using elevation parameters
FitTypes  7: Fit elevation using azimuth parameters
else        : Fit az, el and average common parameters
            : then re-fit holding common parameters fixed
```

The output of the execution of `off2point` for the 1994 August 7 observations is presented below. These calculations occur in 5 phases, *1)* independent elevation calculations, *2)* independent azimuth calculations, *3)* average common parameters *4)* elevation calculations with fixed parameters, and *5)* azimuth calculations with fixed parameters. First the elevation offset is calculated, followed by the azimuth offset. The averaging step, *3)*, consists of averaging $C_2$ and $C_7$, and $C_3$ and $-C_6$. The fits are then repeated, holding these values fixed.

```
% off2Point pat2Off.jan95 9 resid.jan95
Non-Linear Least Squares
FitNonLin: Holding       C[5] fixed at   3.0740e+01
   a[1]     a[2]     a[3]     a[4]     a[5]
   8.6600   4.7300  -6.0000  -0.0800
Iteration #  1      chi-squared:    50.9310    alamda:  1.00e-04
    a[1]     a[2]     a[3]     a[4]     a[5]
  -6.9416   4.9865  -6.5145  -1.4027  30.7400

Iteration #  2      chi-squared:    50.6638    alamda:  1.00e-05
    a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0733   4.9879  -6.5063  -1.2350  30.7400

Iteration #  3      chi-squared:    50.6638    alamda:  1.00e-04
    a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0733   4.9879  -6.5063  -1.2350  30.7400

Iteration #  4      chi-squared:    50.6638    alamda:  1.00e-03
    a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0733   4.9879  -6.5063  -1.2350  30.7400

Iteration #  5      chi-squared:    50.6638    alamda:  1.00e-02
    a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0733   4.9879  -6.5063  -1.2350  30.7400
```

```
Uncertainties:
2.553e-01 1.224e-01 1.237e-01 3.484e-01 0.000e+00
   a[1]     a[2]     a[3]     a[4]     a[5]
  30.7400   5.9900   6.3900   2.9700  -7.1300

Iteration #  1      chi-squared:    27.1562    alamda:  1.00e-04
    a[1]     a[2]     a[3]     a[4]     a[5]
  15.7985   6.5743   5.0348  -0.1224  -5.2435

Iteration #  2      chi-squared:    24.0678    alamda:  1.00e-05
    a[1]     a[2]     a[3]     a[4]     a[5]
  13.9747   6.4668   4.9789  -1.7983  -2.9236

Iteration #  3      chi-squared:    24.0630    alamda:  1.00e-06
    a[1]     a[2]     a[3]     a[4]     a[5]
  13.9009   6.4624   4.9769  -1.8681  -2.8283

Iteration #  4      chi-squared:    24.0630    alamda:  1.00e-05
    a[1]     a[2]     a[3]     a[4]     a[5]
  13.9009   6.4624   4.9769  -1.8681  -2.8283

Iteration #  5      chi-squared:    24.0630    alamda:  1.00e-04
    a[1]     a[2]     a[3]     a[4]     a[5]
  13.9009   6.4624   4.9769  -1.8681  -2.8283

Uncertainties:
1.082e+00 1.912e-01 1.867e-01 1.029e+00 1.380e+00
```

The common parameters are averaged: Averaging a[3] and -b[2], also a[2] and b[3] a[3] = -b[2] = -6.484372e+00, also a[2] = b[3] = 4.982380e+00. The final fitting progress is shown below:

```
FitNonLin: Holding       C[2] fixed at   4.9824e+00
FitNonLin: Holding       C[3] fixed at  -6.4844e+00
FitNonLin: Holding       C[5] fixed at   3.0740e+01
   a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0733   4.9824  -6.4844  -1.2350

Iteration #  1      chi-squared:    50.6958    alamda:  1.00e-04
    a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0796   4.9824  -6.4844  -1.2242  30.7400

Iteration #  2      chi-squared:    50.6957    alamda:  1.00e-05
    a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0797   4.9824  -6.4844  -1.2240  30.7400

Iteration #  3      chi-squared:    50.6957    alamda:  1.00e-04
    a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0797   4.9824  -6.4844  -1.2240  30.7400

Iteration #  4      chi-squared:    50.6957    alamda:  1.00e-03
    a[1]     a[2]     a[3]     a[4]     a[5]
  -7.0797   4.9824  -6.4844  -1.2240  30.7400

Uncertainties:
2.527e-01 0.000e+00 0.000e+00 3.432e-01 0.000e+00
```

```
FitNonLin: Holding       C[2] fixed at   6.4844e+00
FitNonLin: Holding       C[3] fixed at   4.9824e+00
   a[1]     a[2]     a[3]     a[4]     a[5]
  13.9009   6.4844   4.9824  -1.8681

Iteration #  1      chi-squared:    24.0781    alamda:  1.00e-04
    a[1]     a[2]     a[3]     a[4]     a[5]
  13.9393   6.4844   4.9824  -1.8369  -2.8752

Iteration #  2      chi-squared:    24.0779    alamda:  1.00e-05
    a[1]     a[2]     a[3]     a[4]     a[5]
  13.9515   6.4844   4.9824  -1.8251  -2.8911

Iteration #  3      chi-squared:    24.0779    alamda:  1.00e-04
    a[1]     a[2]     a[3]     a[4]     a[5]
  13.9515   6.4844   4.9824  -1.8251  -2.8911

Iteration #  4      chi-squared:    24.0779    alamda:  1.00e-03
    a[1]     a[2]     a[3]     a[4]     a[5]
  13.9515   6.4844   4.9824  -1.8251  -2.8911

Uncertainties:
9.918e-01 0.000e+00 0.000e+00 9.634e-01 1.274e+00

off2Point Results:
   El En    El axis  Az axis   Sag    El col.   El axis  Az axis    axes    beam
    C[1]     C[2]     C[3]     C[4]    C[5]      C[6]     C[7]     C[8]     C[9]
   -7.080    4.982   -6.484   -1.224   13.952    6.484    4.982   -1.825   -2.891
```

Note that although `off2Point` produces considerable output, the last few messages summarize the fitting results. If the uncertainties of the fitting results are large, the output residuals file should be examined to identify which input points appear to be corrupting the results. After editing the input, `off2Point` should be re-run.

## <u>offsetCalc</u>

The `c` program `offsetCalc` is used to calculate the average differences between the locations of maximum and nominal intensity based on the results of the program `pat2Off`. The program `offsetCalc` is used to reject data which does not contain valid measurements of the source location for all bands.

After rejecting invalid data, `offsetCalc` produces three sets of averages,

*1)* **X[A] - X[B]:** The average azimuth and elevation offsets between the two X band polarizations (X-band beam squint),

*2)* **Ku[A] - Ku[B]:** The average azimuth and elevation offsets between the two Ku band polarizations (Ku-band beam squint), and

*3)* **Ku[B] - X[B]:** The average azimuth and elevation offsets between the Ku-band B polarization channel and the X-band B polarization channel (miss alignment of Ku and X band optics).

Often the output of `pat2Off` must first be edited "by-hand" to remove spurious measurements, before running `offsetCalc`. The program `offsetCalc` conforms to the convention of presenting help information if no command line arguments are given:

```
% offsetCalc
offsetCalc usage: offsetCalc <offset.file>
       where <offset.file> is a 11 column offset measurement
```

<u>`peakRatio`</u>

The program `peakRatio` processes the third output of `pat2Off` to produce an estimate of the relative gain of the two polarizations of both X and Ku bands. The program takes two arguments, the name of a file containing measurements of the peak intensities of bright radio sources, and a minimum intensity, used to reject low signal to noise ratio data.

The program `peakRatio` also conforms to the convention of presenting help information if no command line arguments are given:

```
% peakRatio
peakRatio usage: peakRatio <peak.file> <minPeak>
       where <peak.file>    is a 7 column peak file
       where <fit.file>     is the minimum intensity (K)
```

The program execution for the data from 94 August 7 is shown below:

```
% peakRatio peaks.jan95 1
peakRatio: minimum Intensity 1.000000
#Azimuth Elevation   LST    Max XA   Max XB   Max KA   Max KB
-150.856   41.908 4.014102     6.96     4.68     2.57     2.16
#Azimuth Elevation   LST    Max XA   Max XB   Max KA   Max KB
-152.003   42.254 3.998031     6.95     4.81     2.71     2.15
-150.856   41.908 4.014102     6.96     4.68     2.57     2.16
-149.721   41.550 4.030174     6.66     4.71     2.73     2.18
 -25.431   16.558 4.242413     8.22     6.03     2.61     2.10
readPeak: closing file
peakRatio: Average of   83 measurements for X  Ratio (A/B): 1.495171e+00
peakRatio: Average of   25 measurements for Ku Ratio (A/B): 1.235950e+00
```