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TO: VLBA Acquisition and Processor Group

FROM: Alan E.E. Rogers

SUBJECT: Fringe Processing - Mk III Algorithms

The Mk III fringe processing program "FRNGE" runs on the HP1000 F-Series computer as a "quasi" post processing program. As soon as correlator output is available on disk the fringe program processes the correlator output for each baseline. The program is written in FORTRAN and uses a highly efficient microcoded FFT Subroutine so that the modest computing power of the HP1000 is sufficient to keep pace with the 4-station processor. The program searches for the strongest signal within a specified window in delay and delay rate. Having found the strongest signal it "counter-rotates" the visibility data with the values of delay and delay rate which maximize the correlation amplitude. The values of delay and delay rate are used for astrometric/geodetic analysis while the visibility data are used for hybrid and phase reference mapping. Algorithms are as follows:

1. Normalization.

The correlator outputs are normalized and correction factors applied.

2. Derive Spectrum.

The correlation function for each video channel is transformed from delay lags to video frequency.

3. Fractional Bit Shift Correction.

The fractional bit shift correction is applied for each accumulation period (typically two seconds) over which many "bit shifts" may have occured. (This is a simple calculation and requires only a small amount of computing compared with the FFTs which dominate the CPU.)

4. Sideband Addition.

If data were taken with both sidebands the data from both upper and lower sidebands are combined into one cross-spectrum for each pair of correlated video signals or frequency channel.

5. Derive "Single Band" Delay function.

Each frequency channel is transformed back to delay. This is equivalent to averaging over video frequency for several values of delay. This simplifies the fringe search task for bandwidth synthesis over a wide spanned bandwidth.

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6.1 Transform to Fringe Rate.

Each frequency channel is transformed from the time domain to the fringe rate domain. For example a scan of 500 2-second accumulation periods is transformed to 512 fringe rate channels covering -250 milliHertz to +250 milliHertz.

6.2 "Grid" Into the Delay Rate Domain.

The fringe rate axis is converted to a common delay rate axis appropriate for all frequency channels. This step is needed to avoid smearing of the fringes among frequency channels which will have residual fringe rates proportional to the observing frequency. Reversing the order of transformation does not solve this problem. If the data is first transformed to bandwidth synthesized delay or multi-band delay then the delay resolution is sufficient to produce a smearing in delay over the coherent integration interval. If axes are not "regridded" or rescaled a fringe search with 1000 seconds coherent integration would be limited to about ±15 milliHz at 8 GHz for a spanned bandwidth of 300 MHz. The phases are calibrated using phases derived from the coherent averaging of the phase calibration signals over the same coherent integration period.

6.3 Transform to Multiband Delay.

All the frequency channels are transformed to a "multiband" delay function for each value of delay rate.

6.4 Search for the Maximum.

The "pseudo" 3-dimensional array of complex correlation amplitudes as a function of single band delay, multi-band delay and delay rate is searched for a peak magnitude and the values of delay and delay rate which produce the maximum value are saved. Since the multiband and single band delay are not independent quantities the array is really 2-dimensional and the separation into single band or coarse and multiband or fine delay is largely a computational convenience which greatly reduces the size of the FFTs needed to derive the full delay function. For example, a window of ±1 microsecond would require a 1024 complex transform to cover a spanned bandwidth of 500 MHz while splitting up the delay allows the same range to be covered with 16 64-point transforms if the minimum spacing between frequency channels is 10 MHz. While the single band and multiband delays are connected they may not be equal unless they are calibrated. The single band delay depends mainly on the epoch of the sampling in the formatter. While the multiband delay depends on the local oscillator phases in a system without phase calibration and on the phase calibration phases in a system in which delay calibration pulses are injected into the front-end.

7.1 Computation of Delay and Delay Rate.

In order to accurately determine the delay and delay rate the correlation amplitude is determined for a fine grid of points around the values found by the search procedure. In addition, the data is counter rotated with the best fit values of delay and rate to obtain amplitudes and phases for time segments of the full coherent integration.

The algorithms are now repeated in somewhat more detail and a sample FRNGE output is given (this level of FRNGE printout is normally only used for diagnostic purposes):

```
Algorithms used in FRNGE
NORMV-Normalization routine
1. Normalization
   RCos(k)=F*(2*a(k)-c)/c
   RSin(k)=F*(2*b(k)-c)/c
         where a(k)='cosine' output of the correlator
               b(k)='sine' output of the correlator
               c=# of bits correlated in the accumulation period
               k=correlation lag index 1 to 8
               F=normalization factor
               RCos=real component of the normalized correlation
                    in units where 10,000 = 100% correlation
               RSin=imaginary component
   F=(PI/2)*(3/4)*(PI/(4*cos(PI/8)))*(1/(1-PI*PI/288))*10,000
         where 1st factor=clipping correction
               2nd factor=ratio # bits correlated to # bits in accumulation
                          period(1/4 of the time the 3 level approximations
                                 of the sine and cosine functions are zero)
               3rd factor=rotator correction from Whitney et al
                          Radio Science,vol 11,pp 421-432,May 1976
               4th factor=correction for loss in making fractional
                          bit correction automatically within the correlator
2. Derive Spectrum - using 16-point FFTs
         k=8
   S(w)=SUM(RCos(k)-SIGN*i*RSin(k))exp(-2*PI*i*(k-5)*w/16)
         k=1
          where  w=1 to 7=frequency index(w=1=12.5%bandedge,w=7=87.5%bandedge)
               SIGN=+1 for positive fringe rate
               SIGN=-1 for negative fringe rate - to compensate for the
                     correlators ability to perform only positive rotation
               i=SQRT(-1)
3. Fractional bit correction -if no bit shifts are made in correlator
                              during an accumulation period
   S'(w)=S(w)(exp(-2*PI*i*w*FB/16))*(1-PI*PI/288) w=1 to 7
         where FB=Apriori delay minus delay applied through bit shift
                  at the center of the accumulation period
               FB is in units of the sample interval
   Fractional bit correction -if bit shifts are made in the correlator and
                              are accompanied by 90 deg jump in rotator phase
   S'(w)=S(w)exp(-2*PI*i*(w-4)*(FB+DD)*(1-INT(SH)/SH)/16) w=1 to 7
         where SH=# bit shifts in accumulation period
                  a positive floating point number
               INT(SH)= integer # of shifts applied - a positive number
               DD=+0.5 if INT(SH) is odd and FB<0
               DD=-0.5 if INT(SH) is odd and FB>0
               DD=0 if INT(SH) is even
4. Add together both sidebands
            Su+l(w)=Su(w)    w=1 to 7
            Su+l(w)=CONJ(Sl(-w)) w=-1 to -7 if lower sideband present
                   =0         w=0 (D.C.)  and w>7 and w<-7
                              i.e. rest of array is filed out with zeroes
            where  Su+l  is the combined cross-spectral function
                   Su    is the upper sideband
                   Sl    is the lower sideband
5. Derive the "single band" delay function - using 32-point FFTs
         w=7
   B(d)=SUM S(w)(exp(-2*PI*i*(d-9)*w/32))/7
         w=-7
         where d=delay index 1 to 16 (d=9=central index)
```



```
               d has units of half the sample interval
              (note that the delay function is a complex function and is NOT
              the same as (Rcos(k)-SIGN*i*RSin(k)) )
SEARC-fringe search routine
1. FFT-to fringe rate domain -using at most 14 1024-point FFTs
         t=tmax
   D(L,d)=SUM B(t,d)exp(-2*PI*i*(L-LD/2-1)*(t-1)/LD)
         t=1
         where t=1 to tmax = time sample number
               tmax less than equal to 512
               D(t,d)=delay function D(d) for time sample #t
               L=fringe rate index number 1to LD
               LD.LE.1024.and.LD.GE.tmax*2
               i.e.LD is made as large as practical for best interpolation
               D(L,d)=single band delay func. as a func. of fringe rate
2. Sort(or "grid") into delay rate domain and correct for phase cal phase
   D(n,L,d)=(D(n,L',d)*(1-a+L')+D(n,L'+1,d)*(a-L'))exp(-i*A(n))
           a=AMOD((L-LA/2-1)*(f(n)/f(1))*(LD/LA)+(LD*3/2),LD)+1
           L'=INT(a)
           where n=frequency channel index number 1 to 14(max)
                 f(n)=magnitude of total LO frequency of nth ch. in MHZ
                 L=delay rate channel number from 1 to LA in units of
                   1/(LA*f(1)*DT)  microsec per second
                 LA.GE.tmax.and.LA.LE.LD
                 DT=time interval between time samples in seconds
                   i.e. DT= accumulation period
                 A(n)=phase cal. phase(difference station 1 -stn.2) for nth channel
                 AMOD=modulo function
                 INT=truncate to integer value
3. Calculate multi-band delay function  -using at most 512 256-point FFTs
           n=nmax
   D(k,L,d)=SUM D(n,L,d)exp(-2*PI*i*FS(n)*(k-N/2-1)/N)
           n=1

           FS(n)=(f(n)-f(1))/(largest common denominator in the spacing
                                                  between frequencies)
           where k=fine delay in units of
                 1/((largest common spacing)*N)  microseconds
                 N=number of points in FFT required to cover all spacings
                   i.e. N>(maximum value of FS(n)- minimum value of FS(n))
4. SEARC finds values of k,L and d which maximize the magnitude of D(k,L,d)
           where (in a full range search)
                 k runs from 1 to N (k=N/2+1 = central index)
                 L  "     "  1  " LA(=512 maximum)
                 d  "     "  1  " 16
INTR-interpolation routine to find interpolated values of k,L and d
1. Calculate multi-band delay function at single points by direct rotation
           n=nmax t=tmax
   D(T,R,d)=SUM   SUM D(n,t,d)*VROT(T,R,d,n,t)
           n=1    t=1
   VROT(T,R,d,t)=exp(-2*PI*i*(f(n)*R*(DT*(t-1)-E(n))+A(n)
                    +(f(n)-f(1))*T+(d'-d)*B/8))
         where  R=delay rate in microsec per sec
                T=multi-band delay in microsec
                E(n)=Epoch of Apriori calculations relative to time of
                     1st sample (t=1)
                     +ve sign Apriori calculated for a time earlier than
                     the time of the 1st sample
                d'=interpolated single band delay index
```

S=+1 for upper sideband
S=-1 for lower sideband
S=0 if both sidebands are added

2. A parabola is fit through 3 points (using the magnitude of D) where the central point is the current best estimate of T,R and d and the other two points are equally spaced on either side of the central point.

   To estimate the delay rate R the spacing between points is initially:

   1/(LA*f(1)*DT) (i.e.=spacing between delay rate points in SEARC)

   and to estimate delay T the spacing between points is:

   1/((largest common denominator of freq. spacing)*N)

   To estimate the single band delay the spacing between points is half the sample interval.

3. INTR estimates R,T and then d in two iterations and then a 3rd iteration is performed in which the spacing between points for R and T is reduced by a factor of 2.

NOTES:

a) Constrained FRNGE processing

If there are fringes on 2 baselines of a triangle but none on the third to determine the rate, single and multi-band delays for the third baseline and RE-FRNGE with constraints in FRNGE parameter file. (A program called TRGEN can be used to generate the FRNGE parameter file.)

b) Constrained FRNGE processing in the presence of severe atmospheric phase fluctuations

If there are fringes on 2 baselines of a triangle but none or weak fringes on the third determine the approximate rate, single and multi-band delays for the third baseline and RE-FRNGE. Then run FRNGX on FRNGE output to generate segmented complex outputs. A program called AVPHS will then perform the following operation from the FRNGX "A" file output:

AMP (BC) exp iP(BC)=<AMP(BC,t)exp i(P(BC,t)-P(AC,t)+P(AB,t))>

AMP(BC) and P(BC) are optimal estimates of the amplitude and phase (closure phase) on the third baseline. The segments should be made short enough to minimize loss due to atmospheric phase fluctuations. AMP(BC) should be corrected for phase noise loss on baselines 1 and 2 according to the loss factor theorem (see attached memo).

c) Global FRNGE search on 3 baselines simultaneously

FRNGE data with expected single band delay (use calibrator data to determine) then run FRNGR on each of the 3 baselines (using adjacent calibrator, scans for reference). Map size should be chosen large enough to accomadate both position uncertainties and clock rate uncertanties (translated into RA and DEC). Run FRNGT to add together the 3 baselines either incoherently or coherently. A coherent addition is appropriate if there is an apriori reason to assume the closure phase is close to zero. Incoherent addition is appropriate if there is no constraint on the closure phase. A significant peak in the map will indicate the presence of fringes. Clock rate errors will produce an apparent position error while clock closure is constrained.

d) Global FRNGE search on independent baselines

Same as in c) but add together all independent baselines from as many scans as desired.

e) Phase reference mapping

Run FRNGR on FRNGE output for all scans and all baselines with appropriate coordinate offsets and map width. Run FRNGT on the FRNGR output to construct the "dirty" phase reference map. A clean map can be generated by running any standard mapping package on the "offset" complex amplitudes from FRNGT. Region being mapped must be within one single-band delay beamwidth of the reference or FRNGE must be forced to run with appropriate single-band delay. The reason is that the FRNGE output contains complex amplitudes for all frequency channels but for a only one value of single-band delay.

f) "Export" interfaces

For geodesy/astrometry the best interface is via the GSFC CDP database generator which runs directly on the FRNGE output files. The normal astronomy interface is via FRNGX which generates visibility data for a selectable coherent integration period from the FRNGE output files. One minute coherent integration in normally selected and the data from all frequency channels are normally coherently added. For mapping which requires a field of view greater than the size of the multiband delay beam the visibilties from each frequency channel can be used separately. The visibility phases from the FRNGX output are normally selected to be residual to the COREL apriori values which close so that the FRNGE/FRNGX process just filters the visibilities and GLOBAL fringe fitting can be done in the AIPS package provided the fringes were strong enough to determine delay and rate filters or adequately precise control windows must be derived from calibrator sources.

Additional notes:

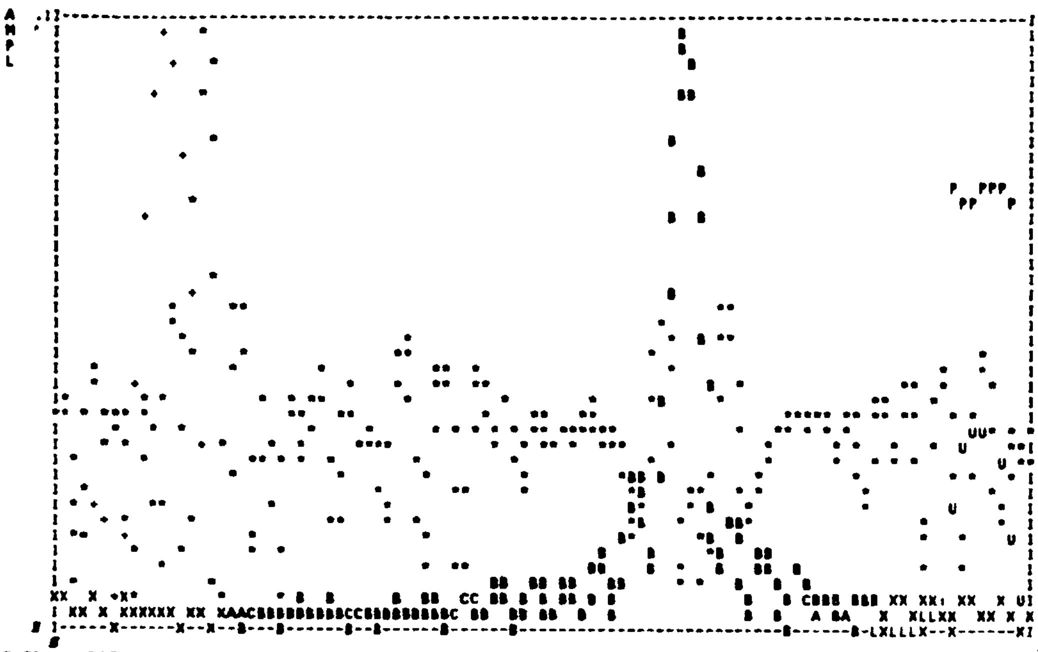
1) Without constraints FRNGE searches through a range of delay and delay rate for a maximum magnitude. Statistics of magnitude is Rayleigh and a "significant" detection depends on number of delay-rate beams searched (see probability of false detection of FRNGE printout), but generally an SNR of greater than 7 is required for high confidence. If FRNGE is run in a contrained mode it rotates the COREL output with specified delay and rate i.e. it determines the complex amplitude within a specified delay-rate beam.

2) FRNGT forms a "dirty" map in which each point has gaussian statistics so that significant detections can be made at SNR's below 7. However if a very large region is searched it should be realized that SNR _> 3 will be seen every 100 points. On the other hand there is an SNR = 3 at the expected point in a map will only be a false detection 1% of the time.

3) Transfer files exist to facilitate many of the special FRNGE, FRNGX, FRNGR, FRNGT operations:

*CLOSE   transfer file for procedure b)
TRGEN   generates transfer files for running FRNGR

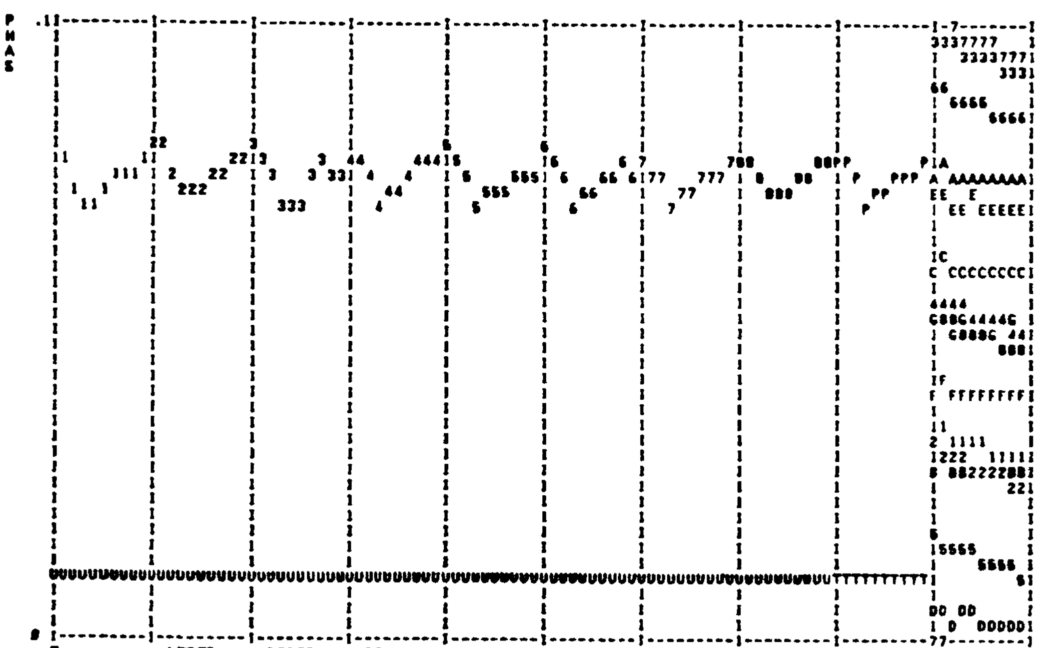
EOF on FNGR file *FRNGE after reading 232 records with approx 12000. chars



```
246-1059      FROG X
02SEP.84     3C273B
GILCREEK-HAYSTACK=AK
11.3  ELEV(DEG) 49.0
FILE(61059::49, 40 )
BN(FR/ASEC)=  211.66
BE(FR/ASEC)= -424.46
EXP POLAR-2  #   439
STARTTIME 185958.000
STOP TIME 190046.000
INTG.TIME  60.000SEC
SEARCH WINDOW WIDTHS
SINGLB(=) 1.300000US
MULTIB(#)  .100000US
RATE  (X)      .320HZ
FREQ SB INDEX#S CAL
 8210.99U 1  0 41 56
 8220.99U 2  0 41 57
 8250.99U 3  0 40 50
 8310.99U 4  0 38 44
 8420.99U 5  0 36 54
 8500.99U 6  0 39 47
 8550.99U 7  0 36 50
 8570.99U 8  0 37 54

FRPRGA400602 CORELO 4
AMP       119.271X.01X
SINGLBAND  .203604US
MULTIBAND -.035073US
FR.RATE    .067925HZ
DC=  0.00X  60.00SEC
XP=.68E-06YP=.14E-03
XCRC=   0.YCRC=    0.
TDIS=   0.NOIS=    0.
DRVS 41 STAT= 000364
SNR   281.9MODE40001
.1200E+03
```

```
E+03     RATE+/-  .25HZ .0304NS/S DELAY+/- .050US SRCH WIDTH(RATE,SBDLY)+/- RA  4.70,12.67 DEC142.0,25.22ASEC
# FREQUENCY EXT#(R,P) PRC#(R,P)  REFERENCE  REMOTE TRKS     PARTNER       TRKS     FRQIN#(R,P)#ACC.PER(R,P)CORR#(R,P)OFFSET(R,P)
 1    8210.99  1, 0 84271,70000 16=.41E-06   16=.12E-03 2  0=.00E+00   0=.00E+00        1, 0   29.., 0.    100, 0      0,   0
 2    8220.99  1, 0 84271,70000  2=.10E-10    2=.13E-03 2  0=.00E+00   0=.00E+00        2, 0   29.., 0.    101, 0      0,   0
 3    8250.99  1, 0 84271,70000 10=.10E-10   10=.20E-03 3  0=.00E+00   0=.00E+00        3, 0   29.., 0.    109, 0      0,   0
 4    8310.99  1, 0 84271,70000  4=.69E-07    4=.16E-03 2  0=.00E+00   0=.00E+00        4, 0   29.., 0.    102, 0      0,   0
 5    8420.99  1, 0 84271,70000 20=.33E-05   20=.17E-03 2  0=.00E+00   0=.00E+00        5, 0   29.., 0.    110, 0      0,   0
 6    8500.99  1, 0 84271,70000  6=.14E-06    6=.96E-04 2  0=.00E+00   0=.00E+00        6, 0   29.., 0.    103, 0      0,   0
 7    8550.99  1, 0 84271,70000 22=.69E-06   22=.10E-03 2  0=.00E+00   0=.00E+00        7, 0   29.., 0.    111, 0      0,   0
 8    8570.99  1, 0 84271,70000  0=.10E-10    8=.10E-03 2  0=.00E+00   0=.00E+00        8, 0   29.., 0.    104, 0      0,   0
#POINTS SRCHED  .2611E+06 PROB OF FALSE DET .00E+00  PCAL RATES(MICROSEC/SEC) -.1275E-05-.3498E-07  MAX PER .30E-01 FS 10.00MHZ
```



```
246-1059      FROG X
02SEP.84     3C273B
GILCREEK-HAYSTACK=AK
11.3  ELEV(DEG) 49.0
FILE(61059::49, 40 )
BN(MHZ/ASEC)   -1.16
BE(MHZ/ASEC)  -34.90
EXP POLAR-2  #   439
STARTTIME 185958.000
STOP TIME 190046.000
INTG.TIME  60.000SEC
SEARCH WINDOW WIDTHS
SINGLB(=) 1.300000US
MULTIB(#)  .100000US
RATE  (X)      .320HZ
FREQ SB INDEX#S CAL
 8210.99U 1  0 41 56
 8220.99U 2  0 41 57
 8250.99U 3  0 40 50
 8310.99U 4  0 38 44
 8420.99U 5  0 36 54
 8500.99U 6  0 39 47
 8550.99U 7  0 36 50
 8570.99U 8  0 37 54

FRPRGA400602 CORELO 4
AMP       119.271X.01X
SINGLBAND  .203604US
MULTIBAND -.035073US
FR.RATE    .067925HZ
PEXD=   0.PEYD=    0.
STATN 70202 CRCMSK04
SUPR=   0.PPUP=    0.
XSLP=   0.YSLP=    0.
TSLP=   0 ERCC=    0
SNR   281.9AP 0 LN 0
```

```
E+03    FRINGE PHASE(-180 TO +180 DEG) AND AMPLITUDE AS A FUNCTION OF TIME BY FRQ. CHANNEL      PCAL PHASES
          FRQ# 1 FRQ# 2 FRQ# 3 FRQ# 4 FRQ# 5 FRQ# 6 FRQ# 7 FRQ# 8 FRQ# 9 FRQ#10 FRQ#11 FRQ#12 FRQ#13 FRQ#14 ALL CHANS     0  0
PHASE =     87.3   91.1   89.4   88.7   87.2   88.9   87.7   91.1    0.0    0.0    0.0    0.0    0.0    0.0   88.9  #SG=10
FR. AMPL   118.6  118.9  120.9  119.0  122.7  120.9  117.8  115.7    0.0    0.0    0.0    0.0    0.0    0.0  119.3  GNA= 5.33H
PCALPH1    -66.7  -70.8  161.0   18.7 -131.0  133.4  171.4     .7    0.0    0.0    0.0    0.0    0.0    0.0         EP1=  -8.0
PCALPH2     89.7  -81.1   37.4 -166.7   75.6  -35.6    6.0  -33.0    0.0    0.0    0.0    0.0    0.0    0.0         EP2= -21.0
SBDBU/#     11.3   11.4   11.3   11.4   11.3   11 1   11.2   11.3    0.0    0.0    0.0    0.0    0.0    0.0   11.3  BW=2 00MHZ
PARAM FILE #FR439::54,    0 SRCH RNGE PARAMS  -.200000E-04  .200000E-04 -.500000E-01  .500000E-01 -.500000E+00   700000E+00
GROUP DELAY USEC       .1104065593690+05 APRIORI DELAY USEC     - 1104BE7006370+0' RESIDUAL DELAY USEC  -.350732E-01  +/-  40E-05
SNGLBAND DEL USEC     -.1104033726010+05 APRIORI CLOCK USEC     .9600000000000D+01 RESIDUAL DELAY USEC   .203604E+00  +/- .98E-07
PHASE DELAY USEC      -.1104062003360+06 APRIORI CLOCK US/S     .0000000000000D+00 RESIDUAL DELAY USEC   .000000E-04  +/- .14E-06
PHAS DEL RATE US/S     .7769793724610+00 APRIORI RATE US/S      .77697100075000+00 RESIDUAL RATE US/S    .036496E-05  +/- .41E-08
TOTAL PHASE DEG       -64.4 (-206.0)      APRIORI PHASE DEG            -153.3      RESIDUAL PHASE DEG    88.9(  88 8)+/-   .41
EPOCH HHMMSS.         185958. (*190019. ) REF FREQUENCY MHZ             8210.99    AMP  119.271(  120.574)+/-  .423 DF= 9 QB=0.X
RA 122633.246 DEC  21543 470      1950.0 APRIORI ACEL US/S/S   .64022042360070-04 REI.ST.CL.EPOCH MS    .000000E+00 TAPED=699425
RMS PH/SEG DG  8.6 RMS AMP/SEG X  1.5 RMS PH/FRQ DG  1.5 RMS AMP/FRQ X  1.7 TH.RMS   .6   1 1   .5   .9 84277:2122:36
OUTPUT IN EXTENT#     4          06 RECS OUTPUT IN CR#    49      SEARCH AMP.INTRP AMP   112.216  113.571 (128X256) OPT 00000S
```

```
EXPLANATION OF FRNGE PRINTOUT:

PLOT#1 5 superimposed plots of:
1) Fringe rate spectrum-plot symbols 123456789ABCDEFG give singleband delay
     1 indicates a residual single band delay of -4 lags(-1 microsec at 2MHZ)
     8 indicates a residual single band delay of-Ø.5lags
     9 indicates a residual single band delay of  Ø lags
     G indicates a residual single band delay of 3.5lags
     X indicates a residual single band delay outside search range
     ^ value off top of plot
 Plot center +4 inches from left edge = Ø residual rate
 Plot full scale amplitude given in units of Ø.Ø1% correlation
2) Single band delay resolution plot symbols + or = when outside search
   Plot starts at 1 point from left edge and runs for 16 points
3) Multi-band delay resolution plot symbols * or # when outside search
   Plot center +4 inches from left hand edge =Ø residual delay
4) All points in 3-dimensional search that have SNR greater than 4 sigma
   Plot symbols 123456789ABCDEFG
  which indicate the single-band delay as in the fringe rate spectrum
  plot.The delay rate of each point is plotted on the same scale as the
  fringe rate spectrum. The multi-band delay of each point is not indicated
  and while the amplitude of each point is scaled in units of Ø.Ø1% the
  points are NOT interpolated and can be as much as 36% low in amplitude.
  Points in this plot are plotted on a character replacement basis : that
  is if 2 points fall on the same point on the page the second point is
  plotted. However search points have priority and are not replaced by
  points from any of the other plots.
5) Cross-spectrum amplitude and phase - only plotted if correlation
  amplitude is greater than 1ØØxØ.Ø1%.
   Plot symbols L:UP
         L indicates lower sideband
         : indicates D.C.
         U indicates upper sideband
         P indicates phase on scale -18Ø deg to +18Ø deg
PLOT#2  superimposed time segmented plots of
1) Fringe amplitude and residual phase for each frequency
   Plot symbols 123456789VWXYZ indicating phase and frequency #
         U indicates that upper sideband predominates
         L indicates that lower sideband predominates
         A indicates that both sidebands are equally represented
  Scale: phase -18Ø deg to +18Ø deg ,amplitude full scale=1Ø% full plot
        (phase is the residual to sum of COREL and FRNGE models, and has
         been corrected for phase cal phases)
2) Fringe amplitude and phase for all frequencies coherently added
   Plot symbols P indicates phase and T indicates amplitude
3) Phase calibration phases by station and frequency
   Reference station plot symbols 123456789VWXYZ
   Remote  station plot symbols   ABCDEFGHIJKLMN
   TIME SEGMENTATION for these plots is 5Ø segments for a single frequency
   processed, 11 segments for 7 frequencies and 6 segments for 14 freqs.
   The first segment for each frequency,all frequencies combined and
   phase cal phases is plotted on the relevant dividing grid.The first
   segment starts at the start time indicated and the last segment stops
   at the stop time indicated.

INFO ON SIDE OF PLOTS

RUN - day of year - hour hour min min  FRQG -frequency group 2-letter name
DATE   SOURCE
```



```
REFERENCE STATION - REMOTE STATION = 2-letter baseline code
elevation of reference station deg ELEV(DEG) elevation of remote station
FILE NAMR,frnge output extent# & baseline number
BN(FR/ASEC)= fringes per arcsecond in direction of increasing declination calculated for the REFERENCE frequency
BN(MHZ/ASEC)=fringe rate/arcsec in milliHertz in dir. of incr.decl.
BV(FR/ASEC)= fringes per arcsecond in direction of increasing R.A.
BV(MHZ/ASEC)=fringe rate/arcsec in milliHertz in dir. of incr. R.A
EXP experiment name and number
STARTTIME HHMMSS.SSS  (time of start of first accum period-unless forced)
STOP TIME HHMMSS.SSS  (time of start of last accum period-unless forced)
INTG.TIME effective integration time in seconds
SEARCH WINDOW WIDTHS full widths
SINGLB(+) width in single band delay search = marks region outside search
MULTIB(#) width in mult-  band delay search # marks region outside search
RATE  (X) width in delay rate in HZ  search X marks region outside search
FREQ SB INDEX#S CAL
freq.in MHZ(U=USB,L=LSB,blank=DSB) correl USB index# LSB index#
reference station cal voltage remote station cal voltage
cal amplitudes are given in units of Ø.1% in voltage.The product of reference
and remote give cross-power of phase cal in units of Ø.ØØØ1%. Phase cal voltages
should be between 1Ø and 1ØØxØ.1% in voltage.
FRPRG frnge program date YYMMDD  COREL# corel version #
AMP correlation amplitude in units of Ø.Ø1% corrected for smearing that
    occurs during accumulation period at large residual fringe rates.
    For low SNRs the amplitude is NOT but should be corrected for noise
    by reducing the number by Ø.5*((1/SNR)**2)%.
SINGLBAND residual single-band delay in microseconds (single band delay
          is coherently determined by FRNGE from all frequency channels)
MULTIBAND resiual multi-band delay in microseconds
FR.RATE residual fringe rate for reference frequency in Hertz
        uncorrected for phasecal. rates
DC= percentage of data discarded - actual duration of run (stop-start)
XP=average parity error rate for all tracks processed for ref.station
YP=average parity error rate for all tracks processed for rem.station
XCRC=#cyclic redundancy check errors for ref."X"   input to correlator
     total number in data acceptped and rejected(bit Ø CRCMSK)
SUPR=#accum.periods discarded due to suppression by correlator(bit 14 STATM)
YCRC=#cyclic redundancy check errors for remote "Y" input to correlator
     total number in data accepted and rejected(bit 1 CRCMSK)
PPUP=#accum.periods discarded due to no parameter update(bit 7 STATM)
TDIS= total number of times decoded that were unexpected
YSLP=#accum.periods discarded due to Y sync slip(bit 5 STATM)
TSLP=#accum.periods discarded due to Tapes out of sync(bit 13 STATM)
ERCC=#accum.periods during which an error correction was initiated(bit 3 CRCMSK)
NDIS=total # of accumulation records not processed through frnge
XSLP=#accum.periods discarded due to X sync slip(bit 4 STATM)
PEXD=#accum.periods discarded due to high parity error rate in X data(set by MAX PER)
PEYD=#accum.periods discarded due to high parity error rate in Y data(set by MAX PER)
STATM correlator error status mask(normal 7Ø2Ø2B)
CRCMSK crc error mask (normal  4B)
SNR signal to noise ratio in units of sigma-NOTE that runs with SNR
    less than 7 carefull tests( like comparing fringe delay and rate residuals
    for adjacent runs) need to be made to be sure that fringes are real and
    not just noise.
MODE correlation modes see correlator manual for definitions
AP #accum.periods discarded due to AP overrrun in correlator(bit 12 STATM)
LN #accum.periods discarded due to large numbers from correlator
DRVS ref. and rem. tape drive #s
STAT= processing status for module of ref. track of FREQ# 1
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INFO BELOW PLOT #1

RATE+/- half scale plot width(4 inches on paper) in Hertz and nanosec/sec
DELAY+/- half scale width of multiband delay resolution plot in microsec
SRCH WIDTH(RATE,SBDLY)+/- half widths of region in the sky covered
 by the search windows used: width in RA due the rate window,due to single
 band delay then dec width due to rate window,due to single band delay
  in units of seconds of arc.
FRQ# Fringe frequency number
FREQUENCY frequency in MHZ
EXT#(R,P) file extent# from which frnge found data for reference/partner sideband
PRC#(R,P) correlation processing dates Year(10=1980) DAY# for reference/partner
REFERENCE track#=parity error rate for reference station ,#slip syncs accepted
REMOTE     track#=parity error rate for remote    station ,#slip syncs accepted
           error rate= 10E-20 indicates zero error rate
           error rate=.00E 00 indicates no data processed
PARTNER        track#=parity error rate for partner(normally USB) tracks
FRQIN#(R,P) Correl frequency index#s for reference/partner sideband (-ve for LSB)
#ACC.PER(R,P) #of acculation periods processed through fringe reference/partner
CORR#(R,P) correlator module number reference/partner sideband
OFFSET(R,P) correlator delay offset for each module in lags
#POINTS SEARCHED #points searched in frnge search
PROB.OF FALSE DET. estimated probability of a false detection of fringes
PHASCAL RATES(MICROSEC/SEC) phasecal drift rates for reference,remote statns.
MAX PER parity error rate above which data is discarded
FS      minimum frequency spacing -group delay ambiguity =1/FS

UNDER PLOT#2

PHASE= phase in deg for each frequency followed by phase for all freqs.
NSG= number of segments used by FRNGE to calculate quality code
FR.AMPL fringe amplitudes for each frequency in units of 0.01%
GHA= greenwich hour angle for source in decimal hours
PCALPH1 phasecal phases in degrees for reference station
EP1= time of first accumulation processed through fringe in sec minus epoch
EP2= epoch minus average time or center of the run
PCALPH2 phasecal phases in degrees for remote    station
        360 degrees indicates that a manual phase cal has been used
        whose value is in PCALPH1
SBDBOX# single band delay box # for independent search in each frequency
        at the fringe rate determined for the coherent addition of all
        frequencies. These numbers are only meaningful in the case of
        fringes strong enough to be detected in each frequency independently
BW= band width of each recorded track in MHZ
PARAM FILE parameter file used to set up the fringe search parameters
           NAME,pointer number
SRCH RNGE PARAMS search parameters residual delay rate start,delay rate stop
       in microsec/sec,multiband delay start,stop in microsec, single
      band delay start,stop in microsec
GROUP DELAY USEC Group delay in microsec ambiguity selected closest
      to APRIORI delay (set equal to SNGLBAND DEL if only one freq. present)
SNGLBAND DEL USEC Single band delay determined from the coherent addition
      of all frequency channels
PHASE DELAY USEC  Phase delay expressed in microsec ambiguity selected closest
      to APRIORI delay
PHAS DEL RATE US/S phase delay rate after correction for phasecal. rates
TOTAL PHASE DEG total observed phase at EPOCH given below
                phase is positive when wavefront arrives at remote station late
```



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                this definition holds regardless of sideband and is consistent
                with the definition of delay
EPOCH HHMMSS. epoch for observables number in parenthesis is central epoch
               computed by FRNGE for accepted data - delay,rate and phase for
               this epoch are in output file but not on printout
               (if there if an "*" in front of this time FRNGE was
                with the option NOT to call VDELY and mean epoch
                numbers will not be in output)
                 phase in parenthesis is total phase for an epoch
                 given by the time a wavefront passes the reference
                 station and arrives at the center of the earth at EPOCH.
                 Thus the epochs are defined by a particular wavefront -
                 the same for all baselines - and not by universal time
                 at the reference station.
RESIDUAL PHASE DEG phase residual to the COREL model at EPOCH
                   corrected for phase cal phases - to uncal phaseuncal=
                   phase+PCALPH1-PCALPH2  Phase in parenthesis is the
                   residual phase corrected to an EPOCH at which the
                   wave front reaches the center of the earth.
AMP      correlation amplitude in units of 10000.Number in parenthesis is
         the incoherent sum of fringe amplitudes for each segment
         corrected for the theoretical noise i.e. reduced by the
         factor 1+1/(2*(segment SNR)**2)
QF= quality factor of the run.0= no fringes 3=poor,9=good
          i.e. higher numbers indicate better quality
QF quality factor starts at 9 and is reduced by:
      1 point if RMS PH/SEG >11.46 and theoretical RMS < 5.73
      2 points if RMS PH/SEG >22.92 and theoretical RMS <11.46
the factor is further reduced by:
      1 point if RMS AMP/SEG >20.00% and theoretical RMS <10.00%
      2 points if RMS AMP/SEG >40.00% and theoretical RMS <20.00%
the factor is futher reduced by:
      1 point  if RMS PH/FRQ  > 11.46 and theoretical RMS < 5.73
      2 points if RMS PH/FRQ  > 22.92 and theoretical RMS <11.46
the factor is further reduced by:
      1 point  if RMS AMP/FRQ  > 20.00% and theoretical RMS <10.00%
      2 points if RMS AMP/FRQ  > 40.00% and theoretical RMS <20.00%
any error condition sets the quality factor to  letter code in which
                         A= freqency sequence cannot be handled by FRNGE
                            requires an FFT of more than 256 points
                         B= interpolation error check search range fringes
                            may be on the edge of range
                         C= epoch error condition all frequencies not at same
                            epoch
                         D= no phasecal or manually entered phasecal values
                         E= single band delay residual too large CAUTION
                            fringe amplitude may be more than 5% low
                         F= no data found- dummy FRNGE output
                      QF=0= probabilty of false detection greater than 1.0E-4
                            i.e. NO FRNGES (i.e. SNR below approx. 7)
                      QF=1= one or more phase cal signals less than 1%
                      QF=2= one or more channels have amplitude less than half
                            the strength of the coherent average and SNR.GT.20
QB= r.m.s. variation between channels in amount of data accepted in %
TAPEQ=6 character tape quality code
             Char 1=ref.tape error rate exponent i.e. 0=1.0E00  9=1.0E-9
             Char 4=rem tape error rate exponent i.e. 0=1.0E00  9=1.0E-9
             Char 2=ref.tape slip sync rate      i.e. 0=10%     9=1%
             Char 5=rem.tape slip sync rate      i.e. 0=10%     9=1%
```

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             Char 3=percentage data discarded    i.e. 0=10%      9=1%
             Char 6=fraction of data processed   i.e. 0=<5%      9=>95%
                 that is INTG.TIME/scheduled run duration
   REF.ST.CL.EPOCH MS reference station (1st station in baseline ) clock
         epoch. The epoch is corrected for the best apriori estimate of
         the station clock -UTC.
   RMS PH/SEG DG r.m.s. phase(in deg) deviation of phases(P symbols in plot)
   RMS AMP/SEG % r.m.s. amplitude(in %) deviation of amplitudes(T symbols)
   RMS PH/FRQ DG r.m.s. phase deviation amoung frequency channels
   RMS AMP/FRQ % r.m.s. amplitude deviation amoung frequency channels
   TH.RMS theoretical estimates for the 4 quantities above
         followed by the FRNGE processing time YYDDD:HHMM:SS

   CALCULATION OF CLOSURE RATES DELAYS AND PHASES (for 3-stations A,B,C)
   (from numbers on frnge printouts)

   CLOSURE rate(in microsec/sec):

      Closure= rate(AB)-rate(AC)+rate(BC)+acel(BC)*delayg*1.0E-6+
             rate(AB)*rate(BC)*1.0E-6
             rates in microsec/sec,acel in microsec/sec/sec,delay in microsec

   CLOSURE delay(in microsec):

      Closure= delay(AB)-delay(AC)+delay(BC)+rate(BC)*delayg*1.0E-6
             delay in microsec, rate in microsec/sec

   CLOSURE phase (in rotations):

      Closure= phase(AB)-phase(AC)+phase(BC)+rate(BC)*delayg*freq*1.0E-6
             phase in rotations,rate in microsec/sec,delay in microsec
             reference freq in MHZ.
             This expression omits aceleraion terms which can produce at most
             approx. 0.3 deg. error at 22GHz. Since observables are used no
             error results from incorrect values of source position,baselines
             or Apriori clocks.
      delayg= measured delay on baseline AB (delay(AB))  minus APRIORI clock
               on baseline AB in microsec

   CAUTION:
      1) ALL BASELINES MUST BE PROCESSED WITH SAME EPOCH
      2) FOR CLOSURE PHASES ALL BASELINES MUST BE PROCESSED WITH
         SAME REFERENCE FREQUENCY
      3) IF MANUAL PHASE CAL PHASES ARE USED THEY MUST CLOSE or phases
         must first be "uncalibrated" before deriving closure phase
   NOTE:
     1) Since aprioris close,residuals can be used in above expressions
        but totals must be used for correction term. aprioris only
        close if the same source positions etc have been used on all baselines.
        That is baselines processed from same root file will have aprioris that
        close while those processed from different root files may not close.

   CLOSURE PHASES -alternate method of calculation(FRNGE PRG800509 and later)

      Closure phase=phase("(AB)")-phase("(AC)")+phase("(BC)")
                    phases  are earth center epoch phases which are in
                    parentheses in printout.
                    Note that this method of obtaining closure phase uses Apiori
                    information to move the epoch and a 1 arcsecond error in
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                    source position or baselines can result in approx. 1 deg.
                    error at 22GHz.
EOF on FMGR file "FRNGP after reading   297 records with approx   16944. chars
```