Frequency in the GBT FITS files

GBT Memo #312

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Change Record

VERSION	DATE	REASON
1.0	27 February 2024	Initial Document
2.0	22 April 2024	Numerous changes from external comments.

	Frequency in the GBT FITS files	Author: O'Neil	GBT Memo Series #312

Contents

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1. Introduction and Documentation

1.1 Document Purpose

There are a number of frequency calculations made in the various GBT FITS files, not all of which are fully documented. Here I go through all the calculations to provide a reference. A list of all previous documentation is included in Section 0.

1.2 Shortfalls of this document

The primary shortfall of this document is in determining the decisions made by the config tool in setting the LO1A. This is better described in Section 0.

This document also does not consider the MUSTANG receiver system, as it does not use the GBT's IF path for their signals. Additionally, it does not describe using the VLBA Mark V backend or the JPL radar backend.

1.3 Errors found

A number of errors have been found within the FITS files themselves, which are documented here:

- Section 11.10: The observing set-up clearly calls for VEGAS mode 3, and the VEGAS fits files state they are running mode 3. However, the channel frequencies are clearly for VEGAS mode 2.
- Directory TRFI_040723_K2: LO1A rest frequency is wrong (e.g. 1.93200000000000E+10 in the LO1A fits file, as opposed to the 1.80000000E+10 entered by the script)

2. Background - Equations

Here are the basic definitions used throughout this document. These are standard definitions and are included here only for completeness.

Optical Velocity Definition: $v_{opt} = \frac{\lambda - \lambda_0}{\lambda_0} c; f = \frac{f_0}{\left(1 + \frac{v_{opt}}{c}\right)}$

Radio Velocity Definition: $v_{rad} = \frac{f_0 - f}{f_0} c; f = f_0 \left(1 - \frac{v_{rad}}{c}\right)$

Relativistic Velocity Definition: This is the redshift definition, or $v_{rel} = \frac{f_0^2 - f^2}{f_0^2 + f^2} c$

<u>Velocity Rest Frames</u>: The majority of these are taken directly form the 3rd World Coordinate Systems paper (Greisen, et al. 2006 A&A 446).

Name	Maximum Magnitude	Reference and notes
Topocentric	0.0 km/s	
Geocentric	0.5 km/s	
Barycentric	30 km/s	Stumpff (1980)
Heliocentric	30 km/s	Stumpff (1980)
LSRK (aka LSR)	20 km/s	RA=18h, Dec=+30d; Delhaye (1965)
LSRD	16.6 km/s	ℓ=53, b=25; Delhaye (1965)
Galactocentric	220 km/s	RA=21h12m01.1s, Dec=+48d19m47s in J2000) Kerr & Lynden-Bell (1986)
Local Group (LGR)	300 km/s	ℓ=90, b=0; de Vaucouleurs (1976)
COB	undefined	Undefined

3. Background – The Hardware

3.1 Simple Block Diagram – Center Frequency only

The GBT frequency chain for all receivers except Ka, MUSTANG, W and Holography

Receiver   LO1A   LO2   LO3   Backer

IF Frequency   8.5 – 10.35 GHz

1.0 – 10.0 GHz   10.5-18.0 GHz   10.5 GHz

LO1A Mulitplier
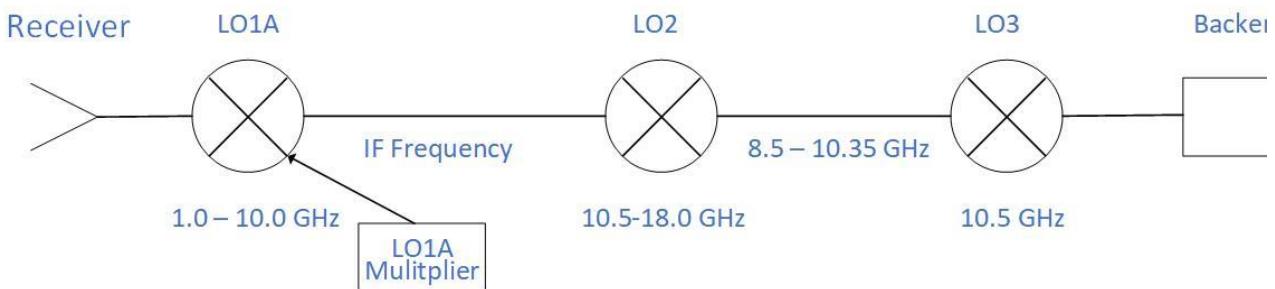
Note that the KFPA receiver uses a combination of filters and diplexers within the signal path, which results in the varied nominal IF center frequency given in Section 0. It also routes some of the beams (5, 7, 8) through the O2

The GBT frequency chain for the Ka- and W-band receivers

Receiver   LO1A   LO2   LO3   Backer

mm Converter   8.5 – 10.35 GHz

IF Frequency

1.0 – 10.0 GHz   10.5-18.0 GHz   10.5 GHz
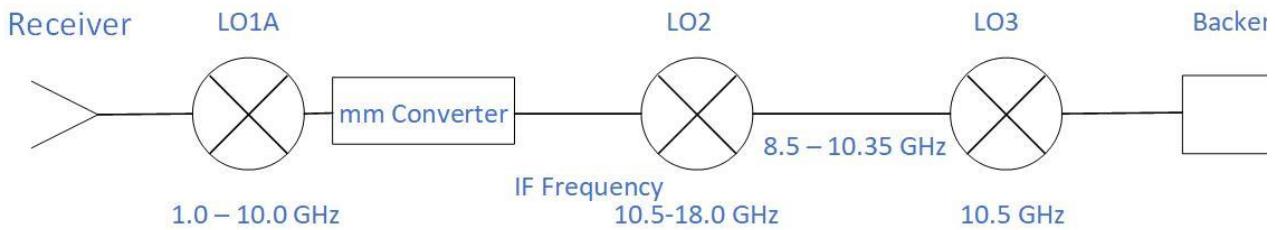
The mm converter, used by the Ka-band and W-band receivers, provides both frequency conversion and filtering for the IF signal.

3.2 Nominal IF Center and Bandwidth for GBT Receivers

All receivers except MUSTANG and Holography

The frequencies in this section are nominal. The actual IF center frequency for observations is often different from these, due to choices made by the config tool. These choices are based on sky frequencies, filters, and backends. Unfortunately, these choices are too complex to readily describe in this memo, and are not documented accurately anywhere. Determining the logic within the config tool choices will take reverse engineering the software code.

Freq Range [GHz]	Receiver	Nominal IF [GHz]	Max Bandwidth [GHz]	Sideband	LO Mult
0.29-0.92	PF1	1.08	0.240	L	1
0.7–4.0	UWBR	6.0	3.30	L or U	1
0.91-1.23	PF2	1.50	0.320	L	1
1.1-1.8	L-band	3.00	1.2	L	1
1.7-2.6	S-band	6.00	1.0	L	1
3.9-6.1	C-band	3.00	2.1	L	1
8.0-11.6	X-band	3.00	3.5	L	1
12.0-15.4	Ku-band	3.00	3.5	U	1
18.0-27.5	KFPA narrow	6.80	1.8	U	2
18.0-27.5	KFPA wide (BW <4.0 GHz)	6.00	4.0	U	2
18.0-27.5	KFPA wide (BW≥4.0 GHz)	4.25	7.5	U	2
26.0-40.0	Ka-band	6.00	4.0	U	1
40.0-48.0	Q-band	6.00	4.0	U	4
68.0-92.0	W-band	6.00	4.0	U	4
74.0-116.0	Argus	Varies	10.0	U	8

The KFPA

The configurations for the KFPA differs depending on whether the observer is requesting the narrow (1.8 GHz limit per beam) or wide band modes (2 beams and up to 7.5 GHz in bandwidth).

For the narrow band case, beams 1,2,3, 4 and 8 are mixed only once and have an IF transmission of 5.90-7.70 GHz, while beams 5, 6, and 7 are mixed twice and transmitted on the IF at 1.20-3.00 GHz.

For the wide band case, if the maximum frequency span is less than 4 GHz, then IF nominal = 6.0GHz, otherwise it is 4.25GHz. Note, though, that again IF nominal is not the same as the actual IF center frequency set by the config tool.

Argus

For Argus, the observer can choose the desired sideband. From MR 5Q12015, we have that based on the input RF and USB/LSB, set LO1a as the following:

- LO1a = (RF -1.525 GHz)/8.0 for USB
- LO1a = (RF +1.525 GHz)/8.0 for LSB

LO1b is not used.

The expression for center/average LO2 is: LO2 = 10.5 GHz + 1.525 GHz - 0.775 GHz

LO3 is fixed at 10.5 GHz, 1.525 GHz is IF1 from the instrument and 0.775 GHz is the center "IF3" frequency for VEGAS.

W-band
The MMC filter selection as a function of the average sky frequency is:
- FL1: $f_{min} \leq f <$ 73.5GHz
- FL2: 73.5 $\leq f <$ 79.5 GHz
- FL3 79.5 $\leq f <$ 85.5 GHz
- FL4: 85.5 $\leq f < f_{max}$ GHz

The nominal IF for the receiver, then, are:
- if FL4 (85.5 $\leq f < f_{max}$ GHz) then
  - IF RF<=92000, then IF0 = RF-66000.
  - IF RF>92000, then IF0 = 26000.
  - IF1=6000. (allowable IF1 range=4000-8000)
  - LO1B = IF0 - IF1
  - LO2 = 10500 + IF1 - IF3 (for spectrometer mode)
- If FL3 (79.5 $\leq f <$ 85.5 GHz) then
  - IF0 = RF-66000.
  - LO1B = IF0 - IF1
  - IF1=6000. (allowable IF1 range=4000-8000).
  - LO2 = 10500 + IF1 - IF3
  - IF LO1B < 8800., then (special case to avoid LO1B leakage). If using above relationships and LO1B is below 8.8GHz, set LO1B to 8800 MHz and adjust IF1 accordingly. This avoids leakage of the LO signal through the 4000-8000 MHz bandpass. Would occur for sky frequency 79.5-80.8 GHz.
  - IF0 = RF-66000.
  - IF1 = RF - 74800
  - LO1B = 8800
  - LO2 = 10500 + IF1 - IF3
- IF FL2 (73.5 $\leq f <$ 79.5 GHz) then
  - IF0 = RF-66000.
  - IF1=6000.
  - LO1B = IF0 + IF1
  - LO2 = 10500 + IF1 - IF3 (for spectrometer mode)
- IF FL1 ($f_{min} \leq f <$ 73.5GHz) then
  - IF RF>=68000, then IF0 = RF-66000.
  - IF RF<68000, then IF0=2000.
  - There is no LO1B.

- o IF1=IF0 (allowable IF range = 2000-8000)
- o LO2 = 10500 + IF1 - IF3 (for spectrometer mode)

UWBR

Like Argus, the observer can choose their sideband. The default, though, is lower, with an IF nominal frequency of 6.0 GHz. If "U"pper sideband is chosen, the IF system bypasses the LO completely,

Holography Receiver

Frequency choice is not an option for the holography receiver. As a result, the following is true:

- ifCenterFrequency parameter of the LO manager will be set to 11150.0 MHz, and the sideband to "upper".
- For calculation of LO2, use IF1 = sky frequency minus 10.7 GHz, and there is no dependence on what the LO1 is set to.
- Normally "obstype" is set to 'Continuum' for Holography observing. But there will also be an option depending on obstype='Spectroscopy.' In this case the LO1 ifCenterFrequency will be set to sky frequency minus 10.7 GHz.
- LO2: use IF1 = sky frequency minus 10.7 GHz, and there is no dependence on what the LO1 is set to.
- IF Manager factor "SFF_MULTIPLIER"= 0.0
- Frequency of the fixed LO is added to "SFF_OFFSET"

3.3 GBT Backends

VEGAS Frequencies Chart

Mode	Bandwidth per Window (MHz)	Channels per Window	Windows per Bank	Maximum # of Banks	Maximum Total # of Windows	Spectral Resolution (kHz)
1	1500	1024	1	8	8	1464.84375
2	1500	16384	1	8	8	91.552734375
3	1080	16384	1	8	8	65.91796875
4	187.5	32768	1	8	8	5.7220458984375
5	187.5	65536	1	8	8	2.86102294921875
6	187.5	131072	1	8	8	1.430511474609375
7	100	32768	1	8	8	3.0517578125
8	100	65536	1	8	8	1.52587890625
9	100	131072	1	8	8	0.762939453125
10	23.4375	32768	1	8	8	0.7152557373046875
11	23.4375	65536	1	8	8	0.35762786865234375
12	23.4375	131072	1	8	8	0.178813934326171875
13	23.4375	262144	1	8	8	0.0894069671630859375
14	23.4375	524288	1	8	8	0.04470348358154296875
15	11.71875	32768	1	8	8	0.35762786865234375
16	11.71875	65536	1	8	8	0.178813934326171875
17	11.71875	131072	1	8	8	0.0894069671630859375
18	11.71875	262144	1	8	8	0.04470348358154296875
19	11.71875	524288	1	8	8	0.02235174179077148437
20	23.4375	4096	8	8	64	5.7220458984375
21	23.4375	8192	8	8	64	2.86102294921875
22	23.4375	16384	8	8	64	1.430511474609375
23	23.4375	32768	8	8	64	0.7152557373046875
24	23.4375	65536	8	8	64	0.35762786865234375
25	16.875	4096	8	8	64	4.119873046875
26	16.875	8192	8	8	64	2.0599365234375
27	16.875	16384	8	8	64	1.02996826171875
28	16.875	32768	8	8	64	0.514984130859375
29	16.875	65536	8	8	64	0.2574920654296875

The CCB

The CCB only works with the Ka Receiver, and when in use it is the only backend available. Because the CCB is directly connected to the Ka receiver, it bypasses the LO and IF system.

VLBI RDBE

For the VLBI RDBE backend, the config tool sets IF1 and IF2 to convert the center frequency ("restfreq") to 768 MHz, at the input to the RDBEs.

- Q-band (IFnom=6000 MHz):
  - rf1=lowest frequency of interest; rf2=rf1+512 MHz
    - rf1=42312 (gbt7mm_c7); 32712 (gbt7mm_b8); 42912 (gbt7mm_c8)
  - lo1=0.5(rf1+rf2)-768 MHz = rf1-512 MHz
  - LO1 = lo1 – (IF1-768) = lo1-5232 MHz
  - LO2 = IF1 + 10500 – 768 MHz = 15732 MHz
  - LO3 = 10500 MHz
- K-band (IFnom=6800 MHz)
  - rf1=lowest frequency of interest; rf2=rf1+512 MHz
    - rf1=21312 (gbt1cm_a1); 21512 (gbt1cm_a2); 21812 (gbt1cm_a3), 23512 (gbt1cm_b3)
  - lo1=0.5(rf1+rf2)+768 MHz = rf1+1024 MHz
  - LO1 = lo1 + (IF1-768) = lo1+6032 MHz
  - LO2 = IF1 + 10500 – 768 MHz = 16532 MHz
  - LO3 = 10500 MHz
- Ku-band (IFnom=3000 MHz)
  - rf1=lowest frequency of interest; rf2=rf1+512 MHz
    - rf1=11912 (gbt2m_a2); 14912 (gbt2cm_d2)
  - lo1=0.5(rf1+rf2)-768 MHz = rf1-512 MHz
  - LO1 = lo1 – (IF1-768) = lo1-2232 MHz
  - LO2 = IF1 + 10500 – 768 MHz = 12732 MHz
  - LO3 = 10500 MHz
- X-band, C-band (IFnom=3000 MHz)
  - rf1=lowest frequency of interest; rf2=rf1+512 MHz
    - rf1=7912 (gbt4cma); 8076 (gbt4cmb); 8376 (gbt4cmc)
    - rf1=3912 (gbt6cma); 4412 (gbt6cmb); 4612 (gbt6cmc)
  - lo1=0.5(rf1+rf2)+768 MHz = rf1+1024 MHz
  - LO1 = lo1 + (IF1-768) = lo1+2232 MHz
  - LO2 = IF1 + 10500 – 768 MHz = 12732 MHz
  - LO3 = 10500 MHz
- S-band (IFnom=6000 MHz)
  - rf1=lowest frequency of interest; rf2=rf1+512 MHz
    - rf1=1680 (gbt16cm); 1876 (gbt13cm); 2076 (gbt13cm_2)
  - lo1=bandcenter+768 MHz

- - - bandcenter=1832 (gbt16cm); 2132 (gbt13cm); 2332 (gbt13cm_2)
  - LO1 = lo1 + (IF1-768) = lo1+5232 MHz
  - LO2 = IF1 + 10500 – 768 MHz = 15732 MHz
  - LO3 = 10500 MH
- L-band (IFnom=3000 MHz)
  - rf1=lowest frequency of interest; rf2=rf1+512 MHz
    - rf1=1100 (g20cm_1); 1376 (g20cm_2)
  - lo1=bandcenter+768 MHz
    - bandcenter=1832 (g20cm_1); 2132 (g20cm_2)
  - LO1 = lo1 + (IF1-768) = lo1+2232 MHz
  - LO2 = IF1 + 10500 – 768 MHz = 13732 MHz
  - LO3 = 10500 MH
- PF600 (IFnom=1080 MHz)
  - rf1=512, rf2=690 MHz
  - lo1=768+768 MHz
  - LO1 = lo1 + (IF1-768) = lo1+312 MHz
  - LO2 = IF1 + 10500 – 768 MHz = 10812 MHz
  - LO3 = 10500 MH
- PF342 (IFnom=1080 MHz)
  - rf1=290, rf2=395 MHz
  - lo1=268+768 MHz
  - LO1 = lo1 + (IF1-768) = lo1+312 MHz
  - LO2 = IF1 + 10500 – 768 MHz = 10812 MHz
  - LO3 = 10500 MH

JPL Radar backend

For the radar backend, the IF conversion is to 720 MHz.

No velocity tracking is done at all.

4. LO1A Fits File

4.1 Primary Header

- RESTFRQ: Rest frequency as given by the observer (Hz).
- IFFREQ: Specified IF center frequency, which depends on the instrumental set-up (Hz). See Section 3 for details.
- LOOFFSET: Typically, this is 0.0 Hz, This value indicates the value of $LO1_{offset}$ in equation (5) of LO1DesignNotes. When non-zero, this value represents a receiver which has an additional mixing stage, which acts as a constant offset in terms of LO frequency. This information is included for engineering purposes only; when non-zero this term will be included in the IF Manager sky frequency formula calculations (Hz).
- LOMULT: This value indicates the LO1 multiplier factor in use. When set to a value other than 1.0, this value represents a frequency multiplier stage between LO and mixer. This information is included for engineering purposes only; when non-unity this term will be included in the IF Manager sky frequency formula calculations.
- REQDPTOL: This is the requested Doppler tracking tolerance in Hz, and is not part of the frequency calculations (Hz). The default value for this is 1 Hz for VEGAS. For he DCR & DCR_ACF, the tolerance should be set to 10Hz.
- SIDEBAND: This value indicates the LO1 sideband setting. The possible values are ``Upper'', ``Lower'', or ``Test Tone''. Again, this is not used in the calculations, but is here for reference.

4.2 State

- FREQOFF: Requested offset for, e.g. frequency switching (Hz)

4.3 SouVel

- VELOCITY: Source velocity as given by the observer (m/s)
- VDOT: Source acceleration as given by the observer (m/s/s)
- VDOTDOT: (m/s/s/s)
- VELDEF: Velocity definition, for the velocities given by the observer. The choices are any combination of columns (1) and (2).

Velocity Def	Rest Frame
VELO	-TOP
VOPT	-GEO
VRAD	-BAR
	-HEL
	-GAL
	-LSD
	-LSR
	-LGR
	-COB

4.4 LO1TBL

- LO1FREQ: This is the doppler shifted frequency sent to the LO1A synthesizer, in Hz.

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

Here, f is the frequency shifted rest velocity, in the chosen velocity frame (VRAD-LSR, VOPT-BARY, etc.). The sign (+/-) is chosen based on using the lower (+) or upper (-) sideband. The LO1A frequency is chosen to match the desired IF Frequency.

- VFRAME: This is the radial velocity of the reference frame with respect to the observer in m/s.

$$VFRAME = V_{frame} - V_{observer}$$

- RVSYS: This is the relativistic addition of the radial velocities of the source with respect to the observer in m/s. The equations for calculating this are as follows. (Note that the documentation on this equation is inconsistent and incomplete).

$$f = frequency\ at\ the\ center\ channel$$

$$f = \begin{cases} \dfrac{f_0}{\left(1 + {(SRCVEL + VFRAME)}/{c}\right)} & Optical\ velocity\ definition \\[3ex] f_0\left(1 - \dfrac{(SRCVEL + VFRAME)}{c}\right) & Radio\ velocity\ definition \end{cases}$$

$$RVSYS = c\ \frac{1 - \left({f}/{f_0}\right)^2}{1 + \left({f}/{f_0}\right)^2}$$

5. IF Fits File

- BACKEND: This lists the backend used for the observations. This is needed, as the VEGAS backend requires a small change in the frequencies of the hardware.
- SIDEBAND: This is the same as for the LO1A Fits. This value indicates the LO1 sideband setting. The possible values are ``U"(pper) (if the IF frequency is greater than the LO1 value) or ``L"(ower) (otherwise). Again, this is not used in the calculations, but is here for reference.
- CENTER_IF: This is the center frequency of the nominal IF bandpass, and set by the hardware configuration.
- CENTER_SKY: This is calculated by the sky frequency formula and shows the relationship between the IF frequency and the sky frequency. Note that IF FITS files do not include the FREQ_OFF in the formula in the comments.

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * LO1 + FREQ\_OFF + SFF\_OFFSET$$

- BANDWIDTH: This is the nominal bandpass of the data, and is set by the configuration tool.
- SFF_MULTIPLIER: Sky frequency formula multiplier coefficient, as defined in Section 3.
- SFF_SIDEBAND: Sky frequency formula sideband coefficient which demarks if the signal is in the upper or lower sideband (see Section 3).

- SFF_OFFSET: Sky frequency formula offset coefficient , which is used to ensure the frequencies reaching the backend are accurate. Note that this value is the result of the LO choices made by the config tool.

6. GO Fits File

6.1 Primary Header

- VELOCITY: This should be the source velocity as entered by the observer, and should match the value of LO1A VELOCITY.
- VELDEF: This is the same velocity definition as for the LO1A VELDEF.
- SKYFREQ: This is the observers 'intended' sky frequency, which is indicative of the center frequency, but is not used for any calculations. It is intended to be the center point between the highest and lowest center frequencies chosen.

$$SKYFREQ = \frac{(first\ rest\ freq + deltafreq) + (last\ rest\ freq + deltafreq)}{2}$$

- RESTFREQ: This is the rest frequency that matches that used for IF calculations, and should match the LO1A RESTFREQ.

6.2 IFWINDOWS

- NCHANS: This comes directly from the VEGAS mode chosen.
- RESTFREQ: This is the rest frequency that matches that used for IF calculations, and should match the LO1A RESTFREQ.
- SUBBAND: This is from the VEGAS mode chosen.
- BACKEND: Backend chosen for observations.

7. VEGAS Fits File

If VEGAS is used, the VEGAS keywords must also be considered in the calculations

7.1 Primary header

- MODE: This is the VEGAS mode being run, which set many of the parameters in the other keywords. Mapping of VEGAS mode to the keywords can be found in the VEGAS sampling frequencies document.
- CHAN_BW: This is the VEGAS mode bandwidth/number of channels. It is defined as:

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

- SUB0FREQ through SUB7FREQ: This is the IF3 frequency. The number of SUB[X}FREQ used is equal to the number of spectral windows (1 for modes 1-19, 1-8 for modes 20-29).

7.2 Sampler

- CRVAL1: This is equal to the SUB0FREQ value for the bank chosen (Hz). This is referred to as IF3 in the SDFITS file calculations
- CDELT1: This is equal to the absolute value of the CHAN_BW (Hz)

- FREQRES: This is the same as CDELT1 (Hz)
- CRPIX1: The is the central pixel + 1 and corresponds to the pixel which matches CRVAL1. This is not the central pixel, due to a spur which arises in that channel.

8. SDFITS Fits File

- BANDWID: This is the bandwidth of the spectral window for the backend of VEGAS bank. It some directly from the backend specification.
- CTYPE1: This is always 'FREQ-OBS'
- CRVAL1: This is calculated by the sky frequency formula and shows the relationship between the IF frequency, as defined by VEGAS, and the sky frequency.

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- CRPIX1: This is the CRPIX1 value in the VEGAS fits file. This is ignored for DCR data, as there is only one frequency channel.
- CDELT1: This is the CHAN_BW value in the VEGAS fits file
- VELDEF: This is the LO1A VELDEF value. This is not written for DCR data
- VFRAME: This is the LO1A VFRAME value
- RVSYS: This is the LO1A RVSYS value
- OBSFREQ: Matches CRVAL1 value
- RESTFREQ: GO FITS RESTFREQ value from table; If the GO fits value is not found, it is ½ the total bandwidth. This is not written for DCR data.
- FREQRES: This is the first VEGAS FREQRES value
- SIDEBAND: This is the IF (L). If the value cannot be found, 'U' is given.
- VELOCITY: This is the GO FITS VELOCITY from table. This is not written for DCR data.
- ZEROCHAN: Value needed for the old GBT spectrometer. It is now simply 'NULL'. It is not written for DCR data.
- DOPFREQ: This is the same as the LO1A RESTFREQ value.

9. Data Reduction

One last item to be noted here. All of the calculations here are done to optimally place the observer's frequency of interest in the center of the observing band, and to ensure the correct information is given to allow an observer to map the frequency and channel information within their data. GBTIDL, the current GBT data reduction system, uses this information in only one way - the CRPIX, CRDELT, and CRVAL information is used for all axis in order to map channels to their appropriate value (e.g. frequency). No other information is used, and all doppler, velocity frame, etc. calculations are done internal to the data reduction program itself.

10.   Previous Documentation

There is a lot of documentation on frequencies, the config tool, and information in the various fits files. Below is a list of all the documentation, including its current location and any issues found, with its accuracy, and listed in order from most recent. Following this table is a list of Modification Requests which appear to relate to the frequency calculations, but which are not relevant to this memo.

Note that there may be more documentation; if so, it should be added to this list for completion.

10.1   Relevant Previous Documentation

Title/Link	Description	Last revision	Issues, if known
ModificationRequest5Q320: Integrating UWBR into GBT M&C System, Part II: No LO1 Usage	Entire signal path for UWBR when the LO1A is not used (aka upper sideband mode)	Aug 11, 2022	
ModificationRequest3Q320: Integrating UWBR into GBT M&C System, Part I: Traditional LO1 Usage	Entire signal path for UWBR when the LO1A is used (aka lower sideband mode)	Aug 11, 2022	
There and Back Again: A Signal's Tale	Good basic description of how the IF system works; Does not include details of frequency calcs.	Unknown	
Config Tool Documentation	Outline/understanding of the functionality of the config tool	Jan 01, 2019	Does not give detailed calcs. Note that only one section is from 2019.
GBT VEGAS FITS File Specification	FITS format structure is presented for the GBT VEGAS scan data files	Dec 11, 2017	
ModificationRequest3Q212 **K**FPA configuration of spectral windows to conform to other receivers	Modification of MR 3Q210: adding the KFPA to the Config Tool	Nov 03, 2017	Good, but does not accurately describe all aspects of the KFPA frequencies
Add the 4mm Receiver to the Config Tool	Described the mm converter settings for the w-band receiver	Sept 13, 2017	
GBT FITS files to output SDFITS files	Includes a significant section on Frequency Axis and Related Information	Sept 12, 2017	Sky frequency equation is incorrect. Also, it is not updated to include VEGAS and the use of the IF3 frequency.
ModificationRequest5Q115: ARGUS Config-tool Updates	Changes the frequency mixing scheme for Argus.	Sep 01, 2016	Gives good approximation top config tool choices, but not exact. (Note –

			cosmetic only edits by A. Schmeidke in 2023)
ModificationRequest7Q312: Config tool changes for signal routing through KFPA broadband IF path	Routing of RF signal from KFPA beams 1 and 2 through the broadband IF path	Jan 09, 2013	
ModificationRequest3Q210: Adding the KFPA to the Config Tool	MR to describe how the KFPA is treated int eh config tool.	Apr 13, 2011	Modified by MR 3Q212
GBO SDD Config Tool Notes	Created by the SDD to understand the software components of the config tool	Jul 1, 2015	Incomplete; Documentation is extensive but unfinished.
ModificationRequest7Q412: Rest Frequencies to GBTIDL ifnum mapping table	No change in freq calcs; just a change to table format in a number of FITS files.	Nov 6, 2014	
ModificationRequest6Q312: Advanced Configuration of VEGAS	Modifications necessary to integrate advanced configuration of VEGAS into the configuration tool	Aug 08, 2012	Not signed as delivered; Discusses how the VEGAS tool could be configured but the config tool, but not how it is configured.
VEGAS sampling frequencies	Report on VEGAS use of samplers and frequencies	Dec 13, 2011	Numerous errors; Use table in this page for accurate values
GBT Frequency Setups for the RDBE	Documents how to make frequency setups for the GBT for the new RDBE back end	Oct 27, 2011	
ModificationRequest1Q311: Improve sdfits algorithm to match rest frequencies with spectral windows	No change to the actual frequency calculations	May 17, 2011	
ModificationRequest1Q110: Add additional rest frequencies to GO FITS file to be used by SDFITS	Explains how the frequency pairs from the observer requests are carried to the SDFITS files	July 20, 2010	
The Configuration Tool	Knowledge wiki description of the config tool. Probably the best documentation from the user standpoint	July 07, 2010	Out of date, does not include a number of changes and receivers, and does not give detailed calcs
ModificationRequest3Q310: Add Heliocentric and Local Group options for the Config Tool "vframe"	Lists the velocity frames and definitions allowed by the config tool	Jun 04, 2010	

ModificationRequest2C409: **Configure the Holography Receiver**	Covers the frequencies and cabling for the Holography receiver (only)	July 30, 2009	
ModificationRequest7C706: **Extend the range of LO1B frequencies for Ka-band**	Change config-tool to use the 9 GHz LO1B power settings anytime LO1B is at or below 9 GHz for KA obs.	Nov 01, 2006	
IF/LO Diagram	Simple diagram giving overview of IF/LO path; intended as a teaching tool	Feb 15, 2006	Oversimplifies and doesn't include all frequencies
ModificationRequest3C805: **Add default LO1 tolerance to config tool**	Sets the tolerance for the LO1 tracking	Feb 07, 2006	Does not include VEGAS, CCB, etc.
GBT IFManager FITS File Specification	FITS format structure for the IF FITS files (GBT Software Project Note 10.6)	Jan 30, 2003	Formula for the sky frequency does not include the FREQ_OFF component.
GBT GO FITS File Specification	FITS format structure for the GO FITS files (GBT Software Project Note 8.5)	Oct 17, 2002	
The GBT Tracking Local Oscillator FITS Keyword Definitions	FITS format structure for the LO1A FITS files (GBT Software Project Note 6.5)	Dec 17, 2001	

10.2   MRs that look like they should be important, but aren't

Listed by year.

2004

- ModificationRequest10C504: Frequency Conversions for LO – Ka-band - Not written

2005

- ModificationRequest7C705: Add Config Tool support for Spigot and Multiple Backend Configurations – Spigot is obsolete
- ModificationRequest12C205-gappy: Change how GFM Calculates Center Frequency - Not written
- ModificationRequest8C205: Handle DCR Observations at Frequencies Outside Receiver Nominal Range – Sinply a check for the observed frequencies.

2006

- ModificationRequest5C406: Re-Configure for Large Velocity changes – not signed, likely never implemented

- ModificationRequest4C606: Config Tool Ka Receiver Manager Modifications – changes relevant only for Zpectrometer, which no longer exists as a backend on the GBT.
- ModificationRequest7C606: Config Tool VLBA_DAR Modifications – cabling changes only; doesn't affect frequencies.
- ModificationRequest4C806: Configuration Tool Default Value Changes – applies to spectral processor only, which is no longer available on the GBT.

2007

-
- ModificationRequest12C107: Config Tool: Multiple Back Ends may include VLBA – changes cabling, not frequencies
- ModificationRequest10C107: Proper Setting of LO1 B Frequency To Avoid Interference – appears to only set the switches for the LO1A, LO1B, etc. Note that the MR was never completed, and is not signed. It is likely not actually implemented.
-
- ModificationRequest10C507: config_tool Changes Regarding LO1B/mm-wave Converters – not signed, and so presumably not implemented.
- ModificationRequest7C507: config_tool Changes Related to Ka Manager Changes – not signed, and so presumably not implemented.
- ModificationRequest8C507: IF Manager Changes Related to Ka Manager Changes– not signed, and so presumably not implemented.

2009

- ModificationRequest19C509: KFPA Configuration Script Development– not signed, and so presumably not implemented.

2011

- ModificationRequest7Q111: Config Tool Changes for VLBI – cabling changes only, for the Mark V backend.
- ModificationRequest7Q411: Changes to the configuration tool in support of VEGAS – discussed frequenciy pairs for the config tool, but not path routing.

2012

- ModificationRequest10Q212: Modifications to RunVLBI for W-band configuration – does not provide information about signal routing.

2014

- ModificationRequest5Q414: Upgrades to the Config Tool for VEGAS – remove if3 offset to avoid spike – accurate, but does not describe frequency choices or routing.

2016

- ModificationRequest4Q116: Software Modifications to Increase C-Band Bandwidth ; This should be the MR to note the changes implemented with the c-band expansion, but it is neither filled out nor signed.

2020

- [ModificationRequest03Q120](#): UWBR Configtool Changes – IF routing plans for UWBR – this has been supplanted by ModificationRequest3Q320, ModificationRequest4Q320, ModificationRequest5Q320

2021

- [ModificationRequest2Q320](#): Auto procedures proper frequency and beam configuration – this fixes issues with Auto procedures setting the requested frequencies correctly.

11.   Examples

Note that calculations from examples are done by hand. As a result, differences in the values at low levels are due to rounding differences.

11.1   Example 1: L-band, Frequency Switching, No Source Velocity, One Bank , VEGAS (VRAD_LSR)

Files: AGBT23A_344_29, Scan #6 (2023_06_23_08:13:22)

Observer Request:

- Receiver = "Rcvr1_2"
- nwin=1
- restfreq=1420.4058
- deltafreq = 0.0
- bandwidth = 11.72
- swtype = "fsw"
- swfreq=-2.0,2.0
- velocity=0.0
- vframe="lsrk"
- vdef="radio"

LO1A Fits

- RESTFREQ: 1.4204058000E+09 (entered by observer)
- IFFREQ: 3.00000E+09 (set by hardware; see nominal IF in lookup table, Section 4)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 1.0000E+00 (set by hardware; see lookup table, Section 4)
- REQDPTOL: 1.0000E+00
- FREQOFF: -2.00E6 (1st state; entered by observer)
- VELOCITY: 0.00E+00 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)

- LO1FREQ: 4.420554383000E+09 (calculated)

$$LO1FREQ = \frac{(IFFREQ + f)}{LOMULT} + LOOFFSET$$

- $LO1FREQ = (3.000x10^9 + 1.4204058x10^9 \left(1 - \frac{-3.13589223581x10^4}{2.99792458x10^8}\right)) /1.0 + 0.00$

$$LO1FREQ = 4.420554x10^9$$

- VFRAME: -3.135892235810E+04 (Determined by JPL ephemeris and based on VELDEF, Time, and source position)
- RVSYS: -3.135892235810E+04 (calculated)

$$f = f_0 \left(1 - \frac{(SRCVEL + VFRAME)}{c}\right) = 1.4204058x10^9 \left(1 - \frac{-3.13589223581x10^4}{2.99792458x10^8}\right) = 1.4205543774x10^9$$

$$RVSYS = c \frac{1-\left(f/f_0\right)^2}{1+\left(f/f_0\right)^2} = 2.99792458x10^8 \frac{1-\left(1.4205543774x10^9/1.4204058x10^9\right)^2}{1+\left(1.4205543774x10^9/1.4204058x10^9\right)^2} = -3.135728x10^4$$

- VELDEF: 'VRAD-LSR' (set by observer)
- SIDEBAND: 'LOWER' (set by hardware; see lookup table, Section 4)

IF Fits:
- BACKEND: VEGAS (set by observer)
- SIDEBAND: L (set by hardware; see lookup table, Section 4)
- CENTER_IF: 2.5000E+08 (set by hardware)
- BANDWIDTH: 2.000E+07 (set by configuration)
- SFF_MULTIPLIER: 1.000E+00 (set by hardware; see lookup table, Section 4)
- SFF_SIDEBAND: -1.000E+00 (set by hardware)
- SFF_OFFSET: -2.75000E+09 (set by hardware)
- CENTER_SKY 1.418554E+09 (calculated)

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CENTER_{SKY} = -1.0 * 2.5x10^8 + 1.0 * (4.42055438300x10^9) - 2.000x10^6 + (-2.75x10^9)$$

$$CENTER_{SKY} = 1.418554240x10^9$$

GO Fits:
- VELOCITY: 0.0 (set by observer)
- VELDEF: 'VRAD-LSR' (set by observer)
- SKYFREQ: 1420405800.0 (equal to RESTFREQ, as there is only one observing band)

- RESTFREQ: 1420405800.0 (set by observer)
- NCHANS: 32768 (set by observer; VEGAS mode 15)
- RESOLN 4.000000000E+02 (channel resolution, set by VEGAS mode 15, in Hz)
- RESTFREQ: 1.420405800000E+09 (set by observer)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:
- MODE: 15
- CHAN_BW: -357.627868652344 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{\left(\frac{750.x10^6}{32}\right)}{(32768 * 2)} = 357.628\ Hz$$

- SUB0FREQ: 250030517.578125 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 2.500305175781E+08 (calculated)
  CRVAL1=SUB[X}FREQ; This is for Bank 0

$$CRVAL1 = SUB0FREQ = 250030517.578125$$

- CDELT1: 3.576278686523E+02 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 357.627868652344$$

- FREQRES: 3.576278686523E+02 (calculated)

$$FREQRES = CDELT1 = 357.627868652344$$

- CRPIX1: 1.6385E+04 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 16385$$

SDFITS
- BANDWID: 1.171875000E+07 (This is the bandwidth of VEGAS mode 15.)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: 1.418523864422E+09 (calculated)

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CRVAL1 = -1.0 * 2.500305175781x10^8 + 1.0 * 4.42055438300x10^9 - 2.000x10^6 + (-2.75x10^9)$$

$$CENTER_{SKY} = 1.41852364x10^9$$

- CRPIX1: 1.6385000E+04 (VEGAS CRPIX1 value)
- CDELT1: -3.576278686523E+02 (VEGAS CHAN_BW value)
- VELDEF: RADI-LSR (Set by observer; LO1A VELDEF value)

- VFRAME: -3.135880066939E+04 (LO1A VFRAME value)
- RVSYS: -3.135880066939E+04 (LO1A RVSYS value)
- OBSFREQ: 1.418523864422E+09 (matches SDFITS CRVAL1)
- RESTFREQ: 1.4204058000E+09 (LO1A RSTFRQ value)
- FREQRES: 3.576278686523E+02 (VEGAS 1st FREQRES value)
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: 0.000E+00 (GO VELOCITY value)
- DOPFREQ: 1.4204058000E+09 (matches LO1A RESTFREQ value)

11.2 Example 2: L-band, Total Power, With Source Velocity, One Bank, VEGAS (VOPT_LSR)

Files: AGBT22B_065_40, Scan #6 (2022_12_29_21:28:24)

Observer Request:

- Receiver = "Rcvr1_2"
- restfreq=1420.4058, 1420.4058
- deltafreq = -0, -0
- bandwidth = 23.44
- swtype = "none"
- swfreq=0.0,0.0
- velocity=0.0
- vframe="lsrk"
- vdef="Optical"

LO1A Fits

- RESTFREQ: 1.4204058000E+09 (entered by observer)
- IFFREQ: 3.00000E+09 (set by hardware; see nominal IF in lookup table, Section 4)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 1.0000E+00 (set by hardware; see lookup table, Section 4)
- FREQOFF: 0.00E+00 (set by observer)
- VELOCITY: 5.6880E+06 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 4.393934378E+09 (calculated)

$$LO1FREQ = (IFFREQ + f + LOOFFSET)/LOMUL$$

- $LO1FREQ = (3.000x10^9 + \dfrac{1.4204058x10^9}{\left(1 + \dfrac{5.6880x10^6 + 5.090582639018x10^3}{2.99792458x10^8}\right)} + 0.0)/1.0$

$$LO1FREQ = 4.393934848x10^9$$

- VFRAME: 5.090582639018E+03 (Determined by JPL ephemeris and based on VELDEF, Time, and source position)
- RVSYS: 5.6391387431641E+06 (calculated)

$$f = f_0/\left(1 + \frac{(SRCVEL + VFRAME)}{c}\right) = 1.4204058x10^9/\left(1 + \frac{5.6880x10^6 + 5.090582639018x10^3}{2.99792458x10^8}\right)$$
$$= 1.3939348297x10^9$$

$$RVSYS = c\,\frac{1 - (f/f_0)^2}{1 + (f/f_0)^2} = 2.99792458x10^8\,\frac{1 - \left(1.3939348297x10^9/1.4204058x10^9\right)^2}{1 + \left(1.3939348297x10^9/1.4204058x10^9\right)^2} = 5.390439492x10^6$$

- VELDEF: 'VOPT-LSR'
- SIDEBAND: 'LOWER'

IF Fits:
- BACKEND: VEGAS
- SIDEBAND: L
- CENTER_IF: 2.5000E+08 (set by hardware)
- BANDWIDTH: 8.000E+07 (set by observer)
- SFF_MULTIPLIER: 1.000E+00 (set by hardware)
- SFF_SIDEBAND: -1.000E+00 (set by hardware)
- SFF_OFFSET: -2.75000E+09 (set by hardware)
- CENTER_SKY 1.393934E+09 (calculated)

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CENTER_{SKY} = -1.0 * 2.5x10^8 + 1.0 * 4.393934x10^9 + (-2.75x10^9)$$

$$CENTER_{SKY} = 1.393934x10^9$$

GO Fits:
- BANDWIDTH: 2.344000E+07
- VELOCITY: 5688000.0 (set by observer)
- VELDEF: 'VOPT-LSR' (set by observer)
- SKYFREQ: 1420405800.0 (equal to RESTFREQ, as there is only one observing band)
- RESTFREQ: 1420405800.0 (set by observer)
- NCHANS: 32768 (set by observer; VEGAS mode 10)
- RESOLN 7.000000000E+02 (set by observer; VEGAS mode 10)
- RESTFREQ: 1.420405800000E+09 (set by observer)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:
- MODE: 10
- CHAN_BW: -715.255737304688 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{\left(\frac{1500.0x10^6}{32}\right)}{(32768 * 2)} = 715.2557373\ Hz$$

- SUB0FREQ: 249938964.84375 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 2. 499389648438 1E+08 (calculated)
  CRVAL1=SUB[X}FREQ; This is for Bank 0

$$CRVAL1 = SUB0FREQ = 249938964.8375$$

- CDELT1: 7.15255737304E+02 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 715.2557373$$

- FREQRES: 7.15255737304E+02 (calculated)

$$FREQRES = CDELT1 = 715.2557373$$

- CRPIX1: 1.6385E+04 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 16385$$

SDFITS

- BANDWID: 2.3437500E+07 (This is the bandwidth of VEGAS mode 10.)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: 1.393995413156E+09 (calculated)

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.393934378x10^9 - 0.0 + (-2.75x10^9)$$

$$CENTER_{SKY} = 1.393995264x10^9$$

- CRPIX1: 1.6385000E+04 (VEGAS CRPIX1 value)
- CDELT1: -7.152557373047E+02 (VEGAS CHAN_BW value)
- VELDEF: OPTI-LSR (Set by observer; LO1A VELDEF value)
- VFRAME: 5.090582639018E+03 (LO1A VFRAME value)
- RVSYS: 5.639138743164E+06 (LO1A RVSYS value)
- OBSFREQ: 1.393995413156E+09 (matches SDFITS CRVAL1)
- RESTFREQ: 1.4204058000E+09 (LO1A RSTFRQ value)
- FREQRES: 7.15255737304E+02 (VEGAS 1st FREQRES value)
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: 5.6880000E+06 (GO VELOCITY value)
- DOPFREQ: 1.4204058000E+09 (matches LO1A RESTFREQ value)

11.3 Example 3: L-band, Total Power, No Source Velocity, Multiple Banks, VEGAS (VOPT_LSR)

Files: AGBT22B_065_04, Scan #5 (2022_08_10_04:31:47)

Here, looking at all eight VEGAS band (A-H), as each is offset in frequency

Observer Request:
- Receiver: Rcvr1_2; VEGAS backend;
- Obs mode: Total power; No freq switch;
- Velocity: LSRK, Optical definition
- Backend: VEGAS, 32768 chan, 23.44 MHz bandwidth
- Rest freq = 1420.4058, 1420.4058, 1420.4058, 1420.4058, 1420.4058, 1420.4058, 1420.4058, 1420.4058,
- Deltafreq=-0,-20,-40,-60,-80,-100,-120,-140

LO1A Fits
- RESTFREQ: 1.4204058000E+09 (entered by observer)
- IFFREQ: 2.93000E+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 1.0000E+00 (set by hardware)
- FREQOFF: 0.00E+00 (set by observer)
- VELOCITY: 0.0000E+00 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 4.350509459000E+09 (calculated)

$$LO1FREQ = \frac{(IFFREQ + f)}{LOMULT} + LOOFFSET$$

- $LO1FREQ = (2.93000x10^9 + \frac{1.4204058x10^9}{\left(1+\frac{-2.187807256264x10^4}{2.99792458x10^8}\right)}) + 0.0$

$$LO1FREQ = 4.350509056x10^9$$

- VFRAME: -2.187807256264E+04 (Determined by JPL ephemeris and based on VELDEF, Time, and source position)
- RVSYS: -2.187807256264E+04 (calculated)

$$f = f_0/\left(1 + \frac{(SRCVEL + VFRAME)}{c}\right) = 1.4204058x10^9/\left(1 + \frac{0.0 - 2.187807256264x10^4}{2.99792458x10^8}\right)$$
$$= 1.4205094651x10^9$$

$$RVSYS = c\ \frac{1-\left(f/f_0\right)^2}{1+\left(f/f_0\right)^2} = 2.99792458x10^8\ \frac{1-\left(1.4205094651x10^9/1.4204058x10^9\right)^2}{1+\left(1.4205094651x10^9/1.4204058x10^9\right)^2} = -2.1878870865x10^4$$

- VELDEF: 'VOPT-LSR'
- SIDEBAND: 'LOWER'

IF Fits:
- BACKEND: VEGAS
- SIDEBAND: L
- CENTER_IF: (set by hardware configuration)
    - Bank A: 3.502547E+08
    - Bank B: 3.302547E+08
    - Bank C: 3.102547E+08
    - Bank D: 2.902547E+08
    - Bank E: 2.750000E+08
    - Bank F: 2.650000E+08
    - Bank G: 2.550000E+08
    - Bank H: 2.450000E+08
- BANDWIDTH: (set by hardware configuration)
    - Bank A-D: 2.594905E+08
    - Bank E: 2.500000E+08
    - Bank F: 2.300000E+08
    - Bank G: 2.100000E+08
    - Bank H: 1.900000E+08
- SFF_MULTIPLIER: 1.000E+00 (set by hardware)
- SFF_SIDEBAND: -1.000E+00 (set by hardware)
- SFF_OFFSET: (set by hardware configuration)
    - Bank A: -2.68000E+09
    - Bank B: -2.70000E+09
    - Bank C: -2.72000E+09
    - Bank D: -2.74000E+09
    - Bank E: -2.76000E+09
    - Bank F: -2.78000E+09
    - Bank G: -2.80000E+09
    - Bank H: -2.82000E+09
- CENTER_SKY: (calculated)
    - Bank A-D: 1.320255E+09
    - Bank E: 1.315510E+09
    - Bank F: 1.305510E+09
    - Bank G: 1.295510E+09
    - Bank H: 1.285510E+09

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

   - Calculation, Bank A:

$$CENTER_{SKY} = -1.0 * 3.502547x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.68x10^9)$$

$$CENTER_{SKY} = 1.320254976x10^9$$

o   Calculation, Bank B:

$$CENTER_{SKY} = -1.0 * 3.302547x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.70x10^9)$$

$$CENTER_{SKY} = 1.320254976x10^9$$

o   Calculation, Bank C:

$$CENTER_{SKY} = -1.0 * 3.102547x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.72x10^9)$$

$$CENTER_{SKY} = 1.320254976x10^9$$

o   Calculation, Bank D:

$$CENTER_{SKY} = -1.0 * 2.902547x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.74x10^9)$$

$$CENTER_{SKY} = 1.320254976x10^9$$

o   Calculation, Bank E:

$$CENTER_{SKY} = -1.0 * 2.750000x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.76x10^9)$$

$$CENTER_{SKY} = 1.315509504x10^9$$

o   Calculation, Bank F:

$$CENTER_{SKY} = -1.0 * 2.650000x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.78x10^9)$$

$$CENTER_{SKY} = 1.305509632x10^9$$

o   Calculation, Bank G:

$$CENTER_{SKY} = -1.0 * 2.550000x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.80x10^9)$$

$$CENTER_{SKY} = 1.295509504x10^9$$

o   Calculation, Bank F:

$$CENTER_{SKY} = -1.0 * 2.450000x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.82x10^9)$$

$$CENTER_{SKY} = 1.285509632x10^9$$

GO Fits:
- BANDWIDTH: 2.344000E+07
- VELOCITY: 0.0 (set by observer)
- VELDEF: 'VOPT-LSR' (set by observer)
- SKYFREQ: 1350405800.0 (calculated)

- o In the GO fits file, the deltafreq (MHz) = -0, -20, -40, -60, -80, -100, -120,-140
- o In the same file, the restfreq (MHz) = 1420.4058, 1420.4058, 1420.4058, 1420.4058, 1420.4058, 1420.4058, 1420.4058, 1420.4058

$$SKYFREQ = \frac{(first\ rest\ freq + deltafreq) + (last\ rest\ freq + deltafreq)}{2}$$

$$SKYFREQ = \frac{(1420.4058000 - 0) + (1420.4058000 - 140)}{2}$$

$$SKYFREQ = 1420.40580.0 - 70.0 = 1350.4058000$$

- RESTFREQ: 1420405800.0 (set by observer)
- NCHANS: 32768 (set by observer; VEGAS mode 10)
- RESOLN 7.000000000E+02 (set by observer; VEGAS mode 10)
- RESTFREQ: 1.420405800000E+09 (set by observer)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:

- MODE: 10
- CHAN_BW: -715.255737304688 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{\left(\frac{1500.0x10^6}{32}\right)}{(32768 * 2)} = 715.2557373\ Hz$$

- SUB0FREQ: 249938964.84375 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 2.49938964843751E+08 (calculated)
  CRVAL1=SUB[X}FREQ; This is for Bank 0

$$CRVAL1 = SUB0FREQ = 249938964.8375$$

- CDELT1: 7.152557373047E+02 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 715.2557373$$

- FREQRES: 7.15255737304E+02 (calculated)

$$FREQRES = CDELT1 = 715.2557373$$

- CRPIX1: 1.6385E+04 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 16385$$

SDFITS

- BANDWID: 2.3437500E+07 (This is the bandwidth of VEGAS mode 10.)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)

- CRVAL1: (calculated)
    - Bank A: 1.420570494156E+09
    - Bank B: 1.400570494156E+09
    - Bank C: 1.380570494156E+09
    - Bank D: 1.360570494156E+09
    - Bank E: 1.340570494156E+09
    - Bank F: 1.320570494156E+09
    - Bank G: 1.300570494156E+09
    - Bank H: 1.280570494156E+09

    Calculation:

    $$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Bank A:

    $$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.350509459x10^9 + 0.0 + (-2.68000x10^9)$$

    $$CENTER_{SKY} = 1.420570624x10^9$$

- Bank B:

    $$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.350509459x10^9 - 0.0 + (-2.70x10^9)$$

    $$CENTER_{SKY} = 1.400570624x10^9$$

- Bank C:

    $$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.350509459x10^9 - 0.0 + (-2.72x10^9)$$

    $$CENTER_{SKY} = 1.380570625x10^9$$

- Bank D:

    $$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.350509459x10^9 - 0.0 + (-2.74x10^9)$$

    $$CENTER_{SKY} = 1.360570624x10^9$$

- Bank E:

    $$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.350509459x10^9 - 0.0 + (-2.76x10^9)$$

    $$CENTER_{SKY} = 1.340570624x10^9$$

- Bank F:

    $$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.350509459x10^9 - 0.0 + (-2.78x10^9)$$

    $$CENTER_{SKY} = 1.3320570624x10^9$$

- o Bank G:

$$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.350509459x10^9 - 0.0 + (-2.80x10^9)$$

$$CENTER_{SKY} = 1.300570624x10^9$$

- o Bank H:

$$CRVAL1 = -1.0 * 2.499389648375x10^8 + 1.0 * 4.350509459x10^9 - 0.0 + (-2.82x10^9)$$

$$CENTER_{SKY} = 1.280570624x10^9$$

- CRPIX1: 1.6385000E+04 (VEGAS CRPIX1 value)
- CDELT1: -7.152557373047E+02 (VEGAS CHAN_BW value)
- VELDEF: OPTI-LSR (Set by observer; LO1A VELDEF value)
- VFRAME: -2.18780725624E+04 (LO1A VFRAME value)
- RVSYS: -2.18780725624E+04 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
    - o Bank A: 1.420570494156E+09 (matches SDFITS CRVAL1)
    - o Bank B: 1.400570494156E+09
    - o Bank C: 1.380570494156E+09
    - o Bank D: 1.360570494156E+09
    - o Bank E: 1.340570494156E+09
    - o Bank F: 1.320570494156E+09
    - o Bank G: 1.300570494156E+09
    - o Bank H: 1.280570494156E+09
- RESTFREQ: 1.4204058000E+09 (LO1A RSTFRQ value)
- FREQRES: 7.15255737304E+02 (VEGAS 1st FREQRES value)
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: 0.0000000E+00 (GO VELOCITY value)
- DOPFREQ: 1.4204058000E+09 (matches LO1A RESTFREQ value)

11.4 Example 4: L-band, DCR

Files: AGBT22B_065_04, Scan #1 (2022_08_10_04:02:55)

Observer Request:

- AutoPeakFocus routine

LO1A Fits

- RESTFREQ: 1.400000000E+09 (entered by observer)
- IFFREQ: 3.00000E+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 1.0000E+00 (set by hardware)
- FREQOFF: 0.00E+00 (set by observer)
- VELOCITY: 0.000E+00 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 4.400000000E+09 (calculated)

$$LO1FREQ = (IFFREQ + f + LOOFFSET)/LOMULT$$

$$LO1FREQ = (3.000x10^9 + 1.3000x10^9 + 0.0)/1.0$$

$$LO1FREQ = 4.4000x10^9$$

- VFRAME: 0.000E+00 (Determined by JPL ephemeris and based on VELDEF, Time, and source position)
- RVSYS: 0.000E+00 (calculated)
- VELDEF: 'VRAD-TOP'
- SIDEBAND: 'LOWER'

IF Fits:

- BACKEND: DCR
- SIDEBAND: L
- CENTER_IF: 3.0000E+09 (set by hardware)
- BANDWIDTH: 8.000E+07 (set by observer)
- SFF_MULTIPLIER: 1.000E+00 (set by hardware)
- SFF_SIDEBAND: -1.000E+00 (set by hardware)
- SFF_OFFSET: 0.00000E+00 (set by hardware)
- CENTER_SKY: 1.4000000E+09 (calculated)

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * LO1 + FREQOFF + SFF\_OFFSET$$

$$CENTER_{SKY} = -1.0 * 3.0x10^9 + 1.0 * 4.40000x10^9 + 0.00 + (0.00)$$

$$CENTER_{SKY} = 1.400000x10^9$$

GO Fits:

- BANDWIDTH: 8.000000E+07
- VELOCITY: 5688000.0 (set by observer)
- VELDEF: 'VRAD-TOP' (set by observer)
- SKYFREQ: 1400000000.0 (equal to RESTFREQ, as there is only one observing band)
- RESTFREQ: 1400000000.0 (set by observer)
- NCHANS: 1 (set by observer; DCR)
- RESOLN 8.000000000E+01 (DCR bandwidth)
- BACKEND: 'DCR

DCR Fits:

No frequency information

SDFITS

- BANDWID: 8.000E+07 (This is the bandwidth of the DCR.)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: 1.400000000E+09 (calculated)

$$CRVAL1 = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CRVAL1 = -1.0 * 3.0000\text{x}10^9 + 1.0 * 4.40000\text{x}10^9 - 0.0 + 0.0$$

$$CENTER_{SKY} = 1400000000\text{x}10^9$$

- CRPIX1: N/A
- CDELT1: N/A
- VELDEF: N/A
- VFRAME: N/A
- RVSYS: N/A
- OBSFREQ: 1.400000000E+09 (matches SDFITS CRVAL1)
- RESTFREQ: N/A
- FREQRES: N/A
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: N/A
- DOPFREQ: N/A

11.5 Example 5: W receiver, Total Power, N0 Source Velocity, Multiple Banks, VEGAS (VRAD_LSR)

Files: AGBT22B_060_03, Scan #10 (2023_01_05_10:38:27)

Here, both VEGAS band (A & E) are the same

Observer Request:

- Receiver = "Rcvr68_92"
- Beam = "B12"
- Nwin=1
- restfreq= 72800.
- deltafreq = 0
- bandwidth = 1080
- swtype = "none"
- swmode='tp_nocal
- swfreq=0.0,0.0
- velocity=0.0
- vframe="lsrk"
- vdef="Radio"

LO1A Fits

- RESTFREQ: 7.280000E+10 (entered by observer)
- IFFREQ: 6.800000000E+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 4.0000E+00 (set by hardware)
- SIDEBAND: 'UPPER'
- FREQOFF: 0.00000E+00 (set by observer)
- VELDEF: 'VRAD-LSR'
- VELOCITY: 0.0000E+00 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 1.650194948600E+10 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

$$LO1FREQ = \frac{-6.80000x10^9 + 7.2800000x10^{10}\left(1 - \frac{-3.211121556604x10^4}{2.99792458x10^8}\right)}{4.0} + 0.0$$

$$LO1FREQ = 1.66501950464x10^{10}$$

- VFRAME: -3.211121556604E+04 (Determined by JPL ephemeris)
- RVSYS: -3. 211121556604E+04 (calculated)

$$f = f_0 \left(1 - \frac{(SRCVEL + VFRAME)}{c} \right) = 7.2800000x10^{10} \left(1 - \frac{0.0 - 3.211121556604x10^4}{2.99792458x10^8} \right)$$
$$= 7.28077977161x10^{10}$$

$$RVSYS = c \frac{1 - \left(f/f_0 \right)^2}{1 + \left(f/f_0 \right)^2} = 2.99792458x10^8 \frac{1 - \left(7.28077977161x10^{10}/7.2800000x10^{10} \right)^2}{1 + \left(7.28077977161x10^{10}/7.2800000x10^{10} \right)^2} = -3.2109495826x10^4$$

IF Fits:

- BACKEND: VEGAS
- SIDEBAND: U
- CENTER_IF: (set by hardware configuration)
  - Bank A&E: 5.500000E+08
- BANDWIDTH: (set by hardware configuration)
  - Bank A&E: 8.000000E+08
- SFF_MULTIPLIER: 4.000E+00 (set by hardware)
- SFF_SIDEBAND: 1.000E+00 (set by hardware)
- SFF_OFFSET: (set by hardware configuration)
  - Bank A&E: 6.26000E+09
- CENTER_SKY: (calculated)
  - Bank A&E: 7.281789E+10

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CENTER_{SKY} = 1.0 * 5.5000x10^8 + 4.0 * 1.650194948600x10^{10} + 0.0 + (6.26x10^9)$$

$$CENTER_{SKY} = 7.2817795x10^{10}$$

GO Fits:

- BANDWIDTH: 1.080000E+09
- VELOCITY: 0.0 (set by observer)
- VELDEF: 'VRAD-LSR' (set by observer)
- SKYFREQ: 72800000000.0 (equal to RESTFREQ, as there is only one observing band)
- RESTFREQ (primary header): 72800000000.0 (set by observer)
- NCHANS: 16384 (set by observer; VEGAS mode 3)
- RESOLN 6.700000000E+04 (set by observer; VEGAS mode 3)
- RESTFREQ (table): 7.2800000000E+10 (set by observer)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:

- MODE: 3
- CHAN_BW: -65917.96875 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(2 * 1080x10^6)}{(16384 * 2)} = 65917.96875\ Hz$$

- SUB0FREQ: 540000000 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 5.40000E+08 (calculated)

$$CRVAL1 = SUB0FREQ = 5.40000000x10^8$$

- CDELT1: 6.59179687500+04 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 6.591796875x10^4$$

- FREQRES: 6.59179687500E+04 (calculated)

$$FREQRES = CDELT1 = 6.591796875x10^4$$

- CRPIX1: 8.1930E+03 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 8193$$

SDFITS

- BANDWID: 1.08000E+09 (This is the bandwidth of VEGAS mode 3.)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: (calculated)
  - Bank A & E: 7.280779794400E+10

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CRVAL1 = 1.0 * 5.4000x10^8 + 4.0 * 1.650194948600x10^{10} + 0.0 + (6.26x10^9)$$

$$CENTER_{SKY} = 7.2807800832x10^{10}$$

- CRPIX1: 8.913000E+03 (VEGAS CRPIX1 value)
- CDELT1: 6.5917968740+04 (VEGAS CHAN_BW value)
- VELDEF: RADI-LSR (Set by observer; LO1A VELDEF value)
- VFRAME: -3.211121556604E+04 (LO1A VFRAME value)
- RVSYS: -3.211121556604E+04 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
  - Bank A & E: 7.280779794400E+10 (matches SDFITS CRVAL1)
- RESTFREQ: 7.280000E+10 (LO1A RSTFRQ value)

- FREQRES: 6.59179687500E+04 (VEGAS FREQRES value)
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: 0.0000000E+00 (GO VELOCITY value)
- DOPFREQ: 7.280000E+10 (matches LO1A RESTFREQ value

11.6 Example 6: W receiver, Total Power, N0 Source Vel, Multiple Banks, VEGAS (VOPT-BAR)

Files: AGBT22B_020_01, Scan #22 (2022_12_14_11:42:17)

Here, looking at all VEGAS band (A-H), as each is offset in frequency

Observer Request:
- Receiver = "Rcvr68_92"
- Beam = "B12"
- Nwin=4
- restfreq= 77414.0.75915.0,76414.0,78414.0
- deltafreq = 0,0,0,0
- bandwidth = 1500.0
- swtype = "none"
- swmode='tp_nocal
- swfreq=0.0,0.0
- velocity=0.0
- vframe="bary"
- vdef="Optical"
- nchan="high"

LO1A Fits
- RESTFREQ: 7.74140000E+10 (entered by observer)
- IFFREQ: 1.1414000000E+10 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 4.0000E+00 (set by hardware)
- SIDEBAND: 'UPPER'
- FREQOFF: 0.00000E+00 (set by observer)
- VELDEF: 'VOPT-BAR'
- VELOCITY: 0.0000E+00 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 1.650090182300E+10 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

$$LO1FREQ = \frac{-1.414000 x 10^{10} + \frac{7.741400000 x 10^{10}}{\left(1 + \frac{-1.397042983181 x 10^4}{2.99792458 x 10^8}\right)}}{4.0} + 0.0$$

$$LO1FREQ = 1.6500900864x10^{10}$$

- VFRAME: -1.397042983181E+04 (Determined by JPL ephemeris)
- RVSYS: -1. 397042983181E+04 (calculated)

$$f = f_0/\left(1 + \frac{(SRCVEL + VFRAME)}{c}\right) = 7.741400000x10^{10}/\left(1 + \frac{0.0 - 1.397042983181x10^4}{2.99792458x10^8}\right)$$
$$= 7.7417607687x10^{10}$$

$$RVSYS = c\ \frac{1-\left(f/f_0\right)^2}{1+\left(f/f_0\right)^2} = 2.99792458x10^8\ \frac{1-\left(7.7417607687x10^{10}/7.741400000x10^{10}\right)^2}{1+\left(7.7417607687x10^{10}/7.741400000x10^{10}\right)^2} = --1.3970755345x10^4$$

IF Fits:

- BACKEND: VEGAS
- SIDEBAND: L (set by hardware)
- CENTER_IF: (set by hardware configuration)
    - Bank A-H: 7.7500000E+08
- BANDWIDTH: (set by hardware configuration)
    - Bank A-H: 1.250000E+09
- SFF_MULTIPLIER: 4.000E+00 (set by hardware)
- SFF_SIDEBAND: -1.000E+00 (set by hardware)
- SFF_OFFSET: (set by hardware configuration)
    - Bank A,E: 1.06650000E+10
    - Bank B,F: 1.11640000E+10
    - Bank C,G: 1.21640000E+10
    - Bank D,H: 1.31640000E+10
- CENTER_SKY: (calculated)
    - Bank A,E: 7.589360E+10
    - Bank B,F: 7.639261E+10
    - Bank C,G: 7.739261E+10
    - Bank D,H: 7.839261E+10

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Bank A, E:

$$CENTER_{SKY} = -1.0 * 7.75000x10^8 + 4.0 * 1.650090182300x10^{10} + 0.0 + (1.0665x10^{10})$$

$$CENTER_{SKY} = 7.5893604352x10^{10}$$

- Bank B,F:

$$CENTER_{SKY} = -1.0 * 7.75000x10^8 + 4.0 * 1.650090182300x10^{10} + 0.0 + (1.1164x10^{10})$$

$$CENTER_{SKY} = 7.6392611840x10^{10}$$

- Bank C,G:

$$CENTER_{SKY} = -1.0 * 7.75000x10^8 + 4.0 * 1.650090182300x10^{10} + 0.0 + (1.2164x10^{10})$$

$$CENTER_{SKY} = 7.7392609280x10^{10}$$

- Bank B,F:

$$CENTER_{SKY} = -1.0 * 7.75000x10^8 + 4.0 * 1.650090182300x10^{10} + 0.0 + (1.3164x10^{10})$$

$$CENTER_{SKY} = 7.8392606720x10^{10}$$

GO Fits:
- BANDWIDTH: 1.50000E+09
- VELOCITY: 0.0 (set by observer)
- VELDEF: 'VOPT-BAR' (set by observer)
- SKYFREQ: 77164500000.0 (Calculated)
  - In the GO fits file, the deltafreq (MHz) = 0, 0, 0, 0
  - Same file, restfreq=77414.0,75915.0,76414.0, 78414.0

$$SKYFREQ = \frac{(first\ rest\ freq + deltafreq) + (last\ rest\ freq + deltafreq)}{2}$$

$$SKYFREQ = \frac{(7.591500x10^{10} + 0.0) + (7.841400x10^{10} + 0.0)}{2}$$

$$SKYFREQ = 7.7164500x10^{10}$$

- RESTFREQ (primary header): 77414000000.0 (set by observer)
- NCHANS: 16384 (set by observer; VEGAS mode 2)
- RESOLN 9.200000000E+04 (set by observer; VEGAS mode 2)
- RESTFREQ (table):
  - Bank A,E: 7.5915000000E+10 (set by observer)
  - Bank B,F: 7.6414000000E+10 (set by observer)
  - Bank C,G: 7.7414000000E+10 (set by observer)
  - Bank D,H: 7.8414000000E+10 (set by observer)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:
- MODE: 2

- CHAN_BW: -91552.734375 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(2 * 1500x10^6)}{(16384 * 2)} = 91552734375\ Hz$$

- SUB0FREQ: 750000000 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 7.50000E+08 (calculated)

$$CRVAL1 = SUB0FREQ = 7.50000000x10^8$$

- CDELT1: 9.1552734375+04 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 9.1552734375x10^4$$

- FREQRES: 9.1552734375E+04 (calculated)

$$FREQRES = CDELT1 = -9.1552734375x10^4$$

- CRPIX1: 8.1930E+03 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 8193$$

SDFITS

- BANDWID: 1.50000E+09 (This is the bandwidth of VEGAS mode 2.)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: (calculated)
    - Bank A & E: 7.591860728800E+10
    - Bank B & F: 7.641760728800E+10
    - Bank C & G: 7.41760728800E+10
    - Bank D & H: 7.841760728800E+10

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Bank A & E:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 4.0 * 1.6500900864x10^{10} + 0.0 + (1.0665x10^{10})$$

$$CENTER_{SKY} = 7.5918606336x10^{10}$$

- Bank B & F:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 4.0 * 1.6500900864x10^{10} + 0.0 + (1.1164x10^{10})$$

$$CENTER_{SKY} = 7.6417605632x10^{10}$$

- Bank C & G:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 4.0 * 1.6500900864x10^{10} + 0.0 + (1.2164x10^{10})$$

$$CENTER_{SKY} = 7.7417603072x10^{10}$$

○ Bank D & H:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 4.0 * 1.6500900864x10^{10} + 0.0 + (1.3164x10^{10})$$

$$CENTER_{SKY} = 7.8417608704x10^{10}$$

- CRPIX1: 8.913000E+03 (VEGAS CRPIX1 value)
- CDELT1: - 9.1552734375+04 (VEGAS CHAN_BW value)
- VELDEF: OPTI-BAR (Set by observer; LO1A VELDEF value)
- VFRAME: -1.397042983181E+04 (LO1A VFRAME value)
- RVSYS: -1. 397042983181E+04 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
    - Bank A & E: 7.591860728800E+10 (matches SDFITS CRVAL1)
- RESTFREQ: 7.591500000E+10 (VEGAS 1st RSTFRQ value)
- FREQRES: 9.1552734375E+04 (VEGAS FREQRES value)
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: 0.0000000E+00 (GO VELOCITY value)
- DOPFREQ: 7.7414000E+10 (matches LO1A RESTFREQ value)

11.7 Example 7: Q-band, Total Power, N0 Source Velocity, Multiple Banks, VEGAS (VRAD-LSR)

Files: AGBT22B_011_02, Scan #11 (2022_10_29_21:03:23)

Here, looking at all VEGAS band (A-H), as each is offset in frequency

Observer Request:
- Unknown (script removed from astrid)

LO1A Fits
- RESTFREQ: 4.2879820000E+10 (entered by observer)
- IFFREQ: 5.4048300000000E+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 4.0000E+00 (set by hardware)
- SIDEBAND: 'UPPER'
- FREQOFF: 0.00000E+00 (set by observer)
- VELDEF: 'VRAD-LSR'
- VELOCITY: 0.0000E+00 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 9.36954034800E+09 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f + LOOFFSET)}{LOMULT}$$

$$LO1FREQ = \frac{\left(-5.4048300 x 10^9 + 4.28798200 x 10^{10}\left(1 - \frac{-2.21721910668 x 10^4}{2.99792458 x 10^8}\right) + 0.0\right)}{4.0}$$

$$LO1FREQ = 9.3695395840 x 10^9$$

- VFRAME: -2.21721910668E+04 (Determined by JPL ephemeris)
- RVSYS: -2.21721910668E+04 (calculated)

$$f = f_0\left(1 - \frac{(SRCVEL + VFRAME)}{c}\right) = 4.28798200 x 10^{10}\left(1 - \frac{0.0 - 2.21721910668 x 10^4}{2.99792458 x 10^8}\right)$$
$$= 4.2882991326 x 10^{10}$$

$$RVSYS = c\,\frac{1 - \left(f/f_0\right)^2}{1 + \left(f/f_0\right)^2} = 2.99792458 x 10^8\,\frac{1 - \left(4.2882991326 x 10^{10}/4.28798200 x 10^{10}\right)^2}{1 + \left(4.2882991326 10^{10}/4.28798200 x 10^{10}\right)^2} = -2.2171371156 x 10^4$$

IF Fits:
- BACKEND: VEGAS
- SIDEBAND: U
- CENTER_IF: (set by hardware configuration)

- o Bank A-H: 5.5000000E+08
- BANDWIDTH: (set by hardware configuration)
  - o Bank A-H: 8.000000E+08
- SFF_MULTIPLIER: 4.000E+00 (set by hardware)
- SFF_SIDEBAND: 1.000E+00 (set by hardware)
- SFF_OFFSET: (set by hardware configuration)
  - o Bank A,E: 5.10483000E+09
  - o Bank B,F: 5.64877000E+09
  - o Bank C,G: 6.25441000E+09
  - o Bank D,H: 6.294377000E+09
- CENTER_SKY: (calculated)
  - o Bank A,E: 4.313299E+10
  - o Bank B,F: 4.367693E+10
  - o Bank C,G: 4.428257E+10
  - o Bank D,H: 4.432254E+10

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Bank A, E:

$$CENTER_{SKY} = 1.0 * 5.50000x10^8 + 4.0 * 9.36954034800x10^9 + 0.0 + (5.1048300x10^9)$$

$$CENTER_{SKY} = 4.3132989440x10^{10}$$

- Bank B,F:

$$CENTER_{SKY} = 1.0 * 5.50000x10^8 + 4.0 * 9.36954034800x10^9 + 0.0 + (5.6487700x10^9)$$

$$CENTER_{SKY} = 4.36769300x10^{10}$$

- Bank C,G:

$$CENTER_{SKY} = 1.0 * 5.50000x10^8 + 4.0 * 9.36954034800x10^9 + 0.0 + (6.2544100x10^9)$$

$$CENTER_{SKY} = 4.4282573x10^{10}$$

- Bank B,F:

$$CENTER_{SKY} = 1.0 * 5.50000x10^8 + 4.0 * 9.36954034800x10^9 + 0.0 + (6.29437700x10^9)$$

$$CENTER_{SKY} = 4.4322537x10^{10}$$

GO Fits:

- BANDWIDTH: 1.00000E+08
- VELOCITY: 0.0 (set by observer)
- VELDEF: 'VRAD-LSR' (set by observer)
- SKYFREQ: 43474990290.16875 (calculated)

- o In the GO fits file, the deltafreq (MHz) = 0, 0, 0, 0
- o Same file, restfreq=77414.0,75915.0,76414.0, 78414.0

$$SKYFREQ = \frac{(first\ rest\ freq + deltafreq) + (last\ rest\ freq + deltafreq)}{2}$$

$$SKYFREQ = \frac{(4.287982x10^{10} + 0.0) + (4.40693670x10^{10} + 0.0)}{2}$$

$$SKYFREQ = 4.3474593163x10^{10}$$

- RESTFREQ (primary header): 42879820000.0 (set by observer)
- NCHANS: 65536 (set by observer; VEGAS mode 8)
- RESOLN 1.500000000E+03 (set by observer; VEGAS mode 8)
- RESTFREQ (table):
  - o Bank A,E: 4.287982000E+10 (set by observer)
  - o Bank B,F: 4.342376000E+10 (set by observer)
  - o Bank C,G: 4.402940000E+10 (set by observer)
  - o Bank D,H: 4.406936700E+10 (set by observer)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:
- MODE: 8
- CHAN_BW: 1525.87890625 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(800x10^6/4)}{(65536 * 2)} = 1525.88\ Hz$$

- SUB0FREQ: 3.000000E+08 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 3.000000E+08 (calculated)

$$CRVAL1 = SUB0FREQ = 3.00000000x10^8$$

- CDELT1: 1.52587890625+03 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 1.52587890625x10^3$$

- FREQRES: 1.52587890625+03 (calculated)

$$FREQRES = CDELT1 = 1.52587890625x10^3$$

- CRPIX1: 3.2769E+04 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 32769$$

SDFITS

- BANDWID: 1.00000E+08 (This is the bandwidth of VEGAS mode 8)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: (calculated)
  - Bank A & E: 4.288299138400E+10
  - Bank B & F: 4.34269138400E+10
  - Bank C & G: 4.403257138400E+10
  - Bank D & H: 4.407253828400EE+10

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Bank A & E:

$$CRVAL1 = 1.0 * 3.00000000x10^8 + 4.0 * 9.3695395840x10^9 + 0.0 + (5.1048300x10^9)$$

$$CENTER_{SKY} = 4.2882985984x10^{10}$$

- Bank B & F:

$$CRVAL1 = 1.0 * 3.00000000x10^8 + 4.0 * 9.3695395840x10^9 + 0.0 + (5.6487700x10^9)$$

$$CENTER_{SKY} = 4.3426926592x10^{10}$$

- Bank C & G:

$$CRVAL1 = 1.0 * 3.00000000x10^8 + 4.0 * 9.3695395840x10^9 + 0.0 + (6.2544100x10^9)$$

$$CENTER_{SKY} = 4.4032569244x10^{10}$$

- Bank D & H:

$$CRVAL1 = 1.0 * 3.00000000x10^8 + 4.0 * 9.3695395840x10^9 + 0.0 + (6.29437700x10^9)$$

$$CENTER_{SKY} = 4.4072534016x10^{10}$$

- CRPIX1: 3.2769E+043 (VEGAS CRPIX1 value)
- CDELT1: 1.525878906250E+03 (VEGAS CHAN_BW value)
- VELDEF: RADI-LSR (Set by observer; LO1A VELDEF value)
- VFRAME: -2.21721910668E+04 (LO1A VFRAME value)
- RVSYS: -2.21721910668E+04 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
  - Bank A & E: 4.288299138400E+10 (matches SDFITS CRVAL1)
  - Bank B & F: 4.342693138400E+10
  - Bank C & G: 4.403257138400E+10

- o Bank D & H: 4.407253828400EE+10
- RESTFREQ: 4.287982000 (VEGAS 1st RSTFRQ value)
- FREQRES: 1.52587890625+03 (VEGAS FREQRES value)
- SIDEBAND: 'U' (IF SIDEBAND value)
- VELOCITY: 0.0000000E+00 (GO VELOCITY value)
- DOPFREQ: 4.2879820000E+10 (matches LO1A RESTFREQ value)

11.8   Example 8: KFPA, Frequency Switch, Source Velocity, One Bank, VEGAS (VRAD-LSR)

Files: AGBT22B_085_01, Scan 6 (2022_10_09_07:25:01) KFPA

Observer Request:

- Receiver = "Rcvr75_116"
- Beam = "all"
- restfreq= 110201,109782
- bandwidth = 23.44
- swtype = "fsw"
- swmode='stp_nocal'
- swfreq=-3,3
- vloq=0.0
- vhigh=0.0
- vframe="lsrk"
- vdef="Radio"
- nchan=4096
- sideband='USB'
- vegas.subband=8

LO1A Fits

- RESTFREQ: 2.36944955000E+10 (entered by observer)
- IFFREQ: 6.800000000000000E+09 (set by hardware)
- LOOFFSET: 0.0000000000000E+00 (set by hardware)
- LOMULT: 2.0000E+00 (set by hardware)
- SIDEBAND: 'Lower'
- FREQOFF: 0.00000E+00 (set by observer)
- VELDEF: 'VRAD-LSR'
- VELOCITY:6.8500000E+03 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 1.524654530500E+10 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

$$LO1FREQ = \frac{6.800000 x 10^9 + 2.3694495510^{10}\left(1 - \frac{6.85000 x 10^3 + 1.09241676339 x 10^4}{2.99792458 x 10^8}\right)}{2.0} + 0.0$$

$$LO1FREQ = 1.5246545348 x 10^{10}$$

- VFRAME: 1.09241676339493E+04 (Determined by JPL ephemeris)
- RVSYS: 1.777424587743+04 (calculated)

$$f = f_0\left(1 - \frac{(SRCVEL + VFRAME)}{c}\right) = 2.36944955x10^{10}\left(1 - \frac{6.85000x10^3 + 1.09241676339x10^4}{2.99792458x10^8}\right)$$

$$= 2.3693090695x10^{10}$$

$$RVSYS = c\,\frac{1-\left(f/f_0\right)^2}{1+\left(f/f_0\right)^2} = 2.99792458x10^8\,\frac{1-\left(2.3693090695x10^{10}/2.36944955x10^{10}\right)^2}{1+\left(2.3693090695x10^{10}/2.36944955x10^{10}\right)^2} = 1.7774694534x10^4$$

IF Fits:
- BACKEND: VEGAS
- SIDEBAND: L
- CENTER_IF: 5.500000E+08 (set by hardware configuration)
- BANDWIDTH: 8.00000000E+08 (set by hardware configuration)
- SFF_MULTIPLIER: 2.000E+00 (set by hardware)
- SFF_SIDEBAND: -1.000E+00 (set by hardware)
- SFF_OFFSET: -6.50000E+09 (set by hardware configuration)
- CENTER_SKY: 2.344309E+10 (calculated)

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CENTER_{SKY} = -1.0 * 5.500000x10^8 + 2.0 * 1.524652530500x10^{10} + 0.0 + (-6.50000x10^9)$$

$$CENTER_{SKY} = 2.344305049610^{10}$$

GO Fits:
- BANDWIDTH: 1.000000E+08
- VELOCITY: 6850.0 (set by observer)
- VELDEF: 'VRAD-LSR' (set by observer)
- SKYFREQ: 23694495500.0 (calculated - here same as GO frequency, as there is only one)
- RESTFREQ (primary header): 23694495500.0 (set by observer)
- NCHANS: 32768 (set by observer; VEGAS mode 7)
- RESOLN 3.100000E+03 (set by observer; VEGAS mode 7)
- RESTFREQ (table): 2.3694495500E+10 (set by observer)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:
- MODE: 7
- CHAN_BW: -3051.7578125 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(800x10^6/4)}{(32768 * 2)} = 3.0517578125x10^3\ Hz$$

- SUB0FREQ: 3.0000000E8 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 3.0000000E+08 (calculated)

$$CRVAL1 = SUB0FREQ = 3.0000000x10^8$$

- CDELT1: 3.05175781250+03 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 3.0517578125x10^3$$

- FREQRES: 3.05175781250+03 (calculated)

$$FREQRES = CDELT1 = 3.0517578125x10^3$$

- CRPIX1:2.0490E+03 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 16385$$

SDFITS

- BANDWID: 1.000000E+08 (This is the bandwidth of VEGAS mode 7)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: 2.369309057400E+10(calculated)

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

$$CRVAL1 = -1.0 * 3.0000000x10^8 + 2.0 * 1.524654530500x10^{10} + 0.0 - 6.50000x10^9$$

$$CENTER_{SKY} = 2.36930908x10^{10}$$

- CRPIX1: 1.63850E+03 (VEGAS CRPIX1 value)
- CDELT1: 3051.7578125 (VEGAS CHAN_BW value)
- VELDEF: RADI-LSR (Set by observer; LO1A VELDEF value)
- VFRAME: 1.09246763394933E+04 (LO1A VFRAME value)
- RVSYS: 1.777424587743+04 (LO1A RVSYS value)
- OBSFREQ: 2.369309057400E+10 (matches SDFITS CRVAL1)
- RESTFREQ: 2.36944955000E+10 (VEGAS 1st RSTFRQ value)
- FREQRES: 3.05175781250+03 (VEGAS FREQRES value)
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: 6.850000E+03 (GO VELOCITY value)
- DOPFREQ: 2.36944955000E+10 (matches LO1A RESTFREQ value)

11.9 Example 9: ARGUS, Frequency Switch, Source Velocity, Multiple Banks, VEGAS (VRAD-LSR)

Files: AGBT22B_085_01, Scan 6 (2022_10_09_07:25:01)

Observer Request:
- Receiver = "Rcvr75_116"
- Beam = "all"
- restfreq= 110201,109782
- bandwidth = 23.44
- swtype = "fsw"
- swmode='stp_nocal'
- swfreq=-3,3
- vloq=0.0
- vhigh=0.0
- vframe="lsrk"
- vdef="Radio"
- nchan=4096
- sideband='USB'
- vegas.subband=8

LO1A Fits
- RESTFREQ: 1.1020000000E+11 (entered by observer)
- IFFREQ: 1.734500000000E+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 8.0000E+00 (set by hardware)
- SIDEBAND: 'UPPER'
- FREQOFF: -3.00000E+06 (set by observer)
- VELDEF: 'VRAD-LSR'
- VELOCITY: 5.9000E+03 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 1.355878915900E+10 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

$$LO1FREQ = \frac{-1.734500x10^9 + 1.10200x10^{11}\left(1 - \frac{5.900x10^3 - 1.627413039864x10^4}{2.99792458x10^8}\right)}{8.0} + 0.0$$

$$LO1FREQ = 1.3558664175 x 10^{10}$$

- VFRAME: -1.627413039864E+04 (Determined by JPL ephemeris)
- RVSYS: -1.037407235287+04 (calculated)

$$f = f_0 \left(1 - \frac{(SRCVEL + VFRAME)}{c}\right) = 1.10200 x 10^{11} \left(1 - \frac{5.900 x 10^3 - 1.627413039864 x 10^4}{2.99792458 x 10^8}\right)$$
$$= 1.1020381340 x 10^{11}$$

$$RVSYS = c \frac{1 - (f/f_0)^2}{1 + (f/f_0)^2} = 2.99792458 x 10^8 \frac{1 - \left(1.1020381340 x 10^{11}/1.10200 x 10^{11}\right)^2}{1 + \left(1.1020381340 x 10^{11}/1.10200 x 10^{11}\right)^2} = -1.0373950904 x 10^4$$

IF Fits:
- BACKEND: VEGAS
- SIDEBAND: U
- CENTER_IF: (set by hardware configuration)
  - Bank A-H: 7.6530000E+08
- BANDWIDTH: (set by hardware configuration)
  - Bank A-H: 1.2250000E+09
- SFF_MULTIPLIER: 8.000E+00 (set by hardware)
- SFF_SIDEBAND: 1.000E+00 (set by hardware)
- SFF_OFFSET: (set by hardware configuration)
  - Bank A-H: 7.75000000E+08
- CENTER_SKY: (calculated)
  - Bank A-H: 1.100048E+11

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * LO1 + FREQOFF + SFF\_OFFSET$$

$$CENTER_{SKY} = 1.0 * 7.6530000 x 10^8 + 8.0 * 1.35587891590 x 10^{10} - 3.0 x 10^6 + (7.750000 x 10^8)$$

$$CENTER_{SKY} = 1.099866030110^{10}$$

GO Fits:
- BANDWIDTH: 2.34444444444E+07
- VELOCITY: 5900.0 (set by observer)
- VELDEF: 'VRAD-LSR' (set by observer)
- SKYFREQ: 109991500000.0 (calculated - here same as GO frequency, as there is only one)
- RESTFREQ (primary header): 110201000000.0 (set by observer) (history has two: 110201, 109782)
- NCHANS: 4096 (set by observer; VEGAS mode 20)
- RESOLN 5.7000000E+03, 2.34400000+01 (set by observer; VEGAS mode 20)
  - RESTFREQ (table): 1.097820000E+11, 1.10201000+E11 (set by observer)
- SUBBAND: 0, 1 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:

- MODE: 20
- CHAN_BW: -5722.0458984375 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(1500x10^6/32)}{(4096 * 2)} = 5.7220458984x10^3\ Hz$$

- SUB0FREQ: 540527343.75 (set by VEGAS mode chosen)
- SUB1FREQ: 959472656.25 (set by VEGAS mode chosen)
- CRVAL1 (IF3): (calculated)
    - Spec Win 1: 5.405273437500E+08
    - Spec Win 2: 9.594726562500E+08

Spec Win 1: $CRVAL1 = SUB0FREQ = 5.4052734375x10^8$

Spec Win 2: $CRVAL1 = SUB1FREQ = 9.5947265625x10^8$

- CDELT1: 5.722045898438+03 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 5.7220458984375x10^3$$

- FREQRES: 5.722045898438+03 (calculated)

$$FREQRES = CDELT1 = 5.7220458984375x10^3$$

- CRPIX1:2.0490E+03 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 2049$$

SDFITS

- BANDWID: 2.34375000E+07 (This is the bandwidth of VEGAS mode 20)
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: (calculated)
    - Spec Win 1: 1.097828408318E+11
    - Spec Win 2: 1.102017861442E+11

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Spec Win 1:

$$CRVAL1 = 1.0 * 5.4052734375x10^8 + 8.0 * 1.35587891590x10^{10} - 3.0x10^6 + 7.750000x10^8$$

$$CENTER_{SKY} = 1.097828352x10^{11}$$

- Spec Win 2:

$$CRVAL1 = 1.0 * 9.5947265625x10^8 + 8.0 * 1.35587891590x10^{10} - 3.0x10^6 + 7.750000x10^8$$

$$CENTER_{SKY} = 1.1020178227x10^{10}$$

- CRPIX1: 2.04900E+03 (VEGAS CRPIX1 value)
- CDELT1: 5.722045898438E+03 (VEGAS CHAN_BW value)
- VELDEF: RADI-LSR (Set by observer; LO1A VELDEF value)
- VFRAME: -1.627413039864E+04 (LO1A VFRAME value)
- RVSYS: -1.037466025286+04 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
  - Spec Win 1: 1.097828408318E+11 (matches SDFITS CRVAL1)
  - Spec Win 2: 1.102017861442E+11
- RESTFREQ:
  - Spec Win 1: 1.09782000E+11 (VEGAS 1st RSTFRQ value)
  - Spec Win 2: 1.10201000E+11
- FREQRES: 5.722045898438+03 (VEGAS FREQRES value)
- SIDEBAND: 'U' (IF SIDEBAND value)
- VELOCITY: 5.9000000E+03 (GO VELOCITY value)
- DOPFREQ: 1.1020100000E+10 (matches LO1A RESTFREQ value)

11.10   Example 10: Ka receiver, Total Power, No Velocity, Multiple Banks, VEGAS (VRAD_LSR)

Files: AGBT22A_398_03, Scan #15 (2022_09_29_22:43:18)

Observer Request:
- Receiver = "Rcvr26_40"
- Beam = "1"
- Nwin=4
- restfreq= 36400,37200,38000,38800
- deltafreq = 0,0,0,0
- bandwidth = 1080
- swtype = "none"
- swmode='tp
- velocity=0.0
- vframe="lsrk"
- vdef="Radio"
- nchan=16384

LO1A Fits
- RESTFREQ: 3.64000000E+10 (entered by observer)
- IFFREQ: 7.6000000000E+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 3.0000E+00 (set by hardware)
- SIDEBAND: 'LOWER
- FREQOFF: 0.00000E+00 (set by observer)
- VELDEF: 'VRAD-LSR'
- VELOCITY: 0.000000E+00 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 1.46670843283300E+10 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

$$LO1FREQ = \frac{+7.60000000 x 10^9 + 3.64000 x 10^{10}\left(1 - \frac{0.00 - 1.032027125597 x 10^4}{2.99792458 x 10^8}\right)}{3.0} + 0.0$$

$$LO1FREQ = 1.4667084800 x 10^{10}$$

- VFRAME: -1.032027125597+04 (Determined by JPL ephemeris)
- RVSYS: -1.032027125597+04 (calculated)

$$f = f_0 \left(1 - \frac{(SRCVEL + VFRAME)}{c}\right) = 3.64000x10^{10}\left(1 - \frac{0.00 - 1.032027125597x10^4}{2.99792458x10^8}\right)$$

$$= 3.6401253060x10^{10}$$

$$RVSYS = c \; \frac{1 - \left(f/f_0\right)^2}{1 + \left(f/f_0\right)^2} = 2.99792458x10^8 \; \frac{1 - \left(3.6401253060x10^{10}/3.64000x10^{10}\right)^2}{1 + \left(3.6401253060x10^{10}/3.64000x10^{10}\right)^2} = -1.0320093620x10^4$$

IF Fits:
- BACKEND: VEGAS
- SIDEBAND: L
- CENTER_IF: (set by hardware configuration)
  - Bank A: 5.45000E+08
  - Bank B-D: 5.5000E+08
- BANDWIDTH: (set by hardware configuration)
  - Bank A: 7.90000E+08
  - Bank B-D: 8.0000E+08
- SFF_MULTIPLIER: 3.000E+00 (set by hardware)
- SFF_SIDEBAND: -1.000E+00 (set by hardware)
- SFF_OFFSET: (set by hardware configuration)
  - Bank A: -7.060000000E+09
  - Bank B: -6.260000000E+09
  - Bank C: -5.460000000E+09
  - Bank D: -4.660000000E+09
- CENTER_SKY: (calculated)
  - Bank A: 3.639625E+10
  - Bank B: 3.719125E+10
  - Bank C: 3.799125E+10
  - Bank D: 3.879125E+10

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Bank A:

$$CENTER_{SKY} = -1.0 * 5.4500x10^8 + 3.0 * 1.4667084328330x10^{10} + 0.0 + (-7.0600x10^9)$$

$$CENTER_{SKY} = 3.6396253184x10^{10}$$

- Bank B:

$$CENTER_{SKY} = -1.0 * 5.500x10^8 + 3.0 * 1.4667084328330x10^{10} + 0.0 + (-6.2600x10^9)$$

$$CENTER_{SKY} = 3.7191258112x10^{10}$$

- Bank C:

$$CENTER_{SKY} = -1.0 * 5.500x10^8 + 3.0 * 1.4667084328330x10^{10} + 0.0 + (-5.4600x10^9)$$

$$CENTER_{SKY} = 3.799125606x10^{10}$$

o Bank D:

$$CENTER_{SKY} = -1.0 * 5.500x10^8 + 3.0 * 1.4667084328330x10^{10} + 0.0 + (-4.6600x10^9)$$

$$CENTER_{SKY} = 3.8791258112x10^{10}$$

GO Fits:

- BANDWIDTH: 1.0800000E+09
- VELOCITY: 0.0 (set by observer)
- VELDEF: 'VRAD-LSR' (set by observer)
- SKYFREQ: 3.76000E10 (calculated - center of highest+lowest frequency)
- RESTFREQ (primary header): 36400000000.0 (set by observer)
- NCHANS: 16384 (set by observer; VEGAS mode 3)
- RESOLN 6.1000000E+0 (set by observer; VEGAS mode 3)
- RESTFREQ (table): 3.6400E+10, 3.7200E+10. 3.8000E+10, 3.8800E+10 (set by observer)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:

- MODE: 3
- CHAN_BW: -91552.734375 (calculated)
  - o Note that this is clearly incorrect, and is the channel bandwidth for VEGAS mode 2. This project is the only example that I could find with this error. E.g. project AGBT22B_287 has a KA receiver and mode 3 for VEGAS, but does not have the same error.

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(1080x10^6 * 2)}{(16384 * 2)} = 6.5918x10^3\ Hz$$

- SUB0FREQ: 750000000.0 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 7.5000E+08 (calculated)
  Spec Win 1: $CRVAL1 = SUB0FREQ = 7.5000x10^8$
- CDELT1: 9.1552734375E+04 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 5.7220458984375x10^3$$

- FREQRES: 9.1552734375E+04 (calculated)

$$FREQRES = CDELT1 = 5.7220458984375x10^3$$

- CRPIX1:8.1930E+03 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 8193$$

SDFITS

- BANDWID: 1.5000000E+09
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: (calculated)
  - Bank A: 3.619125298200E+10
  - Bank B: 3.699125298200E+10
  - Bank C: 3.799125298200E+10
  - Bank D: 3.859125298200E+10

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

  - Bank A:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 3.0 * 1.46670843283300x10^{10} + 0.0 + -7.0600x10^9$$

$$CENTER_{SKY} = 3.6191257x10^{10}$$

  - Bank B:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 3.0 * 1.4667084328330x10^{10} + 0.0 + -6.2600x10^9$$

$$CENTER_{SKY} = 3.6991259x10^{10}$$

  - Bank C:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 3.0 * 1.4667084328330x10^{10} + 0.0 + -5.4600x10^9$$

$$CENTER_{SKY} = 3.7791257x10^{10}$$

  - Bank D:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 3.0 * 1.4667084328330x10^{10} + 0.0 + -4.6600x10^9$$

$$CENTER_{SKY} = 3.8591259x10^{10}$$

- CRPIX1: 8.193E+03 (VEGAS CRPIX1 value)
- CDELT1: -9.155273437500E+03 (VEGAS CHAN_BW value)
- VELDEF: RADI-LSR (Set by observer; LO1A VELDEF value)
- VFRAME: -1.032024948170E+04 (LO1A VFRAME value)

- RVSYS: -1.032024948170 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
  - Bank A: 3.619125298200E+10 (matches SDFITS CRVAL1)
  - Bank B: 3.699125298200E+10
  - Bank C: 3.799125298200E+10
  - Bank D: 3.859125298200E+10
- RESTFREQ:
  - Bank A: 3.6400000E+10 (VEGAS 1st RSTFRQ value)
  - Bank B: 3.7200000E+10 (VEGAS 2ndRSTFRQ value)
  - Bank C: 3.8000000E+10 (VEGAS 3r^d RSTFRQ value)
  - Bank D: 3.8800000E+10 (VEGAS 4th RSTFRQ value)
- FREQRES: 9.155273437500E+03 (VEGAS FREQRES value)
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: 0.0000000E+00 (GO VELOCITY value)
- DOPFREQ: 3.6400000000E+10 (matches LO1A RESTFREQ value)

11.11   Example 11: Ka receiver with CCB

Files: AGBT22B_180_03, Scan #73 (2022_10_15_08:47:05)

Observer Request:
- AutoOOF

LO1A Fits – File created, but not used by the CCB, so ignored.

IF Fits:
- BACKEND: 26_40
- RECEPTOR: R1_C, L2_C
- CENTER_IF: (set by hardware configuration; these are meaningless when using the CCB)
  - Bank A: 5.45000E+08
  - Bank B-D: 5.5000E+08
- LO_CIRCUITL none
- LO_COMPONENT: none
- SIDEBAND: U
- CENTER_IF: (these are the sky values set by the AutoOOF function, when using the CCB)
  - 3.825000E+10; 3.475000E+10; 3.125000E+10; 2.775000E+10; 3.825000E+10; 3.475000E+10; 3.125000E+10; 2.775000E+10
- CENTER_SKY: (calculated)
  - 3.825000E+10; 3.475000E+10; 3.125000E+10; 2.775000E+10; 3.825000E+10; 3.475000E+10; 3.125000E+10; 2.775000E+10

$$CENTER_{SKY} = CENTER\_IF$$

- BANDWIDTH: 3.5E+09 (set by hardware equal to bandwidth of the CCB)
- SFF_MULTIPLIER: 0.000 (set by hardware; always 0.0 for CCB)
- SFF_SIDEBAND: 1.00000E+00 (set by hardware; always 1.0 for CCB)
- SFF_OFFSET: 0.00000E+00 (set by hardware; always 0.0 for CCB)

GO Fits:
- BANDWIDTH: 3.50000E+09
- VELOCITY: 10070.0 (set by observer)
- VELDEF: 'VRAD-TOP' (set by observer)
- SKYFREQ: 3.25000E10 (calculated - center of highest+lowest frequency)
- RESTFREQ (primary header): 112358982000E+11 (this seems to not be relevant to the observations)
- RESOLN 0.0000000E+0 (CCB Default)
  - RESTFREQ (table):2.700000E+10 (this seems to not be relevant to the observations)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'CCB26_40

CCB26_40 Fits:

- No Frequency dependent keywords

SDFITS – No SDFITS files for CCB data

11.12 Example 12: KFPA receiver, Total Power, No Vel, Multiple Banks, VEGAS (VRAD_TOPO)

Files: TRFI_010123_K1, Scan #1 (2023_01_02_04:06:00)

Observer Request:
- Receiver ='Rcvr18_26'
- Beam='B1'
- nwin=2
- restfreq=18000, 18660
- deltafreq = 0.0
- bandwidth = 1500
- swmode='tp'
- swtype = 'none'
- swfreq=0.0, 0.0
- vlow= 0
- vhigh=0
- vframe='topo'
- vdef="radio"
- nchan="high"

LO1A Fits
- RESTFREQ: 1.80000000000000E+10 (entered by observer)
- IFFREQ: 7.130000000000R+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 2.0000E+00 (set by hardware)
- SIDEBAND: 'LOWER
- FREQOFF: 0.00000E+00 (set by observer)
- VELDEF: 'VRAD-TOPO'
- VELOCITY: 0.000000E+00 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 1.25650000000E+10 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

$$LO1FREQ = \frac{+7.13000000x10^9 + 1.80000000x10^{10}\left(1 - \frac{0.00}{2.99792458x10^8}\right)}{2.0} + 0.0$$

$$LO1FREQ = 1.25650000x10^{10}$$

- VFRAME: 0.0 (Determined by JPL ephemeris)
- RVSYS: 0.0E+00 (calculated)

IF Fits:

- BACKEND: VEGAS
- SIDEBAND: L
- CENTER_IF: (set by hardware configuration)
    - Bank E: 7.00000E+08
    - Bank F: 7.75000E+08
- BANDWIDTH: (set by hardware configuration)
    - Bank E: 1.10000E+09
    - Bank F: 1.25000E+09
- SFF_MULTIPLIER: 2.000E+00 (set by hardware)
- SFF_SIDEBAND: -1.000E+00 (set by hardware)
- SFF_OFFSET: (set by hardware configuration)
    - Bank E: -6.380000000E+09
    - Bank F: -5.720000000E+09
- CENTER_SKY: (calculated)
    - Bank E: 1.805000E+10
    - Bank F: 1.863500E+10

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Bank A:

$$CENTER_{SKY} = -1.0 * 7.0000x10^8 + 2.0 * 1.256500000x10^{10} + 0.0 + (-6.3800x10^9)$$

$$CENTER_{SKY} = 1.804500x10^{10}$$

- Bank B:

$$CENTER_{SKY} = -1.0 * 7.7500x10^8 + 2.0 * 1.256500000x10^{10} + 0.0 + (-5.7200x10^9)$$

$$CENTER_{SKY} = 1.8635000x10^{10}$$

GO Fits:

- BANDWIDTH: 1500
- VELOCITY: 0.0 (set by observer)
- VELDEF: 'VRAD-TOP' (set by observer)
- SKYFREQ: 18330000000.0 (calculated - center of highest+lowest frequency)
- RESTFREQ (primary header): 1.8000E+10, 1.8660E+10 (set by observer)
- NCHANS: 16384 (set by observer; VEGAS mode 2)
- RESOLN 9.2000000E+04 (set by observer; VEGAS mode 2)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:

- MODE: 2
- CHAN_BW: 91552.734375 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(1.500x10^6 * 2)}{(16384 * 2)} = 9.1552734x10^3\ Hz$$

- SUB0FREQ: 750000000.0 (set by VEGAS mode chosen)
- CRVAL1 (IF3): 7.500000000E+08 (calculated)
  Spec Win 1: $CRVAL1 = SUB0FREQ = 7.5000x10^8$
- CDELT1: 9.155273437500E+04 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 5.7220458984375x10^3$$

- FREQRES: 9.1552734375E+04 (calculated)

$$FREQRES = CDELT1 = 9.155273437500x10^4$$

- CRPIX1: 8.1930E+03 (calculated)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 8193$$

SDFITS

- BANDWID: 1.5000000E+09
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: (calculated)
  - Bank E: 1.800000000E+10
  - Bank F: 1.866000000E+10

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

  - Bank E:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 2.0 * 1.25650000000x10^{10} + 0.0 + -6.3800x10^9$$

$$CENTER_{SKY} = 1.800000x10^{10}$$

  - Bank f:

$$CRVAL1 = -1.0 * 7.5000x10^8 + 2.0 * 1.25650000000x10^{10} + 0.0 + -5.7200x10^9$$

$$CENTER_{SKY} = 1.8660000x10^{10}$$

- CRPIX1: 8.193E+03 (VEGAS CRPIX1 value)

- CDELT1: 9.155273437500E+03 (VEGAS CHAN_BW value)
- VELDEF: RADI-OBS (Set by observer; LO1A VELDEF value)
- VFRAME: 0.00000000E+00 (LO1A VFRAME value)
- RVSYS: 0.0000000000E+00 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
  - Bank E: 1.8000000000000E+10 (matches SDFITS CRVAL1)
  - Bank F: 1.8660000000000E+10
- RESTFREQ:
  - Bank E: 1.80000000E+10 (VEGAS 1st RSTFRQ value)
  - Bank F: 1.866000000E+10 (VEGAS 2ndRSTFRQ value)
- FREQRES: 9.155273437500E+03 (VEGAS FREQRES value)
- SIDEBAND: 'L' (IF SIDEBAND value)
- VELOCITY: 0.0000000E+00 (GO VELOCITY value)
- DOPFREQ: 1.8000000000E+10 (matches LO1A RESTFREQ value)

11.13 Example 13: KFPA receiver, All Beams, Total Power, Vel, Multiple Banks, VEGAS (VRAD_LSR)

Files: AGBT22A_466_03, Scan #24 (2023_12_15_16:40:41)

Observer Request:

- Receiver ='Rcvr18_26'
- Beam='all'
- restfreq=23694.4955,23722.6336,23870.1296,23963.9010,24139.4163,24532.9887
- dopplertrackfreq = 23694.4955
- deltafreq = 0.0
- bandwidth = 23.44
- nchan = 4096
- swmode='tp'
- swtype = 'none'
- vframe='lsrk'
- vdef="Radio"

LO1A Fits

- RESTFREQ: 2.36944955000000E+10 (entered by observer)
- IFFREQ: 7.21924660000000000E+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 2.0000E+00 (set by hardware)
- SIDEBAND: 'LOWER
- FREQOFF: 0.00000E+00 (set by observer)

- VELDEF: 'VRAD-LSRK'
- VELOCITY: 2.000000E+05 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 1.544928480600E+10 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

$$LO1FREQ = \frac{+7.2192466000000x10^9 + 2.36944955000x10^{10}\left(1 - \frac{200.00 - 8.03861795781216x10^3}{2.99792458x10^8}\right)}{2.0} + 0.0$$

$$LO1FREQ = 1.50449286x10^{10}$$

- VFRAME: -8.03861795781216E+3 (Determined by JPL ephemeris)
- RVSYS: 1.92028098282536E+05 (calculated)

$$f = f_0\left(1 - \frac{(SRCVEL + VFRAME)}{c}\right) = 2.36944955000x10^{10}\left(1 - \frac{200.00 - 8.03861795781216x10^3}{2.99792458x10^8}\right)$$
$$= 2.3678054x10^{10}$$

$$RVSYS = c\ \frac{1 - (f/f_0)^2}{1 + (f/f_0)^2} = 2.99792458x10^8\ \frac{1 - \left(2.3678054x10^{10}/2.3694495500000x10^{10}\right)^2}{1 + \left(2.3678054x10^{10}/2.3694495500000x10^{10}\right)^2} = 1.9200938x10^5$$

IF Fits:
- BACKEND: VEGAS
- SIDEBAND:
  - Banks A, B, E, F, G : L
  - Banks C, D, H: U
- CENTER_IF: (set by hardware configuration)
  - Banks A, B, E, F, G: 7.75000E+08
  - Bank C, D, H: 7.100000E+08
- BANDWIDTH: (set by hardware configuration)
  - Banks A, B, E, F, G: 1.25000E+09
  - Bank C, D, H:1.1200000E+09
- SFF_MULTIPLIER: 2.000E+00 (set by hardware)
- SFF_SIDEBAND:
  - Banks A, B, E, F, G: -1.000E+00
  - Bank C, D, H: 1.000E+00
- SFF_OFFSET: (set by hardware configuration)

- o   Bank A, B, E, F, G: -6.050000000E+09
- o   Bank C, D, H: -7.550000000E+09
- CENTER_SKY: (calculated)
  - o   Bank A, B, E, F, G: 2.40735700E+10
  - o   Bank C, D, H: 2.40585700E+10

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

o   Bank A, B, E, F, G:

$$CENTER_{SKY} = -1.0 * 7.7500x10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 + (-6.0500x10^9)$$

$$CENTER_{SKY} = 2.4073568x10^{10}$$

o   Bank C, D, H:

$$CENTER_{SKY} = +1.0 * 7.1000x10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 + (-7.5500x10^9)$$

$$CENTER_{SKY} = 2.4058569x10^{10}$$

GO Fits:

- BANDWIDTH: 2.344000E+07
- VELOCITY: 200000.0 (set by observer)
- VELDEF: 'VRAD-LSR' (set by observer)
- SKYFREQ: 24113742100.0 (calculated - center of highest+lowest frequency, which is 2.4113742E10)
- RESTFREQ (primary header): 2.3694495500E10 (set by observer)
- NCHANS: 4096 (set by observer; VEGAS mode 20)
- RESOLN 5.7000000E+03 (set by observer; VEGAS mode 20)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:

- MODE: 20
- CHAN_BW: 5722.0458984375 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(2.34400x10^7)}{(4096)} = 5.7226562x10^3\ Hz$$

- SubXFREQ :
  - o   Banks A, B, E, F, G:
    - ▪   SUB0FREQ: 1169311523.4375 (set by VEGAS mode chosen)
    - ▪   SUB1FREQ: 1141113281.25

- - SUB2FREQ: 993530273.4375
    - SUB3FREQ: 899780273.4375
    - SUB4FREQ: 724365234.375
    - SUB5FREQ: 330688476.5625
    - SUB6FREQ: 999938964.84375 [not used, varies with banks]
    - SUB7FREQ: 999938964.84375 [not used, varies with banks]
  - Banks C, D, H:
    - SUB0FREQ: 330688476.5625 (set by VEGAS mode chosen)
    - SUB1FREQ: 358886718.75
    - SUB2FREQ: 506469726.5625
    - SUB3FREQ: 600219726.5625
    - SUB4FREQ: 775634765.625
    - SUB5FREQ: 1169311523.4375
    - SUB6FREQ: 932189941.40625 [not used, varies with banks]
    - SUB7FREQ: 196472167.96875 [not used, varies with banks]
    -
- CRVAL1 (IF3): (calculated)

  Spec Win 1: $CRVAL1 = SUB0FREQ$
  - Banks A, B, E, F, G, H
    - Subband 0: 1.169311523438E+09
    - Subband 1: 1.141113281250E+09
    - Subband 2: 9.935302734375E+08
    - Subband 3: 8.997802734375E+08
    - Subband 4: 7.243652343750E+08
    - Subband 5: 3.306884765625E+08
  - Banks C, D, H
    - Subband 0: 3.306884765625E+08 (set by VEGAS mode chosen)
    - Subband 1: 3.5888671875000E+08
    - Subband 2: 5.064697265625E+08
    - Subband 3: 6.002197265625E+08
    - Subband 4: 7.756347656250E+08
    - Subband 5: 1.1693115234375E+09
- CDELT1: 5.722045898438E+03 (calculated)
$$CDELT1 = abs(CHAN_{BW}) = 5.7220458984375 x 10^3$$
- FREQRES: 5.722045898438E+03 (calculated)

$$FREQRES = CDELT1 = 5.7220458984375 x 10^3$$

- CRPIX1:2.049E+03 (calculated; in header for sampler)
$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 2049$$

SDFITS

- BANDWID: 2.3437500000000E+07
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: (calculated)
  - All Banks:
    - Subband 1: 2.367925808856E+10
    - Subband 2: 2.370745633075E+10
    - Subband 3: 2.385503933856E+10
    - Subband 4: 2.394878933856E+10
    - Subband 5: 2.412420437762E+10
    - Subband 6: 2.451788113544E+10

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- Bank A, B, E, F, G – Subband 1:
  - $CRVAL1 = -1.0 * 1.169311523438Ex10^9 + 2.0 * 1.544928480600x10^{10} + 0.0 - 6.0500x10^9$
  - $CRVAL1 = 2.3679259x10^{10}$
- Bank A, B, E, F, G – Subband 2:
  - $CRVAL1 = -1.0 * 1.141113281250Ex10^9 + 2.0 * 1.544928480600x10^{10} + 0.0 - 6.0500x10^9$
  - $CRVAL1 = 2.3707455x10^{10}$
- Bank A, B, E, F, G – Subband 3:
  - $CRVAL1 = -1.0 * 9.935302734375Ex10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 6.0500x10^9$
  - $CRVAL1 = 2.3855038x10^{10}$
- Bank A, B, E, F, G – Subband 4:
  - $CRVAL1 = -1.0 * 8.997802734375Ex10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 6.0500x10^9$
  - $CRVAL1 = 2.3948788x10^{10}$
- Bank A, B, E, F, G – Subband 5:
  - $CRVAL1 = -1.0 * 7.243652343750Ex10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 6.0500x10^9$
  - $CRVAL1 = 2.4124203x10^{10}$
- Bank A, B, E, F, G – Subband 6:
  - $CRVAL1 = -1.0 * 3.306884765625Ex10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 6.0500x10^9$
  - $CRVAL1 = 2.4517882x10^{10}$
- Bank C, D, H – Subband 1:

- $CRVAL1 = +1.0 * 3.306884765625\text{E}x10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 7.5500x10^9$
- $CRVAL1 = 2.3679259x10^{10}$
  - Bank C, D, H – Subband 2:
    - $CRVAL1 = +1.0 * 3.588867187500\text{E}x10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 7.5500x10^9$
    - $CRVAL1 = 2.3707455x10^{10}$
  - Bank C, D, H – Subband 3:
    - $CRVAL1 = +1.0 * 5.064697265625\text{E}x10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 7.5500x10^9$
    - $CRVAL1 = 2.3855038x10^{10}$
  - Bank C, D, H – Subband 4:
    - $CRVAL1 = +1.0 * 6.002197265625\text{E}x10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 7.5500x10^9$
    - $CRVAL1 = 2.3948788x10^{10}$
  - Bank C, D, H – Subband 5:
    - $CRVAL1 = +1.0 * 7.756347656250\text{E}x10^8 + 2.0 * 1.544928480600x10^{10} + 0.0 - 7.5500x10^9$
    - $CRVAL1 == 2.4124203x10^{10}$
  - Bank C, D, H – Subband 6:
    - $CRVAL1 = +1.0 * 1.1693115234375\text{E}x10^9 + 2.0 * 1.544928480600x10^{10} + 0.0 - 7.5500x10^9$
    - $CRVAL1 = 2.4517882x10^{10}$
- CRPIX1: 2.04900000E+03 (VEGAS CRPIX1 value)
- CDELT1: 5.722045898438E+03 (VEGAS CHAN_BW value)
- VELDEF: RADI-LSR (Set by observer; LO1A VELDEF value)
- VFRAME: -8.038617957812E+03 (LO1A VFRAME value)
- RVSYS: 1.920280982825E+05 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
  - All Banks :
    - Subband 1: 2.367925808856E+10
    - Subband 2: 2.370745633075E+10
    - Subband 3: 2.385503933856E+10
    - Subband 4: 2.394878933856E+10
    - Subband 5: 2.412420437762E+10
    - Subband 6: 2.451788113544E+10
- RESTFREQ:
  - All Banks:
    - Subband 1: 2.369449550000E+10
    - Subband 2: 2.372263360000E+10
    - Subband 3: 2.387012960000E+10

- Subband 4: 2.396390100000E+10
- Subband 5: 2.413941630000E+10
- Subband 6: 2.453298870000E+10
- FREQRES: 5.722045898438E+03 (VEGAS FREQRES value)
- SIDEBAND:
  - Banks A, B, E, F, G: 'L' (IF SIDEBAND value)
  - Banks C, D, H: 'U'
- VELOCITY: 2.0000000E+05 (GO VELOCITY value)
- DOPFREQ: 2.369449550000E+10 (matches LO1A RESTFREQ value)

11.14   Example 14: KFPA receiver, 1 Beam, Total Power, Vel, Multiple Banks, VEGAS (VRAD_LSR)
Files: AGBT21B_316_58, Scan #6 (2 2024_02_19_15:04:18)

Observer Request:
- Receiver ='Rcvr18_26'
- Broadband=1
- Beam='1'
- restfreq= 23525.0,23695.0,23865.0,24035.0,24375.0,24545.0,24715.0
- deltafreq = 0.,0.,0.,0.,0.,0.,0.
- bandwidth = 187.5
- nchan = 131072
- swmode='tp'
- swfreq = 0.
- swtype = 'none'
- vframe='lsrk'
- vdef="Radio"

LO1A Fits
- RESTFREQ: 2.3525000000000E+10 (entered by observer)
- IFFREQ: 6.5950000000000000E+09 (set by hardware)
- LOOFFSET: 0.00000E+00 (set by hardware)
- LOMULT: 2.0000E+00 (set by hardware)
- SIDEBAND: 'LOWER
- FREQOFF: 0.00000E+00 (set by observer)
- VELDEF: 'VRAD-LSRK'
- VELOCITY: 7.000000E+03 (entered by observer)
- VDOT: 0.00E+00 (entered by observer)
- VDOTDOT: 0.00E+00 (entered by observer)
- LO1FREQ: 1.50610652740000E+10 (calculated)

$$LO1FREQ = \frac{(\pm IFFREQ + f)}{LOMULT} + LOOFFSET$$

$$LO1FREQ = \frac{+6.595000000x10^9 + 2.3525000x10^{10}\left(1 - \frac{700.00 - 3.415084380327x10^4}{2.99792458x10^8}\right)}{2.0} + 0.0$$

$$LO1FREQ = 1.5061066x10^{10}$$

- VFRAME: -3.415084380327E+04 (Determined by JPL ephemeris)
- RVSYS: -2.715076215228E+04 (calculated)

$$f = f_0 \left(1 - \frac{(SRCVEL + VFRAME)}{c}\right) = 2.3525000x10^{10}\left(1 - \frac{700.00 - 3.415084380327x10^4}{2.99792458x10^8}\right)$$
$$= 2.3527131x10^{10}$$

$$RVSYS = c\ \frac{1-\left(^f/_{f_0}\right)^2}{1+\left(^f/_{f_0}\right)^2} = 2.99792458x10^8\ \frac{1-\left(^{2.352713100x10^{10}}/_{2.35250000x10^{10}}\right)^2}{1+\left(^{2.352713100x10^{10}}/_{2.352500000x10^{10}}\right)^2} = -2.7158453x10^4$$

IF Fits:
- BACKEND: VEGAS
- SIDEBAND: L
- CENTER_IF: (set by hardware configuration)
  - Banks A, B, C: 5.5000E+08
  - Bank D: 6.137500E+08
  - Bank E: 6.987500E+08
  - Bank F: 7.837500E+08
  - Bank G: 8.687500E+08
  - Bank H: 4.750000E+08
- BANDWIDTH_IF: (set by hardware configuration)
  - Banks A, B, C: 8.000000E+08
  - Bank D: 6.725000E+08
  - Bank E: 5.025000E+08
  - Bank F: 3.325000E+08
  - Bank G: 1.625000E+08
  - Bank H: 0.000000E+08
- SFF_MULTIPLIER: 2.000E+00 (set by hardware)
- SFF_SIDEBAND: -1.000E+00
- SFF_OFFSET: (set by hardware configuration)
  - Bank A: -6.0325000000000E+09
  - Bank B: -5.86250000000000E+09
  - Bank C: -5.692500000000E+09
  - Bank D:- 5.52250000000000E+09
  - Bank E: -5.35250000000000E+09
  - Bank F: -5.18250000000000E+09
  - Bank G: -5.01250000000000E+09
  - Bank G: -4.84250000000000E+09

- CENTER_SKY: (calculated)
  - Bank A: 2.353963E+10
  - Bank B: 2.370963E+10

- o Bank C: 2.387963E+10
- o Bank D: 2.398588E+10
- o Bank E: 2.407088E+10
- o Bank F: 2.415588E+10
- o Bank G: 2.424088E+10
- o Bank H: 2.4080463E+10

$$CENTER_{SKY} = SFF_{SIDEBAND} * IF + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

o Bank A:

$$CENTER_{SKY} = -1.0 * 5.500000x10^8 + 2.0 * 1.506106527400x10^{10} + 0.0 + (-6.032500000x10^9)$$
$$= 2.353963x10^{10}$$

o Bank B:

$$CENTER_{SKY} = -1.0 * 5.500000x10^8 + 2.0 * 1.506106527400x10^{10} + 0.0 + (-5.862500000x10^9)$$
$$= 2.370963x10^{10}$$

o Bank C:

$$CENTER_{SKY} = -1.0 * 5.500000x10^8 + 2.0 * 1.506106527400x10^{10} + 0.0 + (-5.692500000x10^9)$$
$$= 2.3870963x10^{10}$$

o Bank D:

$$CENTER_{SKY} = -1.0 * 6.137500x10^8 + 2.0 * 1.506106527400x10^{10} + 0.0 + (-5.5225000000x10^9)$$
$$= 2.3985881x10^{10}$$

o Bank E:

$$CENTER_{SKY} = -1.0 * 6.987500x10^8 + 2.0 * 1.506106527400x10^{10} + 0.0 + (-5.3525000000x10^9)$$
$$= 2.407088x10^{10}$$

o Bank F:

$$CENTER_{SKY} = -1.0 * 7.837500x10^8 + 2.0 * 1.506106527400x10^{10} + 0.0 + (-5.1825000000x10^9)$$
$$= 2.415588x10^{10}$$

o Bank G:

$$CENTER_{SKY} = -1.0 * 8.687500x10^8 + 2.0 * 1.506106527400x10^{10} + 0.0 + (-5.0125000000x10^9)$$
$$= 2.424088x10^{10}$$

o Bank H:

$$CENTER_{SKY} = -1.0 * 4.7500000x10^8 + 2.0 * 1.506106527400x10^{10} + 0.0 + (-4.8425000000x10^9)$$
$$= 2.4080468x10^{10}$$

GO Fits:

- BANDWIDTH: 1.8750000E+08
- VELOCITY: 70000.0 (set by observer)
- VELDEF: 'VRAD-LSR' (set by observer)
- SKYFREQ: 24120000000.0 (calculated - center of highest+lowest frequency, which is 2.411200E10)
- RESTFREQ (primary header): 2.3525E10, 2.3695000E+10, 2.3865000E+10, 2.403500E+10, 2.4375000E+10, 2.4545000E+10. 2.4715000E+10 (set by observer)
- NCHANS: 131072 (set by observer; VEGAS mode 20)
- RESOLN 1.4000000E+03 (set by observer; VEGAS mode 6)
- SUBBAND: 0 (set by VEGAS mode)
- BACKEND: 'VEGAS'

VEGAS Fits:

- MODE: 6
- CHAN_BW: 1430.511474609375 (calculated)

$$CHAN\_BW = \frac{Effective\ Sampler\ Frequency}{Number\ of\ channels * Number\ of\ polarizations}$$

$$CHAN_{BW} = \frac{(1.875x10^8)}{(131072)} = 1.4305115x10^3\ Hz$$

- SubXFREQ :
  - Banks all:
    - SUB0FREQ-SUB7FREQ: 562500000.
- CRVAL1 (IF3): (calculated)

$$Spec\ Win\ 1:\ CRVAL1 = SUB0FREQ$$

  - Banks all: 5.625000000E+08
- CDELT1: 1.430511474609E+03 (calculated)

$$CDELT1 = abs(CHAN_{BW}) = 1.430511474609x10^3$$

- FREQRES: 5.722045898438E+03 (calculated)

$$FREQRES = CDELT1 = 1.430511474609x10^3$$

- CRPIX1: 6.5537E+04 (calculated; in header for sampler)

$$CRPIX1 = \frac{Number\ of\ channels}{2} + 1 = 65537$$

SDFITS

- BANDWID: 1.87500000000E+078
- CTYPE1: 'FREQ-OBS' (predefined to 'FREQ-OBS' always)
- CRVAL1: (calculated)

- o Bank A: 2.352713053800E+10
- o Bank B: 2.369713053800E+10
- o Bank C: 2.386713053800E+10
- o Bank D: 2.403713053800E+10
- o Bank E: 2.420713053800E+10
- o Bank F: 2.437713053800E+10
- o Bank G: 2.454713053800E+10
- o Bank H: 2.471713053800E+10

Calculation:

$$CRVAL1 = SFF_{SIDEBAND} * IF3 + SFF_{MULTIPLIER} * L01 + FREQOFF + SFF\_OFFSET$$

- o Bank A:
  - o $CRVAL1 = -1.0 * 5.6250000Ex10^8 + 2.0 * 1.506106527400x10^{10} - 6.0325x10^9 = CRVAL1 = 2.3527131x10^{10}$
- o Bank B:
  - o $CRVAL1 = -1.0 * 5.6250000Ex10^8 + 2.0 * 1.506106527400x10^{10} - 5.8625x10^9 = CRVAL1 = 2.3697132x10^{10}$
- o Bank C:
  - o $CRVAL1 = -1.0 * 5.6250000Ex10^8 + 2.0 * 1.506106527400x10^{10} - 5.6925x10^9 = CRVAL1 = 2.3867132x10^{10}$
- o Bank D:
  - o $CRVAL1 = -1.0 * 5.6250000Ex10^8 + 2.0 * 1.506106527400x10^{10} - 5.5225x10^9 = CRVAL1 = 2.4037132x10^{10}$
- o Bank E:
  - o $CRVAL1 = -1.0 * 5.6250000Ex10^8 + 2.0 * 1.506106527400x10^{10} - 5.3525x10^9 = CRVAL1 = 2.4207132x10^{10}$
- o Bank F:
  - o $CRVAL1 = -1.0 * 5.6250000Ex10^8 + 2.0 * 1.506106527400x10^{10} - 5.1825x10^9 = CRVAL1 = 2.4377132x10^{10}$
- o Bank G:
  - o $CRVAL1 = -1.0 * 5.6250000Ex10^8 + 2.0 * 1.506106527400x10^{10} - 5.0125x10^9 = CRVAL1 = 2.4547132x10^{10}$
- o Bank H:
  - o $CRVAL1 = -1.0 * 5.6250000Ex10^8 + 2.0 * 1.506106527400x10^{10} - 4.8425x10^9 = CRVAL1 = 2.4717132x10^{10}$
  - o

- CRPIX1: 6.553700E+04 (VEGAS CRPIX1 value)
- CDELT1: 1.430511474609E+03 (VEGAS CHAN_BW value)
- VELDEF: RADI-LSR (Set by observer; LO1A VELDEF value)

- VFRAME: -3.41507334004E+04 (LO1A VFRAME value)
- RVSYS: -2.715065174943E+04 (LO1A RVSYS value)
- OBSFREQ: (matches SDFITS CRVAL1)
    - Bank A : 2.352713053800E+10
    - Bank B: 2.369713053800E+10
    - Bank C: 2.386713053800E+10
    - Bank D: 2.403713053800E+10
    - Bank E: 2.420713053800E+10
    - Bank F: 2.437713053800E+10
    - Bank G: 2.424713053800E+10
    - Bank H: 2.471713053800E+10
- RESTFREQ:
    - Bank A: 2.35250000E+10
    - Bank B: 2.36950000E+10
    - Bank C: 2.38650000E+10
    - Bank D: 2.40350000E+10
    - Bank E: 2.42050000E+10
    - Bank F: 2.43750000E+10
    - Bank G: 2.45450000E+10
    - Bank H: 2.47150000E+10
- FREQRES: 1. 430511474609E+03 (VEGAS FREQRES value)
- SIDEBAND: L
- VELOCITY: 7.0000000E+03 (GO VELOCITY value)
- DOPFREQ: 2.35250000E+10 (matches LO1A RESTFREQ value)