# Frequency Setup
# IRAM Plateau de Bure Interferometer

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This paper describes the current frequency scheme on Plateau de Bure.
Related information is available in:

- IRAM Plateau de Bure Interferometer: OBS Users Guide
- IRAM Plateau de Bure Interferometer: Correlator Description
- ASTRO: Astronomical Software To pRepare Observations

Revision history:
2.1 support for the 210-245 GHz receivers
2.0 support for the new correlator system.

## Contents

# 1 Basic Equations

For the Plateau de Bure interferometer, the conversion from sky frequencies down to the IF band (100-600 MHz) is done using two local oscillators. The first frequency conversion (with the LO1 oscillator) is double sideband from sky frequency down to 1.5 GHz. The second frequency is a lower sideband conversion with a second oscillator LO2 around 1.875 GHz. In this document, I will use the following frequencies :

- *Fsyn* the synthesizer frequency
- *Flo2* the second LO frequency
- *Flo1* the first LO frequency
- *Fsky* the sky frequency corresponding to the IF band center
- *Fcent* a frequency in the IF band (100-600 $MHz$)
- *Frest* the corresponding rest frequency at the source

All frequencies are derived from *Fsyn*, with frequency multipliers to generate the relevant harmonic numbers, according to the following equations (with frequencies in MHz)

$$Flo2 = Fsyn - 0.5 \tag{1}$$

$$Flo1 = M \times (H \times Flo2 - L \times Eps) \tag{2}$$

$$Fsky = Flo1 + S \times (Flo2 - 350) \tag{3}$$

$$Frest = \frac{Fsky - S \times (Fcent - 350)}{Doppler} \tag{4}$$

$$Frest = \frac{((M \times H + S) \times Flo2 - M \times L \times Eps) - S \times Fcent}{Doppler} \tag{5}$$

Five parameters introduced in these equations, *M*, *H*, *L*, *S*, and *Eps*, depend on the phase lock and receiver system, while *Doppler* depends on the source:

- *H* is the harmonic number used to generate the LO1 from the LO2. With *Flo2* near 1.875 GHz, *H* is roughly 50 at 95 GHz.
- *M* is the multiplier order: 1 for the 3mm system, 3 for the 1.3mm system.
- *L* is +1 if the LO1 is in "HIGH lock", -1 in "LOW lock"
- *Eps* is equal to (100 + 50/512)
- *S* is +1 for the upper sideband of the receiver (USB), -1 for the lower sideband (LSB).
- *Doppler* is the total Doppler correction $(1 - v/c)$ for the current source.

The phase lock system nominal performances are obtained for *Flo2* in the range 1.850 - 1.900 GHz.

# 2 Image Frequency Doppler Tracking

## 2.1 Basic Equations

The LO2 frequency used to track a spectral line at a given frequency *Frest* centered in the IF band (350 $MHz$) is

$$Flo2 = \frac{Frest \times Doppler + S \times 350 + M \times L \times Eps}{M \times H + S} \tag{6}$$

and, from eq. (5), the image rest frequency at the band center is

$$F_I = \frac{(M \times H - S) \times Flo2 - M \times L \times Eps + S \times 350}{Doppler} \tag{7}$$

A little algebra follows

$$F_I = \frac{\frac{M\times H-S}{M\times H+S}\times(Frest\times Doppler+S\times 350+M\times L\times Eps)-M\times L\times Eps+S\times 350}{Doppler}$$

$$F_I = \frac{(M\times H-S)\times(Frest\times Doppler+S\times 350+M\times L\times Eps)+(M\times H+S)\times(S\times 350-M\times L\times Eps)}{(M\times H+S)\times Doppler}$$

$$F_I = \frac{M\times H-S}{M\times H+S}\times Frest + \frac{(M\times H-S+M\times H+S)\times S\times 350-(M\times H+S-M\times H+S)\times M\times L\times Eps}{(M\times H+S)\times Doppler}$$

$$F_I = \frac{M\times H-S}{M\times H+S}\times Frest + \frac{2\times M\times H\times S\times 350-2\times S\times M\times L\times Eps}{(M\times H+S)\times Doppler}$$

and result in

$$F_I = \frac{M \times H - S}{M \times H + S} \times Frest + \frac{2 \times S \times M \times (H \times 350 - L \times Eps)}{(M \times H + S) \times Doppler} \tag{8}$$

This result is not independent of the Doppler effect. Accordingly, it the doppler tracking is not exact for the image frequency. and for 2 different values, $D1$ and $D2$, corresponding to different velocities $V1$ and $V2$, we obtain (assuming no change of $H$)

$$\delta F_I = \frac{D2 - D1}{D2 \times D1} \times \frac{2 \times S \times M \times (H \times 350 - L \times Eps)}{M \times H + S} \tag{9}$$

or, assuming $V1$ and $V2 << c$, and with $H >> 1$, $M > 1$, the frequency shift in MHz is

$$\delta F_I = \frac{\delta V}{c} \times 700 \tag{10}$$

or, in velocity (in km.s$^{-1}$)

$$\delta V_I = \delta V \frac{700}{F_I} \tag{11}$$

## 2.2 Consequences

The velocity variations have three slightly different origins

- the diurnal variation due to the earth rotation. The maximum value is $\delta V = 0.90\ km.s^{-1}$ in 12 hours.

- the yearly variation due to earth orbital motion. The order of magnitude is $\delta V = 15\ km.s^{-1}$ for two months, with a maximum value of $\delta V = 60\ km.s^{-1}$ for 6 months
- the source velocity. Typical value is $\delta V = 60\ km.s^{-1}$ for galactic objects.

Accordingly, the following frequency and velocity differences are induced at 95 GHz USB (harmonic number 50) in the three cases :

- Earth rotation : maximum $\delta F_I = 0.002\ MHz, \delta V_I = 0.007\ km.s^{-1}$
- Earth orbit : typical $\delta F_I = 0.035\ MHz, \delta V_I = 0.11\ km.s^{-1}$,
  maximum $\delta F_I = 0.14\ MHz, \delta V_I = 0.45\ km.s^{-1}$
- Source to source : $\delta F = 0.14\ MHz$

Note that the frequency shifts do not depend on the observing frequency.

# 3 Frequency Setup Choice

## 3.1 Choice of Receiver Band: USB or LSB

Above 114 GHz, only the USB tuning works. Below 114 GHz, if only one line has to be observed, use the LSB setting. Receivers can be tuned with sideband rejection, thus improving significantly the system temperature (up to a factor 2).

When one line must be observed in each band, the Doppler tracking is exact only for one of the two receiver bands. Presently, no software correction is implemented to correct for the resulting frequency shift. Since the elapsed time for any observing project will be typically 2 months, the observer should take care of this peculiarity if the desired spectral resolution is higher than 0.3125 MHz (in practice, this happens for the 20 and 40 MHz band with 256 channels). Otherwise, the effect can be neglected. Source to source variations may be important. In such a case, select the band according to the line to be observed with the highest resolution, or according to the most important line if resolutions are identical.

## 3.2 Choice of Correlator Setup

The correlator offers 6 units, of up to 160 MHz width each, with a total of up to 256 channels per baseline per unit. Each unit is connected to a variable frequency local oscillator (LO3) followed by an image rejection mixer for conversion of the IF band (100-600 MHz) into baseband (0-80 MHz). The LO3 frequencies are adjustable by step of 0.625 MHz, with a small offset of 50/512 MHz added because of the general frequency scheme.

40, 80 and 160 MHz bandwidths are obtained by using the USB and LSB outputs of the LO3 image rejection mixer (separation better than 30 dB), with a filter of 20, 40 and 80 MHz respectively. Sampling is done at 160 MHz. At 160 and 80 MHz bandwith, correlator boards operate with a time multiplex factor (TMF) of 4 and 2, producing 64 and 128 channels respectively. At 40 MHz, 256 channels are obtained. The 20 MHz band is obtained by using the LSB output of the mixer, and cascading two correlator boards in pass-along to obtain also 256 channels, with a resolution of 0.078 MHz.

The frequency coverage of the correlator is thus extremely flexible, but care must be taken of the compromise between bandwidth and resolution. If more than one line has to be observed simultaneously, the observer should be careful to choice the appropriate setup, but many lines can be observed simultaneously, specially when one takes into account coincidences between the Upper and Lower sidebands (lines separated by 2.6 to 3.5 GHz). Note that in practice, 3 or 4 units are left in broad band mode to provide continuum flux measurement (and accurate amplitude and phase calibration), so that the setup currently concerns 2 or 3 units.

The `ASTRO\LINE` command, in the **ASTRO** program implements a graphic display of the frequency setup, with overlaid line frequencies. The spectral correlator bands are displayed according to the setup specified in the `/SPECTRAL` option. The syntax of this option is identical to that of command `OBS\SPECTRAL` in the **OBS** program.

Command `ASTRO\LINE/SPECTRAL Unit Band LO3` can be used to overlay a spectral correlator setup on a plot produced by a previous `ASTRO\LINE/SPECTRAL Unit Band LO3`.

## 3.3 LINE command help

```
          [ASTRO\]LINE Name Frequency Band [Lock [Center [Harm]]]
          [/MOLECULES File] [/SPECTRAL Unit Bandwidth LO3]


     Plot rest frequency coverage of  Plateau  de  Bure  Interferometer.
The  command syntax is identical to that of the corresponding command in
OBS.
     Name is a line name to label the plot
     Frequency is the center frequency in GHz
     Band should be USB or LSB
     Lock (optional) is LOW or HIGH
     Center (optional), the center IF2 frequency in MHz, default 350.
     Harm (optional), the harmonic number.

     The option /MOLECULES enables  to  plot  the  rest  frequencies  of
several  transitions,  found  in  file  File.   This is a text file with
entries:
Freq    'chain'
where Freq is the rest frequency in GHz and 'chain' the line name to  be
plotted by GreG, between single quotes.  Example:
88.632  'HCN'
89.081  'HCO\u+'

     The option /SPECTRAL  is  used  to  specify  the  desired  spectral
correlator configuration.
- Unit is the unit number (1 to 6)
- Bandwidth is the bandwidth in MHz (20, 40, 80 or 160)
- LO3 is the center frequency (in MHz) of the band center,

          [ASTRO\]LINE/SPECTRAL Unit Bandwidth LO3
     Will overlay the specified correlator on a LINE plot

     Because only one synthesizer is used to generate the  1st  and  2nd
LOs,  the  IF  frequency  is  slightly variable (between 1.500 and 1.550
GHz), and the Doppler tracking is correct only for  the  specified  band
```

(USB or LSB). The last specified source is used to get the Doppler shift. The image frequency doppler shift is wrong by at most 0.11 km/s for a two month experiment.