LAMA Memo 808

How To Tune ALMA: An Example

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This note describes the process of setting up the LO system of the ALMA telescope so as to obtain a desired sky frequency and bandwidth. It does this by way of a specific example for which the calculation and control steps are given in detail. One example cannot cover all possible cases, but comments are included about how some steps might be different. This description is based on the system design that is now current [1][2], but some details are subject to change.

Figure 1 is a simplified block diagram of the LO system and signal path, showing the major assemblies involved in the frequency setting process and their relevant parameters. Only one of the 2 GHz bandwidth digitized signal channels is shown and only one will be discussed, even though 8 are available. One of the other channels is always tuned to the same sky frequency but it observes the opposite polarization. The remaining channels are similarly paired and can be tuned to slightly differnt sky frequencies via the 2nd LOs.

Astronomical requirement:

Observe the CO 2-1 transition at an apparent center frequency of $f_{\rm sky} = 229.42$ GHz (Doppler shifted from the rest frequency of 230.538 GHz) over a bandwidth of 500 MHz (or a velocity range of 650 km/sec). Place the line center as close as possible to the center of the processed band.

Solution:

1. The sky frequency range is in ALMA band 6, where the front end has these fixed paramters:

Input frequency range	211 to 275 GHz
Receiver type	2SB
IF band	4 to 12 GHz
Cold LO multiplication factor	$N_c = 3$
LO frequency range	233 to 263 GHz

Since the desired sky frequency is near the low end of the band, it can only be observed in the *lower* sideband of the first mixer. Performance of the receiver will be best if the signal appears near the middle of the IF band. Signals are always digitized in 2 GHz wide channels. Because of constraints in the second frequency conversion, the digitized band should not span the 8 GHz center point of the IF. Given these constraints, we choose to put the digitized band at an IF of approximately 6.0 to 8.0 GHz.

2. Assume that the correlator input filters will be set to process the lowest 500 MHz of one digitized channel. At the digitizer input, this corresponds to 3.5 to 4.0 GHz (of the 2.0 to 4.0 GHz digitizer input channel). Ideally, the line center should appear at the center of this "baseband," at $f_B = 3.75$ GHz.

3. Whereas the second LO is always *above* the IF, we find from steps 1 and 2 that the ideal line center at IF is

$$f_I = f_{\rm LO2} - f_B = 6.25\,{\rm GHz}$$

and the ideal second LO frequency is $f_{\rm LO2} = 10.000$ GHz.

4. The ideal first LO frequency is then

$$f_{\rm LO1} = f_{\rm sky} + f_I = 235.67\,{\rm GHz}.$$

These ideal values of $f_{\rm LO1}$ and $f_{\rm LO2}$ will be adjusted to include tuning constraints imposed by the design.

5. The actual second LO frequency is constrained to be

$$f_{\rm LO2,actual} = (125\,{\rm MHz})N_2 \pm f_{\rm os2}$$

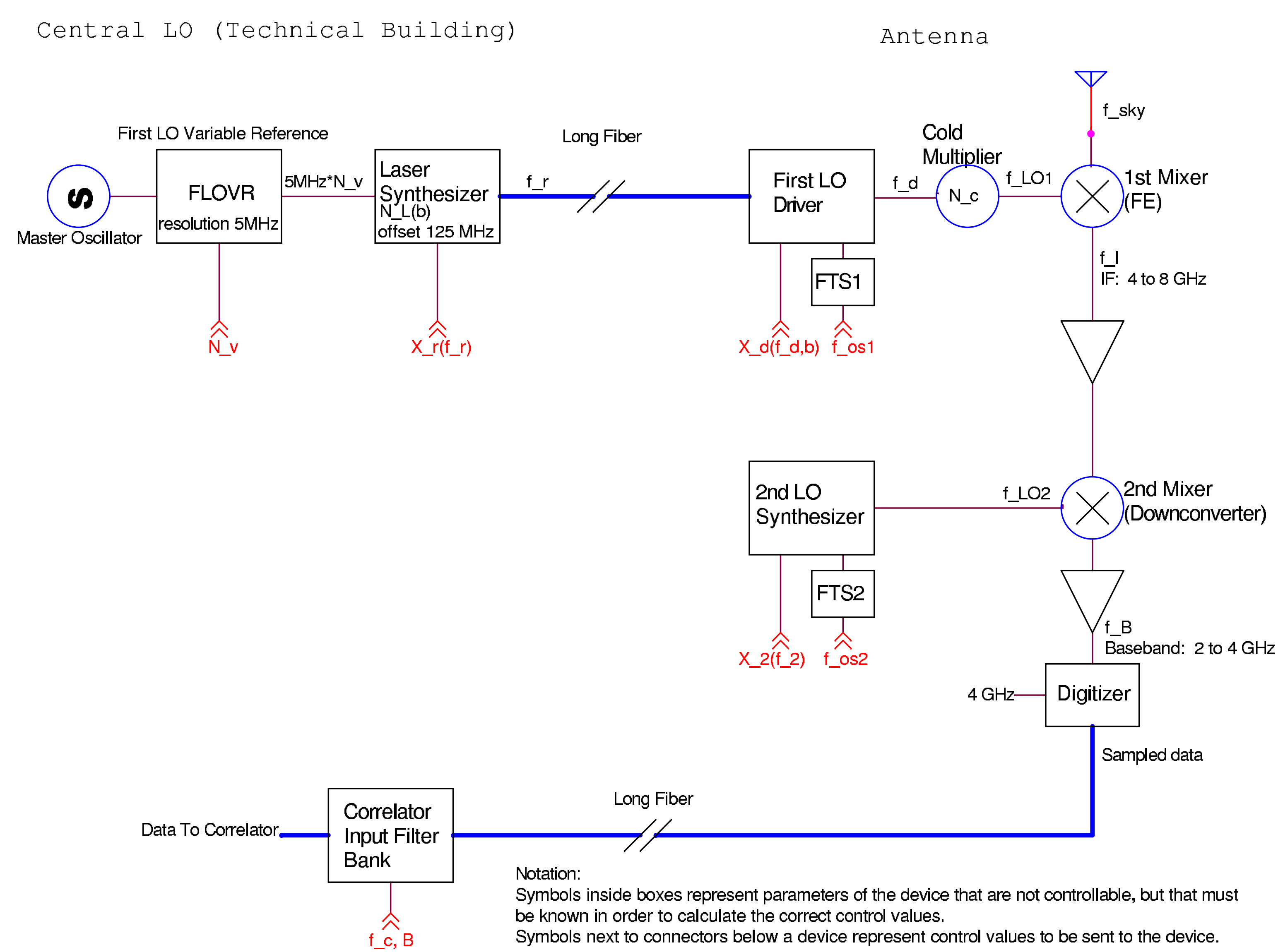

Figure 1: Simplified block diagram.

where N_2 is an integer in the range 64 to 112 and f_{os2} is an offset frequency in the range 20 to 42.5 MHz. Under these constraints, the nearest available frequencies are 20 MHz away from the ideal, at 9.980 and 10.020 GHz. We tentatively select $N_2 = 80$ and $f_{os2} = +20$MHz, giving $f_{\mathrm{LO2,actual}} = 10.020$ GHz.

6. Since we already know that the second LO frequency will be 20 MHz above its ideal value, we can adjust the ideal 1st LO frequency to compensate:

$$f_{\mathrm{LO1}} = f_{\mathrm{sky}} + (f_{\mathrm{LO2,actual}} - f_B) = 235.69\,\mathrm{GHz}$$

where the + sign occurs because the signal is in the upper sideband of the first LO, and the – sign occurs because it is in the lower sideband of the second LO.

7. The actual first LO frequency is N_c times the first LO driver frequency f_d, which is determined by the first LO reference and the first LO offset frequencies:

$$f_d = f_r \pm f_{\mathrm{os1}}.$$

The ideal driver frequency is then $f_d = (235.69\,\mathrm{GHz})/3 = 78.563\,\mathrm{GHz}$. Reference frequency f_r is produced by the laser synthesizer and is given by $f_r = (5\,\mathrm{MHz})N_v N_L(b) + 125\,\mathrm{MHz}$, where $N_L(b)$ is the laser synthesis multiplier for band b, and N_v is the multiplier of the variable reference synthesizer (FLOVR). f_r is the reference that is transmitted photonically from the Technical Building to all antennas of the subarray. The offset f_{os1} must be between 20 and 42.5 MHz; it is generated in the same way as the second LO offset f_{os2}.

Multiplier $N_L(b)$ is fixed for each band b and is always an odd integer[1]. The values are not yet finalized but a likely choice is $N_L(6) = 7$, so that value will be used here.

The FLOVR multiplier N_v may be chosen to be any integer[2].

Our task is to choose N_v and f_{os1} so as to make $f_{\mathrm{LO1,actual}}$ as close as possible to the ideal value f_{LO1}. Begin by setting $f_{\mathrm{os1}} = 31.25$ MHz, the middle of its range. Then an initial estimate of N_v is obtained from

$$N_v = \mathrm{round}(\frac{f_{\mathrm{LO1}}/N_c - f_{\mathrm{os1}} - 125\,\mathrm{MHz}}{5\,\mathrm{MHz}\,N_L(b)})$$

where rounding is to the nearest integer, and where we have chosen the positive option for the offset frequency. For our example, this gives $N_v = 2240$ and $f_{\mathrm{LO1,actual}} = 235.66875$ GHz; this 21.25 MHz below the ideal value. In this case we are able to produce the ideal value of the first LO frequency by adjusting f_{os1} upward by $(21.25\,\mathrm{MHz})/N_c$, to 38.3333 MHz.

It will not always be possible to set the first LO exactly to the desired value. The step size in f_r is $5\mathrm{MHz} \times N_L(6) = 35\,\mathrm{MHz}$, and this is larger than the 22.5 MHz range of f_{os1}. In some bands $N_L(b)$ is larger than 7, leading to step sizes larger than 35 MHz. However, it will always be possible to set f_I within a few percent of the 8 GHz IF bandwidth. Sometimes choosing the negative option for the offset frequency will result in a driver frequency closer to ideal, so that possibility should also be checked. It may also be possible to get closer to ideal by iterating back to step 5 and adjusting the second LO frequency. This should not be necessary, since the frequency obtained in the first iteration should always be close enough.

8. In summary, these considerations have led to the following values of parameters that can be used to control the hardware:

- $f_{\mathrm{LO2,actual}} = 10.020$ GHz (use to coarse-tune the second LO YTO)
- $f_d = 78.56333$ GHz (use to coarse-tune the first LO YTO)
- $f_r = 78.43833$ GHz (use to coarse-tune the laser synthesizer)

[1] The actual laser synthesizer implementation requires N_L to vary with f_r, and there are some ranges of f_r where either of two values might be used. At present it appears that N_L can be constant for each band, as assumed here, but the final implementation may be slightly more complicated.

[2] This assumes that the FLOVR synthesizer just achieves its required resolution of 5 MHz, and that the output is always a multiple of 5 MHz. This device is still being designed, so the actual implementation may be different. In practice only a finite range of N_v will be allowed, but that range will be sufficient to cover all necessary frequencies.

- $N_v = 2240$ (write directly to FLOVR hardware)
- $f_{os2} = 20$ MHz (write directly to second LO FTS[3])
- $f_{os1} = 38.3333$ MHz (write directly to first LO FTS[3])

The Laser Synthesizer, First LO Driver, and Second LO Synthesizer each require an integer "coarse tuning number" calculated from the intended output frequency by a linear expression of the form $X = \text{round}(\alpha f + \beta)$, where parameters α and β are fixed for each device (except for the First LO Driver, where α and β are different for each band). This is indicated in Figure 1 where the control values are the coarse tuning numbers X_r, X_d and X_2, respectively.

9. In principle, the writing of the above parameters to the hardware should cause the FLOVR, Laser Synthesizer, First LO Driver, and Second LO Synthesizer to acquire phase lock at the intended frequencies. In practice, the design of the First LO Driver is such that additional assistance is needed for it to acquire lock. Details of its lock acquisition algorithm are beyond the scope of these notes, but it should be automated at a relatively low level of the monitor/control system. Proper locking of each of the PLLs can be verified by reading appropriate monitor points.

10. Finally, the correlator input filters and other details of the correlator configuration must be set to support the desired frequency range. The correlator has many modes, and details of its configuration are beyond the scope of these notes. Briefly, its usual modes include a bank of 32 digital bandpass filters at the input, each of which can have a bandwidth up to 62.5 MHz and be centered anywhere in the channel, which can be considered to span 0 to 2 GHz. In our example, we wish to cover 0 to 500 MHz. Several setups are possible, one of which involves setting all of the filters to 62.5 MHz bandwidth and setting the center frequencies of the first 8 of them to span 0 to 500 MHz. The remaining filters can cover other parts of the channel, or can re-cover 0 to 500 MHz so as to allow the correlator to obtain narrower spectral channels.

REFERENCES

[1] L. D'Addario and J. Zivick, "ALMA System Block Diagram," ALMA document 80.04.01.00-004, rev H, 2004-02-06.
[2] L. D'Addario, "System Design Description," ALMA document 80.04.00.00-002, rev D, 2004-02-20.

[3] The two fine tuning synthesizers (FTSs) that produce f_{os1} and f_{os2} must be periodically updated to account for fringe rotation and source Doppler shift. This results in very small changes to the frequencies given here.