CHAPTER 5

Spectral Line Observing

5.1 Startup Checklist

Once the scientific goals of the observing session are clearly in mind, you must decide upon the equipment and observing techniques to be used. The decisions to be made and the options are listed below.

Sideband Choice: For double sideband observations, care must be taken in choosing the placement of the image sideband

Spectrometer Configuration: Filter bank spectrometers with several different resolutions are available. The observer must choose which to use and how they should be configured (the **parallel** or **series** option). The Millimeter Autocorrelator (MAC), which has numerous resolution and bandwidth options, is also available.

Observing Mode: Choices are:

- Total Power Scans – **ON** and **OFF** total power spectra are recorded separately for later processing into final spectra. The observer may take several **ON** scans for each **OFF.**
- Position Switching – The telescope moves between an offset, or **OFF**, position (in relative or absolute coordinates) and a source, or **ON**, position. The spectrum is recorded as a ratio of (**ON – OFF**) / **OFF.**
- Frequency Switching – The local oscillator is shifted by several MHz at a rate of 1.25, 2.5, or 5.0 Hz. The spectrum is recorded as a ratio of (**SIG – REF**) / **REF.**
- Beam Switching plus Position Switching – The subreflector is chopped at a rate of 1.25 to 5.0 Hz, and the telescope is repositioned at a prescribed rate (typically every 30-90 seconds). The spectrum is recorded as (**ON – OFF**).
- Grid Mapping – Total power or absolute position or frequency switched data are acquired while the telescope moves to user-specified spatial positions.
- On The Fly Mapping – Total power data are acquired every 0.1 seconds while the telescope is driven continuously over a specified map field.

Observing Time Budget: Prior to the start of observations, you should make a rough budget of observing time requirements. In addition to the integration time on the program sources, you should allow time for “overhead” items such as telescope movement, and pointing and calibration tests.

Before beginning program observations, check the telescope pointing and focus. A few observations of test sources are also advisable. These observations are discussed in Chapters 2, 4, and 6.

5.2 Sideband Choice

All of the 12m receivers operate by default in a single sideband (SSB) mode and require upper sideband (USB) operation. For the 2 and 3mm receivers, it is possible to observe DSB. Equipment constraints, such as the tuning range of the local oscillator or the receiver, may sometimes determine the sideband used in DSB mode. Other times, the presence of telluric lines steer the choice (see Figure 6.1). When using DSB mode, make the sideband choice with care.

The primary things to watch out for when choosing the sideband configuration for a DSB measurement is the presence of “contaminating” lines from the image sideband. Consult a good tabulation of spectral lines such as the Lovas Catalog (F. J. Lovas, J. Phys. Chem. Ref. Data, 15, 251, 1986) to see what spectral lines are present in both the signal and image sidebands. If an image line is too close to the program line in the signal sideband, a small local oscillator shift will usually cure the problem (the frequency axes run oppositely for the upper and lower sidebands). One can also make small adjustments in the IF to change the placement of lines from the two sidebands. Sometimes, lines from the image sideband can be used to advantage for calibrations or system checks.

With a slight rearrangement of Equation 3.4, we can write the expression for the sky frequency as a function of the LO frequency settings

$$f_{sky} \quad = \quad m(N f_{syn} + f_{lock}) \; j \, f_{IF} \tag{5.1}$$

where f_{syn} is the synthesizer frequency, f_{sky} is the sky frequency of the emission (the rest frequency with Doppler corrections), j = +1 for lower sideband and 1 for upper sideband, f_{IF} is the IF frequency (1.5 GHz by default), m is the factor by which the LO frequency is multiplied before injection into the mixer, f_{lock} is the phase lock loop offset frequency (100 MHz), and N is the synthesizer harmonic. The Doppler correction is determined by the choice of velocity type (see Chapter 4).

$$f_{sky}(RAD) \quad = \quad f_{rest}\left(1 - \frac{v_{object} + v_{antenna}}{c}\right) \tag{5.2}$$

$$f_{sky}(OPT) \quad = \quad \frac{f_{rest}}{1 + \frac{v_{object} + v_{antenna}}{c}} \tag{5.3}$$

$$f_{sky}(REL) \quad = \quad f_{rest}\sqrt{\frac{1 - \frac{v_{object} + v_{antenna}}{c}}{1 + \frac{v_{object} + v_{antenna}}{c}}} \tag{5.4}$$

where v_{object} and $v_{antenna}$ are the object and antenna velocities relative to the local standard of rest and c is the speed of light.

5.3 Spectrometers

Two spectrometer systems are available at the 12m: a suite of analog filter banks and a Millimeter Autocorrelator (MAC), which is a digital correlation spectrometer.

5.3.1 Filter Banks

Most of the analog filter banks have 256 channels each. The filters are integrated, multiplexed, and recorded by the control computer every 100 milliseconds. A total of 512 channels can be recorded at a time, which means that two filter banks can be used for each scan. The filter spectrometers available and the ways in which they can be configured are described below. Table 5.1 lists the characteristics of the 12m filter banks

5.3.1.1 The Parallel/Series Option

Most of the 256 channel filter banks can be split into two 128 channel sections that can be fed with independent IF signals. When a filter bank is split into two sections, the bank is said to be in a **parallel** configuration. Each polarization channel of the receiver feeds half of a filter bank in this configuration. The advantage of this mode is that the two halves of the filter bank can be averaged to produce improved signal-to-noise in the final spectrum. The disadvantage of this mode is that the total bandwidth is cut in half. Observers of narrow Galactic lines typically choose the parallel option, and use two filter banks with different resolutions.

Observations that require larger bandwidths, such as CO from other galaxies, usually choose the **series** mode. In the **series** mode, the two filter bank halves are used end-to-end to analyze a single input IF signal. A typical observing mode might be to use one of the 1 MHz filter banks for polarization 1 and the other for polarization 2. The two banks can be averaged in software to improve the signal-to-noise of the final spectrum. Figure 5.1 is a diagram showing how the **parallel/series** option works.

5.3.1.2 Bad Channel Elimination

At times, certain channels in the filter banks are defective. You can identify these "bad" channels by examining the output of a vane calibration cycle, which is called the *gains.* Vane calibration is described in detail in §5.6.1. Bad filter channels usually appear as spikes in the **gains** and will often cause scaling problems in the final spectrum if not eliminated. You can display the **gains** with the *line* data reduction program. To find the bad channels, perform a calibration scan and type **g1** to display the first filter bank and **g2** to display the second bank. If bad channels exist, type the command **badch**. You will be asked to enter the number of bad channels. After doing so, the crosshairs will appear on the screen. Move the vertical crosshair to each bad channel and select any mouse button. When all the bad channels have been entered, the program will give a report of the channel numbers.

Filter Bandwidth[a]	Filter Channels/Bank	# Available	Parallel/Series Optiona	Hardware Center Channel (Par/Ser)
2 MHz	256	2	Yes	64.5/128.5
1 MHz	256	2	Yes	64.5/128.5
500 kHz	256	1	Yes	64.5/128.5
250 kHz	256	1	Yes	64.5/128.5
100 kHz	256	1	Yes	64.5/128.5
30 kHzb	128	1	No	65

Table 5.1: 12m Filter Bank Characteristics

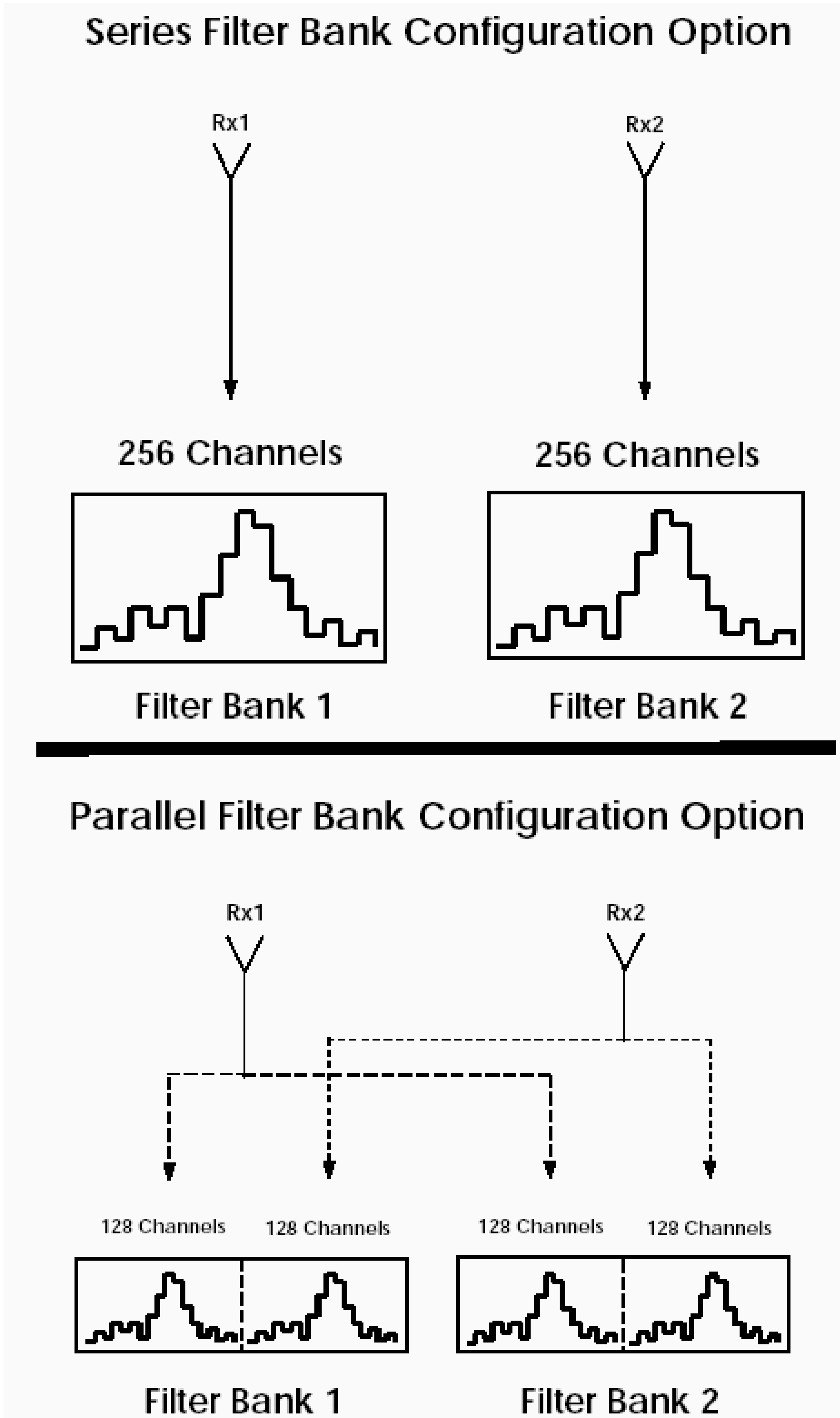

Figure 5.1: The filter bank parallel and series configurations.

Give these numbers to the operator. Up to 16 bad channels can be eliminated, but rarely more than 5 channels out of 512 will be bad. It is also possible to eliminate blocks of 16 channels, but this is seldom necessary. If blocks of 16 channels are bad, notify the Friend of the Telescope.

Once the operator has entered the bad channels, he will perform another vane calibration cycle to set the bad channels to 1.0×10^{-20}, which is the flagged channel value. On all subsequent spectra, those channels will be flagged. These bad channels can be eliminated in reduction software by using the **replace** command (see the *line* manual).

5.3.1.3 Frequency Offsets

Given the broad-band tunability of the 12m receivers, one can shift the rest frequency measured by the filter banks by specifying a frequency offset to be added to the rest frequency. Offsets as large as the entire bandwidth of the receiver (±300 MHz) are possible. Filter bank offsetting is most often used in conjunction with the 4IF Millimeter Autocorrelator (MAC) mode (see §5.3.2.1 for further information).

5.3.2 Millimeter Autocorrelator

The Millimeter Autocorrelator (MAC) offers a number of bandwidth and resolution modes, listed in Table 5.2. Most general single-beam dual-polarization measurements are done using the configurations with 2 IF's. The 8 IF modes are designed for use with the 1mm Array receiver. The 4IF Millimeter Autocorrelator (MAC) mode is a special-purpose observing mode allowing the measurement of two frequencies each at two polarizations simultaneously.

5.3.2.1 The 4IF Observing Mode

One of the more efficient observing modes available at the 12m involves the use of the 4IF configuration of the Millimeter Autocorrelator (MAC) in conjunction with the frequency offsetting capabilities of the filter banks. Within the IF modules which feed the receiver signals to the Millimeter Autocorrelator (MAC) there are oscillators which can shift the input receiver signals by ±300 MHz in 5 MHz steps. Since these oscillators are independent of the Fluke synthesizers which provide the frequency offsetting capabilities of the filter banks, it is possible to measure spectra at three separate frequencies within the 600 MHz bandwidth of the receiver (assuming both mixers are tuned to the same frequency). A graphical description of this mode is shown in Figure 5.2.

To given a practical example, say I want to simultaneously measure the H_2CO emission from the $3_{03} \rightarrow 2_{02}$ and $3_{22} \rightarrow 2_{21}$ transitions at 218222.192 and 218475.632 MHz, respectively. These two frequencies are separated by 253.440 MHz, which would restrict my choice of backends to the 2MHz filter banks in parallel and the 600 MHz Millimeter Autocorrelator (MAC) mode. Since I want to look at galactic sources with narrow lines, this wide-band modes are not acceptable. To use the 4IF mode to measure both transitions simultaneously, I would

Bandwidth and Channels		Useable Bandwidth and Channels[1]		$\Delta\nu^2$	Resolution
(MHz)	Channels	(MHz)	Channels	(kHz)	(kHz)
2 IF Modes					
800	2048	600*	1536	390.6	781.2
800	4096	600	3072	195.3	390.6
400	4096	300*	3072	97.6	195.3
400	8192	300	6144	48.8	97.6
200	8192	150*	6144	24.4	48.8
200	16384	150	12288	12.2	24.4
100	16384	75*	12288	6.1	12.2
100	32768	75	24576	3	6.1
4 IF Modes					
800	1024	600*	768	781.2	1562
800	2048	600	1536	390.6	781.2
400	2048	300*	1536	195.3	390.6
400	4096	300	3072	97.6	195.3
200	4096	150*	3072	48.8	97.6
200	8192	150	6144	24.4	48.8
100	8192	75*	6144	12.2	24.4
100	16384	75	12288	6.1	12.2

Table 5.2: Millimeter Autocorrelator (MAC) Configurations

[1] The useable bandwidth takes account of the 75% efficiency of the analog filters.
[2] NOTE: This is the frequency sampling interval, not the FWHM channel width, for a given channel. The FWHM channel width is 2.0 times this value. See Appendix D for details.

All values in this table refer to each IF.

Modes tagged with a * are produced by dropping the last half of the lags.

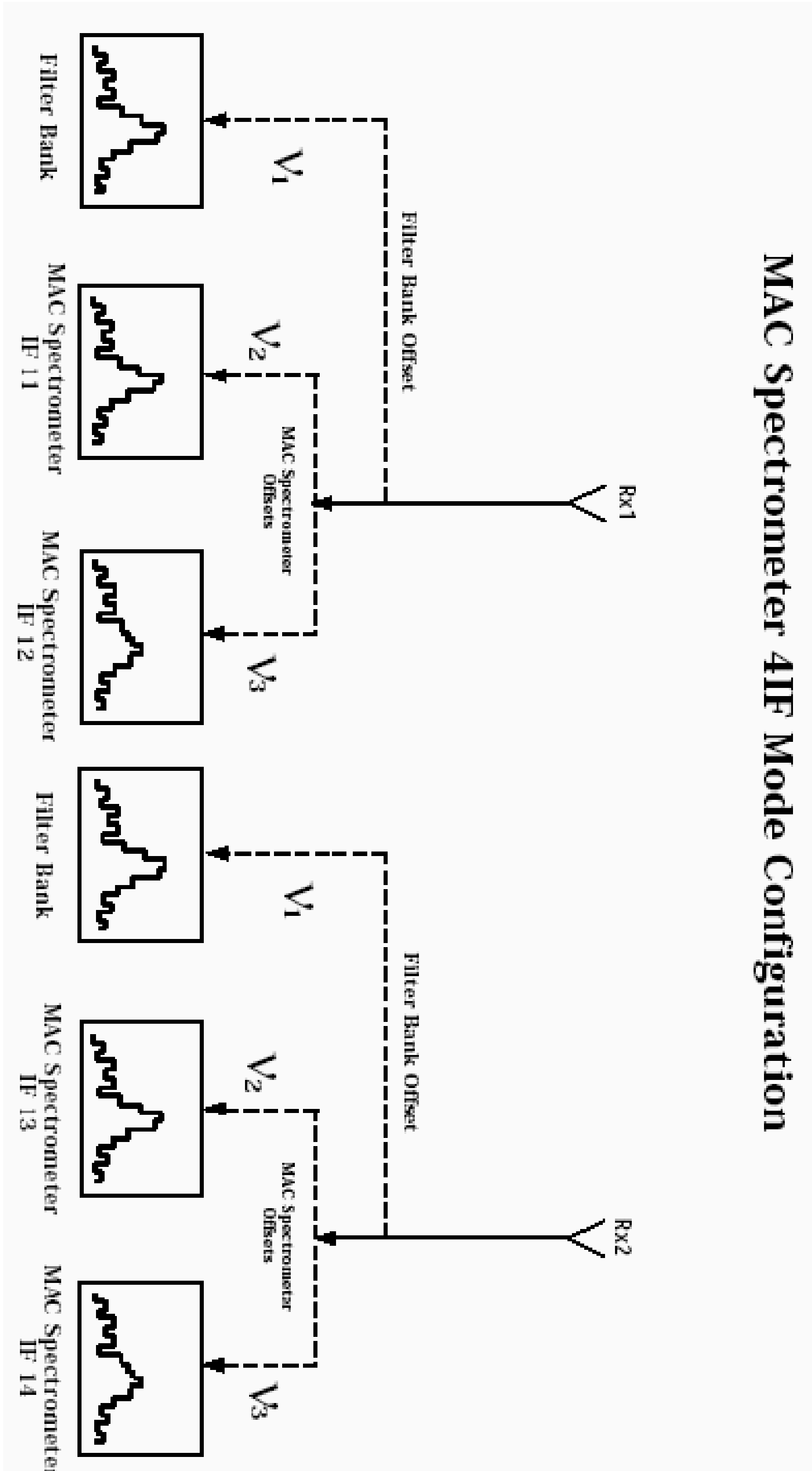

Figure 5.2: Millimeter Autocorrelator (MAC) 4IF mode configuration.

1. Tune the receiver to a frequency midway between the two rest frequencies, which in this case is 218348.912 MHz.

2. Set the filter bank offset so that I can measure the $3_{03} \rightarrow 2_{02}$ transition, which would be 218348.912 – 218222.192 = 126.720 MHz.

3. Set the two Millimeter Autocorrelator (MAC) offsets so that IF's 11 and 13 receive the $3_{03} \rightarrow 2_{02}$ transition and IF's 12 and 14 receive the $3_{22} \rightarrow 2_{21}$ transition. Since the Millimeter Autocorrelator (MAC) offsets must be in 5 MHz steps, I would set these offsets to ±125 MHz. The center frequency for IF's 11 and 13 would then be 218348.912 – 125.0 = 218223.912 MHz, while the center frequency for IF's 12 and 14 would be 218348.912 + 125.0 = 218473.912 MHz.

5.4 Observing Modes

There are six primary spectral line observing modes are available at the 12m. The attributes and applications of each are described in detail below. Signal processing and calibration for each mode are described in §5.6.

5.4.1 Total Power ONs and OFFs

Two observing procedures, called **tpon** and **tpoff**, are available for recording total power spectral line scans. The two procedures are identical, except that **tpon** tracks the **ON** (source) position and **tpoff** tracks the **OFF** (reference) position. You must execute the procedures manually, one scan at a time. As such, these procedures are mainly used for diagnostic purposes. To use **tpoff** and **tpon**, follow this prescription:

- Provide the operator with the following setup information:

    1. The source catalog and the source name (the **ON** position).
    2. The (AZ,EL) pointing corrections and the reference offset position (**OFF**). The offset may be specified in AZ and EL or in RA and DEC.
    3. The integration time of the scan in seconds (the scan will have only one **sample**, i.e., **repeats** does not apply to **TPN** or **TPF** scans).

- Have the operator perform a vane **CALIBRATE**, a **TPF** (the **OFF** scan), and a **TPN** (the **ON** scan) in that order. The scan numbers of the **CALIBRATE** and **TPF** will be stored in the header of the **TPN** scan for use in data processing.

- To look at either the **TPF** or **TPN** scans, type

  Line> scan# f
  Line> scan# s

  to choose either the first or second filter bank, respectively. The displayed scan will be a total power bandpass. Unless the band contains a very strong spectral line, you will probably not be able to see any lines. To display a final spectrum, formed from the ratio (**ON – OFF**)/**OFF * CAL**, type

Line> install ton
Line> scan# ton

(Note that you only need to install the procedure once per session). The ton procedure will use the last **CALIBRATE** and **TPF** scan to form the spectrum.

5.4.2 Position Switching

Position switching, called the PS mode, is the most common and reliable observing mode at the 12m for general spectral line observations. It involves considerable overhead in telescope movement and requires that equal time be spent in the **ON** and **OFF** source positions, but the data quality is usually good. In this mode, the telescope moves between the **ON** position and a relative **OFF** position, which may be specified in either azimuth and elevation, or right ascension and declination offsets. Usually the offset is in azimuth, so that the **ON** and **OFF** positions are taken at about the same airmass. The best rejection of the atmosphere and the best spectral baselines are achieved with small angular switches. Choose the smallest switch possible, so long as you are confident that the **OFF** position is free of source emission.

PS data recorded on disk is a final spectrum formed from the ratio (**ON – OFF**)/**OFF**, where the **ON** and **OFF** data are total power samples. In contrast to the total power observing modes **TPON** and **TPOFF**, the **ON** and **OFF** samples are not saved as separate scans for independent processing. Although the PS mode offers less flexibility in processing data than do the total power modes, it also reduces the total volume of data and makes processing easier.

To reduce telescope movement and provide the best compensation for polynomial drifts in atmospheric emission, choose the number of **OFF – ON** pairs to be a multiple of 2. The observing cycle will then be repeats of an **OFF** – **ON** – **ON** – **OFF** pattern characterized by a Walsh function (see Appendix E). Each **ON** or **OFF** is called a **sample** and each **OFF – ON** pair is called a **repeat**. The observer must tell the operator how long to integrate for each **sample** (the default is 30 seconds) and how many **repeats** per scan, or alternatively, the total length of the scan in minutes. A typical scan might be 6 minutes long, with 30 second **samples** (meaning 6 **repeats**). You can, of course, vary the length of the scan to suit your own needs. Each **ON** – **OFF** pair can be edited individually with the *line* program (see Record Editing in the supplement to the *line* manual). The operator can issue the command to take scans one at a time, or can set the system into an automatic data-taking loop. Figure 5.3 shows an example of a spectrum produced by a PS scan.

The parameters of a PS scan that you must give to the operator are

- The relative offset position, which may be specified in either (AZ,EL) or (RA,DEC) coordinates.

The integration time for an individual sample (**ON** or **OFF**). 30 seconds is the default.

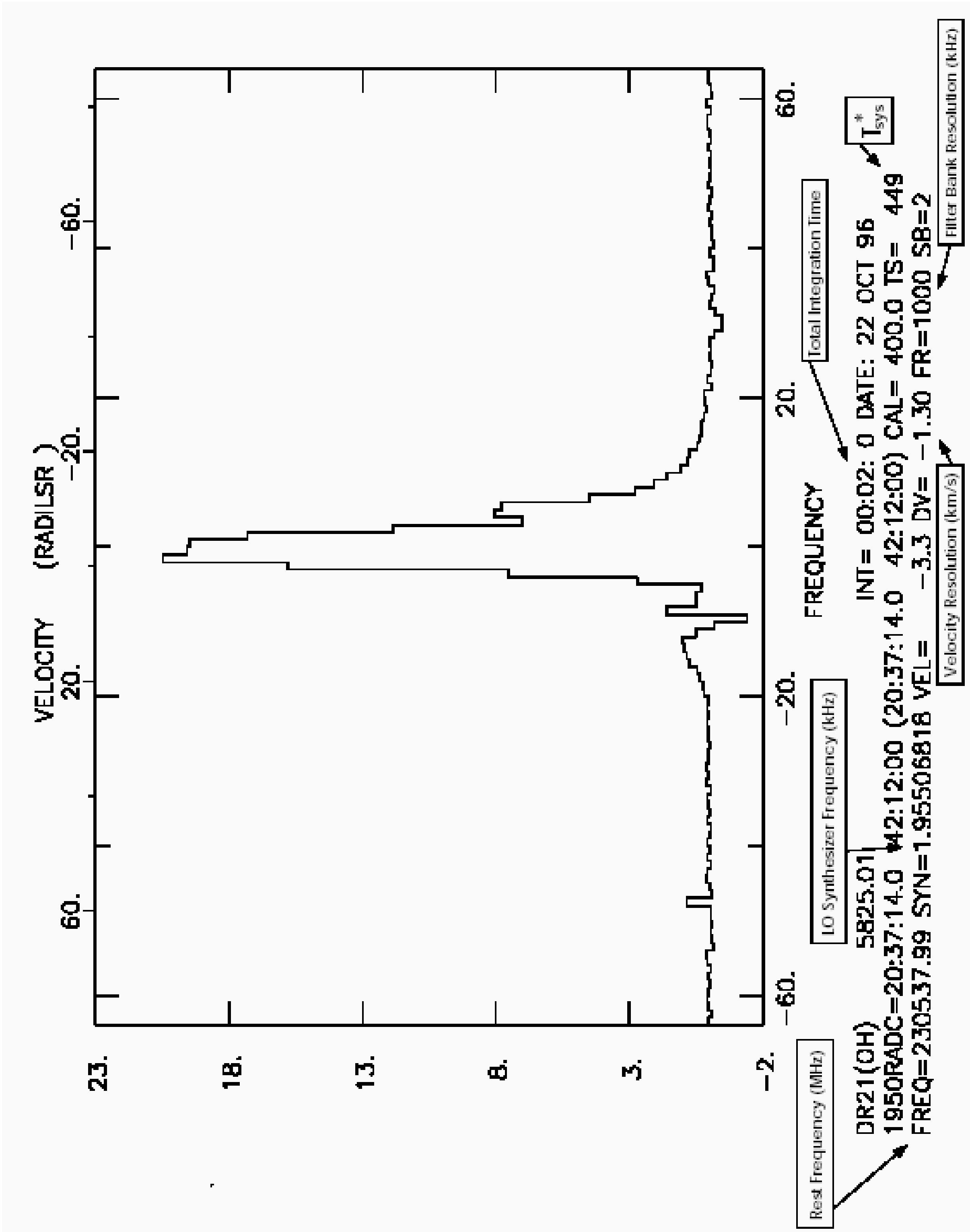

Figure 5.3: Position switched spectral line scan analyzed in the unipops program.

- The number of **ON**/**OFF** pairs (**repeats**) per scan (can be specified to the operator as the total length of the scan).
- The number of scans to be performed for every calibration measurement.

5.4.3 Absolute Position Switching

Absolute position switching, called the APS mode, is useful when observing in complex emission regions where it is difficult to find an emission-free reference position. In such cases, position switching with (AZ,EL) offsets can be dangerous because rotation of the parallactic angle as the source is tracked across the sky may cause emission to rotate into the reference beam. You will want to search for an emission-free position as close to the source position as possible, and use this as the reference position. If you wish, you can compute the (RA,DEC) offsets to this position and use ordinary position switching. Most observers find it most convenient, particularly for future observations, to enter the absolute (RA,DEC) coordinates of the reference position and use the absolute position switching observing mode.

APS is identical to ordinary position switching except that the switching is done between two positions absolutely specified by their celestial coordinates. The reference (**OFF**) position should be given a different name from the signal (**ON**) position and is best placed in a different source catalog from the signal position. Data taking and calibration options are the same as for ordinary position switching.

The parameters of an APS scan that you must give to the operator are

- The name of the source (**ON**) position and catalog which contains it;
- The name of the reference (**OFF**) position and its catalog;
- The integration time for each **sample** (**ON** or **OFF**). 30 seconds is the default;
- The number of **repeats** of an **ON** – **OFF** pair or the total integration time of the scan;
- The number of scans between each vane calibration, if that calibration method is chosen.

5.4.4 Frequency Switching

The frequency switching observing mode has two primary uses: to increase the on-source integration time through “in-band” switching and to alleviate the problem of finding an emission-free reference position when observing in a (spatially) complex emission region. It also entails less system overhead than most other observing modes. In this mode, called an FS observation, a reference spectrum is obtained by shifting the center frequency of the signal spectrum. In principle, this can be done by switching the frequency of the LO or an IF oscillator; at the 12m, the former is generally used. If the frequency shift is small enough, the spectral line will appear in both the signal and reference spectra. When the resultant spectrum is formed, the line will appear twice, once in emission and once in absorption. The spectrum can be "folded" to obtain a $\sqrt{2}$ improvement in signal-to-noise. With this technique, which is called "in-band" or "overlapped" frequency switching, you are effectively observing on-source all the time. Figure 5.4 shows an example of a spectrum produced by a FS scan.

The primary drawback of frequency switching is that the spectral baselines are generally not as good (*i.e. flat*) as with position or beam switching. This is because the two frequency positions each have their own spectral bandpass shapes which do not cancel in the computation of the final spectrum, which leaves a residual standing wave in the overlapped spectrum. We have nearly eliminated this standing wave by using two techniques:

Focus Modulation: Focus modulation is a technique whereby the axial focus is modulated by $+\frac{1}{8}\lambda$ and $-\frac{1}{8}\lambda$ during alternate integrations (usually 30 seconds long). When these alternate scans are averaged, the individual standing waves will be 90° out of phase, thus their amplitudes will cancel.

Beam Peak Scattering: The primary component of the standing wave comes from the reflective path between the receiver feed and the center of the subreflector. By placing an angled reflector (the "Cone of Silence") at the center of the subreflector, power incident at the center of the subreflector will be scattered onto the surface of the primary and scattered onto cold sky, nearly eliminating the main component of reflected power between the subreflector and receiver feed.

If the lines are narrow and the frequency shift is small (say < ±40 MHz), good results can often be obtained. One must also be careful when frequency switching in regions (spatial or spectral) which may contain multiple spectral lines. Note that one common contaminant in a frequency switched observation is mesospheric CO. The CO $J = 1 \rightarrow 0$ emission from the mesosphere is rather weak, but CO $J = 2 \rightarrow 1$ emission is quite strong (see Figure 5.5).

Frequency switching is effected by switching the phase lock loop offset frequency (the Lock IF) between two nearby settings, usually generated by separate oscillators. The oscillator settings must be set manually. The frequency of switching is usually 5 Hz and is generated by the spectral line multiplexer when so instructed by the computer. The phase lock circuitry must be able to lock at both the signal and reference frequencies. This places a practical limit on the magnitude of the shift of typically < ±40 MHz. Some receiver systems use the fundamental frequency of the Gunn oscillator as the LO frequency. For these systems, a shift in the loop offset frequency will produce exactly the same shift in the spectrum. Other receiver systems, particularly the high frequency receivers, use a harmonic multiple of the oscillator source as the LO frequency. The desired frequency shift must be divided by the appropriate multiple before setting the loop offset frequencies.

You will usually want to know whether the reference frequency is higher or lower than the signal frequency, or in other words, where the apparent "absorption" and "emission" features appear in the band. This is dependent upon which sideband (upper or lower) is being used. For upper sideband operation, the signal frequency will be higher than the reference frequency, so that the emission line will appear to the right of the reference signal in spectra. The reverse is true for lower sideband operation.

When performing frequency switched observations, you must decide upon the following parameters and give them to the operator:

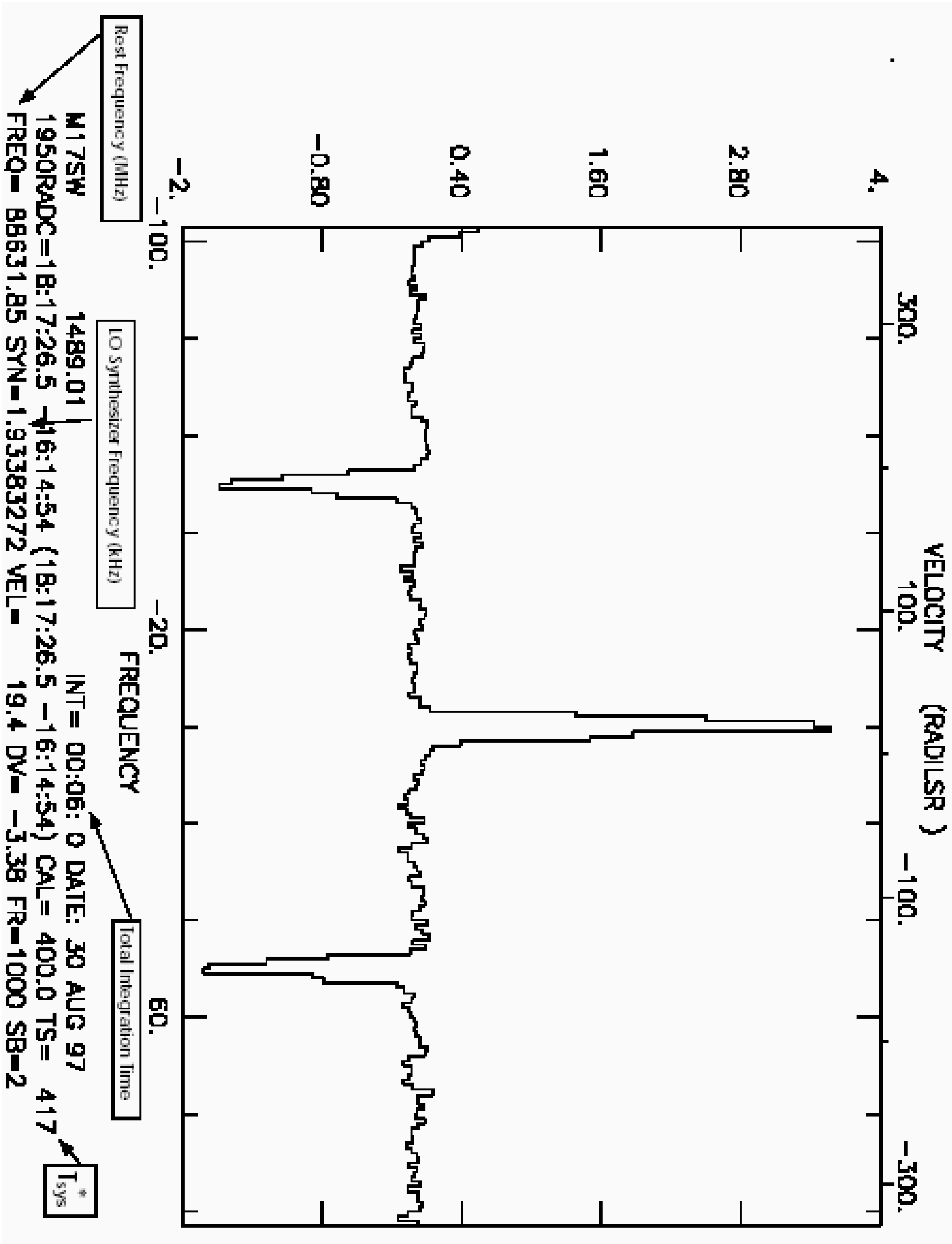

Figure 5.4: Frequency switched spectral line scan analyzed in the unipops program. The frequency switch throw for these measurements was ±25 MHz.

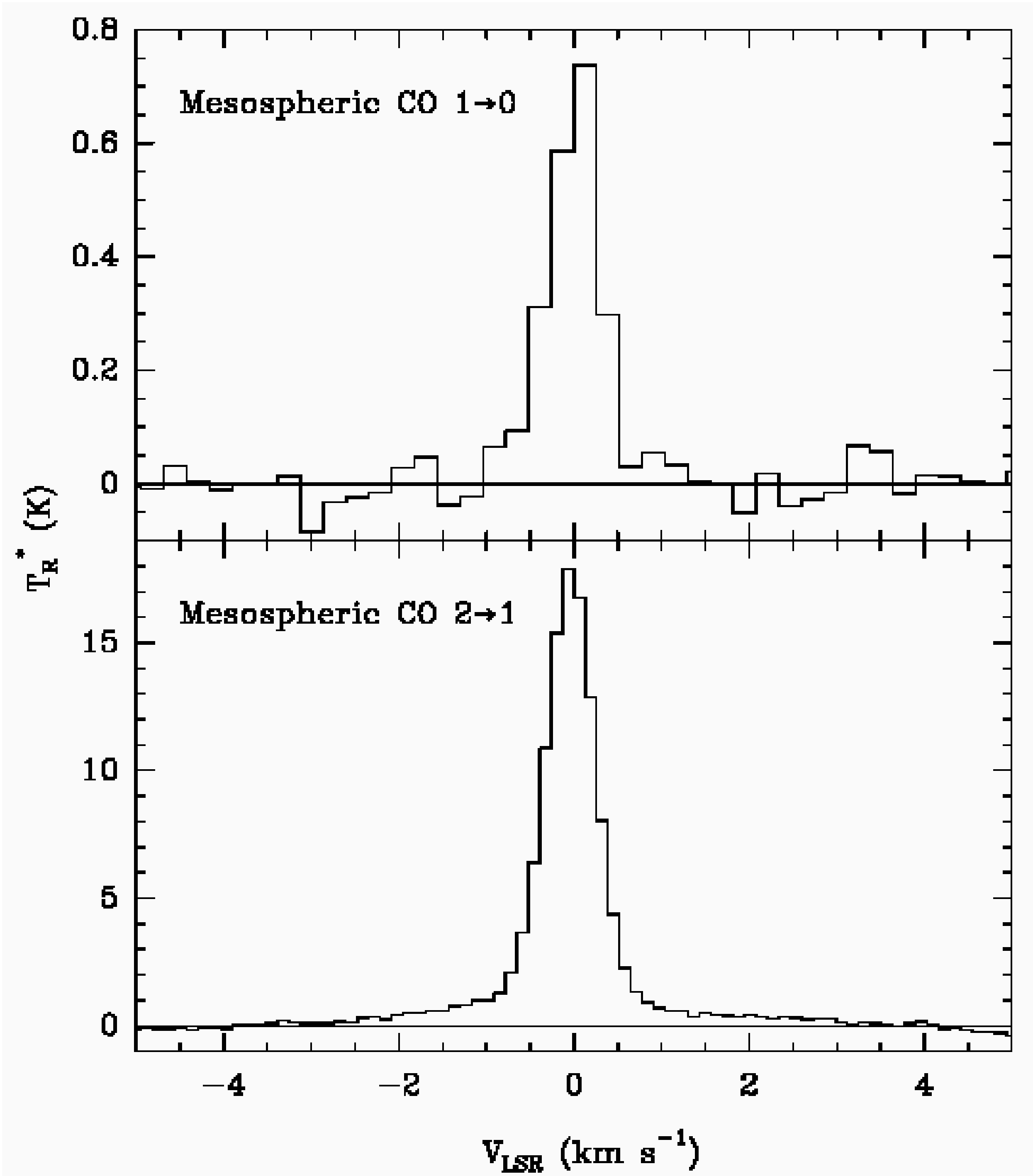

Figure 5.5: Frequency switched spectral line scans of the telluric CO J = 1 → 0 and J = 2 → 1 emission from the Earth's atmosphere.

1. The magnitude, sense, and symmetry of the frequency shift (< ± 5 MHz);

2. The switch rate (the usual setting is 5 Hz);

3. The total integration time of the scan. Note that the time overhead for frequency switching is about 7%.

To reduce "in-band" frequency switched data in the *line* data reduction system, use the **fold** command.

5.4.5 Beam Switching

Spectral line beam switching can be useful when observing small angular diameter sources and when the best possible baselines are needed. This observing mode involves the nutation (chopping) of the subreflector and a positional movement of the telescope and is thus called the BSP (beam switching plus position switching) mode. The technique is much the same as that used for continuum **ON/OFF's** (see §6.4.1.1 and Figure 6.2). With the subreflector nutating at a rate of typically 1.25 Hz, the telescope is moved to place the source first in one of the beam positions and then in the other. The beam position which, for a positive source signal, produces a positive response in the spectrometer is called the "positive beam" and a sample taken in this position is called an "**ON**". Conversely, the beam position which produces a negative response in the spectrometer is called the "negative beam" and a sample taken there is an "**OFF**". A BSP scan always consists of four samples taken in the order **OFF – ON** – **ON** – **OFF**. The samples are taken in this order to get the best atmospheric rejection, the best baselines, and to reduce telescope movement. The integration time of one of the individual **ON** or **OFF** samples controls the total integration time of the scan (sample length times 4).

The beam switching mode usually produces very good spectral baselines. The subreflector switch rate is such that atmospheric changes and filter bank anomalies are most often subtracted out. The primary restriction for beam switching is that the source angular diameter must be smaller than the subreflector throw. The subreflector throw can be varied between 0 and ±4.5', but beam throws larger than ±3 arcminutes are inefficient. The default switching rate is 1.25 Hz. Switch rates of 2.5 and 5.0 Hz are also available. The observing efficiencies are poorer at the faster rates but the cancellation of atmospheric drifts may be better.

You must decide upon the following parameters in a beam switched observation and give them to the operator:

1. The subreflector throw. Changes in the throw must be made manually; the computer must be updated (manually) as to the new value of the throw.

2. The switch rate of the subreflector.

3. The integration time per sample (**ON** or **OFF**). The total length of the scan is the sample time x 4.
4. The vane calibration method is available, although it is applied in a different manner than for position switched data (see §5.6).

5.4.6 Mapping

The 12m system offers three modes of spectral line mapping: mapping by manual offsets, automatic mapping of rectangular grids or catalogs in either the total power (TPM), position-switched (PSM or APM), or frequency-switched (FSM) modes, and On-The-Fly mapping. Mapping with manual offsets or rectangular grids is appropriate for small maps or maps with unevenly spaced points. For most rectangular grid mapping, we recommend the automatic position-switched total power mode. With the total power mode, you can choose to observe several **ON**s per **OFF** and thereby increase your observing efficiency. On-the-Fly mapping is discussed in the separate manual *On The Fly Observing at the 12m*. In the following we describe each of the mapping modes.

5.4.6.1 Manual Offsets

Often an observer will want to make a simple source map consisting of only a few points. In such cases, manual offsets (in RA,DEC) from the center position are the easiest way to proceed. Follow these steps:

1. Enter the center position into a source catalog or tell the operator the name and position so that he can enter it manually;
2. Compute the offsets in angular units. For declination offsets, this is unambiguous. For right ascension, two cases exist:

   (a) You want true angular offsets in the RA direction, *i.e.* with the cos(*DEC*) correction made. Tell the operator the magnitude of the offset in minutes and seconds of arc and whether you want to go East (+RA) or West (-RA). Tell him that these are *true angular offsets;*

   (b) You want an RA offset in units of time. Tell the operator the magnitude of the offset in units of minutes and seconds of time and whether to go East or West. Tell him that these are *offsets in time* (*i.e.* **no** cos(*DEC*) correction applied).

3. After each integration, loop to Step 2 and select a new point in the map.

The header information on the spectrum displayed by the *line* data reduction program will show any offsets that have been entered. The offsets are given in (real) angular units.

5.4.6.2 Grid Mapping

In the grid mapping modes, you can define a rectangular (RA,DEC) or (lII,bII) grid with different grid spacings in the horizontal and vertical coordinates. You can also define a grid to be acquired at an arbitrary rotation angle. The number of rows and columns must be an odd number. In the total power (TPM) and position-switched modes, you can choose between absolute (Absolute Position Mapping, or APM) and relative reference position (Position Switched Mapping, or PSM) measurements, you can choose to observe several map positions (**ON**s) for each reference (**OFF**) position, and you can observe several **OFF**s for each vane calibration scan. Frequency switched mapping (FSM) requires no **OFF** position measurement.

Grid maps can be observed in three different ways: standard grid, which measures all positions on the grid sequentially, spiral grid, which measures all positions on the grid with a spiral pattern, and cross grid, which measures only the points which lie on the central row and column of the grid. Figure 5.6 shows the observing sequence for each variety of grid map.

After defining the grid, you can choose to map a subset by specifying the beginning and ending row numbers, and the beginning and ending column numbers. To use any of the spectral line grid mapping modes, give the operator the following information:

1. The catalog and name of the source (map center position).

2. Standard setup parameters, including the (AZ,EL) pointing offsets, the pointing tolerance, and the focus setting.

3. The reference position offset (relative to the map center) in either the (AZ,EL), (RA,DEC), or (lII,bII) frames if you are doing total power of position-switched mapping.

4. The frequency switch offsets in MHz if you are doing frequency-switched mapping.

5. The horizontal coordinate grid spacing in seconds of arc (real angle).

6. The vertical coordinate grid spacing in seconds of arc.

7. The number of rows in the map. Must be an odd number.

8. The number of columns in the map. Must be an odd number.

9. The beginning and ending rows of the map. (optional)

10. The beginning and ending columns of the map. (optional)

11. The grid rotation angle. (optional)

12. For position- or frequency-switched maps, you must also specify:

    (a) The scan time in seconds.

    (b) The number of **ON-OFF** pairs per point.

    (c) The number of scans per calibration measurement.

    (d) The number of scans per center position measurement.

13. For total power mapping, you must also specify:

    (a) The integration time per **ON** and **OFF** in seconds.
    (b) The number of map positions (**ON**s) to be observed for each reference position (**OFF**).

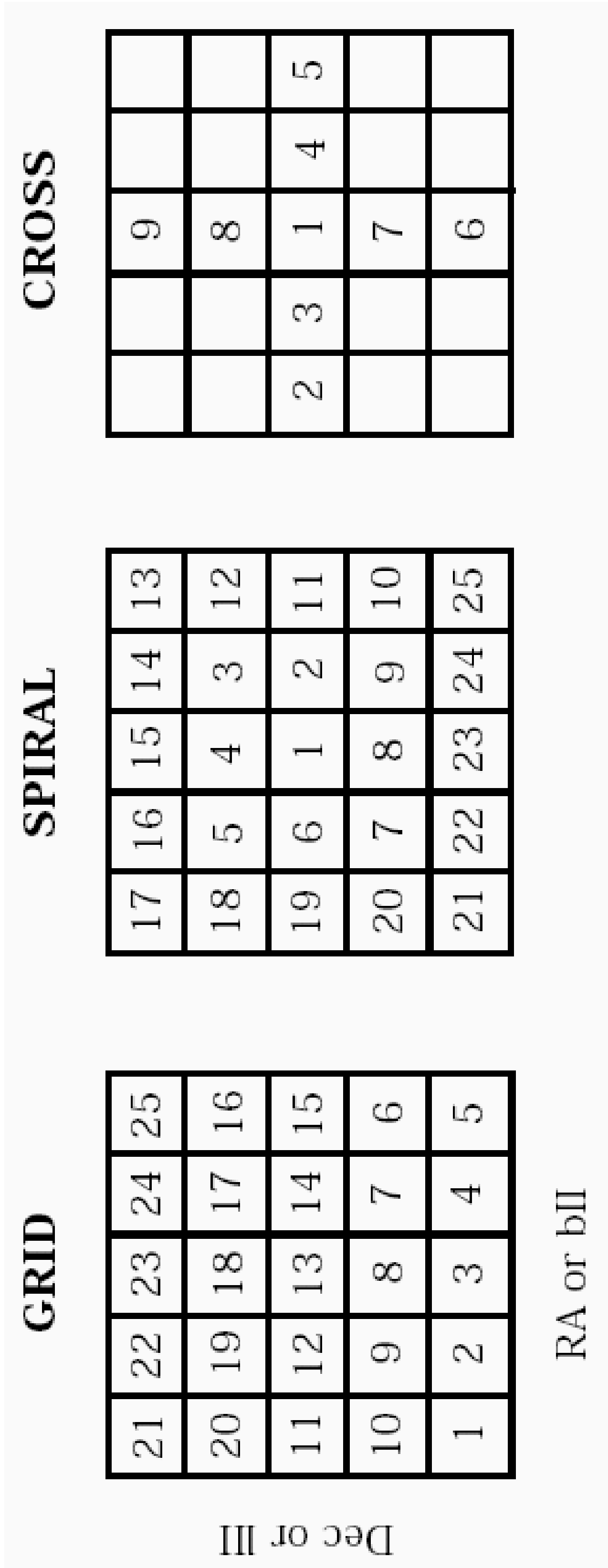

Figure 5.6: Grid map observing sequence for all 12m grid mapping modes.

(c) The number of **OFF**s for each vane **CALIBRATE**.

Display of position- and frequency-switched map measurements is the same as that used to display regular PS or FS measurements. The spectrum of a single total power map point is displayed in *line* using the **ton** procedure:

Line> install ton
Line> scan# ton

where **scan#** is that of the **ON** position.
To display a contour map of peak or integrated intensity versus position, it is best to use the CLASS program. See §2.4.1 for information on how to port your 12m data to CLASS format. Manuals for the CLASS program are also available.

5.4.6.3 When Should I OTF Instead of Grid Map?

As a general rule-of-thumb, it is best to use OTF mapping instead of the step-and-integrate mapping described in this section when your map field is larger than about 60 in either RA or DEC and your target spectral line is expected to be reasonably strong. For those rare cases when OTF is not suitable, one must decide which step-and-integrate mapping technique to use. There is no hard rule to determine whether one should use PSM or TPM, the total power mapping mode. TPM is more efficient in the sense that you can use one **OFF** scan with several **ON**s. However, PSM may produce better baselines because of the switching pattern. As a general recommendation, we suggest that you use TPM for maps of strong lines and large mapping grids; use PSM if the lines are weak and baseline stability is critical. APM is also an alternative to PSM: it uses the same OFF – ON – ON – OFF... pattern but the mapping positions are taken from discrete catalog entries rather than a grid built from offsets from a single central position. FSM is another alternative for those cases where frequency switching can be used (see §5.4.4).

5.4.6.4 An Important Note About Spatial Sampling

The following is due to Darrel Emerson

When setting up your map observations, it is important to keep in mind the following facts about sampling and aliasing in radio astronomical mapping data. If you want to represent the full resolution of the telescope, you have to sample the data often enough to represent all the spatial frequencies detected by the dish. You can think of the extreme edges of the dish of diameter D as part of an interferometer of spacing D, which has to be sampled at $\frac{\lambda}{2D}$. Depending on the illumination taper, this corresponds typically to sampling at about 2.4 or 2.5 points per FWHM. Of course, if there is zero, or by some definition “negligible”, illumination at the edge of the dish, you won't be sensitive to such high spatial frequencies. It will be just the same as a smaller dish of diameter d equal to the diameter of that part of the dish that has significant illumination, and the sampling will be calculated from $\frac{\lambda}{2X}$, where X is defined as the diameter of the illuminated part of the surface.

It's useful to consider what happens if you undersample data. Assume that the undersampling happens on the sky, rather than in later in the data processing. Suppose you have a 10m dish, but you only sample at $\frac{\lambda}{2\times 8m}$ rather than the $\frac{\lambda}{2\times 10m}$ that you should. That means that the spatial frequencies present from the dish baselines of 8m to 10m get reflected back into the spatial frequencies of 8m down to 6m. Not only have spatial frequencies from the 8m to 10m baselines been lost, but valid spatial frequencies from baselines of 6m to 8m have been corrupted. You can't tell if structure in your map with a spatial wavelength of $\frac{\lambda}{7m}$ is genuine, or was really structure at $\frac{\lambda}{9m}$ which has been aliased on top of any genuine $\frac{\lambda}{7m}$ spatial wavelength signal. In this sense, undersampling the sky is really twice as bad as you might have thought.

How important this undersampling is depends on exactly what the illumination taper is, how important it is that you retain the maximum possible resolution of the telescope, how good a dynamic range you want in the observations, and at some level how much fine scale structure there is in the source itself. If you only sample at 0.8 Nyquist (*e.g.* $\frac{FWHM}{2}$ rather than $\frac{FWHM}{2.5}$), what matters is the energy in the data at spatial wavelengths shorter than $\frac{\lambda}{2\times 0.8\times D}$. So in a sense you need to ask what the illumination taper is at a radius of $0.4\times D$ on the dish surface. The spatial frequency response of a single dish is the autocorrelation function of the voltage illumination pattern. So, you need to calculate how much area there is under the 2-D autocorrelation function beyond spatial frequencies of $0.8\times D$, compared to the area within $0.8\times D$. This ratio is some measure of the dynamic range. A better definition of dynamic range might take into account the spatial frequency structure of the source. If the source has no structure on scales smaller than $\frac{\lambda}{2\times 0.8\times D}$, then you don't need to sample at the full $\frac{\lambda}{2\times D}$ anyway.

This is one circumstance where it is perfectly rigorous to undersample the data. If, say, you have a 10m dish, and you are taking data to compare with other observations using a 1m dish at the same wavelength (or the equivalent number of wavelengths at some other frequency) then you only need to sample the data at $\frac{\lambda}{2\times 5.5m}$ or $\frac{\lambda}{11m}$. This is so because, when sampling a 10m dish as if it were a 5.5m dish, the spatial frequency components from baselines of 5.5m out to 10m will be reflected back into the data as if corresponding to baselines of 5.5m down to 1m. So, the spatial frequency terms of 1m baseline and below will not have been corrupted. The data analysis of this undersampled data would apply a spatial frequency cutoff at 1m, and there will have been no corruption in this smoothed data caused by the undersampling. Putting it in more general terms, if you are going to be smoothing a dish of diameter *D* to simulate observations made with a smaller dish of diameter *d*, then the sampling interval only needs to be $\frac{\lambda}{d+D}$ rather than $\frac{\lambda}{d\times D}$.

There are other aspects that make it desirable to sample **more** often than the Nyquist rate, as we recommend for OTF observing. These are practical points like how well gridding or interpolation works with a finite sized gridding or interpolation function. A little oversampling may enable you to reduce the convolution (interpolation) function by a factor of a few, saving a huge amount of computational overhead at the expense of a few percent more data.

5.5 Spectral Line Sensitivities

The spectral line calibration technique generally used at the 12m is the chopper wheel or vane method. The effective system temperature given by this technique includes corrections for atmospheric attenuation and antenna spillover, blockage, and ohmic losses. The method does not include a correction for error pattern losses as the error beam will couple differently to different sources. The effective system temperature, T^*_{sys}, on the scale defined above, is given by

$$T^*_{sys} = \frac{\left(1 + \frac{G_i}{G_s}\right) [T_{rx} + T_A(sky)]}{\eta_l \eta_{fss} \exp(-\tau_0 A)} \tag{5.5}$$

where

G_i is the image sideband gain;

G_s is the signal sideband gain;

T_{rx} is the receiver DSB noise temperature;

$T_A(sky)$ is the temperature of the sky (definition given below);

η_l is the rear spillover, blockage, scattering, and ohmic efficiency;

η_{fss} is the forward spillover efficiency;

τ_0 is the atmospheric optical depth at 1 airmass (the zenith); and,

A is the number of airmasses, generally given by 1/sin(elevation).

$T_A(sky)$ is given by the equation

$$\begin{aligned} T_A(sky) &= T_{sky} + T_{ant} + T_{cmbr} \\ &= \eta_l T_m [1 - \exp(-\tau_0 A)] + (1 - \eta_l) T_{spill} + \eta_l T_{bg} \exp(-\tau_0 A) \end{aligned} \tag{5.6}$$

where

T_m is the mean atmospheric temperature,

T_{spill} is the spillover temperature, and

T_{bg} is the cosmic background temperature.

Note that T_m, T_{spill}, and T_{bg} are actually equivalent Rayleigh-Jeans temperatures of the point on the Planck blackbody curve corresponding to the same frequency. This correction factor is given by Equation 6.10. For simplicity, we will retain the symbol "T" for temperatures, but in calculations "T" should be replaced by "J(ν,T)".

The rms noise level for a given integration time, assuming equal integration time at the **ON** source and **OFF** source reference positions, is given by the radiometer equation (see Appendix F for a general derivation of the radiometer equation for non-equal **ON** and **OFF** source integration times)

$$T_{rms} = \frac{2T^{*}_{sys}}{\eta_{spec}\sqrt{\Delta\nu t_{scan}}} \tag{5.7}$$

where

$\Delta\nu$ is the bandwidth of an individual channel in the spectrometer (in Hz),

η_{spec} is the efficiency associated with the spectrometer used. η_{spec}= 0.81 for the Millimeter Autocorrelator (MAC) and 1.0 for the filter banks. See Appendix D for more information.

t_{scan} is the total integration time, including **ON** and **OFF** source time (in seconds).

Note that for observations of unpolarized signals with receivers that have two polarization channels, the two channels can be averaged to reduce the effective system temperature. In this case, T^{*}_{sys} is the average of the effective system temperatures for the two polarization channels.

5.6 Calibration

5.6.1 Vane Calibration

The calibration mode used for almost all spectral line observations at the 12m is the vane or chopper wheel method. In this method, a calibration signal is generated by differencing the signals recorded first on cold sky and then on an ambient temperature absorber. In 12m vernacular, a vane is a paddle covered with microwave absorber that is switched in and out of the beam at a rate of about 1 Hz. A chopper wheel is, in this case, a chopping blade whose solid portions are covered with absorber and which rotates at a rate of typically 10 - 50 Hz. The calibration technique is identical with the two devices. The receivers currently in use at the 12m all use a common central vane.

Chopper wheel calibration has been discussed extensively in the literature (see Ulich & Haas, 1976, ApJS, 30, 247, and Kutner & Ulich, 1981, ApJ, 250, 341). The technique corrects for atmospheric attenuation and several telescope losses. At the 12m, the temperatures resulting from this technique are on the T^{*}_{R} scale (Kutner & Ulich) which means that the temperatures are corrected for the atmosphere and all telescope losses except for coupling of the source and beam. The beam is defined here to include the central difraction lobe, all near-in sidelobes, and the error pattern (error pattern losses are often the largest of the uncorrected losses). Observers should be aware that other observatories using the chopper wheel method have different definitions of the basic temperature scale. Exercise care when comparing data!

An essential part of the chopper wheel calibration method is the specification of the calibration scale temperature T_C, which is given by

$$T_C = \frac{T_{hot} - T_A(sky)}{\eta_l \eta_{fss} \exp(-\tau_0 A)} \tag{5.8}$$

where $T_A(sky)$ is given by Equation 6.9. For observations under typical atmospheric conditions, $T_C = 400$ for single sideband operation and 800 for double sideband operation. Note that T_C varies with elevation, particularly for double sideband observations on the wings of an atmospheric line such as at 115 GHz.
The procedure for performing a vane **CALIBRATE** is the following:

1. Set the calibration scale temperature T_C. As explained above, T_C is approximately 400 for SSB receivers and 800 for DSB receivers. The precise value of T_C is dependent upon efficiency factors, temperature, atmospheric optical depth and elevation or airmass.

2. Perform a calibration cycle (called a **CALIBRATE**) at intervals which you prescribe. The interval should be small enough that the atmospheric transmission during the interval does not change appreciably. This depends on the atmospheric optical depth and its stability and the elevation. During stable conditions of low optical depth, a **CALIBRATE** every 10-15 minutes is usually sufficient. If the atmosphere is choppy or the elevation is changing rapidly as when the source is rising or setting, more frequent **CALIBRATE**s may be necessary. The operator can command the system to perform a **CALIBRATE** before each position switched scan or before a specified block of scans. The length and number of repeats of a given **CALIBRATE** can also be specified. The default is 30 seconds, with the vane and sky sampled 15 times each at 1 second per sample.
3. The result of a **CALIBRATE** is loaded into the gains array. To examine the gains, type **g1** for receiver channel 1 and **g2** for channel 2. Exact definitions of the signal processing are given in Section §5.7.

4. During position and frequency switched observations, the telescope moves to the **OFF** position to take the **CALIBRATE**.

5.6.2 Direct Calibration

Note: The staff does not recommend this calibration procedure. We describe it here for completeness.

In the direct calibration mode, the data are scaled by the system temperature and the atmospheric attenuation according to the relation

$$T_A = \frac{\text{SIG} - \text{REF}}{\text{REF}} \times T_{sys} \times \exp(A\tau_0) \quad (5.9)$$

where **SIG** is the signal array, **REF** the reference array, T_{sys} the system temperature, τ_0 the zenith optical depth, and A the airmass. The exact expressions for no-cal signal processing are discussed below. The observer is responsible for the computation of T_{sys} and the measurement of τ_0. The value for T_{sys} can include efficiency factors, or the antenna temperature can be scaled up in the data reduction and post-processing stage. One reasonable definition of T_{sys} is

$$T_{sys} = \frac{\left(1 + \frac{G_i}{G_s}\right)(T_{rx} + T_{sky})}{\eta_l \eta_{fss}} \quad (5.10)$$

where G_i and G_s are the image and signal sideband gains, T_{rx} is the receiver noise temperature, T_{sky} is the antenna temperature of the sky (Equation 6.9), η_l is the rear spillover efficiency, and η_{fss} is the forward spillover efficiency. With this definition, the resulting antenna temperature is on the same scale (T^*_R) as with the chopper wheel calibration.

This calibration scheme has a certain appeal because it is direct and easy to understand. However, the method has several difficulties which prevent it, in general, from being as accurate as the chopper wheel method. First, in the absence of an automatic **HOT/COLD/SKY** load system (which the 12m doesn't have), you must make several time-consuming observations. These include tipping scans to measure the atmospheric optical depth, and manual **HOT/COLD** loads to measure the receiver noise temperature and possibly the sky temperature. If these measurements are not made frequently, receiver and atmospheric drifts may introduce calibration errors. In addition, measurement of an average atmospheric optical depth may not adequately correct for local cloudlets and other atmospheric anomalies. Finally, the chopper wheel method depends only weakly on η_l, whereas the direct calibration method depends strongly on it.

Although we do not recommend the no-cal method for most cases, you should follow this procedure if you choose to use it.

1. Perform an ordinary **VANE** cal to look for bad channels and give the operator a list of the bad channels;

2. Tell the operator you will be using the no-cal method. He will first perform a dummy **CALIBRATE** to zero the bad channels. You will not need to perform any more calibrates.

3. Tell the operator the value of T_{sys} you wish to use. It's up to you to decide how to calculate this number, but you will probably want to measure the receiver noise temperature by a **HOT/COLD** load, in the least.

4. Perform a tipping scan (see §6.5.1).

5. Repeat steps (3) and (4) at intervals short enough to catch any significant system or atmospheric changes.

5.7 Signal Processing

5.7.1 Position and Frequency Switched Data

5.7.1.1 Vane/Chopper Calibrates

When a vane calibration is performed, a calibration array called the gains array is computed according to the formula

$$\mathrm{Ci} = \frac{R_{ci} - Z_i}{S_{ci} - R_{ci}} \times T_C \tag{5.11}$$

where

C_i is the effective system temperature for channel i,

S_{ci} is the calibration signal (vane over the feed) for channel i,

R_{ci} is the calibration reference (cold sky) for channel i,

Z_i is the zero value response of channel i with no input signal, and

T_C is the calibration scale temperature.

The array of C_i elements is called the gains array. The average effective system temperature of all channels in the multiplexer,

$$T_{sys} = < C_i >, \tag{5.12}$$

is displayed and updated on the on-line status monitor each time a **CALIBRATE** is performed. Note that T_{sys} is an average of both receiver channels when a two-channel receiver is in use.

The calibrated antenna temperatures (T^*_R) that are recorded on disk are calculated by the formula

$$(T^*_{\mathrm{R}})_i = \frac{S_i - R_i}{R_i - Z_i} \times C_i \tag{5.13}$$

where

$(T^*_R)_i$ is the calibrated antenna temperature for channel i,

S_i is the Source or **ON** signal, and

R_i is the Reference or **OFF** signal.

5.7.1.2 No-Cal Signal Processing

In the no-cal mode, the antenna temperatures are calculated from the relation

$$(TA)i = \frac{S_i - R_i}{R_i - Z_i} \times T_{sys} \times \exp(A\tau_0) \qquad (5.14)$$

where τ_0 is the zenith optical depth (called TAU0 in the control system), and A is the airmass, calculated as 1/sin(*elevation*). All other symbols are defined in §5.7.1.1.

5.7.2 Beam Switched Data

Beam switched data are calibrated using the vane but the signal processing is different from position and frequency switching. When a calibrate is performed during a beam switching session, the gains array is defined as

$$C_i = \frac{1}{S_{ci} - R_{ci}} \times T_C \qquad (5.15)$$

where the terms are defined above. The antenna temperature scale is given by

$$(T^*_R)_i = (S_i - R_i) \times T_C \qquad (5.16)$$

5.8 Changing the Intermediate Frequency

Occasionally an observing situation may arise in which a change in the Intermediate Frequency from the nominal 1.5 GHz is either necessary or desirable. One example of this is when the program line is just outside the tuning range of the local oscillator. Another example occurs when, for double sideband observations, it is advantageous to observe lines from both the signal and image sidebands for pointing, calibration, or simultaneous line search purposes and the image line is just outside the normal spectral bandpass.

These observing situations can be accommodated provided the IF needs to be changed by only a small amount. The IF system has a bandpass filter centered at 1500 MHz with a bandwidth of ±300 MHz. Any change of the IF must thus fit within the 600 MHz IF bandwidth, leaving room to include the filter bank bandwidth. Hence, the minimum IF can be 1200 MHz plus ½ the filter bank bandwidth and the maximum IF can be 1800 MHz less ½ the filter bank bandwidth. Lines in opposite sidebands can be separated by at most 3600 MHz less ½ the filter bank bandwidth, or in the least by 2400 MHz plus ½ the filter bank bandwidth.

To adjust the IF bandwidth, the first IF synthesizer, which is normally set to 109.50000 MHz, must be changed. The equation for determining the synthesizer frequency is

$$f_{syn} = \frac{f_{IF} + 2442 MHz}{36} \tag{5.17}$$

where f_{IF} is the desired IF. If the lines are in opposite sidebands,

$$f_{IF} = \frac{f_u - f_l}{2} \tag{5.18}$$

where f_u is the upper sideband center frequency and f_l is the lower sideband center frequency. This intermediate frequency must be entered into the control computer so that the local oscillator synthesizer frequency will be correctly calculated.

Note that if the two target lines are at the center of their respective sidebands, they will fall on top of each other in the resultant spectrum. To keep this from happening, offset the line rest frequencies from the band center. If the signal sideband center frequency is offset by an amount δ, the signal and image sideband lines will be separated by 2 δ and will be symmetrically displaced about the center of the final spectrum.

To observe with a non-standard IF, follow this procedure:

1. Discuss your intentions with a staff member well in advance of the observations;

2. Calculate the new synthesizer frequency according to the equations above. Make sure that you are not exceeding the 600 MHz bandwidth of the IF system.

3. Ask the operator to dial the synthesizer frequency into the IF synthesizer that is nominally set to 109.5 MHz.

4. Ask the operator to set the new IF into the control computer.

5. If appropriate, offset the signal band center frequency from the line rest frequency to prevent overlap of signal and image lines.

6. Remember to have the synthesizer set back to 109.50000 MHz when the special observations are finished.

Step (6) above is especially important to remember as the computer does not check the IF synthesizer for a correct setting. If you (or the next observer) resume standard observations and the synthesizer is not reset to 109.5 MHz, the band center will be o set from what you intend. In addition, we highly recommend that you check your special observing configuration on a strong test line before conducting program observations on weak lines.

5.9 Spectral Line Status Monitor

The spectral line status monitor provides basic information about the status of the telescope and the observations that are underway. The observer should check the monitor frequently to see that the telescope and control system are configured as they should be. Figure 5.7 shows a sample monitor screen divided into several boxes. Each numbered box indicates a section of the display which describes a particular set of attributes of a spectral line measurement. Only box 7 differs from the continuum status display (see §6.7:

Box 1: Scan number, source name, and timing information.

SCAN: Current scan number.

SOURCE: Source name.

HORIZON: Time to 15° elevation (rise or set).

LST: Current local sidereal time.

UTC: Current coordinated universal time.

DUT1: UT1-UTC time correction.

date: Current year (top) and date (bottom).

OBS: Current observer initials (top) and data le number (bottom).

OPR: Current operator initials.

Box 2: RA/Dec and lII/bII position information.

TOTAL: Current total (apparent plus offsets) RA and Dec.

B1950.0: Current Equinox B1950 RA and Dec.

APPARENT: Current apparent RA and Dec.

GALACTIC: Current lII and bII.

OFFSET: Current applied RA and Dec offsets.

Box 3: Apex position information.

NS: North (top) and south (bottom) focus translation stage offset position in millimeters.
EW: East (top) and west (bottom) focus translation stage offset position in millimeters.

Box 4: Azimuth and elevation position and pointing offset information.

COMMAND: Commanded azimuth and elevation (spherical coordinate conversion plus pointing corrections).

ACTUAL: Actual azimuth and elevation encoder readings.

ERROR: Difference between **COMMAND** and **ACTUAL** azimuth and elevation.

OFFSET: Total azimuth and elevation offsets (sum of pointing offsets plus subreflector beam throw).

POINT: Azimuth and elevation pointing model corrections.

PSREF: Reference position offset in azimuth and elevation.

Box 5: Receiver calibration and tipper information.

ATM: Number of air masses toward current elevation.

RCVR: Receiver name.

RBAY: Receiver bay.

F0: Axial focus zero position in millimeters.

TC: Calibration scale factor for receiver channels 1 (top) and 2 (bottom).

TAU0: Actual (top) and 225 GHz (bottom, measured continuously using a tipping radiometer) zenith opacity.

FWHM: Beam FWHM (top) and HWHM (bottom, used for five-point measurements) in mm:ss.

TSYS: Channel 1 (top) and 2 (bottom) system temperatures in K.

MM_H2O: Millimeters of water vapor at zenith based on the 225 GHz tipping radiometer measurement of τ_0 and a conversion of 1 millimeter H_2O equals an opacity of 0.05 at 225 GHz.

Box 6: Subreflector beam and quadrant detector position information.

+BEAM: Azimuth and elevation position for the +Beam in mm:ss.

–BEAM: Azimuth and elevation position for the –Beam in mm:ss.

QX: Quadrant detector x-axis position in millimeters.

QY: Quadrant detector y-axis position in millimeters.

Box 7: Frequency, velocity, and calibration information.

LINE: Spectral line name for current transition frequency.

BW: First (top) and second (bottom) filter bank spectrometer channel width in kHz.

CHANNEL: The multiplexer channels used for the first (top) and second (bottom) filter bank.

CONF: A code indicating whether the filter banks are configured for serial (SER) or parallel (PAR) operation.

MAC_BW: Millimeter Autocorrelator (MAC) bandwidth in MHz.

OBJ_V: Source velocity in chosen reference frame in km/s.

ANT_V: Antenna velocity in chosen reference frame in km/s.

FRAME: Velocity frame of reference code.

TYPE: Velocity type.

SB: Signal sideband (upper or lower) for channel 1 (top) and channel 2 (bottom).

LO: Local oscillator multiplication factor.

IF'S: Intermediate frequencies in MHz.

FREQUENCY: Rest frequencies for channels 1 (line 1) and 2 (line 2), in GHz, with their associated LO synthesizer frequencies (lines 3 and 4, respectively), in MHz.

CAL: Calibration type.

FB_OFF: Filter bank offset in MHz.

MAC_OFF: Millimeter Autocorrelator (MAC) offset in MHz.

SPEC_RUN: Indicates that this is a spectroscopy measurement with the filter banks.

MAC_RUN: Indicates that this is a spectroscopy measurement with the Millimeter Autocorrelator (MAC).

BAD_CHAN: Filter bank channels flagged by the on-line system.

Box 8: Telescope tracking and weather information.

TOL: Input and actual tracking tolerance in m:ss.

FOCUS: Input and actual axial focus at the current elevation in millimeters.

TORR: Barometric pressure in Torr.

%RH: Relative humidity.

T AMB: Ambient temperature in C.

REFRT: Input and actual refraction constant for elevation refraction pointing correction in arcseconds.

Box 9: Current observation scan and integration time information.

MODE: Observing mode.

SCANS: Number of scans requested.

SAMPLES: Number of continuum on/off samples requested.

SEC: Total (top) and remaining (bottom) sample time in seconds.

TIME: Total (top) and remaining (bottom) integration time for this scan in mm:ss.

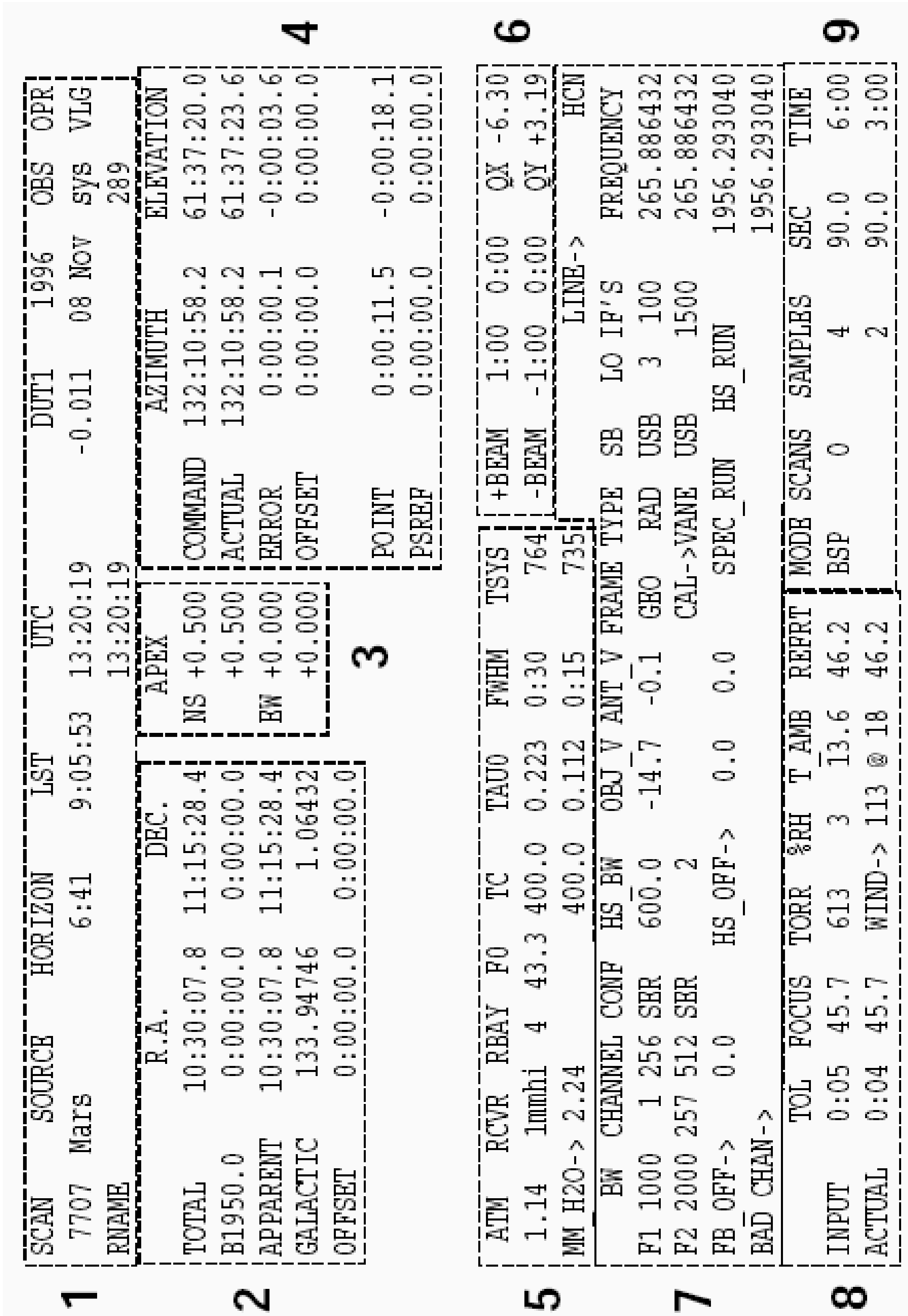

Figure 5.7: Spectral line on-line status monitor. The numbered boxes indicate sections of information on the display which are explained in §5.9