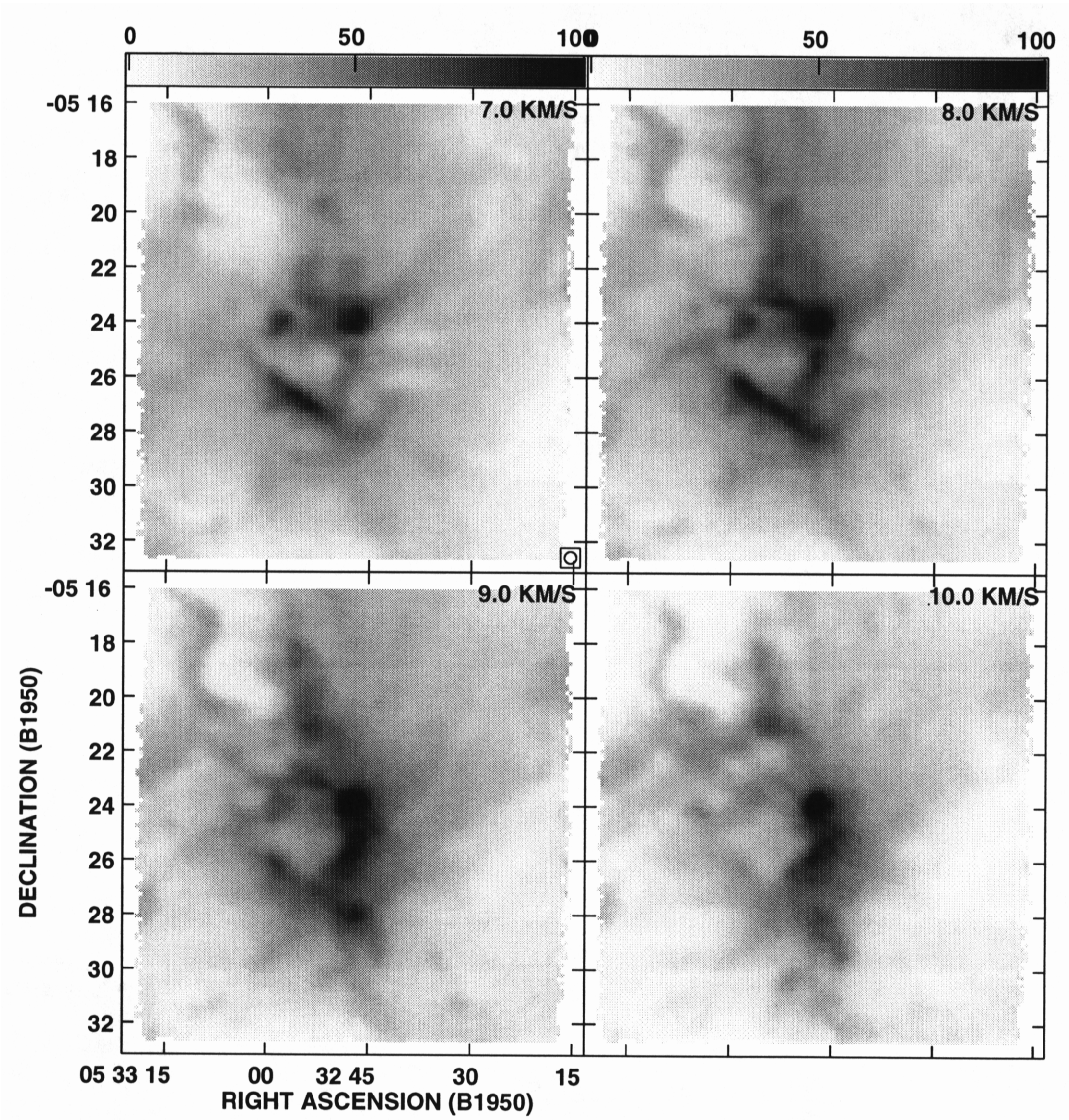

Observing with the NRAO 8-Beam SIS Receiver

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1 Introduction

The 8-Beam 1.3mm SIS receiver is designed for rapid mapping of spectral lines in the 220-260 GHz range. This instrument has 8 independent beams on the sky in a 2×4 array with a separation between beams (θ_{bs}) of 87″ (see Figure 1). The receiver is composed of a single cryostat which houses the eight DSB SIS mixers. LO is supplied by a single Gunn oscillator which drives two triplers.

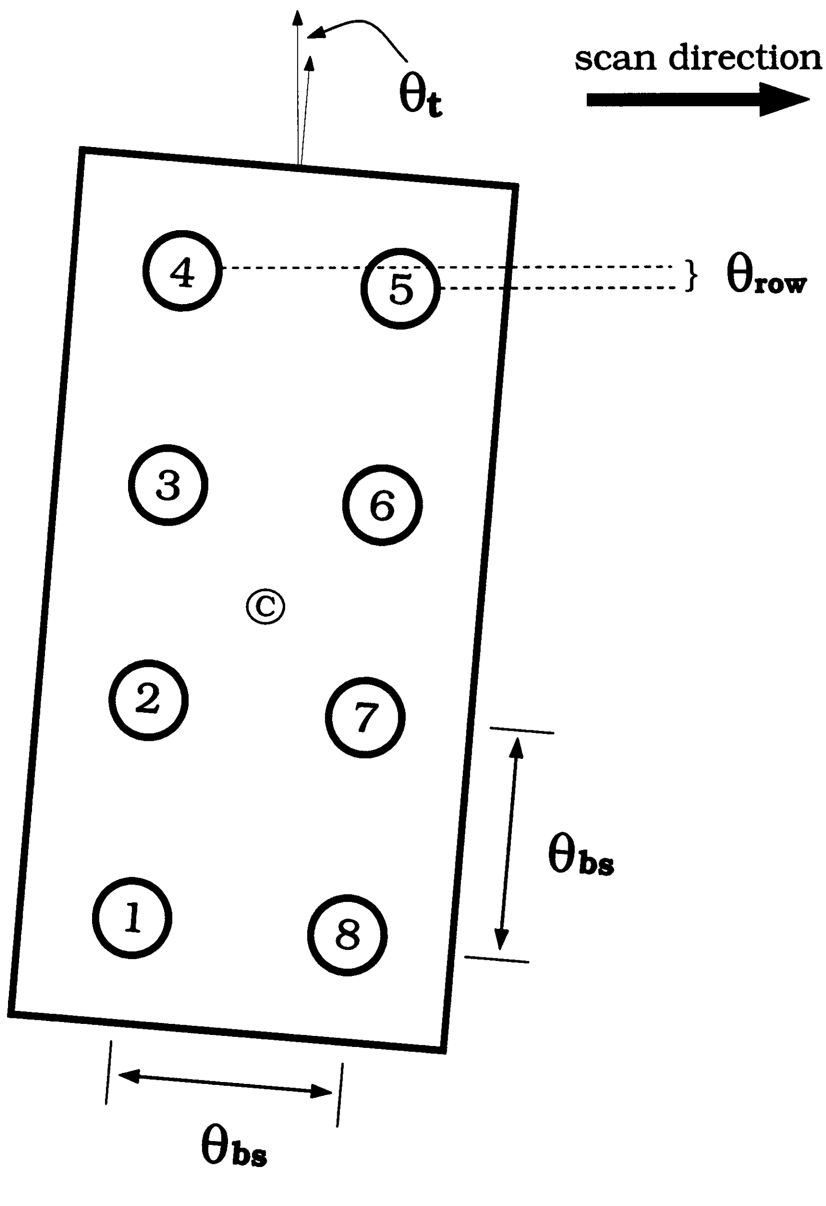

Figure 1: Beam configuration for 8-Beam receiver

The 8-Beam receiver is used mainly for mapping regions larger than $\sim 15'$ in extent.

For these types of observations, the 8-Beam receiver should be able to map a given region to a given sensitivity 2 to 3 times faster than the single-beam dual-channel 1mm receiver. In the following, I describe the backend characteristics, observing modes, and how to process otf measurements made with the 8-Beam system.

2 Spectrometer Capabilities

2.1 Filter Banks

Since there are only two IF's which feed the filter bank spectrometers, only two of the beams are processed through them. We generally connect two of the beams near the center of the array to the filter bank IF's, so that with the point-and-shoot and optimal otf observing modes (see §5), the filter banks spectrometers will not yield a fully-sampled map. All filter bank configurations available to the dual-polarization single-beam systems are also available for 8-Beam measurements.

2.2 Hybrid Spectrometer

The hybrid spectrometer processes the IF's from all 8 beams into 192 channels per IF. There are four possible bandwidths which one can choose, which will yield channel spacings of between 195.3 and 1562.5 kHz. Table 2.2 summarizes the available hyspec modes.

8-Beam Hyspec Configurations		
Bandwidth (MHz)	Channel Spacing (kHz)	Velocity Resolution (km s^{-1}) at ν = 230 GHz
37.5	195.3	0.25
75.0	390.2	0.51
150.0	781.2	1.02
300.0	1562.5	2.04

3 Angle Conventions

There are three rotation angles associated with the 8-Beam receiver: the *parallactic angle*, the *rotator control angle*, and the *user position angle*. These angles are defined as follows:

Parallactic Angle: The parallactic angle is defined as the angle between lines of constant azimuth and hour angle. Thus, it is a function of the azimuth, elevation, hour angle, and declination of the source. The convention employed at the 12m is as follows:

When a source is on the Prime Meridian (0 Hour Angle) in the south, Parallactic Angle is defined to be 0°. While the source is above the horizon *in the south*, Parallactic Angle always *increases* with time. When the source is on the Prime Meridian (upper culmination) *in the north*, Parallactic Angle is defined to be 180°. In the north, Parallactic Angle *decreases* with time.

Rotator Control Angle: This angle describes the rotation of the 8-Beam rotator drive relative to its position encoders. The convention is stated as follows:

When the telescope is pointing due south (180° azimuth) and the long dimension of the array is aligned along the Prime Meridian (up and down in the elevation direction), with beams 4 and 5 at high elevation (and high declination), the array has a rotator control angle of 0°. If the rotator is turned so that beams 4 and 5 move toward larger azimuth, the rotator control angle *increases*.

User Position Angle: The user-defined position angle is available to allow the user to position the rectangular array of beams in the RA/DEC frame to achieve optimal mapping efficiency according to the geometry of the source. The most common example of this would be to position the long dimension of the array of beams along the major axis of a galaxy. The convention for defining User Position Angle is as follows:

The user-defined position angle follows the usual astronomical position angle convention. Position angle *increases* toward the east (increasing Right Ascension). Note that this convention is independent of whether the source is north or south of the zenith.

4 Pointing and Focus Measurements

Pointing and focus measurements are done in essentially the same way as pointing and focus measurements are done with the single-beam frontends. The general procedure for making these measurements is as follows:

1. Make sure that the operator has set the 8-Beam rotator to *not track parallactic angle* and to zero position offset (so that the array will be positioned in an az-el frame).
2. Have the operator enter some rough pointing offsets for the center of the array.
3. Select a beam with which to do your pointing and focus measurements. Try to choose a beam with good stability and low system temperature.
4. Do a continuum 5-point measurement.
5. If you like, choose another beam and do a 5-point measurement. You should get the same center-array pointing offsets no matter which beam you point with. If you get

different pointing offsets, then the array is not in the az-el frame (i.e. the rotator angle has not been set to 0 degrees).

6. Derive the focus position (focalize) on the last beam you point on.

5 8-Beam Observing Modes

There are three basic 8-Beam observing modes, which I will call "point-and-shoot", "conventional otf", and "optimal otf". The point-and-shoot mode is just a simple position switch measurement mode, while the otf modes have many similarities to the otf modes available with the single-beam receivers. OTF 8-Beam map setup is done with the same setup screen as for the single-beam receivers (Figure 2). Details on the parameters associated with conventional OTF measurements are given in "On The Fly Observing at the 12m". The Optimal 8-Beam-specific OTF parameters on this setup screen are:

8-Beam Rows Per Footprint: This is the number of scan rows necessary to fill-in a "footprint" (defined as N_{small} in §5.3, Equation 2).

8-Beam Footprints: This is the number of "footprints" necessary to cover the map field (defined as N_{foot} in §5.3, Equation 5).

8-Beam Rotator Angle: This is the array tilt angle necessary to make each beam sample a different portion of sky while at the same time obtain full sampling (defined as θ_t in §5.3, Equation 1).

8-Beam Row Spacing: This is the distance the array must step between rows (defined as θ_{small} in §5.3, Equation 3).

8-Beam Starting Footprint: The first footprint to measure in your input map field. This parameter is only changed from its default value of 1 if you are going to measure a sub-map of your input field.

8-Beam Ending Footprint: The last footprint to measure in your input map field. This parameter is only changed from its default value if you are going to measure a sub-map of your input field.

All of these parameters are set by the control program and under almost all circumstances should be left at these pre-set values.

In the following subsections I describe each of the 8-Beam observing techniques.

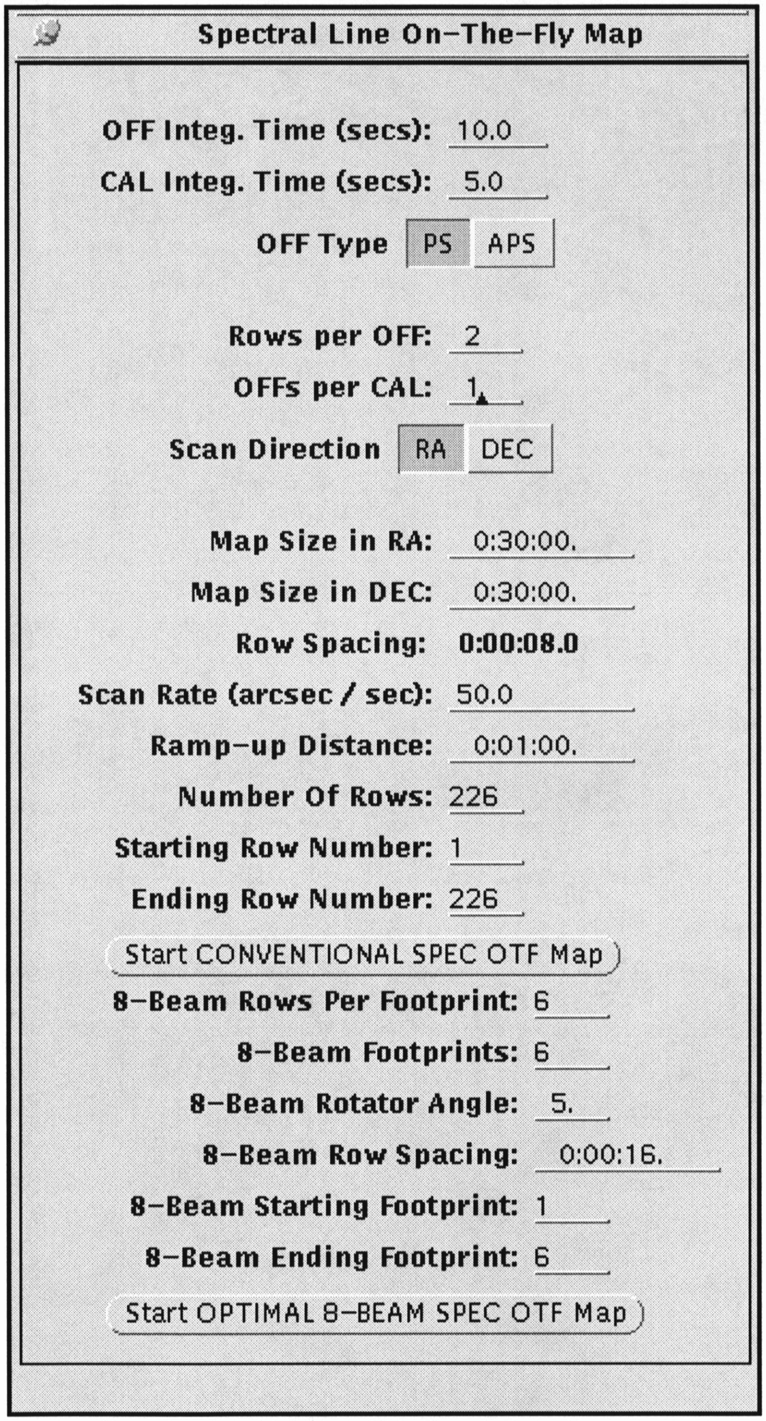

Figure 2: Spectral line OTF observing setup screen

5.1 Point-and-Shoot

In point-and-shoot observing with the 8-Beam receiver, one makes simple position switched measurements. The array will track parallactic angle and can be positioned at a non-zero angle relative to the parallactic angle. Each of the 8 spectra produced from each 8-Beam measurement is tagged with its absolute position on the sky based on its beam offset relative to the center of the array. Analysis of this kind of 8-Beam measurement is done within UniPOPS or CLASS.

5.2 Conventional OTF

In conventional OTF observing with the 8-Beam receiver, one uses the standard OTF observing technique to map a region of sky. In this mode, there is no attempt made to make the array sample the desired region efficiently, and what one gets is a map which takes much longer to complete but results in a high signal-to-noise. The high signal-to-noise aspect results from the fact that, except for an approximately 291″ (3 × 87″) region along the top and bottom and an approximately 87″ region along the left and right sides of your map, each point on your map will be sampled 8 times. Therefore, with the exception of your map border, the map rms will be equivalent to that produced by eight single-beam, single-polarization receiver coverages. The standard AIPS OTF analysis procedures are used to process data acquired with this technique (see "On The Fly Observing at the 12m").

5.3 Optimal OTF

In the optimal OTF observing mode, the array is positioned and scanned over the map region so that all points in the map are fully sampled. A pictorial description of the array geometry in this mode is shown in Figures 1 and 3, where the following quantities are shown:

$\theta_{bs} \equiv$ Adjacent beam separation (87″).

$\theta_{row} \equiv$ Row sampling rate.

$\theta_t \equiv$ Array tilt angle necessary to achieve full sampling.

$\theta_x \equiv$ Horizontal map size.

$\theta_y \equiv$ Vertical map size.

$\theta_{ramp} \equiv$ Ramp-up distance.

$\theta_{small} \equiv$ Step size for row sampling.

$\theta_{foot} \equiv$ Array "footprint" size.

The quantities θ_x, θ_y, θ_{row}, and θ_{ramp} are defined in "On The Fly Observing at the 12m". θ_t is the amount by which the array is tilted to allow two beams along the same scan line to fully sample a given "swath" of sky:

$$\theta_t = \sin^{-1}\left(\frac{\theta_{row}}{\theta_{bs}}\right) \tag{1}$$

The number of passes of the array over the field necessary to fill-in an array "footprint" is given by

$$N_{small} = INT\left(\frac{\theta_{bs}}{2\theta_{row}}\right) + 1 \tag{2}$$

where θ_{row} is defined in the same way as for regular OTF observing (see "On The Fly Observing at the 12m") and the step size is given by

$$\begin{aligned} \theta_{small} &= \frac{\theta_{bs}}{N_{small}} \\ &= \frac{\theta_{bs}}{INT\left(\frac{\theta_{bs}}{2\theta_{row}}\right) + 1} \end{aligned} \tag{3}$$

After the array "footprint" has been fully sampled (after the spaces between the array elements have been fully sampled), the array is stepped up by

$$\begin{aligned} \theta_{foot} &= 4 \times \theta_{bs} \\ &= 348'' \end{aligned} \tag{4}$$

and a second footprint is fully sampled. This cycle of footprint sampling followed by a 4-spacing step is repeated until the requested map field is fully sampled. This will require

$$N_{foot} = INT\left(\frac{\theta_y}{\theta_{foot}}\right) + 1 \tag{5}$$

The RMS noise per cell in an 8-Beam OTF map can be calculated using the same expression used to calculate the RMS noise per cell for a conventional single-beam OTF map

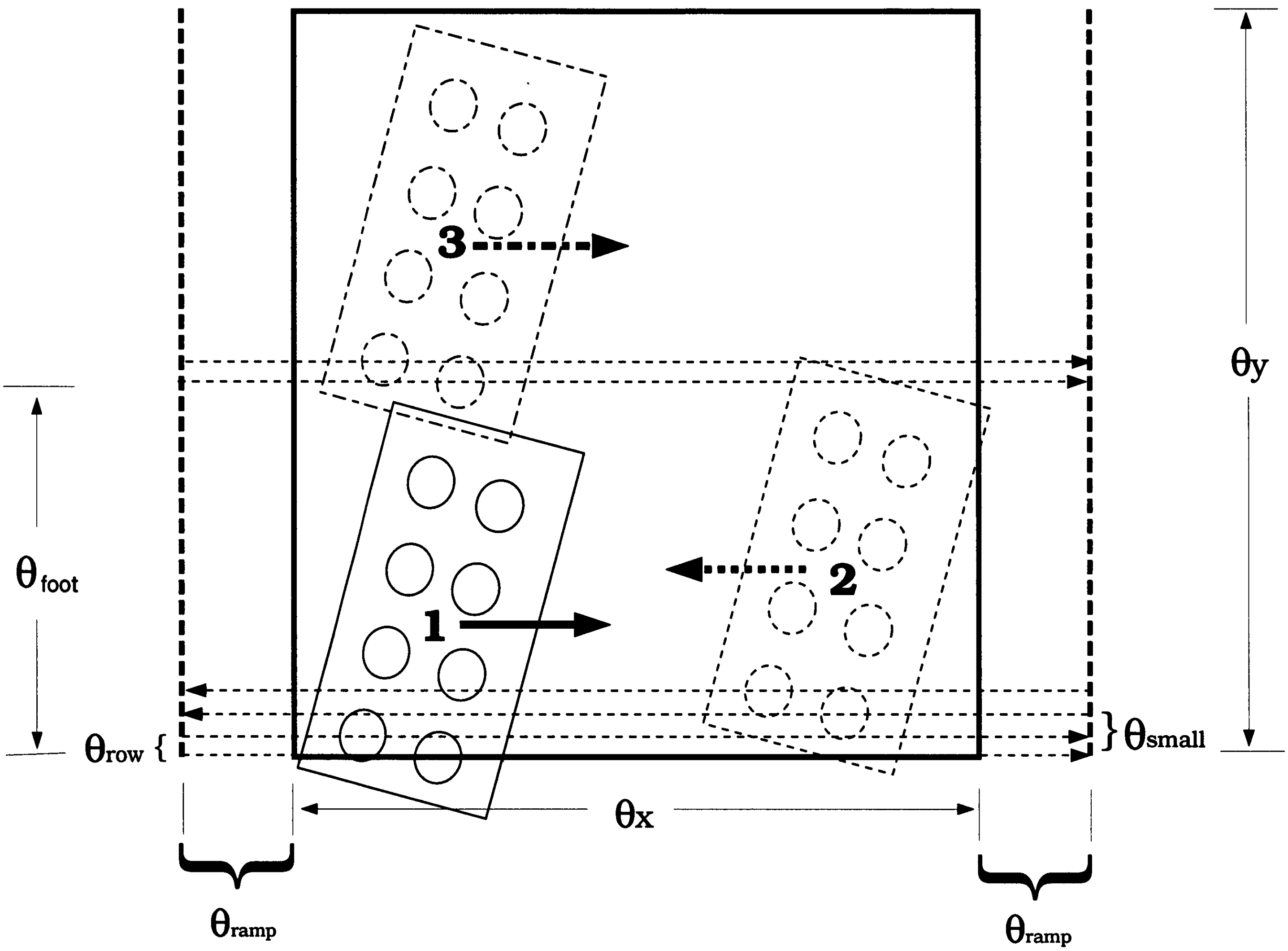

Figure 3: Optimal 8-Beam mapping definitions. Three array locations on the map field are shown. Number 1 indicates the starting configuration of the array as it begins a mapping pass across the bottom of the map field. In number 2, the array has reached the end of the first pass and has turned-around to start the second pass after having stepped-up by θ_{small}. Array location number 3 shows the array after the first footprint has been filled-in and the array has been stepped-up by θ_{foot}. The other parameters in this diagram are defined in §5.3.

$$\sigma_{cell} = \frac{T^*_{sys}}{\theta_N}\left(\frac{R\theta_{row}}{2.9135\Delta\nu}\right)^{\frac{1}{2}} \tag{6}$$

See "On The Fly Observing at the 12m" for more information.

The total time required to acquire a map is given by

$$t_{tot} = N_{small}N_{foot}\left[t_{row} + \frac{t_{off}}{N_{ppo}} + \frac{t_{cal}}{N_{ppo}N_{opc}} + \frac{\epsilon}{N_{ppo}}\right] \tag{7}$$

where N_{small} is the number of passes of the array over the map field necessary to fill-in an array footprint, N_{foot} is the number of footprints in the map, t_{row} is the time necessary to acquire one pass of data (see "On The Fly Observing at the 12m" for further information), t_{off} is the OFF integration time, t_{cal} is the calibration integration time (VANE plus SKY sample times), N_{ppo} is the number of passes per OFF measurement you do, N_{opc} is the number of OFF measurements per calibration measurement you make, and ϵ is the "overhead" time, which is the time that the telescope spends doing things other than integrating (like moving from OFF positions to the map field). The value of ϵ depends mainly on how far away the OFF position is from the map, but 10 seconds is probably a good average estimate. The CAL is taken at the same position and just before the OFF, and so doesn't involve additional overhead. There may be other small overhead losses in moving from row to row and starting scans, but these losses can usually be neglected.

Given equal system temperatures, your map rms will be equivalent to that produced by one single-beam, single-polarization receiver coverage. As with the conventional otf map, optimal otf maps acquired with the 8-Beam receiver are analyzed using the AIPS OTF analysis procedures (see "On The Fly Observing at the 12m"). I have written a program called *MAPCALC* which will calculate your 8-Beam OTF map RMS given your input map parameters. This program is available on any of the 12m telescope computers and is also available by request from Jeff Mangum.

6 Analysis of 8-Beam OTF Measurements

Since unprocessed 8-Beam otf measurements are of the same format as single-beam otf measurements, they are processed with the same AIPS tasks. For the basic analysis of 8-Beam OTF data, one can use the AIPS procedures *otfset* and *otfrun*. To load these procedures, execute the following command within AIPS:

```
> run otfproc
```

Note that you need to load the *otfproc* procedures once. To set many of the static parameters necessary for processing 8-Beam OTF data, run the *otfset* procedure:

```
> otfset
```

After *otfset*, one can process an 8-Beam OTF map with *otfrun*:

```
> otfrun
```

Both of these procedures ask a series of questions which allow you to process your data in a number of different ways. For a more detailed description of these procedures and how to use them, see "On The Fly Observing at the 12m".