Polarization Specs for Band 7 Quarter Wave Plates

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1 General Science Requirements for Polarization

From ALMA-09.00.00.00-001-A-SPE; 2005-05-26:

- It shall be possible to measure all polarization cross products simultaneously.
- For an unpolarized source, the percent error in polarized flux should be less than 0.1% of the total intensity after calibration.
- It shall be possible to measure the position angle to within 6 degrees.
- The differential gain stability between the two polarization channels must be better than 10^{-3} in 5 minutes (typical timescale between polarization calibration observations).
- ALMA shall maximize sensitivity over its frequency bands.
- Meeting the polarization requirements is particularly important for band 7 and could require a quarter-wave plate.

2 Current Band 7 Front-End Quarter-wave Plate Specs

4.3.4 Quarter-Wave-Plate [FEND-40.00.00.00-00280-00 / T]:

A quarter wave plate that can be inserted into the beam of band 7 shall be provided. The center frequency of the quarter wave plate shall be 345 GHz. The combined absorptive and reflective losses shall be less than 0.5 dB. The induced cross-polar component shall be less than 10%. These specifications shall apply over the frequency range from 340 to 350 GHz.

3 Background Assumptions and Science

- The quarter wave plate will be most important for linear polarization observations. There are two types of linear polarization observations that will be interesting for ALMA: continuum and spectral line.
- The band 7 (345 GHz) receivers have 4 GHz wide sidebands with centers separated by 12 GHz. The current spec does not provide sensitivity over both sidebands.
- A combined absorptive and reflective loss of 0.5 dB is equivalent to a 12% loss. This is equivalent to a loss of 6 antennas (assuming 50 antenna array) and violates the ALMA "sensitivity goal" that 95% of antennas shall be operational at any given time.
- In addition to loss in signal, absorptive and reflective losses can cause significant changes in the apparent Tsys that are difficult to predict (but could be measured). For example, for an ambient cabin temperature of 300 K, a 12% absorptive loss could mean a Tsys increase of as much as 36 K (compared to the expected 100 K receiver Tsys)!
- A graduate student at Harvard (D. Marrone) created quarter wave plates (single quartz plates) for the Submillimeter Array that have less than ±3% cross-polar leakage over 14 GHz bandwidth (SMA memo #156; http://sma-www.cfa.harvard.edu/private/memos). Also, there are a several new studies available that suggest very wide bandwidth multi-element wave-plates are possible:

http://www.atnf.csiro.au/observers/memos/AT39.3_106.pdf
http://www.cv.nrao.edu/∼cbrogan/quarter-wave_Terahert_Masson.pdf
From these results it is clear that wider bandwidth (than the current 10 GHz spec) quarter-wave plates are feasible.

- The most important spectral line known to have detectable linear spectral polarization is ^{12}CO. However, spectral line polarization is maximized for transitions with optical depth $\tau = 1$ (Deguchi & Watson 1984, ApJ, 285, 126). It is therefore likely that for deeply embedded regions isotopomers of CO will need to be observed. In order of decreasing abundance the frequencies are: ^{12}CO(3-2) 345.795 GHz; ^{13}CO(3-2) 330.588 GHz; C^{18}O(3-2) 329.331 GHz; C^{17}O(3-2) 337.061 GHz. Thus, we need quarter-wave plates that are sensitive from 329 GHz to 346 GHz from a line polarization perspective. See Figure 1 for a useful spectral line pol. setup example.

- Within the CO isotopomer wavelength range are a number of other diatomic molecules which have strong emission that could also be used to observe line linear polarization such as CN ($\sim$ 340.2 GHz) and SO (340.7 and 344.3 GHz). CN is of particular interest given its hyperfine structure (ability to measure optical depth) and the fact that it also has a strong Zeeman coefficient. Measurement of both effects using the same molecule would prove an extremely powerful probe of the magnetic field in star forming regions – removing many of the ambiguities involved with comparing dust and Zeeman magnetic field measurements.

- In addition to the need to be sensitive to the wavelength range between C^{18}O and ^{12}CO for spectral linear polarization, sensitive continuum linear polarization measurements over both sidebands are also required, i.e. the wave length range that should be spec'ed is 16 GHz at the very minimum. In order to take advantage of the region of the band with the best transmission, while straddling the strong Ozone lines near $\sim$ 332.8 and $\sim$ 343.2 GHz, one would like to be able to setup a continuum polarization observation from 335 to 339 GHz (LSB) and 347 to 351 GHz (USB). See Figure 1 for an example.

4 Proposed Specs

In order to be in compliance with the scientific requirements for ALMA, the Quarter Wave Plate specification should be:

4.3.4 Quarter-Wave-Plate [FEND-40.00.00.00-00280-00 / T] A quarter wave plate that can be inserted into the beam of band 7 shall be provided. The centre frequency of the quarter wave plate shall be 340 GHz. The combined absorptive and reflective losses shall be less than 0.25 dB. The induced cross-polar component shall be less than 3%. These specifications shall apply over the frequency range from 329 to 351 GHz.

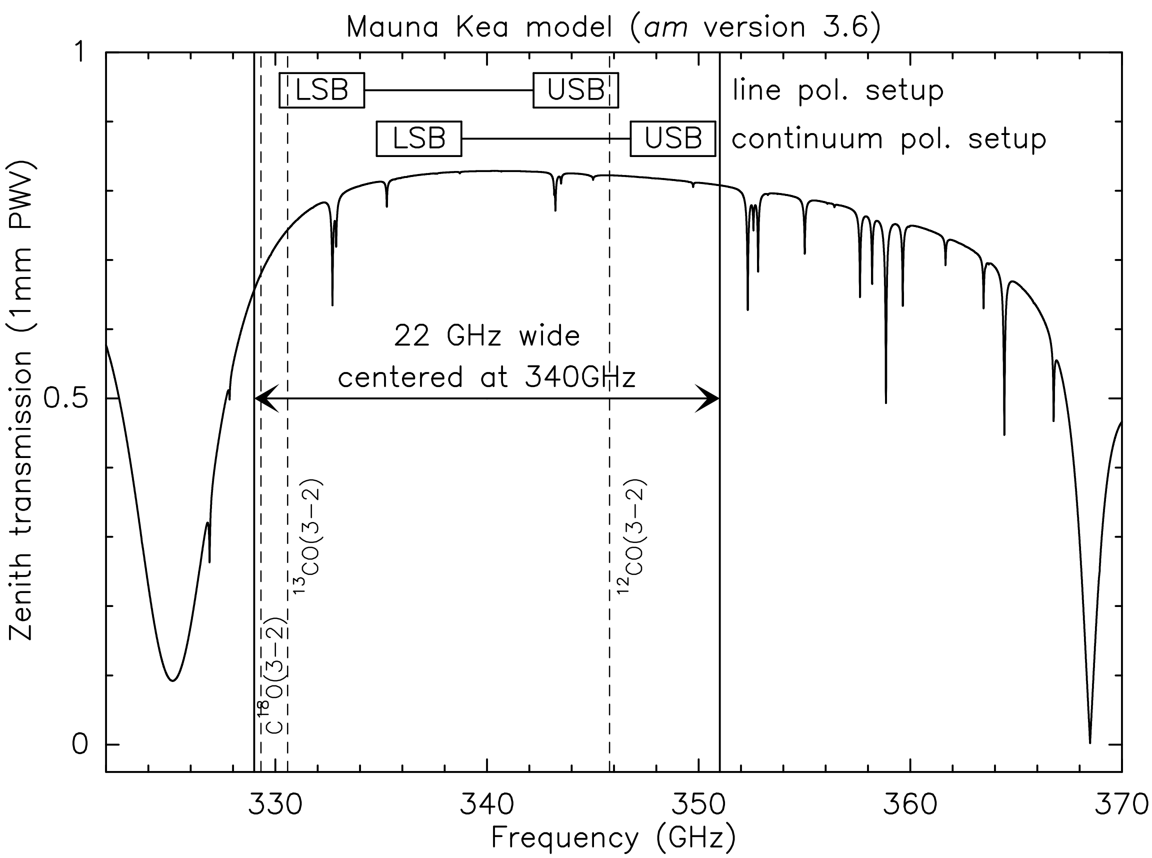

Figure 1: AM transmission model for Mauna Kea showing the relevant CO spectral lines, and a continuum setup that would provide maximum sensitivity. The proposed 22 GHz wide quarter wave plate centered at 340 GHz spec is also shown.