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The Band 3 Receiver Cartridges for ALMA

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Summary

HIA is developing the Band 3 receiver cartridges for ALMA. Band 3 will be used for commissioning, calibration, and science. The pre-production phase of this development is now well-advanced, and the first cartridges have been assembled and tested. Performance specifications have been met, and the first cartridge delivery to ALMA is imminent. The performance of the first deliverable cartridge is presented and the role of Band 3 in the ALMA system is described.

The Atacama Large Millimeter Array

The Atacama Large Millimeter Array is currently under construction in northern Chile. The array will initially consist of 50 (and ultimately 64) 12-metre diameter radio telescopes in an aperture synthesis array. Each antenna in ALMA is designed to accommodate receivers for 10 frequency bands which together are planned to cover the 30-950 GHz atmospheric windows. ALMA will combine unprecedented angular resolution, sensitivity, and frequency coverage, and will lead to profoundly new insights on astrophysical phenomena spanning the time and distance scales from our solar system's frozen outer limits to the formation of the first galaxies. ALMA will be joined by the Atacama Compact Array (ACA, consisting of 12 7-metre and 4 12-metre antennas) currently under development by Japan. Japan will also provide receivers for additional bands to ALMA. The ALMA-ACA combination will result in further enhancement of the sensitivity and imaging capabilities of the observatory.

Band 3

Development and delivery of the Band 3 (84-116 GHz) receivers is the central component of the Canadian contribution to ALMA construction. Since 2002, a team at HIA Victoria has been developing the technology and designing the hardware. A working prototype cartridge was assembled and tested in 2005, and recently the first deliverable cartridge has been built and tested. This first deliverable cartridge satisfies the exceptionally stringent performance specifications set by the ALMA project. A feature of the design is its two sideband operation in each polarization: each of the two 2SB mixer assemblies incorporate RF and IF quadrature hybrids that separate and output the upper and lower sidebands in 4 GHz wide IF outputs. Each cartridge thus requires 4 SIS mixers and 4 cryogenic low-noise IF amplifiers.

Band 3 Specifications

RF Range	84-116 GHz
LO Range	92-108 GHz
IF Bandwidth	8 GHz per polarization
Polarizations	2, orthogonal linear
Noise Temperature	≤ 37 K (SSB) in 80% of RF range ≤ 62 K (SSB) in 100% of RF range
Image Rejection	≥ 10 dB
Gain Compression	< 5% (77 K/300 K load)
Amplitude Stability	Allan variance < 4 E-7 (0.1-1 s) Allan variance < 8 E-5 (100 s)
Phase Stability	< 0.5° up to 300 s
Polarization Purity	≥ 20 dB

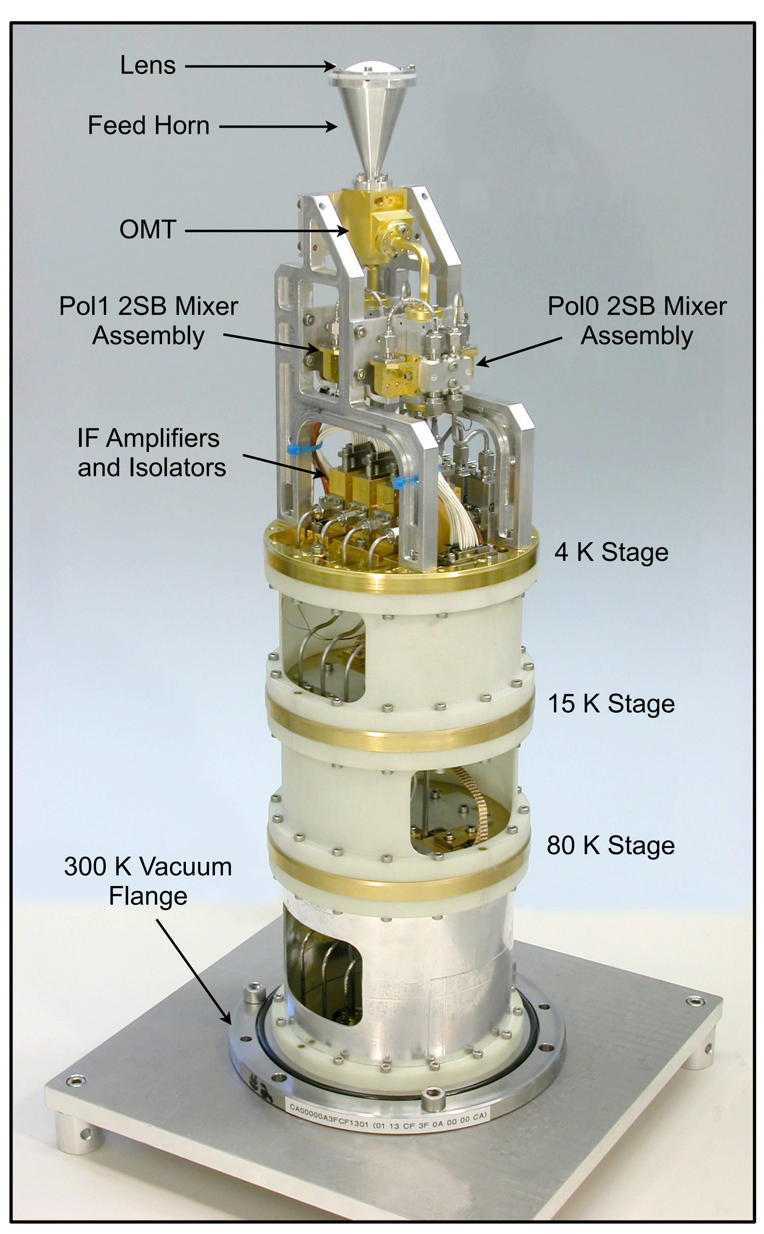


Figure 1. The first deliverable Band 3 cartridge. Actual height 50.85 cm. The cartridge will be mounted in the front end cryostat. External optics guide the signal from the telescope into the front of the cryostat and to the cartridge lens and feed horn. The orthomode transducer (OMT) splits the signal into orthogonal linear polarizations (Pol0, Pol1) which are carried by waveguides to the mixers. The 300 K vacuum flange mounts at the rear of the cryostat.

Cartridge Performance

The first deliverable cartridge has been extensively tested at HIA Victoria using test equipment and procedures developed by the Band 3 Team. In the following figures, we present test data for several of the more critical performance specifications. In addition to these, the cartridge gain compression and phase stability have been measured recently and provisionally meet specifications.

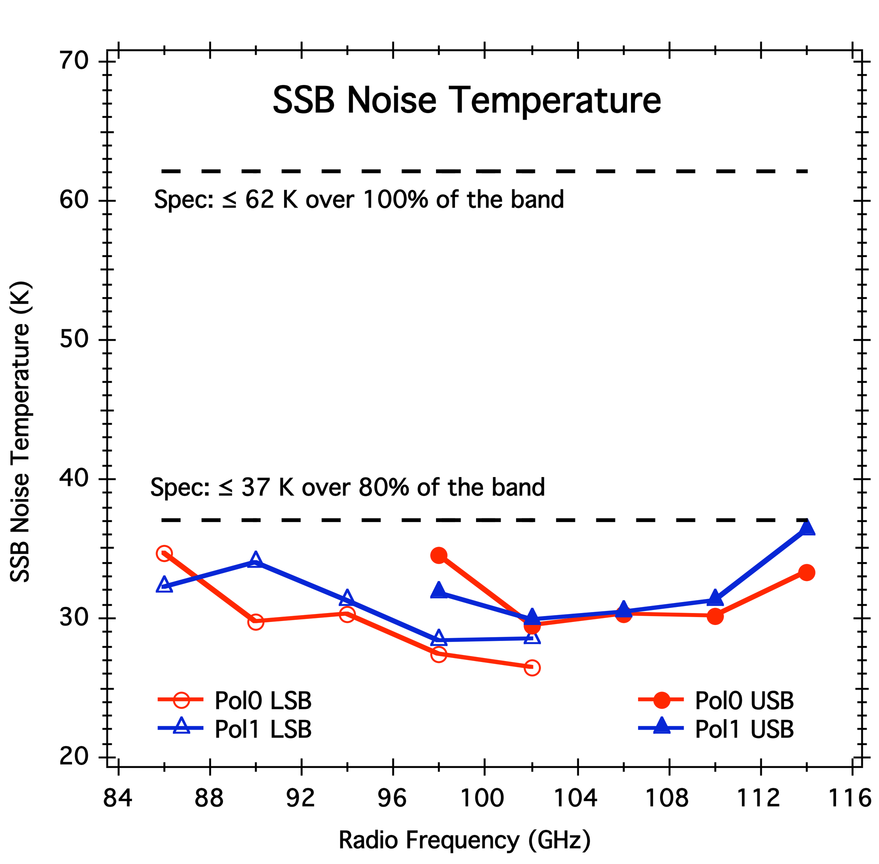


Figure 2. The SSB noise temperature defines the cartridge sensitivity. The specification requires a noise temperature of 37 K or less across 80% of the Band 3 RF range and simultaneously 62 K or less across the entire RF range. A max/min of 36.3 K/26.4 K is measured, with an average of 31.0 K, across the entire band.

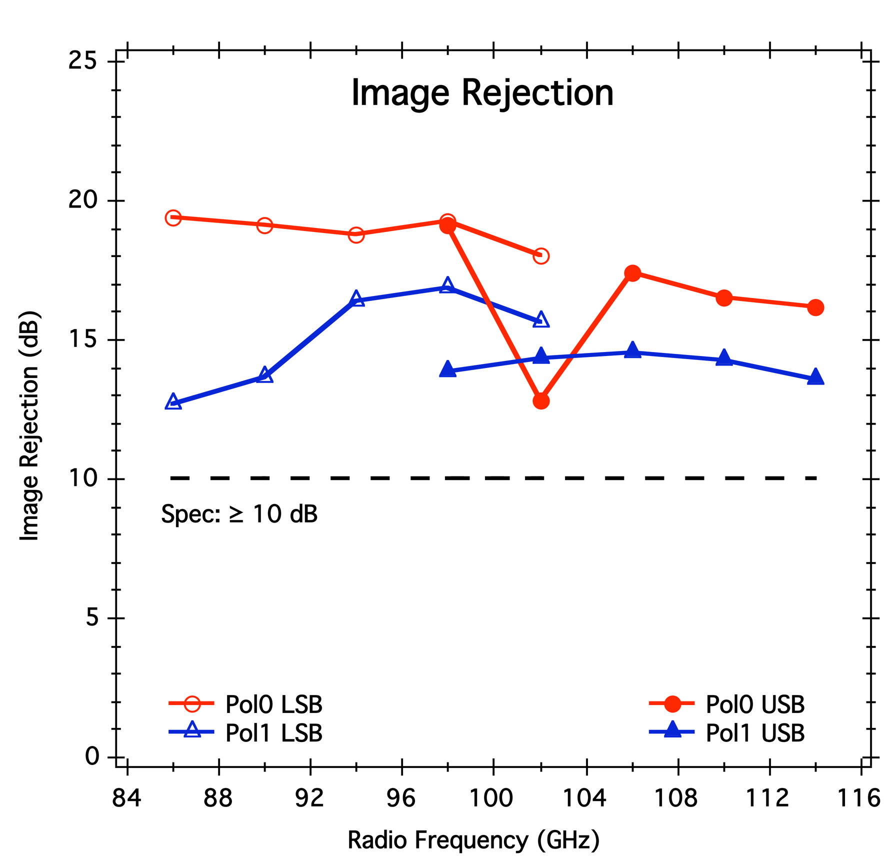


Figure 3. The image rejection measures the extent to which power in one sideband is free of contamination by power in the other sideband. The image rejection specification of ≥ 10 dB (≥ a factor of 10) is met: typical image rejections are about 16 dB (a factor of ~ 40).

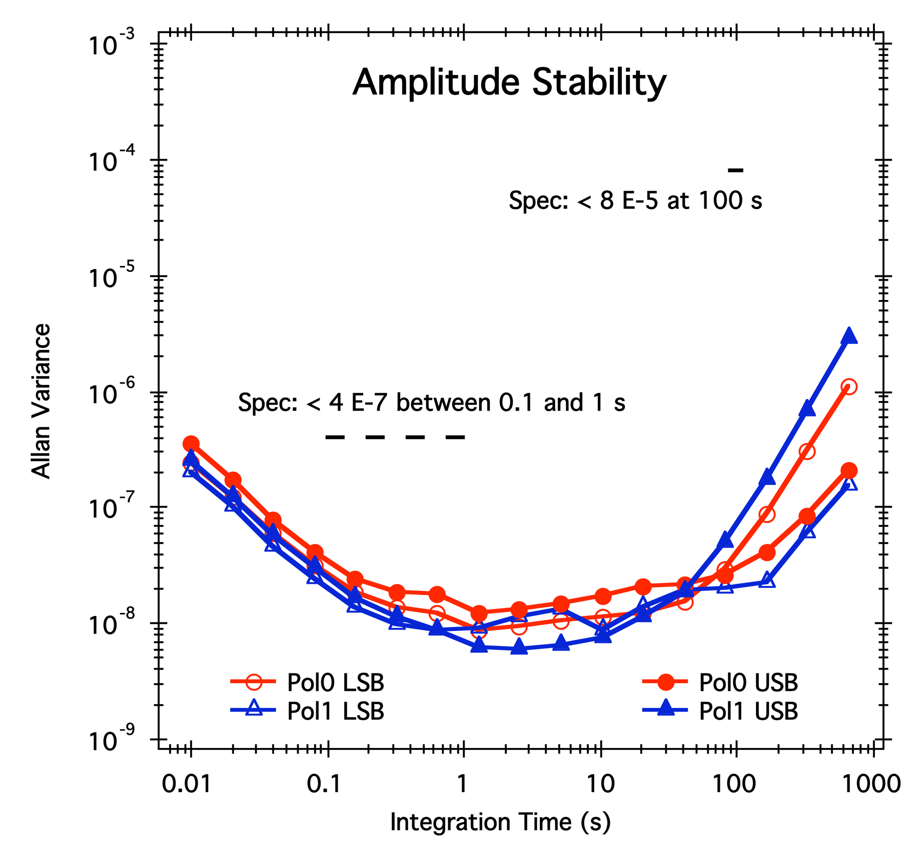


Figure 4. The Allan variance of the output power measures the amplitude stability of the cartridge as a function of integration time. The cartridge handily meets the specification for both short and long integrations. The lowest Allan variance occurs at an integration time around 3 s.

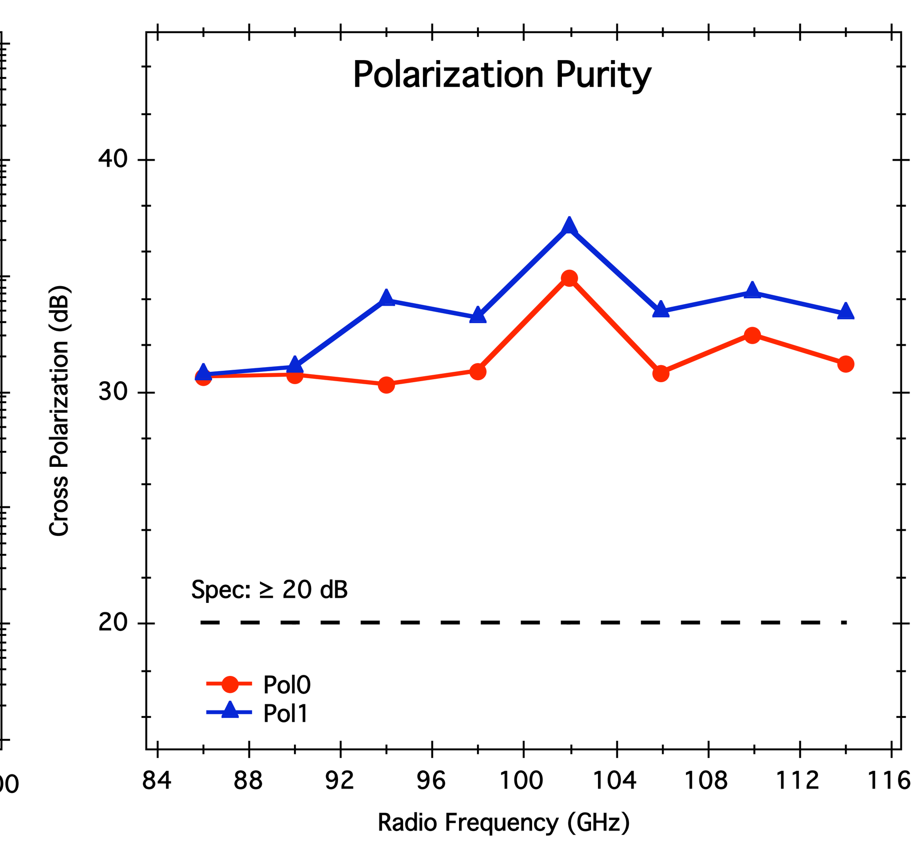


Figure 5. The cross polarization measures the polarization purity of the cartridge. The ALMA specification is ≥ 20 dB (≤ 1% cross-polar contamination). The cartridge achieves typically 32 dB.

The Role of Band 3

Band 3 is of crucial importance to ALMA. It plays a role in array commissioning and will be used during science operations to perform interferometric calibration of observations taken at both Band 3 and higher frequencies. Since the Band 3 cartridges must be "always on" and immediately available for use, they must be robust and reliable.

Antenna Commissioning: Antennas undergo on-sky tests to characterize and verify performance. As these are total power tests, it is desirable that they be performed at low frequencies to minimize the effects of atmospheric variations. Band 3 is the lowest frequency of the bands to be initially delivered, and will be used to, e.g., measure antenna primary beam patterns, determine antenna gain, and gain variation with antenna elevation. Holographic measurements using Band 3 will be used to refine the setting of the antenna panels to achieve the required 25 μm surface accuracy.

Pointing Calibration: Antenna pointing models will need to be determined during commissioning and periodically thereafter during operations. Observations of ~ 100 point sources across the sky will be required, and it is important that these observations can be done with a modest investment (~ 1 hour) of telescope time. The majority of available pointing sources (AGN/quasars) are brightest at lower frequencies, e.g. Band 3, where the antennas have higher sensitivity. Offset pointing corrections must be done periodically during science observations (~ 0.5 hour), and are particularly important during high frequency observations. Again, Band 3 can quickly obtain these measurements.

Baseline Calibration: Accurate baseline determinations will be necessary following movement of an antenna to a new pad location in the array. This can be achieved by interferometric delay measurements of bright point sources with Band 3.

Phase Calibration: During science operations, frequent phase calibration will be necessary, and will be achieved by fast switching to bright reference sources located optimally within 1° of the target source. Given the number density of bright point sources on the sky, phase calibration will often have to be done at Band 3 and transferred to the frequency of the target observation.

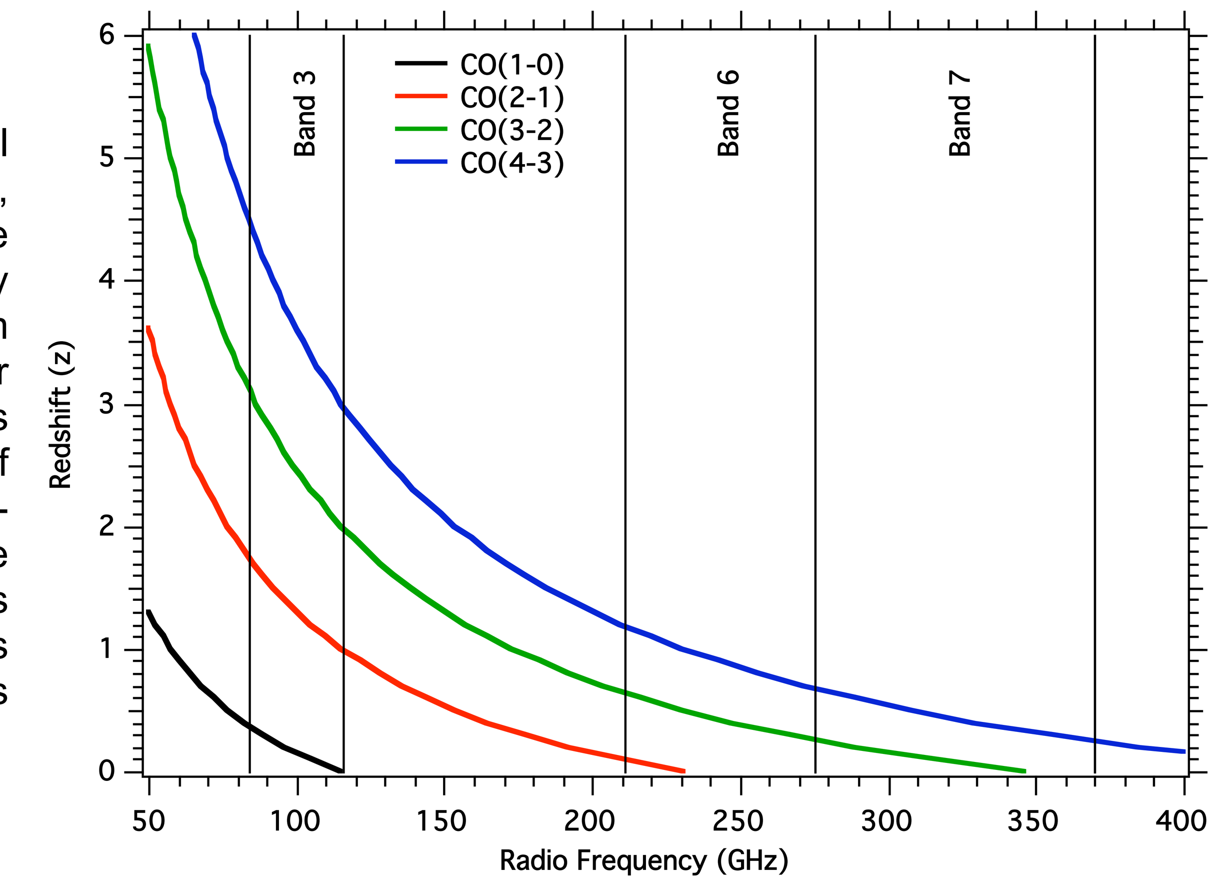
Science with Band 3

Band 3 covers the 100 GHz window of traditional millimetre astronomy, and lines of important molecules such as CO, CS, HCN, and HCO+ will be observable at resolutions as high as ~ 0.03″ for the first time. Some Band 3 science themes can be extracted from the ALMA Design Reference Science Plan.

Galactic: Small scale structure in molecular clouds (characterizing the threshold for self-similar hierarchy in GMCs and searching for the scale on which turbulent or magnetic energy is dissipated). Infall velocity structure of starless cores (understanding the process of collapse) and molecular depletion (searching for evidence of freeze-out or chemistry). Unbiased line surveys (searching for new and exotic molecules, including complex organics). Absorption line studies toward background bright point sources (detecting diffuse and translucent clouds). Molecular gas in disks around young stars.

Extragalactic: Unbiased surveys of submillimetre galaxies (~ 50% of star formation in the cosmos occurs in galaxies highly obscured by dust, and this fraction may rise with redshift). Dust continuum observations (galaxy SEDs). Molecular line studies of submillimetre galaxies (dust-obscured galaxy formation). High resolution imaging of CO in nearby galaxies and the search for dense gas tracers (e.g. HCN). Molecular line absorption studies using background radio galaxies to probe the cold ISM in intervening systems.

Figure 6. Of the four initial bands of ALMA (Bands 3, 6, 7, and 9), only Band 3 is capable of observing the low-energy rotational lines of CO from galaxies at redshifts greater than z ~ 1.2. The figure shows the frequency as function of redshift of the four lowest-excitation CO lines. The frequency ranges of the bands are indicated by vertical lines (the Band 9 frequency range is not shown).



The Atacama Large Millimeter Array (ALMA) is an international astronomy facility. ALMA is an equal partnership between Europe and North America, in cooperation with the Republic of Chile, and is funded in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC), and in Europe by the European Southern Observatory (ESO) and Spain. ALMA construction and operations are led on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI), and on behalf of Europe by ESO.

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