ALMA SIS mixer optimization for stable operation

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ABSTRACT

The Atacama Large Millimeter/Submillimeter Array (ALMA), an interferometric radio telescope will have 66 array elements when complete. The ALMA Front End is designed to accommodate up to 10 receiver bands covering most of the wavelength range from 10 to 0.3 mm. Superconductor-insulator-superconductor (SIS) mixers are employed for Bands 3 (~3 mm) through 10 (~0.3 mm). Ordinarily the SIS bias is selected to achieve the lowest receiver noise temperatures. However, in order to obtain the lowest detection threshold, the SIS bias also needs to be optimized with respect to receiver stability. There are also other parameters to be optimized such as the magnetic field strength used to suppress the Josephson currents and avoidance of Shapiro. This paper will summarize the results of work carried out to derive the optimal operating parameters for the large number of mixers in use on the telescope so as to keep the telescope operating reliably and repeatably.

Keywords: ALMA, SIS mixer, Millimeter-wave, Sub-millimeter-wave, Stability

1. INTRODUCTION

The Atacama Large Millimeter/submillimeter Array (ALMA) is a joint project between astronomical organizations in Europe, North America, and East Asia, in collaboration with the Republic of Chile. ALMA consists of at least 54 twelve-meter antennas and 12 seven-meter antennas operating as an aperture synthesis array in the (sub) millimeter wavelength range. ALMA array operation site (AOS) is located on the Chajnantor plain of the Chilean Andes in the District of San Pedro de Atacama, 5000 meters above sea level [1]. The ALMA receiver system will cover all the available atmospheric frequency windows between 30 GHz and 950 GHz in 10 bands with HEMT or Superconductor-insulator-superconductor (SIS) mixers. The front end (FE) is modular so that one easy-to-install, self-contained receiver covers each frequency band. These self-contained receivers are known as "cartridges". Each band has its own optics to match the wave that arrives at the secondary focus to a corrugated feed horn. The signal is separated into the two polarizations, nominally linear and orthogonal, and delivered in waveguide to the amplifier or SIS mixer.

SIS mixers are employed for Band 3 (~3 mm) through 10 (~0.3 mm). The SIS bands are of two different types: sideband separating (2SB) and double sideband (DSB). The 2SB case supplies two IF outputs simultaneously, carrying opposite sidebands of the LO. The DSB case supplies a single IF output carrying a linear combination (nominally equal) of responses from both sidebands. Bands 3 through 8 use 2SB mixers, and bands 9 and 10 use DSB mixers. In order to utilize fully the signal transmission system and correlator, each polarisation channel delivers 8 GHz of instantaneous bandwidth at IF. Full details of the Front End can be found in [2].

Front Ends are comprised of numerous elements, produced at different locations in Europe, North America and East Asia and are integrated at several Front End integration centers (FEIC) to insure timely delivery of all the units to Chile. The European FEIC is located at Rutherford Appleton Laboratory (RAL); the North American FEIC has been installed at NRAO. A third FEIC has been located in Taiwan.

2. FRONT END TUNING

2.1 ALMA FE tuning algorism

ALMA will have more than 1700 SIS mixers for Band 3 through 10 in 66 antennas at the AOS which need to be remotely tuned. To maximize observation efficiency, FE tunings are performed with look-up tables. Given the first LO frequency, FE tunings are found by looking up the SIS mixer bias conditions in the cartridge configuration database provided by FE Integration center – generally these have been chosen individually to optimize receiver noise temperature. The LO power is adjusted iteratively until the SIS current is as close as possible to the target value. Because the FE look up tables are defined in 4 GHz or 8 GHz steps, corresponding to ALMA receiver IF Band width (4 GHz: 2SB receivers, 8GHz: DSB receivers), linear interpolation is adopted for LO frequencies in between those in the database.

2.2 Magnetic field optimization

Ordinarily the SIS bias is selected to achieve the lowest receiver noise temperatures. In order to obtain the lowest detection threshold, the SIS bias also needs to be optimized with respect to receiver gain stability. A magnetic field (usually provided by an electro-magnet) is necessary for a submillimeter SIS mixer to suppress the noisy Josephson current, which varies with applied field obeying a Bessel function law. Ideally, the magnetic field should be tuned to a Bessel function zero where the total flux across the junction barrier is an integral number of flux quanta. Since a strong magnetic field suppresses the gap voltage as well as the sharp nonlinearity at the gap, the first or second minimum is needed to avoid performance degradation. In ALMA, we usually set the electromagnet currents to the second minimum or higher to provide greater stability and less sensitivity to small changes in the mixer operating point. The main problem when setting of the magnetic field is that the optimum electromagnet current for the SIS device is not always reproducible due to external and statistical effects. Changes in the magnetic environment may change the required current in a non-predictable way. Figure 1 shows that there is a remarkable change of magnet current scans on different days. Wherever feasible it is desirable to optimize the magnetic fields before starting observations [3]. However, it's not realistic in ALMA operation because observation band shall be frequently changed in a dynamic scheduling mode depending on weather and observing requirements. Therefore, a degaussing scheme has been implemented in ALMA software when the FE band is powered up every time. With this procedure, the performance is generally repeatable, but robust and stable operational bias points need to be determined and implement in the ALMA system.

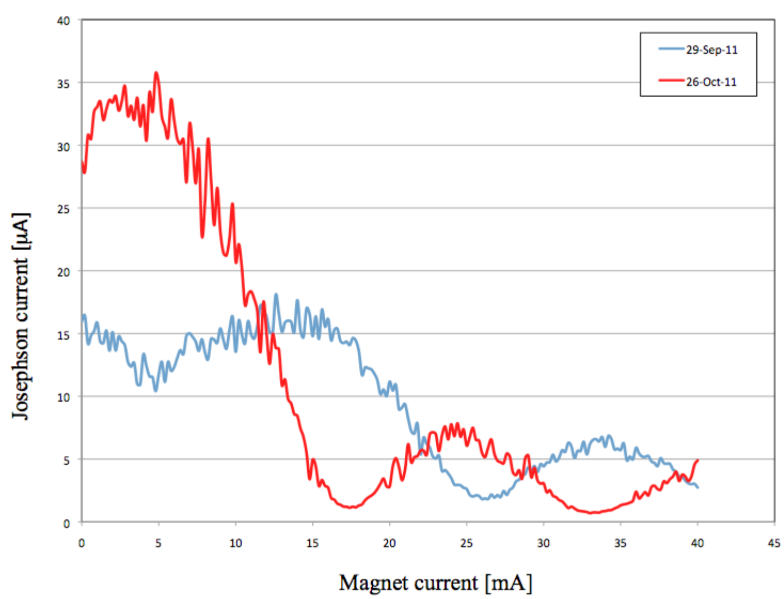

Figure 1. Example of worst case of Band 7 magnetic field scans on different days on antenna. Note that these data were taken before implementing de-flux/de- magnetize procedure.

3. BAND 7 BIAS SETTING FOR STABLE OPERATION

3.1 SIS bias switches between below and above the Shapiro step

An SIS mixer pumped with an LO signal exhibits features known as Shapiro steps at discrete bias voltages S_n (mV) = $n\nu_{lo}/2e = n\nu_{lo}/484$ GHz, where n is an integer, and ν_{lo} is the LO frequency [4]. Biasing near a Shapiro step results in large excess noise in the mixer with subsequent unstable receiver behavior. The Shapiro step voltage is proportional to the frequency and in the case of Band 7 the SIS mixer bias point should be switched between 'below' and 'above' third Shapiro step around LO frequency of 350 GHz. Figure 2 illustrates switching between 'below' and 'above' the third Shapiro step on a Band 7 mixer.

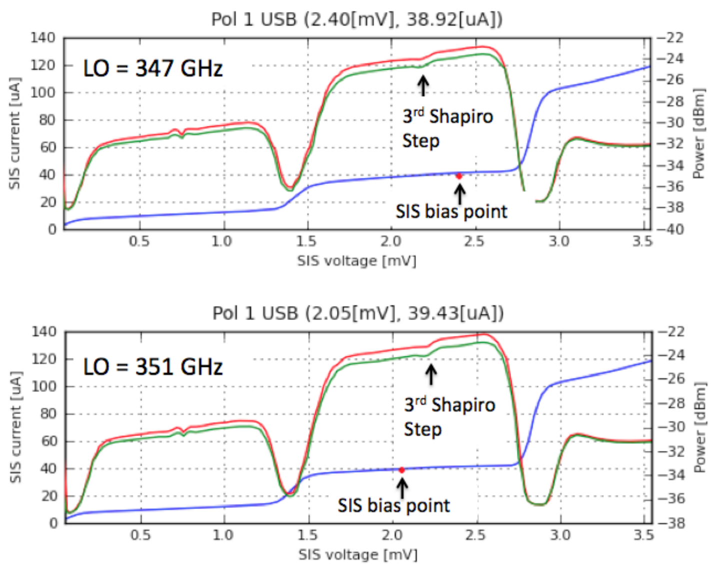

Figure 2. Measured Pumped SIS I-V curves (blue) and two IF-output-powers corresponding to Hot load (~80 C: red) and Ambient load (~15 C: green) signal inputs. Top: LO frequency @ 347 GHz. Bottom: LO frequency is 351 GHz.

It was observed that the Band 7 system temperature of the array showed a jump around ~355 GHz (See Figure 3). This was due to the mixer bias point switching from one side of the Josephson noise peak to the other and this not being correctly implemented in the bias tables provided by the FEIC.

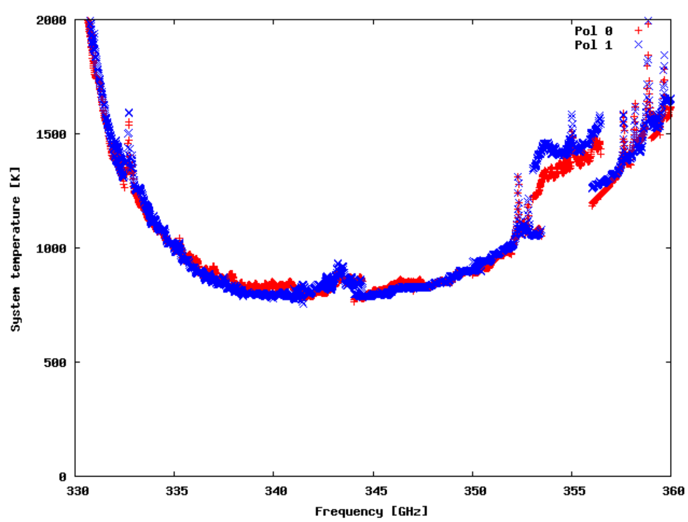

Figure 3. Example of system noise temperature “jump” around 355 GHz.

3.2 Band 7 standard bias settings

For the robust bias points settings, we need to consider not only Shapiro, but also Photon step overlap [5]. The overlap point voltage is calculated $V_{overlap}$ (mV) = $n\nu_{lo}/e - V_{gap}$, where n is an integer, and V_{gap} is the SIS gap Voltage (2.8 mV for a single Niobium SIS junction). Figure 4 shows the measured pumped SIS IV curves and IF output powers with un-optimized mixer tuning. Second and third Shapiro steps and second photon step overlap effects are clearly seen. Therefore, the bias range yielding the good receiver noise and stable operation is a small portion of the photon step between the photon step overlap and the 3rd Shapiro step.

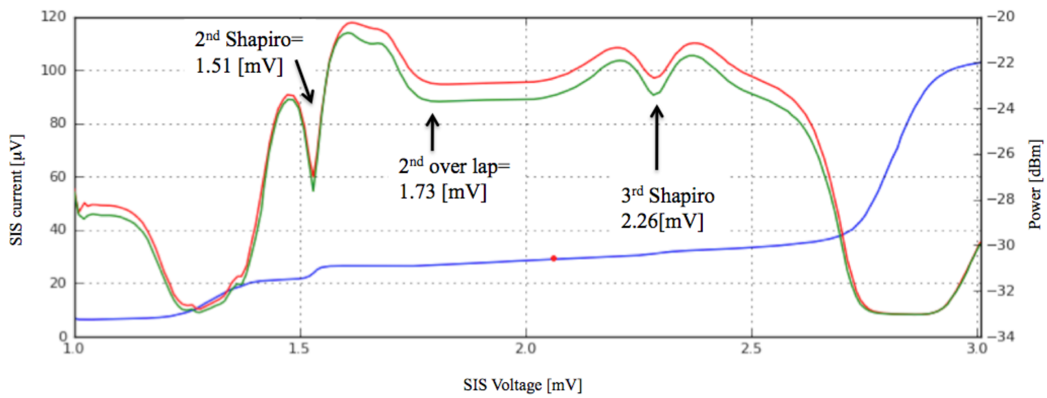

Figure 4. Measured Pumped SIS IV curves (blue) and IF output powers corresponding to Hot (~80 C: red) and Ambient (~15 C: green) loads inputs @ LO = 365 GHz. Note the plot was taken in 'un-optimized" mixer tuning to see Shapiro steps and photon step overlap effects.

Figure 5 shows the "standard bias settings" that have been implemented for ALMA antennas. Bias points are at least 0.2 mV away from Shapiro steps and also avoid Photon step overlaps. Two lines have been implemented in the SIS bias setting table at the frequency where the optimum setting switches from above to below the Shapiro step to avoid interpolation of the SIS bias by software right into the Shapiro region – this is the vertical portion of the curve at 347 GHz.

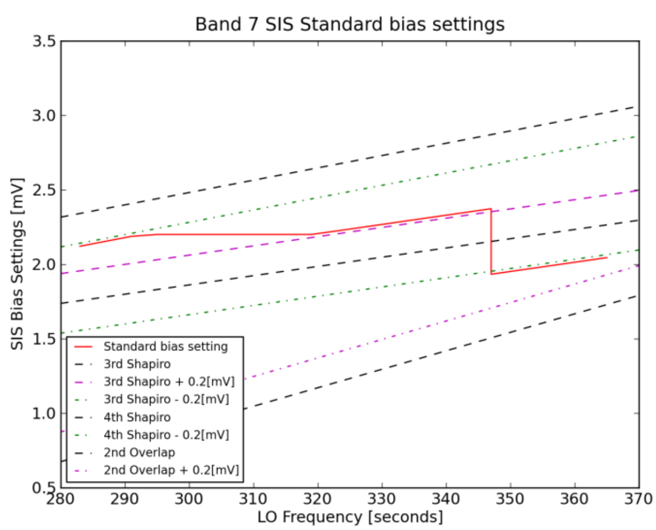

Figure 5. Band 7 Standard SIS bias setting curve that has been implemented. The figure also shows the avoided regions near the third and fourth Shapiro steps and the photon step overlap.

3.3 Receiver noise performance

The overall receiver noise temperatures of 22 array elements in operation at the AOS are plotted in Figure 6. With the new standard SIS bias settings, Band 7 does not show any degradation of receiver noise performance and operation of the large number of mixers in use on the telescope is reliable and repeatable.

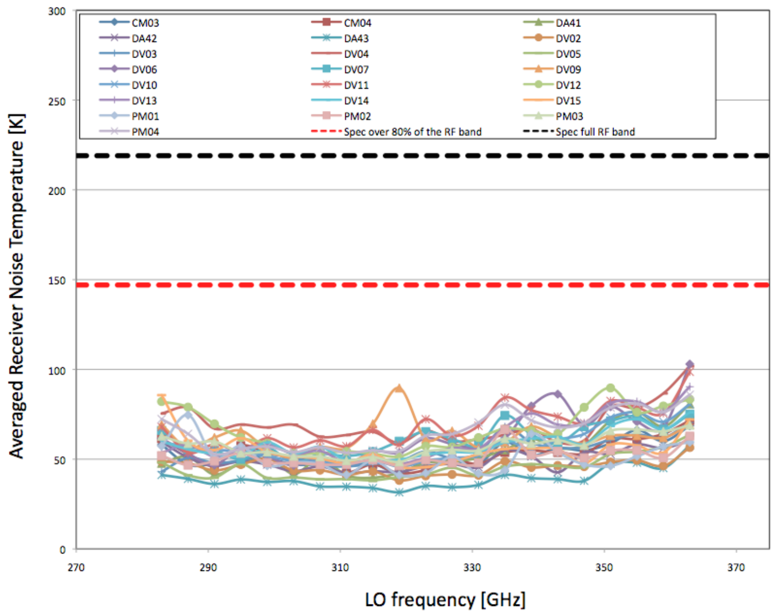

Figure 6. Receiver noise temperature with 4.0–8.0 GHz IF as a function of LO frequency. Four IF outputs corresponding to both polarizations and sidebands (USB/LSB) receiver noise are averaged

4. CONCLUSION

Band 7 SIS mixer configuration files have been updated for all array elements at the AOS. This change implements a major change in the SIS mixer bias as a function of frequency for robust operation by avoiding the noise and instability associated with Shapiro steps. After configuration files updated, Band 7 shows no degradation of receiver noise performances and now the large number of mixers in use on the telescope so as to keep the telescope operating reliably and repeatably. Activities for other bands are ongoing. For example, it appears that re-optimization Band 3 on the telescope will improve up to about 10% in noise from actually optimizing at intermediate frequency points (rather than using the interpolated values from the lookup table). We will keep working on achieving good performances on ALMA FE systems.

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