Solar Observation using ALMA Band 1 Receiver

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Evaluation of solar observation using ALMA Band 1 receiver is presented. Due to the high input power (quiet Sun ~ 9000K and solar flare > 100,000K), system gain must be reduced. For quiet Sun observation, it can be achieved by de-tuning cold LNA biasing. System performance like receiver noise temperature, system stability, and IF output power variation under the new biasing points are measured. No significant impact was found. However, system stability degrades for solar flare mode if only cold LNA is de-tuned. To cover full dynamic range with stable system, de-tuning of the RT amplifier or adding a voltage controlled attenuator have to be employed together with de-tuned cold LNA.

Band 1 System and Gain Compression Bottleneck

The Band 1 system block diagram is shown in Fig. 1. In the current Band 1 receiver system, more than 50 dB gain is required before the mixer to surpress the mixer noise contribution to less than 0.1 K. The system may experience gain compression at RT amplifier (dominant component), RT mixer and IF amplifier in solar observation due to high gain and large bandwidth.

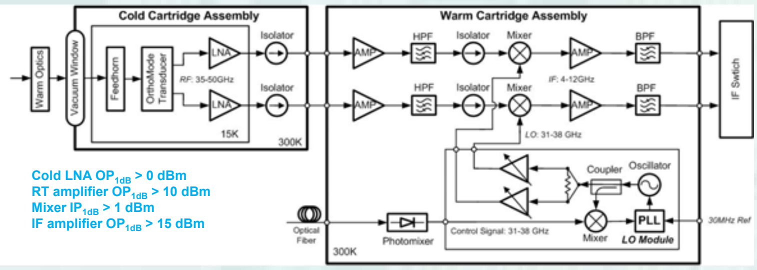

Fig. 1: Block diagram of ALMA Band 1 receiver front-end.

Solar Observation Requirements

Observation campaigns using Band 3 and 6 suggest not to use solar filter due to its time-variant frequency-dependent gain change. WVR might also be blocked by ACD during the solar observation. Therefore, de-tuning of SIS junctions is employed. For Band 1, de-tuning of amplifiers is also investigated. As far as our understanding, the basic requirements for solar observation are:

- Cover wide dynamic range from quiet Sun (~9,000K) to flare (> 100,000K) brightness temperature. This translates to 15 dB (quiet Sun) to 25 to 30 dB (flare) reduction of system gain
- Provide fast snapshot observation mode (time interval < 1 second) with good system stability
- Maintain good system noise temperature and good RF/IF power variation

De-tuning Band 1 Cold LNA

To achieve this without modifying the current Band 1 baseline design, the first amplifier in the system (cold LNA) is de-tuned in the test Dewar. We found that by turning off one stage (2nd or 3rd stage) in the current 5-stage cold LNA, the cold LNA gain can be reduced by ~17 dB without sacrificing power handling capability (OP_{1dB}). System stability is not affected because switched-off transistor acts like a pure resistor. The receiver noise is degraded from 32K to 200 K. And the IF power variation also increases due to uneven cold LNA gain profile. The **quiet Sun** can be observed in this setup with current Band 1 baseline design with little (< 2%) gain compression.

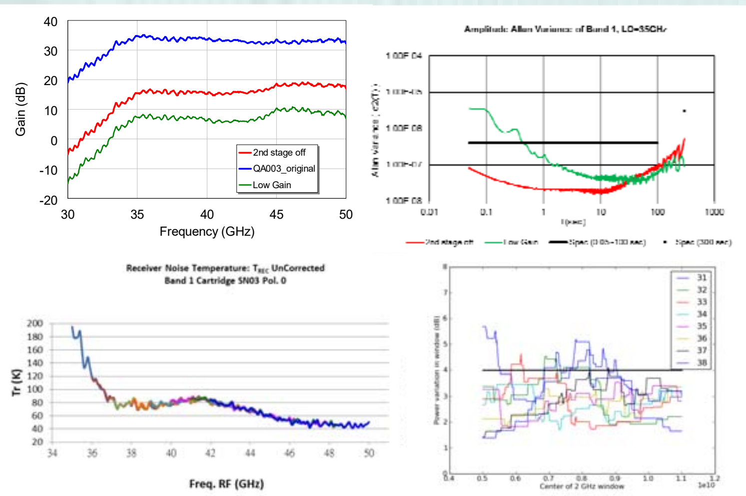

Fig. 2: Receiver noise, system stability, power variation in 2GHz window after switching off LNA 2nd stage.

However, for **solar flare** observation, it is not possible to apply the setting due to high compression (>50%) at RT amplifier. We also cannot apply this method to further reduce the cold LNA gain. Switching off two stages will result into bandwidth shrinkage (very large gain variation, negative gain at lower frequency and 10 dB gain at 50 GHz). Careful manipulating biasing of each stage to achieve another 10 dB gain reduction (*Low Gain* in Fig. 2) is possible with good (< 2%) gain compression level, but it will result into more than one-order magnitude degradation in system stability (green curve). This is not suitable for fast snapshot solar observation.

Solution to Stable Solar Flare Observation

If the system stability shown in Fig. 2 cannot be applied to solar flare observation, there are two possible solutions to avoid high gain compression at RT amplifier:

(1) De-tuning the RT amplifier, and

(2) Inserting tunable attenuator between the cold LNA and the RT amplifier.

Since current commercial RT amplifier in baseline design provides no mechanism to de-tune its bias (amplifiers with this option will be available soon), the tunable attenuator solution is investigated. To avoid mechanical tuning components in the front-end, only voltage-controlled attenuator (VCA) is evaluated. The system block diagram is shown in Fig. 3:

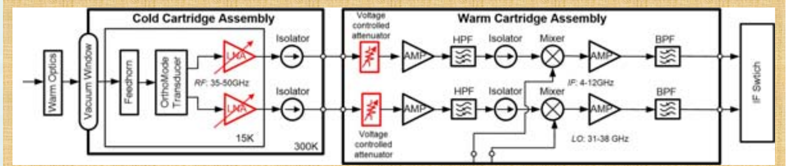

Fig. 3: Proposed system block diagram for solar flare observation.

Commercial VCAs from ELVA are tested by using Keithley current source. System stability as shown in Fig. 3 is also tested. Preliminary results show the tuning range is wide enough for solar flare observation but with very poor stability. We will not consider this solution unless stable operation mechanism is found for the VCA.

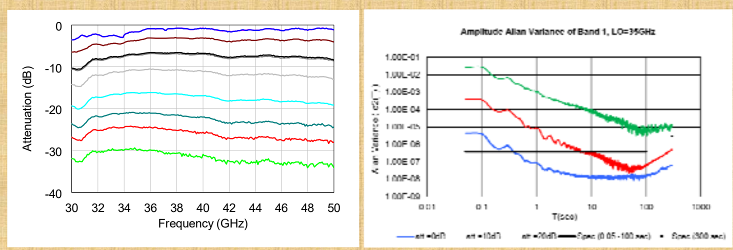

Fig. 4: Dynamic range of commercial VCA and system stability with VCA.

Therefore, with the current Band 1 system, we have to wait for the coming tunable RT amplifier to further investigate if it is possible to have stable system for solar flare observation.

Power and gain compression budget with de-tuned LNA

	Gain (dB)	Power at output port with 9000 K load (dBm)	Gain Compression	Gain (dB)	Power at output port with 100,000 K load (dBm)	Gain Compression
HDPE Lens + Feedhorn + OMT	-0.4	-55.5	-	-0.4	-44.6	-
De-tuned Cold LNA	18 to 22	-37.5 to -33.5	< 0.2% (P_{1dB} > -8 dBm)	6 to 10	-38.6 to -34.6	< 0.5% (P_{1dB} > -15 dBm)
Waveguide + Isolator (CCA) + Vacuum Feedthrough	-2.2	-39.7 to -35.7	-	-2.2	-40.8 to -36.8	-
RT Amplifier	25 to 28	-14.7 to -7.7	0.9%	25 to 28	-15.8 to -8.8	0.7%
Filter + Isolator WCA + WR22-coax transition + Pad	-11.5	-27.2 to -20.2	-	-11.5	-28.3 to -21.3	-
Mixer	-7 to -9	-36.2 to -27.2	0.4%	-7 to -9	-37.3 to -28.3	0.3%
1st IF Pad	-6	-42.2 to -33.2	-	-6	-43.3 to -34.3	-
IF amplifier	30	-12.2 to -3.2	1.0%	30	-13.3 to -4.3	0.7%
IF Filter + 2nd IF Pad	-19.6	-33.5 to -24.5	-	-19.6	-34.4 to -25.4	-

Summary and Future Work

By de-tuning the cold LNA, we can observe **quiet Sun** with little impact on system performance. Receiver noise temperature is still less than 200 K. But for **solar flare** observation, system stability degraded with more than one-order of magnitude for < 1 second, and does not meet ALMA requirement. To have a stable system without gain compression for **solar flare** observation, we have to wait for the new bias-tunable RT amplifiers. We will keep investigate all possible solutions and we express our wish to keep close collaboration with the solar development team to fulfill this mission.