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Preliminary analysis of the individual channel for the 22 GHz array
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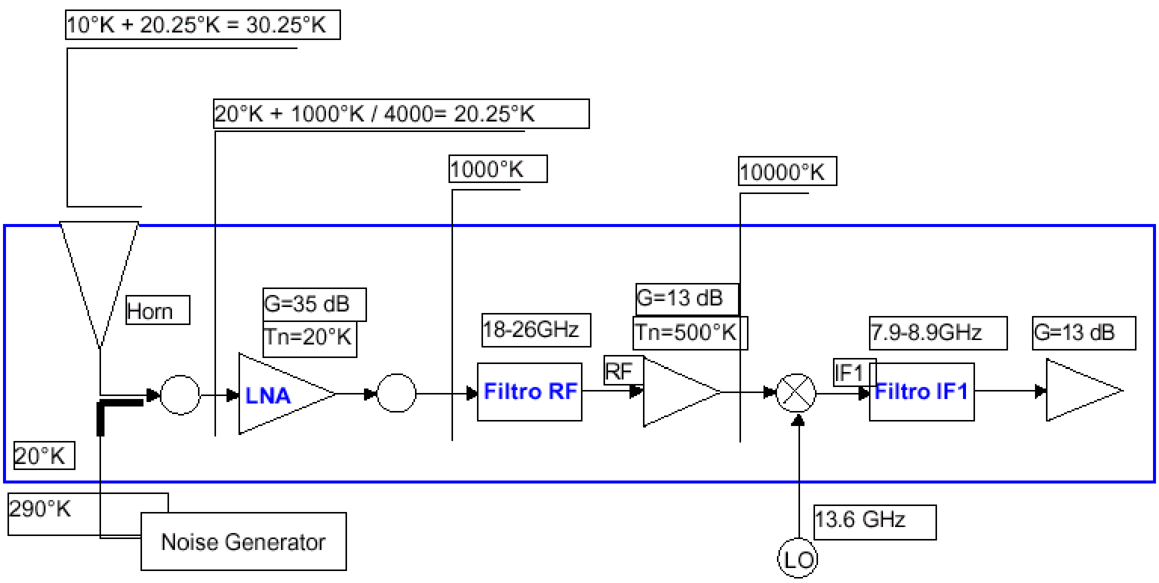
In the following we report the basic configuration of a single channel for the receiver array and the analysis needed to define parameters for each receiver component.
In fig. 1 the block diagram of the cryogenic front-end is shown. The first down conversion is also cooled.
The aim is to get a hybrid configuration which couples the LNA, made in InP MMIC technology, with a following MMIC, which should include filter, mixer, IF amplifier. The technology of the second MMIC has to be defined; also the need of isolators or circulators between the two MMIC's will depend on the available matching capabilities.



Horn

As we plan to include the feedhorns in the cryocooler, the vacuum window gives the major contribution to the receiver noise. Including other passive components, such as coupler for calibration, polarizer and circulator, we give a figure of about 10 K for such noise.

The horn has been designed for broadband, high return loss, low cross polarization. The design is based on a variable profile which reduces the physical length and makes the horn phase center almost frequency independent (see Nesti, 2001).
A first horn prototype has been produced by machined aluminium. In order to reduce the thermal load, alternative solutions in thin aluminium or plastic are also under study.

LNA
NRAO's experience on hybrid InP LNAs has shown that in the 22 GHz band it is possible to achieve 16 K noise temperature almost over the entire band (16-26).
MMMIC technology seems to have some limit in the optimisation of the noise, which could be realistically evaluated around 20 K.
In order to minimize the noise contribution from the following stages, the required gain for the LNA is around 35 dB [check which are the performances of the CSIRO amplifiers].
At 22 GHz the clear sky background through the horn is about 40 K. The available power at the LNA output is then:

$$P_{out\,LNA}^{\min} = K \cdot T \cdot B \cdot G_{LNA} = 1.38 \cdot 10^{-23} \cdot (50+20) \cdot 8 \cdot 10^{9} \cdot 10^{\frac{35}{10}} = 2.444 \cdot 10^{-8} [W]$$

$$P_{out\,LNA\ dBm}^{\min} = 10 \cdot Log_{10}\left(P_{out\,LNA}^{\min} \cdot 1000\right) \cong -46 [dBm]$$

$$P_{out\,LNA\ dBm}^{\min} \Big/ MHz \cong -85 [dBm]$$

The matching capability of the LNA may be another issue. A return loss of about 15 dB could be enough both in input and in output. If not, the insertion of isolators or circulators could be included in the MMIC design. A tradeoff between the two components shows that microstrip ferrite circulators can be realized also for cryogenic applications but with higher losses with respect to waveguide isolators. These latter are more fragile to thermal stresses.
In any case insertion losses are not so crucial if the components operate at 20 K and their noise contribution is lower than the 10 K + atmosphere.
The design of the interface between the MMIC LNA and the waveguide or coax (microstrip launcher) is also needed.

Mixer
Standard versions of MMIC mixers are based on GaAs technology, while little is known in the literature about the InP solution. The comparison is then based on performances, sizes, commuting speed (frequency limit), noise and driver power required for GaAs or InP diodes.
If such device operates at 20 K, and in the case of an array, one of the issues in the design is the low absorption and dissipation required to maintain a low thermal load for the LO distribution. In this context we believe that a passive mixer is more suitable than an active one.
The balanced mixer allows for a better dynamic range, with a higher absorption with respect to the unbalanced mixer. Commercially available balanced mixers would require up to 13 dBm in this frequency range. (Millitech MXP 42).
Not forget that at 20 K the diode conductivity, whenever technology used, changes drastically and the diode current becomes more sensitive to the voltage and I_0 varies quadratically with temperature.

$$I = I_0 \cdot \left(e^{q \cdot V / n \cdot K \cdot T} - 1 \right)$$

$$I_0 = A^{**} \cdot T^2 \cdot W \cdot e^{-q \cdot \phi_b / K \cdot T}$$

The step of the I/V function becomes sharp and the knee voltage, for which the diode is fully conducting, is higher.
These two issues suggest the use of a mixer configuration which includes a polarization network such that it is possible to compensate the change in the bias voltage, when the device operates at low temperature. This solution allows to use a lower LO power (about 0 dBm as in the MITEQ mixers).

RF operating bandwidth : 18 - 26 [GHz]
IF output band: 7.9 - 8.9 [GHz]
Conversion Loss : 5 [dB]
Noise Figure N_F : 6 [dB]

Down conversion chain
To maintain the performance of the LNA front-end the noise temperature of the down converter, referred to the RF filter input, must be kept at levels less than about 1000 K. If so the contribution to the receiver noise temperature is about 0.25 K.
The overall gain should be around 70 dB.

Image rejection mixer