Fundamental limitations of THz and Niobiumnitride SIS mixers

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Appendix A

Performing heterodyne measurements

A.1 Junction performance testing

The standard procedure of SIS junction behavior and sensitivity testing is as follows. First, the direct response is measured with a Fourier transform spectrometer (FTS) to compare with the designed center frequency and bandwidth. An example of such a frequency spectrum is shown in Fig. 3.1 in Ch. 3. A quantitative measurement of the noise and gain contributions of the junction is obtained in a heterodyne experiment. Accurate descriptions of how SIS heterodyne measurements are performed are given in Refs. [1–3].

Fig. A.1 shows the layout of the measurement setup. In short, the LO is injected into the Dewar by a Mylar beamsplitter. Since the use of a beamsplitter implies that the injection of LO is at the expense of the transmission of the signal, the beamsplitter thickness is chosen such that the signal is attenuated as little as possible, whilst maintaining an LO power level sufficient for heterodyne mixing. The LO power level is fine-tuned by a polarizing grid. The output signal of the junction is amplified by three 1.5 GHz amplifiers with a total gain of 80 dB.

For astrophysicists the property of main importance of the receiver is its sensitivity. To allow for a comparison of the strength of the signal to be detected and the integration time needed, the sensitivity of the device is expressed in the noise generated by the device *referred to the input*. The noise power is expressed as an equivalent temperature, the noise temperature T_N, via $P_N = k_B T_N$. In this way the receiver can be viewed as a noiseless amplifier with gain G and a noise generator (a black body or a matched resistor) at temperature T_N. Although the measurable parameters in the laboratory are the input and output powers, the two parameters G and T_N are easily obtained by the so called Y-factor method. In a Y-factor measurement, a hot (300 K) and a cold (77 K) black body load are applied individually to the receiver input, and the ratio, Y, of the receiver output powers is measured. The output powers are given by

$$P_{outc} = G \cdot (P_N + P_{in}(77K)) \tag{A.1}$$

$$P_{outh} = G \cdot (P_N + P_{in}(300K)) \tag{A.2}$$

In which $P_{in}(T)$ is the thermal noise power which is radiated into the device by a black body at physical temperature T. The measured Y-factor is

$$Y = \frac{P_N + P_{outh}}{P_N + P_{outc}} \tag{A.3}$$

The equivalent input noise power is found by inverting this equation:

$$P_N = \frac{P_{outh} - Y P_{outc}}{Y - 1} \tag{A.4}$$

and the gain is obtained from the difference in output powers:

$$G = \frac{P_{outh} - P_{outc}}{P_{in}(300K) - P_{in}(77K)} \tag{A.5}$$

A matter of debate is how the zero-point fluctuation noise temperature, $hf/2k_B$ is to be taken into account in the receiver noise temperature calculation[4,5]. Since this power is always impinging on the receiver input, one could argue that this noise is an intrinsic contribution to the receiver noise temperature and should not be considered part of the signal. However, since this power is actually measurable, we take it as part of the signal rather than part of the intrinsic receiver noise. Therefore we use the complete Callen & Welton[6] equation relating the physical temperature and the radiated power:

$$P(T) = \frac{hfB}{e^{\frac{hf}{k_B T}} - 1} + \frac{hfB}{2} = hfB \coth(\frac{hf}{2k_B T}) \tag{A.6}$$

in which f is the frequency, B the bandwidth, and h and k_B are the Planck and Boltzmann's constants respectively. This power is basically Planck's law with an additional ”half photon” per Hz of bandwidth.

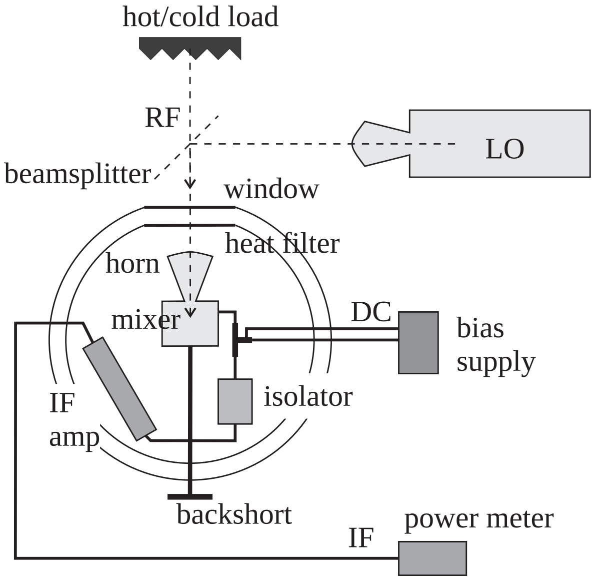

FIGURE A.1. Schematic overview of the heterodyne measurement setup. A crossectional view of the mixerblock is shown in Fig. 1.5, the electrical layout of the DC and IF measurement is illustrated in Fig. 6.2.

A.2 Receiver layout

Since SIS receivers operate below 10 K, thermal shielding is necessary to maintain this low temperature without excessive He consumption. The junction is therefore placed in a Dewar with 300, 77 and 4 K compartments. Windows transparent to submm radiation are placed in the shields to couple in the LO and signal radiation. A heat filter is placed in the optical path to filter infrared radiation out of the incoming beam. A Nb coil to suppress the Josephson supercurrent leading to Shapiro steps as shown in Fig. 5.2 is mounted in front of the mixer block.

The Dewar layout taking into account these considerations is as sketched in Fig. A.1. Noise contributions and descriptions of the components in the RF and IF path are calculated in Chs. 3 and 6 respectively.

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