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Modelling and Performance of Nb SIS Mixers in the 1.3mm and 0.8mm Bands

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Abstract

We describe the modelling and subsequent improvements of SIS waveguide mixers for the 200–270 and 330–370 GHz bands (Blundell, Carter, and Gundlach 1988, Carter *et al* 1991). These mixers are constructed for use in receivers on IRAM radiotelescopes on Pico Veleta (Spain, Sierra Nevada) and Plateau de Bure (French Alps), and must meet specific requirements.

The standard reduced height waveguide structure with suspended stripline is first analyzed and a model is validated through comparison with scale model and working scale measurements. In the first step, the intrinsic limitations of the standard mixer structure are identified, and the parameters are optimized bearing in mind the radioastronomical applications. In the second step, inductive tuning of the junctions is introduced and optimized for minimum noise and maximum bandwidth. In the 1.3mm band, a DSB receiver temperature of less than 110K (minimum 80K) is measured from 180 through 260 GHz. In the 0.8mm band, a DSB receiver temperature of less than 250K (minimum 175K) is obtained between 325 and 355 GHz. All these results are obtained with room-temperature optics and a 4 GHz IF chain having a 500 MHz bandwidth and a noise temperature of 14K.

Design goals

A receiver for radioastronomical use should meet specific design goals besides low noise at a particular frequency such as : reliability, ease of tuning, wide tuning range, capability for SSB tuning (increasingly important when the

atmospheric radiation is a significant contribution to the system noise), good coupling to the antenna, wide IF bandwidth (especially for extragalactic work):

Junctions

The mixers described in this report use Nb/Al₂O₃/Nb junctions fabricated in the IRAM facility (Lehnert *et al* 1991). Two junction series arrays are fabricated with an integrated IF filter. Trilayers are deposited into resist stencils, followed by lift-off. This technique is thought to reduce the mechanical stress in the trilayer (Yuda, Kuroda, and Nakano 1987). The substrate is fused quartz 100 μm thick. The base electrode is 130nm, the counter electrode 30nm, and the wiring layer 240nm thick. The junctions are isolated by anodisation, up to 10V, and a sputtered SiO₂ layer 200nm thick.

Individual junction areas used in this work are about $2\mu\text{m}^2$, but progress in photolithography should allow use of smaller areas. The results presented here are obtained with 2-junction arrays having a total normal-state resistance R_N near 50Ω . Some 4-junction arrays were also fabricated.

The normal resistance of the junctions can be adjusted after fabrication by controlled thermal annealing (Lehnert *et al* 1992).

Mixers currently in use on IRAM telescopes

A simple equivalent circuit was used for the suspended-stripline, reduced-height waveguide mixer mount (Karpov *et al* 1992). The values of the circuit elements were derived from electromagnetic theory. They were then validated by measuring the embedding impedance of the pure SIS junction as measured via a coaxial probe on a scale model, and comparing the results with model predictions. Figure 1 shows the good agreement between modelled and measured values for the return loss.

Figure 2 shows the measured DSB receiver noise. The degradation of receiver noise at the band edges and in the vicinity of 220 GHz was caused by degradations of coupling efficiency at corresponding frequencies, which are intrinsic to the basic mixer structure. Because 220 GHz is an astronomically important frequency: $^{13}\text{CO}(2-1)$, it was decided to adjust one parameter of the mixer—the length of the last section of the suspended stripline filter—to shift this problem to a lower frequency; see fig. 3.

Good agreement is found between predicted and measured values for several parameters: optimum backshort position (fig. 4), upper sideband rejection

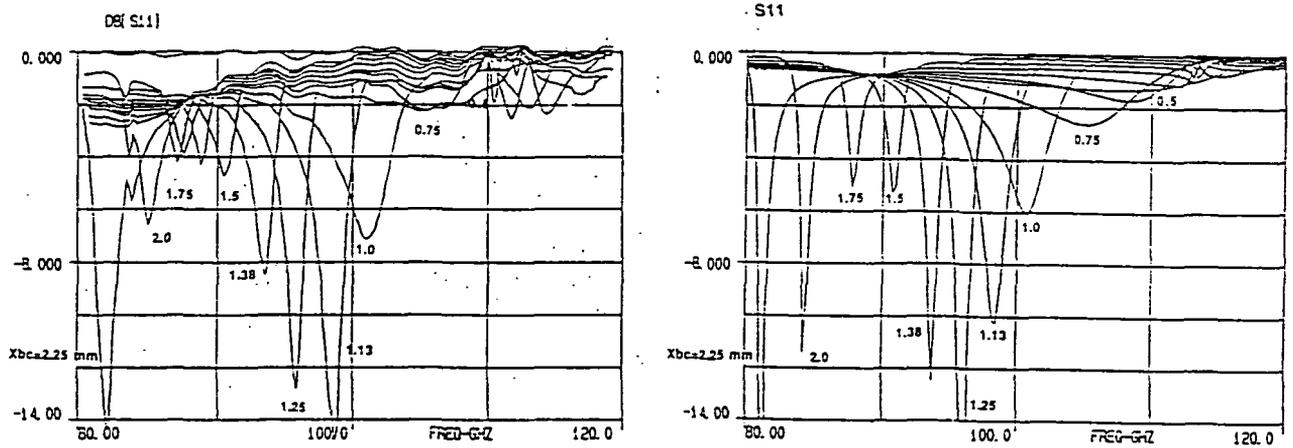


Figure 1. Comparison of measured and computed values for the return loss between the embedding circuit and a 50Ω junction. Frequencies have been scaled to the 3mm range.

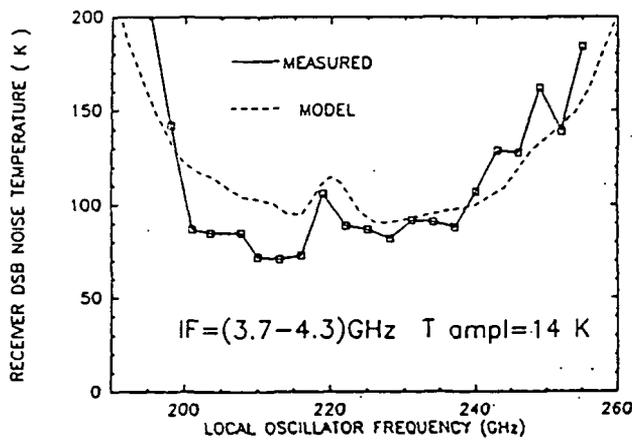


Figure 2. DSB receiver noise versus LO frequency for the original 1.3mm mixer.

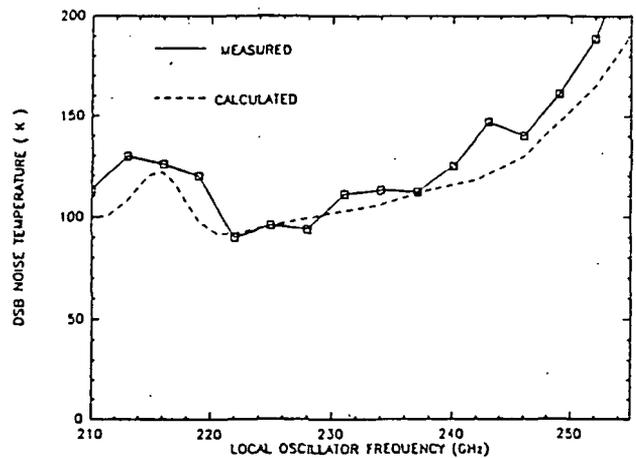


Figure 3. Same as Fig. 2 for modified mixer.

versus backshort position (fig. 5), DSB receiver noise versus backshort position for fixed LO frequency (fig. 6). Note that at 230GHz, an SSB receiver temperature of 135K results when the mixer is tuned for 10 dB rejection of the USB, versus 215K SSB when tuned DSB.

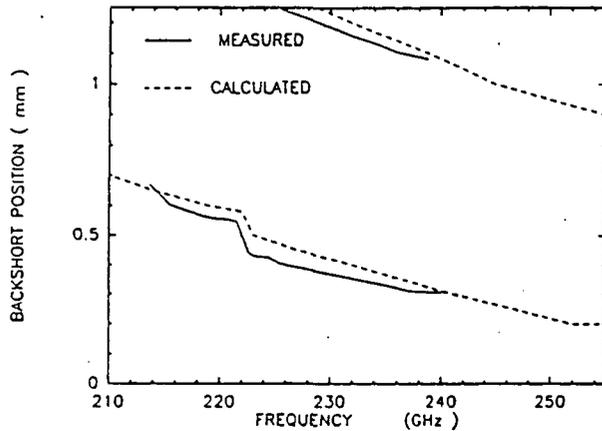


Figure 4. Backshort positions for optimum performance at each frequency. Comparison of predicted and measured values.

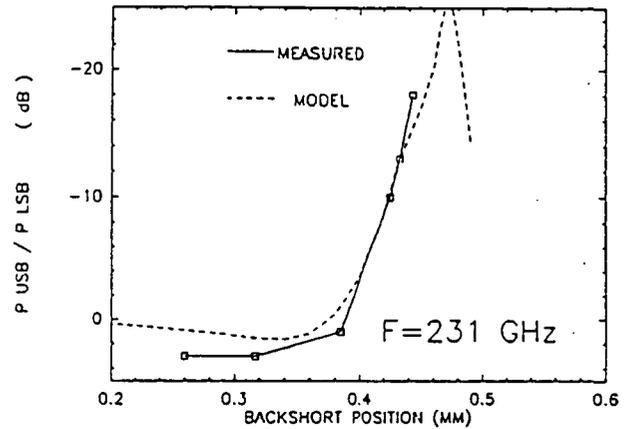


Figure 5. USB rejection versus backshort position. Comparison of predicted and measured values.

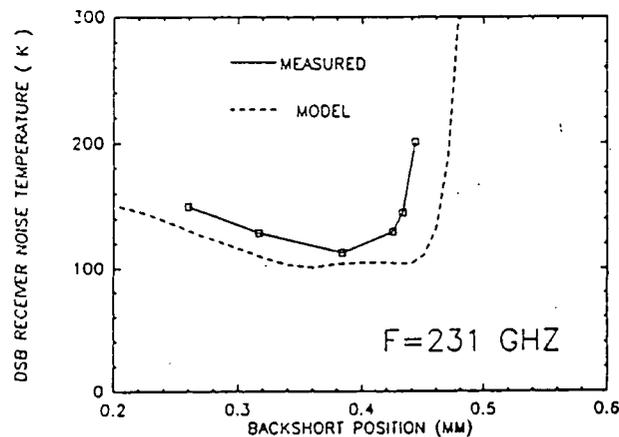


Figure 6. DSB receiver temperature versus backshort position. Comparison of predicted and measured values.

Next generation receivers in the laboratory.

The large capacitance of SIS junctions causes a large mismatch, especially at the higher frequencies. A reactive tuning structure with a high transformation ratio is needed. A backshort can in principle accomplish this, but only

over a limited frequency range (unless one is ready to accept the complication of a two-backshort structure), and the performance is critically sensitive to the backshort losses.

Local tuning with superconducting circuit elements overcomes these limitations. With the junction capacitance tuned out at least approximately over the frequency range, the demand on backshort reactive tuning is considerably diminished, and better performance can be obtained. We have designed optimized tuning structures for the 1.3mm and 0.8mm bands. Figure 7 shows the predicted mismatch loss and the measured laboratory performance for the 1.3mm receiver. Figure 8 shows the same quantities for the 0.8mm receiver. Both receivers were measured with a Mach-Zender diplexer for LO injection, a room-temperature lens producing a beam matched to the f/10 Nasmyth focus of the IRAM 30-M telescope, and a 4 GHz IF chain having a 14 K input noise temperature. We plan to improve these receivers by using cold optics.

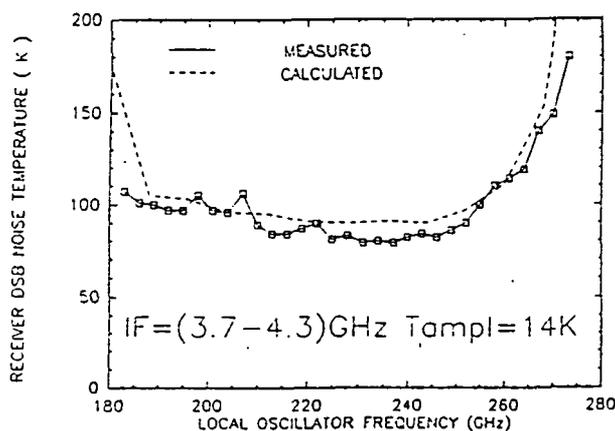


Figure 7. DSB receiver noise versus LO frequency for 1.3mm mixer with inductive compensation. Comparison of predicted and measured values.

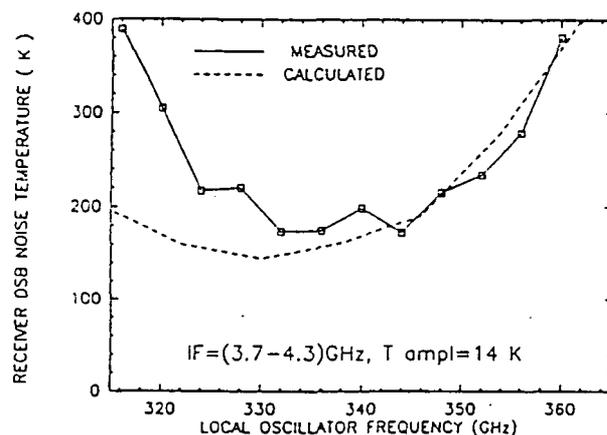


Figure 8. Same as Fig. 7, for the 0.8mm receiver.

Figure 9 summarizes the performance of receivers now operating on the IRAM telescopes, and of improved receivers being developed in the laboratory. Figure 10 illustrates the discovery of Aluminum fluoride in the evolved star IRC+10216, made at the IRAM 30-M telescope with one of the two 1.3mm SIS receivers.

Conclusion.

A relatively simple equivalent circuit can be used successfully to model and

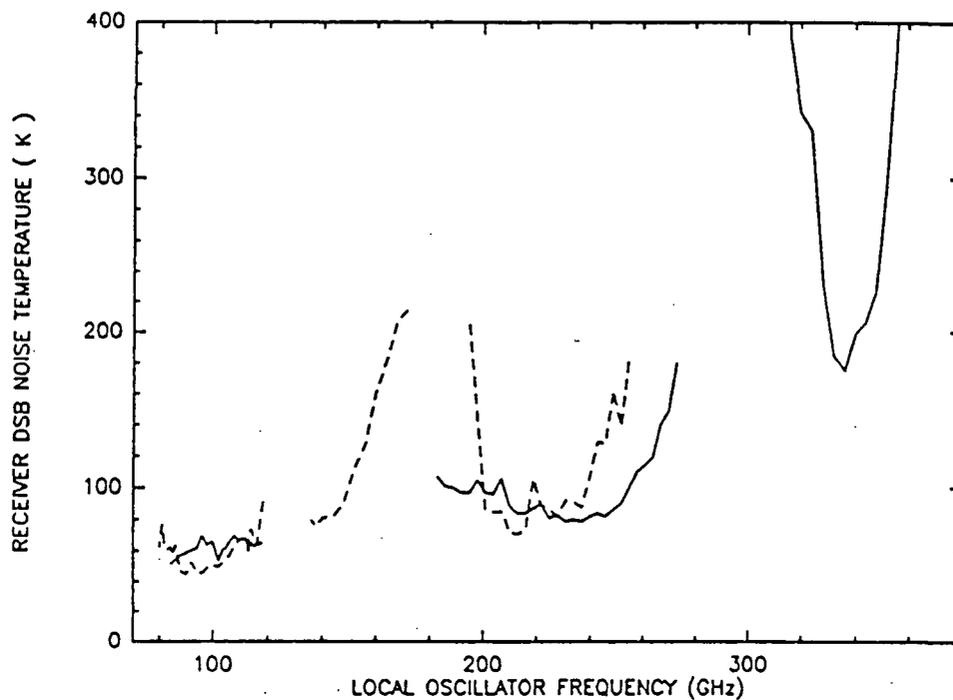


Figure 9. DSB noise versus frequency for IRAM SIS receivers. Dotted lines : receivers now on the telescopes; continuous lines : receivers in the laboratory.

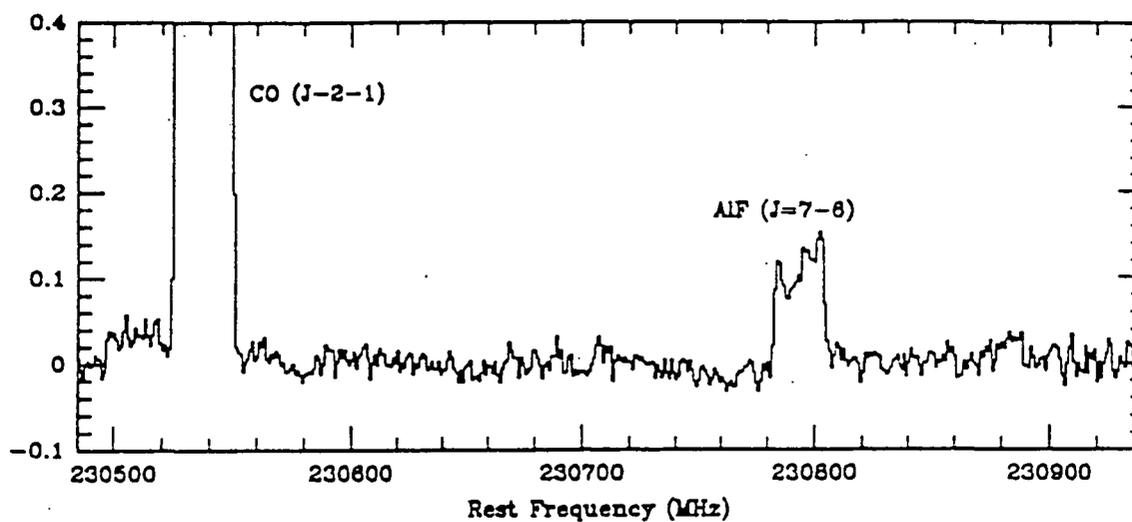


Figure 10. Detection of aluminum fluoride with one of the two 1.3mm SIS receivers at the IRAM Pico Veleta radiotelescope (Cernicharo and Guélin 1987).

improve the suspended stripline mixer mount. The performance of such a mixer using an SIS junction can be significantly improved by employing inductive tuning of the junction capacitance. It is also noteworthy that focusing the design effort on mismatch losses, and leaving aside intrinsic conversion loss, we can show good correlation between computed mismatch losses and measured receiver temperature, and that such modelling can serve as an effective guide to improving significantly the receiver performance.

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