Advanced Tuning Algorithms for High-Frequency SIS Mixers

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Three tuning parameters are key to SIS mixer performance: SIS bias voltage, LO pumping level and Josephson current suppression. The former two are normally determined by an iterative optimization process, although there are a couple of pitfalls. The suppression of the Josephson current, however, is a much more complicated matter. This is especially the case in the high-current-density AlN-barrier junctions that populate most of the ALMA Band 9 receivers (600-720 GHz), as these tend to show hysteretic or multiple-regime behavior for the Josephson current suppression as a function of external applied magnetic field. The Band 9 mixers have other issues, intrinsic to the device physics, as well: since the gap frequency of niobium (~680 GHz) lies within the band, tuning structures get progressively lossy, with a strong dependence on the magnetic field around the point where the superconducting order parameter collapses. Also, the Band 9 junctions use a Al-AlN-Nb trilayer on top of Nb, which means that the superconductivity of the bottom Al layer (with a native Tc of around 1K) is purely induced by the proximity effect, also introducing a strong magnetic field effect. Together, these effects indicate that one should strive for the lowest possible magnetic Josephson suppression field in order to obtain the highest noise performance, especially in the upper part of the band.

The tuning parameters that were supplied with the 186 ALMA Band 9 mixers were biased towards safer and more repeatable regimes rather than ultimate performance, for operational reasons. Here we present the results of the recently concluded ALMA Band 9 Advanced Tuning Study commissioned by ESO. The objectives of this study were to develop "intelligent" automatic tuning algorithm to enable receivers to operate in more critical regimes that were previously avoided, and to investigate the corresponding improvement in noise performance. Secondary benefits of the automatic tuning algorithm are to reduce ALMA array operator's time to find and confirm the tuning parameters for the entire array and to minimize the number of mixers that would be flagged as unusable due to tuning problems during observations.

In the framework of this study, we first had to develop a new software infrastructure. Our original engineering software, while excellently capable of qualifying production receivers (as proven by the successful ALMA Band 9 and Band 5 production campaigns), is not very suitable for adaptive "intelligent" algorithms because of the absence of conditional statements and loop constructions. The new system we developed is structured as a series of extension libraries of the Python language. This gives the full power of an established high-level programming language suitable for implementation of any adaptive or interactive algorithm one can think of.

Using this infrastructure, we first reproduced and fully automated the formerly semi-automatic and "eyeball" algorithms, arriving reliably and repeatably at very similar tuning points as with the classical methods. Working from there, we investigated incrementally several improved and even completely different tuning methods. The final implementation is a three-stage algorithm for optimizing the Josephson suppression: an initial approximation by finding the first minimum in the critical current around zero-bias, followed by a refinement based on the integrated IF power of the Josephson power, and finally a qualification by the width of the Josephson feature. This procedure is preceded by a demagnetization-defluxing step and together they form a loop that is repeated until a qualified Josephson current suppression is found.

As stated before, the delivered Band 9 mixers were supplied with "safe" tuning parameters, meaning in practice that the Josephson suppression current is set to the second minimum. The new algorithm, however, can tune most of the mixers reliably in the first minimum. Together with the almost linear relationship that we find between the achievable noise temperatures and the applied magnetic field, this leads to a significant sensitivity improvement in the set of re-tested mixers, compared to the traditional second-order suppression. We checked, of course, whether the mixers still conform to other important performance specifications (notably the amplitude stability and small-signal gain compression level).

By applying a simplified non-interactive tuning algorithm to the archived qualification data of the delivered mixers, we can make a good estimate of the expected performance improvement when the ALMA Band 9 array is tuned with the new algorithm: in about 80% of the mixers the noise could be improved by 15-30K (from an average of about 100K) in the top part of the ALMA Band 9 frequency range (which contains the CO J=6-5 line at 691 GHz), 10-25K in the middle and 4-7K at the bottom of the band.

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