Submillimeter Array Technical Memorandum

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Correlator Downconversion Architectures

I. Introduction

The digital portion of the cot-relator fixes the specifications of bandwidth and frequency resolution. In a Hybrid correlator (which is the architecture used by the SMA) the analog portion of the correlator (i.e. the downconverters) affects the frequency agility of the instrument. Many of the decisions concerning the digital electronics are complete, but specification of the architecture for the downconverters is just beginning. Therefore, I will discuss some options and the consequences of each approach.

For practical purposes, the downconverters can be viewed as a filter bank. It subdivides the available 2 Ghz input bandwidth into a small number (32) of spectra chunks. In normal operation, these *chunks* will be staggered to cover the entire band. Each separate chunk is sampled and sent to the correlator. In a filter bank, each chunk produces only one measurement, but a hybrid correlator continues to process the sampled data into a spectrum of *the chunk.* By stitching together all the chunk spectra, the entire band is measured with a remarkable frequency resolution(l56 kHz), even at the full bandwidth of 2 Ghz.

Most of the options discussed in this memo refer to the ability to move the chunks within the IF. In the vast majority of experiments, the most desirable location for the chunks is a continous coverage of the available 2 Ghz IF. Most of the correlator flexiblitity is provided by digital switchs on the correlator boards (See memo #62). Thus the ability to move the chunks is not necessary to construct a versatile correlator. However, a certain amount of chunk flexibility may be advantageous. A limited amount of this agility is provided by the BIMA, OVRO and IRAM. However, in these cases, the primary application for frequency agility is to overcome limitations in the digital switches of the correlator. In contrast, the SMA correlator will have substantial mode flexiblity in the digital section.

Frequency agile or not, the proposed SMA correlator is very capable and versatile. The options described by this memo will, at best, increase the efficiency of an observation. This requires some thought on the types of experiments which are envisioned for the array. Feedback from the potential SMA users will help determine if any of these options are useful, essential or simply unnecessary.

II. Downconversion options

Much like the digital modes of the cot-relator, the examples I give are by no means the only possibilities. Many variations are possible, but for the sake of brevity, I will only include some of the more promising variations.

II.A. Fixed Frequency (Filter Band Downconverter)

This approach is the cheapest and simplest. The downconverter uses a fixed analog filter to select a ***chunk*** from the available IF. This option close resembles a filter bank. Figure 1 sketches one downconverter from this architecture. The physical implementation may actually use two conversion steps (two mixers and LO's) to simplify the component cost, but this does not affect the tradeoff analysis.

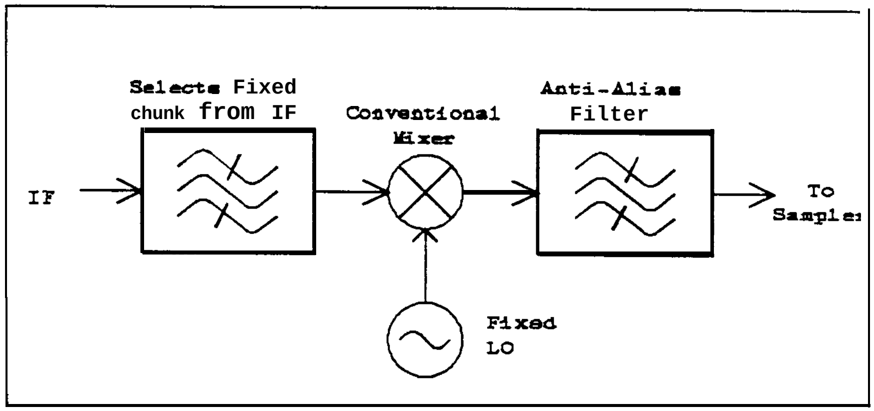


Figure 1 - Fixed "chunk" downconverter

The resulting downconverter is constructed of commonly available components. This solution is the least expensive. However, the location of chunks within the IF is fixed and this limits some correlator options. As it is presently envisioned, there will be a one-to-one correspondence between sections of the IF and physical correlator hardware. Thus in higher resolution modes of the correlator, the "stolen" correlator elements are taken from another (fixed) portion of the spectra. Thus by selecting a high resolution chunk, the resulting low resolution (or ignored chunk in the highest resolution cases) falls on specific portions of the input spectra.[1]

Another negative consequence of fixed chunks relates to seams in the spectra. The hybrid architecture must piece together the final spectrum out of many, independently measured spectral chunks. Strong lines which occur in the seams tend to make the job of matchup (connecting the chunks) more difficult. Thus, it would be beneficial to allow some control over the placement of filter seams.

Finally, a major weakness of this approach concerns the reliability and maintainability of the final instrument. Because each downconverter has a different filter, the number of spares which must be maintained is quite high (32). Also, if a "chunk" fails, Murphy's law dictates it

[1] Note, it would be possible to overcome this limitation with a moderate amount of digital switches. However, at this point the complexity of this possibility is not clear.

will fail in the most inconvenient portion of the spectra possible. Greater flexibility would alleviate these concerns.

Advantages:

1. Cost - this is the cheapest approach
2. Sampling can be baseband, without additional downconversion.

Disadvantages:

1. No frequency agility
2. Maintenance and recovery concerns
3. No seam or overlap control
4. Correlator mode constraints

II.B. Limited Seam Adjustment Downconverter

This architecture is very similar to the previous case. The only difference is the addition of limited control of the *chunk* center position. The incremental cost of this method is quite small compared to the rigid architecture. The main advantage is some control over seam location and the overlap between filters. Unfortunately, the limited range of this adjustment (maybe +/- 20 Mhz) would constrain the scope of the overlap adjustment. For example it would not be possible to just increase the overlap on all *chunks*, because this would require the *chunks* on the edge to move quite far in frequency space. The main disadvantage to this scheme is that it produces non-baseband data, therefore requiring alias sampling or another stage of downconversion (see appendix 1). Also, this scheme does nothing to improve the maintenance problems described in section II.A.

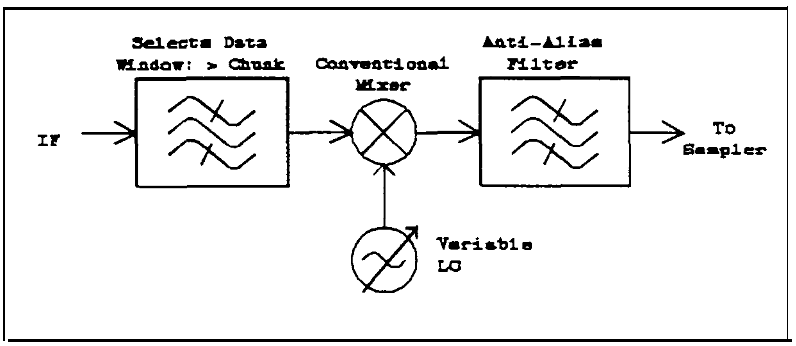


Figure 2 - Limited Adjustment Downconverter

Advantages:

1. Limited seam and overlap control
2. Relatively inexpensive

Disadvantages:

1. No frequency agility (or very little)
2. Maintenance and recovery questions
3. Requires alias sampling or additional mixing stage (appendix 1)
4. Correlator mode constraints

II.C. Frequency agile downconverter

This approach is the most flexible method of downconversion. Each chunk can be independently positioned within the IF to achieve optimum utilization of the available signal. This flexibility provide control over *chunk* overlap and seam position. Also, it removes the high resolution constraint described in Section II.A. Thus if two *chunks* of the spectra are to be observed at high resolution, they could be positioned independently within the IF band.

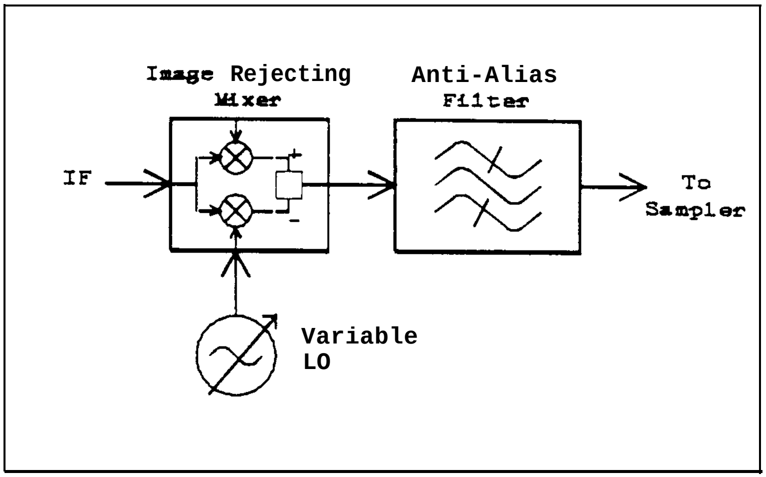


Figure 3 - Frequency Agile Downconverter

An added benefit of this approach is easier maintance and more graceful recover during hardware failures. All the downconverters are identical, which deceases the number of spares. Because each *chunk* is independently tunable (by computer control), a failed correlator, downconverter or sampler can be managed, without adversely affecting the ongoing observation. The computer would simply move the other *chunks* to fill the gap and continue observing without requiring an immediate repair. (The only negative consequence would be the lost bandwidth of the dead chunk, i.e. 64 MHz, but this lost bandwidth can be relocated to the edge of the observing band).

This method has two major drawbacks. First, it will cost somewhat more than the previous options. Each flexible downconverter will cost about $1000 more than the conventional design, for a net cost of around $300k for the whole array. This cost is due to the complexity of the image rejecting mixer (see Figure 3), which has only recently become available from vendors. The other possible disadvantage is the requirement of alias sampling or additional downconversion steps.

Advantages:

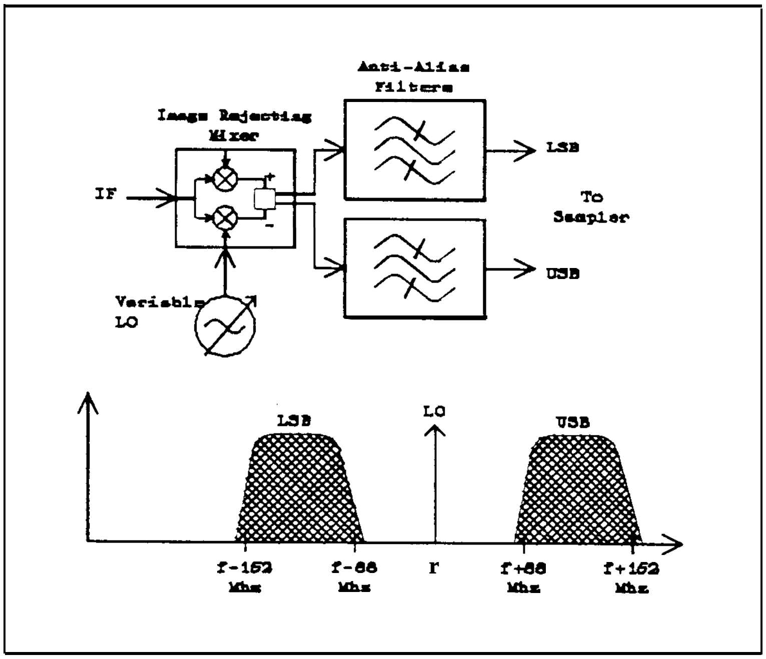
1. Spectra processing can be fine tuned using frequency agility of *chunks*
2. Some correlator mode constrains are removed
2. Maintenance is simplified by identical units
3. More robust operation during component failure

Disadvantages:

1. cost
2. Requires alias sampling or additional mixing to baseband

II.D.. Frequency agile downconverter, using both sidebands of the Mixer

This approach is very similar to the previous example, but has a substantial cost savings by reducing the number of LO's and image rejecting mixers. Each mixer block extracts both the upper and lower sidebands. This method retains many of the benefits of the fully flexible option, but places one constraint on flexibility. The relative position of the upper and lower sidebands is fixed within the IF. By changing the LO, the position of both upper and lower sidebands is moved together. Consequently, in the widest bandwidth mode (2 Ghz), the position of chunk seams will be constrained. In lower bandwidth modes (1 Ghz and less), there are no constraints, because the entire band can be derived using only one set of sidebands.



'igure 4 - Frequency Agile , Both Sidebands

The incremental increase for this approach versus the cheaper methods is roughly half the fully flexible method. Thus, this method will cost roughly 150k more than fixed *chunk* method. This method retains all the reliablity advantages of the fully flexible approach.

Advantage:

1. Moderate amount of frequency agility.
2. Less expensive than the full flexible approach.
3. Maintenance is simplified
4. More robust operation during component failure.

Disadvantages:

1. Cost (although its much better than the completely flexible method)
2. Requires alias sampling or additional mixing to baseband

II.E. Combinations

Naturally, combinations of these methods are possible. For example, most of the modules can be fixed, while a few are given frequency agility. The result is a combination of the various advantages and disadvantages of each. The main argument against a combination architecture is the lack of homogeneity, which will tend to increase development and maintance costs. However, if operational reliability is a driving constraint this may be the most cost effective approach.

III. Conclusion

At first blush, the fully flexible method has some nice advantages. However, the cost of these advantages is not negligible. Originally, I assumed that frequency agility would be a useful feature for the astronomer to allow more control when observing complex spectra features or closely spaced lines. However, this does not seem be an important advantage. The reliability and maintance concerns seem the strongest argument in favor of the flexible options. Also, some overlap and seam control could be useful. However, any one of these options would create a very versatile correlator.

Appendix 1 - Alias sampling

Normally, to perform Nyquist sampling the input spectra will reside between frequency 0 and fs/2, where fs is the sampling frequency. Signals outside this band must be extinguished or they will be added (aliased) into the sampled data. An alternative way to perform Nyquist sampling is to place the input spectrum from fs/2 to fs. If the band from 0 to fs/2 is empty, the input spectrum will be measured just like a baseband signal. The only consequence will be a frequency reversal caused by the aliasing.

Mathematically, there are no negative consequences of non-baseband sampling. However, there are questions which apply to real world components. In alias sampling, the highest frequency which is applied to the sampler is twice the regular case. This may exacerbate some of the inherent problems with samplers. Arguments in the reverse sense are also possible. Since offset sampling from fs/2 to fs only spans one octave, it's possible this will give a smaller effect across the band. It all depends on the form of the non-linearites. A study of this problem is being undertaken to discern the important considerations.

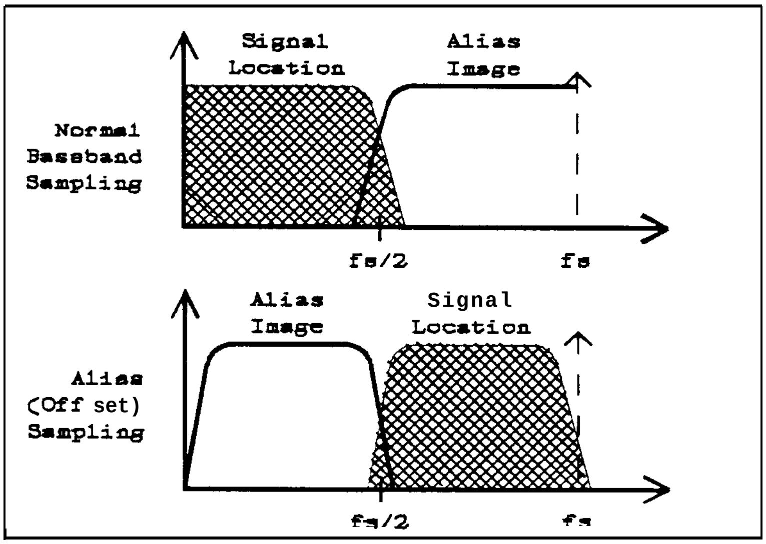


Figure 5 - Alias (Offset) Sampling

If alias sampling is deemed a problem for available samplers, it can be avoided with an additional stage of downconversion. This last stage takes the signal after downconversion and mixes down to baseband. This would require an additional mixer/filter stage, but a relatively simple (and identical for all samplers) set of components. Thus, if one of the frequency agile approaches is preferred, but alias sampling is not within the capabilities of available samplers, there is still a recourse.