MILLIMETER ARRAY
MEMO NO. 70

MMA MEMORANDUM # 70

IMAGE FREQUENCY SUPPRESSION ON THE MMA

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12 December 1991

There has been some discussion of the need for image suppression on the MMA. Image suppression (or separation) is required with the MMA's mixer receivers for two reasons: to remove atmospheric noise received in the image band, which would otherwise substantially degrade the overall system sensitivity, and to remove (or separate) signals from astronomical sources received in the image band which would contaminate the image produced by the array.

To remove atmospheric noise, an image rejection ≥10 dB across the band should be acceptable. However, to produce good images, the MMA will need to reject astronomical image-frequency signals by ≥30 dB.

There are three ways to obtain image suppression (or separation): (i) A filter can be used ahead of the mixer. This could be a two-port filter, or a four-port filter which would allow the image to be terminated in a cold load. (ii) Walsh function phase switching of the LO's allows signal and image signals arriving at the antennas to be separated digitally in the back end. (iii) Image separation mixers provide separate IF outputs for the upper and lower sidebands at each receiver.

The choice of the first intermediate frequency is important if an image filter is used in front of the receiver. However, other factors also affect the choice of IF, including: the desired IF bandwidth (1 GHz for each polarization), the need for an IF isolator between the mixer and IF amplifier, and the penalty in noise temperature of using a higher IF.

This memorandum addresses the following questions:

- Should the image response be suppressed at the front end, either by an image filter or using an image separation mixer?
- Should we plan to include quadrature phase switching of the first local oscillator as a means of image separation?
- What first IF should be used?

IMAGE SUPPRESSION/SEPARATION

RF Input Filtering

The choice of input filter is governed in part by the requirements of the SIS mixers. The tunerless SIS mixers needed for the MMA will operate best when connected to the same optimum value of source impedance at the signal and image frequencies. A simple two-port (reactive) filter is therefore not appropriate, and a four-port filter with a frequency-independent input impedance must be used. The most suitable four-port filter appears to be the quasi-optical Martin-Puplett interferometer [1], which has been widely used in millimeter wave receivers both as a sideband filter and as a LO diplexer [2,3]. The filter is simply tuned by moving a single reflector, and can be adjusted to suppress either upper or lower sideband, or to allow both to be received. Its image port can be coupled quasi-optically to a cold load.

With a Martin-Puplett image filter, the image rejection can be very large at the center frequency, but degrades rapidly towards the band edges. Figs. 1 and 2 show the transmission, as a function of frequency, of M-P image filters operating in receivers with IF's of 1-2 GHz and 2-3 GHz. The image rejection at the band edges is 12 dB and 16 dB, respectively. A 3-4 GHz IF would give an image rejection ≥19 dB across the band, with little penalty in receiver noise temperature.

The theoretical insertion loss at the edges of the signal band for the same three examples is 0.30 dB (1-2 GHz), 0.11 dB (2-3 GHz), and 0.05 dB (3-4 GHz). A loss of 0.3 dB would cause an unacceptable degradation in sensitivity.

Phase Switching

Phase switching of the LO, using different Walsh functions at each antenna, allows upper- and lower-sideband signals from astronomical sources to be separated digitally in the back end. Atmospheric noise in the image band, which is not correlated between the antennas of the array, cannot be removed in this way, however.

Image Separation Mixers

Only by using image separation mixers can MMA observations be made simultaneously in the upper and lower sidebands while suppressing atmospheric image noise.

An image separation mixer uses two simple mixers in parallel, driven by a quadrature-phased LO. The input signal, upper and lower sideband, is divided equally between them, and their IF outputs are combined in a quadrature hybrid coupler. Upper- and lower-sideband information appears at separate ports of the IF hybrid.

In an image separation mixer, the image rejection depends on the phase and amplitude balance through the two paths of the mixer. Using current technology, I would expect it to be difficult to produce image separation mixers with image rejection much above 10 dB across the full IF bandwidth and over the full RF tuning range. This is being investigated by D. Woody.

If image separation mixers turn out to be feasible for the MMA, they may influence the choice of IF. The need for good amplitude and phase balance in the two parallel channels of an image separation mixer is likely to support the use of a moderately high IF (a few GHz) with a correspondingly smaller fractional bandwidth.

IF CONSIDERATIONS

Isolators

It is most likely that IF isolators will be needed for the MMA receivers. SIS mixers do not generally operate well with their output port impedance-matched. The out-going noise wave from the IF amplifier will therefore be reflected by the mixer back into the amplifier, degrading its noise temperature, unless an isolator is used.

Isolators may not be required if it is possible to integrate the IF amplifier into the SIS mixer block. However there are potential difficulties in doing this, not the least of which is the thermal design of the mixer block to prevent the amplifier heating the SIS junctions above 4 K. (With Nb junctions, even a 0.5 K increase in the junction temperature can significantly raise the receiver noise temperature). Another difficulty may arise from the change of output impedance of a tunerless SIS mixer as the LO is tuned; the integrated IF amplifier may be required to maintain a low noise temperature over a wide range of source impedances, which may not be possible. These matters need to be investigated during the preliminary development phase of the MMA.

A conservative initial receiver configuration should therefore include an IF isolator. Cryogenic isolators with 1 GHz bandwidth are commercially available [4] for operation at center frequencies ≥3 GHz.

IF Amplifiers

Cryogenic transistor amplifiers at present can be made with a maximum noise temperature of ~3 K over the 2-3 GHz band, and ~4 K over the 3-4 GHz band, and these figures may improve somewhat in the future.

It has been suggested [5] that a very high IF, possibly 20-40 GHz, could be used for the SIS receivers on the MMA, and would reduce the required tuning range of the first local oscillators. This would carry a penalty in receiver noise temperature whose severity would depend on the conversion loss of the SIS mixer. Such a very high IF may make it difficult to provide desirable embedding impedances at both signal and image frequencies for the SIS junctions, thereby degrading the mixer performance. Furthermore, at 40 GHz the photon energy is sufficiently large that new quantum effects can be expected in an SIS mixer. This is a completely unexplored area at present.

CONCLUSIONS

To achieve acceptable image rejection for both atmospheric noise ($\geq$10 dB) and astronomical signals ($\geq$30 db), we should plan to use LO phase switching together with either RF input filtering or sideband separation mixers. The choice between RF input filtering and sideband separation mixers will depend on developments in the latter during the next few years.

A conservative initial design for the SIS mixer receivers on the MMA might have a 3-4 GHz first IF, and should include IF isolators.

REFERENCES

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[5] M. Pospieszalski, "HFET's and receivers for the millimeter-wave array," Millimeter Array Memo No. 67, National Radio Astronomy Observatory, Charlottesville, VA 22903, Aug. 1991.

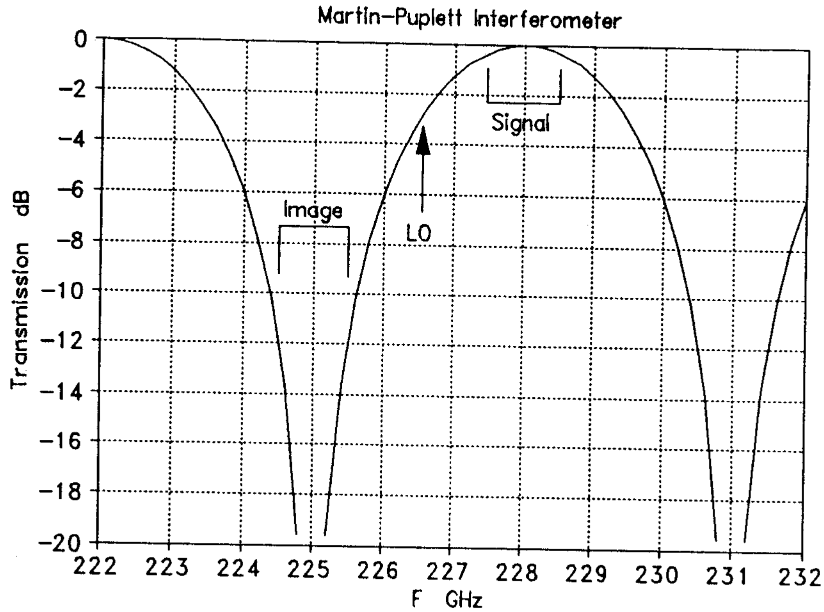

Fig. 1. Response of a Martin-Puplett image filter with 1-2 GHz IF.

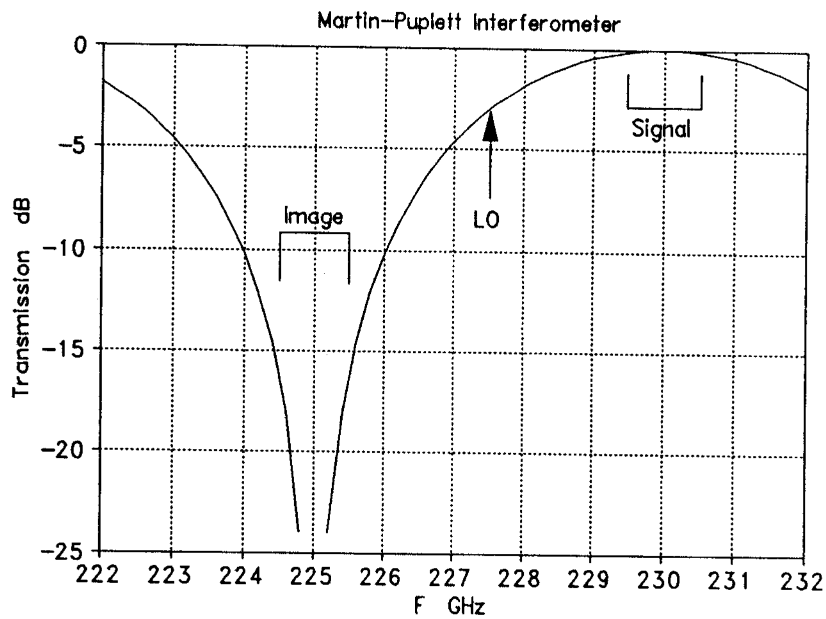

Fig. 2. Response of a Martin-Puplett image filter with 2-3 GHz IF.