MMA Memo 143: Report of the Receiver Committee for the MMA

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I. INTRODUCTION

Apart from the collecting area of the Array, its sensitivity depends principally on the system noise temperature and bandwidth (for continuum), and the receivers have a major effect on these quantities. Three developments since the writing of the MMA Proposal have changed our view of the system design somewhat. These are (a) improvements in receiver noise temperatures, (b) the low sky background temperatures at the potential site in Chile, and (c) increases in receiver bandwidths. Because of (a) and (b) at millimeter wavelengths, it is important that the pick-up of noise radiation from the surroundings be kept as small as possible. In the following paragraphs, we discuss various aspects of the receivers and make recommendations based on our current knowledge of the systems.

II. MMA PROPOSAL SPECIFICATIONS

These were the approximate specifications, with the understanding that improvements were expected.

			Trcvr(DSB)
1. Bands:	(1)	36 - 50 GHz	25K
	(2)	68 - 115 GHz	50K
		130 - 183	50K
	(3)	195 - 314 GHz	75K
		330 - 366	75K

2. Dual Linear Polarization

   or Dual bands with one polarization each

3. Trcvr(DSB) = 0.22 f(GHz)   roughly 5hf/k

4. DSB operation with sideband separation by phase switching.

III. RECOMMENDATIONS WITH SUPPORTING COMMENTS

1. Frequency Coverage. (a) receivers should cover 27 - (approximately)366 GHz, with no gaps except at the 5mm oxygen band, 50 - 68 GHz. (b) The future users should decide on the upper frequency limit near 366 GHz (possibly the water line near 380 GHz).

Astronomical observations of strong masers are now being made close to peak telluric absorptions. In Chile even more will be possible. The 27 - 50 Ghz capability will segue that of the VLA and will be valuable for extragalactic and cosmological studies. Approximate bands will be: (2 HEMTs) for 27-50 GHz; (1 HEMT) for 68 - 90 Ghz; (1 HEMT or SIS) for 90 - 115 GHz; (at least 4 SIS) for 115 - 380 GHz.

The crossover in noise figure between HEMTs and SIS mixers is presently at about 100 GHz. Thus HEMTs are the certain choice for operation at 30-50 Ghz. It is not yet certain that they will be the best choice for the 68-118 GHz band. This is particularly the case at the upper edge of the band where the best available SIS mixers are now quite good. No decision on the use of HEMTs at 2.6mm should be made now.

2. SIS noise temperature specifications. Based on recent experience, we recommend that 2 hf/k be expected at band center and 4 hf/k be expected at the band edges for each receiver. Band edges will frequently coincide with atmospheric lines, where the background temperature is higher in any case.

3. IF bandwidth: 4 GHz BW should be specified with 8 Ghz as the goal.

Padin et al (1994) have achieved an IF band of 0.5 - 4.5 GHz and believe that 8 GHz may be possible. Recent experience with HEMTs suggests that there will be little degradation in noise figure as a result of selecting wider band widths.

4. Optics: The receivers should be located at the Cassegrain focus.

Because the atmospheric background at the site in Chile will be only a few degrees when the weather is good, it appears that a system with as few mirrors as possible is desirable to achieve the best possible noise temperature. Thus, Coude systems with beam waveguides using several mirrors seem undesirable. The SMA study book notes that an ideal smooth mirror has an ohmic absorption of .25% at 230 Ghz and an unpolished surface has an ohmic absorption of .55%. In addition, Ruze scattering losses of .2% for a 5 micron surface RMS and spillover will act like ohmic losses if the mirror is in an ambient temperature environment. After some discussion based on practical experience, it was agreed that the likely losses would be closer to the rough rather than the ideal absorption, and the probable noise per mirror will be 2-3K, including spillover. The Appendix contains a more detailed discussion of probable noise contributions.

At a large focal ratio at the Cassegrain focus, i.e.F>5, the field of view is large, 1.3 F**2 times wavelength, and a number of different receivers may be located slightly off axis with negligible loss in gain. Band changes require only repointing the antenna in this arrangement. Also, multiband atmospheric phase calibration is relatively straightforward, because all recievers are looking out at nearby positions on the sky all the time. Receivers for the long wavelengths, 9mm, should be in the Cassegrain cabin and can be coupled in by sliding a single mirror onto the telescope axis to direct the beam toward the 15K HEMT dewar. At the longer wavelengths the mirror losses are smaller. This arrangement will give excellent 9mm noise temperatures and will not penalize, in any way, the operation of the millimeter receivers. Dual band operation including the 9mm receivers can be achieved with polarizing wire grid mirrors.

5. Image Separation. Use simple DSB mixers for best weather and for frequencies below about 250 GHz. Develop Image separation mixers for the higher frequencies, especially, and for lower frequencies if they are competitive.

For the best conditions and longer wavelengths, 1.3 to 4 mm, the atmosphere in Chile is quiet enough that the receivers, even at 2 hf/k double sideband noise temperatures, will dominate the system noise. (See the Appendix.) This means that double sideband mixers, with low waveguide losses, will be as low noise as any currently available SSB mixer. In this case, they should be used with just the 90 degree phase switching to separate the two sidebands. This should be one option. For times when the atmospheric brightness is high and for the shorter wavelengths, a better sensitivity will be achieved if one sideband can be filtered out. Using both sidebands in this way will require two IF bands and correspondingly dividing the correlator. A design for an integrated circuit device capable of doing this has been completed by Tony Kerr for the 200-300 GHz region, and we look forward to the construction and testing of this important development. Other important options in waveguide are also being developed by John Carlstrom and his collaborators.

In the case that simple DSB mixers are used, there must be a way to separate the sidebands for the single antenna observing (needed for the full observations). This can probably be done through the use of first and second LO switching, but this scheme will have to be developed.

6. Polarization: Dual Polarization is necessary for high sensitivity and for polarization experiments. Polarization capability should not compromise non-polarization experiments, which are the most common.

Linear polarization using waveguide polarization splitters will likely give the lowest noise, and development of such devices should be supported. Dual circular polarizations are the most useful for observing and may be achieved by (a) synthesis in the IF with no degradation in noise temperature or (b) moving into place a linear to circular polarization converter in front of the receiver(quarter wave plate or interferometer). The latter will compromise the noise temperature and must be removable for those observations that don't require dual polarization except for sensitivity.

7. Dual Band Operation: Here the Committee is a little divided. There are two options. (a) Simultaneous observing in two bands, and (b) Time multiplexing observations in two bands. Simultaneous observations will require mirrors and/or beam splitters, and these will degrade the system temperature. Time Multiplexing means spending only half the time at each band, with a loss of sqrt(2). This may be no worse than the result of degrading the system temperatures at the two bands, and it is less complicated. The LO's must be capable of switching to another frequency in a few seconds. Rapid switching in frequency is as important as rapid switching of the antenna pointing for rapid calibration of the phase. Phase calibration of higher frequency observations using lower frequencies can be done either with simultaneous dual band observations or rapid switching (in a few seconds) between the two bands in time. The best choice is not clear at this time.

8. LO Injection: This is mostly an instrumental issue. The two ways of injecting the LO are by either (a) using an optical beam splitter outside the dewar, and (b) using a waveguide directional coupler inside the dewar. In either case, if the source is an oscillator at room temperature, noise introduced is equal to the coupling coefficient times 300K. Here the advantage to the beam splitter is that it does not complicate the dewar design or add heat load to the refrigerator. If the oscillator is a cooled multiplier in the dewar, not a cooled amplifier, then there may be less noise introduced by having the source cooled and coupled inside the dewar. The disadvantage is the added heat load to the dewar.

9. LO Sources: This is another instrumental issue. Current Millimeter Interferometers use phase-locked Gunn oscillators to produce the LO. Their disadvantage is that there are mechanical tuners involved which may eventually be a maintenance problem. A better system, in principle, would be an all electronic system using amplifiers and multipliers. Such a system could retune instantly and have no mechanical maintenance. However, this kind of system may also have too much phase noise. We do have one solution, the mechanically tuned phase locked oscillator, but we urge that the all-electonic system be studied because of its better long term maintenance advantage.

10. There is the question of refrigerator options. The possibilities include JT loop devices with which there is wide experience and which could be either built in-house or purchased commercially, machines from Balzers or Borias, or the low power BIMA G-M machine. The choice will depend upon such issues as (a) the required cooling capacity, (b) how many dewars are needed per antenna, (c) what is the effect of tipping the dewars, and (d) will the compressors be air or water cooled. Because there will be 40 antennas in a remote place, the choice of refrigerator is important in its effect on the total electric power needed. Care must be exercised in the evaluation of the necessary refrigerator requirement that the power load be kept as small as possible.

11. Accurate Radiometry: We propose as a goal that the absolute calibration of maps be accurate to 5% or better.

The ability to make accurate comparison with maps made at other wavelengths requires that accurate intensity calibration be possible routinely. It is customary to use the "chopper wheel method" for calibration at millimeter wavelengths; it gives a temperature scale and takes out the atmospheric absorption at the same time. On the other hand, its accuracy is limited to 10 - 15%, partly because it assumes that the chopper wheel (or vain) has the same temperature as the absorbing air layer. Using a small diameter radio source, e.g. a QSO, is not reliable because they vary on short time scales. The new antennas should have stable gains, and if the radiometers are accurately calibrated, accurate intensity measurements will be possible. Accurate radiometer calibration requires two temperature loads or the equivalent. Ideally, one should be at ambient temperature, and the other should be at a low temperature, close to the sky brightness, 10 - 25K. One alternative would be to have a load in the dewar that can be moved in front of each receiver.

This requires moving mechanisms in the dewar and a separate calibration of the lenses and windows. Another alternative would be to use a load outside the dewar which is cooled by a small refrigerator.

12. Finally, the committee discussed the issue of the availability of good SIS chips for the various bands. Excellent chips have been fabricated by various groups, and it is important that there be a robust source when the time comes to equip the MMA. Indeed, all the present US users are struggling in various degrees to supply themselves with one and three millimeter SIS devices for their telescopes. There have been recent discussions between the NRAO management and the management at JPL about possible collaborations with the JPL solid state group to develop a future source.

IV. APPENDIX Background Noise sources

A. the Cosmic 2.7K
   (a) 43 Ghz: 2.33K
   (b) 115 GHz: .84K
   (c) 230 Ghz: .20K

B. Noise from reflectors at 230 GHz.

1. Ohmic losses: Rough .55%; 1.5K @T=275K (SMA Fig IV-21)
   Polished .25%; 0.8K

2. Ruze losses: .002 for 5 micron RMS (secondary and other small mirrors)
   .057 for 25 micron RMS (primary)

3. Primary mirror(rough): 1.5K (assume the Ruze scattering contribution terminates on the cold sky)

4. Secondary (rough): 1.5K (mostly cold sky again for the scattering)

5. Polished reflector in 275K surroundings: ohmic 0.8K
   (5 micron RMS surface) Ruze 0.5K
   total 1.3K (with no spillover)

6. Realistic evaluation of any small reflector: ohmic 1.5K
   Ruze .5K
   spillover (0-.3%) 0-1.0K
   total 2-3.0K

C. The BIMA antennas have measured antenna temperatures of about 5K, at 90 Ghz, with the cosmic background subtracted. This could possibly be improved a little.

D. Atmosphere from Chile data. 225 GHz

1. best 10% (tau=.024) 6.5K at zenith
   13.0K at E=30

2. best 25% (tau=.036) 9.7K at zenith
   19.5K at E=30

C. System temperatures (DSB). Assume Tant=5K. Trcvr=22.1K, 2hf/k

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   Total at 230 Ghz: 10%:  zenith: 6.5+5.0+0.2=11.7K (bkgnd), +22.1=33.8K
                           E=30:   13.0+5.0+0.2=18.2K (bkgnd), +22.1=40.3

                     25%:  zenith 9.7+5.0+0.2=14.9K (bkgnd),  +22.1=37.0K
                           E=30:  19.5+5.0+0.2=24.7K (bkgnd), +22.1=46.8K
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