DTE 9/23/97

Minutes of the **MMA RECEIVER ADVISORY GROUP** meeting,

08:00 MST, September 17th 1997

Present (via teleconference):

Ray Blundell, John Carlstom, Larry d'Addario, Darrel Emerson, Andy Harris, Tony Kerr, James Lamb, John Lugten, Jeff Mangum, John Payne, Dick Plambeck, Marian Pospieszalski.

Various members of the Charlottesville CDL group also attended as observers.

AGENDA

1. Introduction: the role of the universities.

Darrel Emerson, Peter Napier

2. Summary of MMA Rx plans: which wavebands when, in both the development stage and the later constructional phase.

John Payne

3. Status of sideband separating and balanced mixers.

Tony Kerr

4. Local Oscillators: photonic and conventional.

John Payne, Tony Kerr, Richard Bradley

5. Status of HEMT amplifier development.

Marian Pospieszalski

6. Thoughts on MMA cryogenics.

Larry d'Addario

7. Future meetings.

Darrel Emerson

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1. Introduction.

Darrel Emerson welcomed everyone to the meeting. Today's meeting covers a lot of ground, bringing everyone up to date on NRAO plans and progress. Future meetings will go into more detail in specific areas.

Peter Napier outlined the Role of the Universities.

It is expected that the Universities will play two roles in the MMA Receiver Working Group. First they will act as advisors on all aspects of the design and planning for the MMA Receivers. Second, it is anticipated that the MMA Project will fund some receiver development work within the MDC agreement at BIMA and OVRO. The Receiver Working Group should discuss such possible projects and recommend which ones should get highest priority for funding.

(PJN)

2. Summary of Receiver Plans.

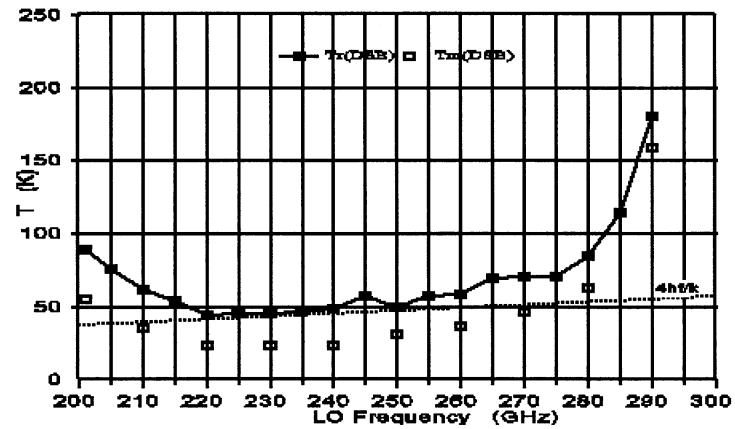
John Payne outlined the current plans. Some timescales are set by the need to support tests of the first prototype antennas. Dual polarization receivers will be built for these antennas at 3mm, 1.3mm and probably 30 GHz. The Dewar or Dewars for these receivers will be, as far as possible, the final design for the MMA system; the receiver inserts used for prototype antenna testing may however be modified 12 Meter systems. The refrigerator to be used initially will similarly be copied from the 12 Meter, but this may change as circumstances allow. A prime focus holography system will also be built, possibly for the 38 GHz LES9 transmission or some other convenient satellite beacon, although initially, near-field holographic measurements will also be made using a local beacon at the prototype antenna site.

In parallel with this support for the prototype antenna tests, receiver systems closer to the "final" MMA design will be developed, but with inevitably longer lead times.

(DTE)

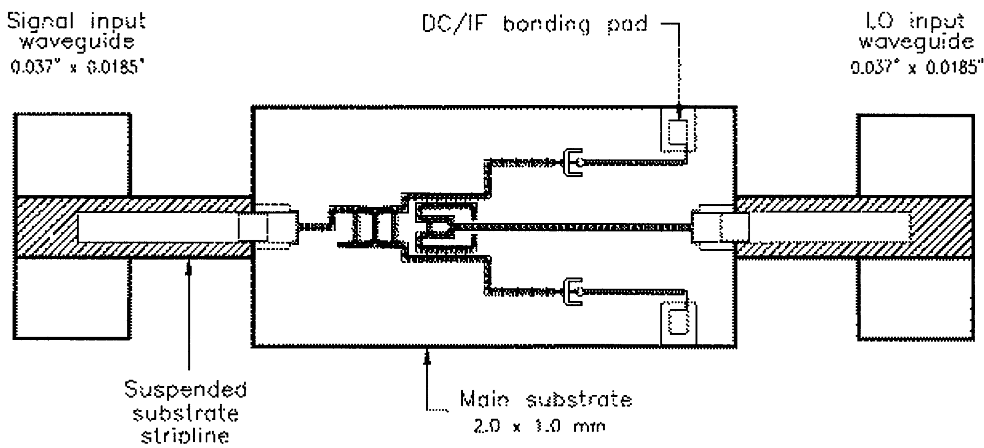
3. Progress on SIS mixers

A new mixer, designated SIS373, for the 200-300 GHz waveguide band has been fabricated at UVa. To accommodate the high IF planned for the MMA, probably 4-12 GHz, the mixer was designed to have a low IF output capacitance. The DSB noise temperature of the mixer and complete receiver are shown in the figure.

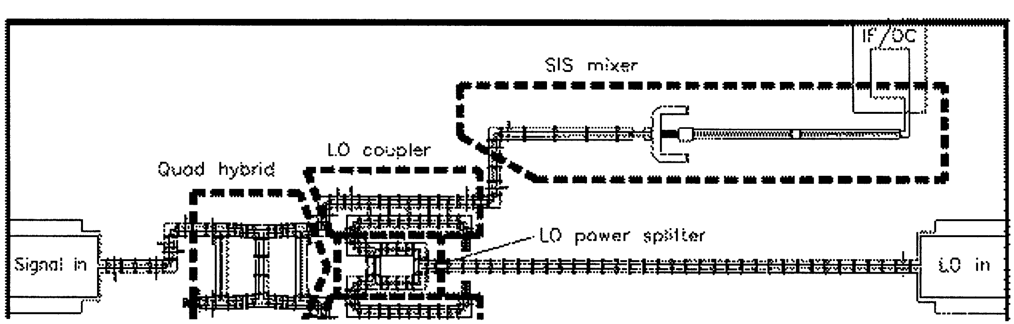


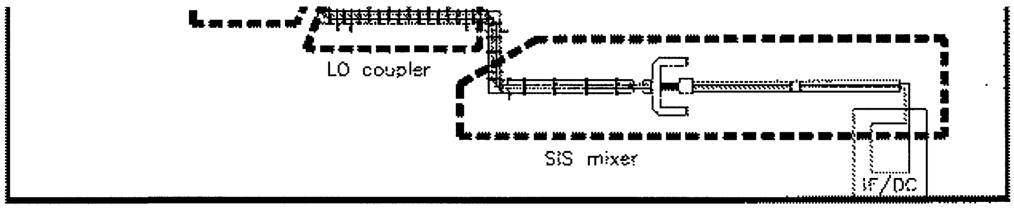
DSB noise temperature of NRAO type 373 SIS mixer (points) and complete receiver (upper line). The dashed line indicates 4hf/k. The mixer was fabricated at UVA.

A single-chip image-separating SIS mixer, ISM371, also for the 200-300 GHz band, was fabricated at JPL. The single 2 x 1 mm quartz chip contains two mixers of the same design as the type 373 described above, an RF quadrature hybrid, an LO power splitter, and two LO couplers. Signal and LO power are connected at opposite ends of the chip as shown in the figures. The design of this mixer is described in detail in MMA Memo 151.



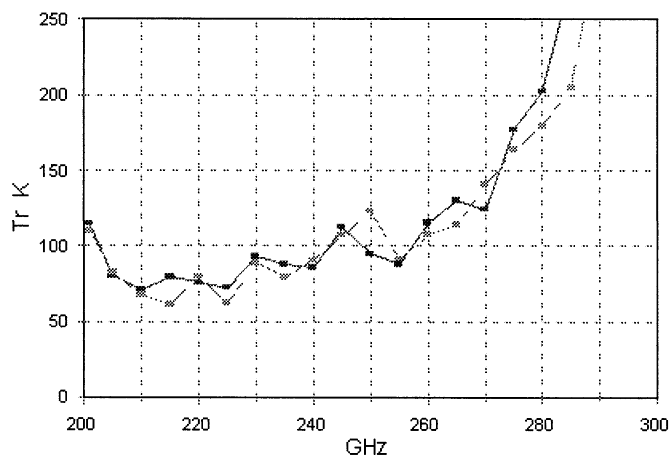
The image separating mixer, showing the signal and LO waveguides, suspended stripline coupling probes, and the main substrate.





Main substrate of the image separating mixer, showing the main components.

At 230 GHz the overall receiver noise temperature of the image-separating receiver is ~70 K DSB with 9-15 dB of image rejection. While this image rejection is sufficient to reduce the contribution of atmospheric noise in the image sideband to an acceptable level, it should be possible to improve it considerably. It is believed to have two main causes: (i) Weak excitation of a waveguide mode under the substrate couples some LO power to the signal port at the other end of the substrate, whence it enters the quadrature hybrid and is coupled to the SIS mixers with inappropriate phases relative to the desired LO power. (ii) The resistance of the cold load on the 4th port of the input quadrature hybrid is 36% too high. Also, for the chips tested, the junctions were not identical, as could be seen from the I-V curves. It is hoped to correct these deficiencies on the next wafer.



Noise Temperature of the complete SSB receiver, measured at each IF output.

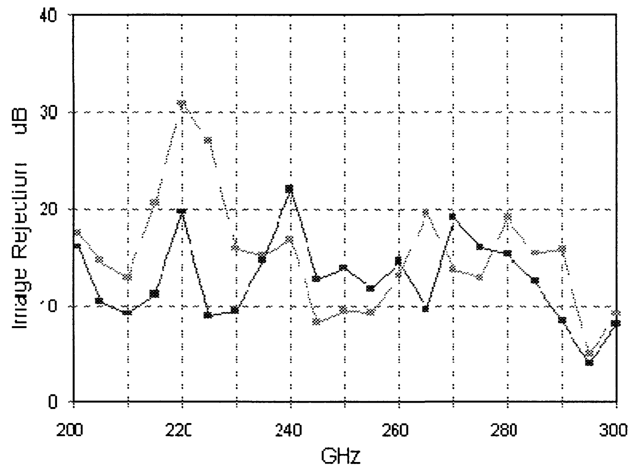


Image rejection of the complete image-separating receiver, measured in each sideband.

The desirability of image-rejecting or sideband-separating mixers in the context of the MMA has been discussed by Thompson & Kerr in MMA Memo 168. A perceived drawback of sideband separating mixers, mentioned by Lugten & Welch in MMA Memo 183, was that the IF circuits in the Dewar would have to be doubled (compared with a DSB receiver). This is not necessary. If only one of the IF outputs from the mixer is used, it can be switched between upper and lower sidebands simply by reversing the polarity of the bias on one of the constituent mixers. In cases in which it is desired to observe both sidebands, it is shown in MMA Memo 168 that there is usually little or no penalty for using a single output of a sideband separating receiver as compared with a DSB receiver.

We have completed the design of a single-chip balanced SIS mixer for the 200-300 GHz band (see MMA Memo 151), and are laying out the masks for fabrication at UVa. Balanced mixers will have two advantages for the MMA: (i) The LO power will be ~ 17 dB lower than required by a comparable single-ended mixer using a 20 dB LO coupler. (ii) The contribution of AM noise on the LO is greatly reduced. We have found that LO noise can contribute significantly to the overall receiver noise.

Eventually, we hope to produce single-chip balanced sideband-separating SIS mixers for use on the MMA. The additional work to produce balanced and sideband-separating mixers, compared with simple single-ended DSB mixers, lies mostly in the design and not in the fabrication. Except for the additional resistor layer in the sideband-separating mixer, there are no additional steps required, and the critical components are still the junctions and their tuning elements, which can be exactly the same as for a simple single-ended mixer.

A new mixer for the 240-370 GHz waveguide band, fabricated at UVa, is intended for use on the 12-m telescope. Initial tests of a number of these mixers indicate that they are tuned substantially too high in frequency. This is a good demonstration of the need to develop on-wafer test circuits which allow the important electrical parameters to be measured before time is spent assembling and testing mixers. A project to design suitable test circuits is under way in conjunction with UVa.

A collaboration between SAO, UVa and NRAO is exploring traveling-wave SIS mixers as proposed and demonstrated by Blundell & Tong of SAO. Traveling-wave mixers may be a desirable solution for the MMA's submillimeter bands. Originally these used a long thin SIS junction fabricated by electron-beam lithography. Lichtenberger at UVa has developed a process using conventional lithography to produce edge-junctions suitable for traveling-wave mixers. Tests on the initial wafer gave an overall receiver noise temperature of 61 K (DSB) at 260 GHz, but with relatively narrow tuning range. This may be the result either of some problem in the optics ahead of the mixer, or of incorrect operation of the on-chip tuning circuit -- another indication of the need for on-wafer test circuits. It is planned to continue this work in the future.

(ARK)

4. Local Oscillators: photonic and conventional.

NRAO is pursuing parallel paths for the MMA local oscillator system. The photonic approach offers, potentially, much greater simplicity and reliability, with considerably lower cost. However, this is a development project and, although we are optimistic, there is some risk. As a backup, and for use during the development phase, a more conventional local oscillator scheme is also being developed.

Photonic system:

John Payne outlined the plans to develop a photonic local oscillator system for the MMA. This will involve phase-locking the difference frequency of two solid-state lasers, which will operate at 1550 nanometers. The pair of laser signals will be sent along a single fiber (per antenna) from a central building to each of the antennas. At each antenna, the optical signals will be put into a photomixer, with the mm-wave difference frequency becoming the receiver local oscillator. There will probably be a separate photomixer for each receiver, with the incoming optical fiber being switched under computer control, using off-the-shelf fiber switches, to the appropriate receiver.

There is a great deal of research happening in industry in this area at present; line widths as small as 1 millihertz have already been reported at mm wavelengths.

A test of concept has already been successful in Tucson; two lasers were phase-locked to give a difference frequency of 1.4 GHz, with good stability and low phase noise. Much of the expected phase noise in such a system should be independent of laser difference frequency, so we are very encouraged that development of the system to produce an l.o. at hundreds of GHz seems quite feasible. The photomixer used in these early tests limited the highest difference frequency that could be investigated; part of the NRAO development plan will be on photomixers capable of producing difference frequencies into the sub-mm part of the spectrum.

The potential advantage of the photonic local oscillator system is the much greater simplicity, and lower cost, compared to conventional techniques.

(DTE)

Photomixer development for LO generation

There are three approaches being taken to generating power at millimeter wavelengths by mixing two laser signals. Photoconductive mixers are being studied by Elliott Brown *et al.* (Lincoln Lab/DARPA). These use low-temperature-grown GaAs as a photoconductor. The extremely short carrier lifetime of LTG GaAs gives a wide output frequency range (~ 1 THz), but results in poor collection efficiency of carriers generated by the incident optical photons. Conventional photo-Schottky diode mixers can be fast if a thin depletion layer is used, but the thin depletion layer absorbs only a small fraction of the normally incident photons. To improve the absorption efficiency, Bowers *et al.* (UC Santa Barbara) have developed a traveling-wave Schottky photodetector in which photons are absorbed from an optical waveguide buried in the semiconductor substrate and running under an extended diode whose electrodes form a transmission line for the mm output. The shortcoming of this device is the limited output bandwidth resulting from the difference in velocities in the optical waveguide and the mm transmission line. To remove this bandwidth restriction, Itoh and Wu (UCLA) have made velocity-matched traveling-wave photodetectors. These also use an optical waveguide running below the surface of the semiconductor, but groups of small Schottky photodiodes are located at appropriate intervals along the waveguide to compensate for the velocity mismatch.

NRAO is initiating a contract with UCLA to develop velocity-matched traveling-wave photomixers suitable for use as local oscillator sources on the MMA. Initially work will concentrate on the WR-10 band (75-110 GHz) for which we are well instrumented and can use the HP8510 vector network analyzer for diagnostic measurements.

(ARK)

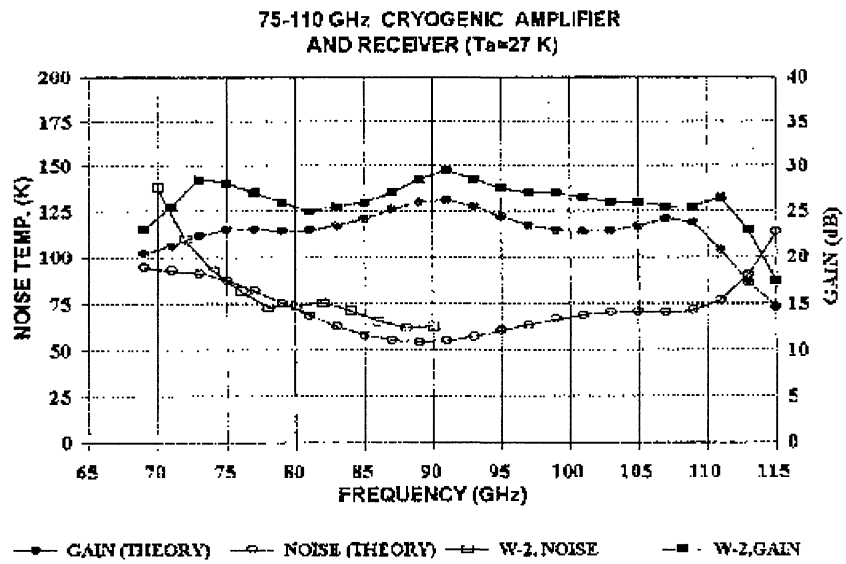
Conventional Local Oscillator approach:

Precursory MMA LO development work is currently underway at the CDL. A 690 GHz heterodyne tipping radiometer is being designed by UVa EE graduate student, K. Saini. The tipper will use a 115 GHz Gunn oscillator followed by a 115/230 GHz doubler and a 230/690 GHz tripler. Both multipliers will use fixed-tuning structures with planar Schottky varactors. A small contract with UVa has been set up for custom varactor fabrication. These multipliers are being considered as first generation components for the MMA LO. The doubler design is based on a successful 40/80 GHz doubler developed by UVa EE graduate student D. Porterfield. We are currently building a test fixture for evaluating the performance of this doubler at cryogenic temperatures. Finally, we are evaluating the room temperature and cryogenic performance of 30 GHz MMIC power amplifiers from Lockheed-Martin. Such amplifiers at 30 and perhaps 100 GHz will be required as part of the MMA LO chain if low frequency YIG-type sources are used.

A Conventional LO Development Plan has been written which describes the LO development effort for the next several years. Most of the work will be toward systems for the MMA prototype (nominal bands of 30, 100, and 230 GHz) and will be divided into four Technical Development Areas (TDA). TDA One will focus on building several 100 GHz phase-locked LO chains and evaluating them on the basis of available power, as well as amplitude and phase noise performance. A system that meets the MMA specifications will be chosen for further development in TDA Two, which will concentrate on building a working prototype LO system for 30 and 100 GHz that is compatible with the MMA (having appropriate fringe rotation, adequate tuning range, use of MMA reference oscillator, etc.) TDA Three will focus on extending the 100 GHz system to 230 GHz through the use of a fixed-tuned, planar varactor frequency multiplier, building upon the one developed for the tipping radiometer. Finally, TDA Four will concentrate on developing planar frequency multipliers to extend the 100 GHz system to 700 GHz. Once again, the foundation for this work will be the multipliers developed for the tipping radiometer project.

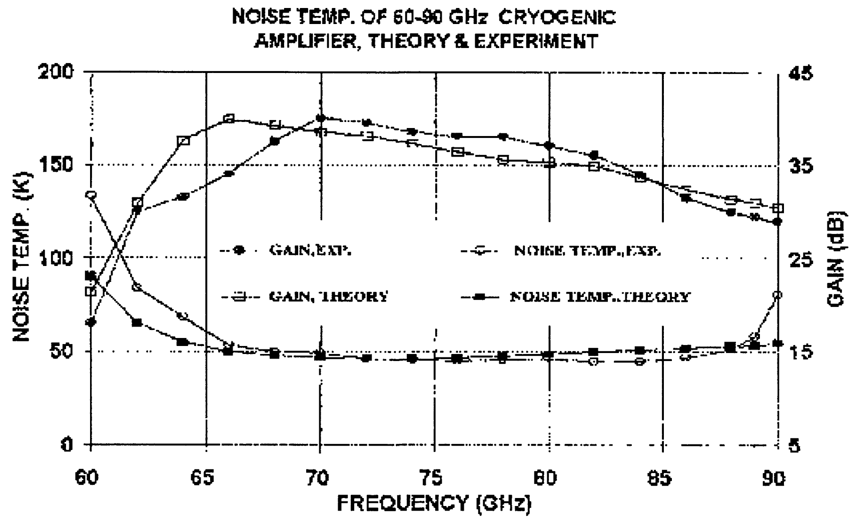
(RFB)

5. Status of HEMT amplifier development.

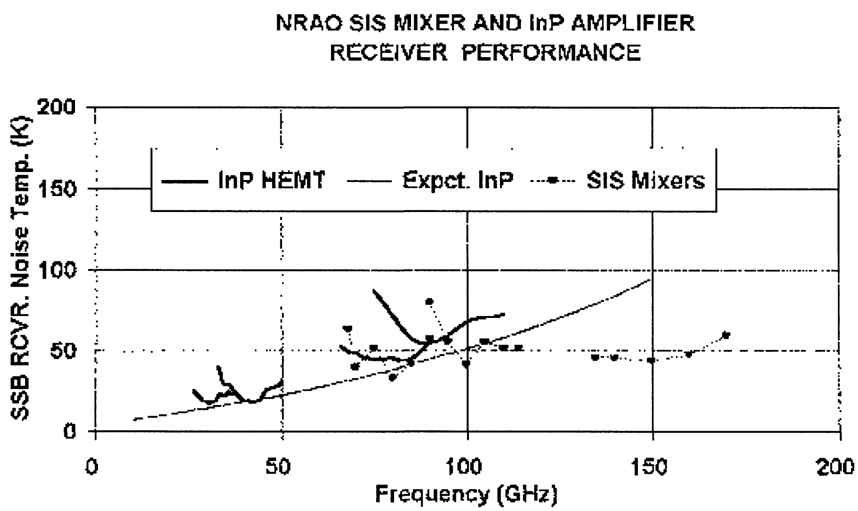


A comparison of measured gain and noise characteristics of a W-band amplifier with model prediction at cryogenic temperature (Ta = 27 K). Measured noise temperature includes the contribution of Dewar window, pyramidal horn (Ta = 27 K) and room temperature receiver (Ta 2000 K).

Marian Pospieszalski presented the state-of-the-art performance of HEMT amplifiers; graphs showing the gain and noise performance achieved up to 115 GHz were presented, with a comparison with SIS mixers. Up to 100 GHz the HEMTS are competitive with SIS performance; the breakpoint where SIS mixers have better performance is around 110 GHz. Marian considers that this situation is not likely to change in the near future. The data presented showed measured noise performance of InP-based HEMT amplifiers of 50 K over 65 - 90 GHz and 75 K over 75 - 110 GHz, with gains respectively of ~35 dB and ~25 dB. HEMT receivers offer the advantage of instantaneous coverage of a full waveguide band, relaxed cooling requirements (15 K versus 4 K) and a very graceful degradation of noise temperature upon increase in ambient temperature.



Example of gain noise and performance of E-band cryogenic (Ta = 27 K) amplifier compared with model prediction. Noise temperature includes the contribution of Dewar window, pyramidal horn (Ta = 27 K) and room temperature receiver (Tn 2000 K).



Comparison of noise temperature of NRAO cryogenic receivers using InP HEMT amplifiers cooled to about 20 K and SIS mixer receivers (A.R. Kerr and S.-K. Pan) cooled to 4 K.

There was some further discussion of the pros and cons of HEMT versus SIS receivers, and at what frequency for the MMA the changeover from one technology to the other should occur. This topic will be revisited at a later receiver group meeting.

(DTE)

6. MMA cryogenics.

The NRAO has already built many successful 4K and 15K cryogenic systems, so the simple and conservative approach would be to make many copies of existing designs to support the MMA. But there are reasons to believe that large improvements are possible in four areas: efficiency (power consumption), reliability, temperature stability, and cost. Achieving such improvements will be very important to the operation of the telescope, and the size of the project justifies a significant effort.

Typical NRAO 4K systems (GM+JT) achieve 1W of cooling at a cost of 9.7kW of power consumption. This would be 621kW for a 64 antenna array (cf. 188kW for a 64-station correlator, according to current estimates). It gives an overall efficiency of .0001; a hypothetical ideal engine (Carnot cycle) pumping 4K to 300K would achieve .013, so we are getting .0076 of ideal. Improving this to a few percent of ideal should be feasible, and would produce very large savings.

More efficient systems tend to involve cyclic flow (Sterling, Gifford-McMahon, pulse tube) rather than continuous flow (Joule-Thompson, Brayton). This leads to temperature cycling at rates of 0.2 to 10 Hz. In some cases, long term temperature instabilities have also been observed (e.g., Plambeck, CryoEngrConf, 7/97). At present, it appears that short term stabilization to 20-30mK is possible by passive means, but that tighter control (if needed) will require an active servo. Stability better than 1mK may be extremely difficult to achieve.

The receiver group is asked to consider carefully the following questions:

- What will be the receiver configuration (number of Dewars, number of receivers in each, resulting distribution of cold stations)?

- What is the required cooling capacity at 4K? at 40-80K? How severely is the design constrained if the cooling capacity at 4K is 100-300mW and not 1-2W?

- What is the required (not "desired"!) temperature at each SIS mixer block? We are proceeding on the assumption that a stabilized temperature of 4.0K is satisfactory. It is emphasized that every 0.1K below this comes at a high cost in money and power, and perhaps in reliability.

- What is the required temperature stability, especially for SIS mixers? Presumably, this is a reflection of the required gain stability, which depends on observing strategies. The answer must be given as a function of time interval (like an Allen variance).

At least three companies now offer 2-stage Gifford-McMahon refrigerators that reach 3.1K with no load, and that pump 0.5 to 1.0W at 4.2K. Power consumptions are mostly 6.5 to 7.5kW, but one new unit claims 2.5kW and it looks fairly promising. In addition, there has been extensive development of pulse tube refrigerators reported in the literature. They tend to be significantly more efficient, and some reach 4K. No suitable PT systems are commercially available yet, but that could change in a few years. We cannot afford to wait, but we should keep a close eye on this and other emerging technologies.

(LRD)

There was some discussion following Larry's report. In particular, Tong (CfA) and Plambeck pointed out, on the stability issue, that temperature instabilities of a few mK at an SIS mixer caused output instabilities of about 1 part in 1000.

7. Future meetings.

It was agreed that this group should meet monthly, as far as possible on the third Wednesday of each month. The next meeting would therefore take place on Wednesday, 15th October at 08:00 MST, 15:00 UTC. The agenda will be sent out nearer to the meeting, but will probably include discussion of receiver wave-bands, and the issue of how many Dewars there should be at each antenna.

(Minutes compiled by Darrel Emerson, 20 Sep 1997)