A Design for the HET Receiver on FIRST

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We present a design for the HET Instrument on FIRST which has a minimum of optical components, and is very compact. The small number of optical components, especially in the signal path, keeps the receiver simplified without compromising its scientific capabilities. This document describes a revised version of the design described in the fax of 21 February which was distributed to the FIRST Payload Working Group. In particular, improvements have been made to the design of the mirrors M4 and M6.

Our HET Instrument design philosophy can be summarised as follows:

- Redundancy of the HET device in terms of frequency coverage.
- Maximum possible simplicity of the optics; only reflecting optical elements are in the signal path. There is therefore no loss associated with lenses, grids and dichroics. Moreover, the two latter may be difficult to fabricate at THz frequencies.
- Maximum possible simplicity of the mixers.
- Double Side Band operation only, but it is possible to add Single Side Band capability into the design.
- Integrated modules and a layered design provides accessibility and flexibility.

System Overview

Eight mixer modules are placed in a circular array around the pyramidal mirror M6. All mixer modules are located at the same level, each attached directly to the cold plate. M6 is used as a switch which couples four of the modules simultaneously to the telescope. The other four modules are connected to the telescope by a 45° rotation of M6. Mirror M4 must also rotate 45° in conjunction with M6. The focussing mirrors on M6 and M4 are designed for the frequency band covered by two mixers, which includes a 50% overlap in frequency coverage. Thus, the optics are optimised for each mixer.

Coupling to the telescope is achieved by the Gaussian Beam Telescope formed by the mirror pair M6 (the pyramid) and M4. There is a flat mirror, M5, between M6 and M4 which directs the beam away from the mixers and LO multipliers. The flat mirror M3 directs the telescope beam into the HET receiver box.

Local Oscillator power comes into the mixers from the LO multiplier chain through two lenses forming a Gaussian Beam Telescope. One of these lenses is integrated into the mixer module, while the other one can be mounted on a 20K thermal shield. The lenses can be made of teflon or crystal quartz with anti-reflecting coating.

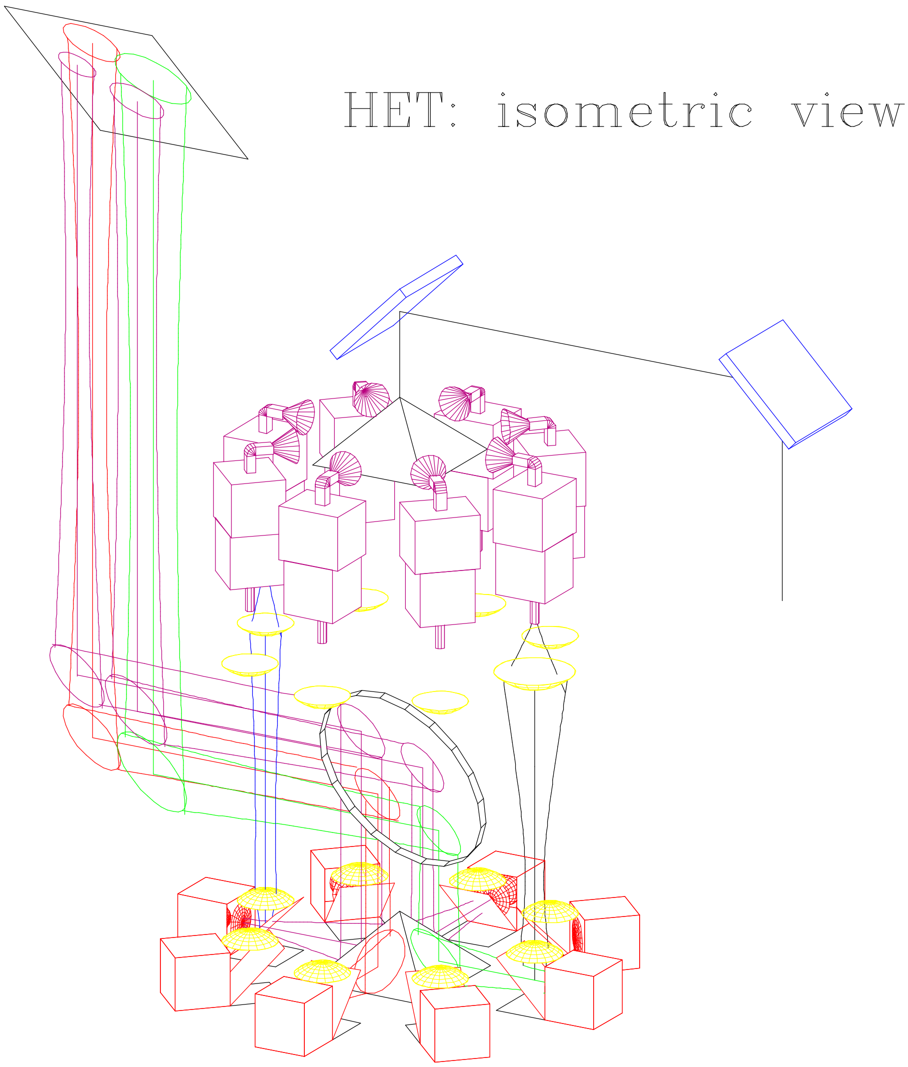

Figure 1: This isometric view of the HET shows the eight mixer units at the bottom attached to the cold plate, and arranged in a ring around the pyramidal switch mirror. The four beams shown are the accurate drawings of the 35dB edge taper of Gaussian beams for frequencies 490GHz, 695GHz, 1130GHz, and 855GHz (anti-clockwise from the right). The two beams shown coming straight down through two lenses are the LO for 490GHz and 1130GHz (the others are not shown for clarity). Above the ring of mixers sits a similar ring consisting of the LO multiplier chains. At the top left is the mirror M3 which directs the beam to the FIRST telescope.

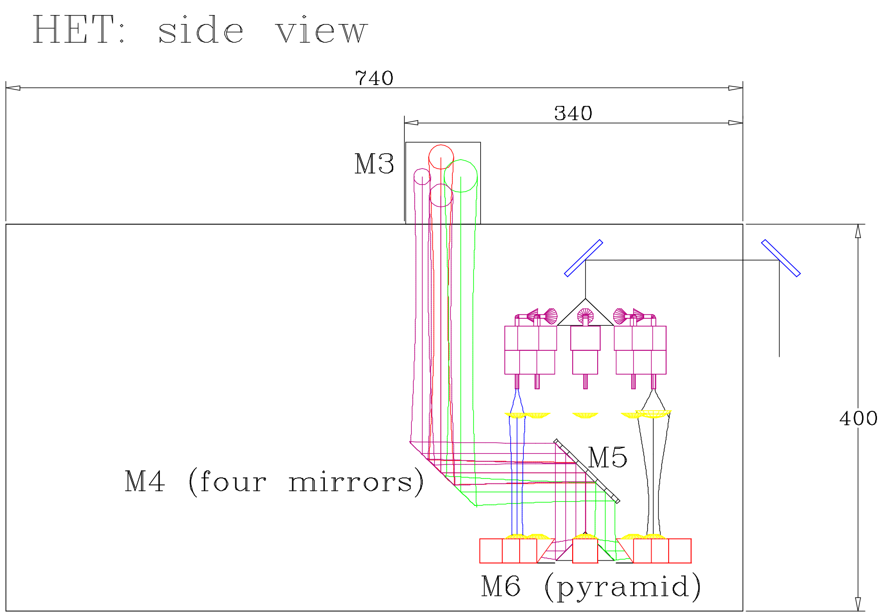

Figure 2: The side view of the HET design shows some dimensions indicating that the entire system fits into less than 50% of the volume presently reserved for this instrument**.**

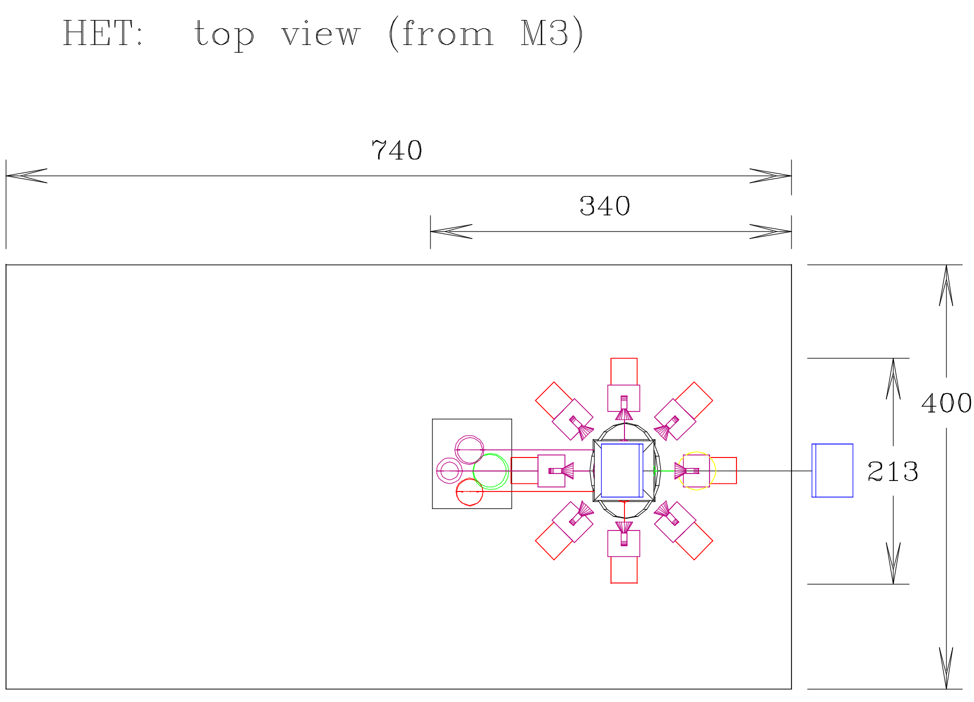

Figure 3: This is a view from the direction of the mirror M3 (the top view). The circular foot prints of the Gaussian beams on M3 can be seen on the

left. The HET design takes up less than half the available space now reserved in FIRST.

The SIS Mixer Assembly

Table 1 gives the frequency bands of the 8 mixers. With the simultaneous operation of four mixers, the HET gives continuous coverage in the bands 480-1090GHz or 550-1170GHz. This is accomplished by the pyramidal mirror M6 which switches the optics between mixers #1, #3, #5, #7 and mixers #2, #4, #6, #8. There is redundancy built into the system by the overlapping of the mixer operation bands. In the case of failure of the M6 switch mirror, we still have continuous coverage of either the 480-1090GHz band or the 550-1170GHz band.

Table 1

	Frequency Range [GHz]	Overlapping BW with	% of BW	Polarisation
Mixer #1	480-620	Mixer #2	25%	‖
Mixer #2	550-690	Mixer #1, #3	23%	⊥
Mixer #3	620-770	Mixer #2, #4	22%	‖
Mixer #4	690-850	Mixer #3, #5	21%	⊥
Mixer #5	770-930	Mixer #4, #6	19%	‖
Mixer #6	850-1010	Mixer #5, #7	17%	⊥
Mixer #7	930-1090	Mixer #6, #8	16%	‖
Mixer #8	1010-1170	Mixer #7,	15%	⊥

Each mixer module consists of a submillimetre SIS mixer (25x25x25 mm^3), a beam-splitter for quasi-optical LO injection, a termination load, and a teflon or quartz lens to collimate the LO input beam (see Figure 4). The beam splitter is a crystal quartz substrate at 45° to the input beam with thickness chosen to provide 10/90 power splitting across the band of operation. At present we consider a quasi-optical SIS mixer which includes a silicon hyperhemispherical lens (with anti-reflection coating) and an extra objective lens for better control over the beam profile [Zmuidzinas, 1994]. There is potential for further simplification of the mixer by using an elliptical lens in place of the hyperhemispherical lens. This gives a good beam profile and does away with the need for a secondary objective lens. The fixed tuned SIS waveguide mixer could also fit naturally into the design, in which case, it should be equipped by a scalar horn, or a lens corrected horn at the higher frequencies where corrugations are more difficult to manufacture.

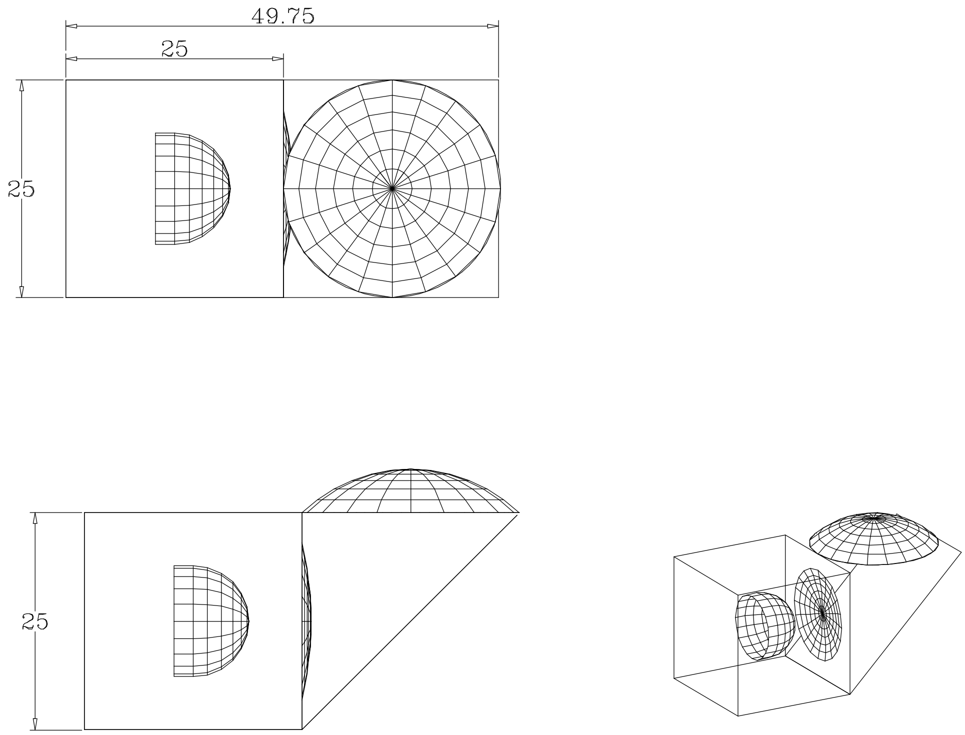

Figure 4 Each mixer unit incorporates a 90/10 beam splitter with an absorber below to take the unused LO power, and a lens above to couple the LO into the mixer

The mixers will likely have linear polarisation, especially if they are waveguide type mixers. The nature of the pyramidal mirror means that mixers on adjacent arms of the pyramid will receive opposite polarisations (see Figure 5).

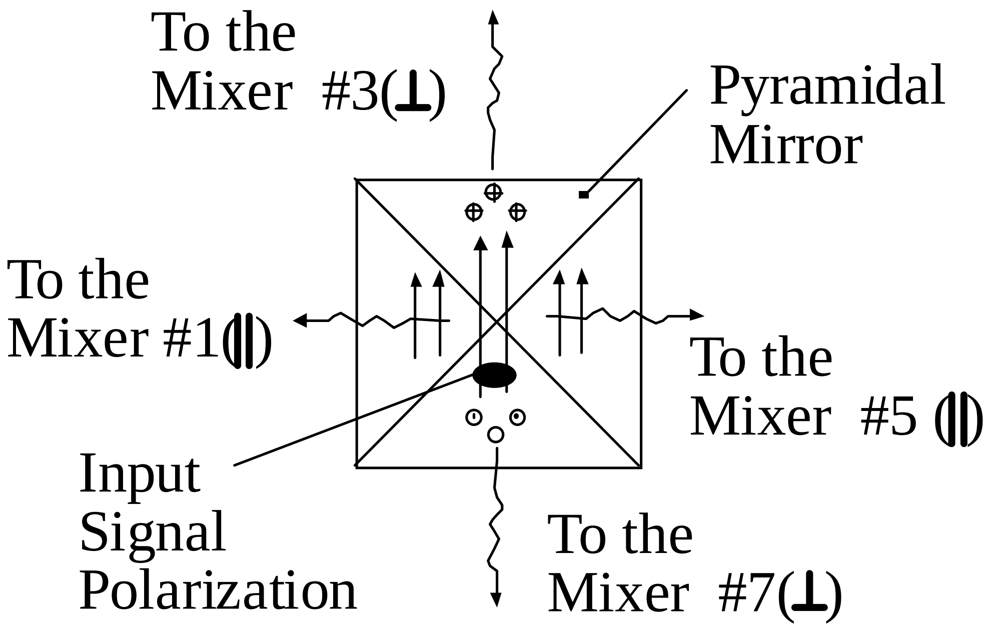

Figure 5: Schematic of the pyramidal mirror as viewed from above. Each mixer receives the polarisation orthogonal to that of its neighbour. Mixers #1 and #7 should have their polarisation axis orientated at 90° to that of mixers #3 and #5.

The IF System

Integrating the first stage of IF amplifier into the mixer module would be the most desirable solution. This eliminates the need for matching the SIS mixer to the IF amplifier through a 50Ω cable. The SIS mixer can instead be matched directly to the IF amplifier, providing an efficient coupling which is especially important for high IF (10 GHz, for example).

The problem to overcome with the integrated IF amplifier is the relatively large power dissipation in the vicinity of the SIS mixer. However, one can be optimistic about on-going work with Indium Phosphide transistors (see Heterodyne Instrument Concept for FIRST, M. Frerking ed.) This technology will be ideally suited to integrated low noise IF amplifiers in SIS mixers.

The LO Sources

The Local Oscillator chain consists of multipliers sitting inside the HET box, and pumping sources outside. The multipliers are pumped quasi-optically by the pumping source at around 90GHz. As with the mixers, the LO multipliers form a ring around a pyramidal focussing mirror. A 45° rotation of the pyramidal mirror switches the pumping signal between pairs of multiplier chains, which must be coordinated with the M6 and M4 switches.

To operate four mixers simultaneously we need four LO sources, hence 4 pumping oscillators at different places away from HET box.

Single Side Band Capability

In the present design we do not include Single Side Band capability. However this can be done by replacing the flat mirror M5 above pyramidal mirror M6, with a polarisation interferometer of the same type described in the PDD. There is room to include the grid and image load. Since the mixer beams do not overlap at M5, the SSB filter can be made as a ring of separate interferometers tuned individually for each frequency band.

Data Correlation in Post Processing

It is worthwhile considering the use of digital recording of the IF signals instead of having onboard spectrum analysers as backends. Analog-to-Digital Converters have made great progress recently, and real time data compression techniques can reduce data file sizes by factors of 2 to 2,5. Solid state mass-memory, possibly together with a very fast hard disk could easily handle the temporary data storage. Removing backend spectrometers from the payload takes away a great deal of mass and power consumption from the satellite. Mass memory would be much more light weight, and requires much less power. Such a scheme moves the complexity of data correlation onto the ground where there are no constraints on power consumption or processing complexity. Also, the primary data is then available for subsequent reprocessing by improved techniques to be developed in the future.

Summary

The HET design is very compact. There is plenty of space for IF cabling, DC bias and magnetic field wiring and also to put the first stage of IF amplifiers in the close vicinity of the mixers (as an alternative to integration of the IF amplifier into the mixer module). The design takes up only 50% of the volume presently reserved for the HET on FIRST.

The mixers are each separate modules, placed far enough from each other to avoid interference of the magnetic field used for Josephson current suppression across the SIS junction. Mixers can be independently replaced during the process of assembling and tuning of the receiver without disturbing other components. Each mixer module incorporates a beam splitter, absorber, and anti-reflection coated lens for LO coupling which simplifies optical alignment since each mixer module is a pre-aligned package.

Each frequency band has individual optics (shared by two mixers with the overlapping frequency bands) and optimised for this frequency. There are no grids, dichroics, nor lenses in the signal path resulting in a much less lossy optical system.

We need one optical switch (M6) working at cold plate temperature and rotating mirror M4. The most critical situation would be the simultaneous failure of

M4 and M6 stalling in opposite positions, as well as failure of the switch in the LO system. The mechanical design of these switches must consider forced positioning to prevent total HET Instrument failure (*ie.* A fail-safe operation).

This optical scheme is very flexible and can be modified to accommodate alternatives. Single side band operation can be realised by adding a filter at the flat mirror M5 in a manner similar to that suggested in the PDD. Internal calibration is possible by introducing a chopper mirror between M4 and M3 which throws the mixer beam onto a calibration load.

As the mechanical switch at the cold plate is a potential trouble spot, we have devised a solution to avoid using rotating mirrors. The set-up would consist two rings of four mixers, instead of one ring of eight. The resulting receiver would take up twice the space of the design considered in this paper (*ie.* It would fit into the present HET box, as specified in the PDD) but it would have **no** mechanical switches.

References

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