MMA Project Book, Chapter 3 Section 2.

Calibration: Hardware Schemes

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Revision History
1998-07-16: First version.
1998-11-12: Principal Milestones added, minor updates

Summary

In this section, hardware solutions to the problem of calibrating the MMA amplitude and phase are described. Both solutions use the blocked area in the center of the subreflector as the source of radiation from either a two-temperature load or a coherent signal source. A simple mirror mechanism is used to select between the two systems. The coherent source may be made phase stable through a round-trip measurement scheme so raising the possibility of continuous phase measurement and correction as well as providing a valuable trouble shooting tool.

Table 3.2.1 Principal Milestones in Hardware Calibration Schemes

	Task	**Completion Date**
1)	Demonstration of two temperature load. Hat Creek.	1999-October
2)	Demonstration of coherent calibration signal with round trip phase measurement.	1999-March

3.2.1 Introduction

The previous section describes a number of schemes for calibrating the MMA amplitude and phase. This section outlines two specific hardware calibration schemes which can help to calibrate the instrumental phase and amplitude of the MMA. Other instrumental calibration schemes, such as round-trip phase calibration for the local oscillator, and AGC/total power monitors in the I.F. chain, are described elsewhere.

The two calibration schemes outlined here are:

Absolute temperature sensitivity calibration, single dish mode

Relative amplitude and phase calibration, with an artificial coherent calibration signal suitable for interferometric calibration

3.2.2 Absolute Temperature Calibration

This technique is only relevant to single dish total-power observations; it has been suggested by Jack Welch and others, and is currently (July 1998) the subject of a joint MDC development between BIMA and NRAO. It gives an absolutely calibrated signal of a few K at the receiver, over the complete frequency range covered by the MMA. It has been described in MMA Memo 225 by Bock, Welch, Flemming and Thornton.

The essence of this technique is that a black body radiator is placed at the center of the subreflector of each antenna, within the unused area of subreflector matching the central blockage of the antenna. In this way there is no effect on antenna sensitivity.

Within this central part of the subreflector, a plane mirror switches between two (or more) hot loads of different temperatures. The two loads have very precisely controlled and calibrated temperatures. The total power output of the receiver is sampled synchronously with the mirror switching between the two calibrated loads.

The added switched receiver noise is, to a first approximation, equal to the difference in temperature of the two hot loads, multiplied by the beam solid angle of the absorbers at the subreflector seen from the receiver feed, divided by the beam solid angle of the subreflector - assuming the receiver feed itself is matched to the angle subtended by the receiver. This ratio will be reasonably constant with frequency, but at a given frequency can be calibrated precisely by measurements of the feed antenna pattern.

For more details see the memo by Bock, Welch, Flemming and Thornton. The joint development with BIMA will show, on a timescale of a few months, how well the technique can be expected to work in practice.

3.2.3 Interferometric relative phase and amplitude calibration

In the debugging stage of the MMA, there will be a need for a generic test signal that can be used to debug the entire electronic system of a given antenna or antenna pair, from front-end to correlator. When the antenna surface and pointing are sufficiently reliable, astronomical sources can be used for this purpose, but having an independent, artificially generated signal that is not dependent on antenna performance will be invaluable in checking out and maintaining the system.

If the calibration signal can be made coherent at all individual antennas, it opens up the possibility of calibrating the entire receiver system, front-ends, back-ends and correlator, amplitude and phase as a function of frequency, in a way independent of antenna tracking, pointing, or efficiency performance. The calibration system should be sufficiently stable that it can be used as a secondary calibration system, with only occasional cross-calibration with astronomical sources.

3.2.4 The Photonic Calibration System

The photonic calibration system has a broad-band, radiating antenna situated at the center of the subreflector, where no extra antenna blockage is introduced. At the feed of the broadband antenna, there is an uncooled photomixer device. A single optical fiber, carrying laser signals generated at a central laboratory or control room, feeds this photomixer. In the simplest form, the optical signal would come from two lasers, whose difference frequency corresponds to the telescope observing frequency, and which is phase-locked to the telescope frequency standard. The equipment required to do this would be nearly identical to that being developed for the photonic laser local oscillator system. Only one pair of lasers would be required for the entire array; the combined laser output would be split optically N ways (where N is the number of antennas) and routed via N independent fibers to each antenna.

In slight variants of this scheme, either a single laser signal, or the dual laser system tuned to the required mm-wave difference frequency, could be modulated. The modulation might take the form of a regular comb spectrum, simulating broadband noise. This becomes quite analogous to the pulse cal system developed for the VLBA, and could be used for checking the relative amplitude and phase response over the entire interferometric IF passband. The modulation might also be a truly random, or a pseudo-random digitally generated sequence, which would also provide a broad-band coherent test signal. This random or pseudo-random noise needs to be coherent at each antenna, so timing considerations, within a fraction of the reciprocal bandwidth, are important.

Naturally this injected signal needs to be stable, both in amplitude and phase. It may require round-trip delay compensation of some type, and perhaps an AGC system to keep the signal amplitude constant. However, attention to the stability of this calibration signal may relax the technical requirements elsewhere in the system.

Most of the development for this coherent photonic calibration scheme is already being undertaken in the context of the photonic local oscillator development. The calibration scheme should in principle be much simpler, because several orders of magnitude lower radiated mm-wave power is required. The main additional development needed is that of the broad-band radiating antenna, to be sited at the subreflector, fed by the signal from the photomixer. The broadband antenna is the subject of a joint NRAO-MDC (OVRO) development project.

3.2.5 Combined Calibration System

The incoherent calibration scheme described earlier switches between blackbody radiators of different temperatures using a mirror. In principle, by allowing an extra position on this mirror, the radiated calibration signal can be switched between the incoherent blackbody loads and the coherent radiator. At a later stage in the development, when the feasibility of both coherent and incoherent calibration schemes has been demonstrated, the combination of the different calibration radiators into one package will receive attention, as will studies of how to achieve the necessary amplitude and phase stability.

3.2.6 Work to be done

Much of the work is being carried out at BIMA (incoherent calibrator) and OVRO (coherent calibrator). The photonic calibration builds on work already in progress in the context of the photonic local oscillator scheme, with the exception of the broadband antenna. Some simple design work is required now (e.g. exactly how much coherent power needs to be radiated from the subreflector, with what requirements on amplitude and phase stability?) but the bulk of the effort can be expected fairly late in the MMA development phase.

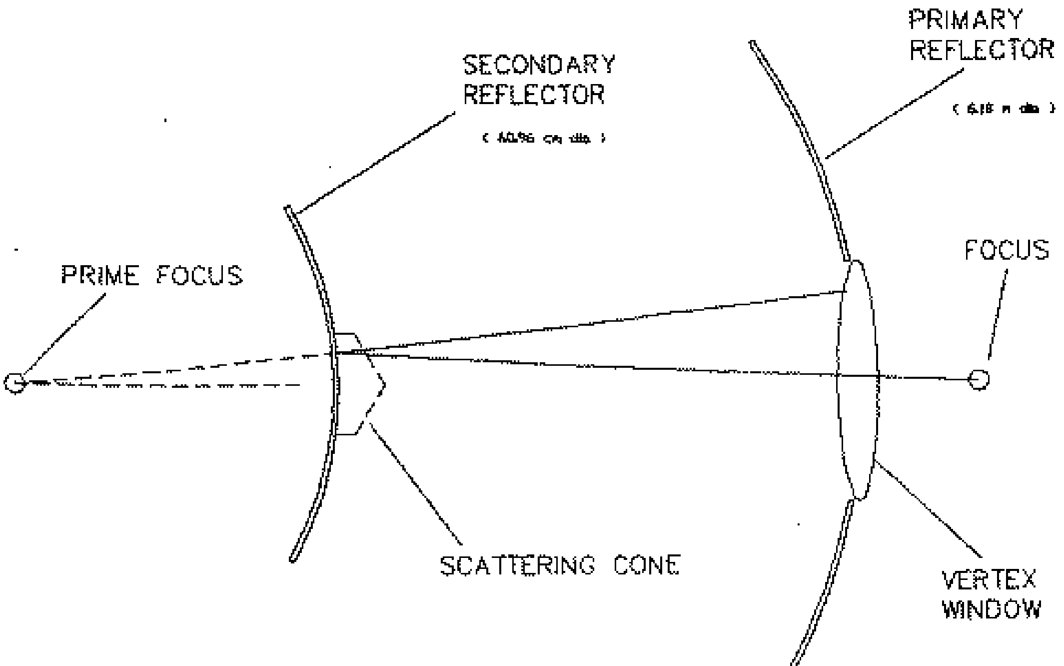
Reference:

D. Bock, J. Welch, M. Flemming and D. Thornton, MMA Memo 225: *"Radiometer Calibration at the Cassegrain Secondary Mirror."* (See also the Appendix below.)

APPENDIX

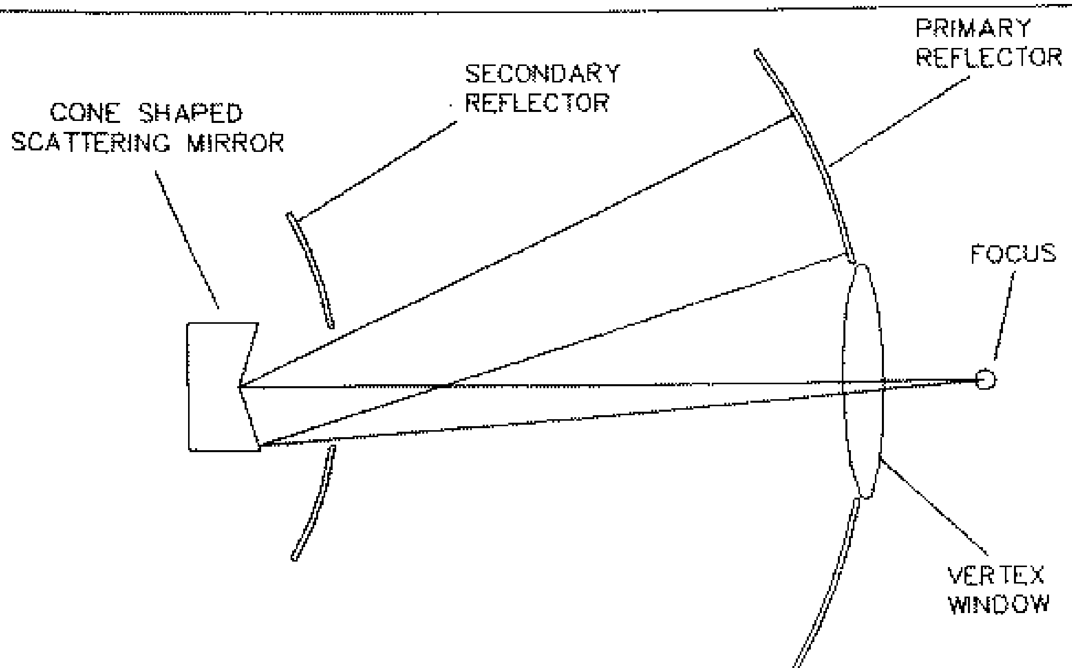
The following figures are from the MMA Memo 225 by Bock, Welch, Fleming and Thornton, *"Radiometer Calibration at the Cassegrain Secondary Mirror."*

Figure 1 shows the general Cassegrain optics, which normally has a scattering cone covering the central part of the subreflector to direct unwanted rays on to cold sky. **Figure 2** shows a scattering mirror behind the subreflector, giving much the same effect.



OPTICS

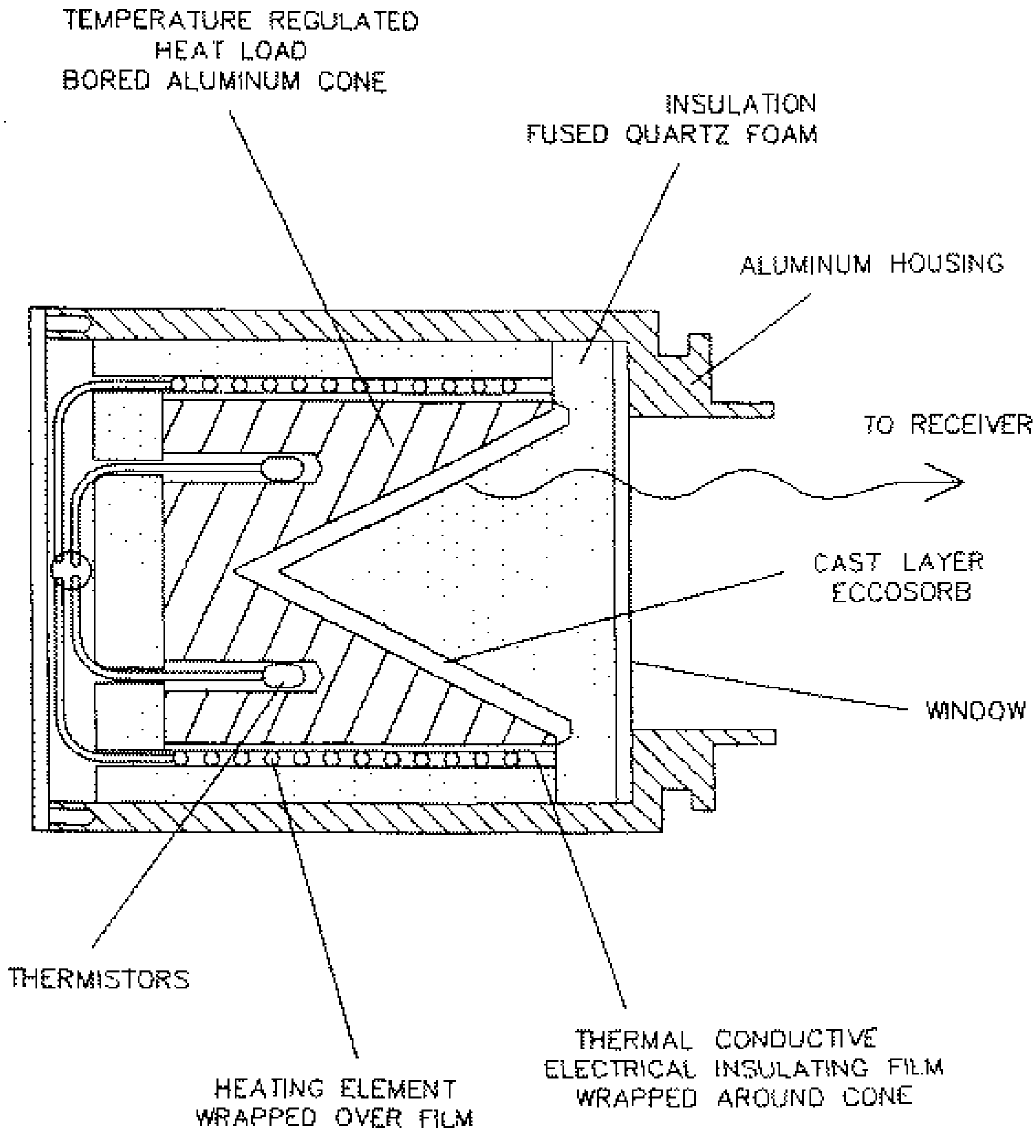
FIGURE 1



SCATTERING MIRROR

FIGURE 2

Figure 3 shows the absorbing black body load that would be placed behind the central hole of the subreflector



BLACK BODY LOAD

FIGURE 3

Figure 4 shows the arrangement of a rotating 45-degree mirror which will choose between one of two hot loads, whose temperatures differ by ~100 K, and the scattering cone from which rays which eventually reach cold sky.

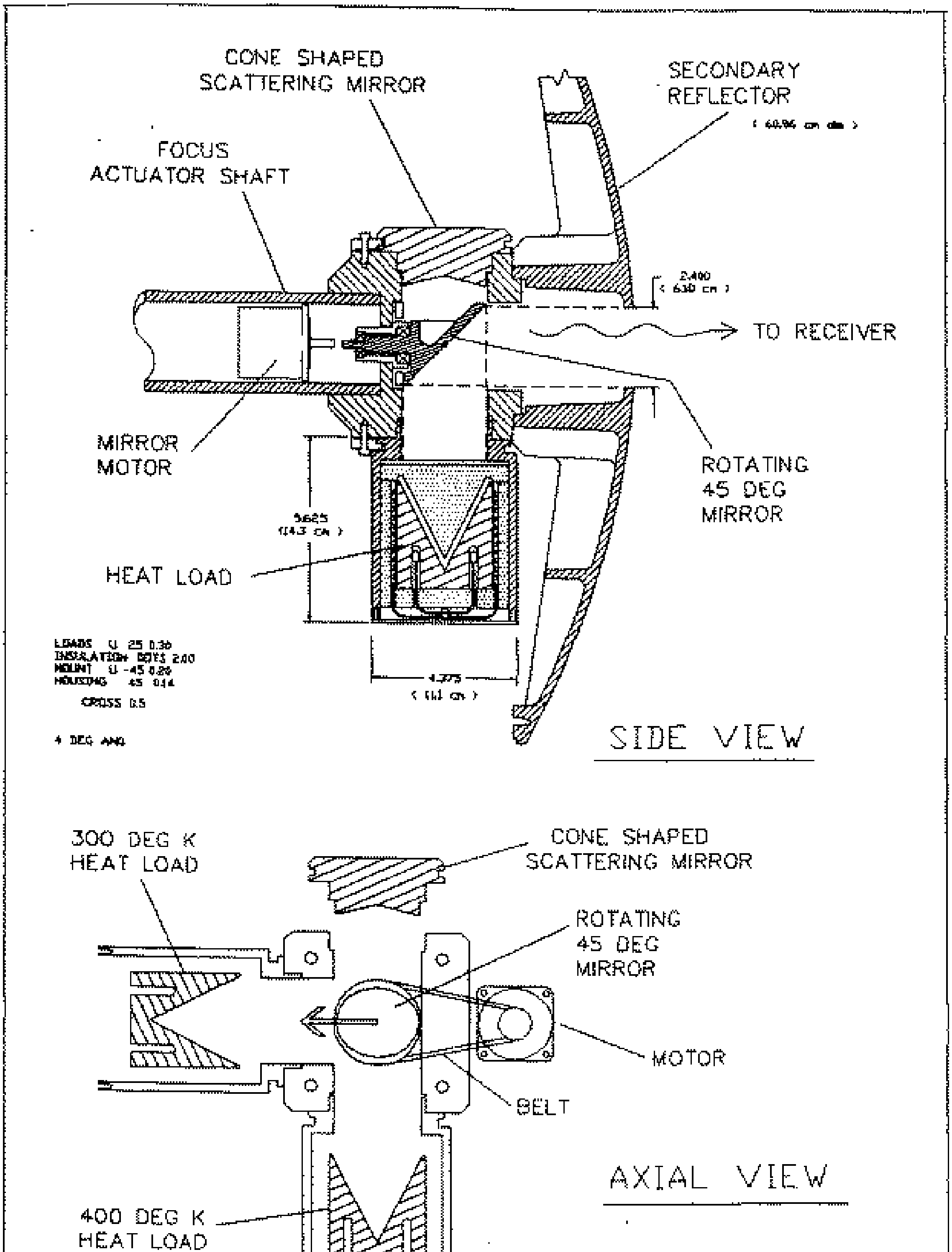

CONE SHAPED
SCATTERING MIRROR
SECONDARY
REFLECTOR
FOCUS
ACTUATOR SHAFT
TO RECEIVER
MIRROR
MOTOR
ROTATING
45 DEG
MIRROR
HEAT LOAD
SIDE VIEW
300 DEG K
HEAT LOAD
CONE SHAPED
SCATTERING MIRROR
ROTATING
45 DEG
MIRROR
MOTOR
BELT
AXIAL VIEW
400 DEG K
HEAT LOAD

FIGURE 4