Interoffice

NATIONAL RADIO ASTRONOMY OBSERVATORY

TUCSON, ARIZONA

April 3, 1980

To: H. Hvatum

From: J. M. Payne JP

Subject: 25-m Electronic System

Attached is a memo that briefly outlines the 25-m electronic systems, a best estimate of the cost and suggestions as to who should work on the various parts of the system.

Some of the work that needs to be done will carry on regardless of the 25-m funding. Receiver development, for instance, will obviously continue. At some point we are going to have to commit manpower to those items that are peculiar to the 25-m project.

Certain jobs that have to be done may require a longer period than the year of design work. The two that come to mind are:

1) A reference platform, if needed.

2) Work on setting the surface, particularly the laser ranger.

Some things need to be done soon regardless. The most important that come to mind are:

1) Do we need a reference platform?

2) A complete set of mechnaical parameters for the servo design.

3) Access to the vertex room must be provided.

These points are important in that they may affect the structure of the instrument.

I'm sure I've forgotten some things in this quick estimate but at least it is a start and maybe we can discuss it when I'm in Charlottesville at the end of April.

c: M. Balister
S. Weinreb

Memo #1

25-M Electronics

J. M. Payne

4/10/80

Introduction

The purpose of this memo is to define the electronic systems required for the 25-m telescope, to give approximate costs and construction times and also to suggest ways in which the systems may be built with minimum disruption to our maintenance of the 36' telescope.

It appears that in Tucson, Charlottesville, Green Bank, and the VLA we have people in the electronics division that are enthusiastic about working on the 25-m telescope. All these people have expressed a willingness to move to Hawaii for a couple of years. It certainly seems feasable to build the electronics for the 25-m by having people at the various sites produce certain well defined parts of the electronic system, although there are obvious disadvantages to such a scheme.

At the end of the memo is a table giving the various items in the system, their cost, construction time, where best fabricated and who could work on them. These estimates are, of course, very preliminary and will be refined later.

The basic components of the electronics system will be briefly described.

The Telescope Optics

The design parameters of the optics for the 25-m are as follows:

Diameter	25-M
Focal Length	10.5-M
Subreflector diameter	1.4-M
Magnification	15.8

This proposed optical arrangement represents a series of compromises. Accepting the fact that the telescope will be used mainly in the Cassegrain configuration, for a given $\frac{F}{D}$ for the main reflector one has flexibility in changing the size of the secondary mirror. The advantages and disadvantages of a large secondary are listed below.

Advantages	Disadvantages
1) Diffraction losses minimal at lowest frequency of operation.	1) Large blockage reduces gain and increases sidelobe level.
2) Lower baseline ripple for spectral line observations.	2) Low off axis scanning without high coma.
3) Feed design is simpler for low magnification optics.	3) High torque required for nutation.
	4) Rapidly converging beam at vertex may lead to high loss in quasi optical devices.
	5) Accuracy is difficult to achieve for large diameters.

It is interesting to compare the other NRAO telescopes.

Telescope	Ratio of diameter of subreflector to diameter of main reflector
140'	0.075
36'	0.042
VLA	0.092
25-M	0.056

For an 11 dB taper at the edge of the subreflector we have the following approximate feed diameters:

λ	Diameter of feed, CM
9 mm	14.4
3 mm	4.8
2 mm	3.2
1.2 mm	1.9
0.87 mm	1.4

At the longest wavelength the diffraction losses due to the subreflector are 3%.

One important question that has to be answered is how easily may quasi optical devices be incorporated into the proposed geometry. The f/13.8 beam at the 36' telescope has some definate advantages. The slowly converging beam makes the secondary focus an ideal place for various quasi optical devices. Another way of saying the same thing is that the large aperature required to illuminate the small subreflector provides a large wave front that is essentially plane for a conveniently large distance in front of the aperature.

A good example of a quasi optical device is the diplexer we now use on the cooled 2 mm receiver. The low loss through the device dpends on splitting the signal from the subreflector and then recombining the two resultant beams, one of which is delayed by two aperature diameters. Erickson and Martin have derived expressions for such losses in the case of Gaussian beams, a very close approximation in the case of lens corrected scalar feed horns. Applying their expressions to a diplexer designed around the feeds above we calculate a loss to the signal of 0.02 dB.

The device scales linearly with frequency and this loss remains constant (resistive losses are not included). The percentage instantaneous bandwidth remains the same, changing from a 3 dB bandwidth at 3 mm of 1.5 GHz to 5.36 GHz at 0.87 mm.

Also of interest are the various parameters that affect the pointing and the ease with beam switching may be accomplished by switching the subreflector.

Change in main beam direction for lateral shifts in vertex feed position	1.2 arc sec/mm
Change in main beam direction for lateral shifts in subreflector position	18.3 arc sec/mm
Change in main beam direction for rotation of subreflector (assuming no translation of subreflector vertex)	-6.8 arc sec/min

To switch 3 beamwdiths at a wavelength of 9 mm will require a subreflector rotation of approximately 40 arc minuts. The 140 ft system uses a subreflector 3.2M in diameter and switches 140 arc minutes in 40 milliseconds so nutating the subreflector at 5 Hz should be possible. In view of the high precision required of the subreflector and the structure generally we should consider other means of beam switching. One possibility is shown in figure 4. A simple beam switching system is incorported in the optics associated with each receiver and consists of a reflecting chopper wheel that displaces the beam at the secondary focus. For a transition time of 0.1 of a half cycle the largest wheel diameter (at 3 mm) required would be 30 cm. The plate scale at the receiver is 1.2 arc seconds/mm so in order to switch three beamwidths at 3 mm the distance d has to be 3.6 cm. This arrangement has the advantage that high switching rates are possible.

The relatively high magnification (16.3) results in a standing wave that may prove troublesome in spectral line observations. B. L. Ulich has calculated the ratio of peak to peak standing wave amplitude to total power to be 0.24 λ % for this particular geometry. For a total power signal of 100K for λ = 1 mm the 0.24K peak to peak amplitude standing wave could seriously impare the quality of spectral line observations especially when frequency switching. Fortunately the high magnification also results in a large depth of focus at the secondary focus. This means that the path length from the subreflector to the receiver feed may be modulated by mechanical means to change the phase of the scattered signal from the subreflector by many wavelengths during an integration period. For a decrease in gain of 2% the pathlength may be changed by approximately 34 λ. Our experience at the 36-ft suggest that such a modulation should reduce the effect of the standing waves to negligable levels.

One potential problem with the proposed design is the accuracy requirement on the subreflector. We are hoping for an RMS surface accuracy on the panels of at least 40 μM and ideally the effects of subreflector surface errors should be negligable compared to those contributed by the panel errors. Ike Ghozeil of KPNO gave me an informal estimate of less than 20K for the optical shop to grind a roughly shaped aluminum blank to a final surface to better than 10 μM RMS.

Figure 1 shows one method of positioning the various receivers in the vertex room. A particular receiver may be selected simply by rotating a plane mirror inclined at 45° to the incoming beam. A mirror 30 cm in diameter positioned in the azimuth and elevation axes by an 18 bit encoder would be satisfactory. A particular receiver may then be calibrated by rotating the mirror by 90° in elevation as shown in figure 2 so that the selected receiver input is terminated in a load maintained at a known temperature by a closed cycle refrigerator.

The receivers in this scheme would be mounted vertically with a path length modulator/focussing arrangement mounted above each receiver as shown in figure 3. The individual focussing of each receiver is provided to accommodate different path lengths between receivers during dichroic operation which could easily be accommodated by replacing the mirror with a dichroic plate and several plane mirrors.

An alternative method of mounting the receivers is to mount four receivers in a circle around the telescope axis. This configuration results in a more crowded environment for working on the receivers. Also as Peter Napier points out, for the two circulary polarized beams to be coincident to 2% of a beamwidth the different receiver feeds have to be placed on a circle of less than 30 cm in diameter.

Spectral Line Receivers

At the present time it is unclear which devices will give the best spectral line receivers at millimeter wavelengths in the next year or so. Shottky barrier mixers followed by a low noise IF amplifier (possibly a maser) are one possibility. With today's components we could expect a single sideband receiver temperature of 100-150 K at 3 mm. Another possibility is the new SIS junctions that seem to offer extremely low noise. The exact form of the receiver probably will not greatly influence the cost and manpower needed to produce the receivers. We should plan on four receivers to cover the 3 mm, 2 mm, 1.2 mm and 0.87 mm atmospheric windows..

John Archer's recent work on doublers promises far more trouble free local oscillator systems for the future. It seems that solid state sources may replace klystrons in the future, a development that will greatly reduce both the cost and the difficulty of operation at millimeter wavelengths.

My feeling is that the optical and electronic portions of the receivers will not be greatly influenced by what device is used as the mixer. In fact the design of the basic receiver could probably begin almost immediately.

The operating temperature of the receiver could have a large impact on the cryogenics installation. I believe we should keep all the receivers cold whenever possible.

Continuum Receivers

The most senstive continuum receiver for the future appears to be a background limited bolometer system. Simultaneous observations in the 3 mm, 2 mm, 1 mm and 0.87 mm windows should be possible by using quasi optical filters and having four detectors in the same dewar. This is a major job and we may initially want to have one detector with selectable filters. To operate a 0.3 K refrigerator on Mauna Kea will require the development of a closed cycle ^{3}He refrigerator. We should start on this job as soon as possible.

A background limited ^{3}He system should have a sensitivity of approximately 5 mJ/ sec in the 1.2 mm atmospheric window.

LO System

It is anticipated that the expensive and troublesome klystrons that we now use as local oscillator sources will be replace over the next few years by solid state sources driving frequency multipliers. We should plan on having two separate LO systems at the telescope in order to operate at two frequencies simultaneously. Another point that should be made is that there seems to be the possiblity that we may operate an interferometer in conjunction with the Leighton 10-m antenna. We should therefore build the LO system with an eye towards operating a second phase stable LO remote from the 25-m LO system.

Spectrometer

It seems we have a basic choice to make as regards the spectrometer. Do we stay with filter banks or do we develop something new? We will need a bandwidth of 500 MHz; an extremely difficult specification for an autocorrelator to meet in a clean manner. The accousto optical analyzer is an attractive, apparently simple alternative to filter banks. There do seem to be some snags however and one wonders if we can really afford the man power to develop the device. Itek has recently announced an accoustic optical analyzer that has a bandwidth of 500 MHz. The price is $ 55K and perhaps we should invest in one or maybe loan one for evaluation. There are so many other jobs to do on the telescope that require a high level of engineering talent that the best decision may well be to stick with something we know all about. The filter banks at the 36' are very reliable and we could probably build versions with higher stability components with a minimum of engineering effort. Resolutions below 100 kHz could be obtained with either a spectrum expander or a correlator.

Telescope Drive & Servo

The design of the electronic part of the drive and control system should be very straightforward. In my opinion it is of the utmost importance to establish the mechanical parameters of those parts of the telescope that become an integral part of the servo. Locked rotor resonant frequencies, viscous friction, stiction, interaction between track and readout, etc. Once numerical values are assigned to these quantities we can design a servo system in a few days that will work.

This is what happened on the 45' system and as I recall we saved a considerable sum of money.

I notice that Bill Horne has estimated 18 man weeks of NRAO time to prepare specifications that will enable an outside company to do a paper analysis and design for the servo. I feel strongly that this is a mistake and is quite simply a waste of money. The NRAO effort on the drive system should concentrate on the mechanical aspects of the servo. We don't want a repeat of the German 100-m experience. If the drive is mechanically sound the servo will work.

The 65-m servo design is a good example of us paying for a so-called analysis that is merely an exercise in simple servo theory. I see no reason to pay someone to spend weeks figuring on a hand calculator when we have programs set up to do the same job in minutes.

There seems to be a possibility that we will resurrect the reference platform concept for the 25-m. If this is the case I would suggest that we do not revert to the very cumbersome 65-m concept that incorporated seven autocollimators. I believe that technology has changed over the years and we should re-examine the inertial platform concept. Bob Cameron of NASA, Ames gave me information on the stable platform in the C141 airborne observatory. In a benign environment (i.e., aircraft on the ground) the table drifts by less than 0.1 arc sec/hour. Gerald Ouellette of the Draper Lab gave me information on the platform stability of the O.A.O. The satellite has been in orbit for 8 years with the gyros running continuously and the drift is less than 1 arc sec/hour. Ouellette seems to be an expert on the general problems of pointing telescopes with high accuracy and I think a visit by someone from NRAO would be worthwhile.

With a highly stable platform one could rely on a single autocollimator on the ground to check and correct the platform whenever the autocollimator beam was unobscured. Note that the platform would always be "looking" at the autocollimator so that updating would be automatic whenever the autocollimator received an adequate return signal.

Compute Control and Data Reduction System

This will be the subject of a future memo. Betty Stobie is working on a system and the first figure for all the computer equipment is 200K.

Surface Setting

Setting the surface of the instrument to the required precision is a very difficult task and J. W. Findlay will require help from the electronics group very soon. The development of a well engineered laser ranger of the accuracy required (better than 40 μM) will need at least a year from a good engineer and probably a year from a technician. The consolidation of the stepping bar, the laser ranger and the gravity referenced beam into a complete measuring system is a major task. To be certain that we can set the surface to the required accuracy we should start work on the most difficult components (the laser ranger) as soon as possible.

Manpower and Cost Estimate

25-M Electronic Systems

Note: Machine shop costs are not included.

Labor estimates in man years

Cost estimates in K$

Telescope Optics

	COST	LABOR	ENGINEER
Subreflector	40	0.2	?
Steerable Mirror and Controls	12	0.5	Lacasse
Optical Design	–	0.5	Fisher
Nutating Mechanism?	20	1.0	Brockway
Feeds, Lenses, Receiver Optics	20	0.5	Fisher

Total 92 K 2.7 MY

Note that the subreflector positioning mechanism is not included.

Continuum Receivers

	COST	LABOR	ENGINEER
Closed cycle ^{3}He system	50	4	Nolt
Single Channel Frequency Selectable System	30	2	Nolt
Channel Dropping System-Multidetectors (May be delayed)	50	3	Nolt/Davis

Total 130 K 9 MY or 80 K 6 MY For single Channel

Spectrometer

		COST	LABOR	ENGINEER
512 Ch	1 MHz/Ch	25	1	Mauzy
	500 kHz	25	1	
	250 kHz	25	1	
	100 kHz	25	1	
Multiplexer		25	1	?
Digital Interface		10	0.5	?
Spectrum Expander		20	1	Lacasse

Total 155 K 6.5 MY

Note this assumes conventional filter banks.

Line Receivers

	COST	LABOR	ENGINEER
70-120 GHz	150	2.5	?
130-170 GHz	150	2.5	?
190-310 GHz	150	2.5	?
325-360 GHz	150	2.5	?
Calibration System	20	0.5	?

Total 620 K 10.5 MY

Note: Estimate for receivers assumes a maser IF.

Local Oscillator System

	COST	LABOR	ENGINEER
LO System	50	2	Archer

Telescope Drive and Servo

	Cost	Labor	Engineer
Servo	190	1.5	Payne or Lacasse

This assumes a complete structural analysis has been made and that all mechanical parameters are known.

Instrumentation for Setting Surface

	Cost	Labor	Engineer
Electronics for stepping bar	5	0.5	Lacasse
Laser ranger	20	2	Brockway

Total 25 K 2.5 MY

Auxiliary Instrumentation

		COST	LABOR	ENGINEER
(1)	Focus Servo	8	0.3	
(2)	Polarization Servo	8	0.3	
(3)	Elevation Servo	8	0.3	
	Temp Monitors	5	0.5	
	Astrodome Servo	30	1.00	
	Weather Instrumentation	7	0.1	
	Microwave Link	100	0.5	?
	Water Vapor Monitor	20	1.0	

Total 187 K 5.0 MY

(1), (2), and (3) include electronics and motors but not the mount.

Receiver Cabling

Cables, Connectors, Etc. 90 K

Total Cos of electronic systems: 1532 K and 40 MY

Note: Temperature control of vertex room is not included in this estimate.

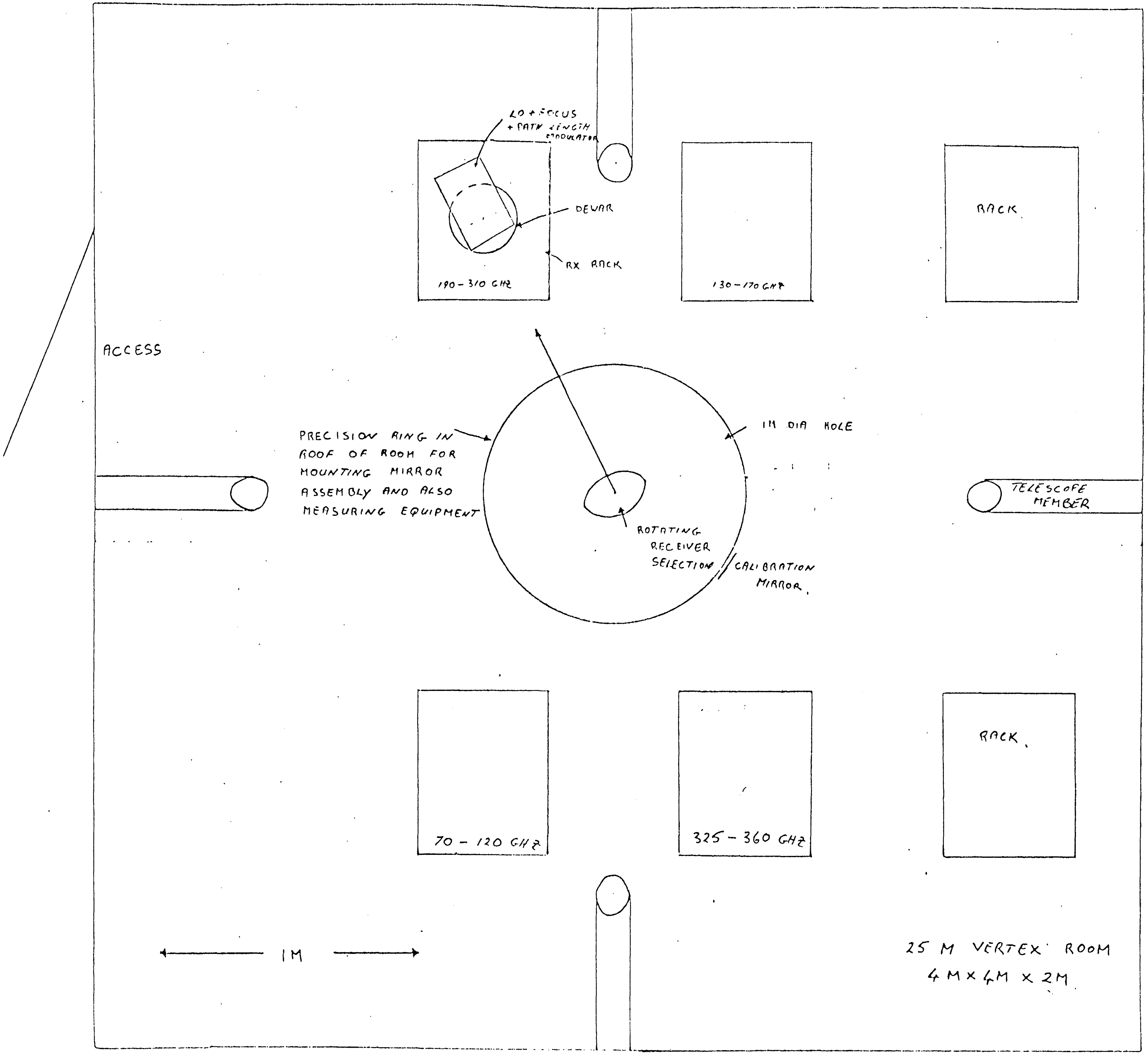
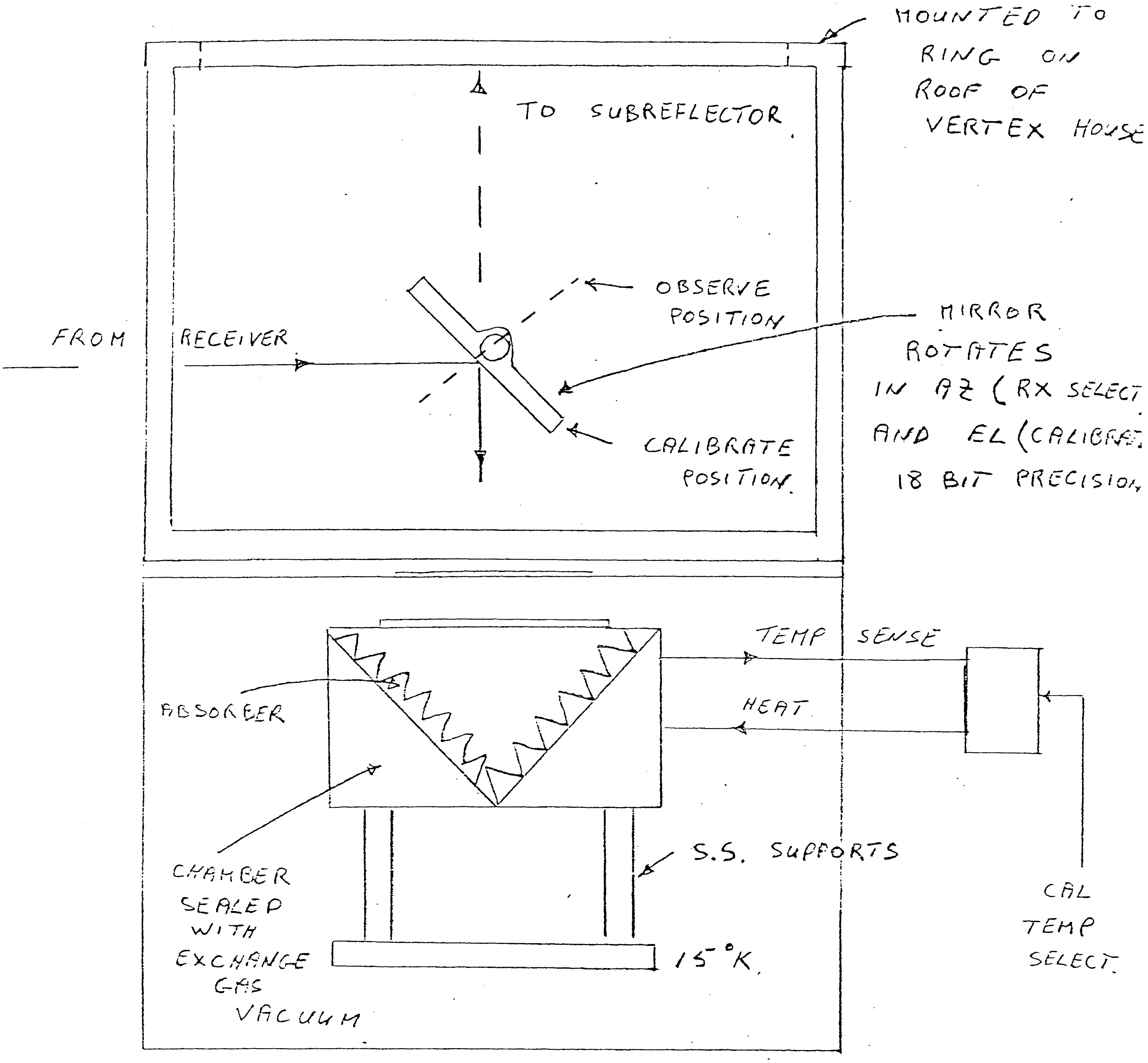


FIG 1

25M VERTEX ROOM
TOP VIEW



RECEIVER SELECT / CALIBRATE SYSTEM

FIG 2

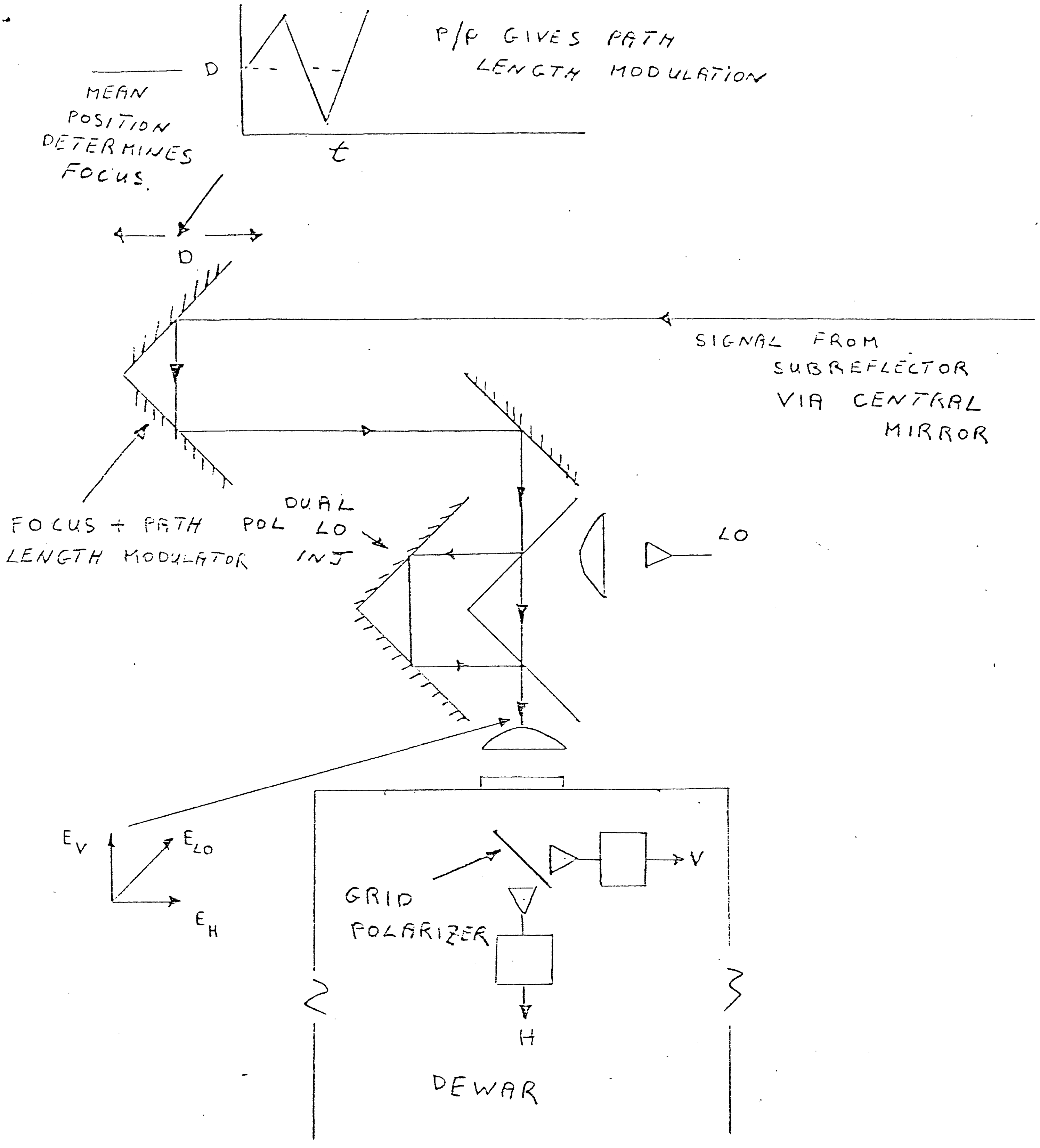


FIG 3

SPECTRAL LINE RECEIVER CONFIGURATION
25 M VERTEX ROOM

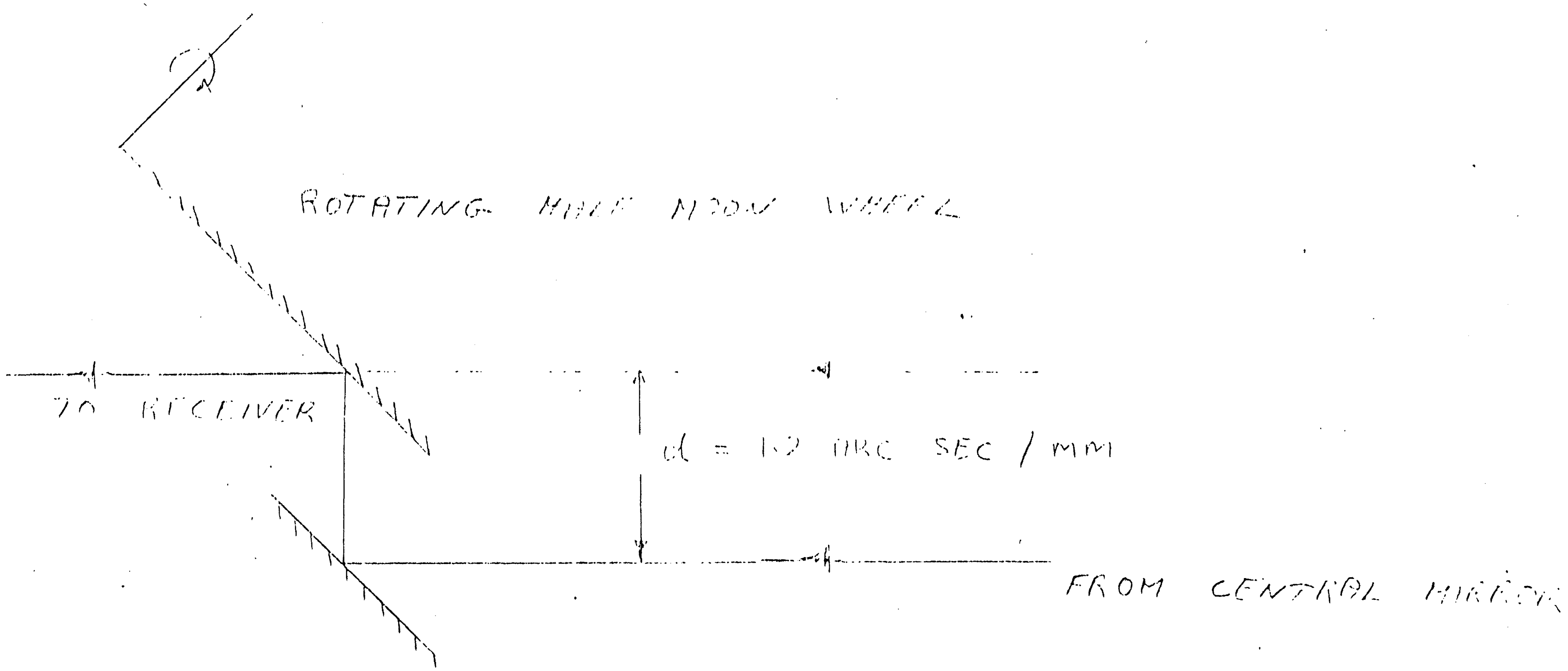


FIG 4 POSSIBLE BEAM SWITCHING ASSEMBLY TOP VIEW