GBT MEMO 144

MONITORING THE GBT ARM MOVEMENT

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INTRODUCTION

The non-repeatable pointing errors for the GBT will be due to:

1) Wind
2) Thermal
3) Dynamic

The thermal effects will be large (1) but will have a long time constant. Although our final plan is to deal with these thermal effects using the laser rangefinders, there is no doubt that offset pointing will be effective over a time scale of hours.

Over the past year, concern has developed over the dynamic pointing changes, mainly due to possible vibration of the feed arm. These vibrations may be excited by either wind or telescope motion and may be troublesome at the shorter wavelengths of operation. If arm motion is sensed in real time, the possibility exists of applying pointing corrections via a tertiary mirror.

This memo examines the alternatives available for sensing the arm motion and concludes with some recommendations.

REQUIREMENTS

The two relevant pointing coefficients for subreflector movement are as follows:

Subreflector translation	3.6 arc sec/mm
Subreflector rotation	0.15 arc sec/arc sec

Subreflector translation does result in subreflector rotation if we consider the feed arm to be "hinged" about its base, the scale being approximately 2.2 arc sec/mm. This adds to the translation-induced pointing shift and increases the sensitivity to about 4 arc sec/mm. To measure pointing changes at the one arc second level resulting from subreflector translation will, therefore, require sensing lateral movement to an accuracy of 250 microns. The expected frequency of vibration of the arm is in the region of 0.7 Hz, so the bandwidth of the measurement system could be restricted; however, for initial operation of the telescope, it would be desirable to operate a broadband system to check the frequency and amplitude of the various modes of vibration.

SOLUTIONS

Possible solutions to the measurement problem are discussed here.

1) Laser Rangefinder — By having dedicated rangefinders on the roof of the receiver room (for example) and measuring range to fixed points on the structure, it should be possible to measure lateral movements of the subreflector. This is illustrated in Figure 1.

Several configurations are possible here.

a) Measure range from three dedicated rangefinders on the roof of the receiver room to targets on the rim of the reflector. The sensitivity of the rangefinders is sufficient to measure movements of less than 200 microns in the two orthogonal directions and the measurement bandwidth is more than adequate. The major problem here is that the lip of the dish is coupled to the arm vibration and there can actually be a phase reversal between the direction of the arm movement and the direction of the movement of the rim for different modes of oscillation. This could be measured and accounted for by measuring to the rim with the ground-based rangefinders and it could also be that the lowest frequency mode is the only one of interest. Nevertheless, this is an objection to this configuration.

b) Measure range from two dedicated rangefinders to retroreflectors on the ends of the elevation axle. In this case, due to the steep angle of measurement, the sensitivity is reduced. A simple calculation shows that for a lateral movement of 200 microns, the measured range changes by 45 microns. An additional disadvantage is that only cross elevation movement may be measured, although this is the movement that is expected to dominate. There should be no interaction between the arm and the measurement points in this case.

2) Quadrant Detector — From the start of the GBT project, it has been planned to use a quadrant detector to monitor movements of the subreflector. One of these devices was installed on the 140 ft about 25 years ago and used to monitor the feed leg oscillation, and one is in use on the 12m telescope at present.

Marty Valente has built a complete system designed to monitor the movement of a 50m high tower — this system is now in Green Bank. Marty designed and partially built a second system that was designed to be permanently installed on the GBT.[1]

There were several differences between the first unit and the design of the second. Firstly, the subreflector moves with respect to the main reflector by about 18 cm over the operating range of elevation angles. This led to the design of a linear translation stage to keep the quadrant detector centered in the transmitted beam. The second major change was an increase in the transmitted laser beam diameter

[1] Included as appendices to **GBT Memo 143**

in order to minimize angular fluctuations caused by atmospheric turbulence. The beam waist radius was increased from 3.5 mm to 15.5 mm. The turbulence-induced beam wander goes as the beam waist radius to the power of -0.33, so we expect the beam wander to be reduced by a factor of 1.6 with the increased diameter optics.

The effects of turbulence are so dependent on the local environment that measurements over the ground are probably irrelevant. It may be shown (2) that range-only measurements are less affected by turbulence than range/angle measurements. Here, of course, we are concerned with the angular fluctuations, so turbulence is of great concern. The relative insensitivity of range measurement to turbulence was the deciding factor in choosing the range-only method for the surface metrology for the GBT.

D. Hogg dealt with the difficulty of predicting the value of C_n^2 on the GBT (3) in part due to our lack of knowledge of the effect of the surface. He suggests that "in a temperate climate over a vegetation-covered area C_n^2 may fall to $5 \times 10^{-15} m^{-0.666}$ at night." C_n^2 is a strong function of height above the ground and may fall by over two orders of magnitude for an altitude change from 1 to 100 m. The values for C_n^2 used here come from (4).

Further information is available from Chiba (5), who derives the radial variance of beam wander:

$$\sigma^2 = 1.9 C_n^2 \, (2 W_0)^{-0.333} L^3$$

σ = beam wander in m

W_0 = beam waist radius (m)

L = range in m

C_n^2 = index structure function

Taking the values from the GBT MKI unit

$W_0 = 3.45 \text{ E} - 3 \text{ m}$

$C_n^2 = 2.5 \text{ E} - 13 \text{ m}^{-0.666}$ (strong turbulence)

$C_n^2 = 1.6 \text{ E} - 15 \text{ m}^{-0.666}$ (medium turbulence)

$C_n^2 = 6.4 \text{ E} - 17 \text{ m}^{-0.666}$ (weak turbulence), we have for different ranges:

Range (m)	Beam Wander (microns) Turbulence		
	Weak	Medium	Strong
50	9	45	560
60	12	58	730
70	15	73	920
80	18	90	1130
90	22	106	1350

The value of 9 microns at 50 m for weak turbulence agrees with our value of 10 microns in the test tower. The references imply that strong turbulence values apply over a path close to the ground on a sunny day and are probably not relevant. My guess would be that at night on the GBT the values will tend to the weak numbers. Note that there is no consideration of bandwidth here, but the references imply that a tracking system "with a bandwidth of a few Hz" will be sufficient to remove this effect. The success of the quadrant detector system is so dependent on the turbulence effects that it is important to obtain some realistic numbers as soon as possible.

COMPENSATION

It is possible to at least partially separate real displacements in the beam and apparent displacements caused by turbulence-induced angular fluctuations. Angular fluctuations may be measured independently of displacement (an autocollimator, for example) and correction applied to the measured displacement. Such a correction will not be exact, however, due to the fact that the final displacement of the beam is not rigidly related to the angle of arrival of the beam. (5)

Any detailed design considerations should be deferred until after the tests suggested later in this memo.

A PRACTICAL QD SYSTEM

The following is a proposal for a system that may be built and tested quickly with a minimum design effort. The key components are the MKI GBT system, which has already been delivered and tested, and the servo-controlled mirror already purchased and tested by Brockway. Moving parts at the subreflector are avoided, which is considered to be an advantage.

LOCATION

Roger Norrod has already produced a very useful memo on "Possible Locations for a GBT Quadrant Detector." (6) From his memo, we take the location of the laser transmitter to be Node 10030 — at the top of the box structure. The location of the receiver is taken to be Node 40710 (Figure 2).

From the memo, the range from the transmitter to the detector is approximately 72 m and the angle from the transmitter to the detector changes by approximately 8.5 minutes from El = 0 to El = 90°. This is an angular change in the plane of symmetry. Out of the plane we expect changes far less: pointing changes of an arc minute will result in angular changes of around 0.7 arc minutes for the laser angle.

BLOCK DIAGRAM

A block diagram of the proposed system is shown in Figure 3. At Node 10030, an assembly consisting of the laser transmitter, piezo-electric controlled mirror, and electronics is contained within a weather-proof enclosure. The laser beam emerges through a quartz window, through a hole in the surface (3-inch diameter should be more than sufficient) and is aimed at the quadrant detector 72 m away located at Node 40710 on the receiver room. The output from the quadrant detector provides the error signal for a closed-loop servo system, the actuating element being the controlled mirror. Some systems considerations follow.

THE PIEZO-ELECTRIC TILTING MIRROR

The specifications on the mirror are as follow:

- Two tilting axes
- Maximum tilting angle > 7 arc min
- Frequency response 120 Hz
- Operating temp range -40° c to +80°c
- Resolution - better than 1.2 arc sec (this specification is unclear at present)
- (Note that the beam deviation angle is twice the mirror angle.)

The mirror comes with its own electronic devices.

THE QUADRANT DETECTOR

The original (GBT MKI) quadrant detector has been checked in both Tucson and Green Bank; in Tucson in a 50m tower, and in Green Bank in the basement of the Jansky Lab at a range of 40 m. On reviewing the two sets of results, it appears that the gain of the electronics may have been changed between measurements. The tests in Green Bank (Figure 4) give a linear response of 1.75 V per mm over a range of ± 11.4 mm. The Tucson tests gave a gain of 5 V per mm with a linear range of ± 4.0 mm. The effects due to turbulence were very low in both tests. Taking the Green Bank test results, we conclude that the quadrant detector will provide a linear output for mirror tilts of ± 15 arc seconds.

ACQUISITION

Once the mirror has acquired lock, the system should remain locked. However, provision must be made for acquisition due to beam interruption, power failures, etc. Out of the plane of symmetry, the beam will always lie in the quadrant detector range and acquisition should be no problem. In the plane of symmetry, though the beam from the transmitter has to deflect by 8.5 minutes over the full range of elevation angles, a mirror movement of ± 2.1 arc minutes. For acquisition, this should have an "open loop" input to bring the mirror tilt in the plane of symmetry to within ± 15 arc secs. For this reason, the electronics will need to be supplied with the elevation encoder reading. The required tilt angle will be a trigonometric function of the elevation angle, and the electronics will need some processing to do the conversion. The accuracy required is very modest and it could well be that an A/D converter followed by an analog module would suffice.

SUGGESTED ACTION ON QUADRANT DETECTOR

For meaningful tests to be performed on the system, it is vital that we have a stable, vertical test range that can provide a range of 72 m. Conversations with Martin Barkley and Mike Holstine suggest that the water tower adjacent to the work area would provide a good site. The vertical distance from the ground to the base of the working platform is 109 feet (33m), so two passes would provide close to the necessary path length. Here is a suggested course of action with dates that seem reasonable. The question of who does the work is not addressed here.

	Action	Completion Date
1)	Renovate quadrant detector and design data acquisition system.	1 March 1996
2)	Design test setup — concrete base, tower mounting, and complete.	1 March 1996
3)	Install simple system (no mirror) and start measurements over 33 m path. Check tower stability.	1 March -1 April 1996
4)	Design final system, mirror, interface, enclosure, etc.	1 April - May 1996
5)	Fabricate final system.	15 May 1996
6)	Install on tower—test at 33 m.	1 June 1996
7)	Modify test installation—double pass to 66 m.	1 July 1996

COSTS

Provided the above program goes smoothly, the cost of the system should be less than 15K. The most costly item, the Piezo controlled mirror, has already been purchased. One major advantage of the proposed system is the elimination of the translation stage at the quadrant detector location. This will result in significant cost and manpower reduction as well as eliminating a possible high maintenance item at a difficult location.

OTHER POSSIBILITIES

Accelerometers and strain gauges are other candidates for monitoring arm vibration. The Sunstrand accelerometers already purchased by the GBT project are more than sensitive enough to monitor arm vibration at the lowest levels predicted. Given the fact that we have two of these accelerometers, it would seem prudent to mount at least one in the quadrant detector location and transmit the data along with its quadrant detector output. Again, the cost of doing this is low.

Strain gauges have not been considered here.

RECOMMENDATIONS

1) The quadrant detector program outlined above should be implemented without delay.

2) A Sunstrand accelerometer should be incorporated into the quadrant detector system.

3) Retroreflectors should be mounted at the end of the elevation axle and suitable holes through the surface should be provided to allow the planned rangefinders on the feed room to view these retroreflectors.

4) Additional, dedicated rangefinders on the feed arm should not be planned at this time.

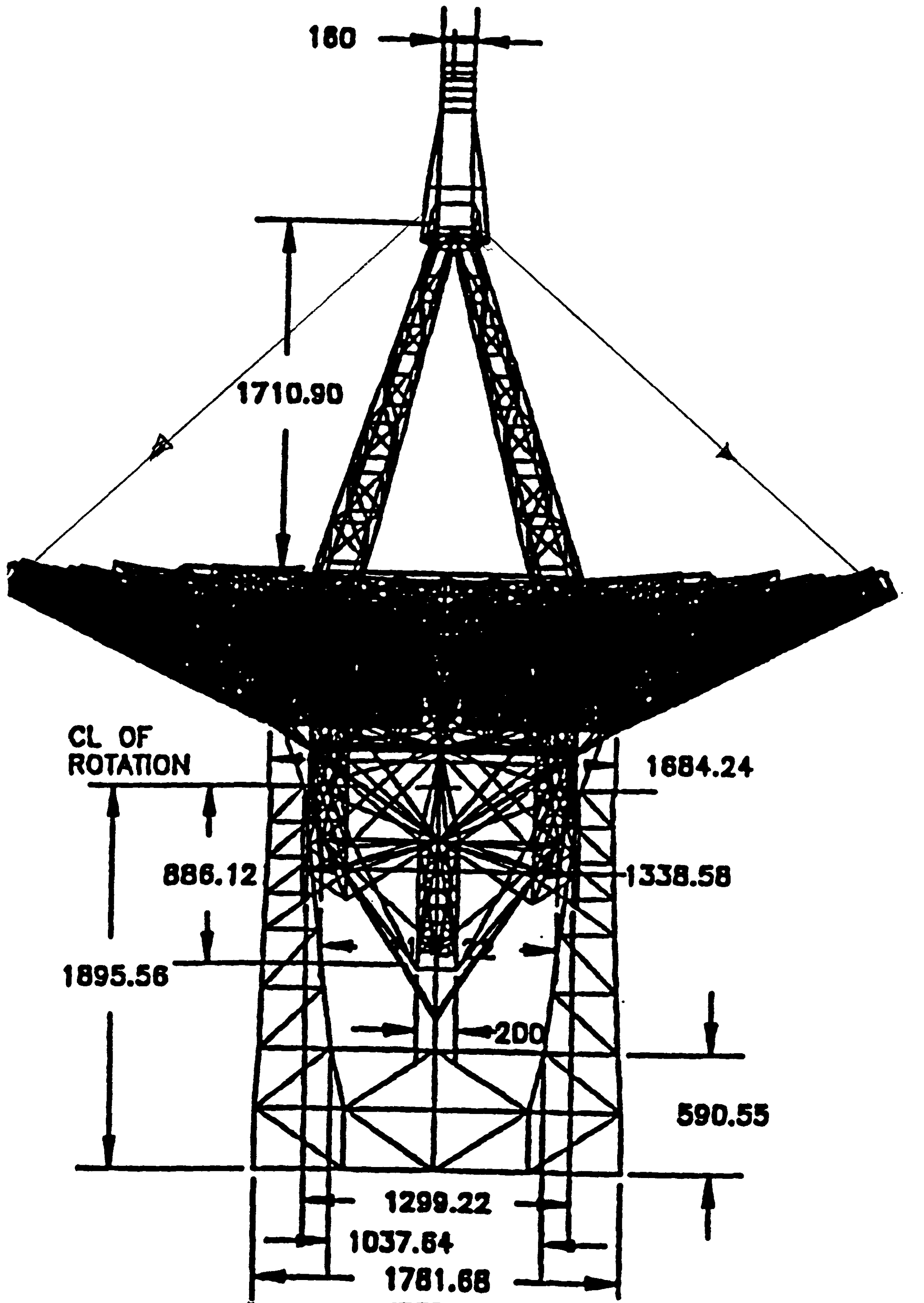
CONCLUSIONS

The successful operation of the quadrant detector depends crucially on the atmospheric turbulence being in the range "intermediate" to "weak". If turbulence renders the system unusable, the rangefinders on the receiver room viewing retros on the elevation axle will provide information on the cross-elevation vibration and in this event we may wish to install dedicated rangefinders.

There is reason for optimism, though, both from our measurements in the tower and from the literature. The proposed tests on the water tower in Green Bank will be valuable but not decisive. If these tests prove satisfactory, we may wish to consider a 140' installation as giving some more information of turbulence over a white painted surface during night and day.

REFERENCES

1) GBT Memo #84
2) GBT Archives, 09/17/90 Correspondence L0024
3) GBT Memo #45
4) Laser Beam Propagation in the Atmosphere, Hugo Weinchel
5) T. Chiba, "Spot dancing of the laser beam propagated through the turbulent atmosphere," *Appl. Opt.* **10**, 2456 (Nov. 1971)
6) GBT Memo #143



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CL OF
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FIGURE 1

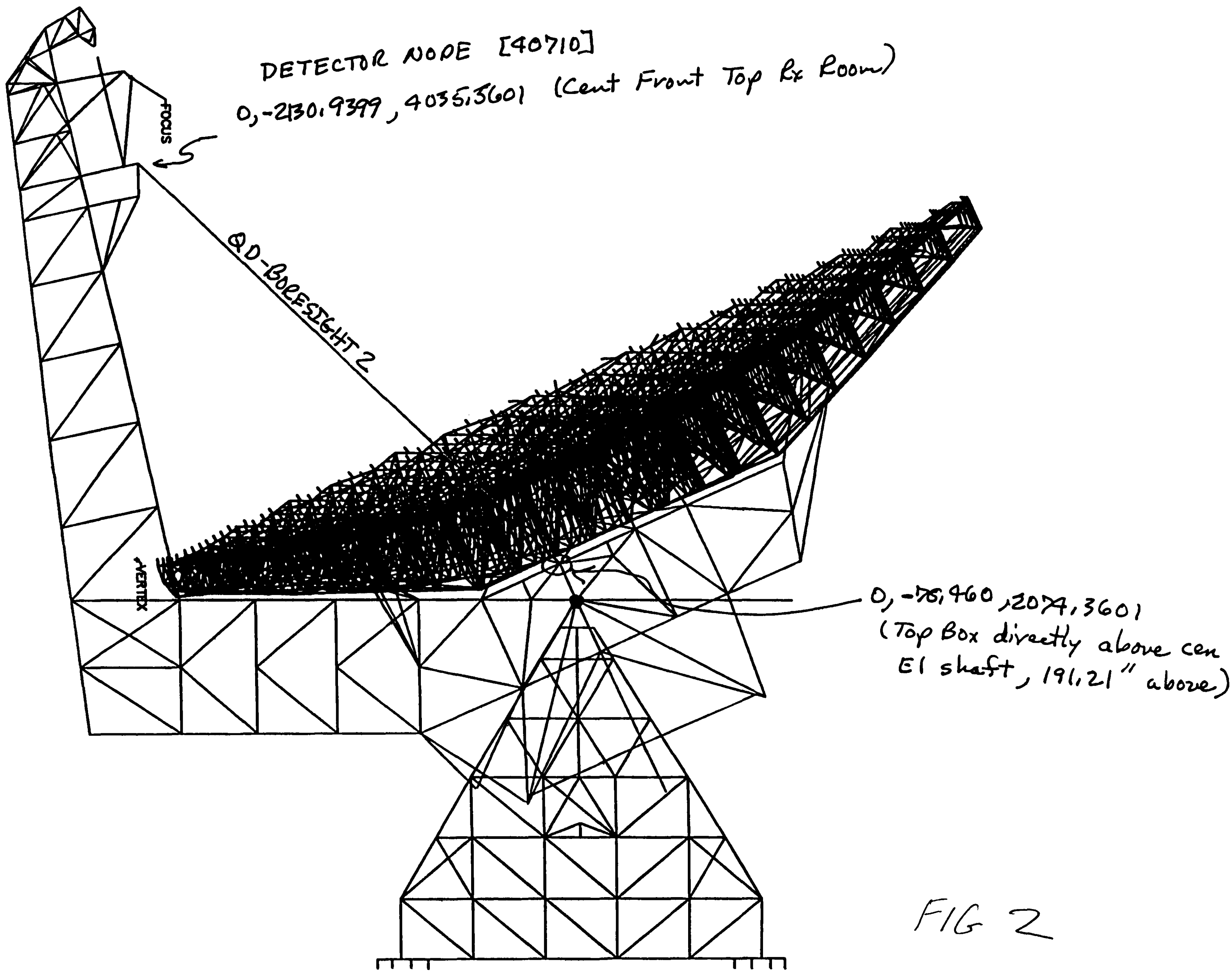
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FIG 2

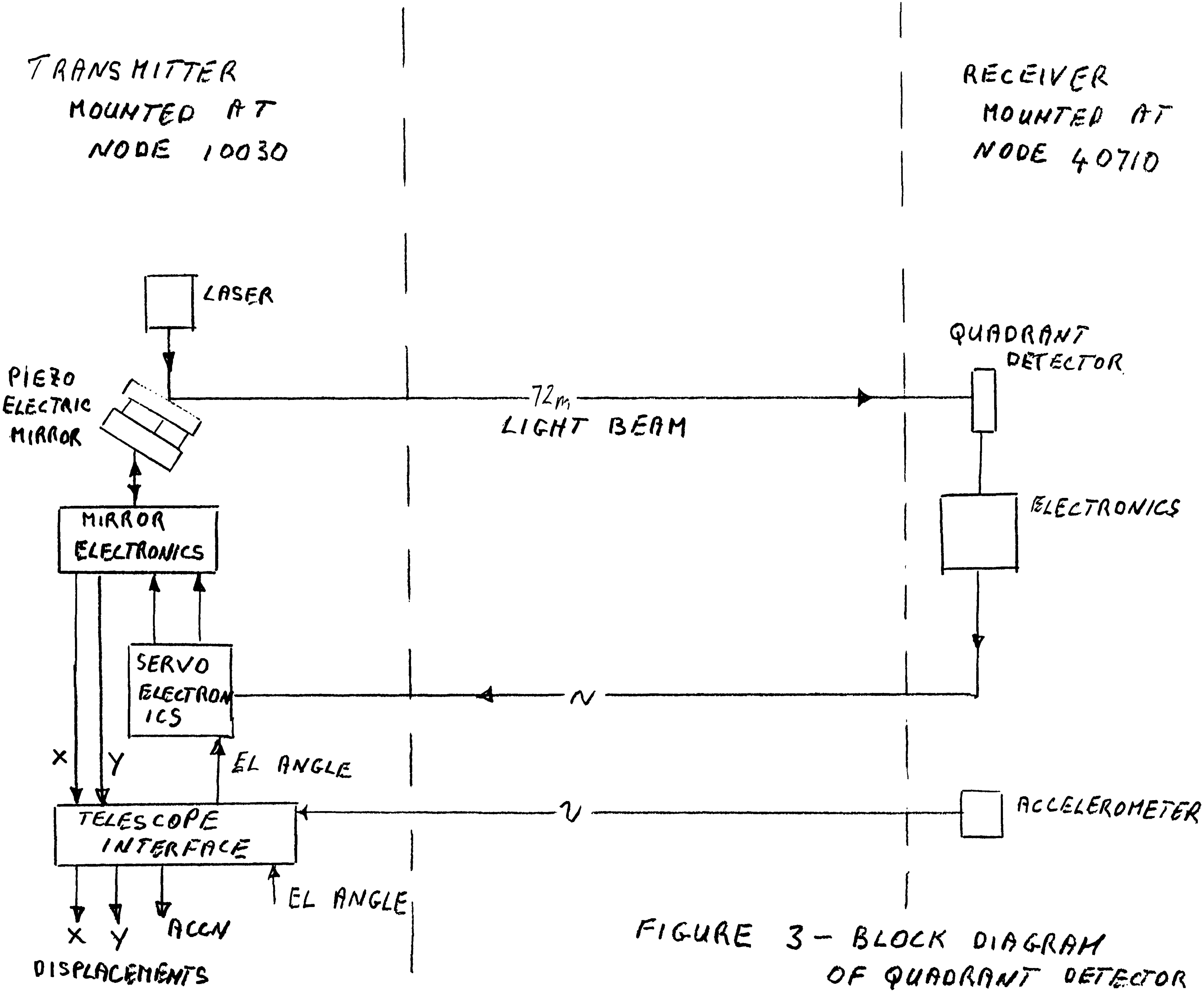

FIGURE 3 – BLOCK DIAGRAM
OF QUADRANT DETECTOR

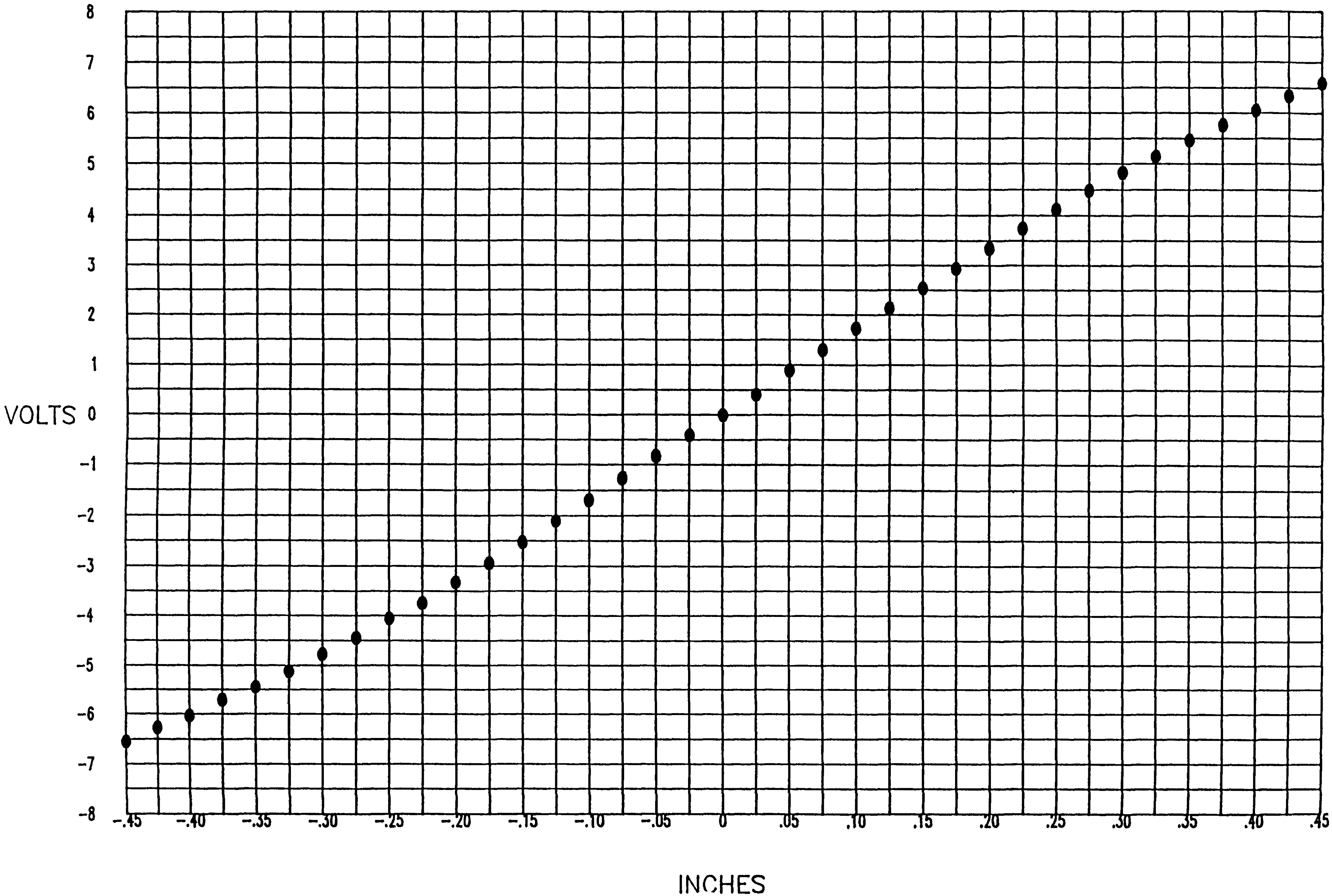

FIGURE 4: QUADRANT DETECTOR RESPONSE