GBT Memo No. 36

NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

February 27, 1990

MEMORANDUM:

TO: Addressee

FROM: J. Payne

SUBJECT: Pointing and Surface Control of GBT

1. Introduction

This note briefly describes a technique that could be used to provide active control of the surface and also to give the information needed for precise pointing. The proposed system will provide corrections to the surface figure for thermal and gravitational disturbances but not for wind disturbances. It will provide corrections to the pointing for deformations of the surface support structure (even for those disturbances with frequency components outside the bandwidth of the drive system - wind, for example), but will not correct for pointing changes resulting from wind induced changes in the surface figure.

2. Description of Method

2.1 Outline of Method

The basic method is illustrated in Figures 1, 2 and 3. Three rangefinders are mounted on the feed arm structure as shown. Each of these rangefinders can measure a range to any chosen point on the surface of the antenna or to any of eight targets on the ground. Each rangefinder may also measure the range to either of the two neighboring rangefinders.

The three rangefinders lie at the corners of a triangle. The dimensions of the triangle are approximately 50 m per side and these dimensions are checked frequently by the rangefinders "looking" at one another. The plane of this triangle is the reference plane for both the surface and the pointing measurement.

Any reflector on the surface of the antenna may be measured by each of the three rangefinders and its position is then defined absolutely with respect to the reference plane. Each of as many as 2,000 reflectors may be measured and the best-fit surface calculated.

The absolute pointing of this surface with respect to the reference plane is now known. The position of the reference plane with respect to the ground is then determined by range measurements from each corner of the plane to anv two targets on the ground.

The following points should be made:

1) Although we have access to 2,000 measurement points on the surface (one above each actuator), it is extremely unlikely that measurement to all these points will be necessary to adequately define the surface. Probably 100 points will more than suffice; this will become clearer when the structural behavior is better known and the measurement system is tested.

2) It may well be that the deformations in the structure are such that triangulation is not required and two, or maybe even one, range measurement per point will sufficiently characterize the surface deformations.

3) Although in this brief description, I have assumed that the same rangefinders are used for the surface and the pointing measurements, this is not essential. In practice, several (perhaps four) separate rangefinders would continuously measure the position of the reference plane with respect to the ground. In this way, pointing corrections for high-frequency, wind-induced deformations may be measured and corrected by tilting the subreflector. This will enable pointing correction to be made at frequencies above the response of the telescope drive system. An obvious alternate arrangement would be to replace the eight targets on the ground with rangefinders tracking targets on the reference plane. This arrangement may have some advantages.

2.2 <u>Components</u>

2.2.1 <u>The Rangefinders</u>

To position the reference plane with respect to the ground to an accuracy of 0.5 arcseconds requires a range measurement accuracy of around 50 μm over a range of around 130 m. Commercial ranging instruments are not available with this accuracy. Previous work at NRAO suggests that such performance is possible (see attached paper), and an initial look at the limitations imposed by the atmosphere gives no reason for pessimism.

The proposed instrument would transmit an infrared signal, modulated at 1.5 GHz. This transmitted beam would be narrow and steered to its target by means of a moveable mirror. The target, on the ground or on the antenna surface, will be a retroreflector, a commercially-available reflector that has the property of returning an input beam exactly along its path. This property of the retroreflector, along with the divergence of the transmitted beam, results in a range measurement that is insensitive to mirror position. Initial calculations indicate that with commercially-available components, we should be able to measure ten points per second to the required accuracy. This calculation was made solely on signal to noise considerations; other unknown effects may predominate.

Over the past year, significant advances in laser diode performance have been made, and it appears that a suitable instrument may be constructed for a surprisingly low cost.

2.2.2 The Retroreflector

A data sheet on a suitable device is attached. The cost should be close to my original estimate of $150.

2.2.3 The Steering Mirrors

Each rangefinder has a steering mirror associated with it. No work has been done on the design of such a mirror to date, but measuring many targets per second, either in a stop/start or continuous scan mode, will be easy.

3. Conclusions

This approach seems to offer the advantage of solving the pointing and the surface setting problems using the same basic measuring system. The plan outlined here requires instrumentation which is only a modest advance on that currently available. It is necessary to confirm that range measurements can be made over the distances needed with sufficient accuracy, and I plan to set up a test in Green Bank to prove this. As our knowledge of the structure leads to better estimates of gravitational, wind and thermal deflexions, we shall be able to judge whether the basic system proposed will meet the performance specifications or whether more advanced features need to be added.

An analysis of the errors in this proposed system will be performed by Fred Schwab.

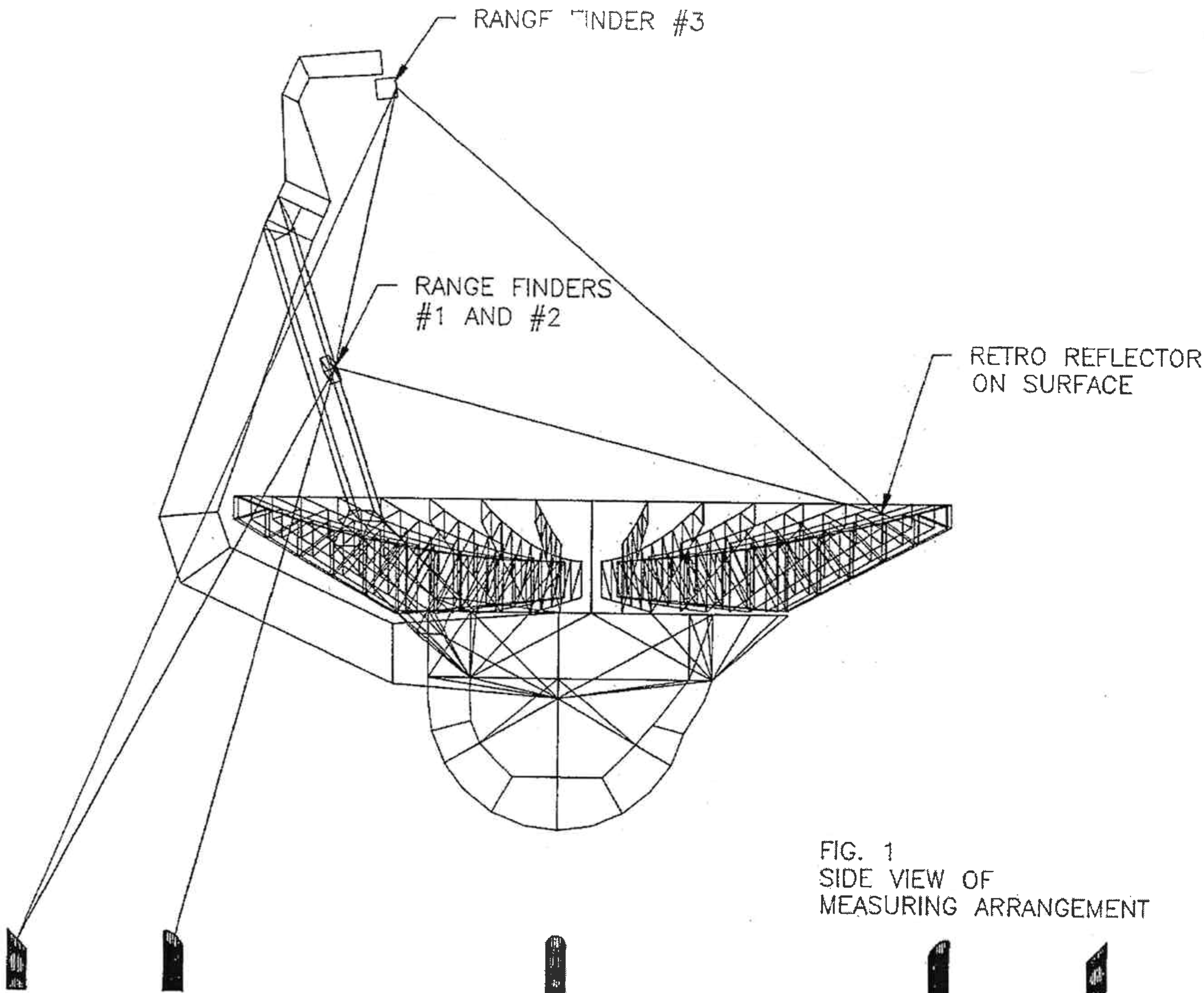

FIG. 1
SIDE VIEW OF
MEASURING ARRANGEMENT

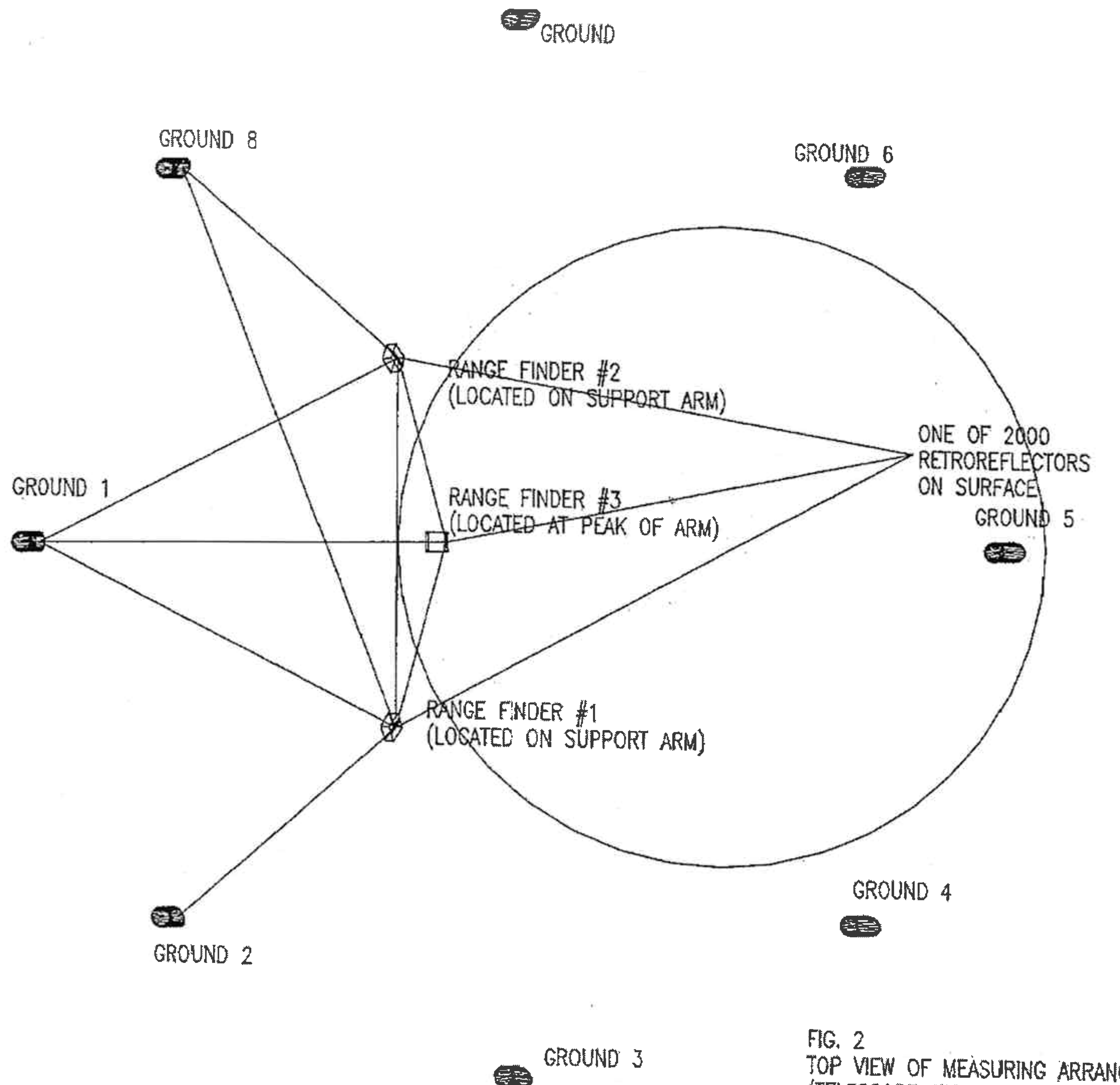

FIG. 2
TOP VIEW OF MEASURING ARRANGEMENT
(TELESCOPE STRUCTURE OMITTED)

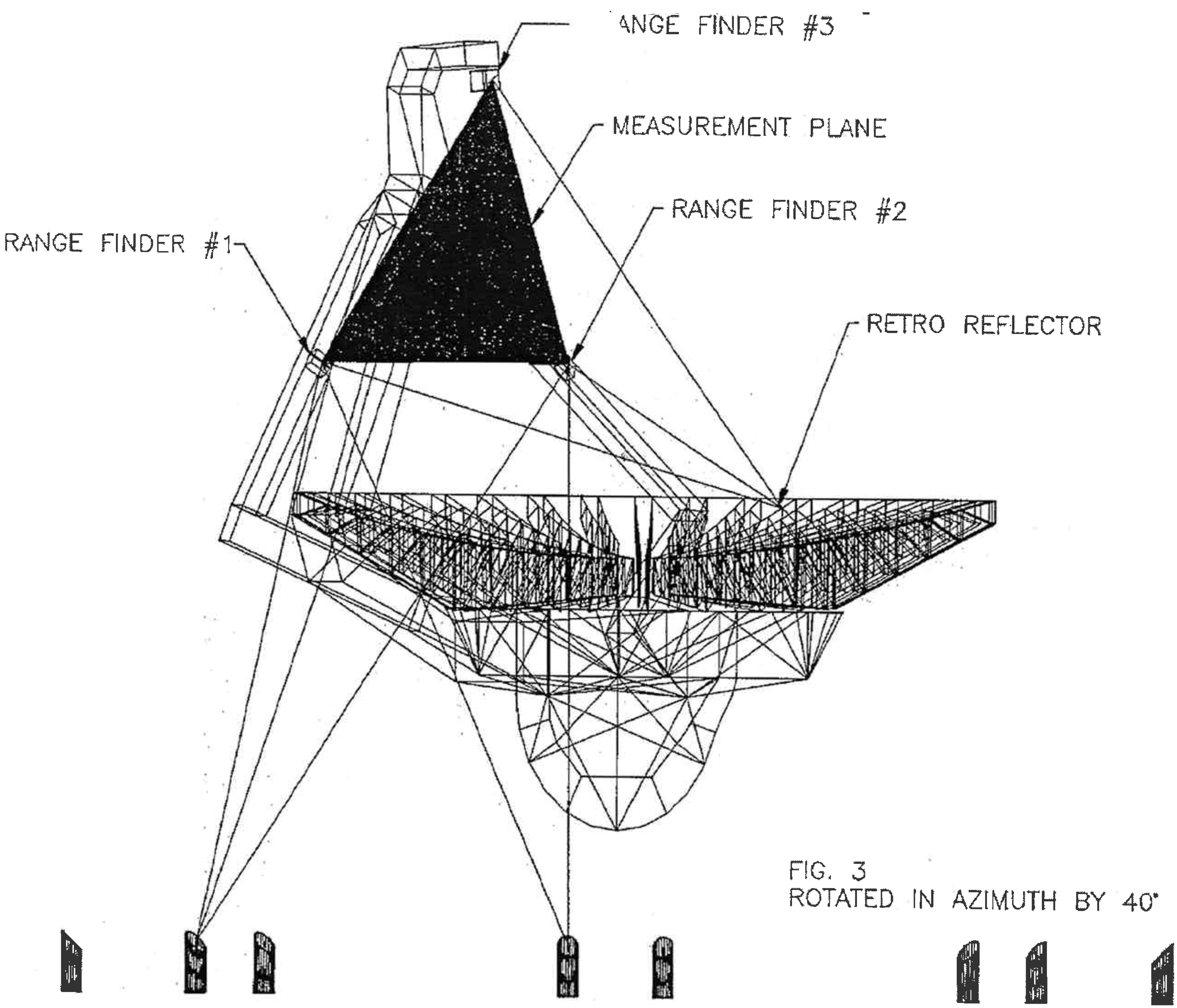

FIG. 3
ROTATED IN AZIMUTH BY 40°

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Aperture: 1 inch/25 mm, 1½ inch/38 mm, 2½ inch/63 mm, 5 inch/125 mm

Accuracy: 5 minutes, 1 minute, 30 seconds, 5 seconds, 2 seconds, 1 second, ½ second

Dimensions in millimeters:			Weight In Grams
Aperture	Diameter	Length	
25	39	32	29
38	50	38	127
63	80	58	202
125	155	147	1023

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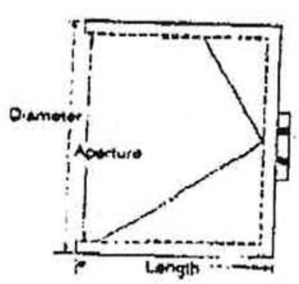

- Now, in production quantities, ½-second of arc accuracy, with an exiting wave front flat to better than ½ fringe.
- Hollow corner cube construction with optical path in air permits full optical spectrum coverage.
- Constructed of 3 coated optical flats assembled by a patented process into a mutually orthogonal "corner." This method is *more* accurate and *less* costly than grinding and polishing conventional prisms.
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Reprinted from:
THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 44, NUMBER 3 MARCH 1973

An Optical Distance Measuring Instrument

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(Received 2 October 1972; and in final form, 1 December 1972)

This paper describes an instrument that measures the transit time of a modulated light beam out and back over the path whose length is required. The instrument has a digital readout and an rms (1σ) accuracy of ± 0.08 mm on a single measurement over ranges up to 60 m. The measurement time is 2.7 sec.

INTRODUCTION

As radio astronomers become increasingly interested in the higher radio frequencies, engineers strive to build parabolic reflectors of large size and high precision.

The National Radio Astronomy Observatory has recently completed a design for a 65 m diam radio telescope to operate (under benign atmospheric conditions) at a wavelength of 3.5 mm.[1]

To achieve this performance about 3000 points on the surface of the parabolic reflector have to be set by range measurement from two fixed points (such as the focus and the vertex of the parabola) with an accuracy of better than ± 0.1 mm. These range measurements, over distances from a few meters up to about 60 m, must be made rapidly, preferably by an automated system.

A ranging instrument using a light beam is very convenient for this application.[2–5] The light beam may be directed to targets (small optical corner cubes) on the surface of the reflector by means of programmable mirrors and by using a small digital computer to control the measurements and to record the results the survey of the surface may be completed in a fast, automated manner.

This paper describes a prototype distance measuring instrument that has been developed to meet these requirements. Various commercial instruments exist that use the general principle described here, but none have both the accuracy and rapidity that this application requires.

PRINCIPLE OF OPERATION

A high-intensity light beam (in this case a helium neon laser beam) is amplitude modulated, transmitted over the path to be measured, and reflected back to the instrument. The phase of the returned beam is measured with respect to a reference, the phase shift being proportional to the total distance traversed.

This principle is illustrated in Fig. 1 in which the light beam is modulated at a frequency f_m, the one-way distance to be measured is d, and the phase of the returned signal is ϕ_s.

The returned light beam will be shifted in phase by $2d/\lambda$ where λ is the wavelength of the modulating frequency. If $\lambda < 2d$, then the phase will be shifted through more than one cycle and ambiguities in distance reading will arise.

The instrument described in this paper uses a modulating frequency of 550 MHz, so range ambiguities will occur about every 27 cm. This means, of course, that the distance to be measured has to be known in advance to better than this value. A dual-frequency system is often used to resolve such ambiguities, and although the present instrument could be modified to work in this way, it is unnecessary for measuring radio telescopes.

Referring to Fig. 1, the phase detector output will be proportional to

$$\phi_r - \phi_s,$$

where ϕ_r is the reference phase and ϕ_s is the phase of the returned signal.

$$\phi_s = [(2d - n\lambda)/\lambda]\,360°,$$

where $(2d - n\lambda) < \lambda$ and n is an integer.

The velocity of light through air varies with air temperature, pressure, and relative humidity. To measure a range of 60 m to ± 0.1 mm we need to know air temperature to about 1.5°C and air pressure to about 4 mm of mercury. The effects of relative humidity over such a distance can be neglected.

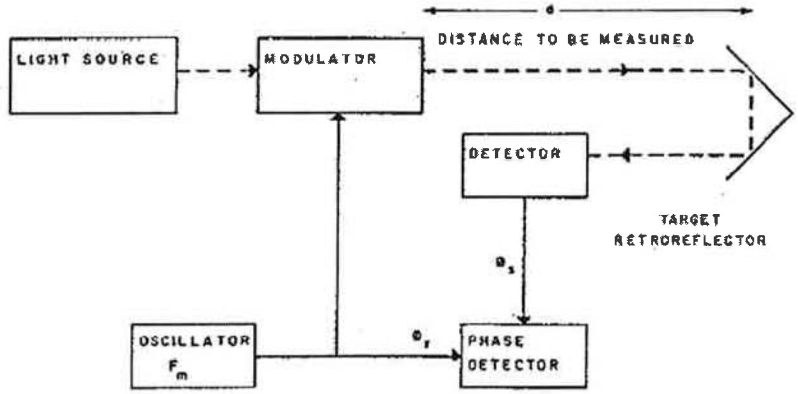

FIG. 1. Simplified block diagram.

DESCRIPTION OF INSTRUMENT

There are many ways of implementing the simple principle shown in Fig. 1. The Mekometer III[5] uses an ingenious mechanical phase nulling technique that has the advantage of eliminating electronic phase detectors but has the disadvantage of fairly long measurement time.

To achieve a measurement accuracy of ±0.1 mm at the modulating frequency used in the instrument described, a phase detection accuracy of 0.13° is required. After testing the various components involved it was clear that, provided temperature was controlled, this accuracy was obtainable.

A block diagram of the instrument is shown in Fig. 2. The light source used is a linearly polarized neon laser with an output of 3 mW. The laser beam passes through a KDP crystal in the high electric field region of a cavity tuned to the modulating frequency. The KDP crystal is biased by a high dc voltage into its linear region.

On emerging from the cavity the beam passes through a polarizer that converts the polarization angle modulation,

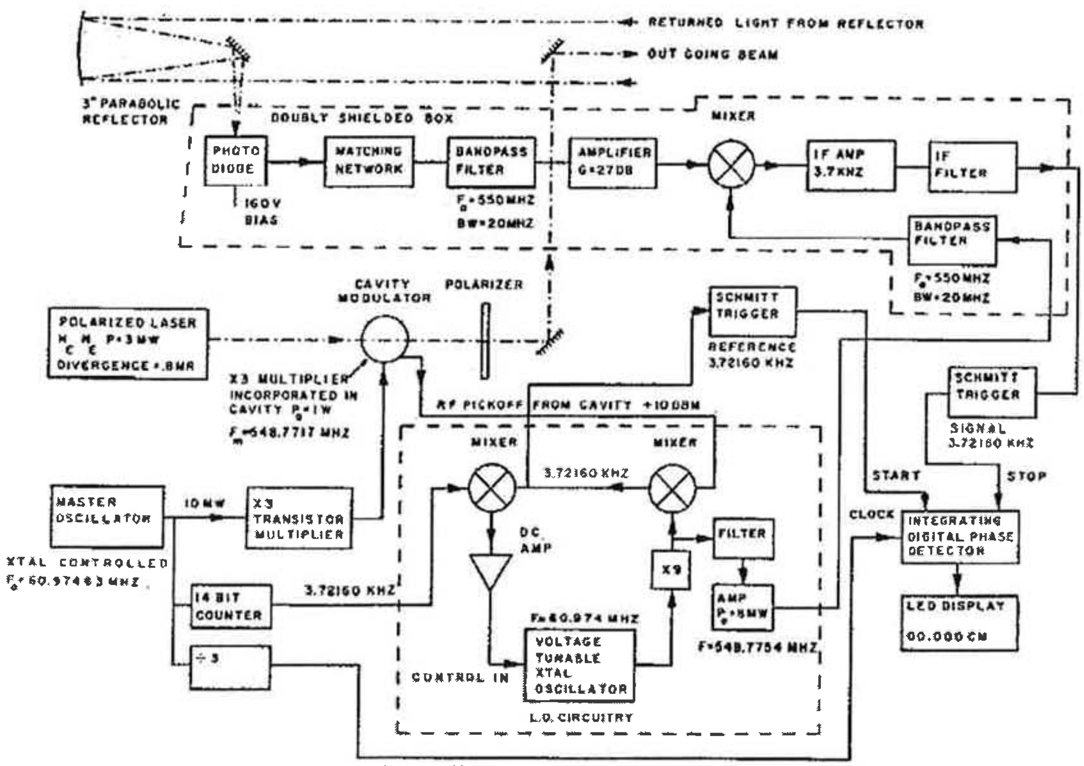

FIG. 2. Block diagram.

imposed by the KDP crystal, into amplitude modulation. Two mirrors then direct the beam to the distant target which is a corner cube reflector to return the light back along its incident path. The returned light is then focused, via a mirror, onto the receiving avalanche photodiode. The detected signal is amplified and mixed down to give a signal at an intermediate frequency (IF) of 3.7 kHz. The phase of this signal is then compared with a reference signal, the phase difference being proportional to the total transit time.

All frequencies within the instrument are derived from a single crystal-controlled oscillator with a frequency of 60.97463 MHz. The frequency of this oscillator is multiplied by nine to produce the modulating frequency of 548.7717 MHz, and is divided by a 2^{14} counter to produce a frequency of 3.72160 kHz. This frequency is to be the IF used in the phase comparison, so that it is added to the modulating frequency to provide the local oscillator frequency of 548.7754 MHz. This is done in the phase-locked loop shown in the dashed-line box in Fig. 2. The 60.97463 MHz signal is also divided by three to give a digital clock frequency of 20.324877 MHz.

The IF reference signal is squared and the leading edge is the start of a gate sending digital clock pulses into the clock pulse counter. The clock pulses are stopped by the leading edge of the squared waveform of the returned signal. The accumulated clock pulses thus are a measure of the phase difference between the two waveforms and the whole of this part of the circuit acts as a digital phasemeter.

The frequencies have been purposely chosen so that for an atmosphere at 0°C and 760 mm of mercury the scale factor is 20 clock pulses per millimeter of distance per IF cycle. At the end of an integration period, which includes the sum of 10 000 IF cycles, the accumulated count is displayed on a five digit display, the least significant digit being 0.001 cm. The display is automatically updated every 2.7 sec.

TESTS WITH INSTRUMENT

Outdoor tests were performed at a 60 m range since this is the maximum range the instrument will be used in its intended application. The target was a 2.54-cm diam corner cube reflector mounted on a micrometer bench 91.4-cm long and calibrated in inches.

The first test was of instrument stability over the 60 m pathlength under fairly stable atmospheric conditions. A reading was taken from the instrument with the corner cube stationary every minute for 1 h with a resultant standard deviation of ± 0.0043 cm on a single reading.

The retroreflector was then moved in increments of 2.54 cm over a total of 81.28 cm (giving a total phase shift of three wavelengths). An analysis of the results gave a slope of 2.540180 ± 0.00015 cm/in. (when corrected for the prevailing atmospheric conditions) and a 1 σ rms on a single reading of ± 0.00757 cm.

A plot of the error in reading at each 2.54-cm over the 81.28-cm movement showed the error to follow a cyclic pattern, the result of leakage of the modulating signal from the cavity modulator into the receiver. In a fully engineered version of the instrument this leakage could be considerably reduced. When these cyclic effects were subtracted out the rms error was ± 0.0043 cm and thus it seems possible that a developed version of the instrument could achieve this accuracy.

ACKNOWLEDGMENTS

The author would like to acknowledge the help and advice of J. W. Findlay, who assisted in the testing of the instrument and analyzed the results. Also, the contributions of C. Pace, who designed and built the digital circuits, and R. Becker and S. Mayor, who constructed the instrument, are gratefully acknowledged.

*Operated by Associated Universities, Inc., under contract with the National Science Foundation.

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[4] *Surveyor's Guide to Electromagnetic Distance Measurement*, edited by J. J. Saastamoinen (University of Toronto Press, 1967).

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