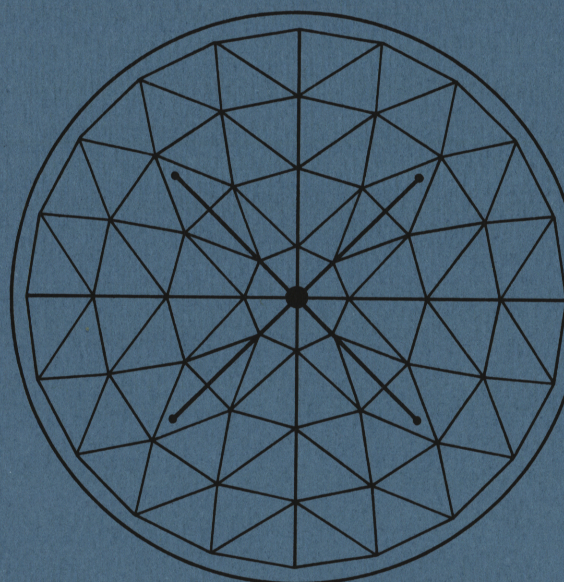

# SECTION 3.0

PROJECT: 300 FT. DIA. HOMOLOGY RADIO TELESCOPE

SUBJECT: POSITION REFERENCE PLATFORM CONCEPT DESCRIPTION

## 3.0 CONCEPT DESCRIPTION



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3.1 GENERAL

In most radio telescopes the angular pointing position is measured at the axis of rotation in reference to a structural base which is inherently flexible. Since the structure, which normally serves as reference base, is usually subject to deormations caused by external loads (wind, temperature and dynamic perturbations), a significant, uncompensated error is introduced.

In order to minimize this "unaccountable" error contribution, it appears most logical that the point of reference should be located as close as possible to the vertex of the parabolic reflector and that the reference base should be independent of any flexible structure.

This can be accomplished by "slaving" a servo controlled platform to fixed signal sources on the ground, so as to establish a "North-South" and "level" reference plane from which the reflector position can be obtained. This technique is commonly applied on space vehicles such as satellites and space probes, which are usually equipped with optical pointing devices (star trackers, etc). These devices "lock in" on the bright rim of the earth or sun, or to some bright star, for establishment of position reference, for instance.

There are several feasible methods of accomplishing the "fixing" of the reference platform in space relative to the direction of gravity in elevation and North-South in azimuth in this application. These are as follows:

In azimuth:
1) By optical method, or
2) By means of gyro-compass.

In elevation:
1) By optical method, or
2) By means of sensing the direction of gravity.

This study concentrates on the application of optical and gravity reference methods; the feasibility of application of a gyro compass for azimuth reference is also being studied at the present time, however. The results of this study will be outlined in Section 8.0 of this report upon its completion.

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PROJECT: 300 FT. DIA. HOMOLOGY RADIO TELESCOPE

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## 3.2 OPTICAL REFERENCE SYSTEM

There are at least two types of optical systems commercially available, which could be successfully used in this application for azimuth reference.

a) An optical beacon tracking system by "Kollsman Instrument Corporation."

b) A laser auto collimation system by "Keuffel and Esser."

### 3.2.1 DESCRIPTION OF THE "KOLLSMAN" SYSTEM

The Kollsman system consists of optical trackers, which are rigidly attached to the reference platform and an equal number of beacons, which are positioned on the ground. These beacons project a light beam onto the optical trackers located on the platform; the trackers furnish electrical signals proportional to the azimuth angle by which the tracker axis departs from the line-of-sight between tracker and beacon. The beacon trackers actually have quadrature cells and thus could detect Az and El errors simultaneously.

The linear range of either axis output is approximately ±30 sec. for a 1 sec. accuracy and saturates at approximately ±60 sec.

The platform must be slaved (by servo control) to these signals and must be located at the intersection of azimuth and elevation axes of the radio telescope. This point of intersection, however, does not remain fixed in space, but is subject to excentric and vertical motions due to load flexure of the supporting structure or uneveness of the telescope azimuth turn-table, which results in slow heave motions during rotation of the telescope. These heave motions are estimated to be ±1.0 in., which makes a simultaneous Az-El reference impossible because the beacons would eventually lose their targets.

Thus, the beacon trackers can, therefore, be designed to generate linear azimuth output only.

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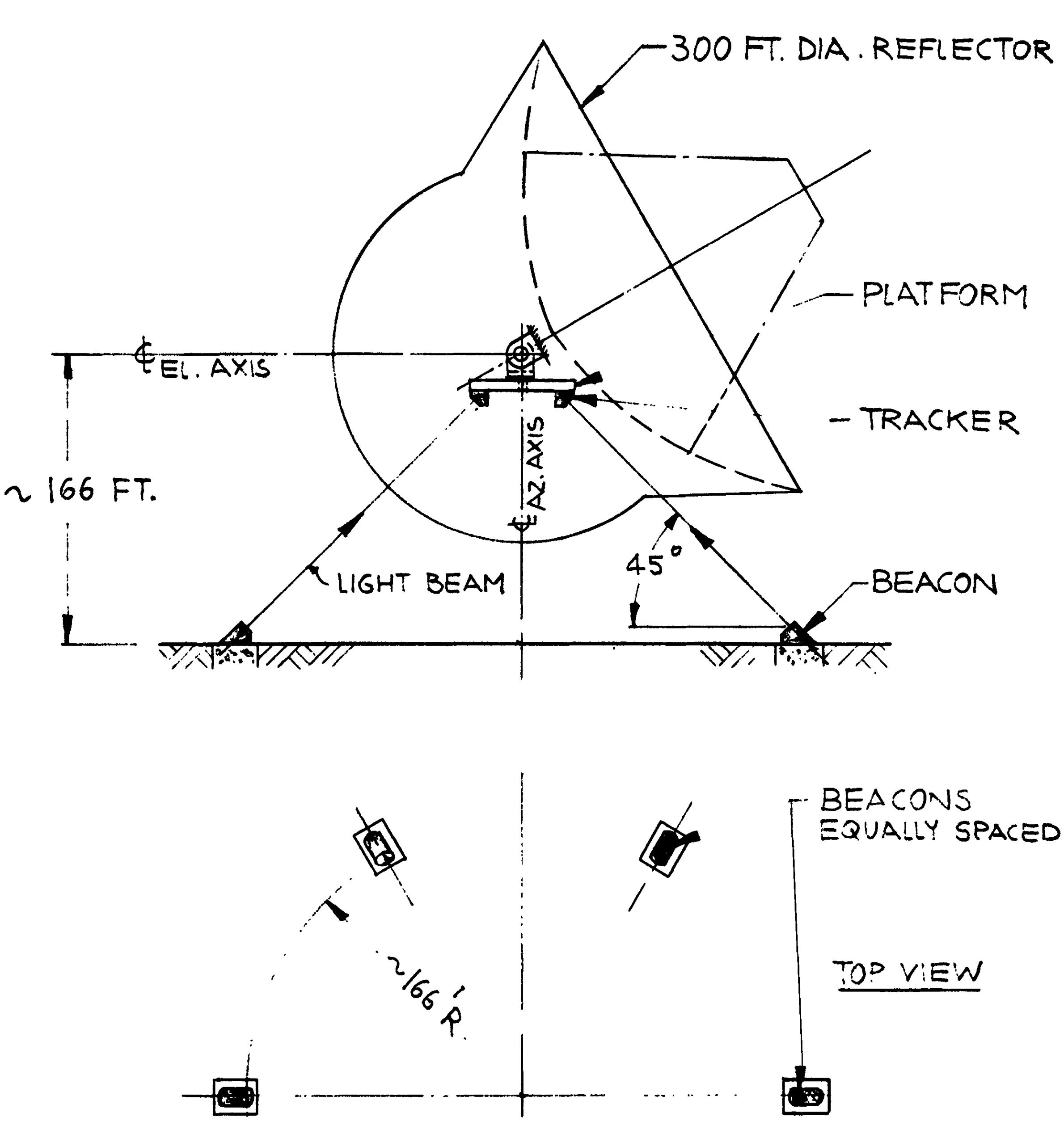
REFERENCE PLATFORM WITH KOLLSMAN SYSTEM




SK-1

3.2.2 THE "KEUFFEL AND ESSER" SYSTEM

A better and also less expensive approach is to utilize a "K&E laser auto collimation" system for both azimuth and elevation reference.

This instrument functions as follows:

Narrow modulated laser light beams are generated by laser tubes located on the ground and are reflected each by a perpendicular mirror surface of a "polygon" mirror located on the azimuth axis of the reference platform. The reflected laser beams are then projected on quad-cell detectors which are located at the points from which the laser beams originate.

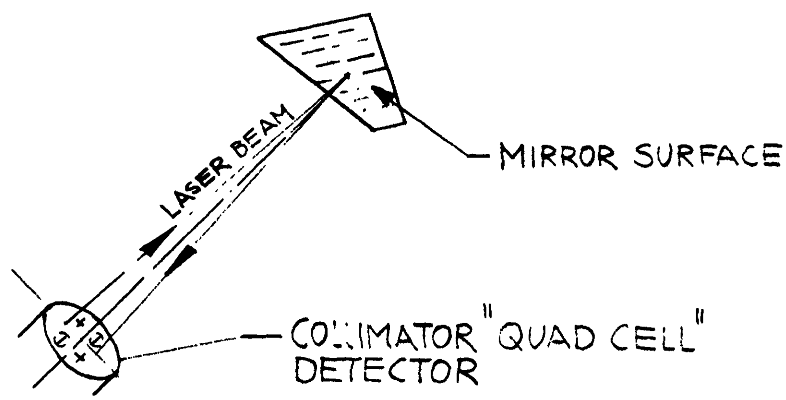



FIGURE -1-

Since it is easily possible to get large enough flat mirror surfaces, deviations from the theoretical Az-El axes intersection point can be tolerated without losing the targets, resulting only in insignificant position errors.

The K&E system has the following operating characteristics (K&E Cat. #71-2605):

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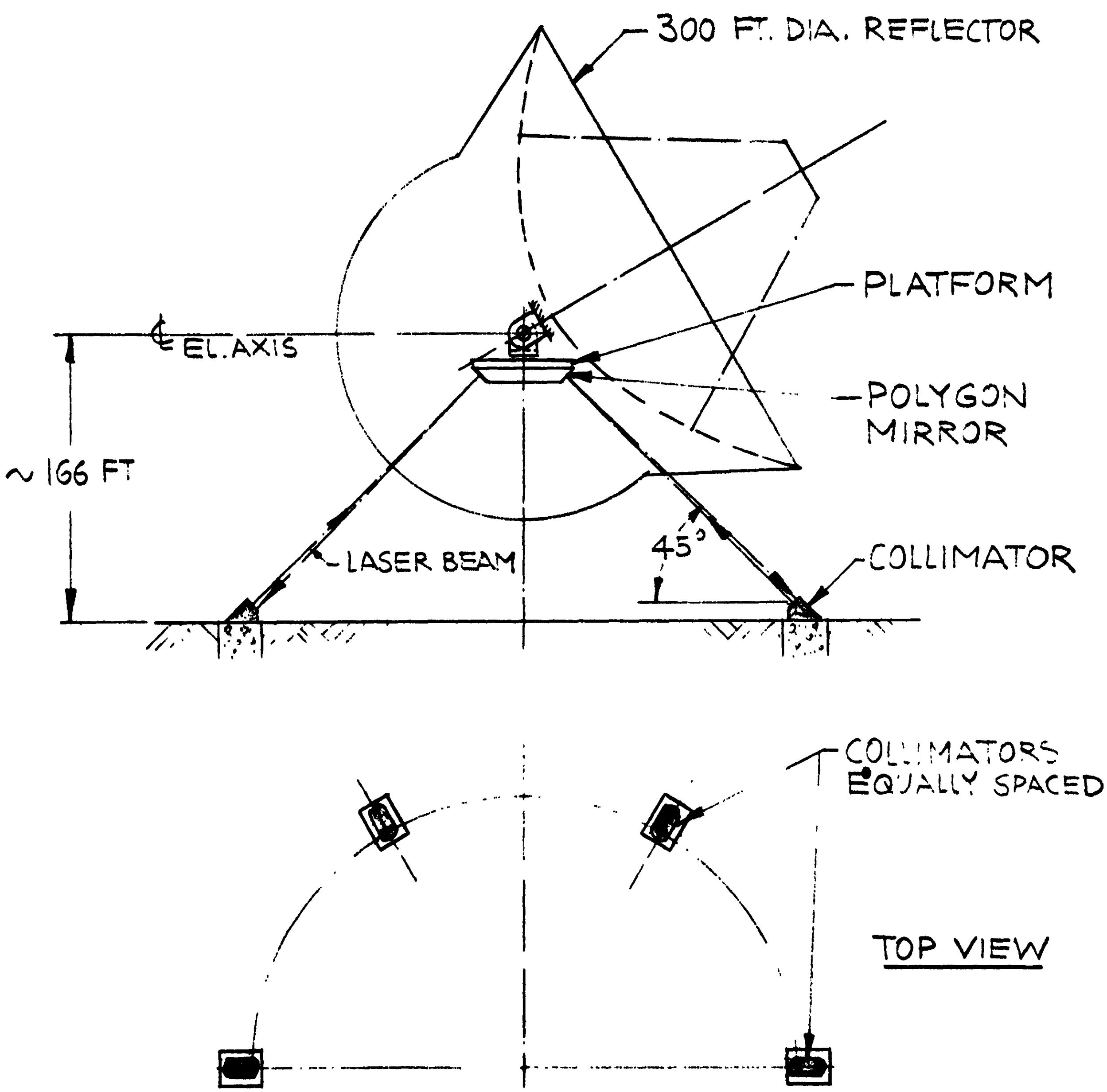
REFERENCE PLATFORM WITH K&E SYSTEM




SK-2

PREPARED BY O. R. Heine
J. MURADLIYAN
APPROVED BY
SUBMITTED BY S.D.L.

3.2.2.1 SYSTEMS CHARACTERISTICS

1) Because of beam modulation the system is not affected by sunlight or other light interference.

2) System hysteresis is less than ±.30 arc.sec.

3) System accuracy is better than ±.50 arc. sec. at a range of ±10 arc. sec.; output saturates after ±30 arc. sec.

4) Maximum distance between light source and mirror is 300 ft.

5) Frequency response is 50 C.P.S. min. as measured from in to output.

6) There is cross-talk between the two axes output if simultaneously operated; thus, selective interrogation must be applied.

The multiple side reflecting mirror (optical polygon) would be specially made in one piece and would have the following typical characteristics.

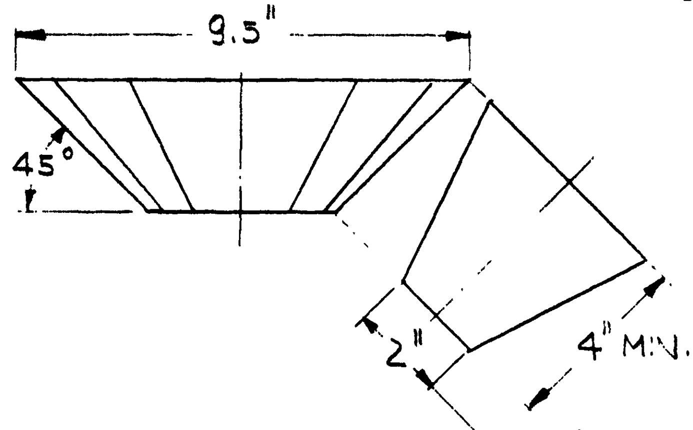



FIGURE-2-

1) Material : Quartz

2) Worst surface error : 5 arc. sec. peak to peak

3) Repeatability : Within .20 arc. sec.

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Present state-of-art limits alignment of sides to a tolerance of 5 arc. sec.; however, each side can be calibrated and the error of each side can be determined with respect to a reference side. The 5 arc. sec. error can thus be reduced to approximately ±.50 arc. sec. by application of proper compensation methods.

3.2.2.2 SCHEMATIC OF COLLIMATION

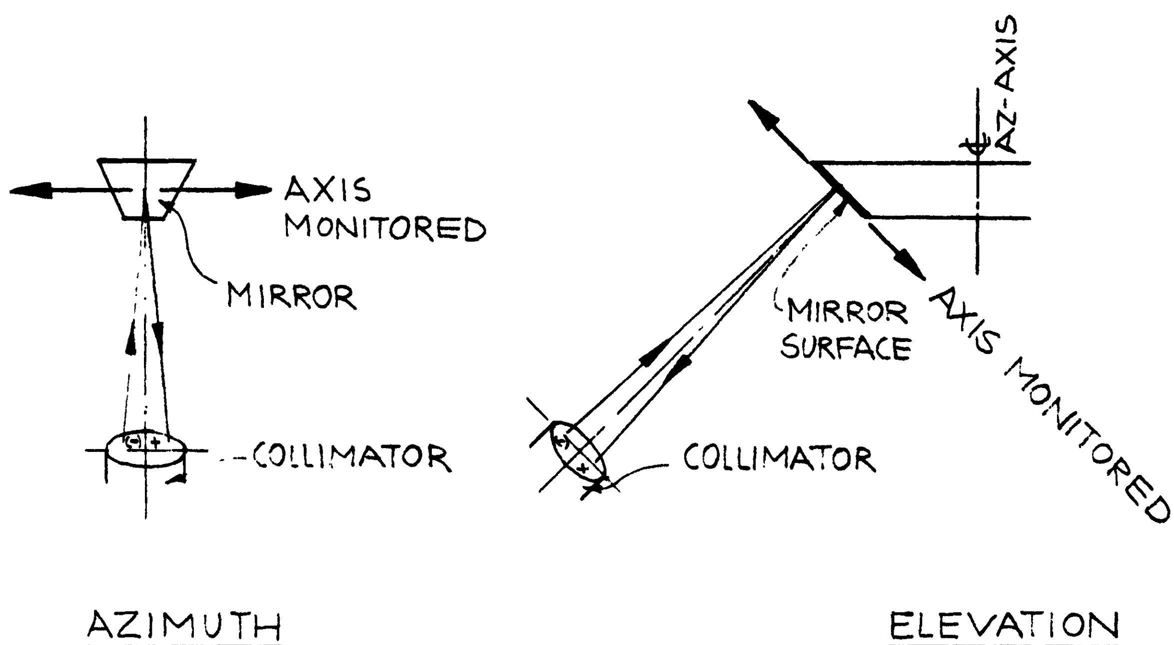


FIGURE-3-

Azimuth and elevation signals can be generated by the same mirror by successively interrogating the collimator once for one axis and subsequently for the other axis. This will tend to minimize signal interference (cross-talk) between the axes.

The high frequency response (50 C.P.S.+) of the instrument permits high interrogation and storage rates.

Only mirror surfaces offset to the elevation axis can be utilized for feedback and reference purpose; the sides coinciding with the El axis will, of course, not generate any signals as a function of platform tilt.

Each individual collimator/mirror will have a different tilt servo loop gain characteristic in elevation; a collimator programming matrix must thus be applied in order to correct the individual gain for the selected mirror in-phase signal component.

### 3.2.2.3 SELECTION OF COLLIMATION SEQUENCE

If there would be no blocking of the light paths, a single auto collimator/mirror would suffice for this application. However, since the telescope structure rotates around the reference platform during tracking operation, blockage of the beam would occur from time to time as part of the structure crosses the light path. Thus, multiple auto collimator/mirror elements are required to assure that at least one unit is unobstructed and operational, in order to assure continuity.

Hence, the free collimator/mirror combination must be selected either by memory or by method of sensing (change in light intensity for instance during begin of blockage). There are two approaches for collimator sequence selection based on memory data as to which collimator can clear the structure and operate in a certain range.

Both azimuth and elevation data will be needed for the programming of successive selections.

Approach No. I:

This approach makes use of mechanical memory and consists of one azimuth and one elevation instrument servo; both are slaved to the respective reflector motion.

Each instrument servo would contain a mechanical cam for each auto collimating station. The cams would be made adjustable over the full telescope travel range. A dial indicator, mechanically coupled to the cam shaft would indicate the respective axis position, thus making the calibration of the unit independent from the digital read-out devices of other equipment. Both instrument

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servos would make use of the synchro transmitters which are located on the platform axes, after proper buffering. It is estimated that a selection reference position accuracy of ±.50° and repeatability will be satisfactory for this purpose.

SK-3 on the following page shows the servo approach for the collimation matrix.

Signal "A" switches the respective collimator on. Signal "B" corrects the azimuth axis for the indexing error of the precalibrated mirror. Signal "C" compensates the elevation tilt servo loop gain based on the in-phase value of the selected mirror.

The advantages of this approach are:

a) Ease of adjustment.
b) Flexibility.
c) Non-volatile memory in case of power failure, power transient or noise.

Approach No. II:

Another approach is logic programming of the collimator selection. For a resolution of 1°, 9 bits of position information have to be gated in logic programming. With 9 bits of information from each axis, a total of 18 bits are needed for each of the collimator positions defining range.

This required digital information is derived from the nine most significant bits of each axis; this data is already available in the system and needs only be buffered for this use. Fig. 4 shows the logic approach for the collimation matrix.

Explanation of Fig. 4:

Gated nine bits of azimuth and elevation provide position No. 1. Similar gating defines position No. 2. Between these positions collimator No. 1 can operate. The memory module prevents transients or bit noise from effecting the matrix and is reset only if another range is satisfied.

Collimation control chassis and signals A, B and C are identical for either Approach I or II.

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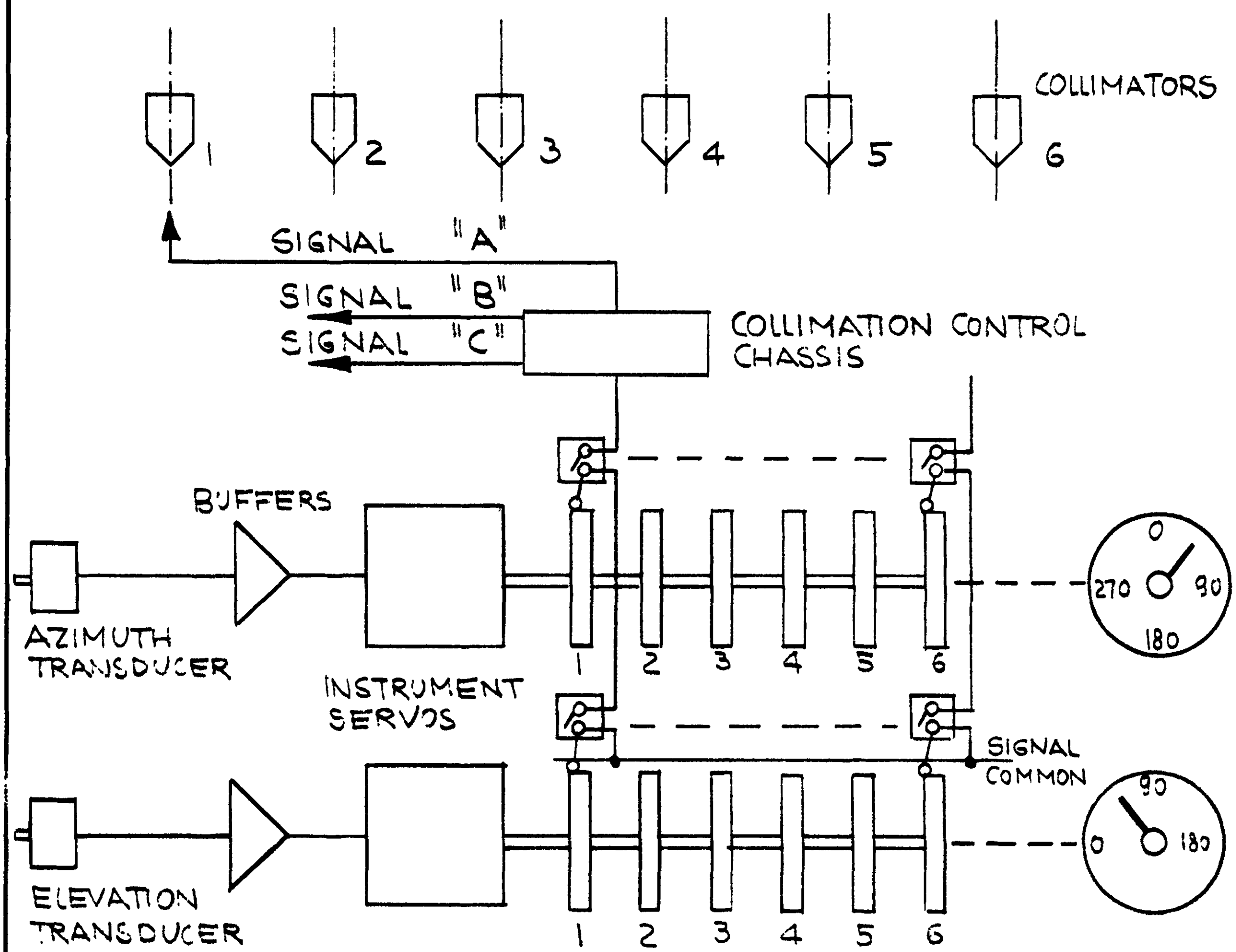


SERVO APPROACH FOR COLLIMATION MATRIX

SK-3

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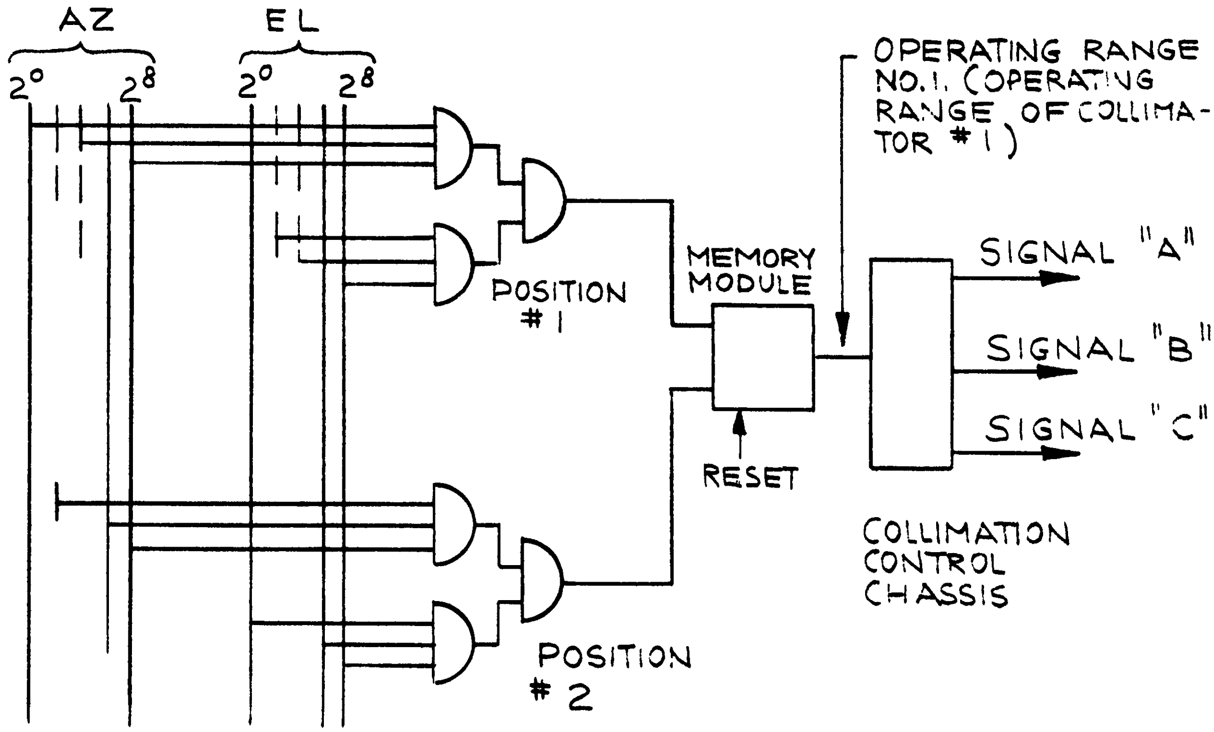


FIG. 4

LOGIC APPROACH FOR COLLIMATION MATRIX

The main features of this approach are:

a) It is down-stream in the signal path; hence, any up-stream failures in the subassemblies will render this system non-operative. This could cause shut-downs and difficulty in trouble shooting.

b) Even though highly reliable "solid state" components can be used, its component population is high, which results in decreased overall reliability.

c) This system is more noise sensitive and the memory is volatile in nature, i.e., can be lost due to power failure or transients.

3.2.2.4 ENVIRONMENTAL CONSIDERATIONS

Three factors are of main concern:

a) Temperature variations; b) reflection and refractions; c) change of refraction due to turbulance or temperature gradients in the air.

a) Temperature Variations

Temperature gradients within the collimators or polygon mirror will cause dimensional distortions resulting in positional errors. In order to eliminate this error source, it will be necessary to maintain a selected constant temperature for either component. It is estimated that a local ambient temperature of +130°F controlled to ±1/4°F will satisfy this requirement.

b) Reflections and Refractions

In order to protect the polygon mirror or the collimator from the environment, either unit will have to be enclosed. These housings must have window openings for passage of the laser beams. These should be quartz windows so as to minimize reflection of the laser beam. The windows must furthermore be installed perpendicular to the optical path for minimization of beam refraction errors due to errors in parallelism of the quartz window surfaces.

c) Change of Refraction

Since both the projected and reflected beams have almost identical paths, their refractions will be almost the same and would cancel out.

Only the change in refraction as a function of air temperature will produce errors; for the distance considered, however, these errors should be insignificant. Air turbulance is not a problem either since the beam travels at the speed of light.

## 3.3 GRAVITY REFERENCE SYSTEM

There are two types of gravity sensing instruments which could be utilized for elevation angle reference purpose. They are:
a) A pendulous vertical sensor by "Kearfott" and
b) A bubble type tilt meter by "Ideal-Aerosmith."

Only the Kearfott sensor application is described herein. The advantages of application of a gravity sensing device over optical reference are that blocking is eliminated and that the accuracy of the instrument would not be affected by rain or snow, etc. However, if an optical system is required anyway for azimuth reference, then the elevation reference may as well be optically also. But if it should be feasible and practical to utilize a gyro compass for azimuth reference, the elevation reference system must then be gravitational. Such a platform could be installed right behind the vertex of the parabolic reflector, which would improve the pointing reference of the radio telescope still further.

### 3.3.1 KEARFOTT - "PENDULOUS VERTICAL TILT SENSOR"

This instrument, as the name implies, utilizes a precision pendulum for the detection of the direction of gravity. The pendulous element is suspended in a viscous fluid and the output is sensed electro magnetically (1000 HZ pickoff). For this application, a custom made, high performance unit will be required. In order to achieve sufficiently high response, the length of the pendulum is kept shorter and the fluid less viscous than for standard precision units. The model considered for this application is: Kearfott #C 70-1815 002, which has the following characteristics:

#### 3.3.1.1. SYSTEMS CHARACTERISTICS

1) High signal to noise ratio, as one arc. sec. of tilt is equivalent to .30 millivolts of output.

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2) Moderate dead band, hysteresis is about 1 arc. sec. about null. The dead band can be minimized by biasing of the sensor and operation above or below null.

It is estimated that the hysteresis thus can be reduced by a factor of 2 or 3 (see figure below).

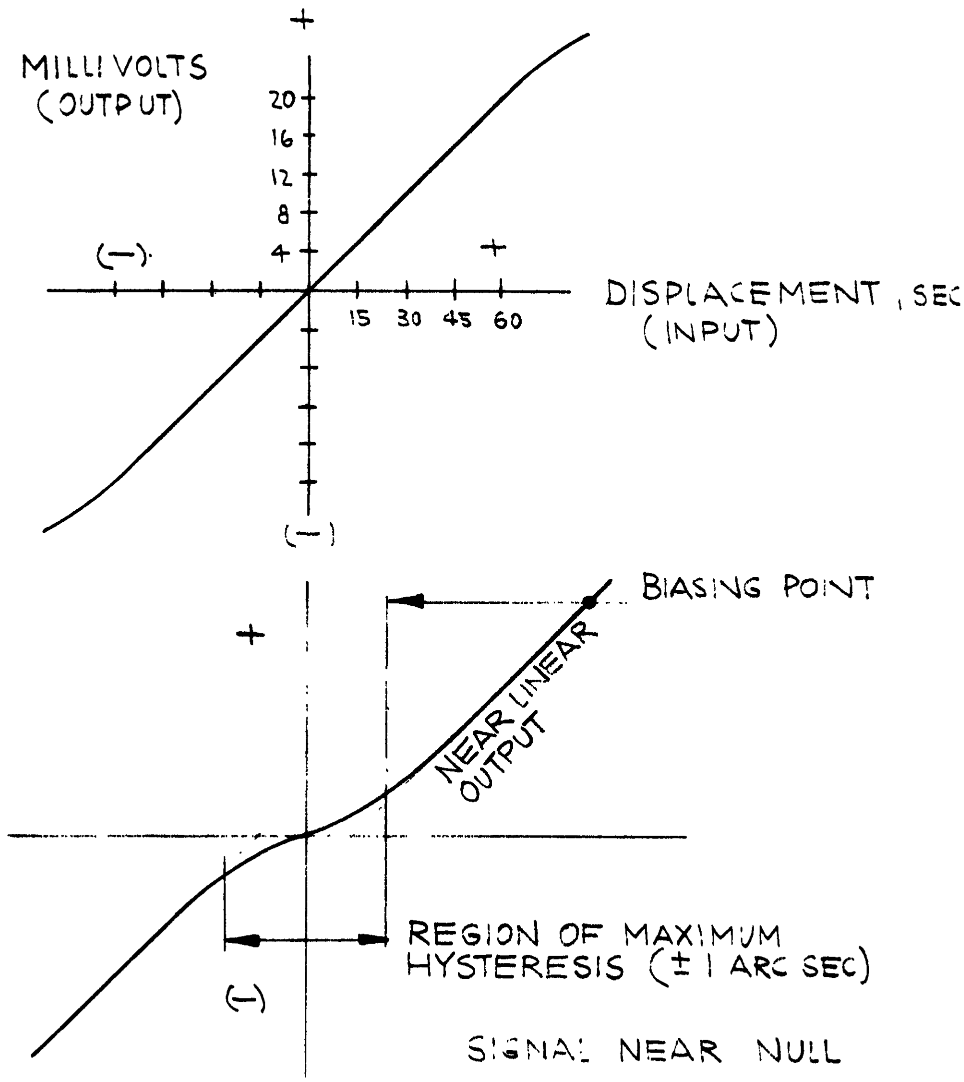


FIG. 5

3) Linearity is within ±.50 sec. between 3 sec. and approximately 40 sec. Since the unit is expected to operate in biased form and in a limited range, i.e., in a null seeking servo application, the non-linearity error will be greatly reduced.

4) Response for small signal input is around 12 milliseconds per arc. sec. of displacement. Since platform displacement should be limited to ±3 arc. sec., the time required to reach 2/3 of this value is 24 milliseconds or $\tau = .024$ sec.

5) Damping, the unit will have a nominal damping ratio of 1.0 (100%); worst case damping ratio will not be below .80, which means that the over-shoot for step input will be limited to 5% of the step input and that only one over-shoot will occur at worst.

### 3.3.1.2 APPLICATION

Linear and angular perturbations due to wind gusts, telescope motions, etc., will result in transient outputs from the pendulous tilt sensor, even though the platform is actually level. Thus, compensation for the effects of accelerations on the tilt sensor is required in order that the true tilt signal may be extracted and differentiated from transient or sustained (sinusoidal) acceleration perturbations. This requires the application of a low threshold "force-balance type" linear accelerometer and a highly sensitivity rate gyro. Since both of these signals will go through networks with heavy RC, very high frequency responses are required (100 ÷ 200 Hz).

The characteristics of these instruments are as follows:

1) Linear Accelerometer: Kearfott, Type C 70 2401 003 (force balance accelerometer)

| | | |
|---|---|---|
| a) Range of measurement | : | ±20 g |
| b) Threshold | : | .0000005 g |
| c) Natural frequency | : | 220 CPS |
| d) Zero stability | : | .00001 g |
| e) Linearity | : | .01% |
| f) Output (scale factor) | : | 5 m A/g |
| g) Scale factor variation | : | ±.01% |

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2) Rate Gyro: Kearfott, Type C 70 2027

| | | |
|---|---|---|
| a) Range | : | Up to 400°/sec. |
| b) Natural frequency | : | Up to 150 CPS |
| c) Threshold | : | Less than .005°/sec. |
| d) Resolution | : | Less than .005°/sec. |
| e) Sensitivity | : | Up to 350 mV/°/sec. |
| f) Maximum output | : | 8 volts |
| g) Linearity | : | 2% of full scale |
| | | .50% of full scale to half scale |

The accelerometer can convert both angular and linear accelerations into electrical signals. While the conversion of linear accelerations to electrial output is needed, angular accelerations indicate an actual tilt, thus no correction or compensation is required in this case. The rate gyro converts angular accelerations to electrical signals; however, it does not have an output under linear accelerations. Thus, the output of the rate gyro is used to interlock the accelerometer signals.

SK-4 on the next page shows the applicable tilt sensing block diagram to be utilized for this system.

Below is a brief explanation:

The signal conditioning modules "A," "B" and "C" have the following functions:

1) To convert the 400 HZ exitation signal (AC) to (DC).
2) To provide the proper voltage scaling.
3) To adjust the frequency response such that the signals are compatible, i.e., can be added or subtracted.

The integrating stages "D" and "E" convert the acceleration signal to a velocity signal and subsequently to position signal by double integration. Thus, at the input of the comparator stage "F" the tilt sensor and the accelerometer signals have the same scaling factor and frequency response. The natural frequency of both components should remain stable within .10% or better, since the platform is temperature controlled. This is compatible with the linearity of the instruments.

PREPARED BY O. R. Heine
J. MURADLIYAN
APPROVED BY
SUBMITTED BY S.D.L.

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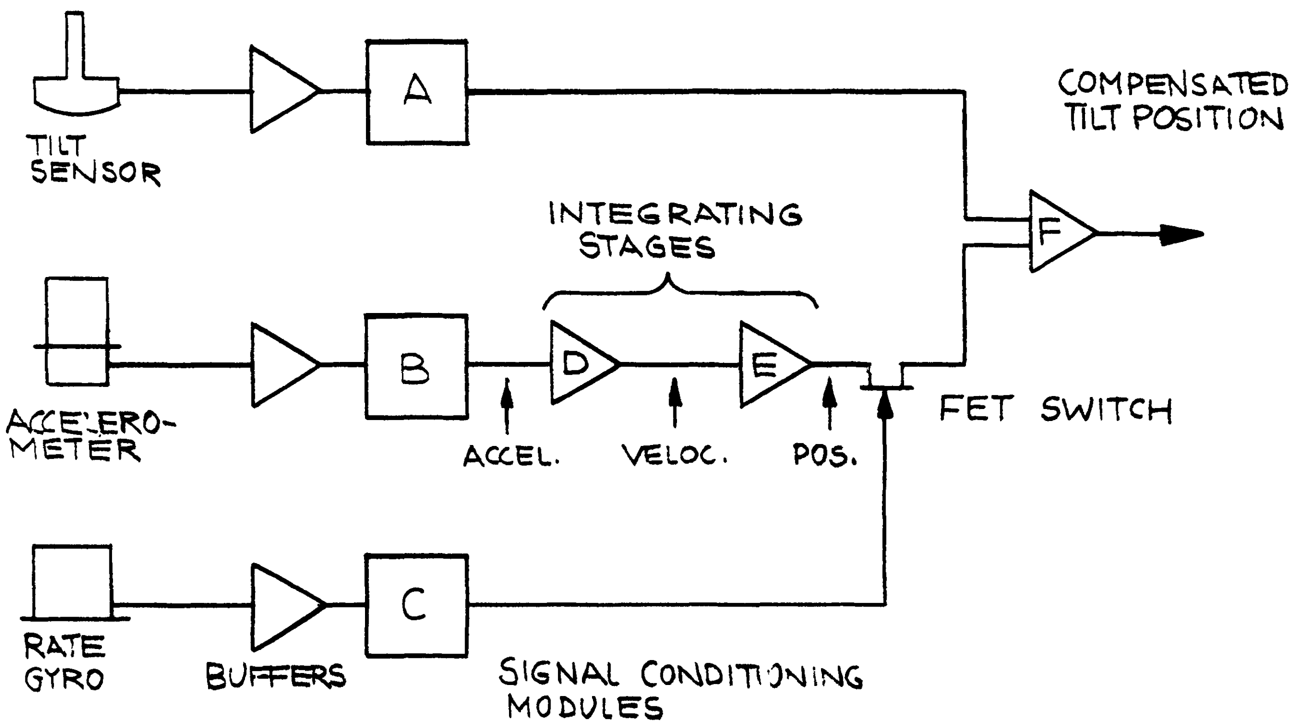
## TILT SENSOR BLOCK DIAGRAM




SK-4

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## 3.4 PLATFORM SYSTEM DESCRIPTION

The beforegoing described the basic instruments which can be used for fixing the platform in both azimuth and elevation direction. Since the platform, as implied, must remain fixed in space while the telescope reflector moves about azimuth and elevation to track a radio source, it is obvious that the platform should move in the opposite direction relative to the rotating structure at exactly the same speed. This is accomplished by using the amplified error signal generated by the position sensors for feedback purpose to drive a null seeking platform servo system. The position between the platform and the telescope reflector is detected on the platform by means of a readout transmitter; the transmitted position is then received by a receiver on the ground and the signal is there digitized.

At the same time the position readout signal which is initially in analog form is re-transmitted to the telescope drive servo for position correction of the telescope, if a digital comparison between the position commanded by the computer and the actual position should indicate a telescope position error.

The applicable block diagram for this system is shown on SK-5 on the following page.

### 3.4.1 POSITION CONTROL SYSTEM

#### 3.4.1.1 INSTRUMENTATION

An analysis of the error contribution of the various control components and instruments indicates that the readout instrumentation would contribute significantly to the total system's error if a precision synchro transmitter would be used.

This error contribution can be greatly reduced by application of an "inductosyn" transducer instead. The "inductosyn" is a trade name for a transducer made by "Del Electronics" and "Ferrand Controls" and consists basically of two plates separated by a precision air gap.

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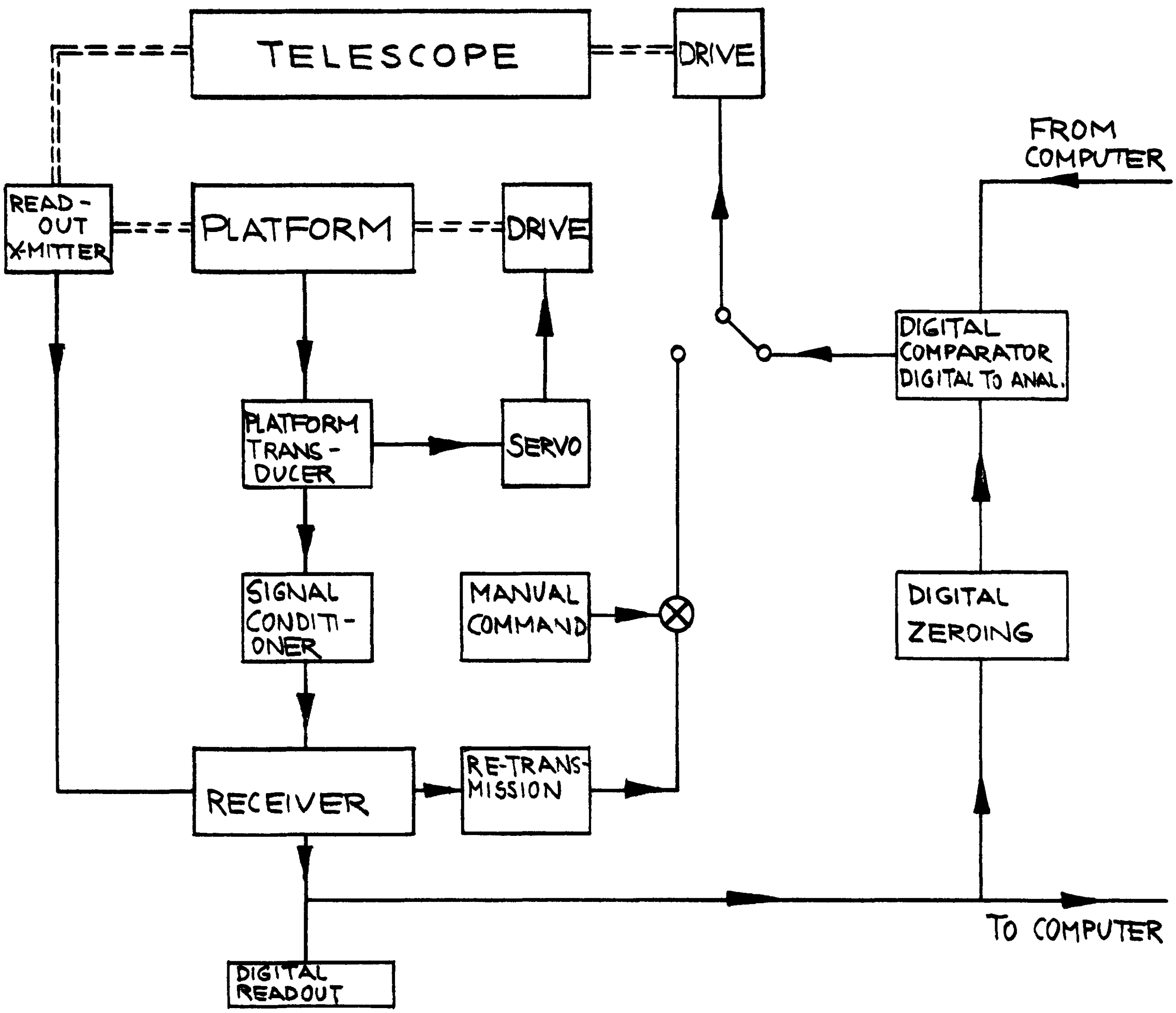
REFERENCE PLATFORM SYSTEM BLOCK DIAGRAM
(TYPICAL, EITHER AXIS)




SK-5

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Printed circuitry on each plate creates the effect of an electro magnetic coupling. If one plate printed circuitry is used as an excitation coil, the other plate can be designed to give outputs similar to the output of a resolver or synchro.

A 12 in. dia. "1024 pole" inductosyn unit will have a basic accuracy of .50 arc. sec. (largest unit made). However, housing the plates reduces the accuracy to about ±1.2 arc. sec., mainly because of tolerance build-ups in the housing (bearings, supports, etc.) produce misalignment between transducer-rotor and stator (.001 in radial misalignment or .003 in tilt in the air gap can cause approximately 1.0 arc. sec. error). The 1024 pole unit is used for binary output generation of 21 bits.

If decimal output is required, a "720 pole" unit will have to be used instead. In order to keep resolution and accuracy compatible, 7 decimal digits with .0001 degree resolution (.36 rac. sec.) will be needed.

The output signal of the inductosyn unit is around 2 to 8 microvolts per arc. sec., which is very low. Therefore, "state-of-the-art" amplification and noise suppression techniques must be applied. Thus, filters, high performance amplifiers and a rotary signal transformer (to eliminate noise generated by slip rings) must be used. Present experience is that inductosyn signals will have to be filtered and buffered (amplified) within a distance of 24 in. to the unit. The buffered analog output should be fed to the digitizing electronics, prefereably within 50 ft. (100 ft. max.). Special twisted, shielded wiring will have to be used (commercially available).

Compared to synchro systems, the inductosyn excitation voltage is at high frequency; 2 ÷ 10 KHZ is normally used. Some jitter is inherent in an inductosyn system. This can be limited to ±.30 arc. sec., however. A block diagram of the inductosyn system with major components is shown on Fig. 6 on next page.

For this application, the two amplifiers and the filter should be put in the same housing with the inductosyn plates. The digitizing electronics, which are packaged in a 19"x7"x18" chassis, have to be located on the telescope structure. The digital output of this unit can be transmitted up to 500 ft. with ease.

PREPARED BY O. R. Heine
J. MURADLIYAN
APPROVED BY
SUBMITTED BY S.D.L.

NATIONAL RADIO ASTRONOMY OBSERVATORY
POST OFFICE BOX 2
GREEN BANK, WEST VIRGINIA 24944
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SCHEMATIC OF INDUCTOSYN SYSTEM

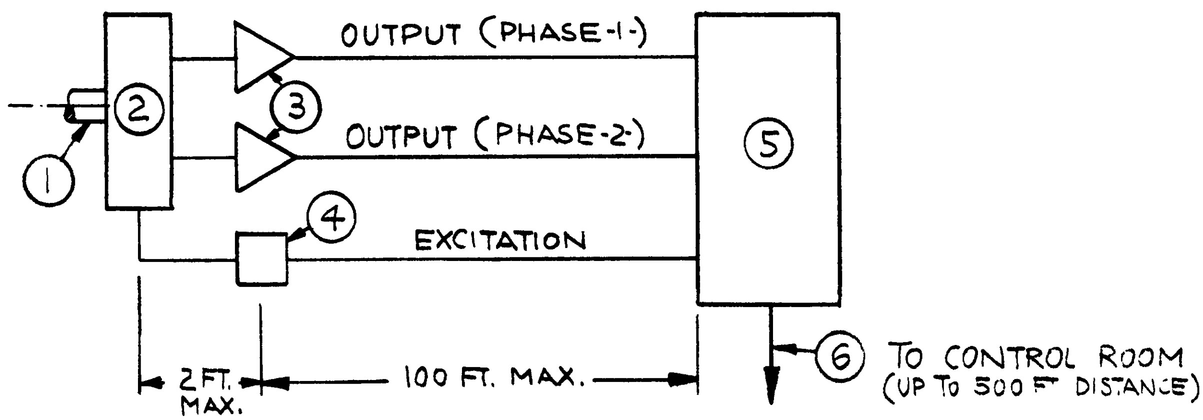


FIG. 6

| ITEM | DESCRIPTION |
|---|---|
| 1 | Inductosyn input shaft or flexible coupling. |
| 2 | Housed inductosyn plates. |
| 3 | Output signal amplifiers. |
| 4 | Excitation voltage filter. |
| 5 | Digitizing electronics. |
| 6 | Digital output to the control room. |

PREPARED BY O. R. Heine
J. MURADLIYAN
APPROVED BY
SUBMITTED BY S.D.L.

3.4.1.2 SERVO REQUIREMENTS

The platform positioning servo characteristics should closely fit the required overall dynamic performance and error budget considerations. To cope with the disturbances due to wind gusts, structure, travel, etc., the servo loop should have a high natural frequency (at least two octaves higher than the perturbation frequency). The open loop gain of the feedback control system should be high enough to operate within the ±1 arc. sec. dead band required by error budgeting.

1) Drive:

The required drive should be able to position the following loads:

a) Azimuth:

| | |
|---|---|
| Weight: | Approx. 60 lbs. |
| Inertia: | .09 lb-ft-sec$^2$ |

b) Elevation:

| | |
|---|---|
| Weight: | Approx. 69 lbs. |
| Inertia: | 0.23 lb-ft-sec$^2$ |

It appears possible that these loads can be reduced during the final design by as much as 30% for increased servo band width.

As the elevation axis also carries the azimuth axis full weight, the elevation axis performance requirements are more difficult to meet (worst case). The frictional torque on this axis is approximately 70 OZ-in. if commercially available bearings are used. State-of-the-art components, techniques and alignment methods can reduce this to 35 OZ-in.

2) Performance:

The performances of the selected hardware and techniques are discussed below:

The "Inland" servo (torque) motor T-5730 which produces 7 lb.-in of torque fits the loading conditions best. The hysteresis requirements dictate an open loop gain of 435,000 volts/radian. This high gain, in turn, makes it necessary to use lead-lag compensation techniques for stable operation.

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The suggested compensation can give a closed loop band width of 50 radians per second which compares very favorably with the estimated 6-8 rad/sec antenna structural natural frequency and 2-4 rad/sec of perturbance inputs.

Applicable transfer functions, response calculations and bode diagrams are contained in Section 5, Appendix I. On page 5.13 of Section 5 is shown that servo stability and desired max. 1 arc.sec. dead band is attainable if tachometer compensation is applied.

In any event, the relative high closed loop band width dictates use ot light weight, low inertia components; thus, the proposed application of the polygon mirror is ideally suited for this requirement.

### 3.4.1.3 ERROR BUDGET ESTIMATE

The following error budget estimate appears feasible for the before described instrument systems and components:

1) Sensor errors:
   a) Basic error, including linearity and hysteresis : ±.10 arc. sec.
   b) Interface errors, due to small temperature differentials in the mirror ( ~ .25°F) : ±.40 arc. sec.

2) Platform servo errors:
   a) Servo loop hysteresis error : ±1.0 arc. sec.
   b) Dynamic lag error : Negligible

3) Readout Instrumentation errors:
   a) Inductosyn transducer readout error : ±1.2 arc. sec.
   b) Inductosyn digitizing electronics error (digitizing accuracy can be ± 1 count) : ±.30 arc. sec.
   c) Inductosyn hysteresis error due to shaft and coupling wind-up : ±.20 arc. sec.

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4) Error due to cabling:

| | | |
|---|---|---|
| a) Temperature effect error, on 500 ft. long transducer transmission cable | : | ±.50 arc. sec. |
| b) Drift error: (10 KHZ carrier is used) | : | Negligible |

| | | |
|---|---|---|
| Total worst case sensor loop error (Items 1 and 2 combined) | : | ±1.5 arc. sec. |
| Total worst case readout instrumentation error: (Items 3 and 4 combined) | : | ±2.2 arc. sec. |

Combining the two worst case component results in the following:

| | | |
|---|---|---|
| a) Worst case peak to peak error | : | ±3.7 arc. sec. |
| b) Root-sum square error (combining each error component) | : | ±1.7 arc. sec. |
| c) Root-sum square error (combining worst error of sensor loop and readout instrumentation) | : | ±2.6 arc. sec. |

The above applies for both azimuth and elevation reference.

It is believed that a ±3.0 arc. sec. RMS system accuracy is well within the state-of-art at the present time.

Allowing 4 arc. sec. RMS error for the telescope drive system and structural deformations in the reflector structure, secondary reflector, support legs, etc., it appears feasible that a 5 arc. RMS pointing accuracy of the radio telescope is obtainable with the application of this system, providing the above dynamic telescope drive system accuracy can be achieved.

PREPARED BY O. R. Heine
J. MURADLIYAN
APPROVED BY
SUBMITTED BY S.D.L.

3.4.2 MECHANICAL CONFIGURATION

The mechanical configuration of the reference platform is shown on Dwg. No. 107-D-003.

As can be seen, the platform consists basically of a hollow tubular member (1), which is mounted on bearings and is free to rotate with a "U"-shaped base (2). The axis of this tubular member is mounted level and coincides with the elevation axis of the radio telescope. The rotor of a torque motor (3) is attached to one end of the tubular member, while the stator (4) is mounted to the base. On the same end is mounted an inductosyn unit (5) via a flexible coupling (12). The tubular member supports the polygon mirror (6), which is attached to a hollow azimuth shaft (7). The axis of this azimuth shaft is held perpendicular to the elevation axis and coincides with the azimuth axis of the telescope. This shaft is running on precision bearings (8) and is also driven directly by a torque motor (9). A readout transmitter arrangement (10) is incorporated on the shaft and in the shaft housing, and an inductosyn transducer (11) is coupled to the shaft via the bellows coupling (12).

The entire rotational portion of the platform assembly is covered with a "fiberglass-polyurethene" sandwiched housing (13), which has window openings containing quartz windows (14), through which the laser light beam is projected onto the mirror (6).

Dwg. 107-D-003 shows provisions for mounting of tilt sensor (15), accelerometer (16) and rate gyro (17), which are "alternatives" only. The "optical only" platform will not have these instruments and hence the elevation shaft would not have the cutouts required for the accommodation of the gravity sensing system instruments.

The "U"-shaped mounting base (2) is also covered with insulation (18) to eliminate temperature distortions in this structure. A twist cable (19) passes through tubular member (1) and is designed to allow rotation about the el-axis through ±45°.

The entire platform assembly is kept at a constant temperature of +130° within an accuracy of ±1/4°F by means of built-in, controlled "circulating air" hearing units (not shown).

NATIONAL RADIO ASTRONOMY OBSERVATORY
POST OFFICE BOX 2
GREEN BANK, WEST VIRGINIA 24944
TELEPHONE ARBOVALE 456-2011



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### 3.4.3 PERFORMANCE REQUIREMENTS

The position reference platform studied herein must function at maximum accuracy (3 ÷ 5 arc. sec.) under the following environmental conditions and external perturbations:

| | | |
|---|---|---|
| 1) | Environmental temperature range | : -20°F to +120°F |
| 2) | Wind velocity (tracking condition) | : 22 MPH, gusty |
| 3) | Rain or snow | : Reduced accuracy permissible |
| 4) | Angular velocity (Az & El) | : 0 to .105°/sec. |
| 5) | Angular acceleration (Az & El) | : .330°/sec.$^2$, max. |
| 6) | Vertical, linear acceleration | : .013 cm/sec.$^2$ |
| 7) | Lateral, linear acceleration | : .060 cm/sec.$^2$ |
| 8) | Frequency range of perturbations | : 0 to 1.0 C.P.S. |
| 9) | Excentricity of Az axis | : ±1.0 in/360° |
| 10) | Heave motion at full Az rotation | : ±1.0 in/360° |
| 11) | Light condition | : Night to full daylight |

PREPARED BY O. R. Heine APPROVED BY ______ SUBMITTED BY S.D.L.