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Green Bank, West Virginia

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NUTATING SUBREFLECTOR FOR 36-FOOT TELESCOPE

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1.0 Introduction

This report describes a nutating subreflector that has been developed for use at the 36-ft telescope when used in a Cassegrain configuration.

The purpose of nutating the subreflector is to provide the beam switching which is essential for most continuum observations. This method of switching has the obvious advantages of being broad band and lossless.

The mechanism described will switch the antenna beam three beamwidths at wavelengths down to 1.35 cm at a frequency of 5 Hz. The transition time is approximately 20 ms.

The nutating subreflector is packaged so as to be easily installed in the existing prime focus Sterling mount.

Also included is a small horn at the center of the reflector for calibration purposes.

2.0 Subreflector Specifications

The tolerances on the geometry of the Cassegrain system are dealt with fully in S. Weinreb's memo of March 1, 1971. The critical tolerances for the nutating mechanism concern the angular positioning accuracy of the subreflector and the time taken to switch through a given angle. The subreflector used is 18" in diameter and must be positioned to within ± 40 arc seconds (± 0.003" at the edge). To give a beam deviation of 15 arc minutes (3 beamwidths at a wavelength of 1.35 cm), a subreflector rotation of 212 arc minutes is needed. This corresponds to a total edge movement of 0.556". This movement should take place in less than 30 ms after which the edge of the reflector must be stable to better than ± 0.003". The switching frequency is 5 Hz or 432 thousand operations per day so the mechanism should be simple, reliable and not prone to mechanical wear.

3.0 Description of Nutating Mechanism

3.1 Design Considerations

To meet the required transition times with a subreflector moment of inertia of 0.03 ft lbs sec^2, a torque of about 15 ft lbs is needed. This assumes that the transition time is equally divided between acceleration and deceleration.

We were initially concerned with the effects of the reaction forces on the feed support structure, but tests on the telescope with a prototype system showed no significant vibration.

It was felt that the most practical way of implementing the nutation requirement was to use a positional servo system to accurately set the angular position of the reflector and to supply this servo with a square wave position command corresponding to on-source and off-source positions.

3.2 Principle of Operation

A block diagram of the nutating mechanism with the electronic controls is shown in Figure 1.

Two solenoids are used to position the reflector, one for each direction of movement. The solenoids are driven by a switching type power amplifier, the input to the power amplifier being the position error signal. Linear position and velocity sensors at the edge of the reflector provide signals to the servo electronics.

When switching from one position to another, acceleration and deceleration are divided equally between the two solenoids. The solenoids never come up against a mechanical stop which means there is virtually nothing to wear out. The position and velocity transducers consist of rods moving within coils of wire with no bearing surface, so again wear should be almost non-existent.

A block diagram of the position servo loop is shown in Figure 2. A velocity servo loop serves to reduce the non-linearities inherent in the solenoids and also provides damping. The position loop is closed around this velocity loop, the overall closed loop transfer function being 315 volts/radian, and the 3 dB closed loop bandwidth being 800 rads/sec.

A photograph of the subreflector assembly and the control rack is shown in Figure 3.

3.3 Circuitry

The servo circuitry is shown in Figure 4.

The position signal (5.2 mV/.001") is buffered and amplified in A1 and A2. The position signal is compared with the position command signal in A3 and summed with the velocity signal in A4. The resultant error signal is used to drive the power amplifier for the solenoids.

The position signal is displayed on a digital panel meter. The gain of the position indication circuits is arranged so that the digital panel meter reads the telescope beam deviation.

The position command signal originates from either of the position pots on the front panel. Two FET switches select which of these two pots supply the position command signal. A switch on the front panel selects either position 1, position 2, or "nutate". In the "nutate" position the subreflector switching between position 1 and position 2 is controlled by the signal/reference signal.

The solenoid driver is an NC102 amplifier manufactured by Control Systems Research. The arrangement used to drive the solenoids is shown in Figure 5. Diodes in series with each of the solenoids serve to energize one solenoid or the other dependent on the polarity of the input signal. The amplifier is used as a current amplifier to virtually eliminate phase shift due to the solenoid inductance and also to reduce non-linearities due to the diodes. The amplifier has a gain of 3.5 amps/volt, a peak current rating of 24 amps and a continuous rating of 5 amps.

The reference generator and interface circuitry is shown in Figure 6.

A 20 Hz oscillator is divided down for providing the signal/reference waveform to the subreflector and also the 100 ms sync pulses to the multiplexer. There is a delay of approximately 8 ms in the response of the subreflector to a change in position command so the signal/reference output and sync output are also delayed by this amount. A blanking signal is also provided to indicate when the subreflector is moving. Input and output signals are available in either 3C or TTL logic levels.

3.4 Performance of Subreflector

A position waveform for the subreflector switching ± 2 arc minutes beam displacement at 5 Hz is shown in Figure 7.

The mechanism was tested from June 15 to September 15, 1972, running continuously at 5 Hz with a beam displacement of ± 2 arc minutes. This is about 40 million cycles and no significant wear could be detected at the end of this period. The performance of the subreflector at different beam deviations is given in the table below.

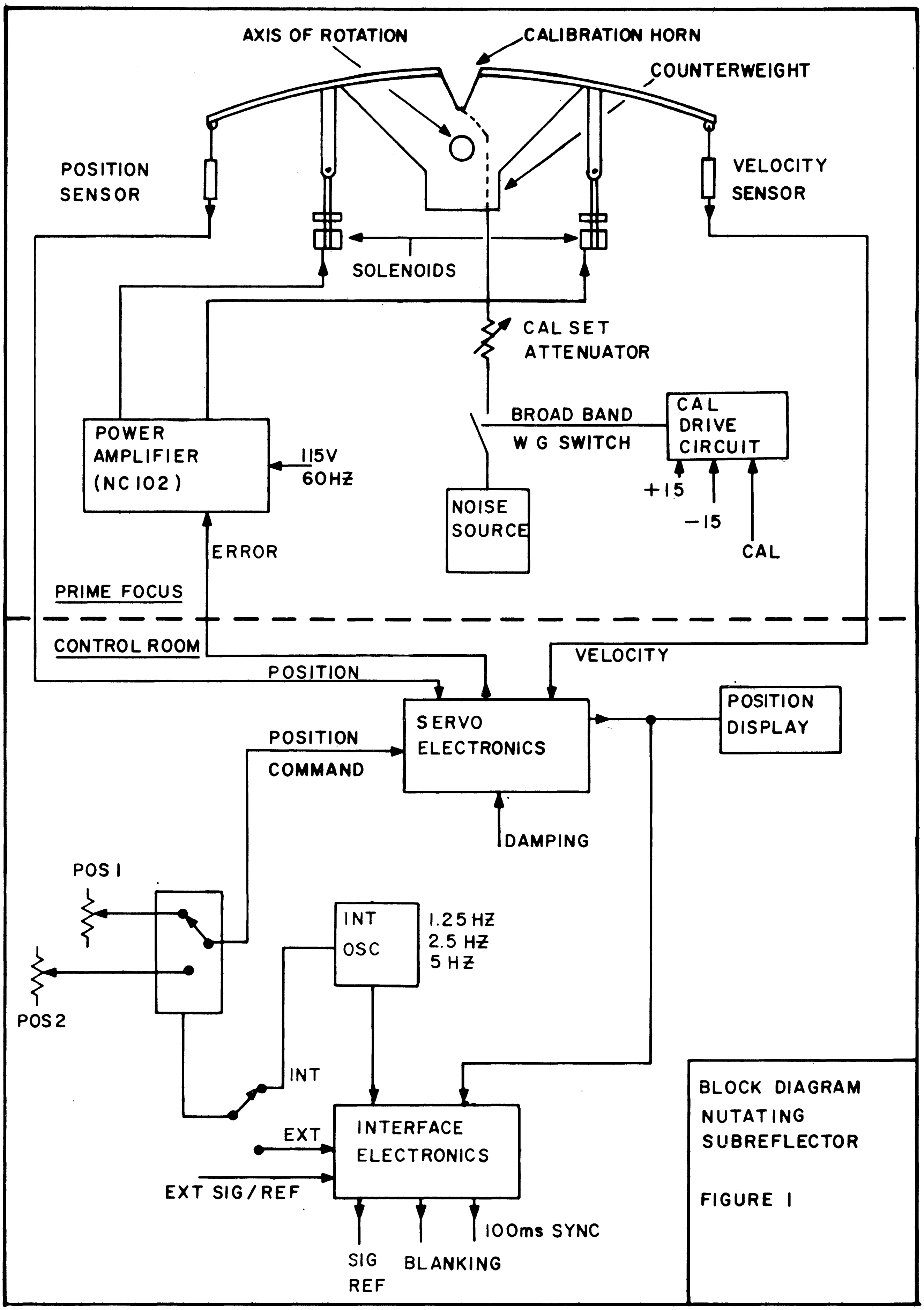
Beam Deviation $\Delta\theta$	Subreflector Rotation α	Actual Measured Transition Time	λ for $\Delta\theta$ = 3 Beamwidths	Subreflector Edge Movement
15' (± 7.5)	212.0'	30 ms	1.35 cm	± 0.278"
10'	141.8'	22 ms	9.0 mm	± 0.186"
4'	56.7'	18 ms	3.6 mm	± 0.074"

4.0 Calibration Circuits

The calibration circuits are shown in Figure 8. A servo loop similar to the subreflector servo accurately positions an attenuator vane in the waveguide. This arrangement has the advantage of fast switching and mo mechanical stops. The switching time is about 5 ms. A TTL cal on/cal off signal selects the on or off position of the vane.

The calibration signal may be manually controlled or computer controlled. When in the manual mode the cal comes on synchronously with the subreflector switching frequency. A phase switch permits the cal to come on when the subreflector is either in position 1 or position 2.

The size of the calibration signal may be changed by an attenuator in the waveguide run. The size of the calibration signal at the receiver will be variable up to 10°K.



BLOCK DIAGRAM NUTATING SUBREFLECTOR

FIGURE 1

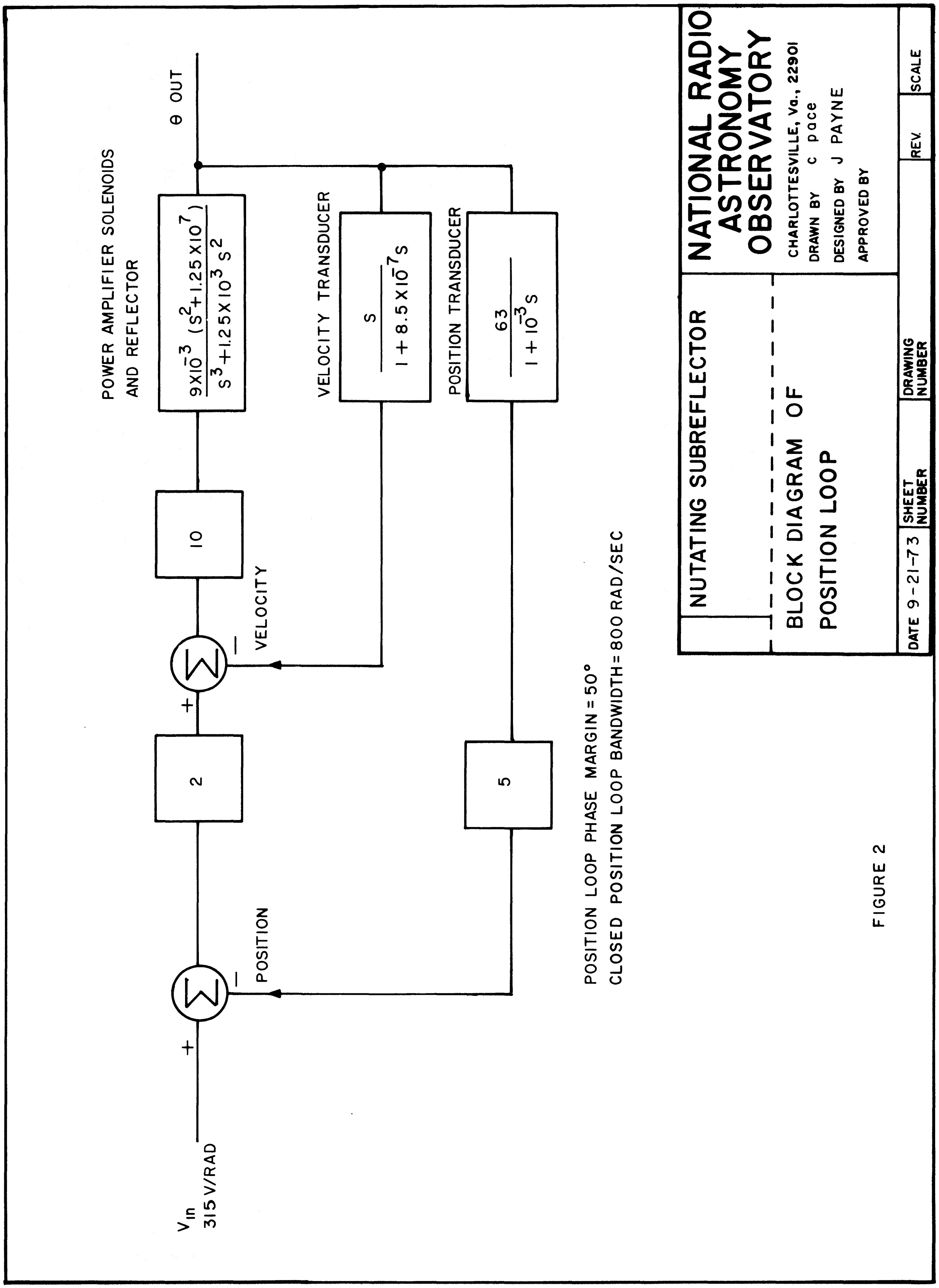

V_{in}
315 V/RAD
POSITION
VELOCITY
2
10
5
POWER AMPLIFIER SOLENOIDS AND REFLECTOR
$\frac{9\times10^{-3}(S^2+1.25\times10^7)}{S^3+1.25\times10^3 S^2}$
VELOCITY TRANSDUCER
$\frac{S}{1+8.5\times10^{-7}S}$
POSITION TRANSDUCER
$\frac{63}{1+10^{-3}S}$
θ OUT
POSITION LOOP PHASE MARGIN = 50°
CLOSED POSITION LOOP BANDWIDTH = 800 RAD/SEC
NUTATING SUBREFLECTOR
BLOCK DIAGRAM OF POSITION LOOP
NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, Va., 22901
DRAWN BY C pace
DESIGNED BY J PAYNE
APPROVED BY
DATE 9-21-73
SHEET NUMBER
DRAWING NUMBER
REV.
SCALE

FIGURE 2

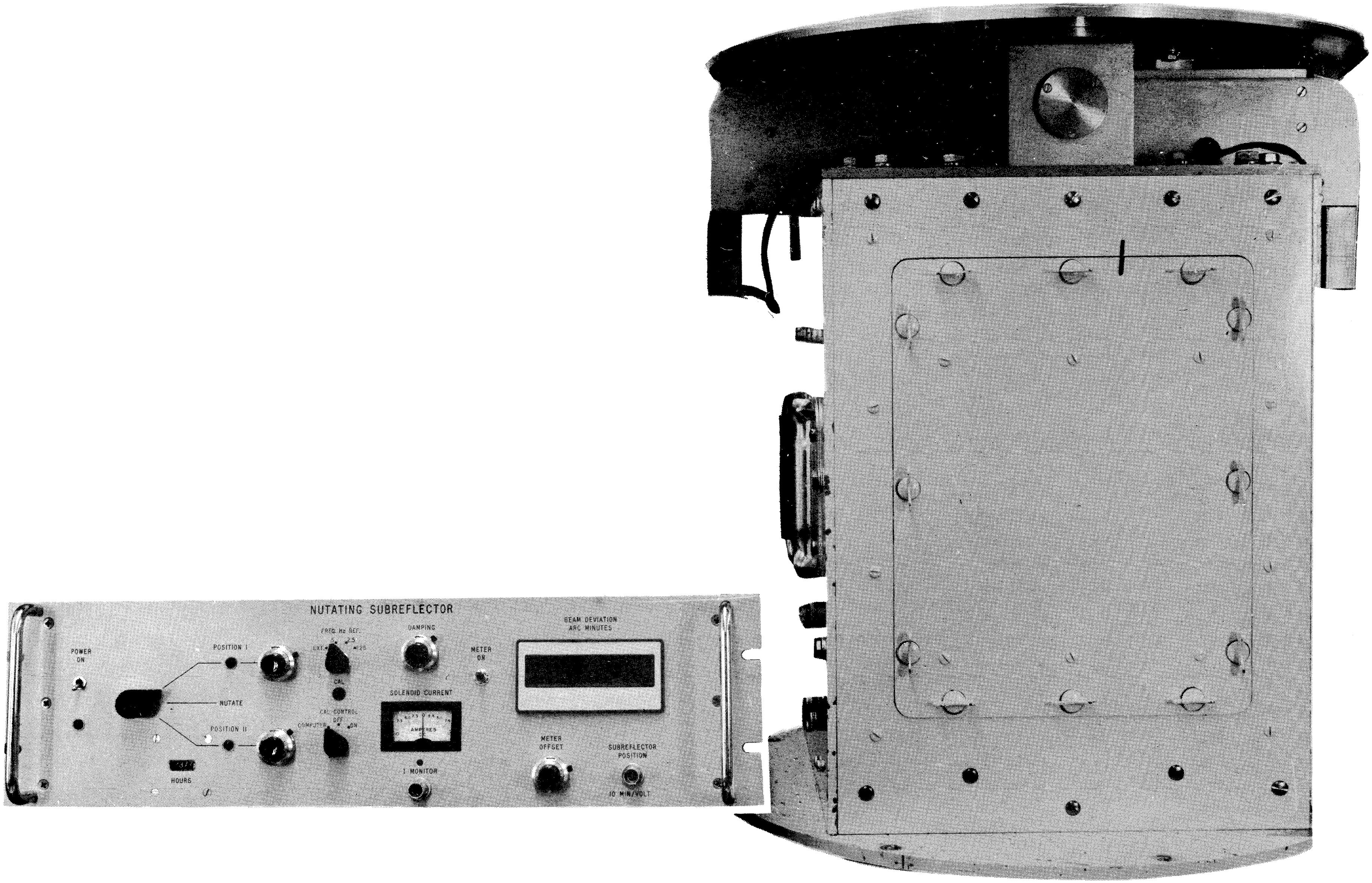


Figure 3 — Photograph of Nutating Subreflector and Control Rack.

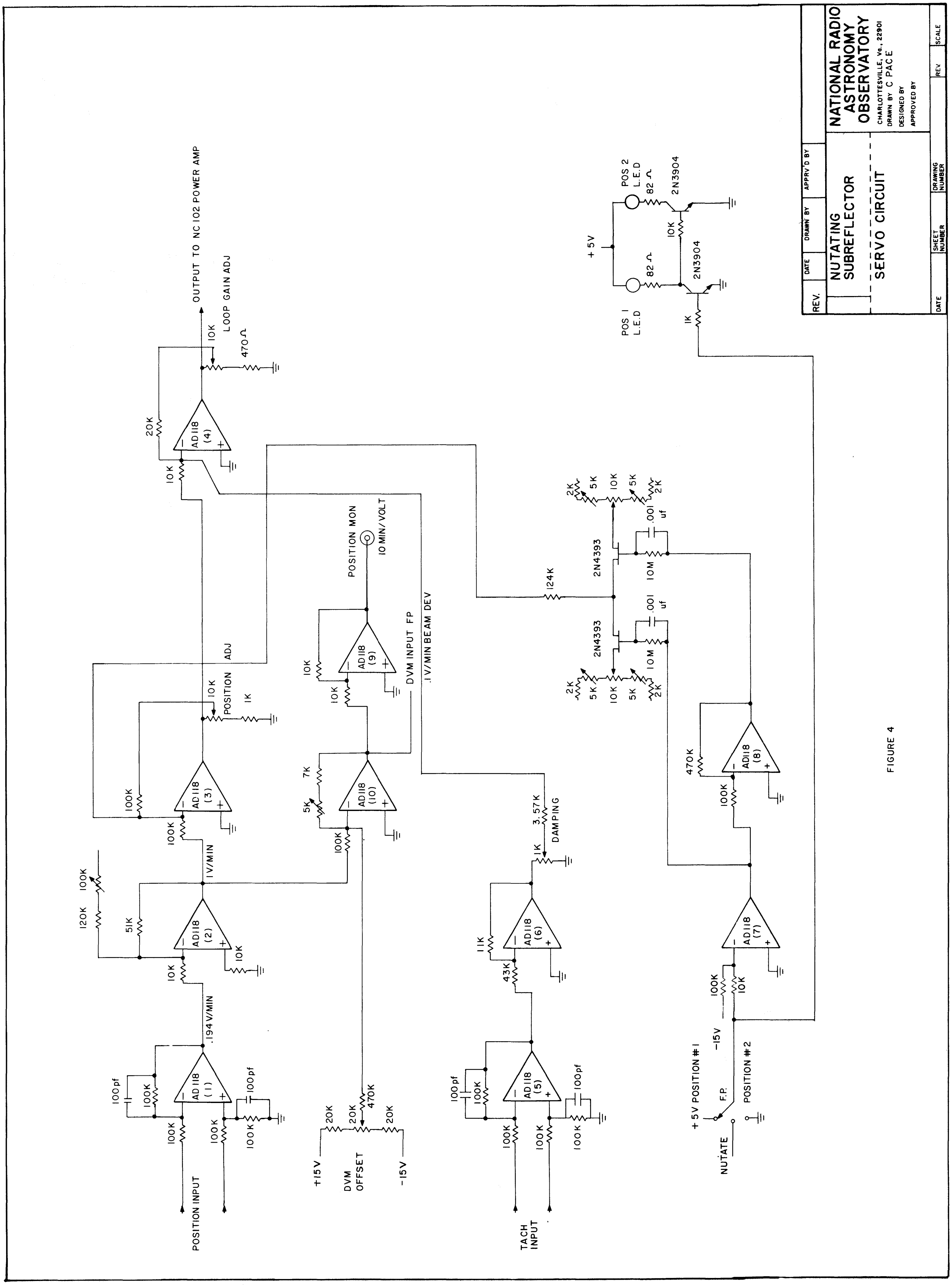

NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, Va., 22901
DRAWN BY C PACE
DESIGNED BY
APPROVED BY
NUTATING SUBREFLECTOR
SERVO CIRCUIT
REV.
DATE
DRAWN BY
APPRV'D BY
SHEET NUMBER
DRAWING NUMBER
SCALE
OUTPUT TO NC 102 POWER AMP
LOOP GAIN ADJ
POSITION ADJ
POSITION INPUT
TACH INPUT
DVM OFFSET
DVM INPUT FP
.1 V/MIN BEAM DEV
POSITION MON
10 MIN/VOLT
.194 V/MIN
1 V/MIN
DAMPING
POS 1 L.E.D
POS 2 L.E.D
2N3904
2N4393
+5V
+15V
-15V
NUTATE
F.P.
+5V POSITION #1
POSITION #2
AD118 (1)
AD118 (2)
AD118 (3)
AD118 (4)
AD118 (5)
AD118 (6)
AD118 (7)
AD118 (8)
AD118 (9)
AD118 (10)

FIGURE 4

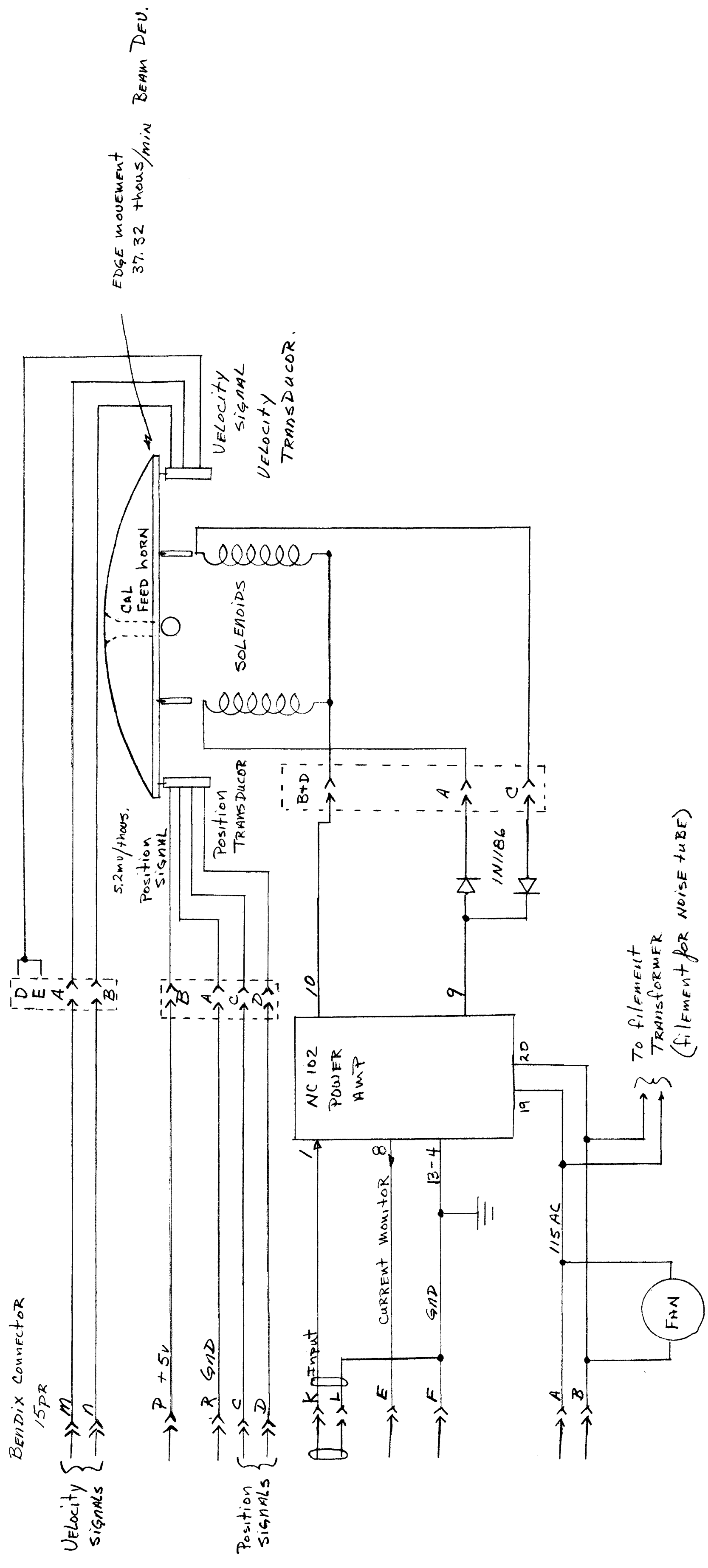


Figure 5 — Prime Focus Nutating Subreflector

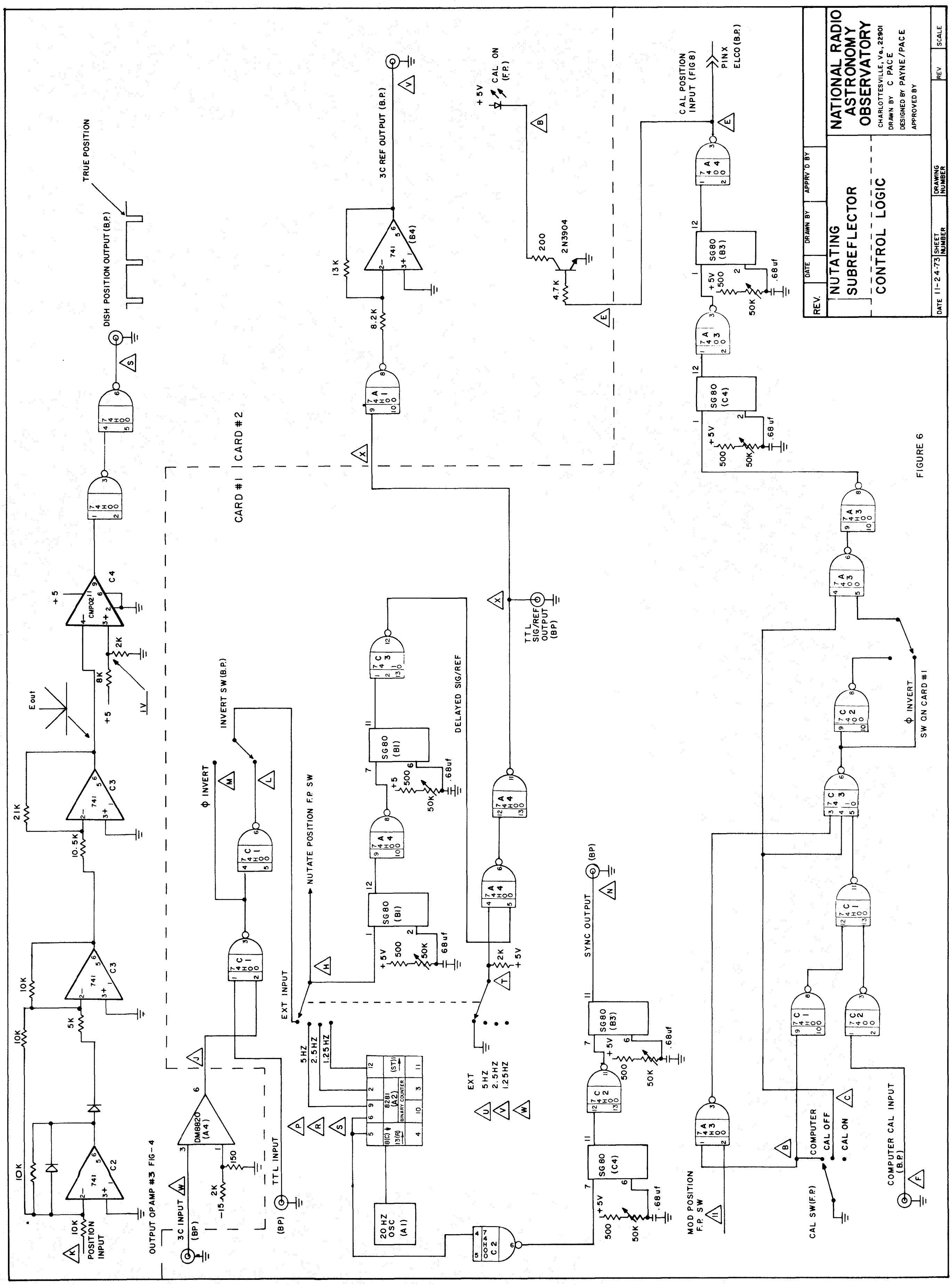

NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, Va., 22901
DRAWN BY C PACE
DESIGNED BY PAYNE/PACE
APPROVED BY
NUTATING SUBREFLECTOR
CONTROL LOGIC
DATE 11-24-73
CARD #1
CARD #2
TRUE POSITION
DISH POSITION OUTPUT (B.P.)
3C REF OUTPUT (B.P.)
CAL ON (F.P.)
CAL POSITION INPUT (FIG 8)
PIN X ELCO (B.P.)
POSITION INPUT
OUTPUT OPAMP #3 FIG-4
3C INPUT (BP)
TTL INPUT (BP)
EXT INPUT
NUTATE POSITION F.P. SW
INVERT SW (B.P.)
φ INVERT
DELAYED SIG/REF
TTL SIG/REF OUTPUT (BP)
SYNC OUTPUT (BP)
20 HZ OSC (A1)
MOD POSITION F.P. SW
CAL SW (F.P.)
COMPUTER CAL OFF
CAL ON
COMPUTER CAL INPUT (B.P.)
φ INVERT SW ON CARD #1

FIGURE 6

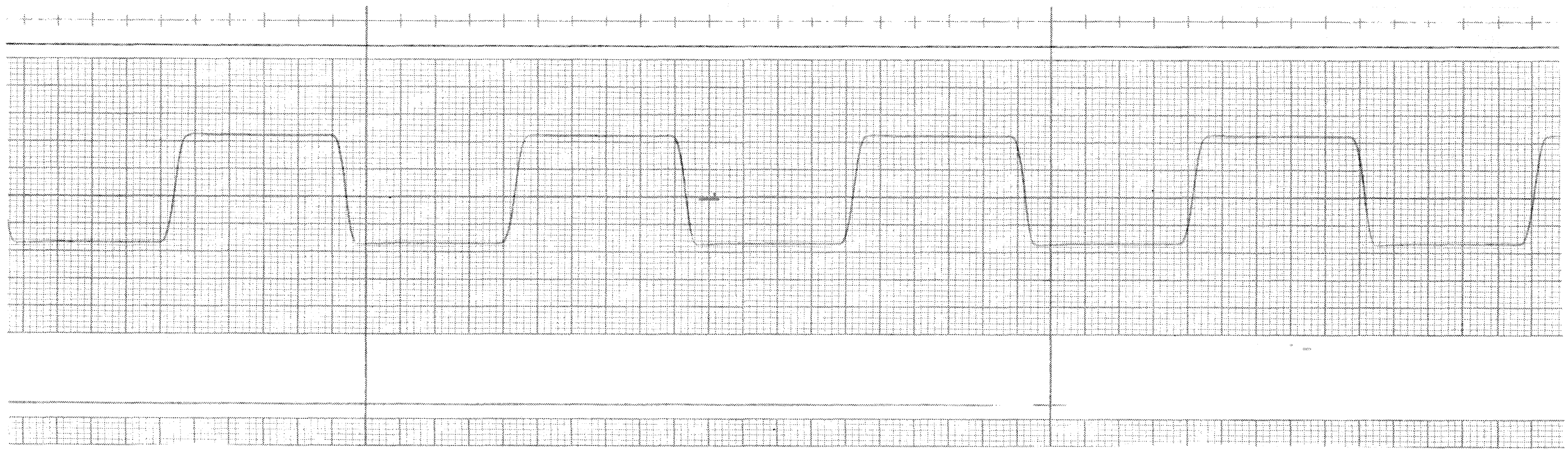


Figure 7

Position Waveform When Switching Antenna Beam 4 Arc Minutes at 5 Hz.

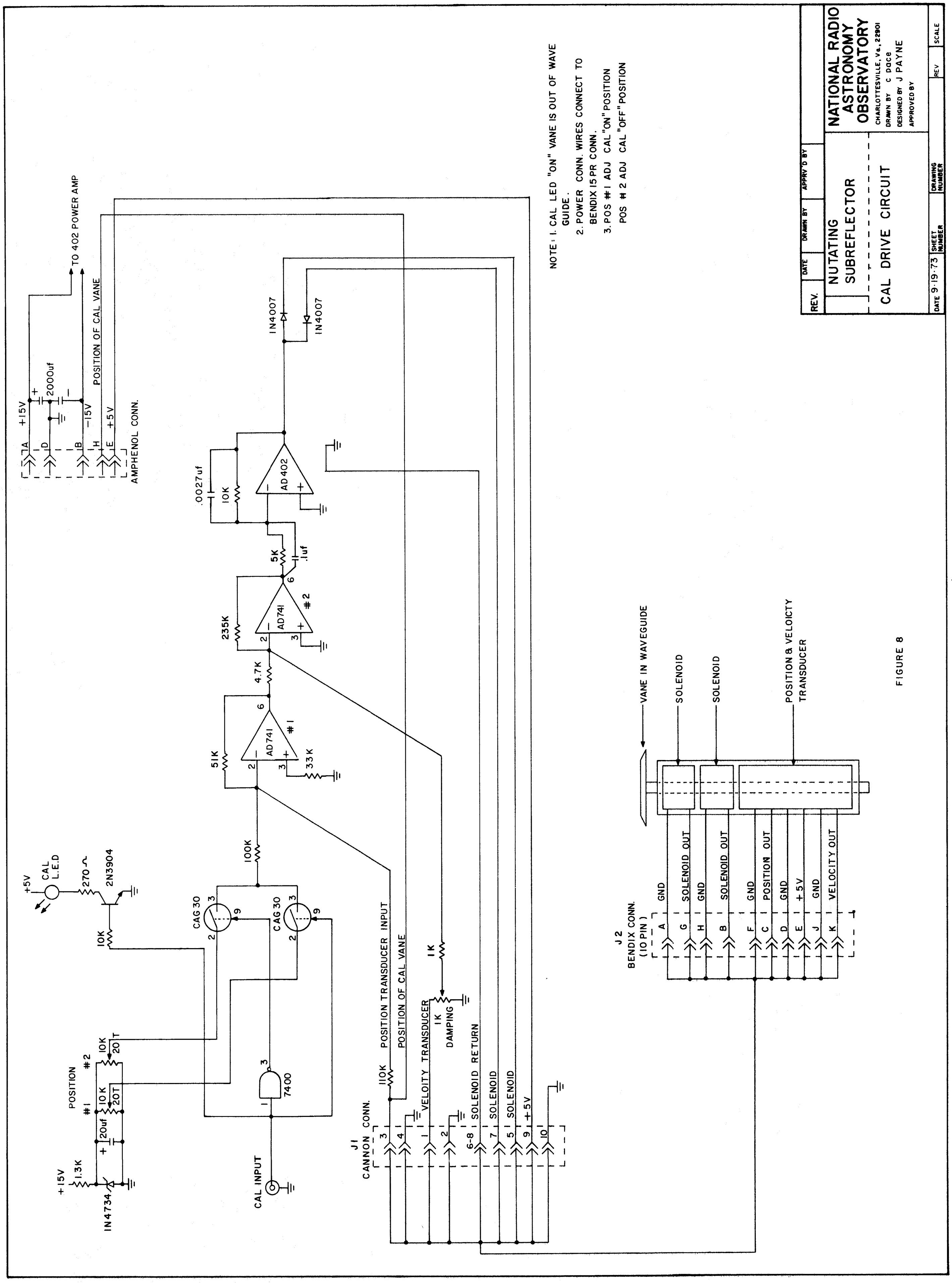

NOTE: 1. CAL LED "ON" VANE IS OUT OF WAVE GUIDE.
2. POWER CONN. WIRES CONNECT TO BENDIX 15 PR CONN.
3. POS #1 ADJ CAL "ON" POSITION
POS #2 ADJ CAL "OFF" POSITION
TO 402 POWER AMP
POSITION OF CAL VANE
AMPHENOL CONN.
+15V
-15V
+5V
2000uf
.0027uf
10K
AD402
IN4007
IN4007
5K
.1uf
235K
AD741
#2
4.7K
51K
AD741
#1
33K
100K
CAL L.E.D
+5V
270
2N3904
CAG 30
CAG 30
7400
POSITION
#1
#2
10K 20T
10K 20T
20uf
1.3K
IN4734
CAL INPUT
J1 CANNON CONN.
110K
POSITION TRANSDUCER INPUT
POSITION OF CAL VANE
VELOITY TRANSDUCER
1K
1K DAMPING
SOLENOID RETURN
SOLENOID
SOLENOID
+5V
VANE IN WAVEGUIDE
SOLENOID
SOLENOID
POSITION & VELOICTY TRANSDUCER
J2 BENDIX CONN. (10 PIN)
GND
SOLENOID OUT
GND
SOLENOID OUT
GND
POSITION OUT
GND
+5V
GND
VELOCITY OUT
NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, VA. 22901
DRAWN BY C DOCE
DESIGNED BY J PAYNE
APPROVED BY
NUTATING SUBREFLECTOR
CAL DRIVE CIRCUIT
DATE 9-19-73

FIGURE 8