NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

Electronics Division Internal Report No. 89

GENERAL DESCRIPTION AND OPERATING INSTRUCTIONS FOR THE WATER VAPOR RECEIVER

James L. Dolan

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In an attempt to correlate water vapor density and interferometer phase changes, radiometers to measure water vapor in the atmosphere have been designed and constructed. Units 1 and 2 have been built and installed on the 85-1 and 85-2 telescopes. A general description of the system will be given along with operating instructions. Reference will be made to the block diagrams.

Theory

It is known that water vapor causes phase delays to microwave signals propagating through it. These effects of water vapor extend over many wavelengths. Although the thermal emission from water vapor molecules is centered at $\lambda = 1.35$ cm (22.235 GHz), the emission is smeared and may be observed over a wide range of frequencies. The radiometers described in this note are designed to measure the differential water vapor in two (or more) non-overlapping paths. The radiometers are switched frequency types, as opposed to switched load, although it is possible to use them as switch load systems. One frequency, 23.3 GHz, is positioned near the peak of the thermal emission curve. This frequency is referred to as the "signal" frequency. The other frequency, 20.3 GHz, is positioned at a lower point on the curve and is referred to as the "comparison" or "reference" frequency. The differential water vapor can be measured in the following manner:

The overall system temperature at 20.3 GHz (F_1) is given by

$$T_{S_1} = T_R + T_A \qquad (1)$$

where T_{S_1} = overall system temperature at F_1

T_R = radiometer temperature

T_A = antenna temperature.

The overall system temperature at 23.3 GHz (F_2) is given by

$$T_{S_2} = T_R + T_A + T_W \qquad (2)$$

where T_{S_2} = overall system temperature at F_2

T_W = fraction of antenna temperature caused by water vapor emission.

(It should be noted that all temperatures referred to here are equivalent temperatures.)

It follows that

$$T_{S_2} - T_{S_1} = T_W \qquad (3)$$

With two radiometers we can measure

$$T_{W_1} - T_{W_2} = \Delta T_W \qquad (4)$$

the differential temperature caused by water vapor in the two paths. By observing phase changes, $\Delta\phi$, in the interferometer fringes from a reference source and comparing $\Delta\phi$ to ΔT_W, a correlation may be found (providing the observed phase delays are actually caused by water vapor). If phase changes can be correlated with differential water vapor information, the knowledge could be usefully applied to large synthesized arrays.

Reference 1 — Joe W. Waters, VLA Scientific Memorandum No. 8, September 14, 1967, "Atmospheric Effects on Radio Wave Phase and the Correction of Vapor-Caused Phase Fluctuations by Radiometric Measurements of Water Vapor Emission."

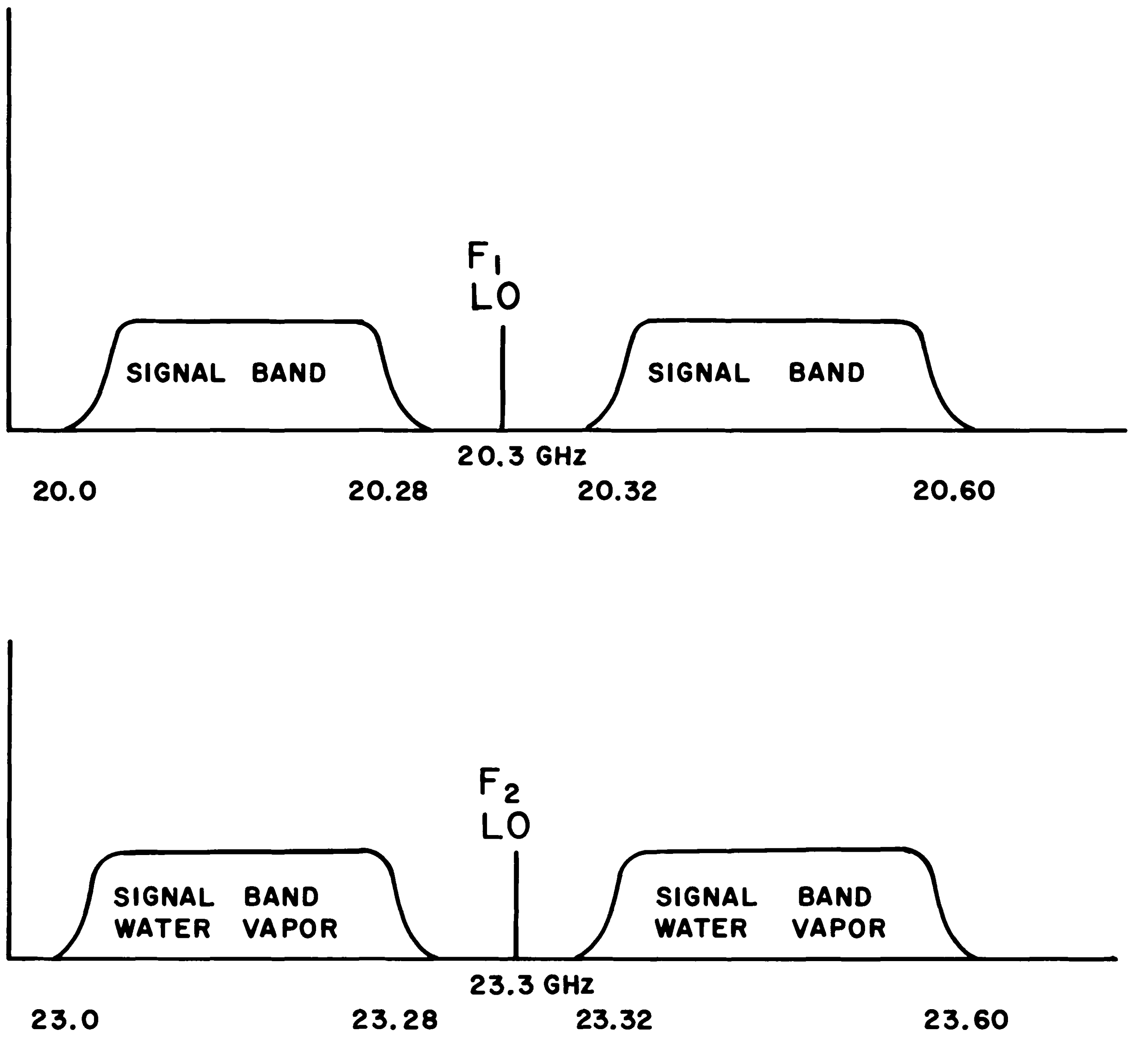
Front-End Description

Refer to block diagram B2. 502-1. The antenna used for the system is a 3-foot parabola covering the general frequency band of 18 to 26 GHz (K band). K-band waveguide is used for all the signal and local oscillator circuits. When the system is being used as a water vapor detector system the Dicke switch is locked to the antenna position and the local oscillator is switched between 20.3 GHz and 23.3 GHz. Physically, two oscillators are used, switched on and off by a DC voltage in phase with the synchronous detector. It is also possible to lock either of the oscillators on for continuum use if that mode is desired. Calibration is accomplished by a K-band argon excess noise diode. In the frequency switching mode it is necessary to modulate the noise diode for calibration. This is accomplished by leaving the noise tube on and switching the output on and off by means of a ferrite switch. The calibration mark on units 1 and 2 has been adjusted to 60 ± 2 °K.

Signal Tracing

The wideband signal from the antenna is routed through the crossguide coupler (used for calibration signal insertion) through the ferrite switch (normally locked to the antenna input) and then through the isolator to the balanced mixer-preamp circuit. Here the signal is mixed with the local oscillator signal to the intermediate frequency of 160 MHz ± 140 MHz, for a total IF bandwidth of 280 MHz. The local oscillator signal is derived in the following manner.

Two Gunn effect oscillators are used, oscillating at 20.3 GHz (F_1) and 23.3 GHz (F_2), respectively. The oscillators are turned on and off by the synchronizing drive voltage at a switch rate of 10 Hz. Switching voltage is symmetrical, making the duty cycle for each oscillator 50 percent. (In continuum mode, one oscillator is used 100 percent.) From the Gunn oscillators the signal is routed through level adjusting attenuators to an isolator and finally to the local oscillator (LO) input on the balanced mixer. The mixer crystal current is sampled and the amplified error signal is fed back to the current controlled attenuator to keep the LO power level constant while switching between F_1 and F_2. Because there are no frequency discriminating components ahead of the mixer, this is a double sideband system, center signal frequencies being 20.3 ± 160 MHz and 23.3 ± 160 MHz, the bandwidth at each frequency being equal to the IF bandwidth of 280 MHz. (See Figure 1 for a pictorial presentation of RF signal bands.) From the double sideband balanced mixer-preamp the IF signal is further amplified by a wideband transistor amplifier and then detected (demodulated) by a square law detector. The video or varying DC signal is then amplified and synchronously detected by a standard NRAO standard receiver unit. (See Standard Receiver Instruction Manual, August 1967.) The output of the synchronous detector is the signal T_W referred to in the "Theory" section. This signal is sampled and recorded on magnetic tape for further analysis.



RF SIGNAL BANDS FOR THE WATER VAPOR RADIOMETERS

FIG. 1

Control Functions and Operating Instructions

A brief description of the purpose of the front panel controls and normal settings will be given. There are no operator controls on the front-end enclosure — any adjustments required in the RF system normally require experienced personnel and laboratory equipment. The control panel is located in each telescope control room in an accessible place. This description is for unit 1. However, the units are practically identical and the instructions apply to both units.

Control	Function
NT On-Off	Fires the argon excess noise diode. The "NT Current" meter should read 175 mA when the noise diode is "on".
CAL-LO	Places the "Atten Current" meter in the calibration injection current-controlled attenuator circuit or in the LO leveler circuit. In the "LO" position the meter should read up scale indicating enough power for proper leveling action. In the "Cal" position the reading depends on the cal mode switch. With the cal mode "Off" the meter reads approximately 155 mA. With the cal mode "On" the meter reads 0. With the cal mode switch on "Mod" the meter reads approximately 75 mA.
XTAL 1, 2	Places the xtal current meter in either of the balanced mixer crystal circuits. Normal reading for both crystals is about 0.7 to 1.0 mA.
NOISE TUBE CURRENT ADJUST	Used to set noise tube current to 175 mA. Seldom needs attention.
REFERENCE FREQUENCY	Selects reference generator switch rate. Should not be set faster than 10 Hz in the frequency switching mode.
CAL "ON", "MOD", "OFF"	See "Cal-LO".
LO - HI - MOD - LOW	Selects either 23.3 GHz (Hi) or 20.3 GHz (Low) or switches between the two frequencies (Mod). Normally set on "Mod".

Continued --

Control	Function
DICKE SWITCH SIG-MOD-COMP	Used mostly for laboratory testing and calibration. Locks the front-end switch to the antenna ("Sig") or a comparison termination ("Comp") or switches between the two ("Mod"). For water vapor work, normal setting is on "Sig".
TOTAL POWER - SW. POWER	Selects the meter scale in volts for either total power or switched output. Normally set to sw. power, 1 volt.
GAIN RATIO - "ON - OFF"	The "On-Off" switch puts the post-detection gain modulator in or out of the circuit. The ten turn dial adjusts balance.
INPUT LEVEL	DC gain adjust. Can be used to adjust full scale temperature readings to proper level. Does not need regular attention.
FULL SCALE TEMP	AC gain control normal setting is marked (usually 100°).
TIME CONSTANT	Selects RC time integration. Normally set to 1 or 10 sec.
SW (BNC JACK)	Presents radiometer output to front panel.
TP (BNC JACK)	Presents radiometer post-detection signal to front panel.

FRONT-END PARTS ONLY — WATER VAPOR RECEIVER PARTS LIST

Component	Manufacturer	Model	Price	Comment
Antenna	TRG	---	$ 1,000	---
Waveguide section (flex.)	Airtron	AF-3-B-042-600	28	---
Bends, E-Plane 90°	Waveline	832-2 ($35)	245	7 required
Bends, H-Plane 90°	Waveline	833-2 ($35)	70	2 required
Coupler crossguide	Waveline	870-20	115	---
Termination	Waveline	854 ($35)	70	2 required
Ferrite switch	E&M	K111LTS	950	---
Isolator	E&M	K854LI ($250)	500	2 required - 20.23-24.23 GHz
Current cont. atten.	E&M	K126VAM	400	---
Ferrite switch	E&M	K122VAM	400	20-23 GHz
Attenuator	Waveline	813	100	---
Attenuator	TRG	K513-17	145	---
Attenuator	TRG	K513-14	145	---
Waveguide 90° twist	Waveline	890-2	55	---
Hybrid	Waveline	858	110	---
Waveguide section	Waveline	842	25	---
Noise tube mount	Waveline	22008	225	---
Detector mount	Waveline	816	70	---
Frequency meter	FXR	K410AF	280	---
Signal source	Varian	VSK9008C	695	---
Signal source	Varian	VSK9008B	695	---
Pad	Texscan	FP-50	16	---
Mixer amplifier	Space-General	9126R-1	7,450	Price quoted for 2 mixers
Amplifier	C-COR	3596	185	---
Power supply	Acopian	6S50	90	---
Power supply	Acopian	15D20D-15D20D	120	---
Assorted circuits	NRAO	---	500	(Misc.)
Total			$14,704	

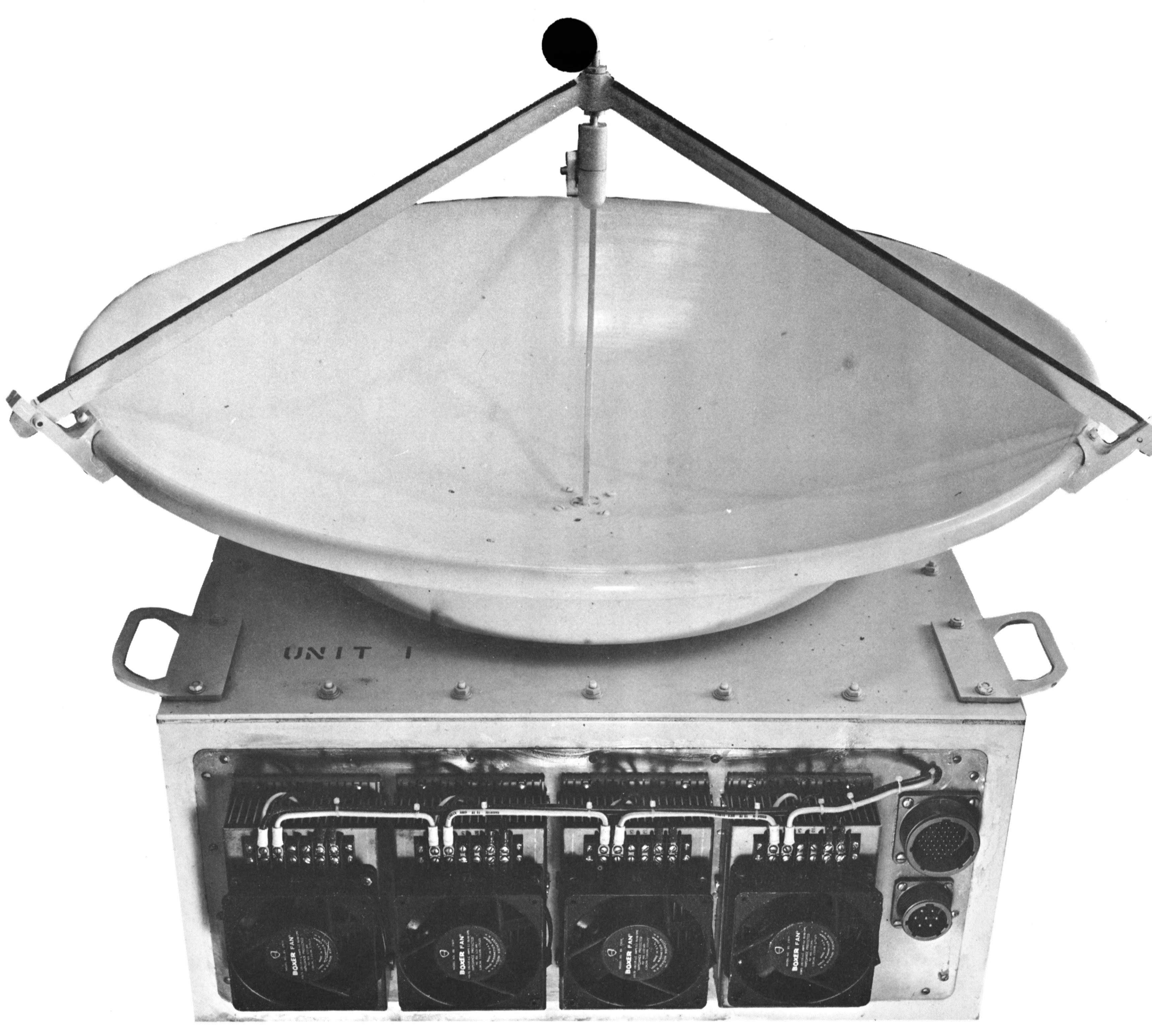
Acknowledgments

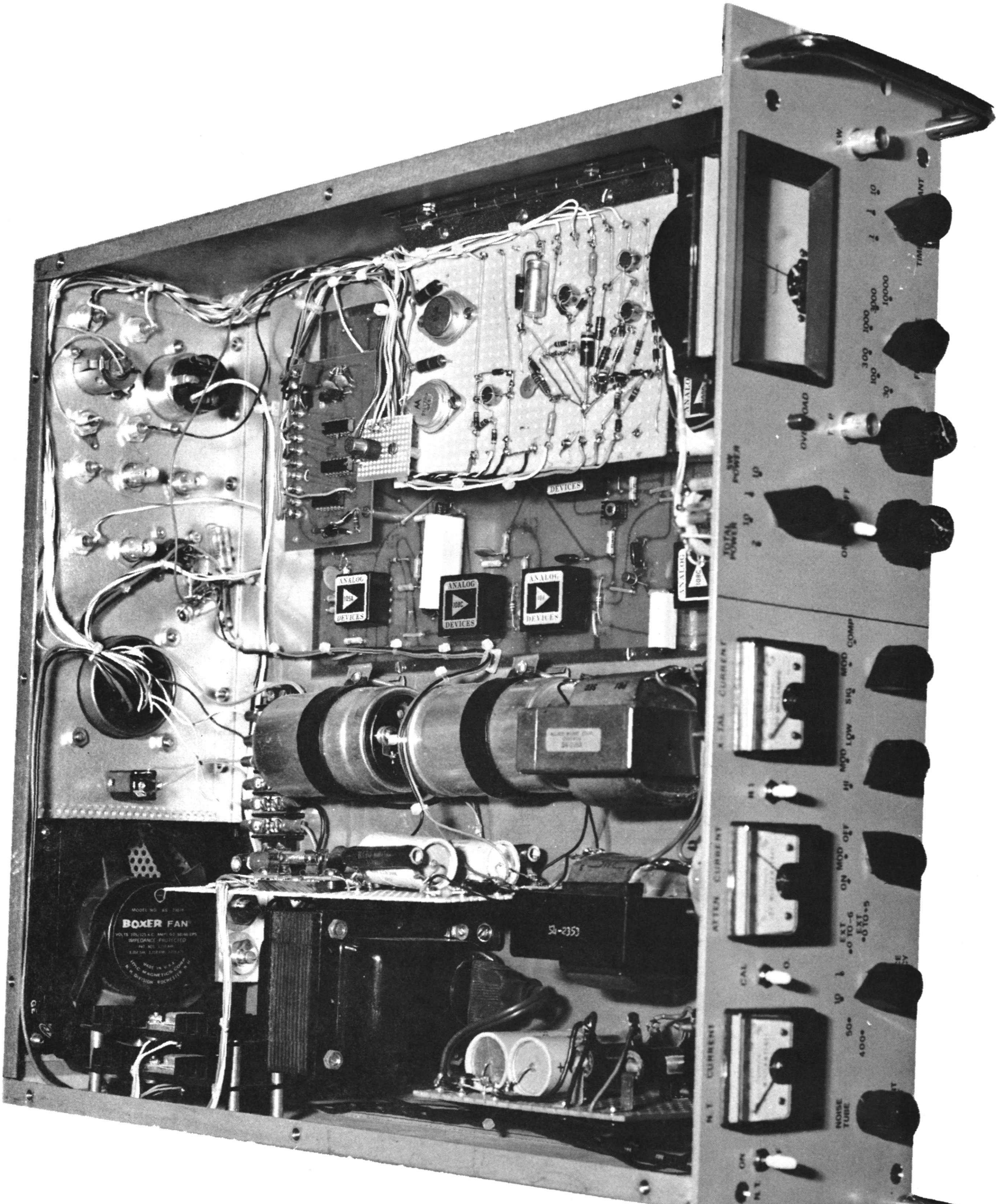
This project was initiated in 1967 under the direction of Dr. Sander Weinreb. Many people contributed their particular specialties to the project. I will list as many as I can remember, or find record of, along with their part in the successful completion of the two operating systems.

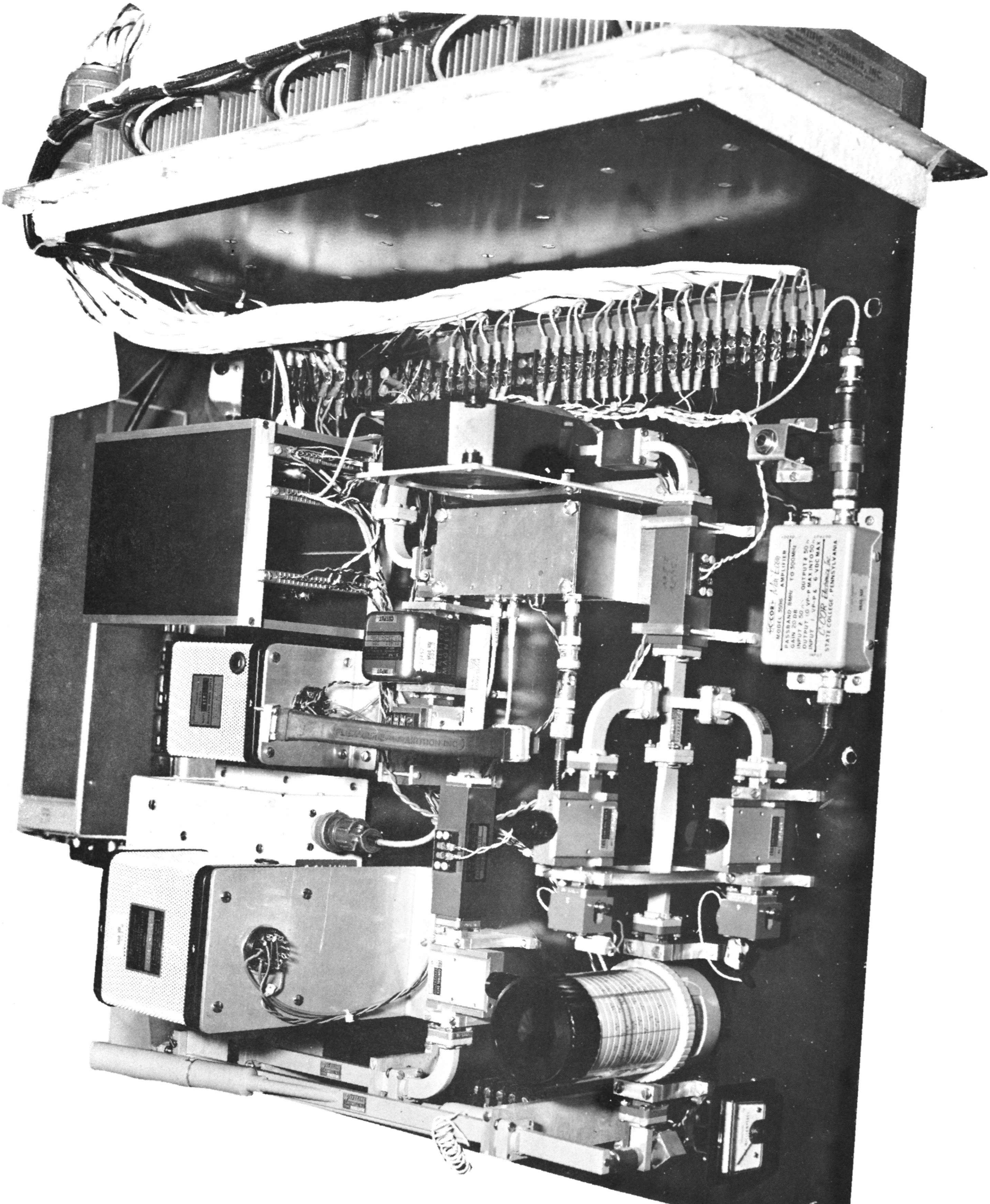
S. Weinreb	Initial conception and design.
*K. Wesseling	Preliminary research.
*J. Waters	Preliminary research.
*D. Logan	Initial procurement.
*D. L. Thacker	System construction supervision and detail circuit design.
L. Beale	Construction

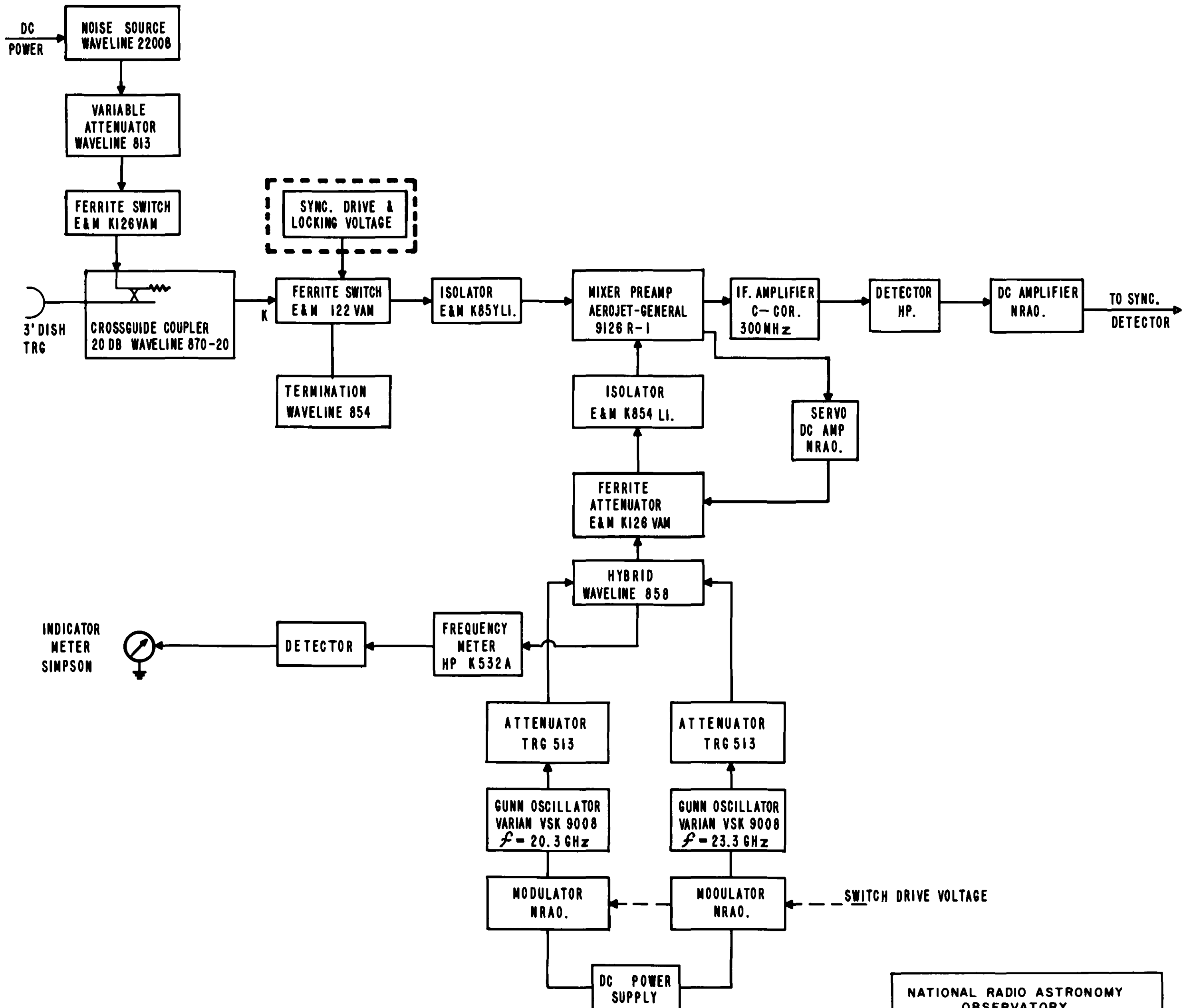
* No longer with the NRAO.

The remainder of the project — finalizing systems, check out, calibration, report writing, installation and operatioh — was done by the author with the assistance of S. Mayor and Telescope Operations.


UNIT 1
BOXER FAN


ANALOG DEVICES
BOXER FAN
X-TAL CURRENT
ATTEN CURRENT
CAL
NOISE TUBE

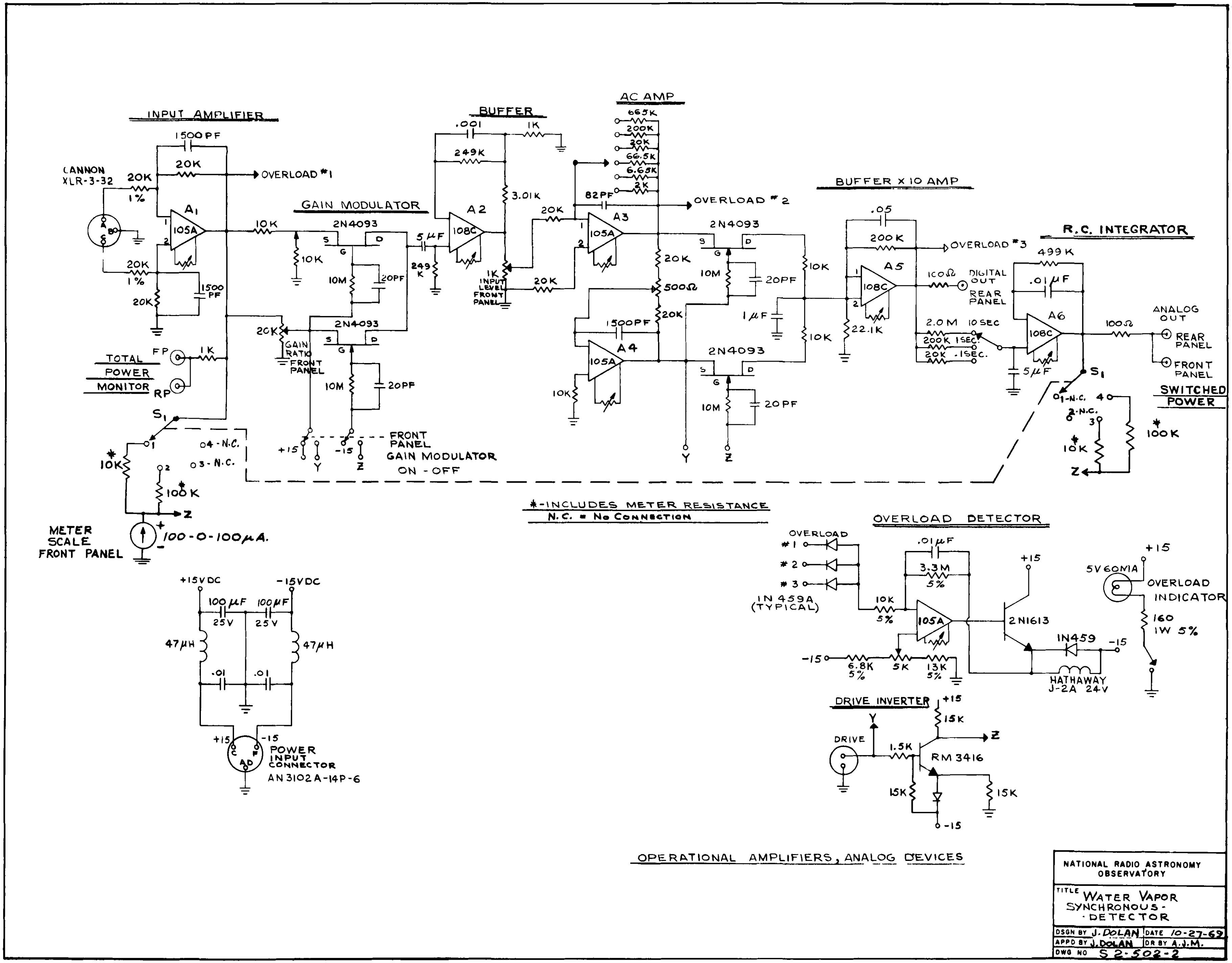

AMPLIFIER
STATE COLLEGE, PENNSYLVANIA



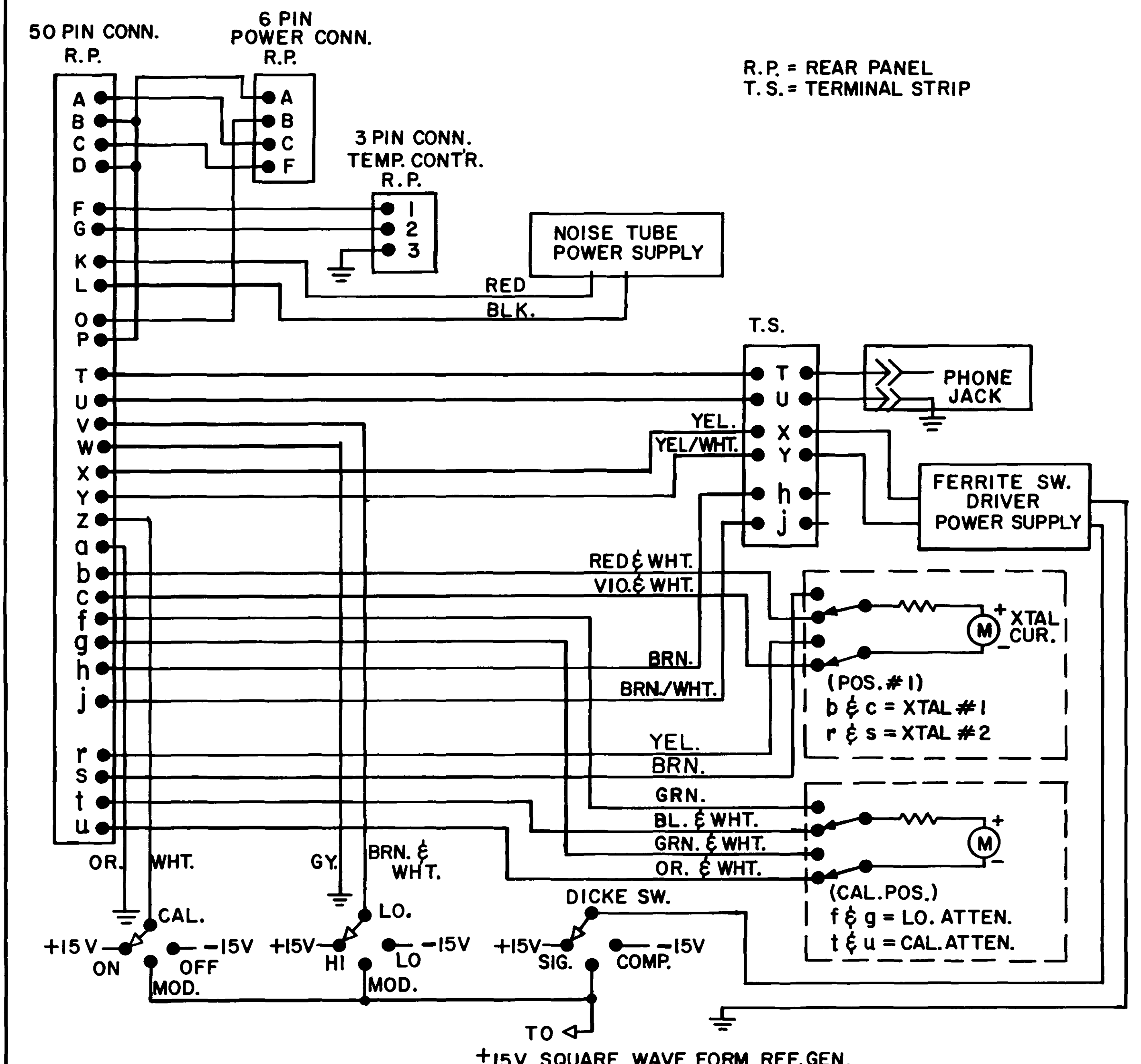
NATIONAL RADIO ASTRONOMY OBSERVATORY

TITLE: WATER VAPOR RECEIVER FRONT END BLOCK DIAGRAM

DSGN BY S. WEINREB	DATE: 8-7-67
APPD. BY	DR. BY J. DOLAN/A.M.
DWG. NO B 2-502-1	



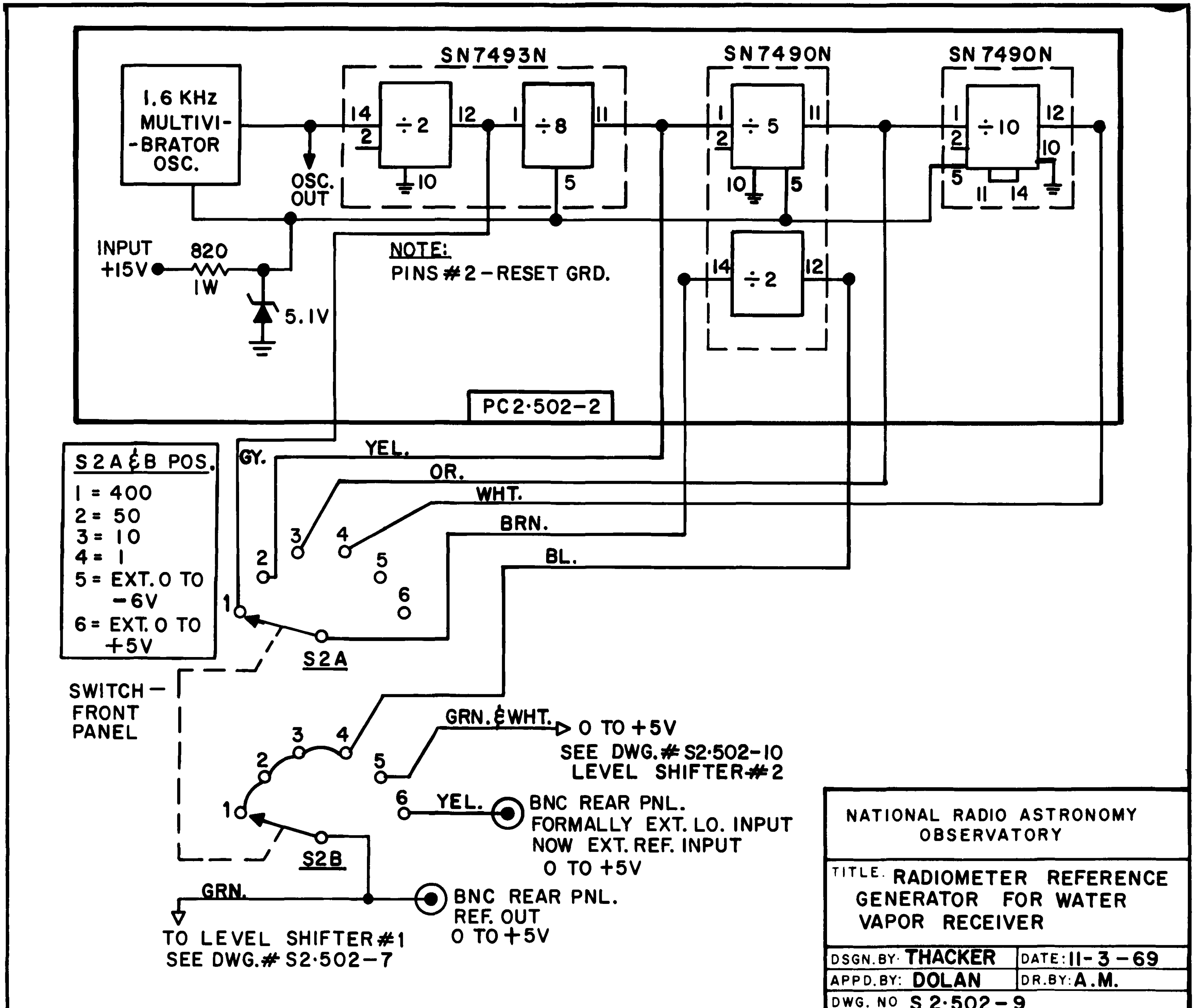
INPUT AMPLIFIER
CANNON XLR-3-32
1500PF
20K
OVERLOAD #1
20K 1%
A1
105A
20K 1%
20K
1500 PF
TOTAL POWER MONITOR
FP
RP
1K
S1
10K
100K
04-N.C.
03-N.C.
METER SCALE FRONT PANEL
100-0-100μA.
GAIN MODULATOR
10K
2N4093
10K
10M
20PF
20K
GAIN RATIO FRONT PANEL
2N4093
10M
20PF
FRONT PANEL GAIN MODULATOR ON-OFF
+15
-15
Y
Z
BUFFER
.001
1K
249K
A2
108C
5μF
249K
3.01K
1K INPUT LEVEL FRONT PANEL
AC AMP
665K
200K
20K
66.5K
6.65K
2K
82PF
OVERLOAD #2
20K
A3
105A
20K
20K
500Ω
20K
1500PF
A4
105A
10K
2N4093
10M
20PF
1μF
10K
10K
2N4093
10M
20PF
BUFFER X10 AMP
.05
200K
OVERLOAD #3
A5
108C
22.1K
100Ω
DIGITAL OUT REAR PANEL
R.C. INTEGRATOR
499K
.01μF
A6
108C
2.0M 10SEC
200K 1SEC.
20K .1SEC.
5μF
100Ω
ANALOG OUT
REAR PANEL
FRONT PANEL
SWITCHED POWER
S1
1-N.C.
2-N.C.
3
4
10K
100K
*-INCLUDES METER RESISTANCE
N.C. = NO CONNECTION
+15VDC
-15VDC
100μF 25V
100μF 25V
47μH
47μH
.01
.01
POWER INPUT CONNECTOR AN3102A-14P-6
OVERLOAD DETECTOR
OVERLOAD #1 #2 #3
1N459A (TYPICAL)
.01μF
3.3M 5%
10K 5%
105A
+15
2N1613
1N459
-15
6.8K 5%
5K
13K 5%
HATHAWAY J-2A 24V
5V60MA
OVERLOAD INDICATOR
160 1W 5%
DRIVE INVERTER
DRIVE
1.5K
15K
RM3416
15K
15K
OPERATIONAL AMPLIFIERS, ANALOG DEVICES
NATIONAL RADIO ASTRONOMY OBSERVATORY
TITLE WATER VAPOR SYNCHRONOUS-DETECTOR
DSGN BY J. DOLAN
DATE 10-27-69
APPD BY J. DOLAN
DR BY A.J.M.
DWG NO S2-502-2



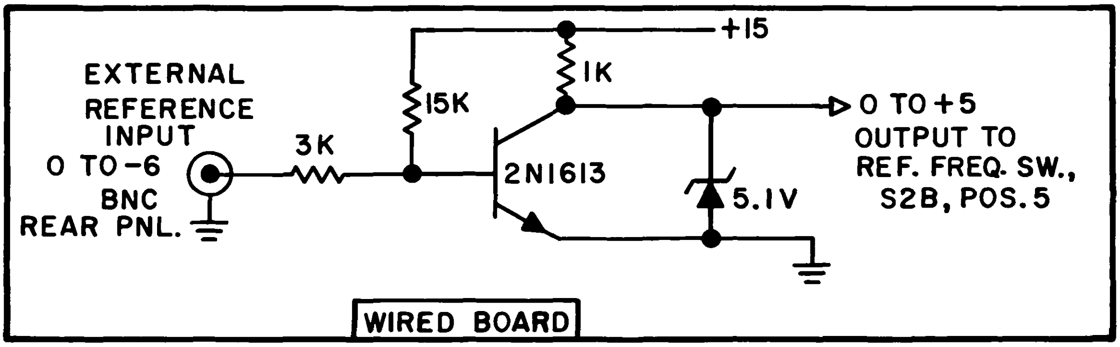
NATIONAL RADIO ASTRONOMY OBSERVATORY

TITLE: BACKEND CABLE & SWITCH CONNECTIONS FOR WATER VAPOR RECEIVER

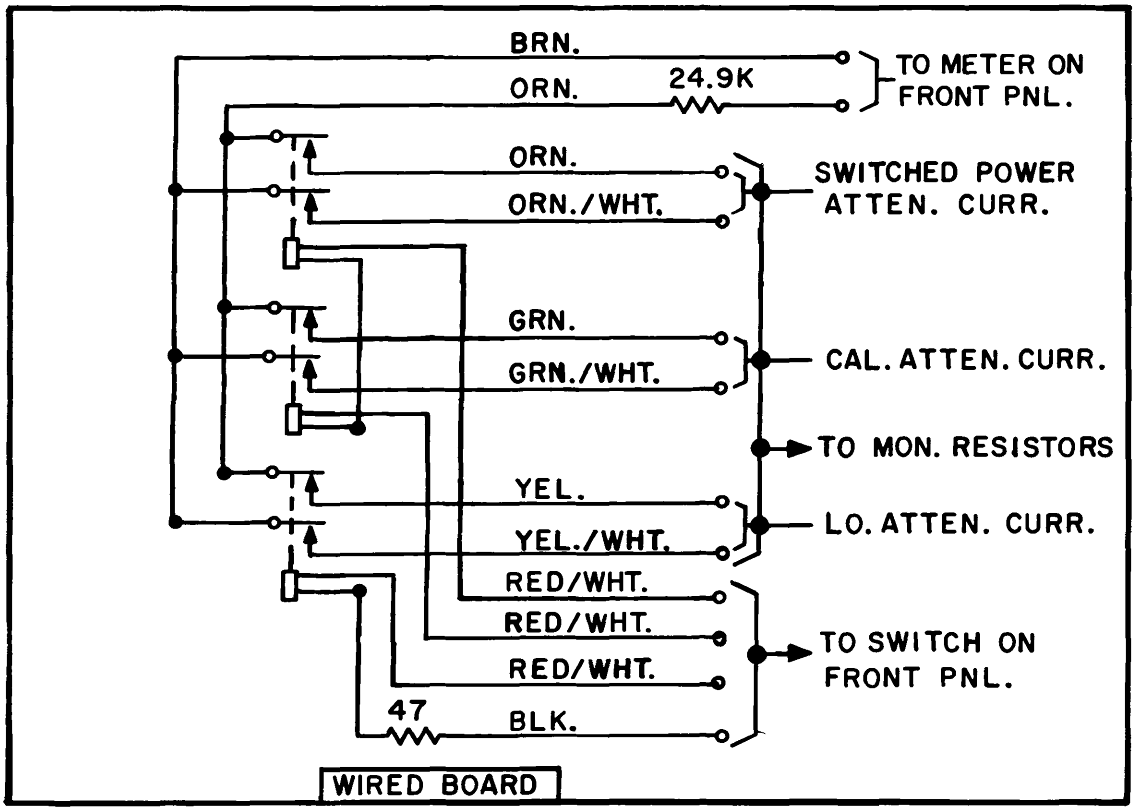
DSGN. BY: THACKER	DATE: 10-30-69
APPD. BY: DOLAN	DR. BY: A.M.
DWG. NO. S 2-502-8	



SN7493N
SN7490N
SN7490N
1.6 KHz MULTIVI-BRATOR OSC.
14
2
÷2
10
12
1
÷8
5
11
÷5
11
10
5
÷10
12
10
11
14
OSC. OUT
INPUT +15V
820 1W
5.1V
NOTE:
PINS #2 - RESET GRD.
÷2
14
12
PC2·502-2
S2A & B POS.
1 = 400
2 = 50
3 = 10
4 = 1
5 = EXT. 0 TO -6V
6 = EXT. 0 TO +5V
GY.
YEL.
OR.
WHT.
BRN.
BL.
S2A
SWITCH - FRONT PANEL
GRN. & WHT.
0 TO +5V
SEE DWG. # S2·502-10
LEVEL SHIFTER # 2
YEL.
BNC REAR PNL.
FORMALLY EXT. LO. INPUT
NOW EXT. REF. INPUT
0 TO +5V
S2B
GRN.
BNC REAR PNL.
REF. OUT
0 TO +5V
TO LEVEL SHIFTER #1
SEE DWG. # S2·502-7
NATIONAL RADIO ASTRONOMY OBSERVATORY
TITLE. RADIOMETER REFERENCE GENERATOR FOR WATER VAPOR RECEIVER
DSGN. BY: THACKER
DATE: 11-3-69
APPD. BY: DOLAN
DR. BY: A.M.
DWG. NO S 2·502-9

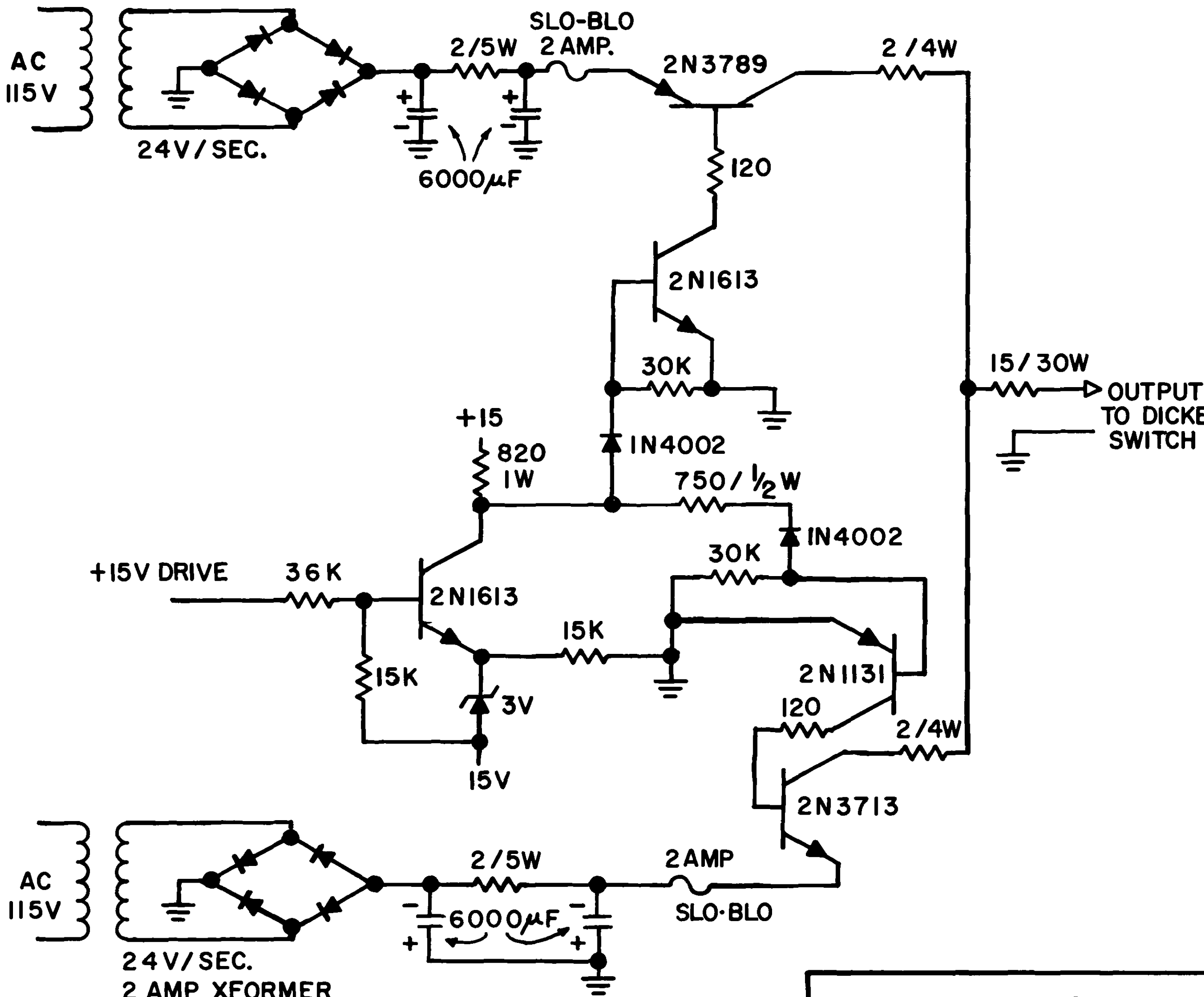


LEVEL SHIFTER #2



ATTEN. CURR. MON. CKT.

NATIONAL RADIO ASTRONOMY OBSERVATORY	
TITLE: LEVEL SHIFTER #2 & ATTEN. CURR. MON. CKT. FOR WATER VAPOR RECEIVER	
DSGN. BY: THACKER	DATE: 11-6-69
APPD. BY: DOLAN	DR. BY: A. M.
DWG. NO. S 2·502-10	

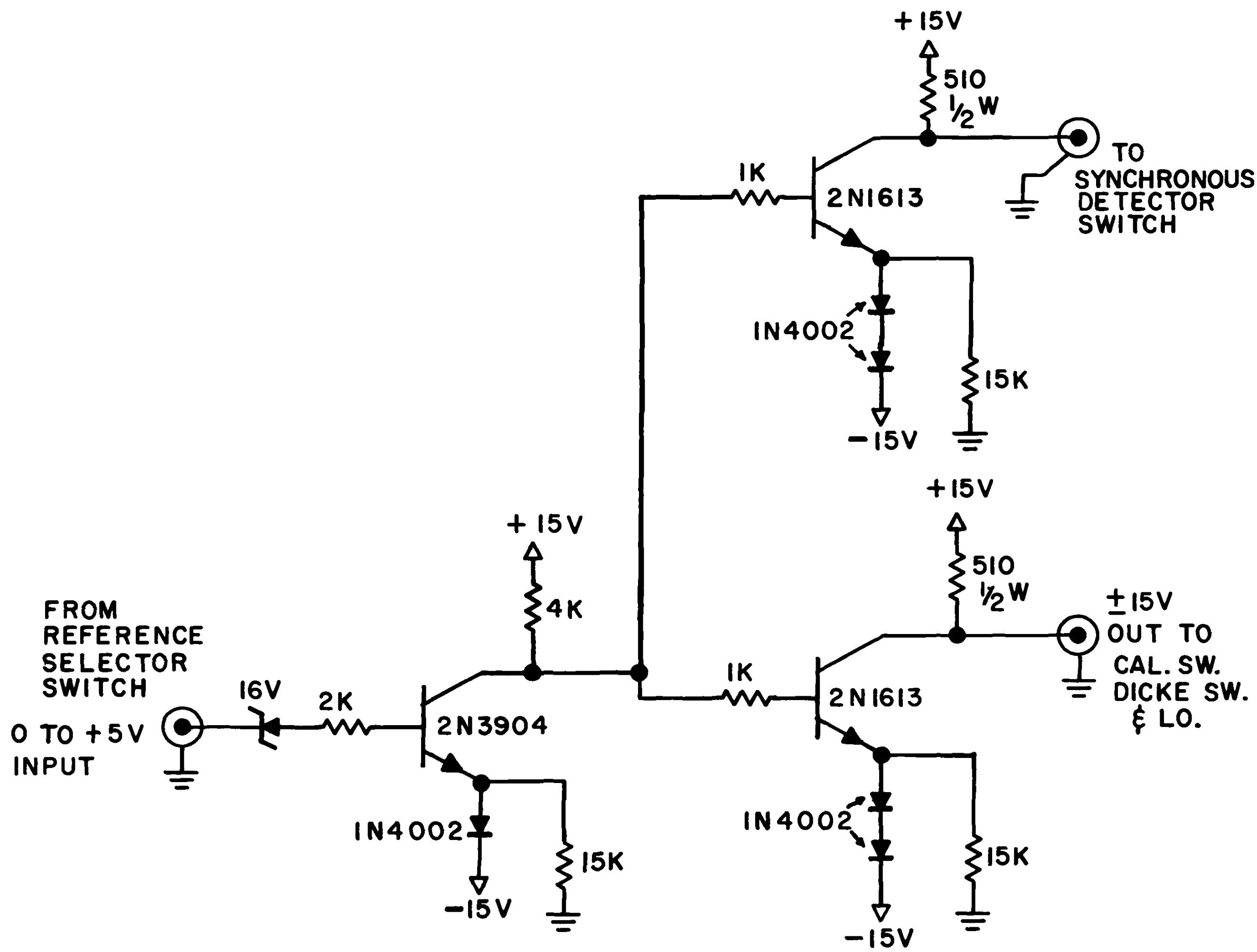


WIRED BOARD

NATIONAL RADIO ASTRONOMY OBSERVATORY

TITLE: FERRITE SW. DRIVE POWER SUPPLY FOR WATER VAPOR RECEIVER (FRONT END CKT.)

DSGN. BY: THACKER	DATE: 10-29-69
APPD. BY: DOLAN	DR. BY: A. M.
DWG. NO. S2·502-6	

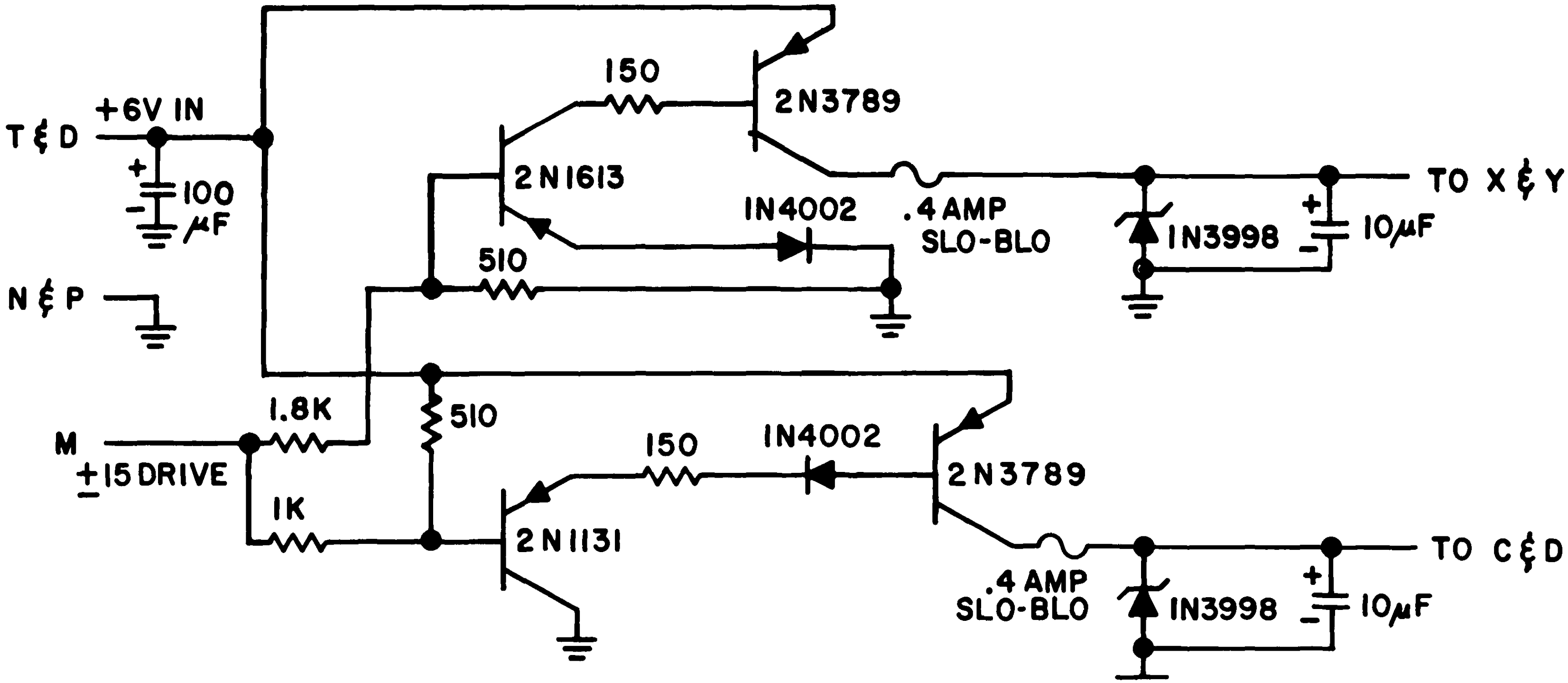


BACK END
WIRED
BOARD

NATIONAL RADIO ASTRONOMY
OBSERVATORY

TITLE: +15V & −15V DRIVER
FOR WATER VAPOR RECEIVER
(LEVEL SHIFTER #1)

DSGN. BY: THACKER	DATE: 10-29-69
APPD. BY: DOLAN	DR. BY: A.M.
DWG. NO. S 2·502−7	

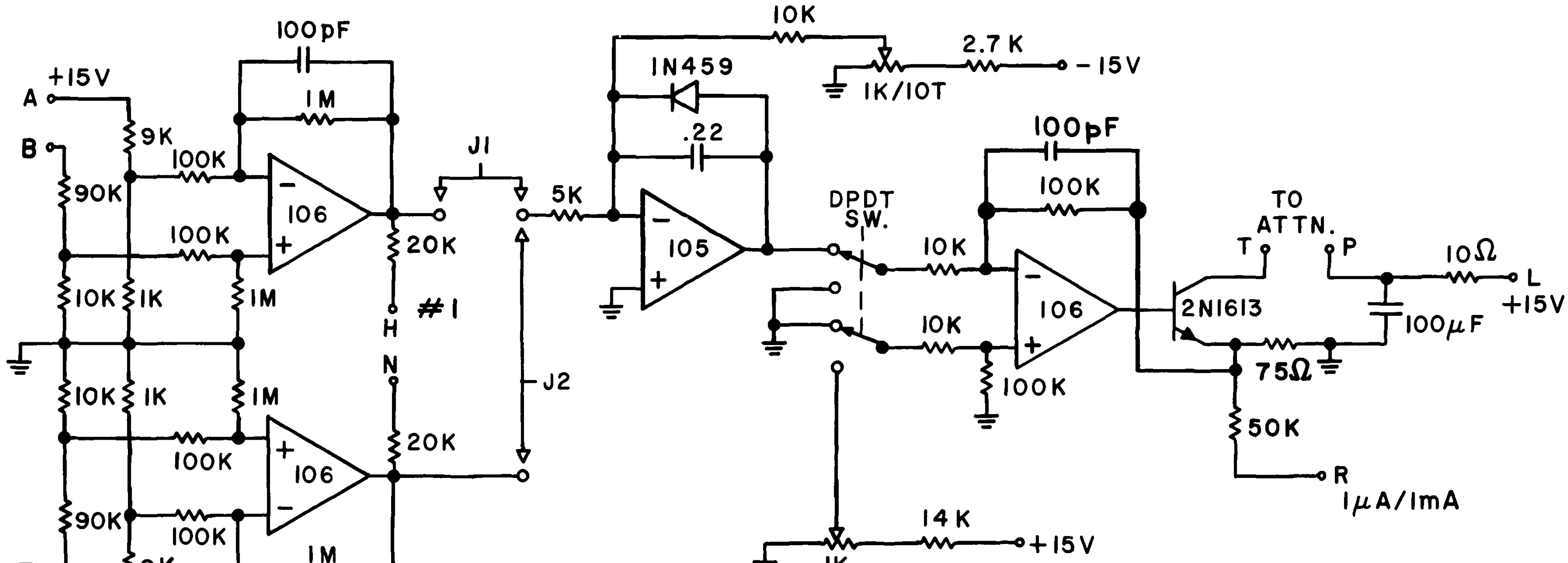


FRONT END
WIRED
BOARD

NATIONAL RADIO ASTRONOMY OBSERVATORY

TITLE: MODULATOR FOR SOLID-STATE FREQUENCY SOURCES IN WATER VAPOR RECEIVERS

DSGN. BY: THACKER	DATE: 10-28-69
APPD. BY: DOLAN	DR. BY: A.M.
DWG. NO. S 2·502-4	



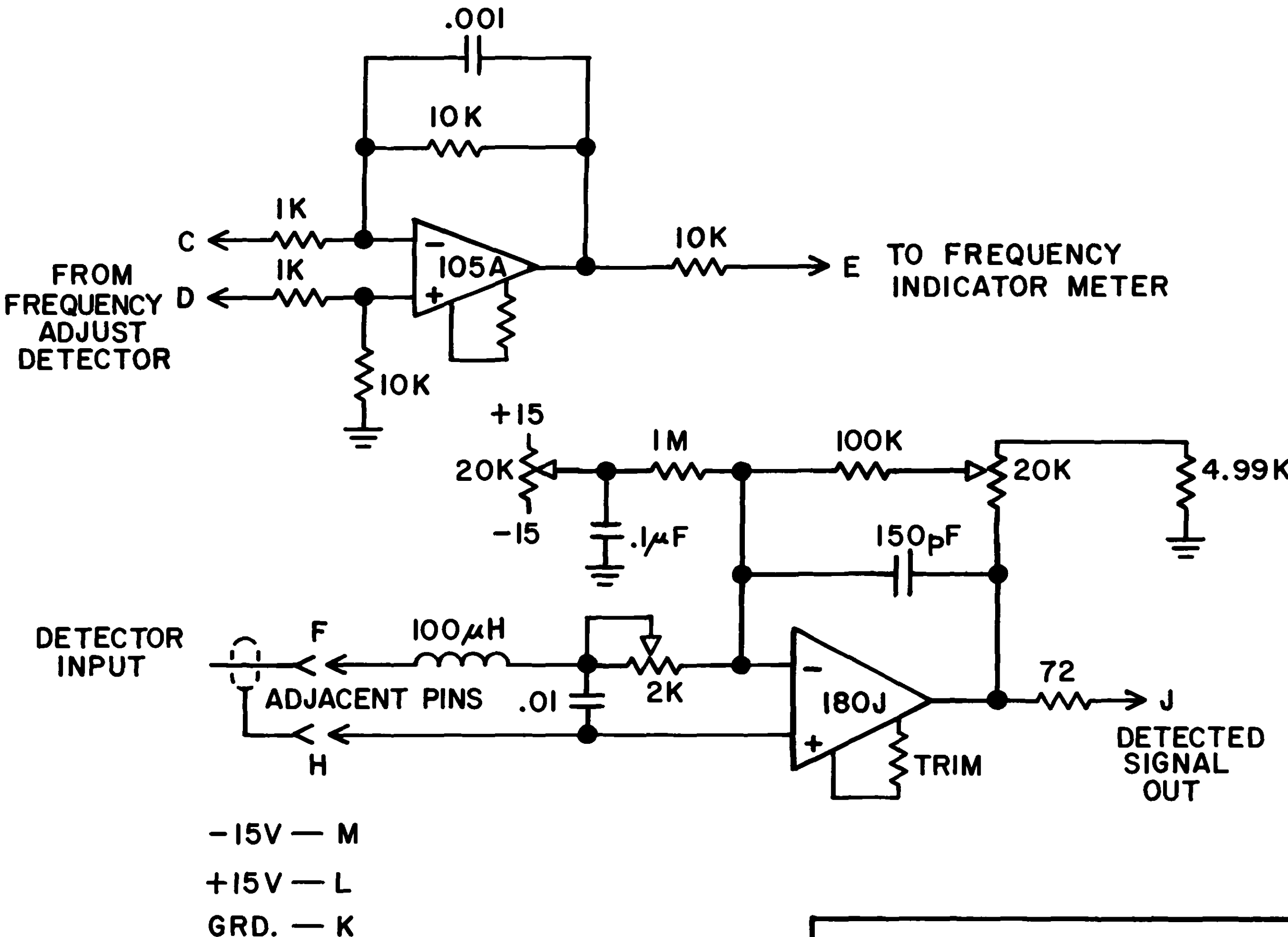
J1 & J2 = JUMPERS.
J+K+S = GRD.
L +15V
M -15V

FRONT END
PRINTED CKT.
BOARD
PC 2·502-1

NATIONAL RADIO ASTRONOMY OBSERVATORY

TITLE: LO. LEVELER FOR WATER VAPOR RADIOMETER

DSGN. BY: S. THACKER	DATE: 10-10-68
APPD. BY: J. DOLAN	DR. BY: A.M.
DWG. NO. S 2·502-1	



FRONT END
PRINTED CKT.
BOARD
PC 2·502-3

NATIONAL RADIO ASTRONOMY OBSERVATORY	
TITLE: SQUARE LAW DETECTOR & FREQUENCY MONITOR	
DSGN. BY: THACKER	DATE: 10-28-69
APPD. BY: DOLAN	DR. BY: A. M.
DWG. NO. S 2·502-3	

CABLE NUMBER 18-19-20-21 TYPE 15 Twisted Pair No. 18

Color Code Per Pair	Color Code	Pin No.	Remarks	
	Red	A-1	+15	
Blue Tracer	Yellow	B-2	Common	
	Shield	E		
	Red	C-3	-15	
Purple Tracer........	Yellow	D-4	Common	
	Shield	J		
	Red	O-5	+28	
Gray Tracer	Yellow	P-6	Common	
	Shield	H		
	Red	F-7)	Thermistor	(Blue)
Green Tracer	Yellow	G-8)	Control	(White)
	Shield	M		
	Red	T-9)	Audio	(Blue)
Yellow Tracer	Yellow	U-10)		(White)
	Shield	N		
	Gray	K-11	Noise (K - Red, 11- White)	
Center Pair, No Tracer	Yellow	L-12	Tube (L - Black, 12-Red)	
	Shield	R		
	Blue	X-13	Ferrite Sw.	(Gray)
Center Pair, No Tracer	Yellow	Y-14	Drive	(Red)
	Shield	Q		
	Gray	Z-15)	Op Amp	(Green) (N.T.
Center Pair, No Tracer	Red	a-16)	Cal Sig - 7	(Yellow) Attn.)
	Shield	S		
	Red	V-17	LO Sig (Card 3)	(Blue)
Center Pair, No Tracer	Yellow	W-18	(Switch)	(White)
	Shield	d		
	Red	m-19	Det Sig (Card 2)	(Orange)
Black Tracer	Yellow	n-20		(Black)
	Shield	e		
	Red	b-21	Xtal Curr	(Yellow)
Orange Tracer	Yellow	c-22	No. 1	(Black)
	Shield	k		
	Red	r-23	Xtal Curr	(Blue)
Red Tracer	Yellow	s-24	No. 2	(Black)
	Shield	x		
	Red	t-25	Spare	
Brown Tracer	Yellow	u-26		
	Shield	y		
	Blue	f-27	LO Atten	(Green)
Center Pair, No Tracer	Gray	g-28	Current	(Black)
	Shield	p		
	Red	h-29	Spare	
Center Pair, No Tracer	Blue	j-30		
	Shield	q		
		v		
Spare Pins (3)		w		
		z		