NOAA Technical Memorandum ERL WPL-31

AN OPTICAL SYSTEM FOR PROFILING WIND AND REFRACTIVE-INDEX FLUCTUATIONS

G. R. Ochs
Ting-i Wang
E. J. Goldenstein

Wave Propagation Laboratory
Boulder, Colorado
October 1977

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

NOAA Technical Memorandum ERL WPL-31

AN OPTICAL SYSTEM FOR PROFILING WIND AND REFRACTIVE-INDEX FLUCTUATIONS

G. R. Ochs
Ting-i Wang
E. J. Goldenstein

The primary support for this project was provided by the U.S. Army Electronics Command, Atmospheric Sciences Laboratory, White Sands, N.M. 88002, under contract W43P6S 76-8016. The Scientific Monitor was Mr. Thomas H. Pries.

Wave Propagation Laboratory
Boulder, Colorado
October 1977

UNITED STATES
DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator

Environmental Research
Laboratories
Wilmot N. Hess, Director

Printed for Atmospheric Sciences Laboratory,
U.S. Army Electronics Command, White Sands Missile Range,
New Mexico 88002, as Research and Development Technical Report
ECOM-77-7. Approved for public release; distribution unlimited.

TABLE OF CONTENTS

AN OPTICAL SYSTEM FOR PROFILING WIND AND REFRACTIVE-INDEX FLUCTUATION

G. R. Ochs, Ting-i Wang, and E. J. Goldenstein

An instrument is described that measures the crosswind and the refractive-index structure parameter (C_n^2) at six locations along an optical path. Operating instructions, calibration procedures, and circuit diagrams are included.

1. INTRODUCTION

Recent theoretical and experimental work has shown that it is possible to measure the transverse wind across an optical path, and the refractive-index structure parameter (C_n^2) along the path, by observing the scintillation of an extended incoherent light source (Ochs et al., 1976a; Wang et al.,1978; accepted by JOSA). In fact there are distinct advantages over the use of coherent light sources because the deleterious effects of both the saturation of scintillation for paths of high integrated refractive turbulence and of the inner scale of refractive turbulence on short paths are largely eliminated. It has also been shown that by using the proper proportions of transmitter and receiver aperture diameters, it is possible to peak up the measurement in different portions of the path.

Cross path techniques are also effective in restricting the measurement to a portion of the optical path (Wang et al., 1974; Ochs et al., 1976b). This technique requires more apertures, however, and the array aperture and spacing must be rather large to avoid saturation effects on paths of several kilometers. While in principle rather sharp path definition may be obtained by cross path techniques, in practice on paths of 0.5 km or more, the intermittent nature of C_n^2 seems to require impractically long averaging times and results in somewhat broader weighting functions.

Considerations such as these led us to abandon the original crossed-path proposal and to develop a profiler based upon the use of a single extended incoherent transmitting source with two tangent receiver apertures for each path location to be measured.

2. DESCRIPTION OF THE INSTRUMENT

The transmitter consists of two incoherent light sources 8.4 and 27.9 cm in diameter. Both use quartz-iodine lamps. The smaller source uses a frosted bulb at the focus of a concave mirror; the larger source has its lamp at the focus of a fresnel lens and uses a separate piece of frosted glass to insure sufficient uniformity of illumination over the aperture.

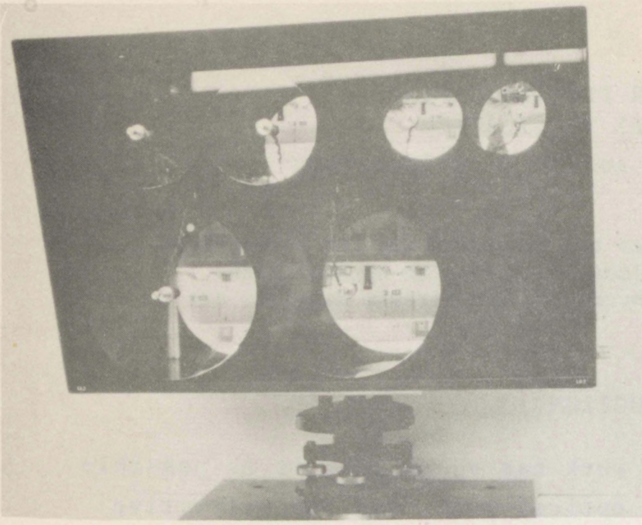


Figure 1. The optical receiver

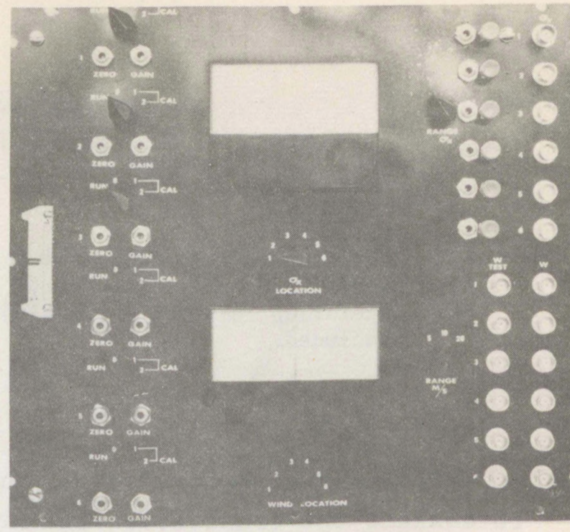


Figure 2. The signal processor

The receiver (Figure 1) has three pairs of tangent apertures, 15.2, 9.8, and 6.7 cm in diameter. Dual photodiodes placed at the focus of concave mirrors measure the irradiance of the apertures. By spacing the transmitters and aligning the receiver properly, the irradiance of the six apertures by one transmitter is measured by one group of six diodes, and the irradiance of the six apertures by the second transmitter is measured by the second set of six photodiodes. In this way six transmitter - receiver pair aperture ratios are obtained with two transmitting apertures and six receiving apertures.

Twelve preamplifiers at the receiver provide both a low gain signal suitable for C_n^2 measurement and a higher gain signal subject to limiting for wind measurement purposes. The signal processor (Figure 2) uses this information to calculate transverse wind and also C_n^2 at six locations along the optical path.

A block diagram of the circuit used to compute wind and C_n^2 at one path location is shown in Figure 3. Six of these circuits, which differ only in calibration, are used so that measurements are made simultaneously at the six locations. The circuit used to compute wind utilizes the slope system and is similar to that employed in the saturation resistant optical wind measurement systems. The wind calibration is independent of path length over the range 0.5 2.0 km.

The C_n^2 circuit is arranged so that, for received signals A and B, a calibrated measurement of the ratio

$$\sigma_I^2 = \frac{\langle (A-B)^2 \rangle}{(A_0 + B_0)^2} \qquad (1)$$

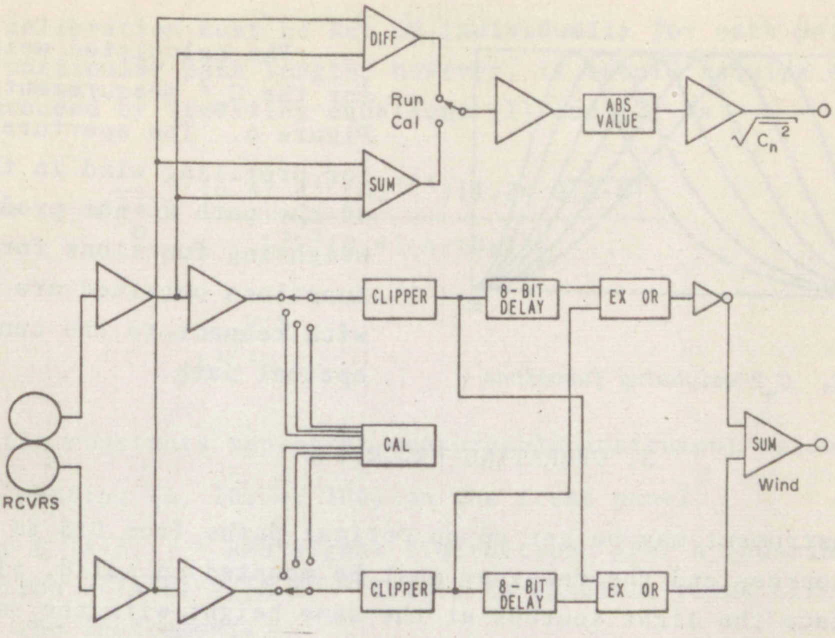


Figure 3. Block diagram of system

is obtained. It can be shown that (Wang et al., 1978)

$$C_n^2 = \frac{K \sigma_I^2 D_t^{7/3}}{L^3} \qquad (2)$$

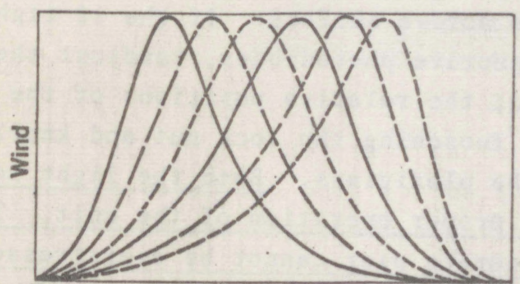


Fig. 4. Individual wind weighting functions

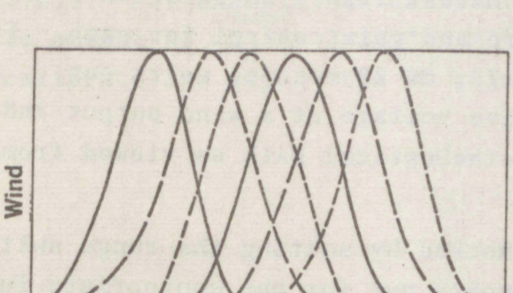


Fig. 5. Combined wind weighting functions

where L is the path length, D_t is the incoherent transmitting aperture diameter, and K is a function of the ratio of transmitting and receiving aperture sizes.

The six path weighting functions for wind are shown in Figure 4. Any one of these six outputs can be displayed on the instrument panel meter, and all are available from BNC outputs on the panel. By a linear combination of these weighting functions, somewhat sharper functions can be obtained. Such a linear combination is made in the instrument and a second set of wind outputs is available on the panel with the weighting functions shown in Figure 5.

The instrument is primarily designed to measure wind profiles, and the optical arrangement is not optimum for C_n^2. Useful measurements can be made, however.

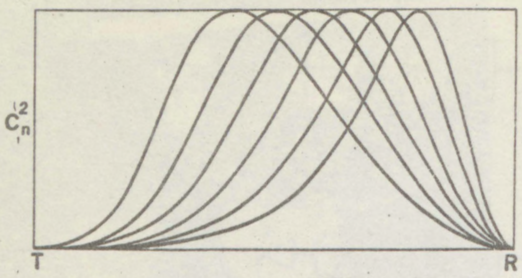


Fig. 6. C_n2 weighting functions

The calculated weighting functions for the $C_n{}^2$ measurement are shown in Figure 6. The aperture sizes chosen for profiling wind in the middle 2/3 of the path do not produce the same weighting functions for $C_n{}^2$; hence the functions obtained are not symmetric with respect to the center of the optical path.

3. OPERATING PROCEDURE

The instrument may be set up on optical paths from 0.5 to 2 km long. The light sources and the receiver must be mounted on solid, vibration-free mounts. Place the light sources at the same height with the smaller diameter source on the left, as viewed from the receiver. The light sources should have a horizontal angular separation of 6.8 mrad as viewed from the receiver.

An initial receiver alignment may be made by using the sight built into the receiver. However this optical alignment must be checked by observing the images of the light sources on each dual photodiode. Hold an inspection mirror at 45 degrees in front of each of the six receiving mirrors to observe the light source images on the photodiode active surface. If the 12 light source images are not focused on the respective photodiodes, readjust the pointing. If this cannot be accomplished, the relative positions of the individual photodiodes can be changed by loosening the lock nut and knurled nut that holds the photodiode mount to the plexiglass. Both the light source image position and focus are critical to proper operation of the unit. The importance of a solid mount such as a concrete pier cannot be overstressed.

The front panel controls on the processor (Figure 2) are divided into groups numbered 1 (measurement position nearest light) to position 6 (nearest receiver), with a function switch and zero and gain control for each. Full scale wind measurement may be set for 5, 10, or 20 m/s (±4 volts out). A meter deflection to the right or a positive voltage at a wind output indicates a wind direction from left to right across the optical path as viewed from the receiver.

The zero and gain settings may be checked by setting the range switch at 10 m/s and adjusting for zero and ±4 volts out for the appropriate function switch settings for each path position. The wind calibration, once set, remains correct over the operating path range of the instrument.

The C_n^2 calibration must be set up individually for each path length. Once set up for a particular path length, however, it should require only occasional checks. We proceed by rewriting equations (1) and (2) as

$$\sqrt{C_n^2} = \frac{[0.47\ K^{1/2} D_t^{7/6}][1.26\ G\overline{|A-B|}]}{L^{3/2}[0.47(A_0+B_0)]G} \tag{3}$$

$$= \frac{K'S}{L^{3/2}G\ C}$$

In this form the constants represent measureable instrument values as follows:

G = gain setting (1, 10, or 100) on the front panel.

$S = [1.26\ G\ \overline{|A-B|}\ ]$ = RMS signal fluctuation. (For a gaussian amplitude distribution $\sqrt{<(A-B)^2>}/\overline{|A-B|} = 1.26$.) An absolute value circuit measures $\overline{|A-B|}$ in the instrument.

$C = [.47(A_0+B_0)]$ = DC signal level determined by setting toggle switches to calibrate (DC coupling), and turning the light sources on and off at night.

K' = calibration constant derived from propagation theory for each position as follows:

Position	K'
1	0.141
2	0.0853
3	0.0588
4	0.176
5	0.137
6	0.118

The system can be calibrated by setting the DC gain with the panel gain controls. For example, to calibrate position 1 on a 500-m path for full scale output of $\sqrt{C_n^2} = 2\times10^{-6}\ M^{-1/3}$ (4 volts). and G=10, set the toggle switches to calibrate and adjust the DC gain at night to

$$C = \frac{K'S}{L^{3/2}G\sqrt{C_n^2}}$$

$$= \frac{0.141\times4}{500^{3/2}\ \times10\times2\times10^{-6}}$$

$$= 2.52 \text{ volts}$$

4. ALIGNMENT PROCEDURE

All electronic adjustments are in the processor. The preamplifiers in the receiver contain no adjustments. Remove the processor from its case by removing the panel screws. All components are fastened to the front panel. An individual circuit board is used for each path position, starting with the top board which processes position Figure 7. The bottom (7th) board is the combiner board and requires no adjustment. All boards except the combiner board are identical and except for calibration frequencies the following alignment procedure applies.

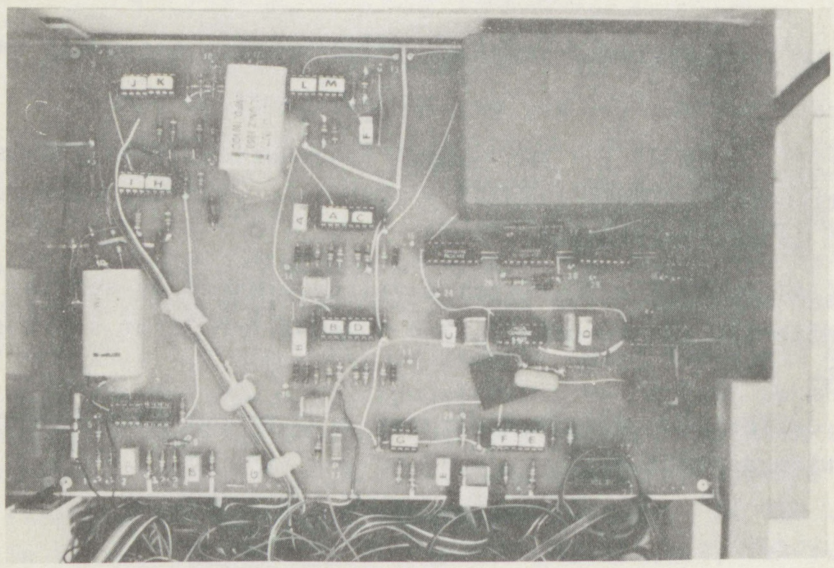


Figure 7. Processor board

1. connect the receiver and processor units. Set the range switch to 10 m/s and the C_n range switch to X10. Set pot D for 40 kHz at TP 29.
2. With the function switch on CAL (either 1 or 2) set pot C to obtain the frequencies at T14 or T16.

Board	Calibration Frequency
1	18.2 Hz
2	25.2
3	33.8
4	13.4
5	18.0
6	23.1

3. Cover the optics with opaque material and with the function switch in RUN position, set pots A and B for +5 volts average at TP15 and TP17.

4. Set the panel zero pot for zero wind reading at the W TEST outputs, with the function switch set to 0.

5. With the range switch set to 10 m/s, and the function switch set to CAL 2, set the panel gain pot for +4.0 volts at the W TEST output. Check for -4.0 volts in the CAL 1 position and reset the panel zero pot if necessary.

6. Set pot for full scale meter deflection with the function switch set to CAL 2.

7. With the σ_χ gain panel controls fully CW (maximum gain) and the receiver covered with opaque material, adjust pot F for zero volts at the σ_χ output.

8. Disconnect the receiver cable. Insert a sine wave test signal of about 2 volts RMS and 100 Hz at T1 or T3. With the σ_χ range in the X10 position, adjust the panel σ_χ gain to obtain +4.0 volts at the σ_χ output. Then adjust pot G for full scale σ_χ meter deflection. This procedure merely assures that a full scale σ_χ meter reading corresponds to a σ_χ output of 4.0 volts. The actual calibration procedure is explained under section 4. OPERATING PROCEDURE.

9. Observe a brightly illuminated white card with the receiver and set pot A' for zero volts at pin 6 of op amp N.

5. REFERENCES

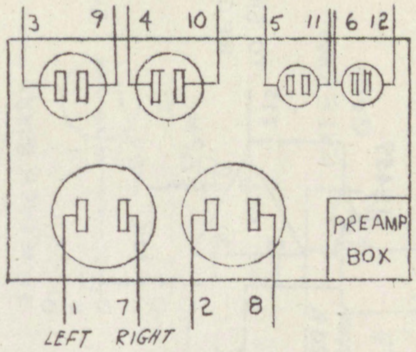
Ochs, G. R., S. F. Clifford, and Ting-i Wang (1976a): Laser wind sensing: the effects of saturation of scintillation, *Appl. Opt.* 15:403-408.

Ochs, G. R., S. F. Clifford, and Ting-i Wang (1976b): Wind and C_n^2 profiling with crossed laser beams and spatial filter detectors, NOAA Tech. Rept. ERL 367-WPL 45.

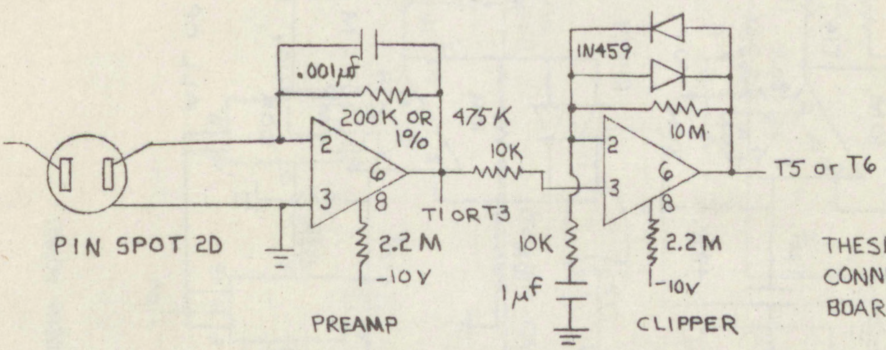
Wang, Ting-i, G. R. Ochs, and S. F. Clifford (1978): A saturation resistant optical scintillometer to measure C_n^2. (Accepted for publication, JOSA).

Wang, Ting-i, S. F. Clifford, and G. R. Ochs (1974): Wind and refractive-turbulence sensing using crossed laser beams, *Appl. Opt.* 13:2602-2608.

PHOTODIODE NUMBERS CORRESPONDING TO PREAMP OP AMPS. ONE PINSPOT 2D PER MIRROR. LEFT PHOTODIODES LOOK SMALL TRANSMITTER; RIGHT ONES AT LARGE TRANSMITTERS.



FRONT VIEW PHOTODIODES FACE THE MIRRORS

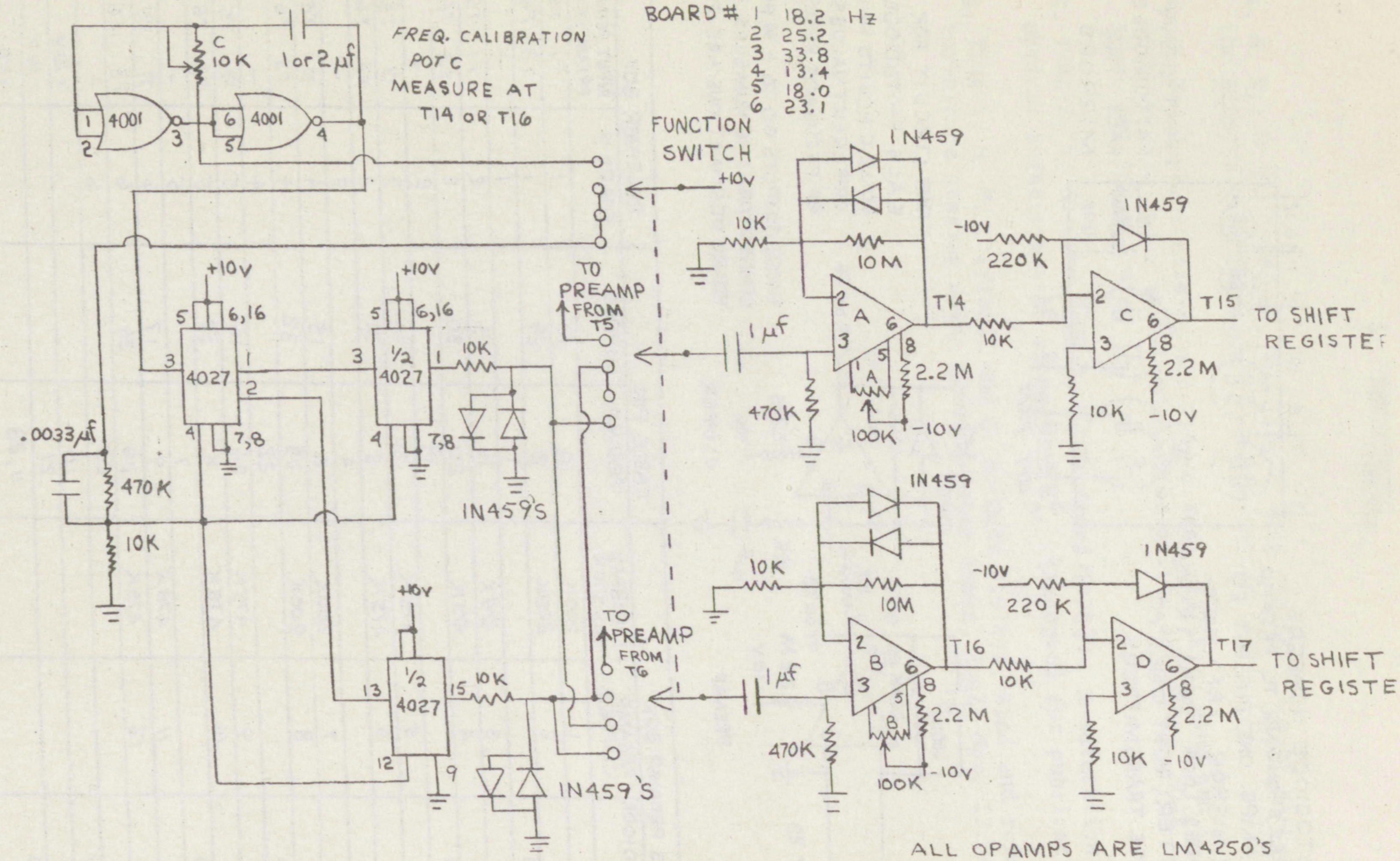


ONE CIRCUIT FOR EACH PHOTODIODE. SOME CIRCUITS HAVE DIFFERENT VALUES OF FEEDBACK RESISTORS.

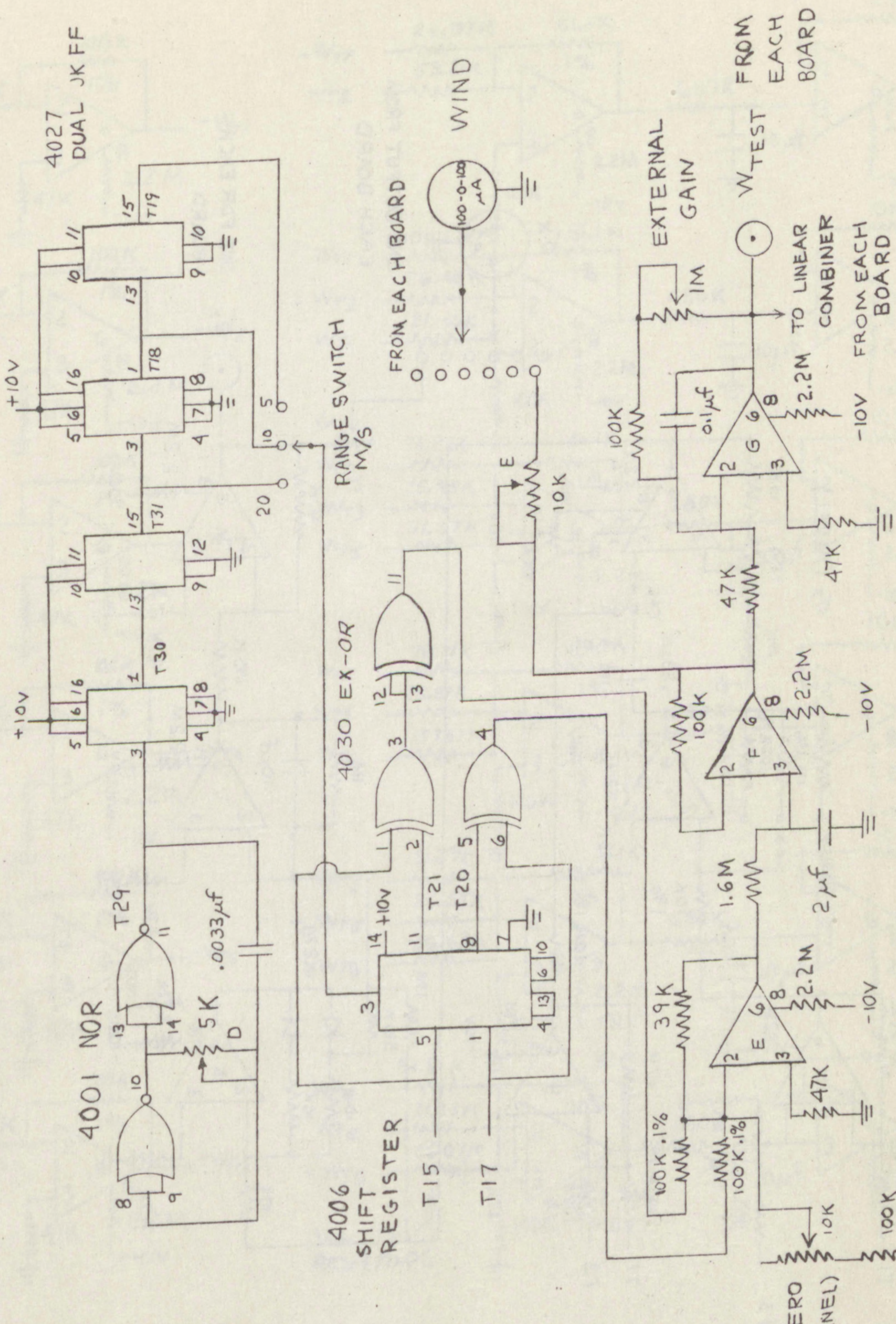
THESE OUTPUTS GO TO A 34 PIN CONNECTOR. THE NUMBERS AND BOARD DESTINATIONS ARE GIVEN.

OPTICS PREAMP BOX			CABLE PIN		RECEIVER BOX	
PHOTODIODE	PREAMP CLIPPER	FEEDBACK RESISTOR	PREAMP	CLIPPER	BOARD #	INPUT POINT PREAMP; CLIP.
1	1	200K	18	12	1	T1 T5
2	2	200K	2	29	1	T3 T6
GND			1		1	—
3	3	475K	3	13	2	T1 T5
4	4	475K	20	30	2	T3 T6
GND			19		2	—
5	5	475K	21	14	3	T1 T5
6	6	475K	5	31	3	T3 T6
GND			4		3	—
7	7	200K	6	15	4	T1 T5
8	8	200K	23	32	4	T3 T6
GND			22		4	—
9	9	475K	24	16	5	T1 T5
10	10	475K	8	33	5	T3 T6
GND			7		5	—
11	11	475K	9	17	6	T1 T5
12	12	475K	26	34	6	T3 T6
GND			25		6	—
+10V			10			+10V
-10V			27			-10V
GND			11, 28			GND

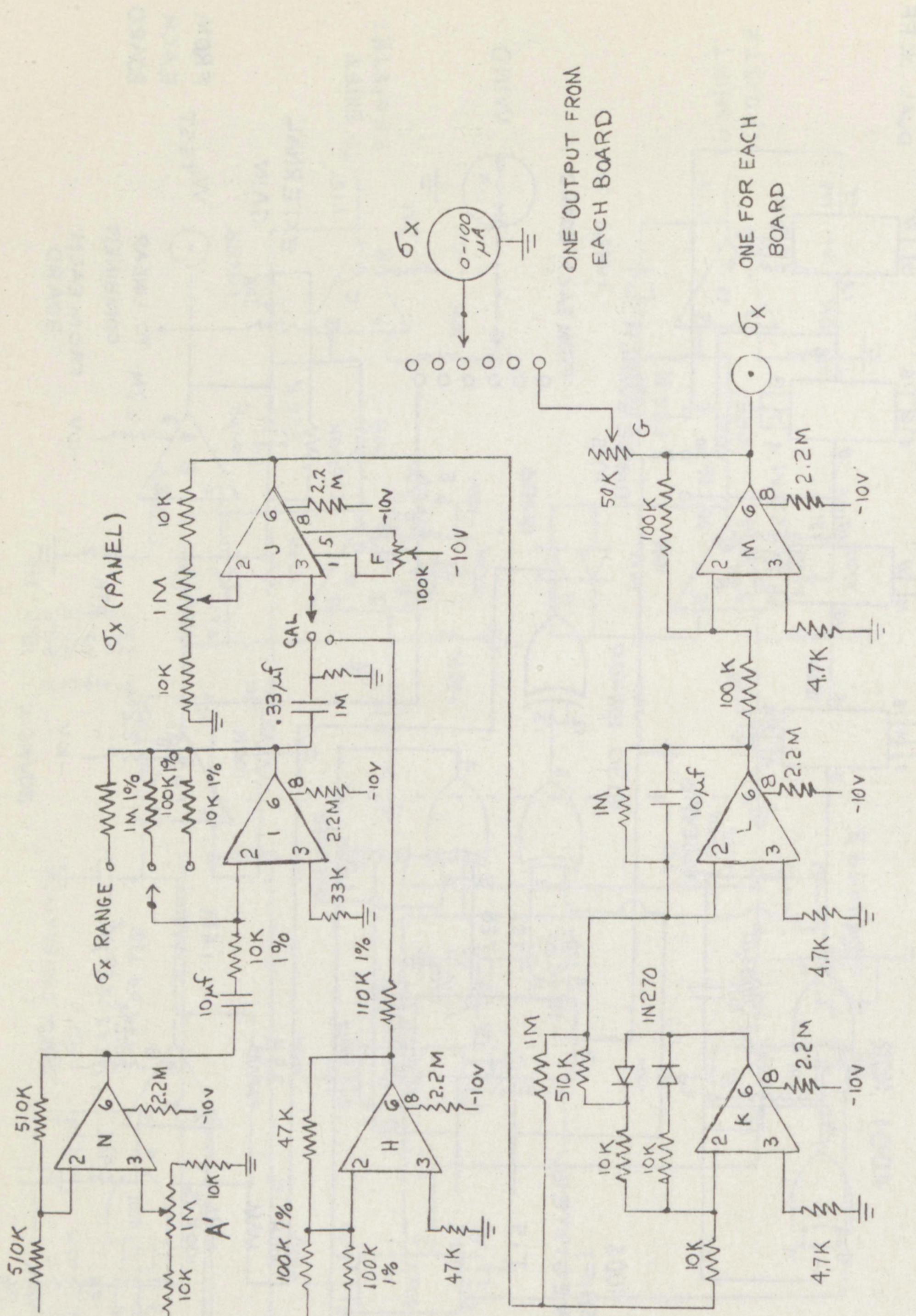
PREAMPLIFIER



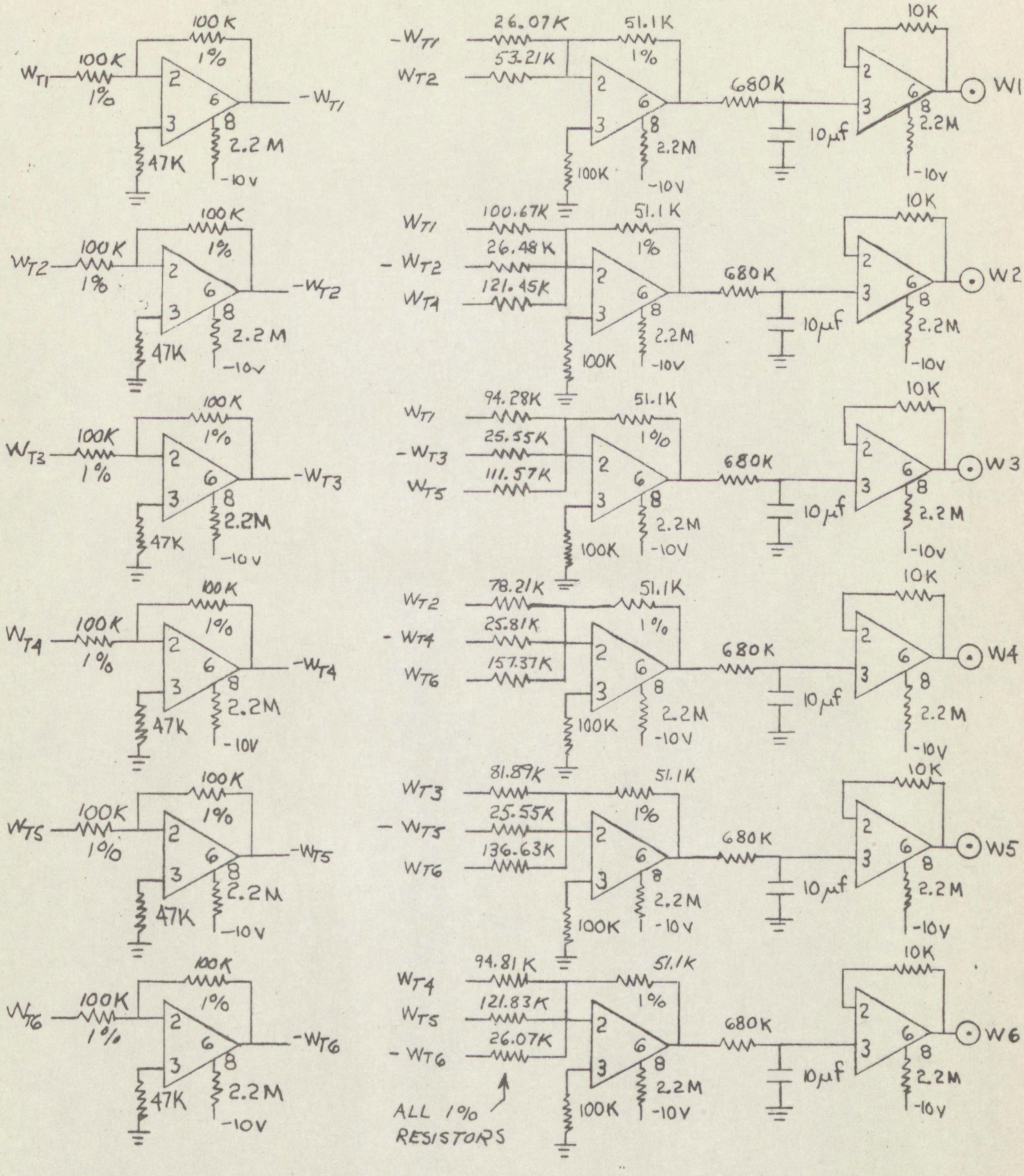
PROCESSOR BOARD



PROCESSOR BOARD



PROCESSOR BOARD



COMBINER BOARD