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DEPARTMENT OF COMMERCE ★ UNITED STATES OF AMERICA

OPTICAL SYSTEM MODEL III FOR SPACE-AVERAGED WIND MEASUREMENTS

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Boulder, Colorado
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NOTICE

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This instruction book describes an improved optical system for measuring crosswinds over optical paths from 100 m to 10 km. Operating instructions, alignment procedures, and circuit diagrams are included.

1. INTRODUCTION

The Wave Propagation Laboratory of NOAA has developed a number of optical systems that measure the component of wind at right angles to a line-of-sight path to a light source by analyzing the motion of the scintillation pattern seen by a suitable receiver[1,2,3,4,5,6,7]. Most of these systems obtain the average crosswind by measuring the slope of the normalized covariance at zero time delay of the fluctuations of irradiance seen by two apertures in the received scintillation pattern. The slope of this function can be shown to be proportional to the average crosswind on the optical path if the refractive index structure parameter (C_n^2) is statistically uniform along the path and the total integrated C_n^2 along the path is sufficiently small. The latter imposes the most severe limit in practice but the problem has been overcome by using sufficiently large apertures and incoherent light sources.

The irregularity of C_n^2 along the path at the least adds noise to the wind measurement when C_n^2 is statistically uniform; when statistically non-uniform, both the weighting function and the calibration are affected. These adverse effects can be reduced by making use of more of the information contained in the covariance function. Rather than a one-point slope measurement, the model III observes the covariance at 14 time delays. The details of the analysis are discussed in the circuit description. Tests on a 500-m optical path have shown that this system is superior to the slope system for most atmospheric conditions.

The performance of any wind measurement system of this type is difficult to analyze theoretically because it depends upon the actual variation of C_n^2 and wind along the optical path. However, computer simulation of the optical propagation through typically irregular atmospheric conditions does indicate the superiority of the model III system.[8]

Earlier systems used a quartz-halogen cycle light bulb together with a fresnel lens or a concave mirror to produce a smoothly illuminated incoherent light source. This source had some disadvantages since it could not readily be distinguished from background light in the daytime. This created alignment problems and poorer signal-to-noise (S/N) on longer paths during daylight hours. The present system avoids these problems by employing a modulated light emitting diode operating in the near infrared (.94 μm).

2. OPERATION

The receiver and light source are shown in Fig. 1. The light source consists of a light emitting diode (LED) at the focus of a 15-cm diameter concave mirror of 28 cm focal length. Since the LED emitting surface is less than 0.4 mm in diameter a ground glass diffuser is used in front of the LED to assure that the aperture is uniformly illuminated and to make a larger beam that is easier to point. The ground glass should be removed, however, when the system is used over paths longer than 2 km, as the larger beam will not be bright enough, and uniform source illumination is not so important at these ranges. The ground glass can be taken out after removing the back plate holding the concave mirror.

The power supply modulates the LED at 25 kHz. There is a modulation switch but it should be on at all times when using this system. Also there is provision for frequency modulation for data transmission at a future time. There is an adjustment for LED current on the front panel. For paths from 0.5 to 10 km, set the current to 300 ma. DO NOT EXCEED 300 MA AT ANY TIME. The automatic gain control (AGC) circuit in the receiver will adjust for

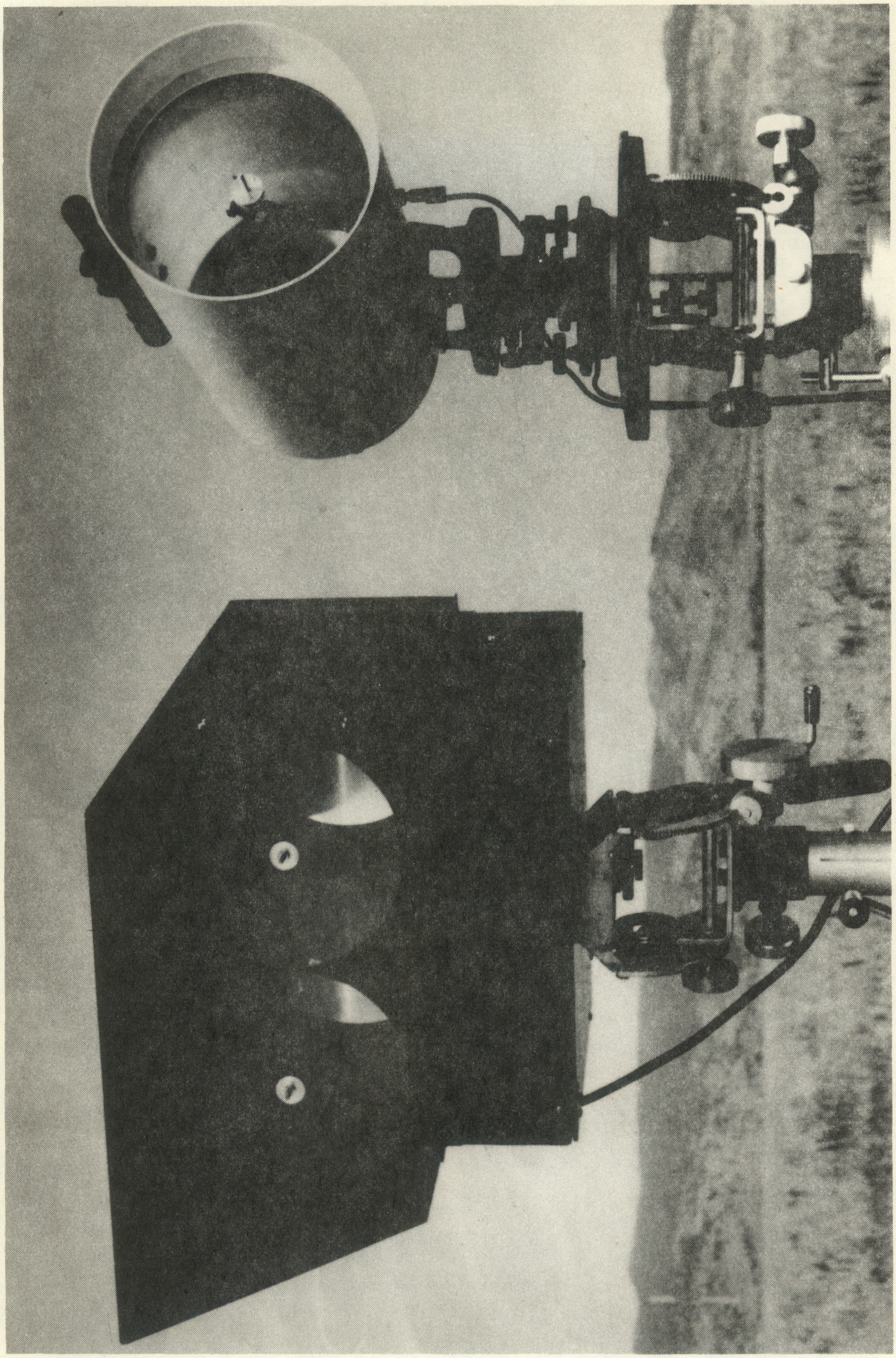

Figure 1. Light source and receiver.

proper signal level. For paths less than 500 m, the current must be reduced approximately in proportion to the square of the path length to prevent receiver saturation. For example, at 100 meters, set the current at $300(1/5)^2 =$ 12 ma.

Both the light source and the receiver should be mounted on firm vibrationless mounts. To set up the system point the light source at the receiver using the sighting telescope. Then align the receiver by looking through its sight. When a signal is received, the green LEDs will light up. Now move the receiver up and down and sideways fairly rapidly, watching when the LEDs go out, and set at the midpoint for the best alignment. The AGC will affect this procedure somewhat. When the receiver is first turned on the AGC is at lowest gain. When not receiving a signal it will go to maximum gain in about one minute. When receiving a signal the AGC time constant is about 5-10 seconds.

For maximum signal-to-noise on long paths we recommend connecting an oscilloscope to the panel signal jacks. Peak up the modulated signals by adjusting the light source and receiver pointing, and by adjusting the modulation frequency at the light source. When the system is properly aligned, and the function switch turned to LOCK, the meter should read in the region from 10 to 50 (+ or - depending on wind direction across the path). If the wind is almost directly down the path, this test may fail and the reading will be zero even with proper alignment.

The front panel controls function as follows:

<u>FUNCTION SWITCH</u> - This switch displays various functions on the front panel meter and also controls other operation as indicated.

<u>0,+,-</u> - These positions (zero, +full scale, -full scale) serve as calibration points for circuit alignment and for wind signal recording convenience. At the WIND BNC the output for ± full scale is ± 3.0 volts.

LOCK - In this position, the meter reads a relative indication (0 to full scale) of the signal available for wind measurement. The polarity of the signal indicates the wind crossing direction. If the reading is zero or fluctuates + and - around zero, the wind is directly down the optical path, the servo system has not yet locked on, or there is insufficient signal-to-noise to operate.

RUN - The normal operating position with the panel meter indicating crosswind speed. When the meter is to the right of zero (or + output at the WIND BNC), the wind is crossing from left to right.

FULL SCALE M/S - This control sets the full scale reading for both the front panel meter and the WIND BNC output.

SIG - The modulated optical signals may be seen at these two test points.

LOCK - The lock voltage is available on the panel for test purposes.

TIME CONSTANT - The wind measurement can be averaged over 1, 10, or 100 second periods. Generally, the 1 second position is used for testing, with 10 or 100 second averaging used in operation.

3. CIRCUITRY

A block diagram of the instrument is shown in Fig. 2. Photodiode op amp combinations having aperture areas of 1 mm^2 are placed at the focus of 15-cm diameter tangent concave mirrors. A gelatine photographic filter (87C) in front of the photodiode cuts off light energy below 0.8 μm while the photodiode response cuts off above 1.1 μm. The preamplified signals pass through an AGC circuit, a bandpass filter (1300 Hz, centered at 25 kHz), and a detector having both logarithmic and linear outputs. The linear output controls the AGC circuit, maintaining approximately 2 volts RMS at the detector input. The logarithmic outputs are conditioned by a highpass filter, precision

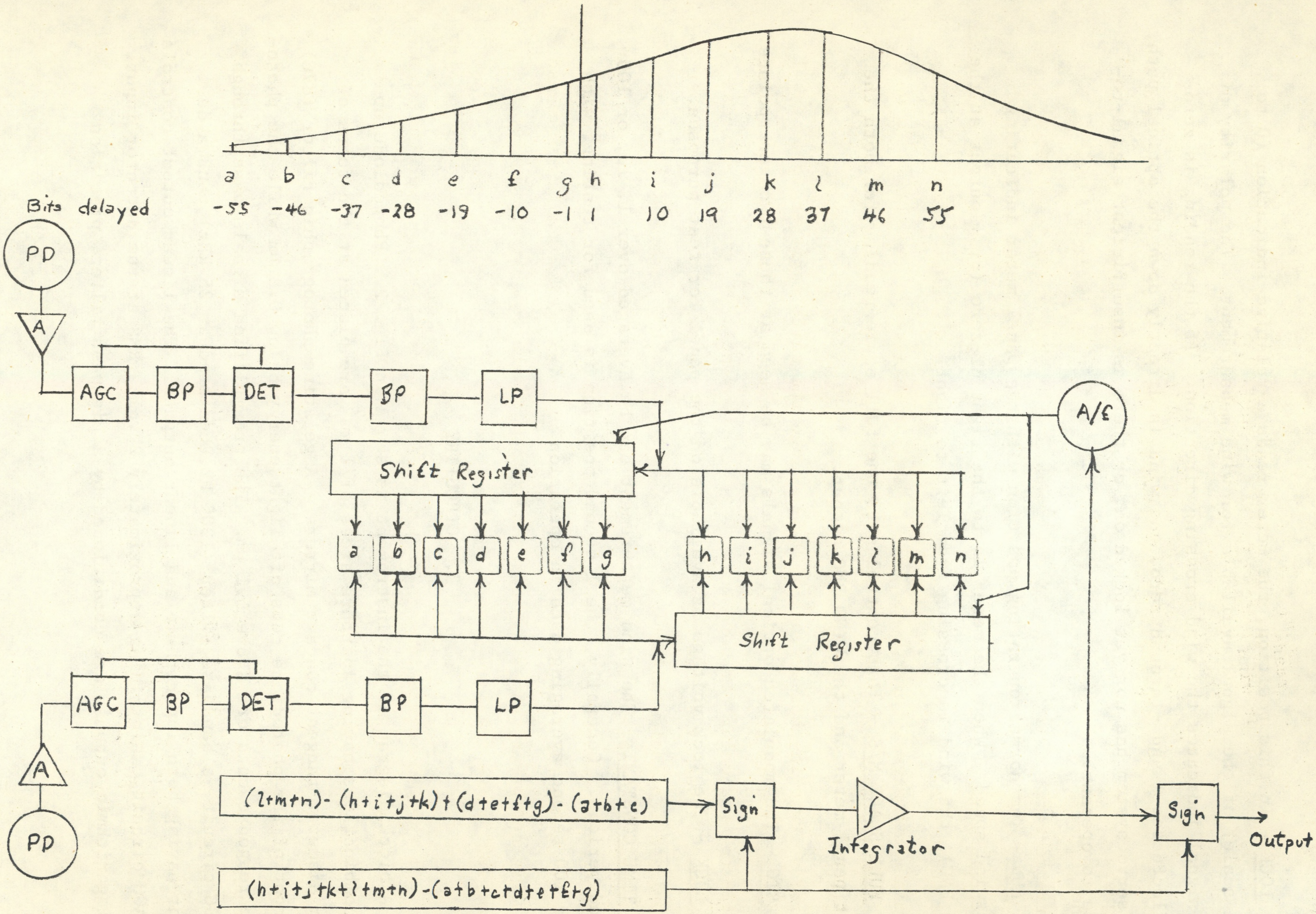

Figure 2. Block diagram of receiver.

clipped, and then passed through a digital lowpass filter to the shift registers.

In operation, the shift registers delay the incoming signals so that one signal is delayed with both positive and negative time lags relative to the other signal. We use exclusive-or circuits to obtain the normalized covariance at 14 time lags on the covariance function. These 14 signals (a,b,c,d,e,f,g,h,i,j,k,l,m,n), biased as shown, are combined as (l+m+n)-(h+i+j+k)+(d+e+f+g)-(a+b+c). This summation will be positive if the time lags are short relative to the signal covariance and negative for time lags long compared to signal covariance. The signal is integrated, converted to a frequency proportional to the integrated signal, and used to clock the shift registers. If the polarity and time constants are properly arranged, the error voltage in this servo loop will change the shift register delay until the summation is zero. The shape of the covariance function will of course influence the delay for zero sum. This arrangement efficiently measures the mean frequency of the coherent portions of the signals, weighting most heavily the signals that are 90° out of phase. If the analog-to-frequency converter is linear, then its input voltage will be proportional to the mean frequency of the coherent portion of the signals. The circuit will very nearly obtain the frequency of the coherent portion of the signals at phase differences other than 90°, tapering to zero weight for signals having a 0 or 180° phase relationship.

If the phase relationship of the input signals reverses sign, the sign of the servo voltage to the integrator must also be reversed. This information is obtained by summing (h+i+j+k+l+m+n)-(a+b+c+d+e+f+g). The sign of this sum is used to change the sign of the error voltage in the servo loop. It is also used to change the sign of the output. Thus the amplitude of the output voltage is proportional to the mean frequency of the coherent portion of the signals and its sign indicates whether input A or B is leading.

Since the slope of the covariance function is proportional to the mean frequency, the measurement has characteristics similar to the slope technique.

There are two important differences, however. A disadvantage is that for signals with zero average time delay, the answer is indeterminate; for the slope system it is definitely zero. An important advantage, however, is that incoherent noise present with the signals does not have a first order effect on the answer; for the slope system it certainly does.

The above discussion outlines the principles of operation, but of course the actual circuit design must consider such things as optimum servo time constants, servo capture problems, optimum shift-register frequency response, sign switching time constants, and also arrange for convenient calibration and scale switching. The circuit also incorporates various compromises dictated by experience. The resulting circuit is shown in Appendix A.

4. ALIGNMENT

This section discusses the adjustment procedures used for initial alignment of the instrument. They should not require adjustment in normal operation.

a. Optical Alignment

The two receiver optical systems use concave mirrors to gather the light and focus it upon 1-mm diameter photodiodes. Initial alignment consists of focussing both systems and aligning their optical axes within 1 mrad. To accomplish this, set up a bright light source about 500 m from the receiver. The gelatine filters must be removed for this adjustment. Aim one edge of the receiver at the light source. Loosen the knurled nuts holding the photodiode mount to the glass and adjust until the light image is exactly in focus on the photodiode surface. When in focus, the image should be stationary when observed from any portion of the mirror. It helps to use an inspection mirror to avoid obstructing too much of the light to the mirror. After both systems are focussed, adjust the position of the photodiode mounts so that both light images are exactly in the center of the respective photodiodes.

Assuming that the photodiodes have already been focussed, another procedure is to look at the LED light source at about 500 m. Observe the signals at the test points with a scope and peak up one of them. Then loosen the knurled nut holding the other photodiode and adjust its position to peak up the other signal.

b. Circuit Alignment

Refer to the Appendix for circuit diagrams and layout.

1. Disconnect the cable to the optics and connect the signal inputs (pins A and B) to a 25 kHz sine wave of about 0.5 volts RMS. Observe the 25 kHz signal at the microdot signal test jacks on the panel. Peak up the signal by adjusting the input signal frequency, allowing for the effect of the AGC action. When the signal amplitude has stabilized, set potentiometer (pot) 2a for +1 volt output at pin 6 of op amp 2D, and set pot 2d to +1 volt output at pin 6 of op amp 2I. A midrange setting of pots 2b and 2e is adequate in this application.

2. Set panel controls as follows:
   Function- RUN.
   Time Constant- 1 second.
   Full Scale- middle position.
   Signal Input- grounded.

3. Set pot L approximately to midscale. This step is necessary for the initial calibration only.

4. Adjust gain pot h and offset pot g for + and -3.00 volts at the wind output, with the function switch in CAL + and -, respectively. This can be done by adjusting gain pot h for a 6 volt difference between the CAL + and - positions, and then adjusting offset pot g to obtain +3.00 and -3.00 volts in the respective CAL + and -positions.

5. With the function switch in CAL + or −, adjust pot i for meter full scale.

6. With the function switch in CAL + or −, and the full scale switch set to each pot in turn, adjust pots for 2.27, 4.53, 9.06, 18.13, and 36.26 kHz, respectively, at the clock TP.

7. Apply a sine wave signal of about 2 kHz to both inputs. This frequency will not get through the low pass digital filters so that nonchanging DC signal levels are applied to the following digital circuitry. Adjust pot e for full scale in the appropriate direction to keep the meter deflected right or left of zero during these adjustments. Set the full scale switch to the middle position. Turn the function switch momentarily to CAL and back to RUN so that the meter is neither zero nor full scale (right of center). Adjust pot d so that the meter drifts slowly toward zero (takes approximately 10 seconds to go from 50 to 40). It is very important that the drift tendency is toward zero, rather than full scale. Now adjust pot c in the same way for the left hand portion of the meter scale. Then repeat both adjustments as they may be slightly interactive.

8. Continue the 2 kHz sine wave to the inputs. With the function switch set to the 0 position, check for zero wind output and adjust pot g for zero if necessary.

9. Using the same inputs as used in 7, set the function switch to the zero position and adjust pot e for zero volts average at pin 6 of op amp EE.

10. Apply about 10 Hz sine wave signals, 90° out of phase, to the circuits. With the function switch set to LOCK, adjust pot f for full scale on the meter.

11. Plug in and cover the optical unit, and leave the unit on at least one minute. Adjust pots 2c and 2f so that the green panel LEDs are just flickering on and off. Then turn both pots 4 turns in the LED off direction.

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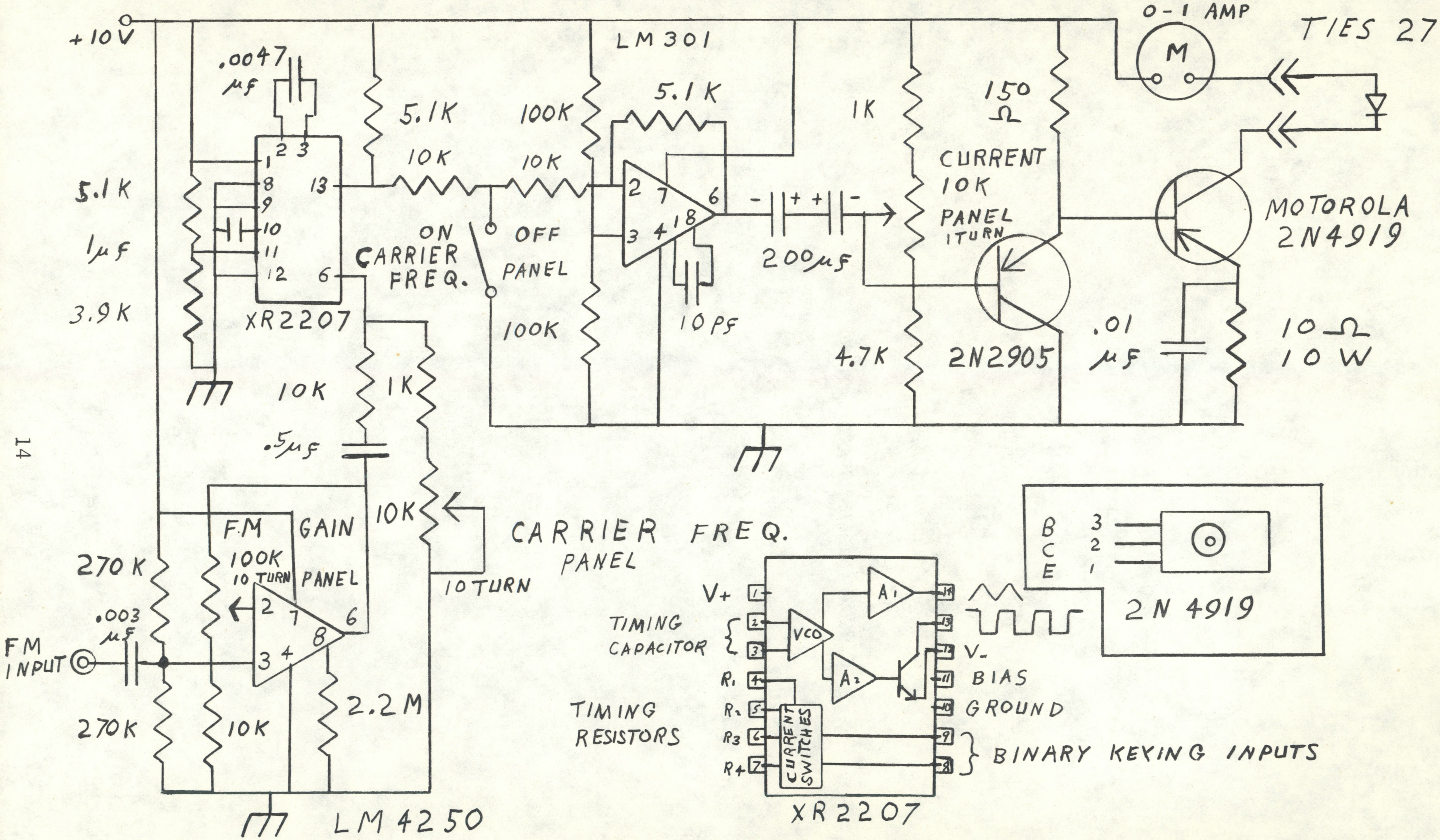
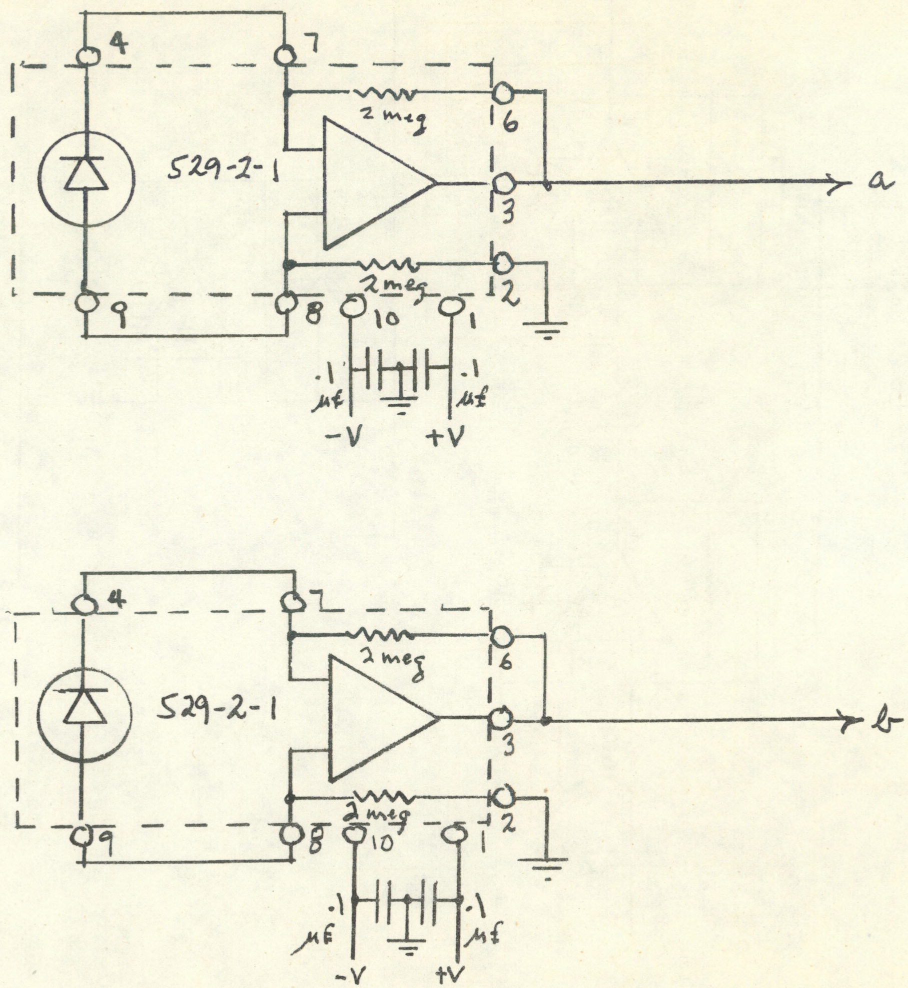
APPENDIX A.

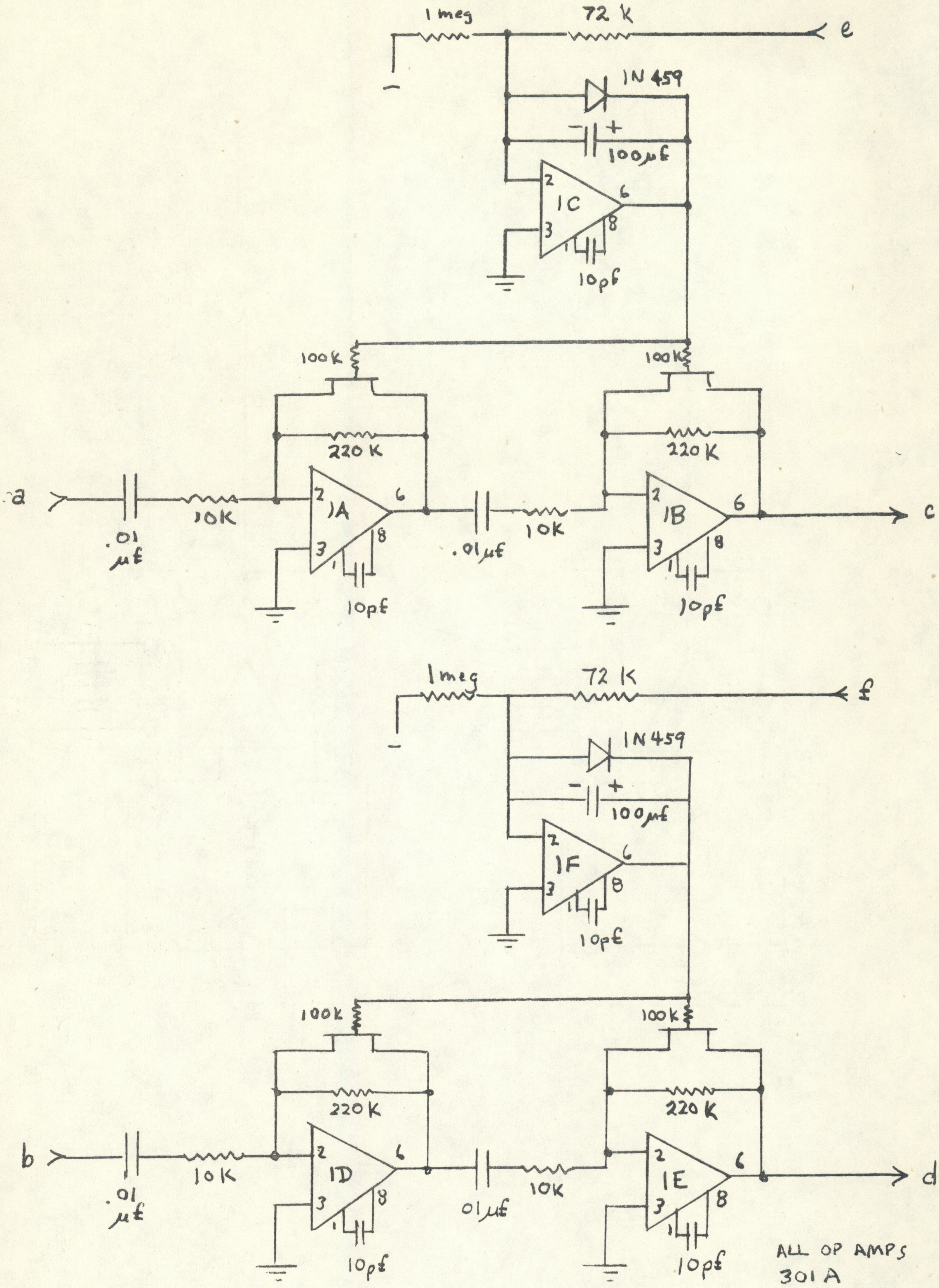
CIRCUIT DIAGRAMS AND LAYOUT



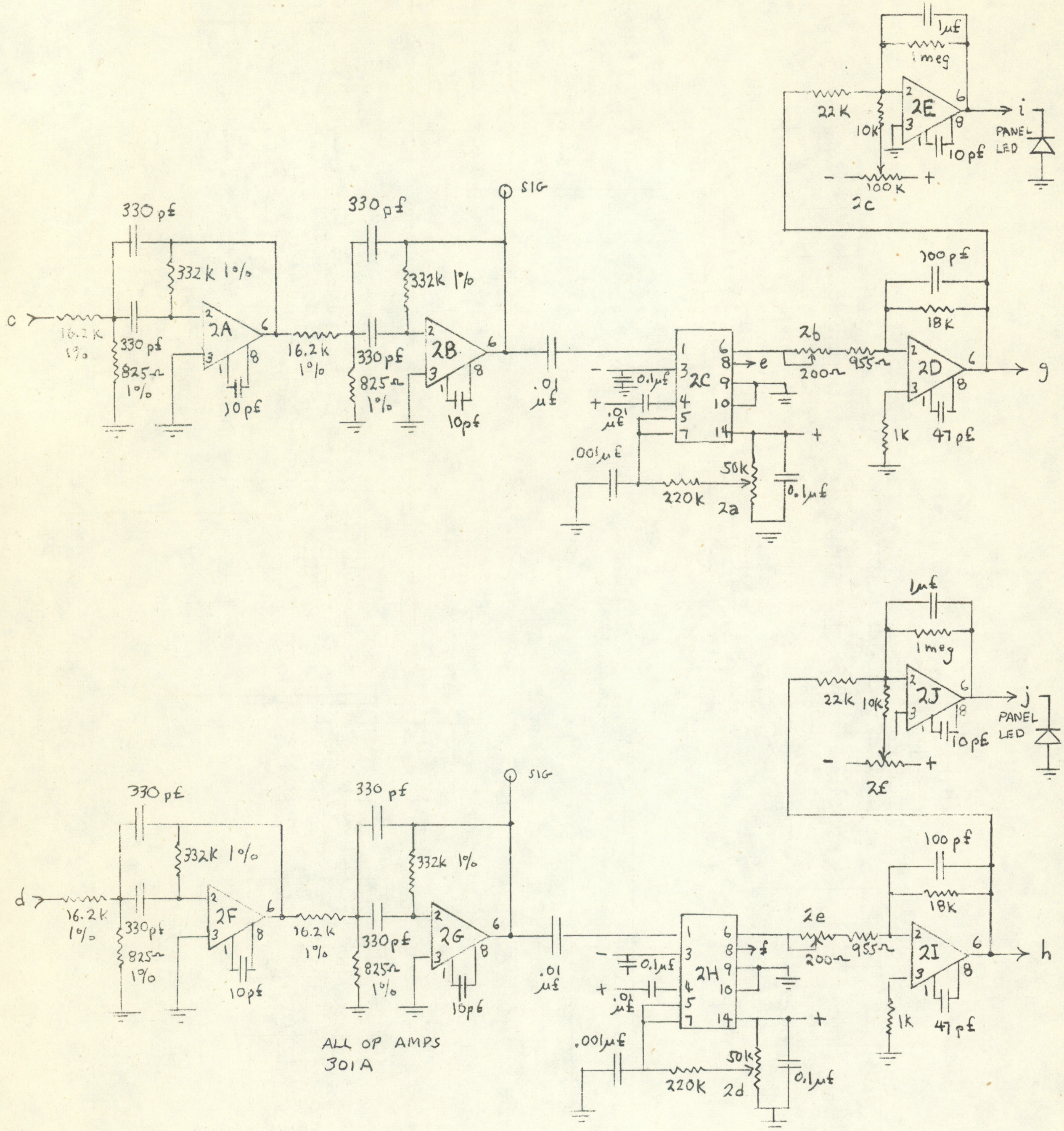
Light emitting diode driver circuit.



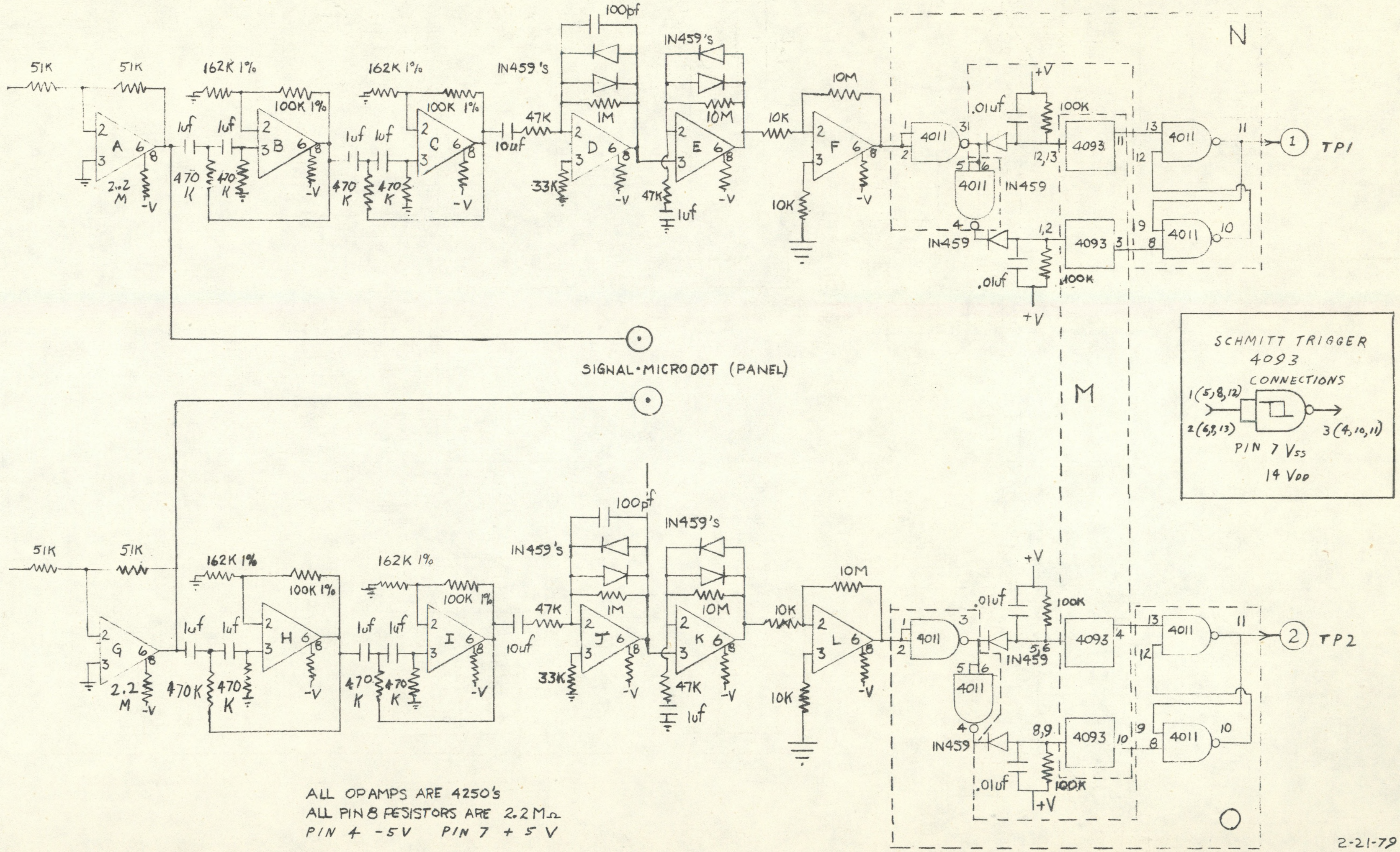
Photodiode preamplifier.



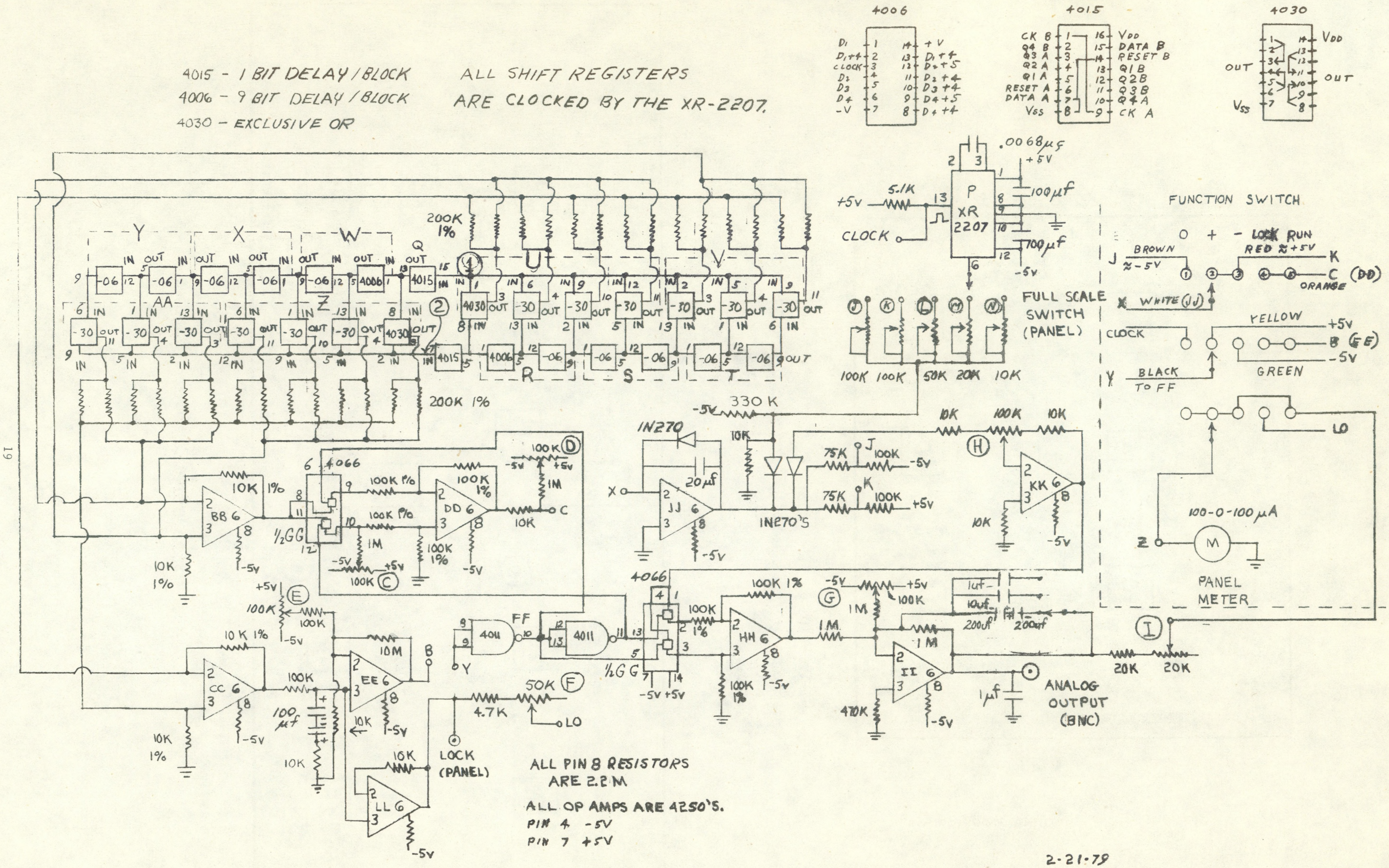
Automatic gain control circuit.



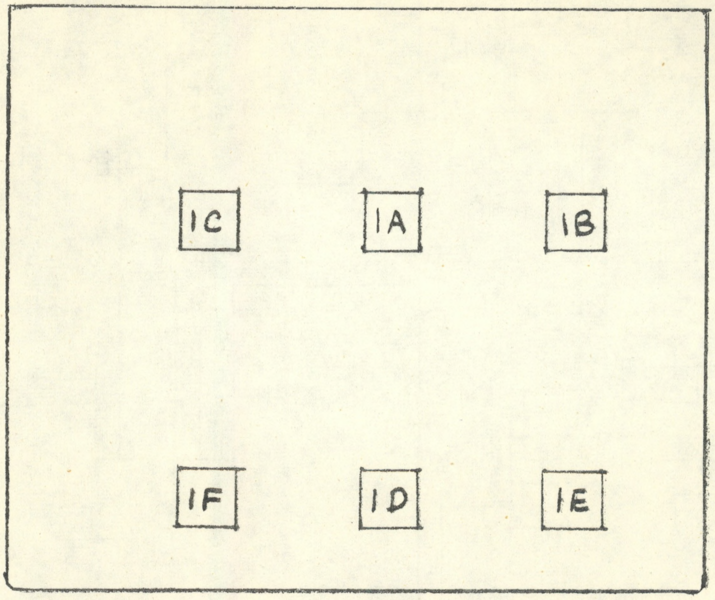
Demodulator circuit.



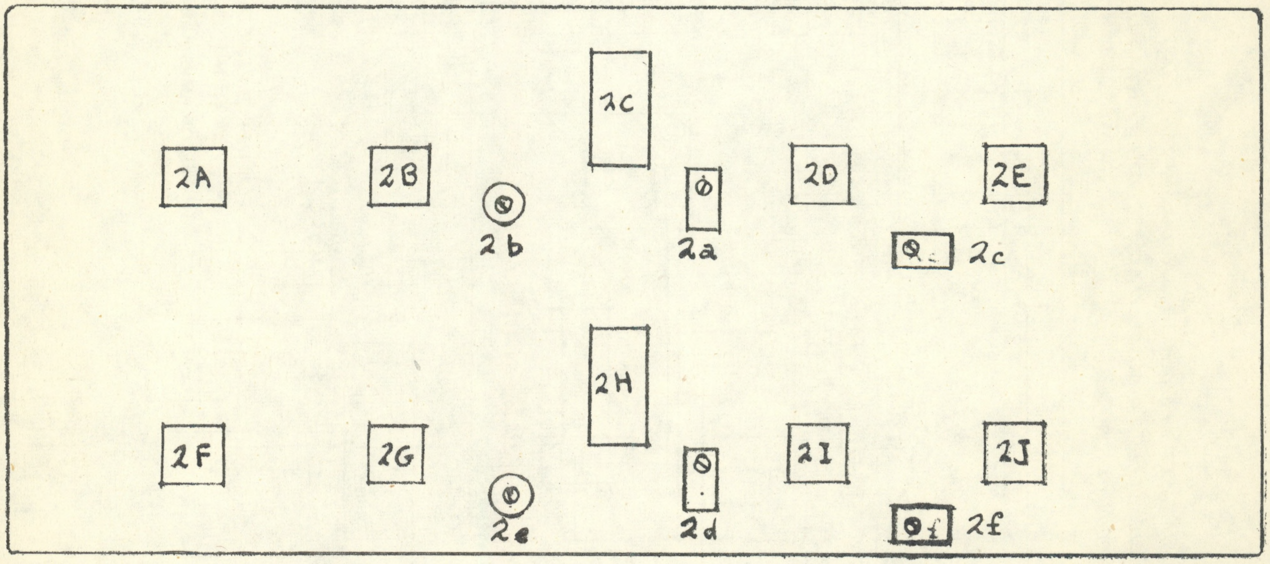
Covariance analyzer circuit 1.



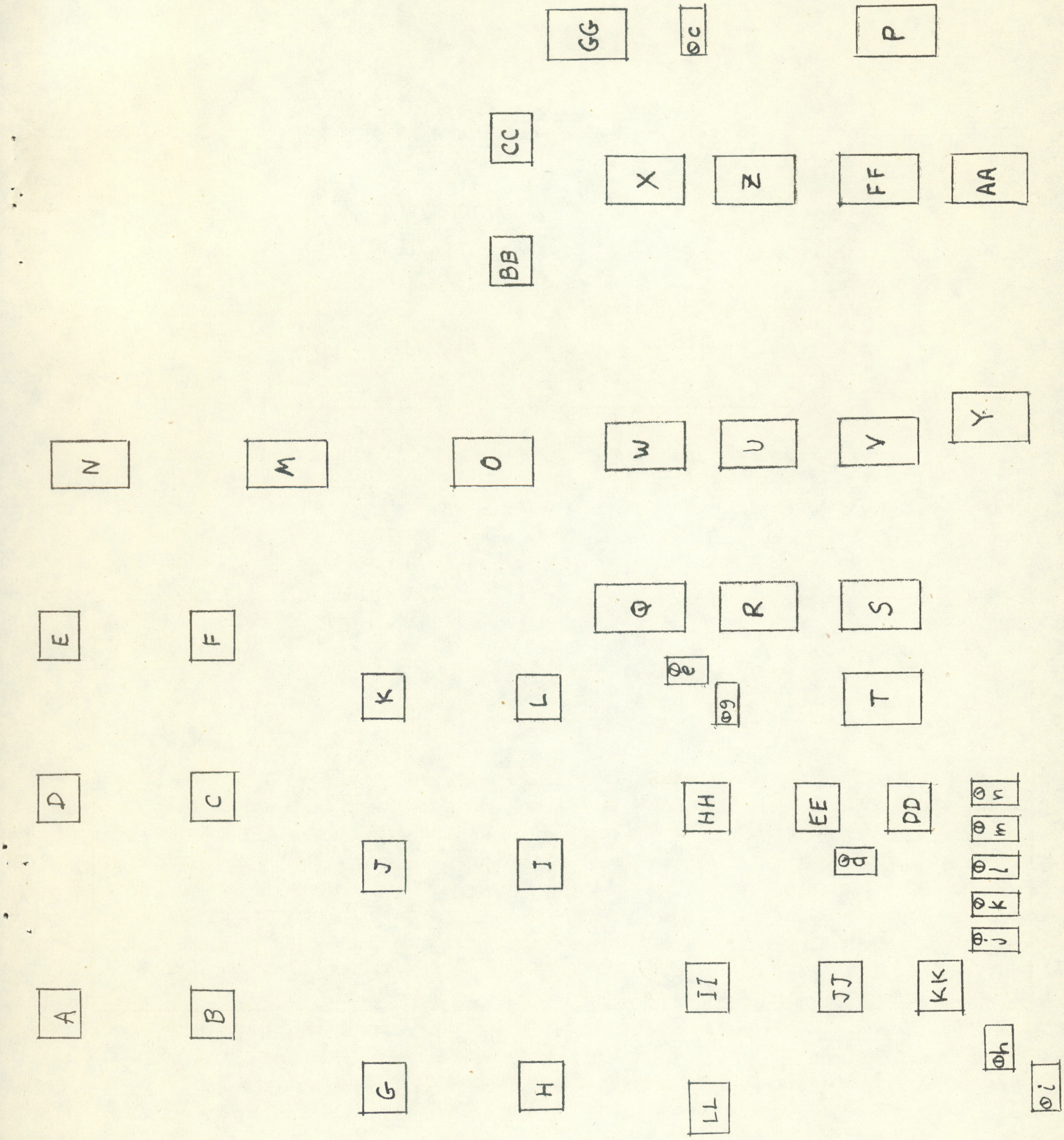
Covariance analyzer circuit 2.



Automatic gain control circuit board layout.



Demodulator circuit board layout.



Covariance analyzer circuit board layout.

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