NOAA Technical Memorandum ERL WPL-23

A RESEARCH LASER WEATHER IDENTIFICATION INSTRUMENT

K. B. Earnshaw
Brian Keebaugh

Wave Propagation Laboratory
Boulder, Colorado
March 1977

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

NOAA Technical Memorandum ERL WPL-23

A RESEARCH LASER WEATHER IDENTIFICATION INSTRUMENT

K. B. Earnshaw
Brian Keebaugh

Optical Propagation Program

Wave Propagation Laboratory
Boulder, Colorado
March 1977

UNITED STATES
DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

Environmental Research
Laboratories
Wilmot N. Hess, Director

CONTENTS

A RESEARCH LASER WEATHER IDENTIFICATION INSTRUMENT

K. B. Earnshaw and Brian Keebaugh*

We describe an experimental laser weather identification instrument designed to test the feasibility of making automatic identification of precipitation and other obscurations to visibility. The nature of the optical signals and electronic processing of these signals to make weather identification are discussed in detail. We have given instructions for preparing the instrument prior to taking data, as well as a complete set of electronic circuit diagrams needed for instrument maintenance.

1. INTRODUCTION

The Laser Weather Identifier was designed as a research instrument to test the feasibility of making automatic identification of precipitation and other obscurations to visibility, as suggested by Derr, et al.[1] None of the optical parameters measured by the instrument has been extensively tested or proven in use, but each has been incorporated in the instrument so that such tests may be made. As many optical parameters were incorporated in the instrument as were considered feasible, although not all measurements can be made simultaneously. In general the instrument must be set up and adjusted in advance for each type of weather identification experiments desired (depending on the type of weather, i.e., rain, fog, snow, etc. anticipated). Since the instrument is a protype, we expect that design changes in the optical systems and electronic data processing systems will be suggested by field tests. No attempt was made to develop an instrument that could be reproduced in volume for use as a weather identifier, although it is hoped that such an instrument can be built using the test results of the research prototype described in the following pages.

At the request of the National Weather Service, the instrument includes laser measurements at both the He-Ne red (.6328 μm) and CO_2 infrared (10.6 μm) wavelengths. The measurements using the .6328 μm wavelength, along with possible identifications of weather parameters are shown in table I. Measurements using the 10.6 μm wavelength and the corresponding possible identifications of weather parameters are shown in table II.

---

*Equipment Development Laboratory, National Weather Service, Silver Spring, MD.

[1] "A Theoretical Analysis of the Information Content of Lidar Atmospheric Returns" V. E. Derr, M. J. Post, R. L. Schwiesow, R. F. Calfee, and G. T. McNice. NOAA Tech. Report, ERL 296-WPL 29, Nov. 1974.

Table I: Measurements at .6328 μm vs possible weather identification parameters.

	Measurement		Possible Weather Identification Parameters
1)	Laser beam transmittance		Fog, smoke, dust, haze, prevailing visibility, snow.
2)	Forward Scatter Intensity from a laser beam vs. scattering angle	a)	Presence, density and intermittency of fog, smoke, dust, haze, snow, ice crystals, rain.
		b)	Particle sizes of fog, smoke, dust, or haze below approximately 250 μm particle size.
3)	Depolarization of forward scattered light vs. scattering angle		Differentiation of particle shapes such as fog vs. smoke, dust, snow, or ice crystals. Incident polarized light is depolarized when scattered by irregular shapes.
4)	Measurement and comparison of 500 and 2000 Hz forward scatter scintillations at zero scattering angle from a collimated laser beam		Differentiation of precipitation types, such as rain, sleet, snow, and hail.
5)	Variance of scintillation signals above 200 Hz from a collimated laser beam	a)	Presence of rain, sleet, or snow precipitation.
		b)	Rough measurement of precipitation intensity for rain, sleet, or snow.
6)	Peak height of scintillation signals from a collimated laser beam		Identification of large particles such as hail, or large snow flakes.
7)	Correlation of forward-scatter signals in a collimated laser beam from two horizontal line receivers having a vertical separation	a)	Identification of rain, snow, sleet or hail precipitation.
		b)	Measurement of rain rate.
		c)	Measurement of drop size distribution in rain and sleet.
8)	Backscatter from a collimated laser beam at angles above and below the rainbow backscatter angle		Identification of rain.

Table II: Measurements at 10.6 μm versus the possible weather identification parameters.

Measurement		Possible Identification Parameter
1) Laser beam transmittance		Fog, smoke, dust, or haze, prevailing visibility, rain, snow.
2) Forward scatter intensity from a laser beam vs. scattering angle.	a)	Presence, density, and intermittency of fog, smoke, dust, haze, rain, or snow.
	b)	Particle size of fog, haze, smoke, dust, blowing sand, mist, drizzle, or rain (below 1 mm.)
3) Depolarization of forward scattered light vs. scattering angle.		Differentiation of particle shapes such as fog vs. smoke, dust, snow or ice crystals. (Incident polarized light is depolarized when scattered by irregular shapes).

2. DESCRIPTION OF INSTRUMENT

The physical layout of the Laser Weather Identifier (LWI) system is shown in Figure 1. The laser source (transmitter) and detector (receiver) systems are mounted on motor driven rotating platforms so that the laser beams and receivers can be pointed in azimuth. This allows the transmitter and receiver systems to be pointed in direct alignment for measurement of transmittance, optical scintillation (peak height and variance), frequency spectra and correlation between spaced horizontal line receivers. Alternatively, the two ends of the system may be synchronously scanned in azimuth so that the transmitted and received light beams intersect at the path midpoint. This azimuth-scan mode allows measurements of forward-scatter intensities versus forward-scatter angle (twice the azimuth-scan angle at one end of the path) to a maximum of approximately 20°. A position-sensing potentiometer, geared to the transmitter platform, provides an output voltage proportional to the angular position of the platform.

A second receiver system is located near the transmitter end and is aimed to receive backscattered light at the rainbow backscatter angle for He-Ne red light. This receiver is set at a fixed angle and is therefore used only when the rotating platforms are pointed in direct alignment.

As shown in Figure 1, the LWI system uses two laser transmit-and-receive systems. The He-Ne red system is located above and parallel to the CO_2 infrared system on both transmitter and receiver platforms. The transmitted intensity of the red laser beam is monitored by the red I_o detector by partial reflection from a thin glass plate. Most of the laser beam passes

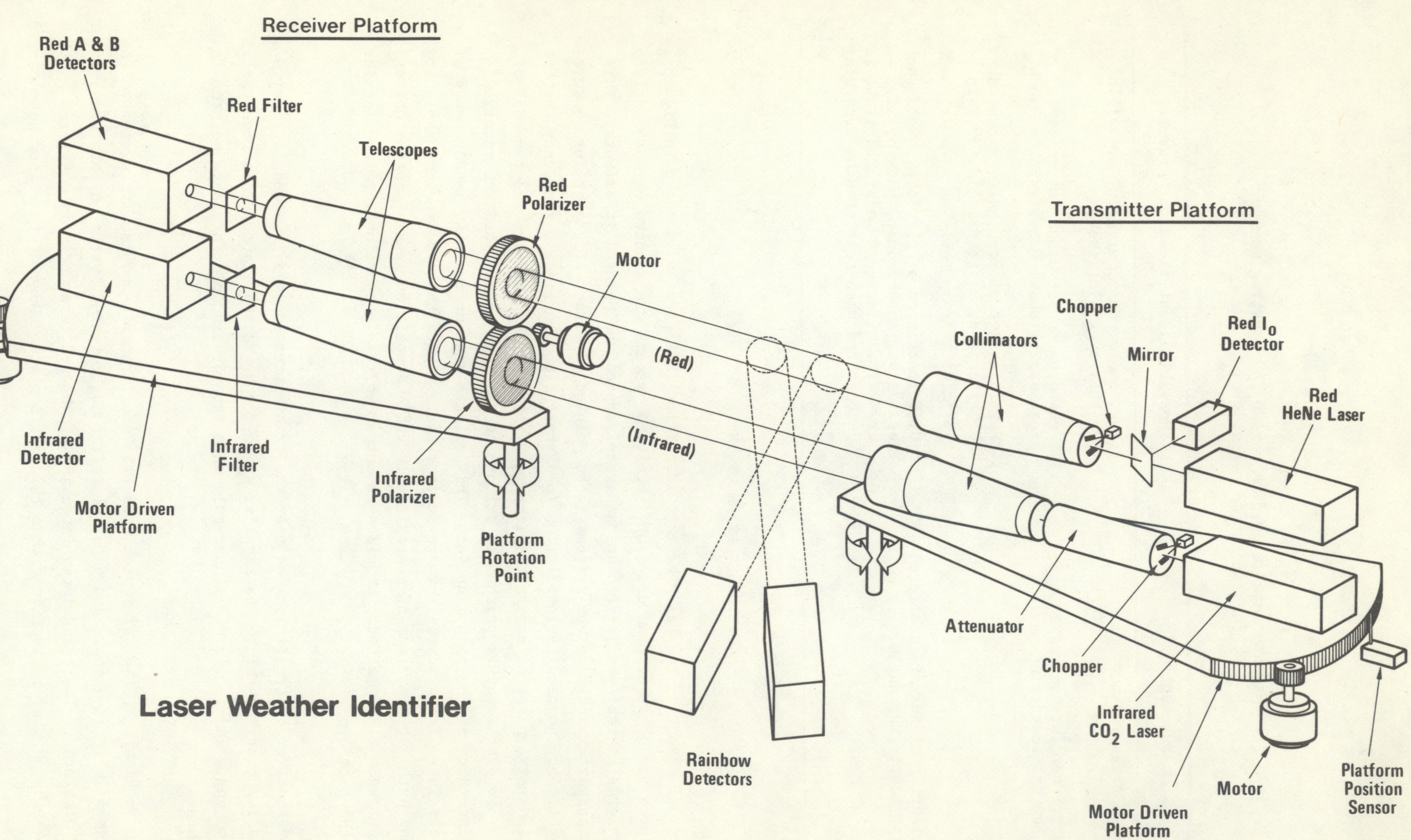


Figure 1. Physical layout of the Laser Weather Identifier system.

through the glass plate, through the blades of a tuning-fork light chopper, and into the collimating telescope that enlarges the beam to a 2 inch diameter. The red-light chopper, (or modulator) operating at 400 Hz, can be turned on or off at the central control site depending on the type of measurement desired. The 400 Hz modulation allows the laser light to be distinguished from background scattered sunlight, etc. during the most sensitive light detection requirements — i.e., forward scatter vs. scatter angle measurements, or rainbow backscatter.

The CO_2 infrared laser beam passes through the blades of a continuously operating 10 Hz tuning-fork chopper, through a variable attenuator and into a collimator that enlarges the beam to a 4 inch diameter. Thus the light transmitting system sends out two parallel collimated laser beams; a 2" red beam in the upper position and a 4" infrared beam in the lower position. The rotating platform allows the beams to be rotated from zero to approximately 10° in azimuth, corresponding to a forward scatter angle of 20°.

At the receiving platform, the red beam passes through a polarizing window to a telescope lens that brings the beam to an approximate focus, with a narrow-band optical filter to eliminate unwanted background light. The polarizing filter at the red receiver aperture is motor controlled to be either parallel or perpendicular to the polarization of the red laser beam. This motor is controlled remotely by switches at the central control site. An aperture plate (not shown in Figure 1) may be placed at the entrance to the red receiver, just ahead of the polarizer, to receive light along two parallel horizontal slits. The split detector arrangement allows the light from these two linear apertures to be received independently. The received beam impinges on a photodiode detector at a point beyond the telescope lens focus so that the lower half of the transmitted beam is collected on the upper half of the detector and the upper half of the transmitted beam is collected on the lower half of the detector.

The infrared receiving system is located below the red receiving system and incorporates the same polarization, focusing, and filtering functions as the red receiving system. However, no aperture slit is used on the infrared system. The infrared beam is brought to a focus at a single detector, and the polarizing filter is actually located behind the telescope for convenience in mounting. Thus, the receiving system detects .6328 μm and 10.6 μm light along parallel axes from narrow cone shaped volumes which include all or part of the projected cylinders of red or infrared light.

To allow for differences in red detector sensitivity, gain setting switches (labeled low, medium, and high) are provided at the receiver site. These switches are needed because of the large differences in received light for (1) direct "straight on" measurements using full aperture or dual slit apertures, and (2) indirect forward scatter vs. scatter angle measurements using full aperture. The difference in sensitivity required for direct vs. angular measurements in the infrared is controlled by manually adjusting the infrared variable attenuator at the transmitter site.

Transmitter, receiver, and rainbow detector stations are aligned vertically before operation using the three jacks which support each of the respective instruments. Horizontal alignment is accomplished by sliding the stations on the supporting bases. When horizontal and vertical alignment is achieved, the station being aligned is locked into position using the locking clamps which attach the station firmly to the mounting base.

3. NATURE OF THE OPTICAL SIGNALS

The LWI has been designed to process some of the characteristics of the optical signals generated by weather particles passing through a collimated laser beam. The observed optical phenomena associated with various types of weather are discussed in the following list of weather phenomena:

3.1 Clear Air-No Weather Particles

In the absence of weather particles, turbulence and temperature gradients in clear air cause scintillation of a projected optical beam. The scintillations are caused by random variations of refractive index resulting in a complex illumination pattern and forward scatter at very small scattering angles (about 150 μradians maximum). No polarization effects are observed. If the projected optical beam is observed with a thin horizontal line detector, the received signal will be the average received intensity modulated by the atmosphere, with a modulation frequency-spectrum extending from near zero Hz to over 500 Hz. A typical spectrum analysis of atmospheric turbulence signals from a line detector (shown in Figure 2) gives large signals at the lower frequencies with rapidly decreasing amplitudes at higher frequencies. The frequency spectrum in Figure 2 is typical for most clear weather; however, temperature and wind may change the amplitude and frequency-spectrum of the received signals. The turbulence signals are ever present, but can decrease considerably during long rain or snow storms. One of the principle challenges of laser weather identification is to identify the weather induced signals (which are usually small in amplitude) in the presence of the larger atmospheric scintillation signals.

3.2 Rain

Rain drops in a collimated laser beam create interference patterns that sweep downward past the optical receivers at the fall velocity of the drops. A typical amplitude-scintilla-

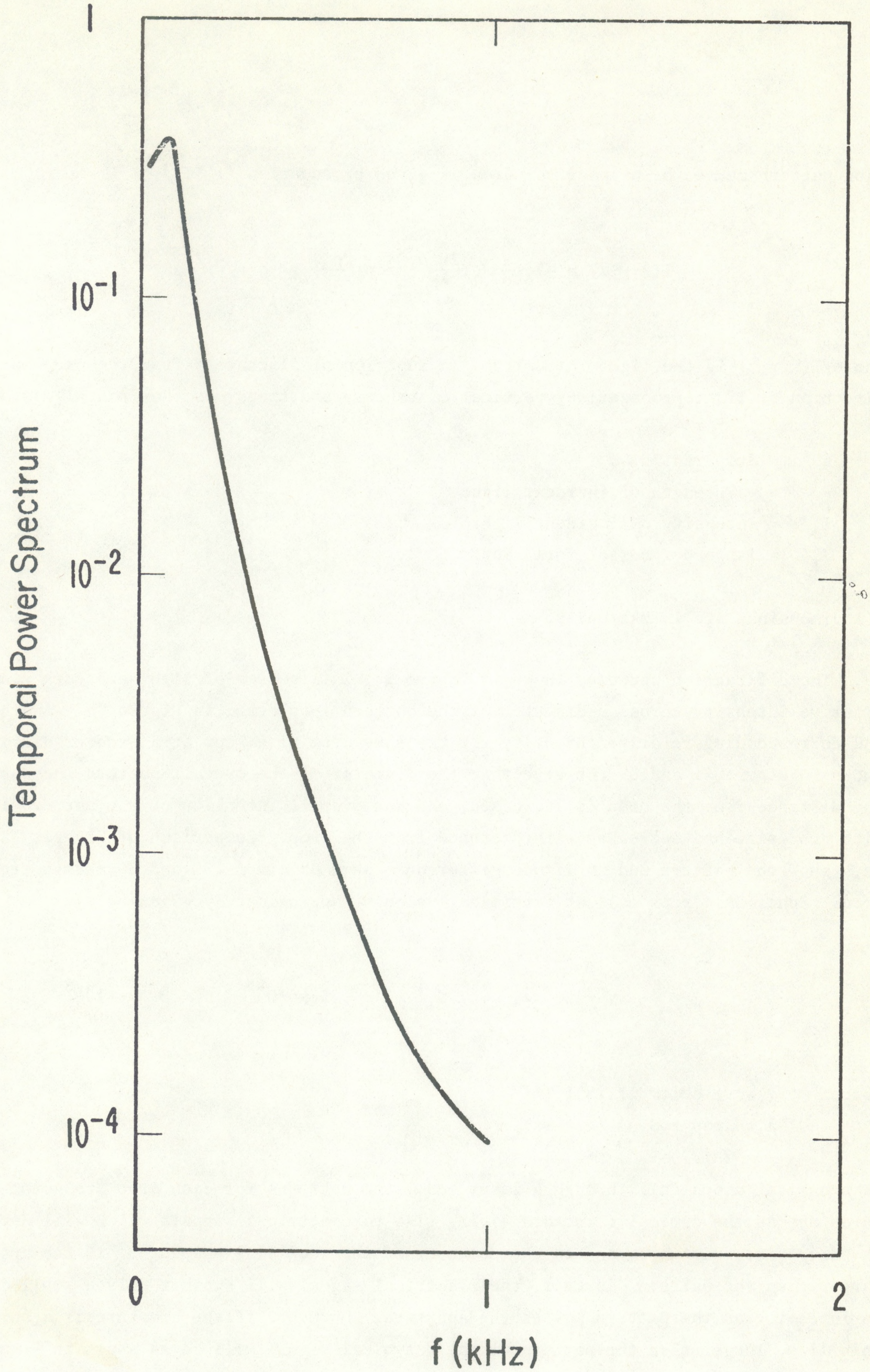


Figure 2. Spectrum analysis of atmospheric turbulence signals from a line detector.

tion pattern caused by a spherical drop is given by equation (1)[2]:

$$I(x,y,z) = -I_o \frac{a}{\rho} J_1(\frac{2\pi a\rho}{\lambda x}) \sin(\frac{\pi\rho^2}{\lambda x}) \ ; \quad \rho = \sqrt{y^2+z^2} \qquad (1)$$

where I(x,y,z) is the light intensity as a function of distance x from the drop in the direction of light propagation, vertical distance y and transverse horizontal distance z.

a = drop radius
λ = wavelength of incident light
I_o = intensity of incident light
$J_1(\ )$ = 1st order Bessel formation.

All dimensions are in mks units.

The diffraction pattern, shown in Figure 3a, is a series of light and dark rings. The relative intensity across a diameter of the pattern is plotted in Figure 3b. Another pattern and corresponding relative intensity for the same drop size, but at a greater distance is shown in Figure 4a and b. Observe that the diameter of the overall pattern increases as the distance from the drop is increased, and the overall intensity of the pattern increases with drop size and decreases with distance from the drop. Comparison of Figures 3a,b and 4a,b show the pattern and amplitude differences when observed 100 and 50 meters from the drop. Spherical drops fall at a terminal velocity approximately given by[2]:

$$V = 200\sqrt{a}, \qquad .25 \times 10^{-3} < a < 2.5 \times 10^{-3} \qquad (2)$$

where: V = velocity of fall (m/s)
a = drop radius (meters)

As spherical drops fall through a laser beam, the patterns for each drop are swept downwards across the optical detectors giving rise to electrical signals which will depend on the drop size, distance, and on the geometry of the receiving aperture. If the aperture is larger than the pattern diameter, the electrical signal will exhibit only a small decrease in intensity as the pattern passes the aperture. However, if the aperture is a horizontal thin line, longer than the pattern width, a typical signal will be as shown in Figure 5.

---

[2] Ting-i Wang, G. Lerfald, R. S. Lawrence, and S. F. Clifford, Measurement of Rain Parameters by Optical Scintillation, Submitted to Applied Optics.

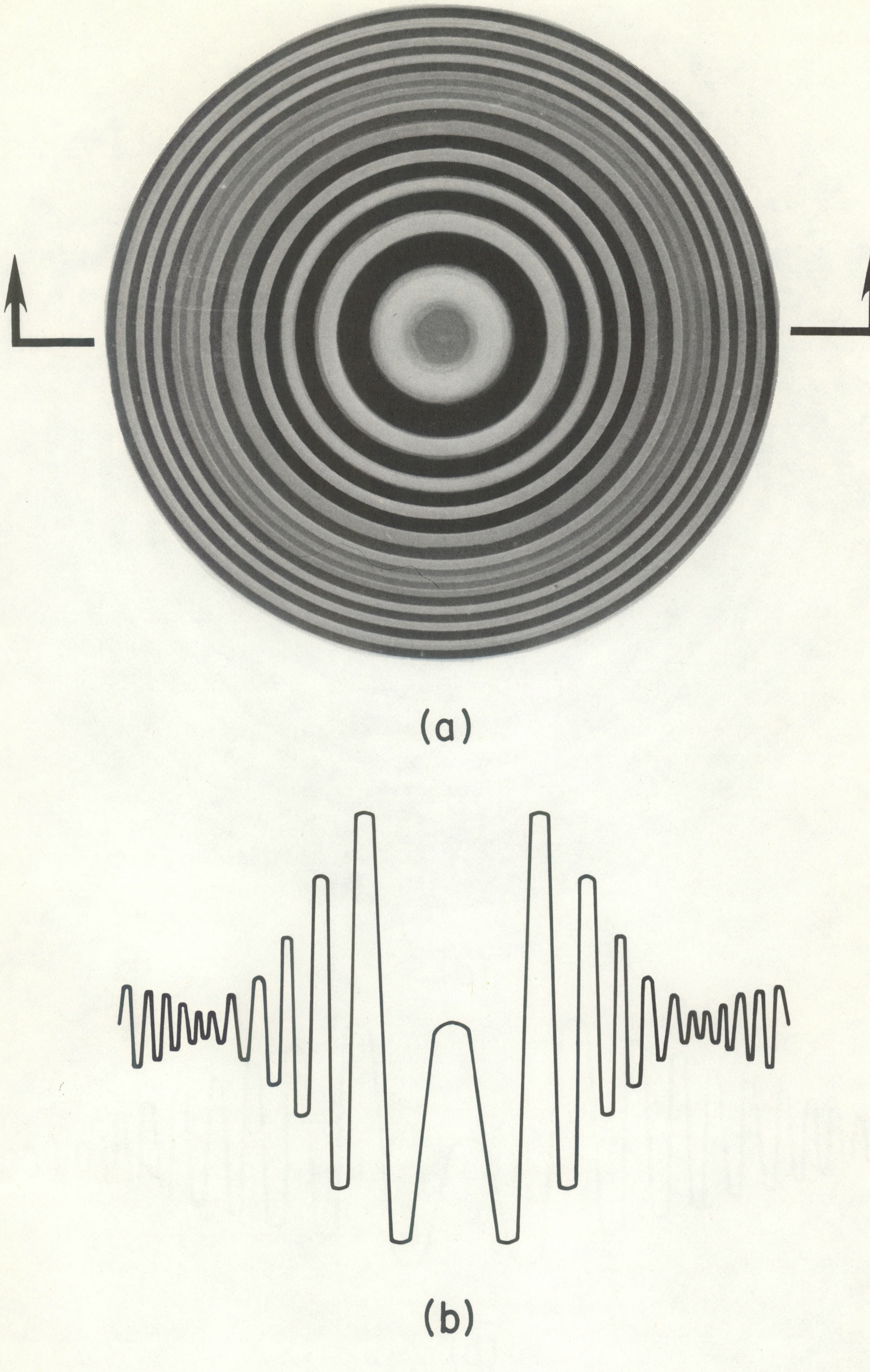
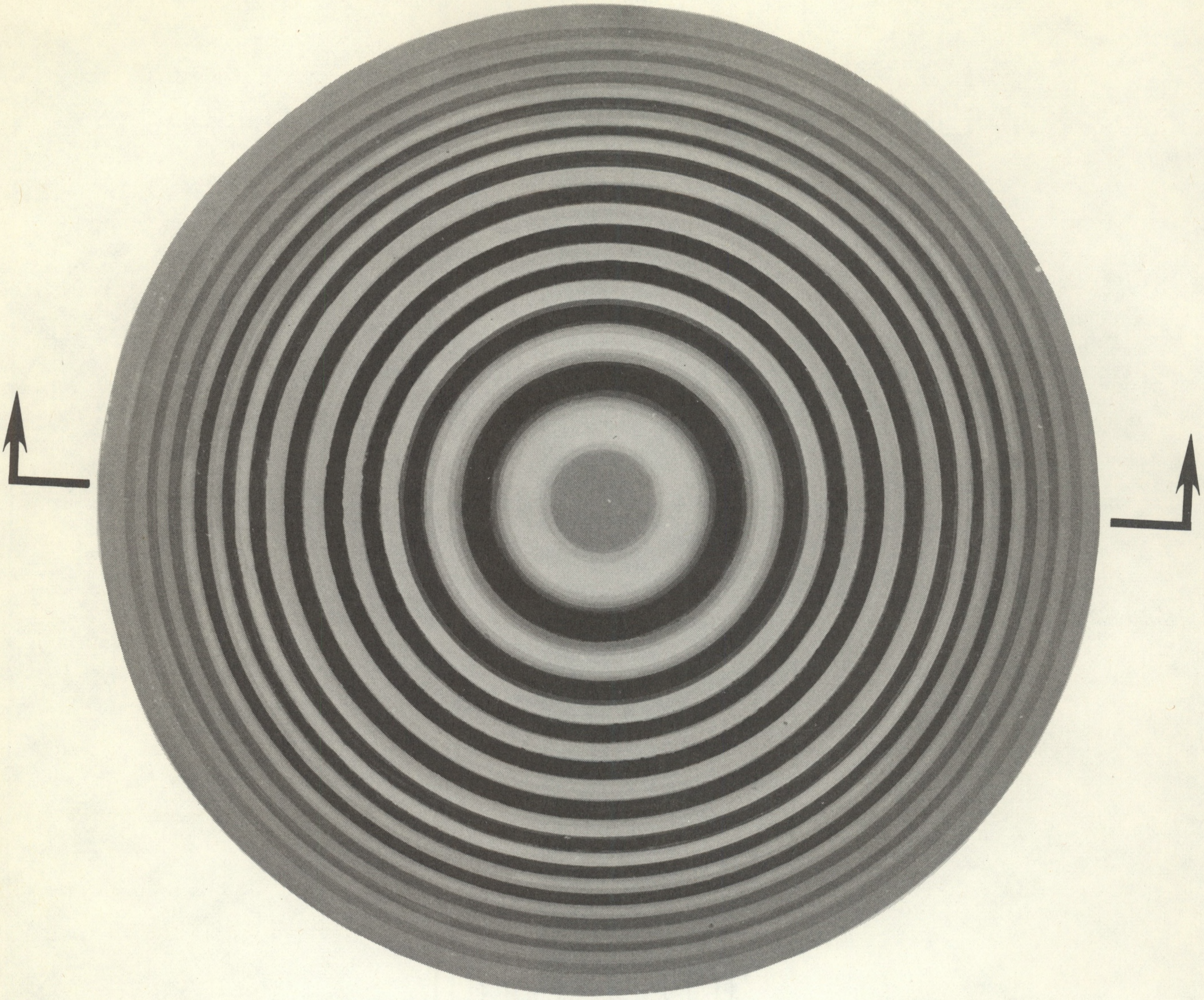
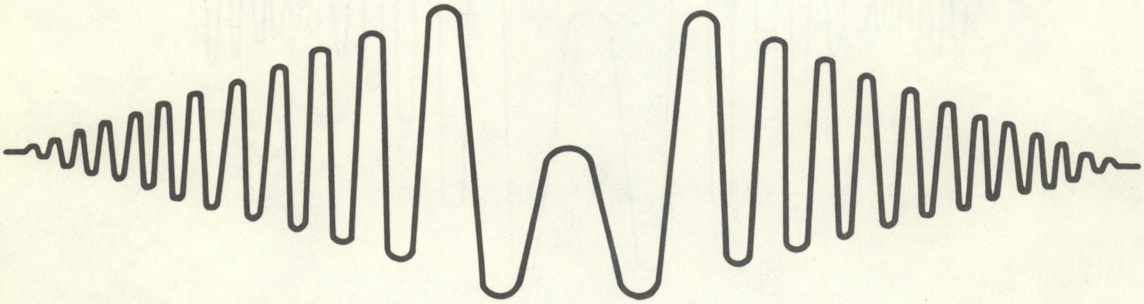


Figure 3. Artist's conception of a raindrop pattern (a) and the relative intensity (b) across a diameter at a distance of 50 meters from a 2 mm diameter drop.



(a)



(b)

Figure 4. Artist's conception of a raindrop pattern (a) and the relative intensity (b) across a diameter at a distance of 100 meters from a 2 mm diameter drop.

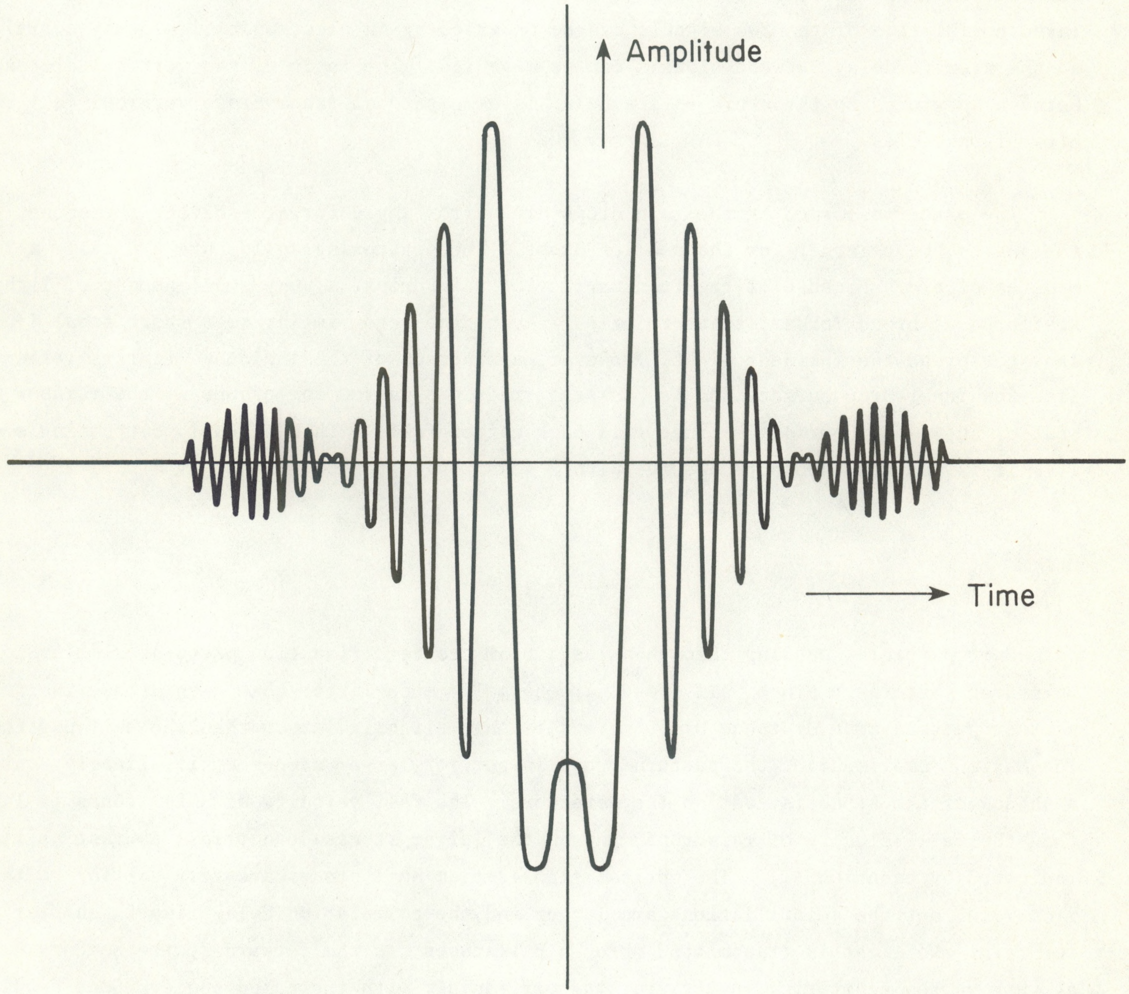


Figure 5. Time varying signal detected from a single 2 mm diameter drop 50 meters away from a thin line detector.

When a large number of drops are falling through a laser beam, the individual signals add in a random fashion to give time varying signals as shown in Figure 6. If the drops were all of the same size and of identical fall velocity the signals from channel 1 (upper line aperture) and channel 2 (lower line aperture) would be identical with a relative time delay observed in the channel 2 signal. Since rain drops vary in size, there will be no obvious correlation that can be seen by direct comparison of the signals. However, the time delayed correlation of the two signals can be observed by an electronic time-delay correlator, so the average delay between signals can be measured. The ratio of the vertical distance between apertures to the average time delay is a measure of the average vertical fall velocity of particles.

The patterns formed by the rain drops are narrow-angle forward-scatter phenomena, with the angles being larger for the smaller drops. The scattering angles are typically a few minutes of arc. Because of the transparency of rain drops, a very small amount of light is scattered at broad forward scatter angles. Each drop acts similar to a short focal length lens to spread the incident light. However, a fraction of the incident light is reflected from the inner drop surface and is backscattered in a narrow angle cone at the rainbow backscatter angle of about 42°. Since this backscatter falls within a small scatter angle (about 1°), it is intense enough to observe with a sensitive detector.

3.3 Hail

Hail particles passing through a laser beam create diffraction patterns similar to rain drop patterns. Since hail stones are normally much larger than rain drops, the forward-scatter pattern at a distance of 50 meters is only slightly larger than the hail particle. The maximum amplitude of the pattern grows larger for larger stones until, finally, only a shadow of the stone is cast on the detectors. The fall velocity of hail stones is larger than the fall velocity of raindrops, though the larger stones do not fall as fast as is indicated by equation (2). The optical signals from hail stones are very similar to those from rain, but the scintillations are larger and the correlation delay time is shorter than for rain. No light is transmitted through hailstones, so the forward scatter occurs only at very narrow scattering angles, falling off rapidly with increased angle. Some depolarization of light may occur at small forward scatter angles because of the irregular surface of most hail stones. The peak heights of optical signals above 200 Hz may be much larger than for either rain or turbulent air, and should be monitored during hail storms as a possible definite indicator for hail. The high velocity and larger size of hail will give optical signals having high frequencies which may be observed at 2000 Hz.

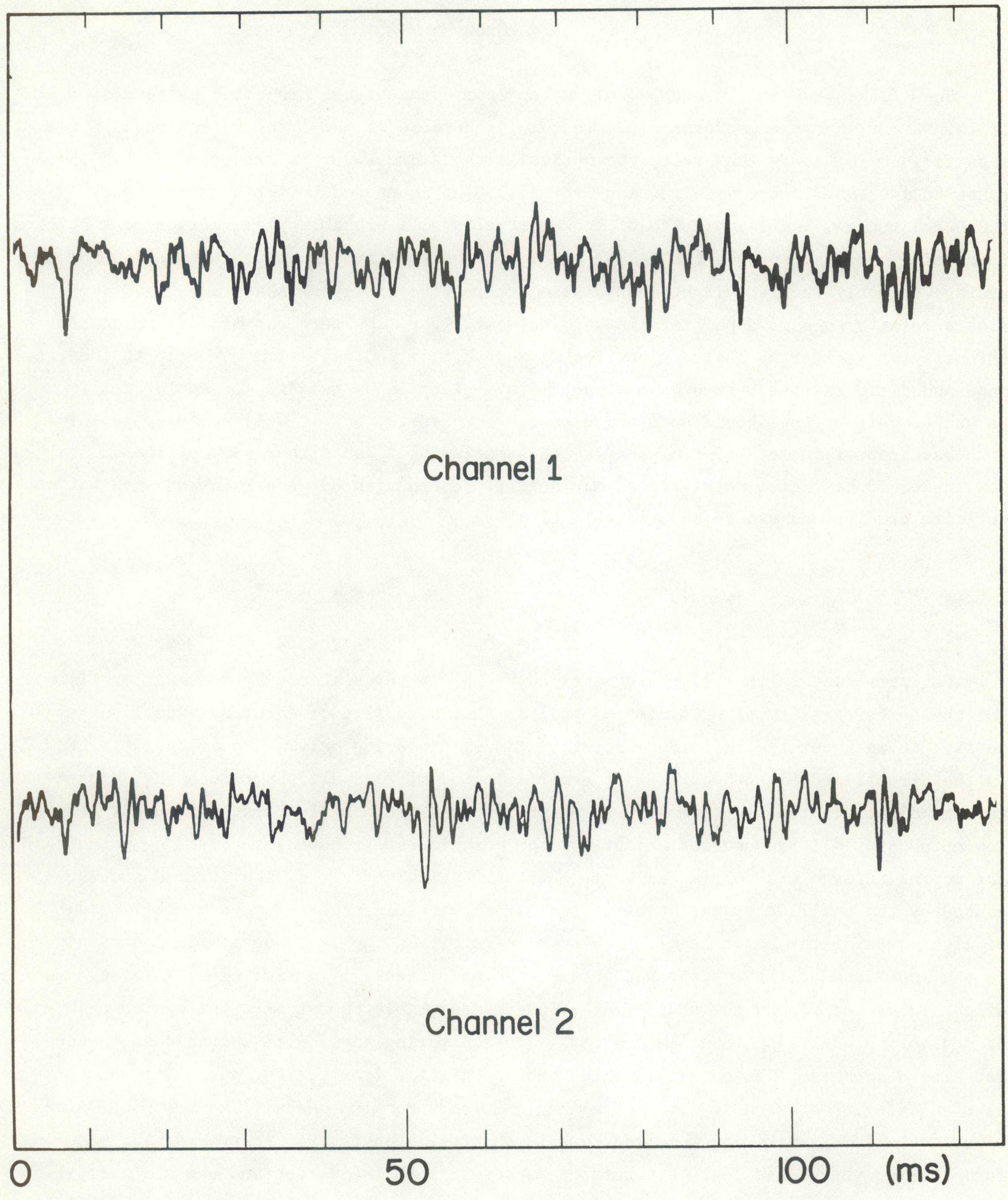


Figure 6. Upper and lower aperture scintillation signals during a rain shower.

3.4 Snow

Snow flakes falling through a collimated laser beam give a projected pattern similar to rain drops, but the patterns are more complex because of the irregular shapes. Since snow falls more slowly than rain, the optical signals are lower in frequency. This should cause an increase in the mid frequency range (500 Hz) compared to the high frequency (2000 Hz) range. The larger size of snow particles will probably yield larger peak heights than rain. Because most of the flakes are large and relatively opaque, attenuation of average directly received light should also occur. The irregular shape and density of the flakes results in some depolarization of incident light. Measurement of forward-scatter intensity vs scattering angle at horizontal and vertical polarization may help to identify snow and differentiate between snow types (i.e., sleet, snow pellets, graupel, etc.). Backscatter from snow should be intense enough to observe, but it will not vary rapidly with backscatter angle, being of nearly the same intensity on either side of the 42° rainbow angle. Backscatter observations may help to distinguish between rain and snow but no definite predictions can be made at this time.

3.5 Fog

Fog particles scatter light to make individual patterns according to equation (1), but the number density of particles as well as the large size of each individual pattern combine to wash out the individual scintillations, producing only attenuation of light in the directly received beam. Since general fog or mist conditions reduce the temperature gradients in the air, atmospheric scintillations are usually greatly reduced, giving low outputs at all frequencies except for the very lowest frequencies caused by patches of fog moving through the collimated beam. Another optical effect is the forward-scatter caused by the small water particles in fog. Each particle scatters a very small amount of light outside the laser beam. Each small particle in the laser beam will contribute to the amplitude of light scattered outside the beam, thus, if a sufficiently large number of particles are within the scattering volume a measurable amount of light can be observed at scattering angles up to a few degrees. The scattering angle will increase as the droplet size decreases. The manner in which the intensities from the fog particles add to give an integrated intensity at a given angle is very complex and will be best determined experimentally by measuring received forward scatter intensity vs. scattering angle during fog. During very dense fogs, attenuation may cause both the direct and the scattered light signals to be very weak, depending on the distance between the transmitter and the receiver. No depolarization effects are expected from fog at small scattering angles.

3.6 Dust

Dust particles exhibit optical properties similar to fog, except that the irregular shapes cause some depolarization of forward scattered light at scattering angles below 20°. Also, the distribution of particle size will not generally be the same as for fog, giving a different forward scatter intensity versus scatter angle "signature". Thus measurement of forward scatter intensity vs. scattering angle at horizontal and vertical polarization may help to identify dust. Separating the identities of dust and snow may require simultaneous observations of straight line attenuation and spectrum analysis at 500 and 2000 Hz. Simultaneous observation of forward-scatter versus angle at visible and infrared wavelengths may also be an important method of distinguishing dust from snow. Individual dust particle patterns in the direct optical beam should not cause observable scintillations, only a cloud of dust will be observed by the attenuation of light. This will further aid in separating snow from dust.

3.7 Smoke

Smoke particles will exhibit optical properties very similar to dust and will be difficult to distinguish from it. Experimental measurements may discover distinguishable forward scatter signatures for some smoke types, but, since no standard size, size distribution, or shape can be set, no general predictions can be made of what can be observed. Certainly, smoke should cause attenuation, forward scatter, and backscatter proportional to smoke density.

4. BASIC MEASUREMENTS

Seven basic measurements are made by the various detectors on the laser weather instrument. These measurements are:

1. Red upper beam detected light (labeled A).
2. Red lower beam detected signal (labeled B).
3. Infrared detected signal (labeled IR).
4. Red laser output (labeled I_o).
5. Red rainbow backscatter less than 42° (labeled C).
6. Red rainbow backscatter greater than 42° (labeled D).
7. Platform angular position (labeled θ).

5. ELECTRONIC DATA PROCESSING

The optical signals are processed by analog electronic circuitry into various information outputs, i.e., correlation, peak height, variance, etc. so that all signal outputs are low-frequency direct-current voltages that can be used as inputs to a chart recorder. Figure 7 is a block diagram of the electronic system. Figure 8 shows the central control panel layout, and Figures 9 through 24 show the electronic circuit diagrams for the system.

Line transmitters and receivers are used to transmit all signals from the receiver to the central control site. These circuits are needed because of the relatively long transmission lines existing between these two sites, with the accompanying chance for noise to be picked up in the transmission lines.

The IR signal is amplified with a narrow bandwidth 10 Hz filter-amplifier that selects only the IR laser signal, chopper-modulated at 10 Hz. The amplified 10 Hz signal is converted to a filtered-dc signal before going to the IR output BNC connector. The IR signal is used for attenuation measurements along a straight line or for IR forward scatter intensity vs. angle.

The red A and B signals are branched into three separate processing circuits. The first circuit, which uses only the B signal, is the peak height detector. This detector measures the maximum signal amplitude occurring over a few seconds of time and outputs a voltage proportional to that signal. This measurement is intended to help identify the size of any particles that obstruct the red laser beam, since larger particles will give larger peak amplitudes.

It is expected that only large changes in peak height over relatively short time periods will be significant in identifying weather particles (such as hail stones 1/4" or larger in diameter). This is because atmospheric turbulence can cause quite large changes in amplitude peaks during clear weather due to wind, ground heating, etc. The peak height output may turn out to be useful mainly for measuring atmospheric turbulence and correlating it with the rest of the measurements to make more distinctive weather identifications.

The second branch of red signal processing uses a set of logarithmic amplifiers to normalize the red A and B signals so that signal amplitudes are independent of transmitted power. After normalization, the A signal is delayed by an analog delay line that steps off 32 discrete delay times. The time interval between each delay step may be set at .25, .5, of 1 msec by the delay step size switch on the central control panel (see Figure 8, left side under vertical velocity controls.) The delayed A signal is multiplied by the undelayed B signal in a multiplier circuit; the product of the A and B signals is integrated and the integrated output is sampled at the end of each integration period, and held until the next

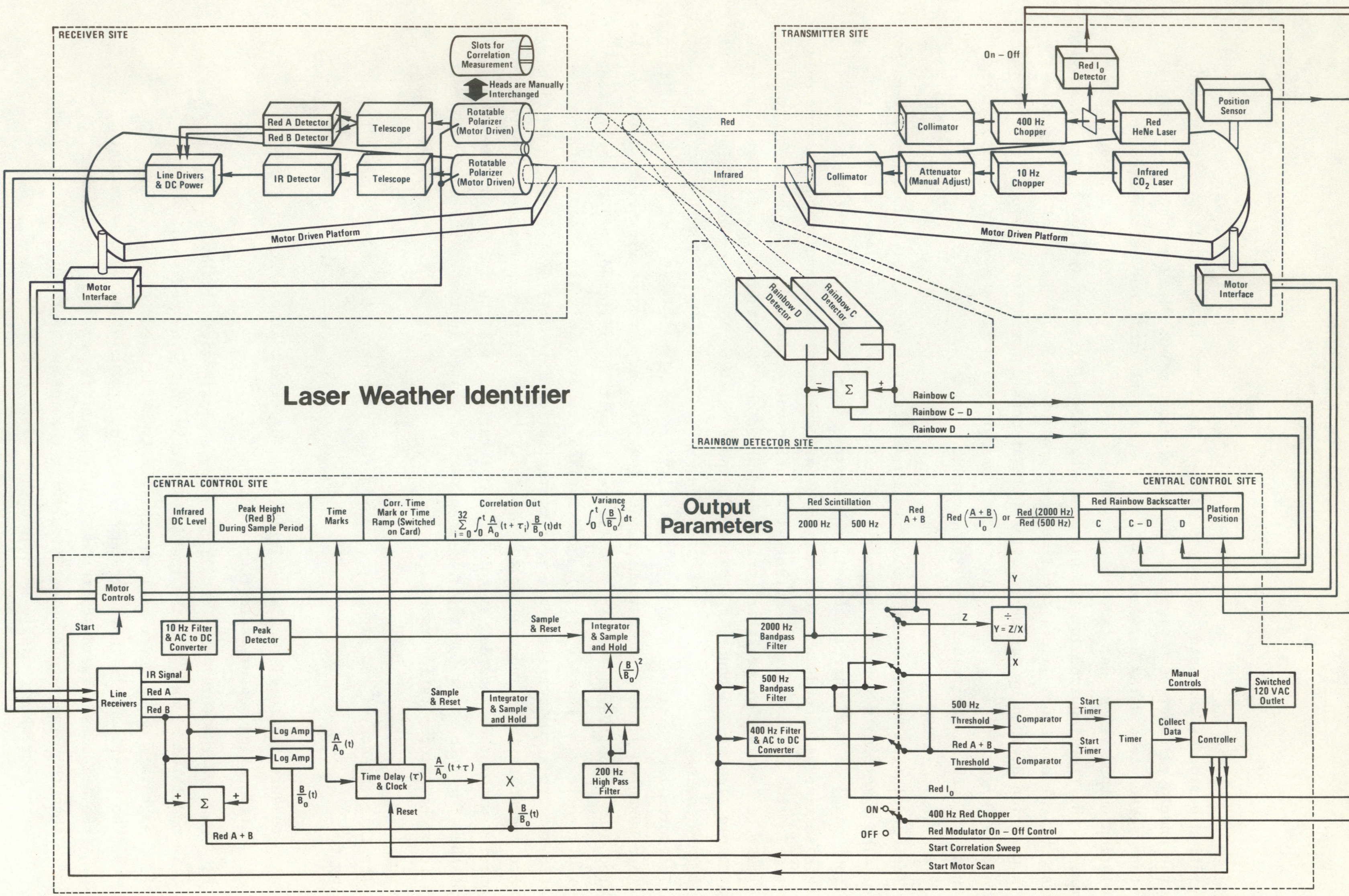


Figure 7. Overall block diagram of the Laser Weather Identifier.

integration period is complete. Thus the delayed upper red beam signals are correlated with the undelayed lower beam signals; the correlation output measures the correlation amplitude versus time delay between signals. When a peak amplitude is observed in the correlation output vs. signal time lag (τ) relationship, the time lag at the peak is a measure of the time required for the particles to fall a distance defined by the separation between optical detectors (i.e., the line aperture separation). Fall velocity is thus the slit separation divided by the correlation time at peak correlation. Associated with the A time delay circuitry is a time delay marker circuit which gives a voltage pulse at the beginning of each new correlation vs. time output.

The correlation amplitude output occurs in 32 separate steps between each start-marker pulse. The time length for each pulse is determined by the sample time switch setting (on front panel of the control cabinet, see Figure 5) and is typically set at 2 seconds. For this setting 64 seconds are required to obtain one complete correlation vs. time delay output. To read the correlation output with sufficient accuracy, the recorder chart drive speed must be somewhat faster than would be required for the other outputs. For example, for a sample time of 2 seconds, a chart drive speed of 10 or 15 cm per minute is desirable.

The normalized B signal from the log amplifier (now labeled B/B_o) is high pass filtered to remove unwanted signal fluctuations due to low frequency atmospheric scintillations. The filtered B/B_o signal is squared in a multiplier circuit and filtered to give the variance ($_o\int^t v^2 dt$) where v is the B/B_o signal) of received red signals. The signal variance is expected to give a qualitative measure of precipitation intensity (larger variance signal for more precipitation), and will be one of the weather identifiers that will be used in conjunction with other recorded signals. Signal variance will be larger for sleet or snow storms than for rain storms, but for a given particle size, increased variance will correspond to higher precipitation rate.

The third branch of red signal processing sums together the A and B signals for processing to:

a) measure the total received light (A+B) for direct line absorption or attenuation measurements (Red modulator off).

b) measure the total received light after amplification of the 400 Hz modulated signal when the red modulator is on. (The red modulator is turned on whenever maximum sensitivity is desired, such as when the instrument is in the azimuth-scan mode.) During azimuth scanning, the off-axis forward-scattered light intensities are very much weaker than the direct-beam intensities, with the intensity falling off rapidly with increasing forward scatter angle.

c) measure 500 Hz and 2000 Hz frequency spectra of the total received light. These signals are converted to dc voltages for slow, analog recording purposes. The 500 and 2000 Hz outputs are useful only when the red modulator is off. Additional circuitry divides the 2000 Hz dc output by the 500 Hz dc output to obtain the $\frac{2000\ \text{Hz}}{500\ \text{Hz}}$ ratio. When the modulator is turned on, the same circuitry divides the 400 Hz filter output by the laser monitor output I_o, to give the normalized received light output ($\frac{A+B}{I_o}$) for measurements of attenuation (when transmitter and receiver are in direct alignment) and for forward scatter intensity vs. scattering angle (when transmitter and receiver are being scanned in azimuth). Detector sensitivity must be adjusted to high, medium, or low settings corresponding to forward or scan operation modes (as well as for receiver aperture being used) so that the maximum gain is obtained without exceeding the maximum output of A+B, $\frac{A+B}{I_o}$, 500 Hz, or 2000 Hz circuits during weather identification measurements.

The rainbow detector signals C and D are measurements of backscattered light below and above the rainbow angle. These signals are processed at the rainbow receiver to detect only the 400 Hz narrow band frequency component whenever the modulator is on. The 400 Hz C and D signals are converted to dc signals prior to being transmitted to the main chassis and are independently available as C and D outputs. The difference in C and D outputs is measured at the rainbow receiver and transmitted to the main chassis as an independent output. Since backscatter of the laser light is strongest at or just below the rainbow angle of 42°, the difference C-D should be significant during a rain storm. However, very little difference should be observed for any other type of scattering particles. The amount of light backscattered from any of the weather particles is expected to be small and must be determined experimentally. During fog, dust, hail, or snow, backscattered light may be sufficient to be measured and may serve as an identifying characteristic when compared with other measurements such as 400 Hz, 2000 Hz, forward scatter and A+B.

The platform-position indicator voltage is a positive indication of the angular position of the transmitter platform. Since both the transmitter and the receiver platforms are moved through the same angle by identical stepping motors, the forward-scatter angle is double the angle measured at the transmitter. A potentiometer adjustment permits the calibration of output voltage with angle. The platform-position voltage is used with red $\frac{A+B}{I_o}$ signals and IR signals to measure scatter intensity versus scatter angle and to verify that the transmitter platform position motor is performing properly.

6. PREPARATION FOR MAKING LWI MEASUREMENTS

Prior to using the LWI instrument for making weather identification measurements, several preliminary adjustments must be made. In general, the nature of the adjustments will depend on just what type of weather is expected and on the type of data that have previously been collected for that type of weather. The LWI instrument has been made to accomodate a wide variety of measurements, but not all measurements can be made during a single storm. The adjustments are listed below according to where they are to be accomplished.

6.1 Transmitter and Receiver Alignment

6.1.1 IR Attenuator

When using the LWI in the straight-line mode the IR attenuator must be set on the maximum attenuation position, otherwise the IR detector will be damaged. This is accomplished by setting the attenuator scale to zero on the red scale mark. For the scan mode of operation, when maximum IR power is desired, the attenuator is set to minimum attenuation by setting the scale to 90 on the red scale mark.

6.1.2 Optical Platforms

Before making any adjustment of the optics, the transmitter and receiver optical mounts must be adjusted so that they are in a common plane, with the edges of the rotating platforms in line. To make this adjustment, first set the rotating platforms to the zero angle position. Next, sight along the surface of the rotating platform and line up the platform to be parallel with the receiver rotating platform (use the front platform adjusting jack). Finally, line up the edges of the rotating platforms by sliding the entire optical mounts on the optical mounting stands. These adjustments are slightly interacting; therefore, it is necessary to go through at least one iteration before alignment is complete.

6.1.3 Red Optical System

After the optical platforms are aligned, set the rotating platforms at the zero position to start the alignment of the red transmitter and receiver. Using the knurled adjusting screws holding the red collimator, adjust the transmitter pointing to bring the center of the red beam onto the center of the red receiver aperture. Adjustment of both front and rear adjusting screws on the collimator may be necessary to maintain uniform intensity in the laser beam. Next, adjust the knurled adjusting screws on the rear of the receiving telescope to image the laser light going into the two slits onto the upper and lower halves of the photodiode detectors. Using the dual optical alignment meters, adjust the horizontal aim until maximum light is received by either the upper or lower detector. Next adjust the vertical aim to image the upper slit on the lower detector and the lower slit on the upper detector. This is accomplished by observing the two meters while alternately blocking the upper and lower slits. Correct adjustment will result in both meters reading about half scale when neither slit is blocked, and either meter going to near zero when the corresponding slit is blocked. If either meter reads a significantly large value when the corresponding slit is blocked, it is an indication that one of the slits is imaged too near the center of the dual detector so that some light is received on the wrong detector half. Even during correct adjustment some light will "leak" into the wrong detector half, and the two meters may not read the same maximum when neither slit is blocked. This occurs whenever the laser beam is not perfectly symmetrical in intensity as it leaves the laser collimator.

6.1.4 Slit Aperture

The slit aperture is adjusted when the polarizer has been switched to the parallel position (using the switch on the central control panel). The apertures must be adjusted to horizontal by rotating the entire red receiving telescope tube.

6.1.5 Red Polarizer

The red polarizer is located just behind the slit aperture on the red receiving telescope. It must be rotated to receive minimum light when the polarizer has been motor driven to the perpendicular position. Adjustment is made by removing the slit aperture, loosening the two flat head screws that hold the polarizer in place, and rotating the polarizer to obtain the desired null. To rotate the polarizer use a sharp metal point, such as a needle, placed near the outside edge. When the polarizer is correctly positioned, tighten the holding screws to lock this position. Final very fine adjustment may be made by rotating the entire receiving telescope; however, only slight rotation is allowed, since this adjustment will also misalign the slit aperture.

6.1.6 IR Optical System

The IR transmitted beam is aligned after the red beam is aligned. While the red beam is still in alignment, adjust the IR transmitted beam pointing so that the beam is centered on the IR receiver. Use the knurled adjusting screws on the rear of the IR collimator to aim the beam. To locate the beam position use a laser power meter; start at the transmitter and "chase the beam" to the receiver end. When the beam is aimed into the IR receiving telescope, use the IR receiving system to complete the optimization of IR beam pointing. Using the rear knurled adjusting screws on the receiving telescope mount, optimize the pointing of the IR receiver until maximum IR signal is received. Then repeat the adjustment of the IR beam pointing to obtain a maximum of received IR signal.

6.1.7 IR Polarizer

The IR polarizer is located behind the IR receiving telescope in a motor driven mounting. Rotate the polarizer mount to the perpendicular position using the switch on the central control panel. Loosen the polarizer holder and rotate the polarizer until a minimum of IR signal is received when the platform is in the zero position. Tighten the polarizer mount to lock the position of the polarizer.

6.1.8 Alignment Telescopes

After both the red and the IR optical systems have been aligned, adjust the crosshairs in both transmitter and receiver alignment telescopes so that the center of the crosshairs intersect the image of the opposing alignment telescope on the other platform. This adjustment is made while the rotating platforms are in the zero-start position, (transmitted and received beams are in straight alignment). The alignment telescopes may be used for any future optical alignment checks, such as when the path length is changed, or when either transmitter or receiver are moved for repairs.

6.1.9 Red Detector Sensitivity

The red detector sensitivity must be set for maximum, medium, or minimum sensitivity depending on the mode of operation anticipated. For straight line measurements with full aperture, the sensitivity is set at minimum because of the large amount of light being received. For straight line measurements with dual slit apertures, medium sensitivity setting is required, because only a moderate amount of light is received at the detector. For full aperture scan measurements, maximum sensitivity is required because of the very small amount of light received at the detector. The detector sensitivity is set by the three-position switch on the rear of the red detector, with the sensitivities in the clockwise direction being minimum, medium, and maximum respectively.

6.1.10 Red Slit Installation and Removal

The full aperture for straight line attenuation measurements is achieved by removing the slit apertures from the red receiver. Loosen the wing nut at the bottom of the slit-aperture disc at the receiver telescope entrance and pull the disc off the polarizer holder. Install the disc by the reverse procedure. The slit spacing is established by masking off the slits not being used as receiving apertures. For example, to get a 2 cm slit spacing, the middle, and two outside slits are covered with black electrical tape. Thus the slit spacing is determined by which slits are being covered. A 3 cm slit spacing will normally be used for 50 and 100 meter paths with narrower spacing used for shorter paths and wider spacing used for longer paths.

6.1.11 Scan Limit Switches

The scan limit switches are the micro-switches on the transmitter and receiver platforms that open whenever the rotating platforms reach the end of their travel. The limit switches are adjusted by loosening the screws that attach them to the base platforms. These switches are pre-set during the initial instrument installation so that transmitter and receiver rotating platforms scan through the same angle before the switches are actuated. During forward-scatter measurements, it may be desirable to place shims on the rotating platforms where the platforms make contact with the switches. On the transmitter end, the shim should be thick enough to offset the pointing of the red beam at least two inches at the receiver end. This is observed at the receiver end by measuring the distance between the center of the red beam and the center of the red receiver. The shim placed on the receiver platform should be 1/2 the thickness of the transmitter shim because of the shorter distance from the axis of rotation to the limit switch. To prevent accidental damage to the IR receiver, it is desirable to place an opaque target in such a position as to block the IR beam during straight alignment. The target is removed whenever IR straight line transmittance measurements are being made.

6.2 Rainbow Detector Alignment

6.2.1 Aiming

The rainbow detector is aimed so that the two received beams intersect the red transmitted beam just above and below the rainbow angle of 42°. To aim the detector, start by replacing the detector "can" with the duplicate can assembly which contains two holes covered by translucent scotch tape. The objective lens of the rainbow receiver will cast an image of the field of view onto the tape, so that the aiming can be observed by viewing the images on the tape. Have an assistant move the white target along the red laser beam while the images are being viewed at the back of the detector. Bring the vertical pointing into alignment so that the target image may be seen in the center of the two holes alternately as the target is moved along the transmitted path. Then aim the detector horizontally so that the 42° intersection point lies between the two holes. Replace the alignment can with the detector can and fine tune the rainbow receiver using the dc signals received when the white target backscatters light into the receiver, remembering that when the target is at the 42° point, a null should occur on both detectors.

6.2.2 Rainbow Detector Sensitivity

The rainbow detector sensitivity is controlled by a three-position switch located on the back of the detector can. The sensitivity should be set at the maximum or clockwise position for all weather conditions.

6.3 Central Control Chassis

6.3.1 Vertical Fall Velocity Adjustments

These adjustments are located in the upper left corner of the control panel and consist of the sample time, output gain and the input gain potentiometers,, the reset button, the sample time switch, the delay-step-size switch, the 4 BNC output jacks, and the record-playback switch. These controls and jacks are identified on Figure 8.

Adjustment of these controls a) sets the desired gain for signals being processed by the time-lag correlator, b) determines the step size for the correlator, c) determines the averaging time for each step of the correlation, d) selects the use of the A/A_o and B/B_o BNC jacks, and e) starts the correlation delay to minimum delay for starting a recording sequence.

The input gain potentiometer is adjusted to obtain ± 10 volt peak amplitude signals going to the correlation multiplier as observed at the A/A_o and B/B_o BNC output jacks. Adjustment is necessary to compensate for differences in received signal caused by differing path lengths, different particle sizes, and different precipitation intensities. In the usual case, the particle sizes are somewhat predictable so the input gain can be set in advance; in other cases the input gain will have to be re-adjusted during a storm in order to be sure that the multiplier will not be over-driven by signal amplitudes which are too high.

The desired delay range for the correlator is determined by the range of fall velocities of precipitating particles. For example, rain drops fall at velocities ranging from 4 to 9 meters per second depending on drop diameter. The range in time for these drops to fall past 2 cm spaced slits is 5 ms to 2.2 ms respectively. Here a 0 to 8 ms range of correlation measurement would be appropriate. This corresponds to using a step size of 0.25 ms. For a sleet or snow storm a range of 16 or 32 ms would be more appropriate since the particles are falling more slowly. The correct delay setting for any expected weather will have to be determined by experience, so that for first measurements the delay step size may be adjusted during a storm.

The averaging time for each step of delay is determined by the amount of averaging time desired for correlation measurements. This is determined by the path length being used for measurements, the amount of turbulence in the atmosphere, the amount of precipitation, and the type of precipitation particles. As in the previous case, this adjustment will have to be determined from experience, but a .5 second averaging time will be a good starting point for most cases.

The record-playback switch controls whether the A/A_o and B/B_o jacks are used for tape recorder outputs or for tape recorder inputs. When a tape recorder is not being used, the switch is set in the recording position, since in this position signals are connected through to the rest of the time-lag correlator electronics. The playback switch position is used only when it is desired to process previously recorded data for time-lag correlation, and variance measurements.

The reset pushbutton is used to start the time-lag correlator at minimum time delay during any data-recording sequence.

6.3.2 Variance Gain Adjustment

The variance is the average of the signals above 200 Hz after they have been "squared" in a multiplier circuit. The variance-gain adjustment controls the maximum output of the variance circuit. It must be set so that the variance output does not exceed 10 volts. Since the variance will change during a storm, as precipitation changes it should generally be set for a nominal output, say 5 volts, during fairly heavy precipitation. As experience is gained in recording data, the variance gain setting can be better predicted for any expected weather.

6.3.3 Red Modulation Control

The red modulator should be turned on whenever the received red light is very weak. The light received by the red rainbow backscatter detectors is expected to be weak at all times so that the modulator must be on whenever it is desired to use the C, C-D, or D signals. The light received by the red A and B detectors is weak during very heavy precipitation for straight line operation, and for all forward scatter measurements during the scan mode of operation. Thus, if the A+B signal is very small, increased sensitivity can be obtained by switching on the red modulator. Since the 2000 Hz and 500 Hz signals are useful only when strong red signals are available, they are not used when the red modulator is on. The circuit which normally divides the 2000 Hz by the 500 Hz signal is used for dividing the A+B 400 Hz signal by the I_o reference signal when the red modulator is on. Note that when the modulator is on, only red A+B transmittance can be measured in the "straight on" alignment mode. All other signals are invalid.

6.3.4 A+B Gain Adjustment

The red A+B gain step switch sets the gain of the red A+B summing amplifier. This gain control is needed to increase the gain of the A+B signal going to the 2000 Hz, 500 Hz, and 400 Hz amplifiers, and of the A+B output as increased attenuation weakens the red signal. The correct gain setting for a particular storm must be determined by trial and error until some experience is gained in using the LWI instrument.

6.3.5 Automatic Turn-on Operation

The automatic turn-on switch should be off whenever an operator is present to control the LWI instrument. However, if it is desired to have the instrument on standby operation so that data recording begins automatically at the onset of precipitation or the occurrence of fog, the switch may be placed in the "on" position. Before data recording can be made automatically, the instrument adjustments must be preset for the type or mode of measurements desired. When the automatic turn-on switch is in the "on" position, the comparator circuits are put into operation (see Figure 7) to sense the conditions for automatic turn-on. Only one of the comparator circuits is in operation at any given time. When the red modulator switch is on, only the bottom comparator is used. This comparator causes power to be switched onto the automatic recording power outlet whenever the red A+B signal falls below a preselected level. Thus, whenever fog, rain, snow, etc cause sufficient attenuation, power is supplied to the recording system and to the IR laser, and IR laser water cooler. Recording is thereby started in the absence of an operator to record that data for which the instrument has been preset.

When the red modulator is off, only the upper comparator is in operation. This comparator monitors the 500 Hz output and turns on the automatic power system whenever the precipitation causes sufficient 500 Hz signal to exceed the preset turn on level of the comparator. The comparator reference level is set high enough so that atmospheric scintillations will not be "seen", but signals from light rain or snow will be "seen".

Further options for use of automatic scan have been built into the instrument, but can not be used until some changes are made in the instrument electronics.

6.3.6 Polarization Control

The polarization control switch is used to control the position of the polarizers on the red and infrared receivers. These polarizers can be preset in either vertical polarization, horizontal polarization, or automatically alternating vertical and horizontal polarization. In the automatic mode, the polarization is tied to the platform position control so that when the platforms for transmitter and receiver are scanning outward, the received polarization is vertical. When these platforms are scanning back, the received polarization is horizontal. Thus, the forward-scatter depolarization can be observed by comparing the received signals (A+B and IR) for outward and inward scans.

6.3.7 Platform-scan Adjustments

The platform-scan adjustments are made with the controls on the right side in Figure 8. These controls determine the maximum angle of platform scan, the angular movement during each scan step, the length of time allowed for optical measurement at each scan step, the starting time of a scan cycle, and whether single or continuous scan measurements are made. Additional controls allow the scan to be manually set at start or end positions, or allow the scan to be stopped or "frozen" in any position and to begin again at the same point in the scan cycle.

The maximum angle of platform scan is determined by the settings of the three end-position switches. The numbered switch settings correspond to the number of steps the stepper motors take to the end of a scan. Each motor step gives a platform rotation of 0.0231 degrees, so that a setting of, say, 500 would give a maximum rotation of 11.55 degrees.

The angular movement for each scan step is determined by the three step-size switches. The numbered switch settings correspond to the number of steps the stepper motors take between each scan measurement. The angular rotation for each digit of switch movement is the same as for the end-position switch. Thus a switch setting of 42 will give scan steps of 0.97 degrees.

The length of time allowed for each optical measurement between scan steps is set by the sample-time control. The length of time desired for each step will normally be one or two seconds, but cases may arise in which longer or shorter times are desired, such as when measurements are very noisy or when special measurement techniques are employed to obtain more sensitivity.

The starting time for a scan or series of scans begins when the begin-cycle pushbutton is pushed. Either a single or continuous scan may be made depending on the position of the sweep switch to the left of the pushbutton. A scan may be stopped at any point in the scan cycle by using the instant-stop switch to the right of the pushbutton. When in the "freeze" position, this switch "freezes" the platform movement. When the switch is returned to the "unfreeze" position the platform continues its rotation at the point where it left off.

The platforms may be manually positioned at the start or end positions by using the platform-control switch in the upper right hand corner of the control panel. This switch is used primarily during initial instrument alignment and during alignment checks. It may also be used to make continuous measurements at one angle. In this case the end position switch is set for the desired measurement angle.

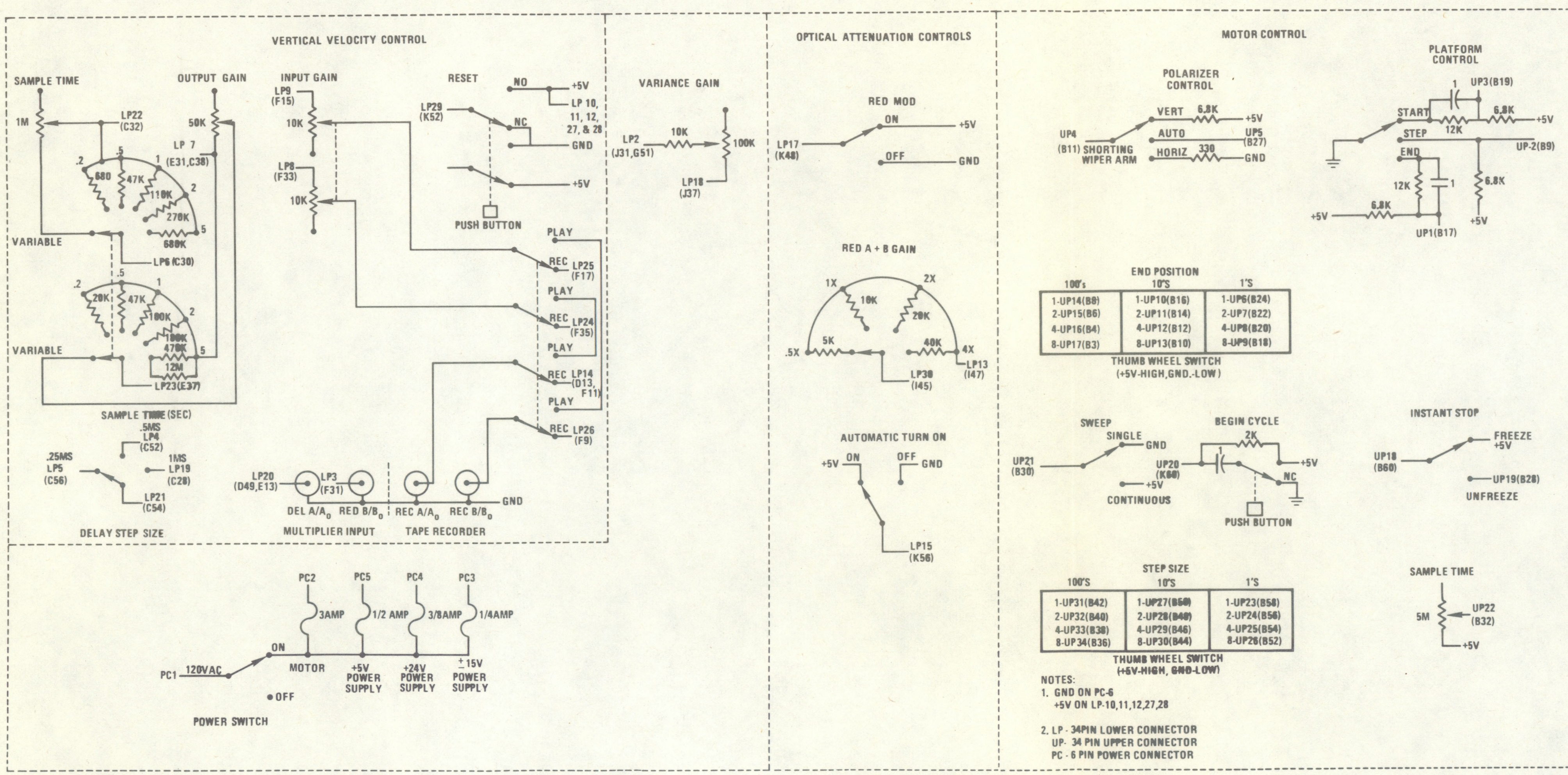
7. BIBLIOGRAPHY

1. "A Theoretical Analysis of the Information Content of Lidar Atmospheric Returns", V. E. Derr, M. J. Post, R. L. Schwiesow, R. F. Calfee, and G. T. McNice. NOAA Tech. Report, ERL 296 #PL 29, Nov. 1974.

2. "Measurement of Rain Parameters by Optical Scintillation", Ting-i Wang, G. Lerfald, R. S. Lawrence, and S. F. Clifford, "to appear in Vol. 16, August issue of Applied Optics".

8. ELECTRONIC CIRCUIT DIAGRAMS

The following figures are the schematic diagrams for all of the electronic circuits in the Laser Weather Identifier. The circuits, placed in order of their chassis location (where applicable) include the following:



NOTE:
1. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE MARKED

Figure 8. Front Control Panel.

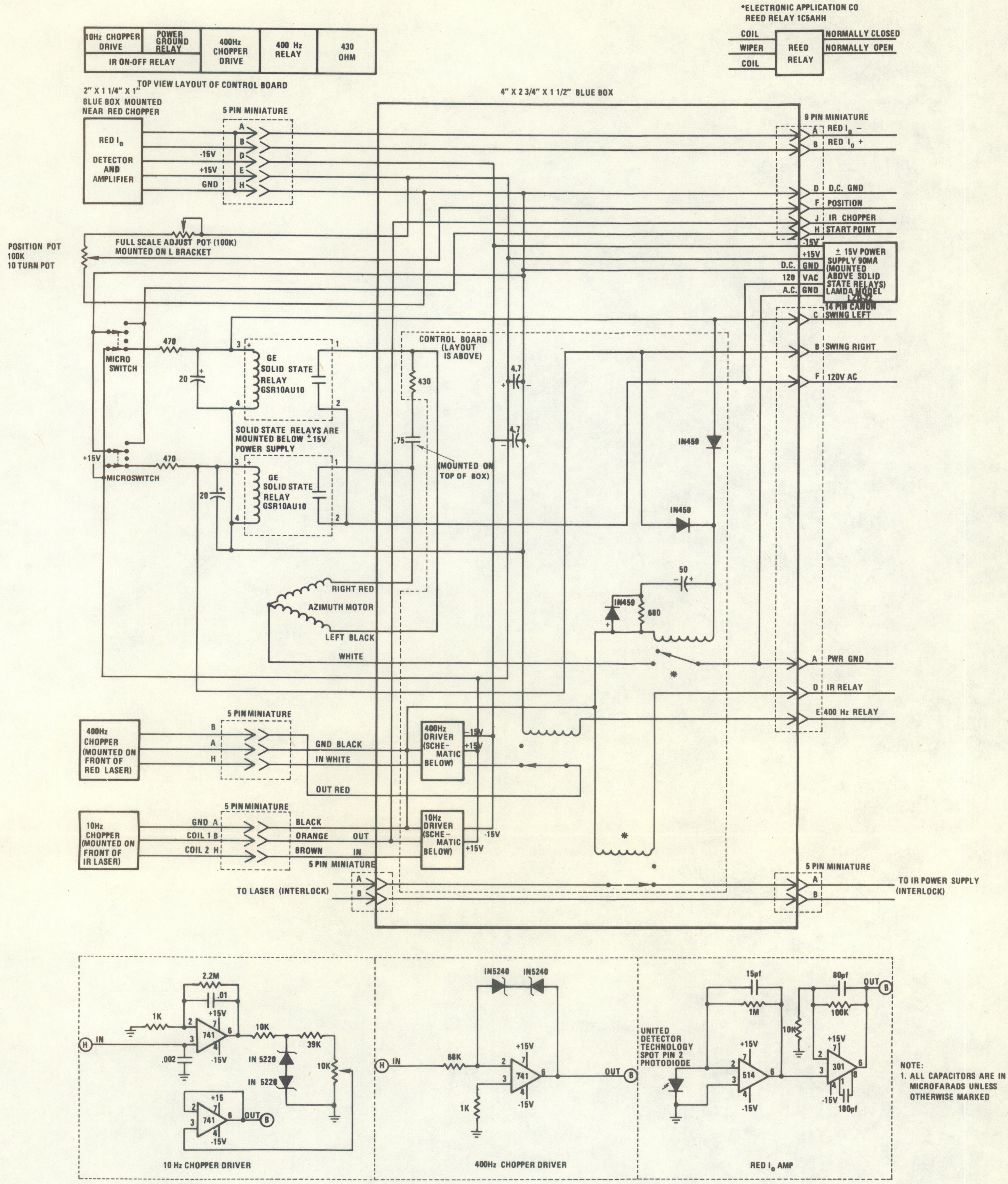


Figure 9. Transmitter Chassis.

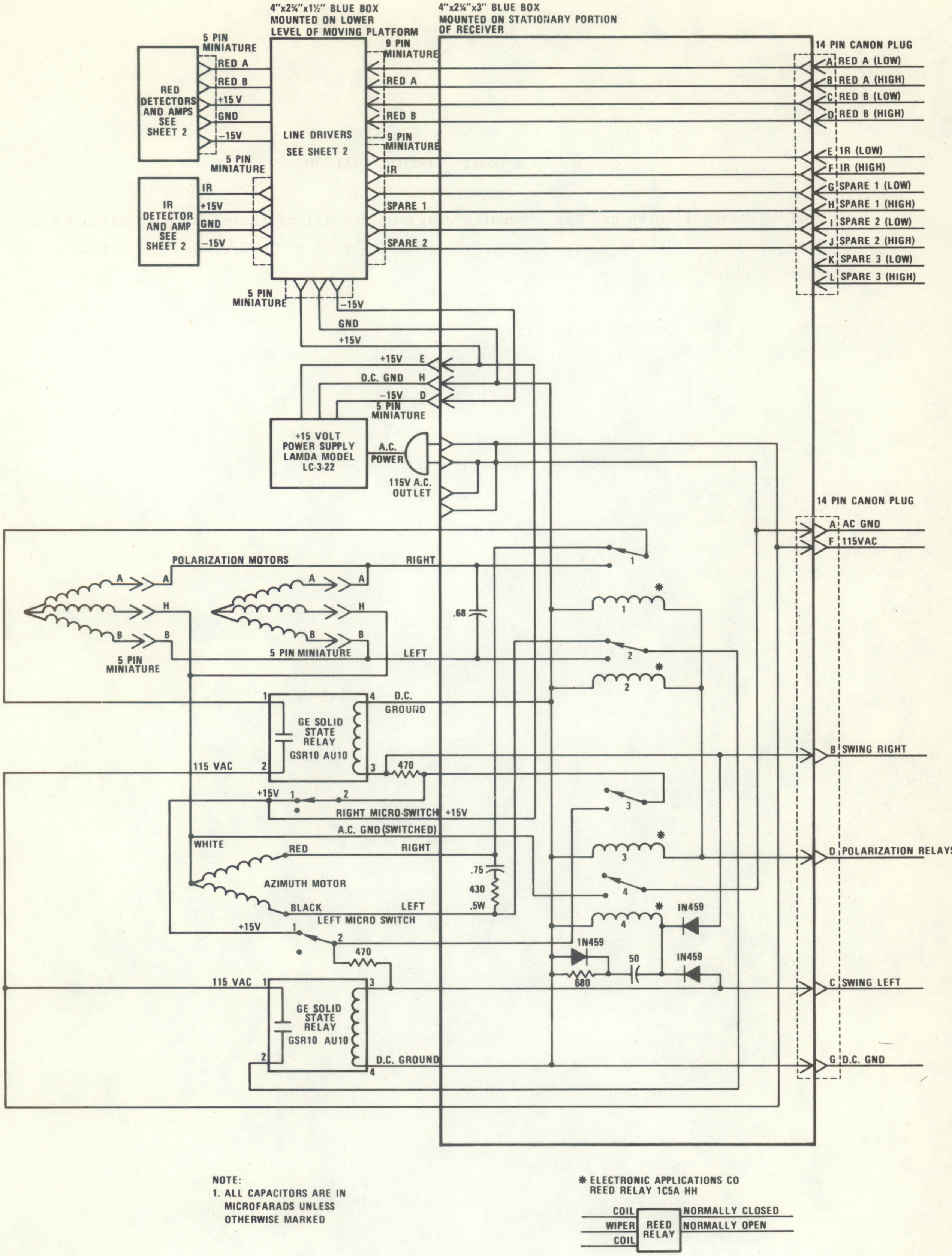
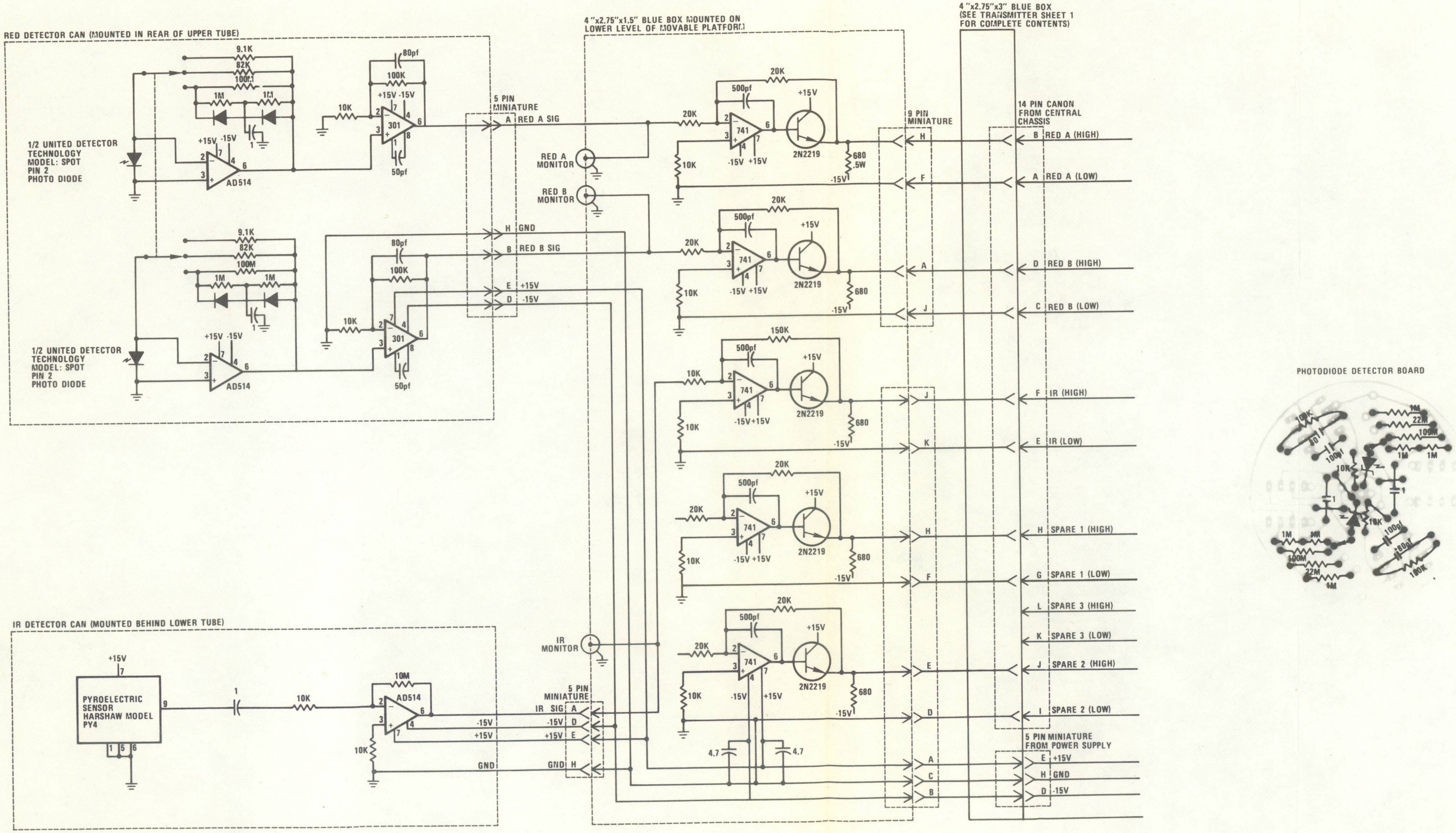
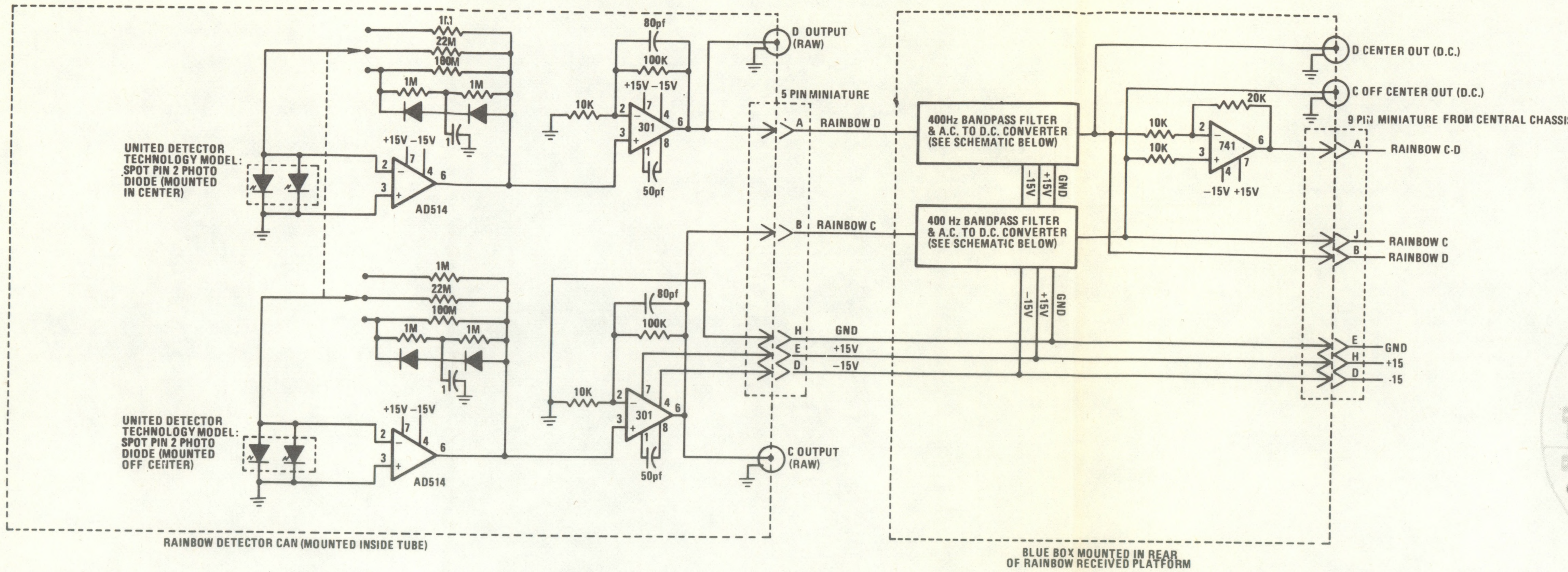


Figure 10. Receiver Chassis: Sheet 1.

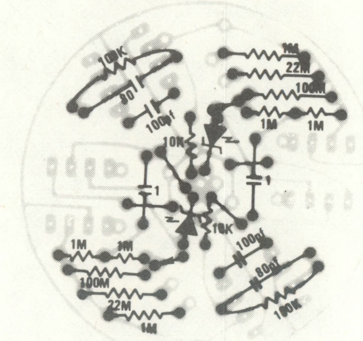


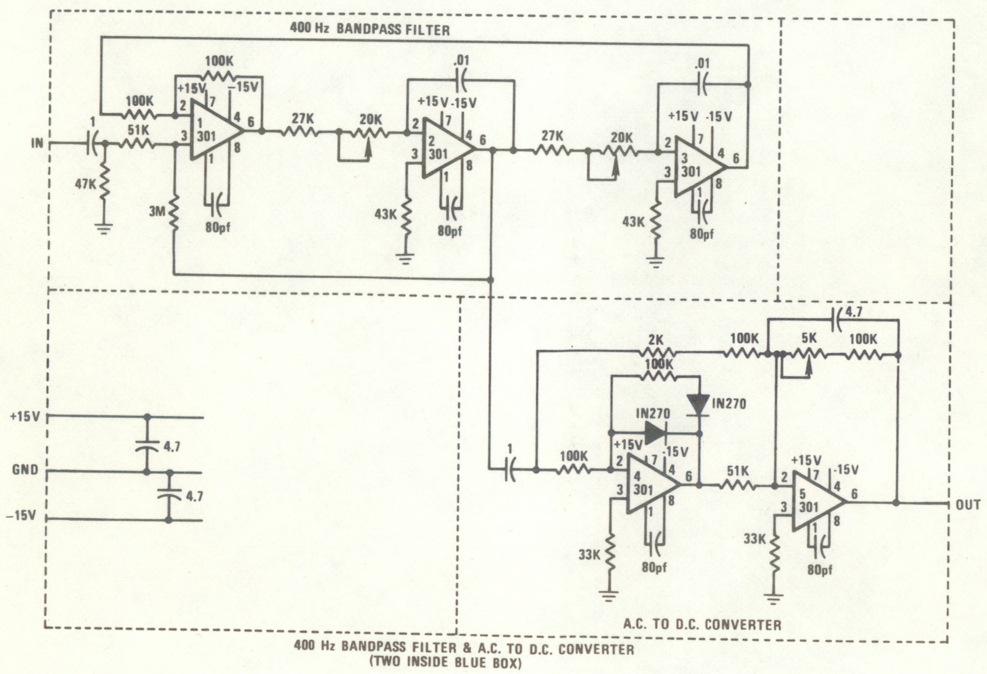
NOTE:
1. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE MARKED

Figure 11. Receiver Chassis: Sheet 2.



PHOTODIODE DETECTOR BOARD





NOTE:
1. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE MARKED

400 Hz BANDPASS FILTER
COMPONENT SIDE

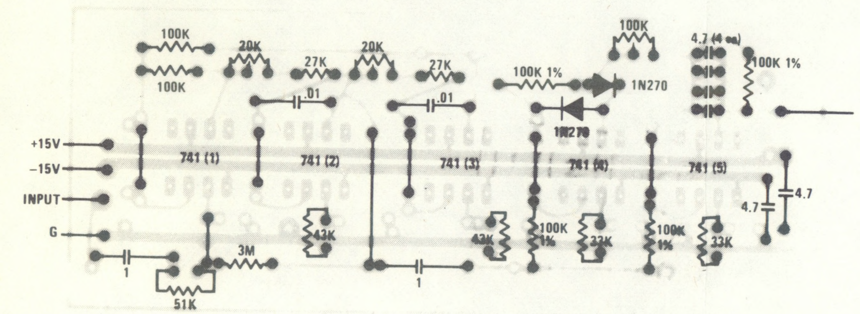


Figure 12. Rainbow Receiver Electronics.

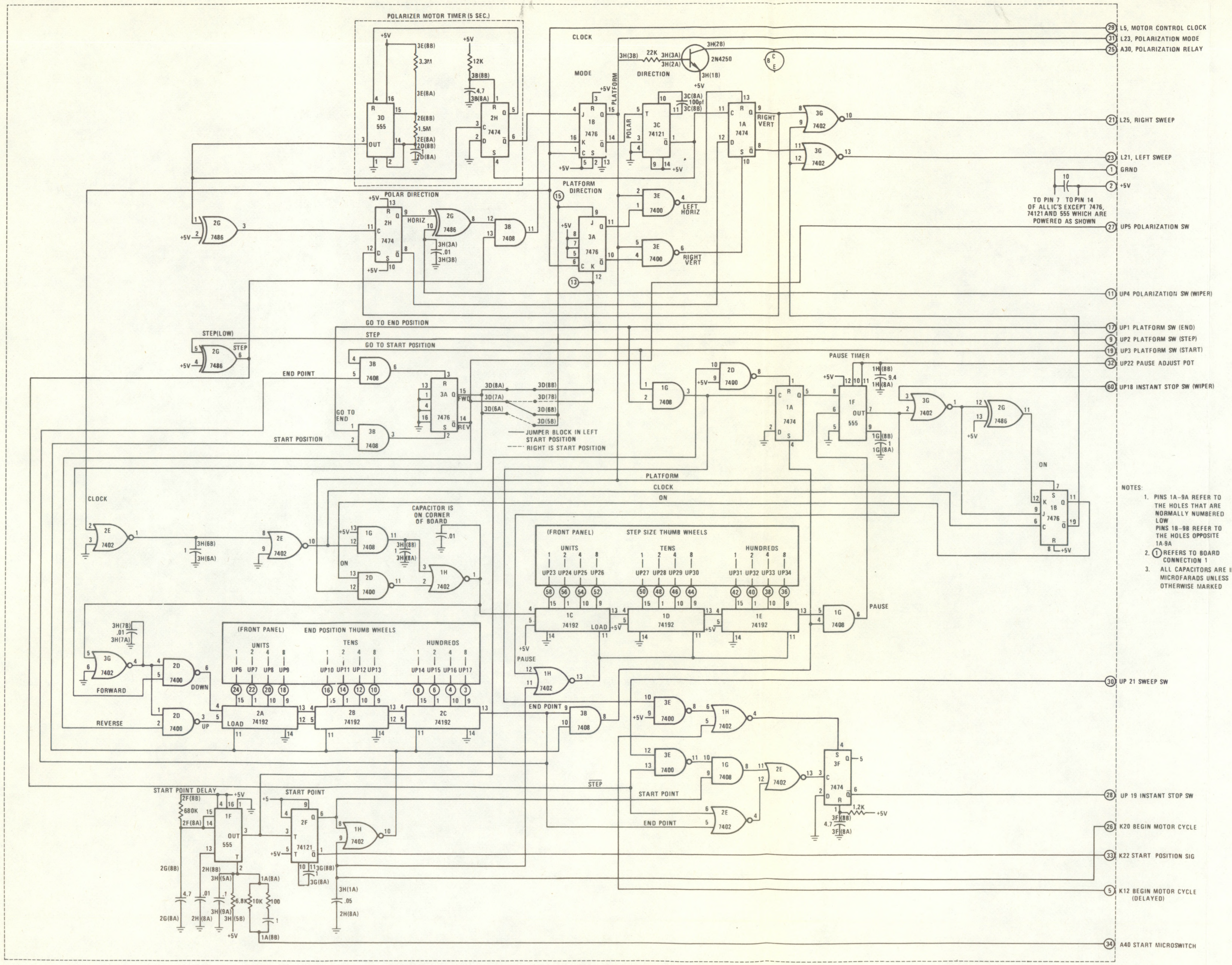


Figure 13. Motor Control Board: Slot B.

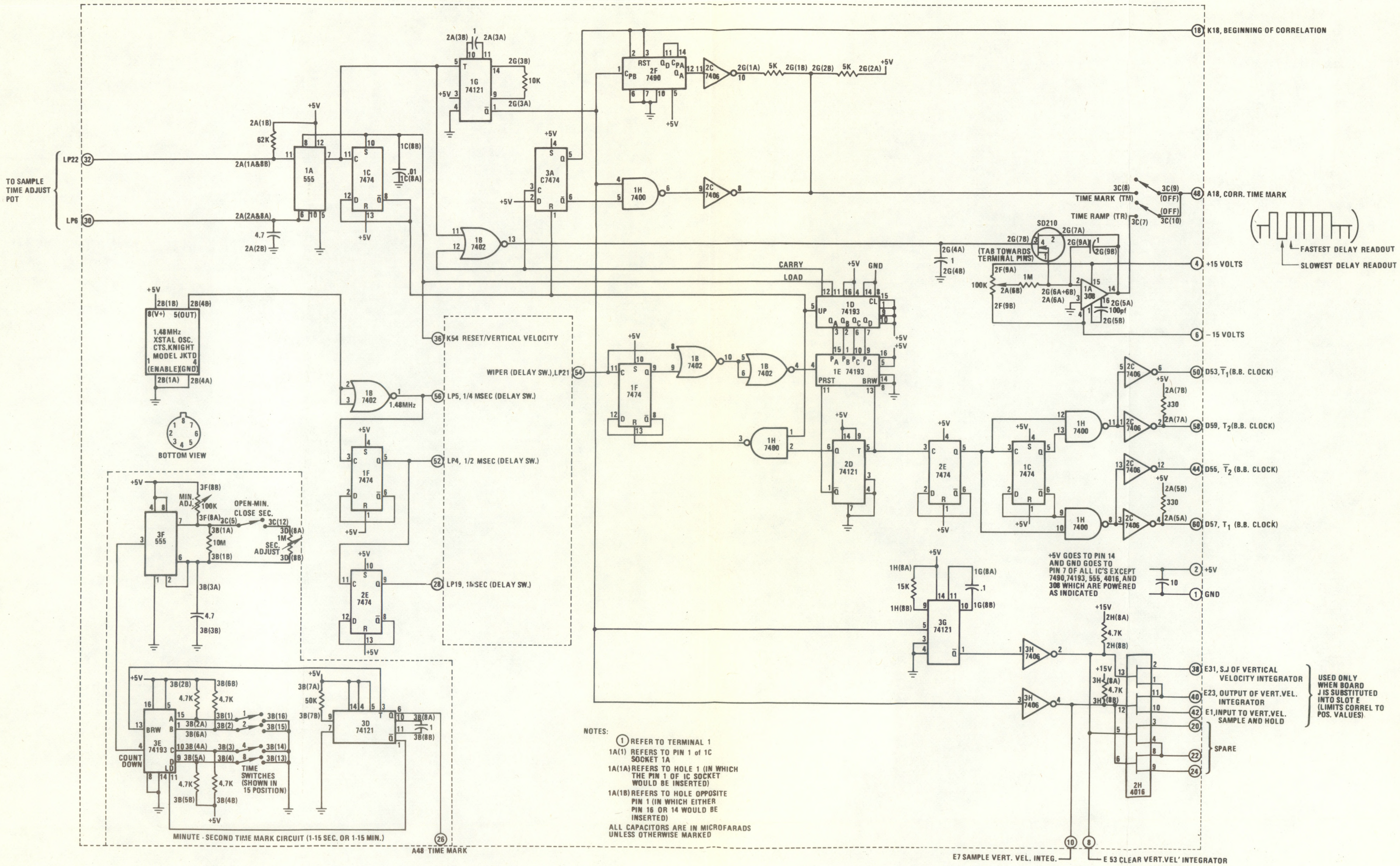


Figure 14. Bucket Brigade Clock and Time Marker: Slot C.

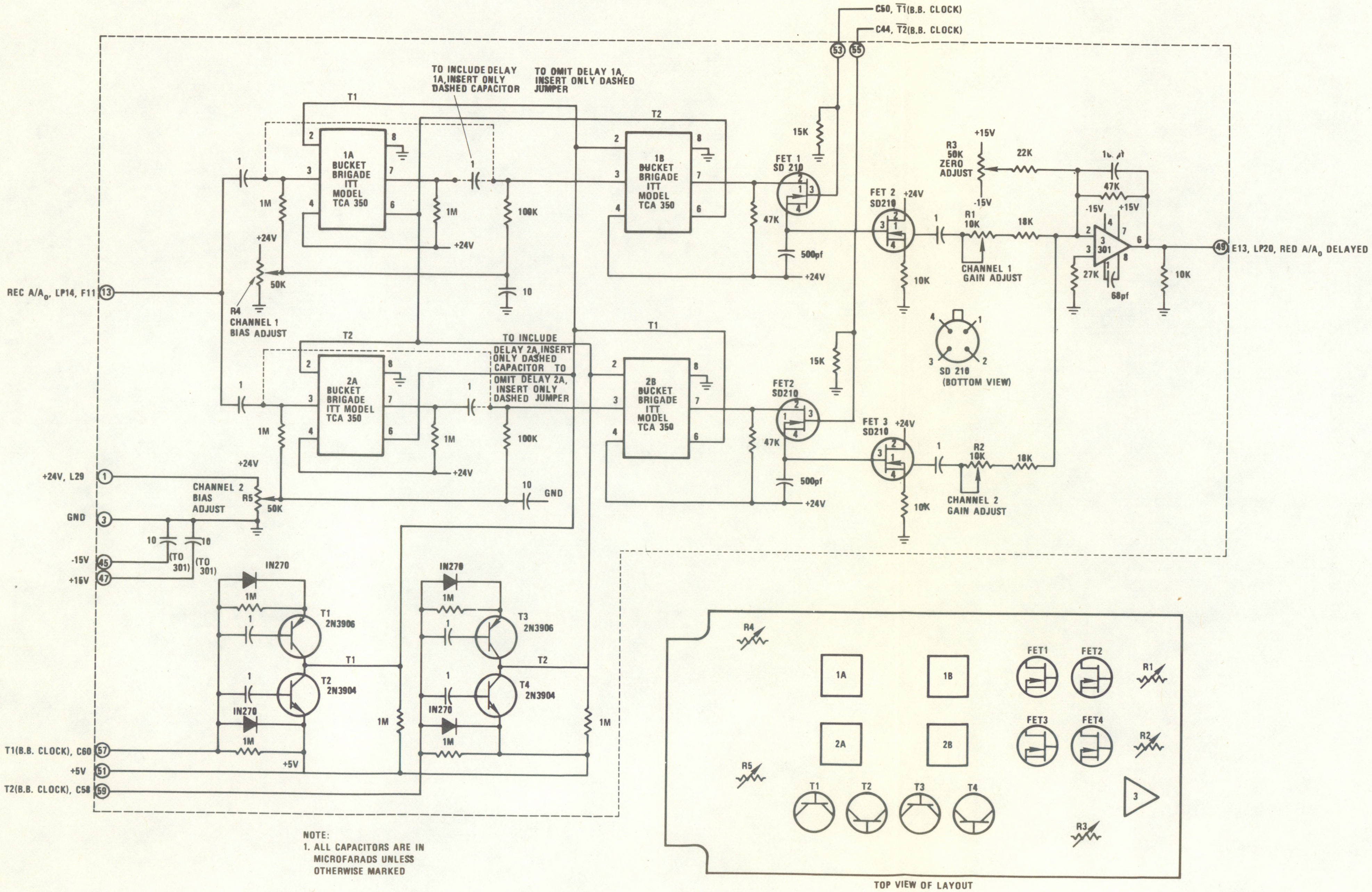
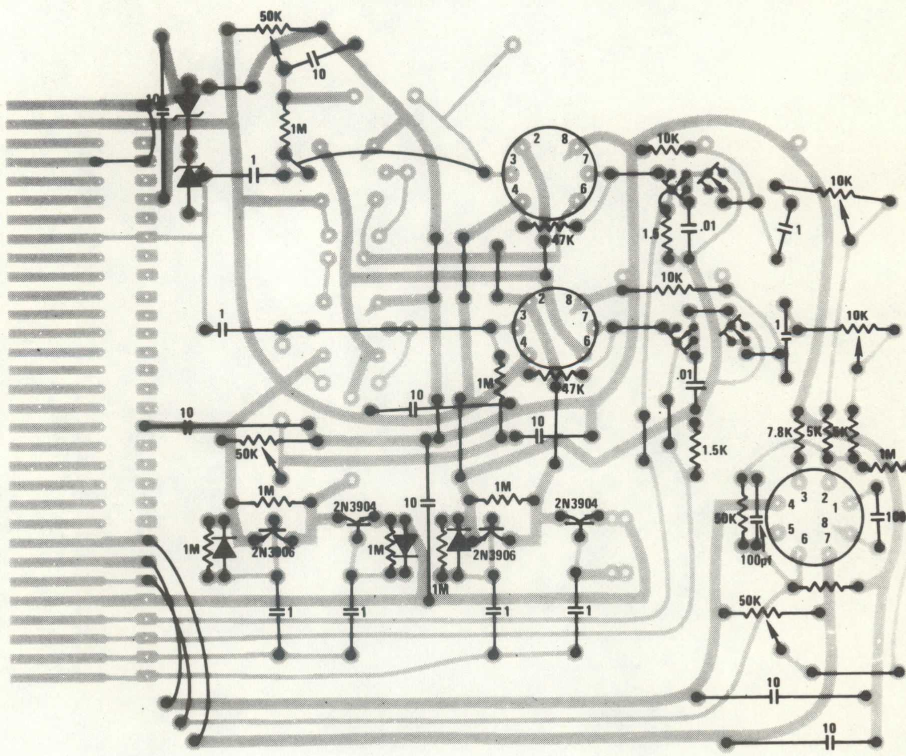


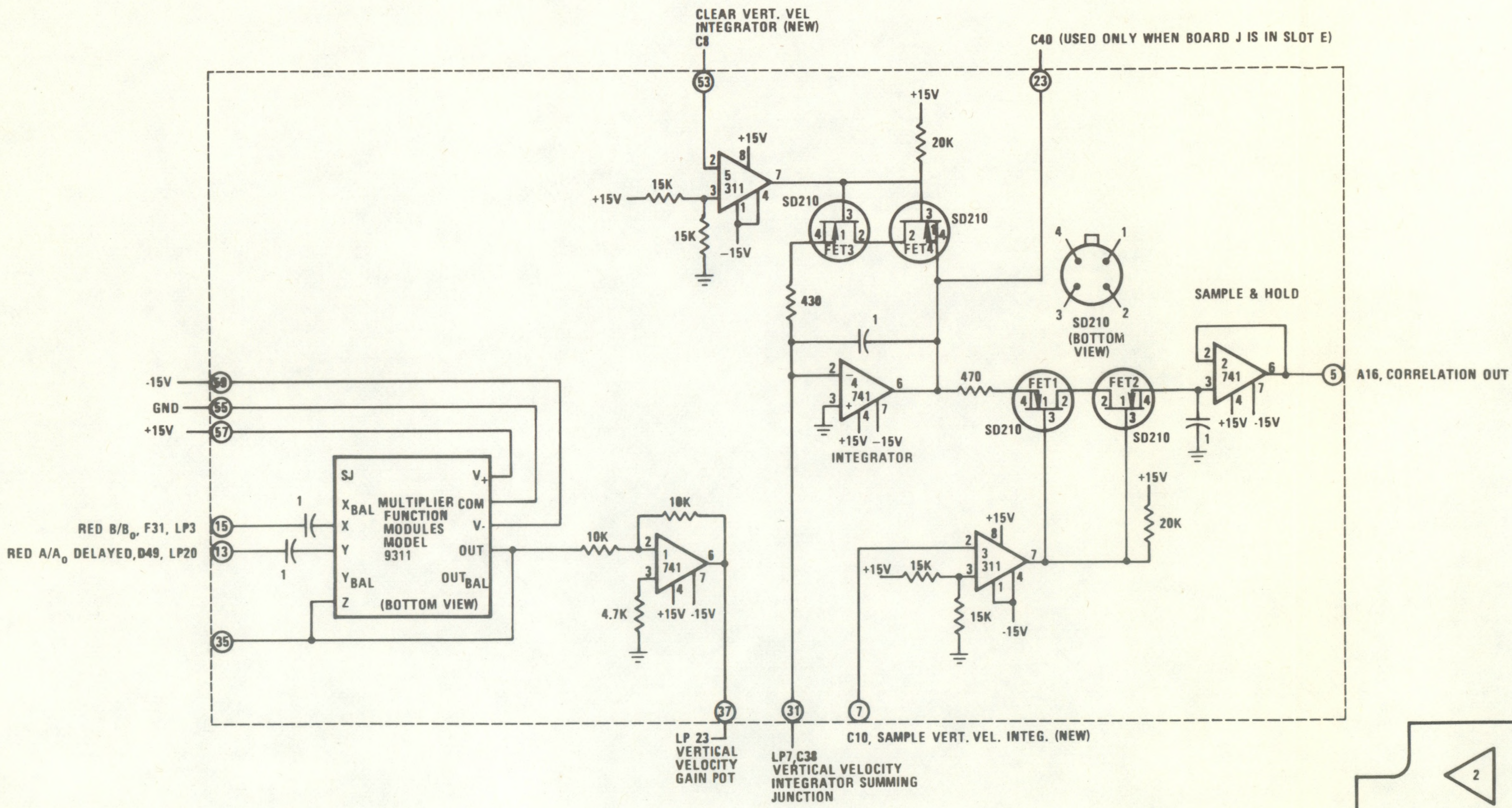
Figure 15. Bucket Brigade Delay Line: Slot D - Sheet 1.

ANALOG DELAY LINE, DUAL PHASE CLOCK AND ADDER CIRCUIT

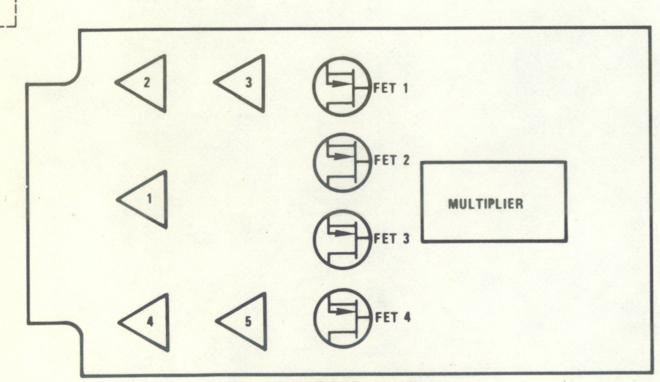


NOTE: ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE MARKED

Figure 16. Bucket Brigade Delay line: Slot D - Sheet 2.

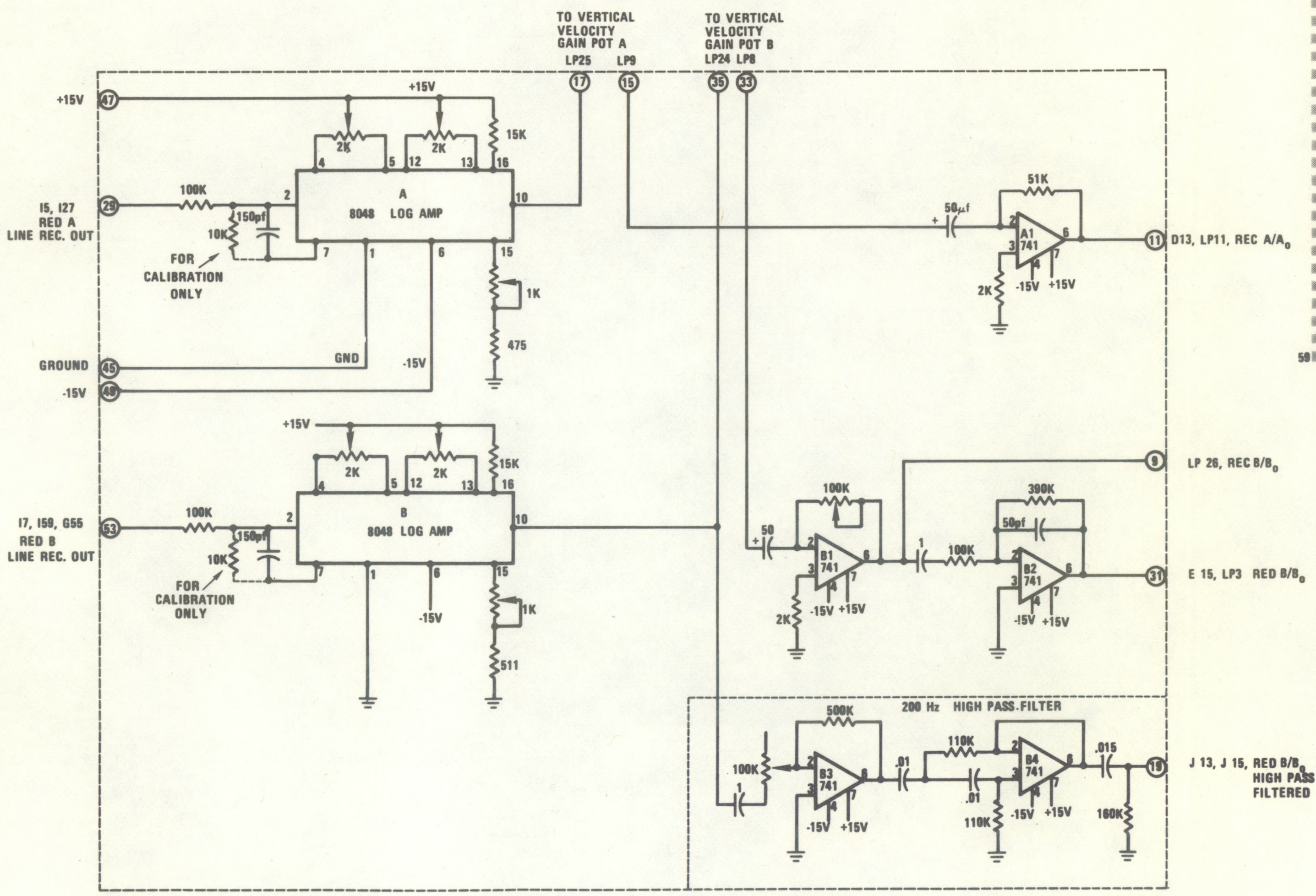


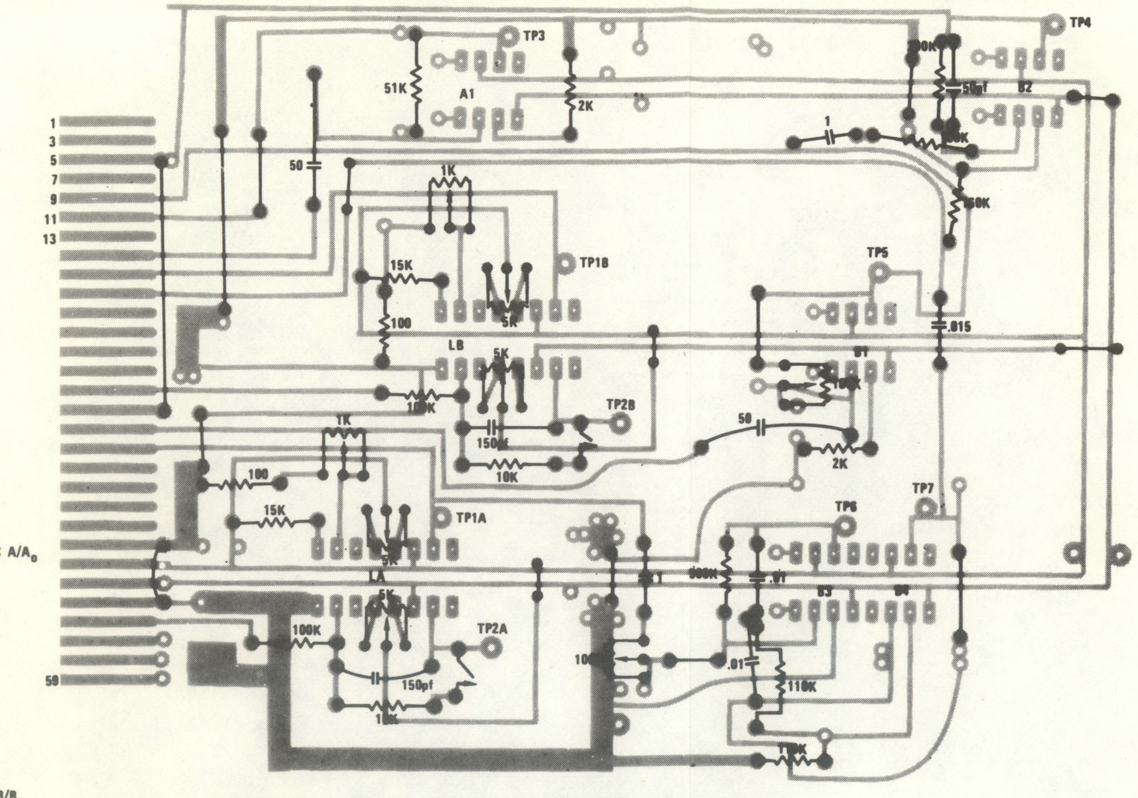
NOTE:
1. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE MARKED

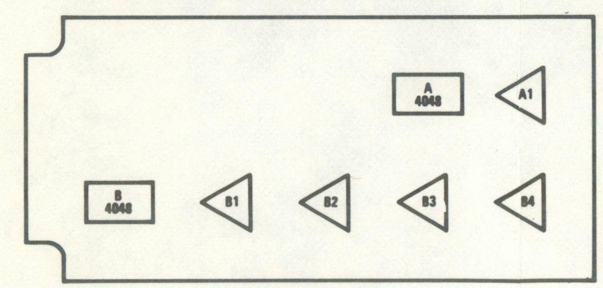


TOP VIEW OF LAYOUT

Figure 17. Vertical Velocity Correlator Multiplier, Integrator, & Sample and Hold: Slot E.







TOP VIEW OF LAYOUT

NOTE:-
1. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE MARKED

Figure 18. Log Amplifier Card Sheet 1: Slot F.

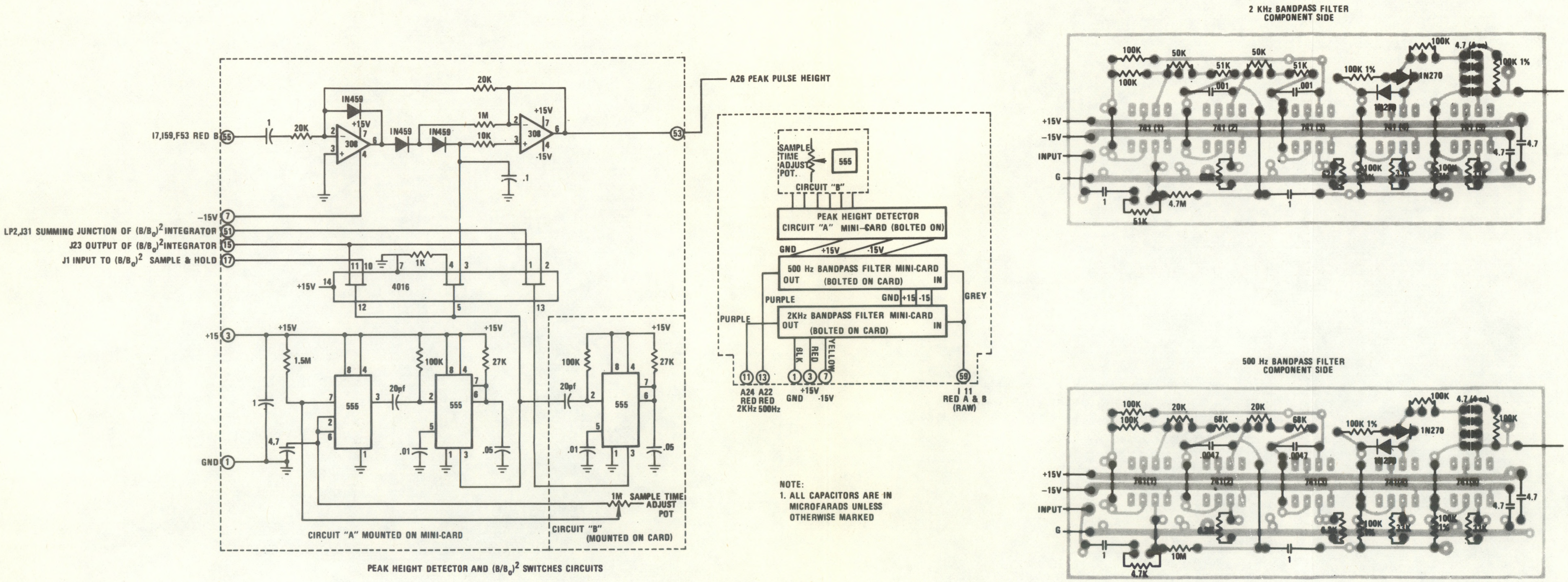
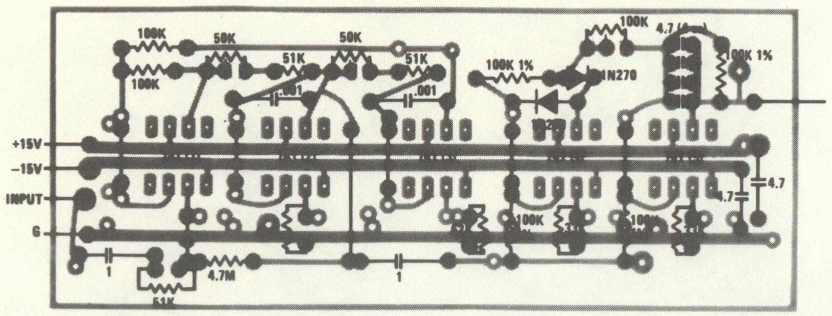
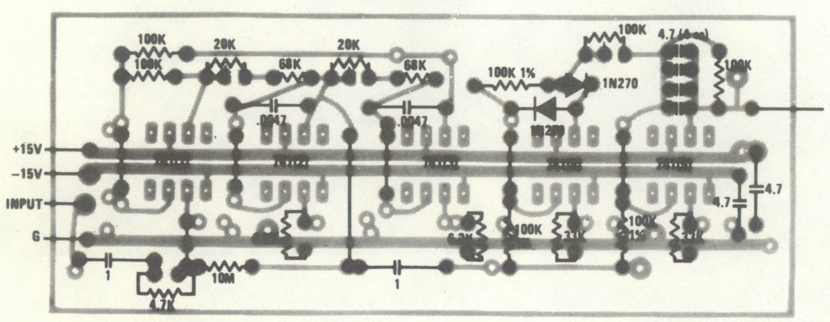


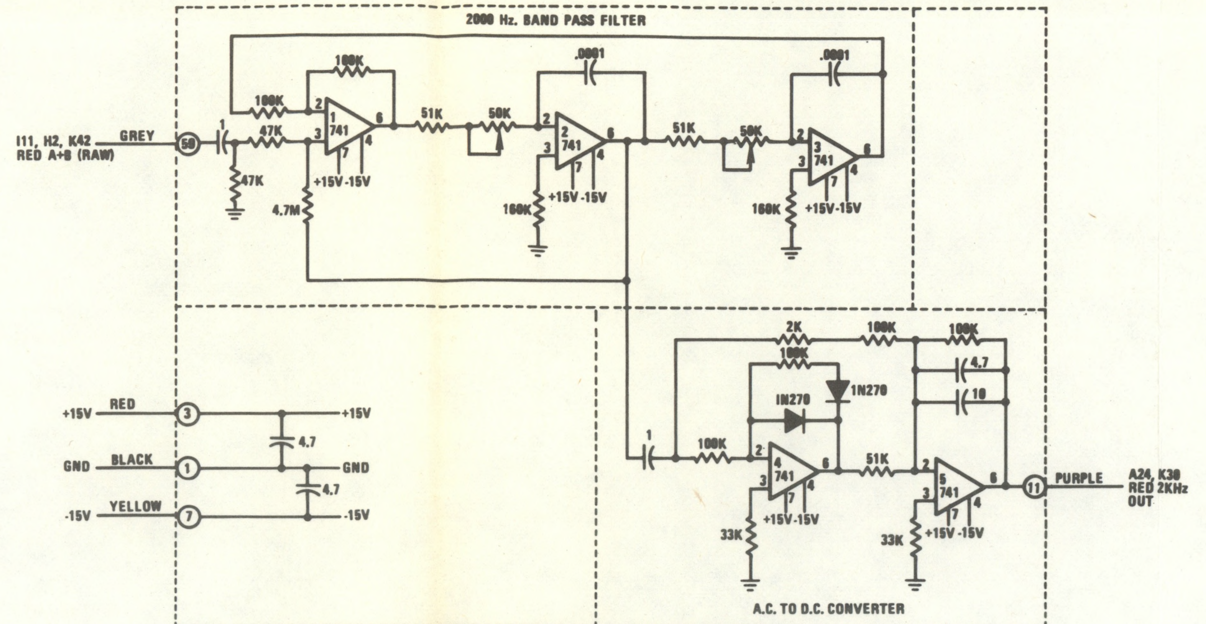
Figure 19. 2K Hz and 500 Hz Bandpass Filters, and Peak Height Detector Card: Sheet 1 - Slot G (500 Hz and 2K Hz, Filters are on Separate Drawings)

2 KHz BANDPASS FILTER
COMPONENT SIDE

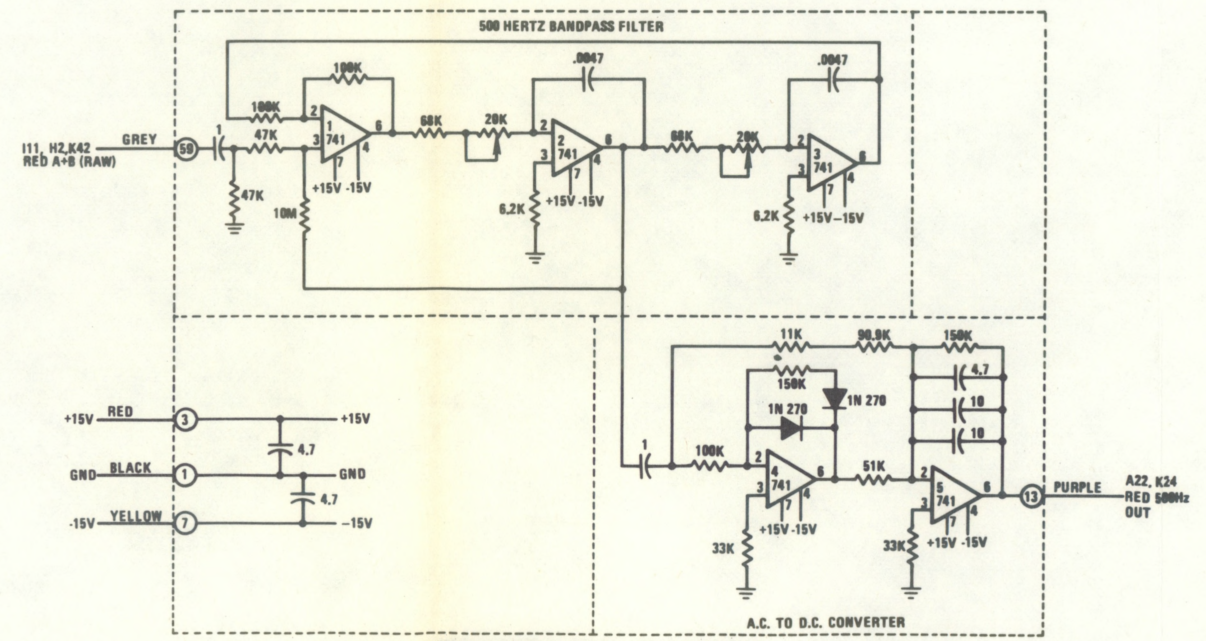


500 Hz BANDPASS FILTER
COMPONENT SIDE





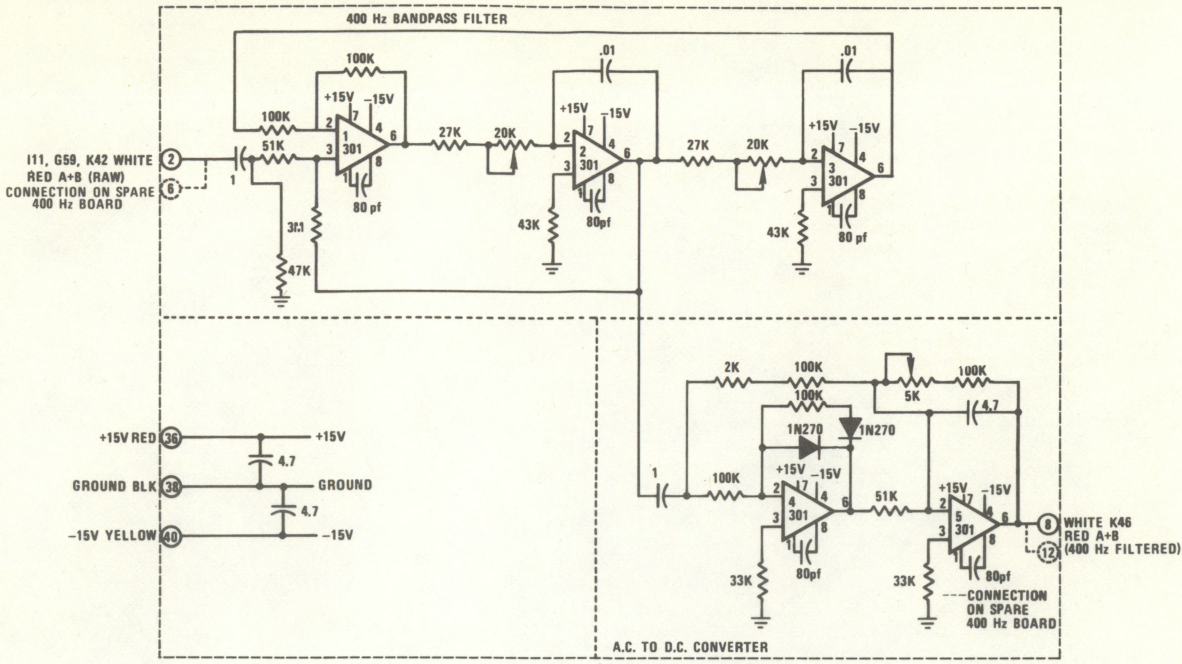
2000 Hz BANDPASS FILTER & A.C. TO D.C. CONVERTER



500 Hz BANDPASS FILTER & A.C. TO D.C. CONVERTER

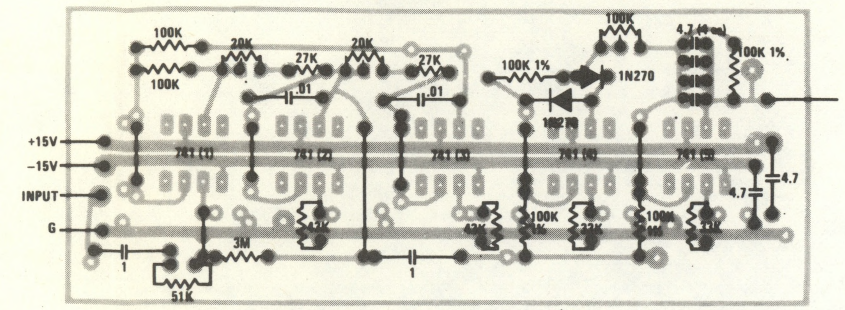
NOTE:
1. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE MARKED

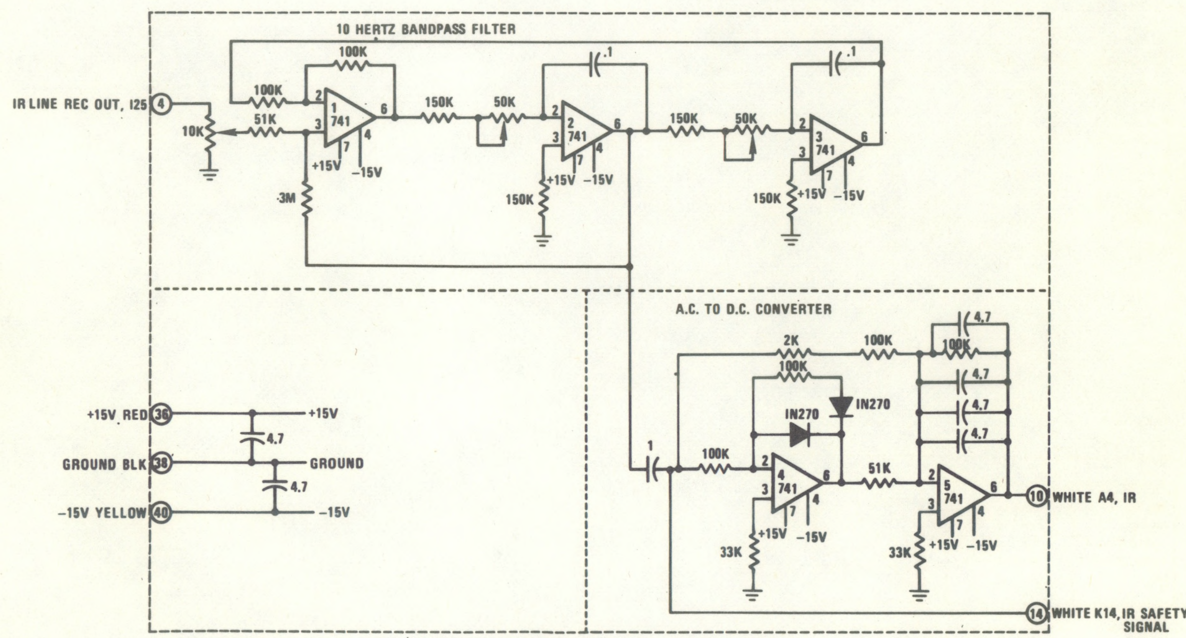
Figure 20. 2K Hz and 500 Hz Bandpass Filters, and Peak Height Detector Card: Sheet 2 - Slot G.



400 Hz BANDPASS FILTER & A.C. TO D.C. CONVERTER

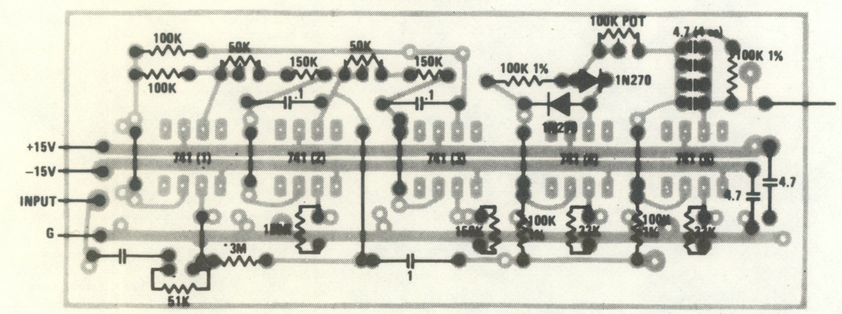
400 Hz BANDPASS FILTER
COMPONENT SIDE

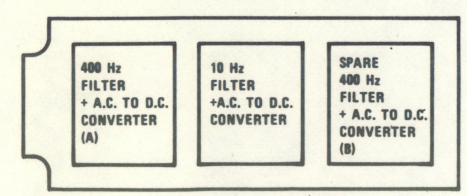




10 Hz BANDPASS FILTER & A.C. TO D.C. CONVERTER

10 Hz BANDPASS FILTER
COMPONENT SIDE





CARD LAYOUT (TOP VIEW)

NOTE:
1. ALL CAPACITORS ARE IN
MICROFARADS UNLESS
OTHERWISE MARKED

Figure 21. Chopper Filters and A.C. to D.C. Converters: Slot H.

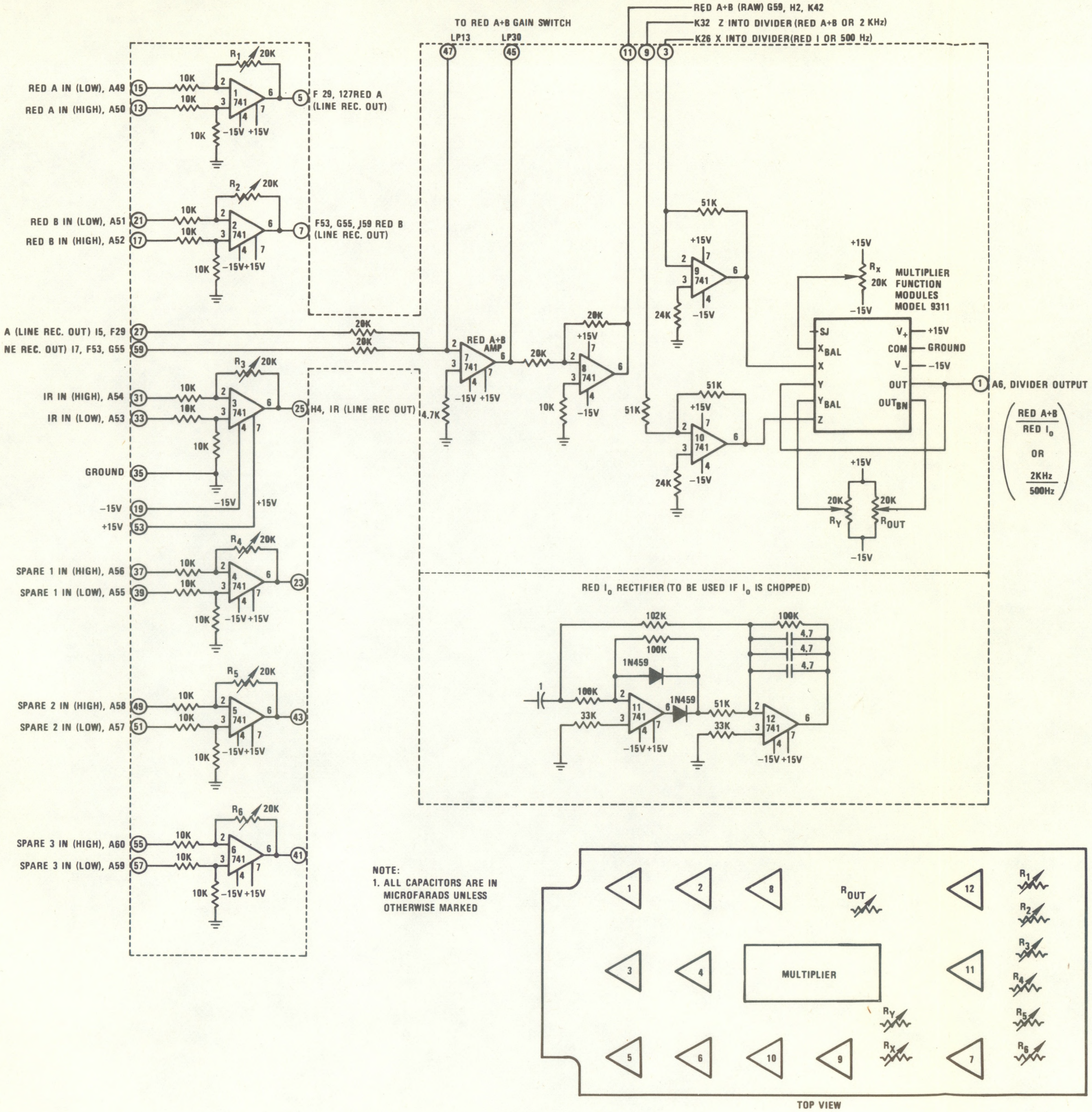
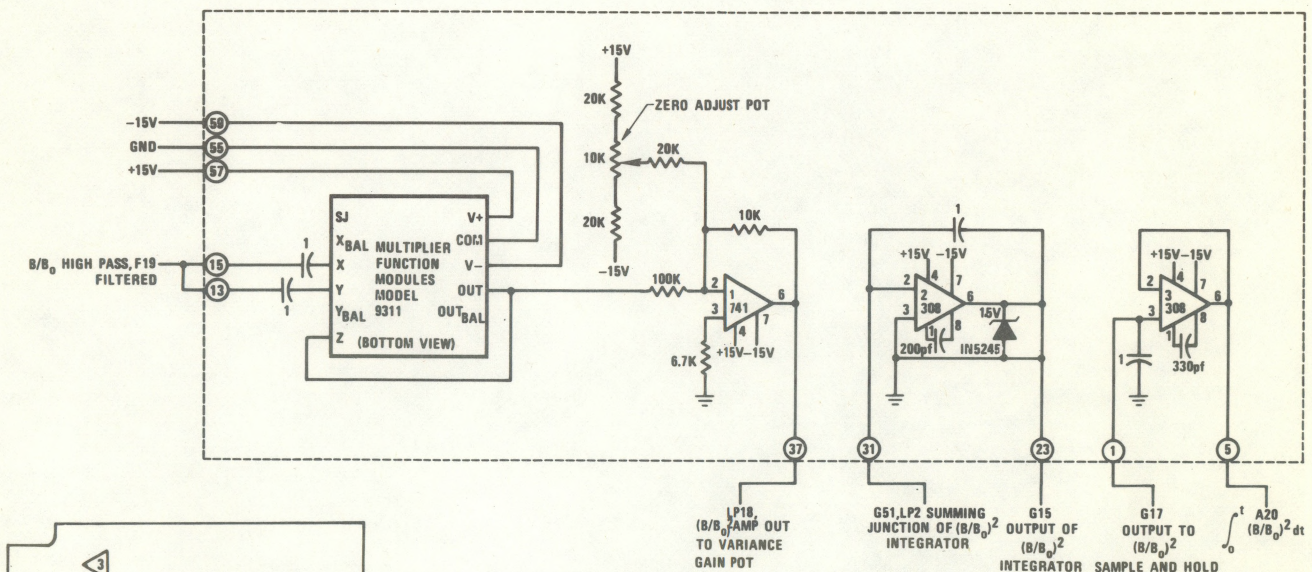
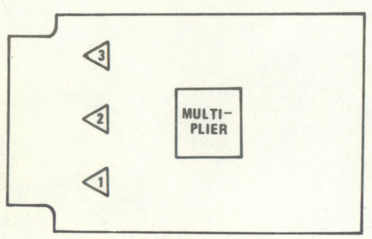
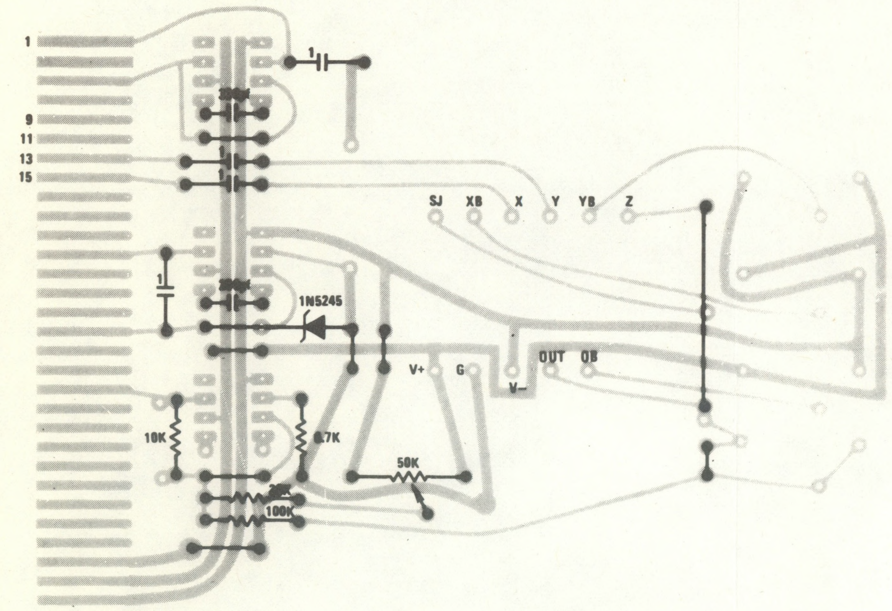


Figure 22. Line Receivers and Divider: Slot I.





TOP VIEW OF LAYOUT



NOTE:

THIS BOARD CAN BE USED FOR VERTICAL VELOCITY CORRELATION (SLOT E) IF:

1. 4016 IS INSERTED INTO 2H OF BOARD C
2. ZERO ADJUST POT IS ADJUSTED SO NO NEGATIVE VALUES ARE FED INTO SAMPLE AND HOLD (PIN 23)
3. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE MARKED

Figure 23. Red B/B Multiplier, Integrator, & Sample and Hold: Slot J or E (See Note).

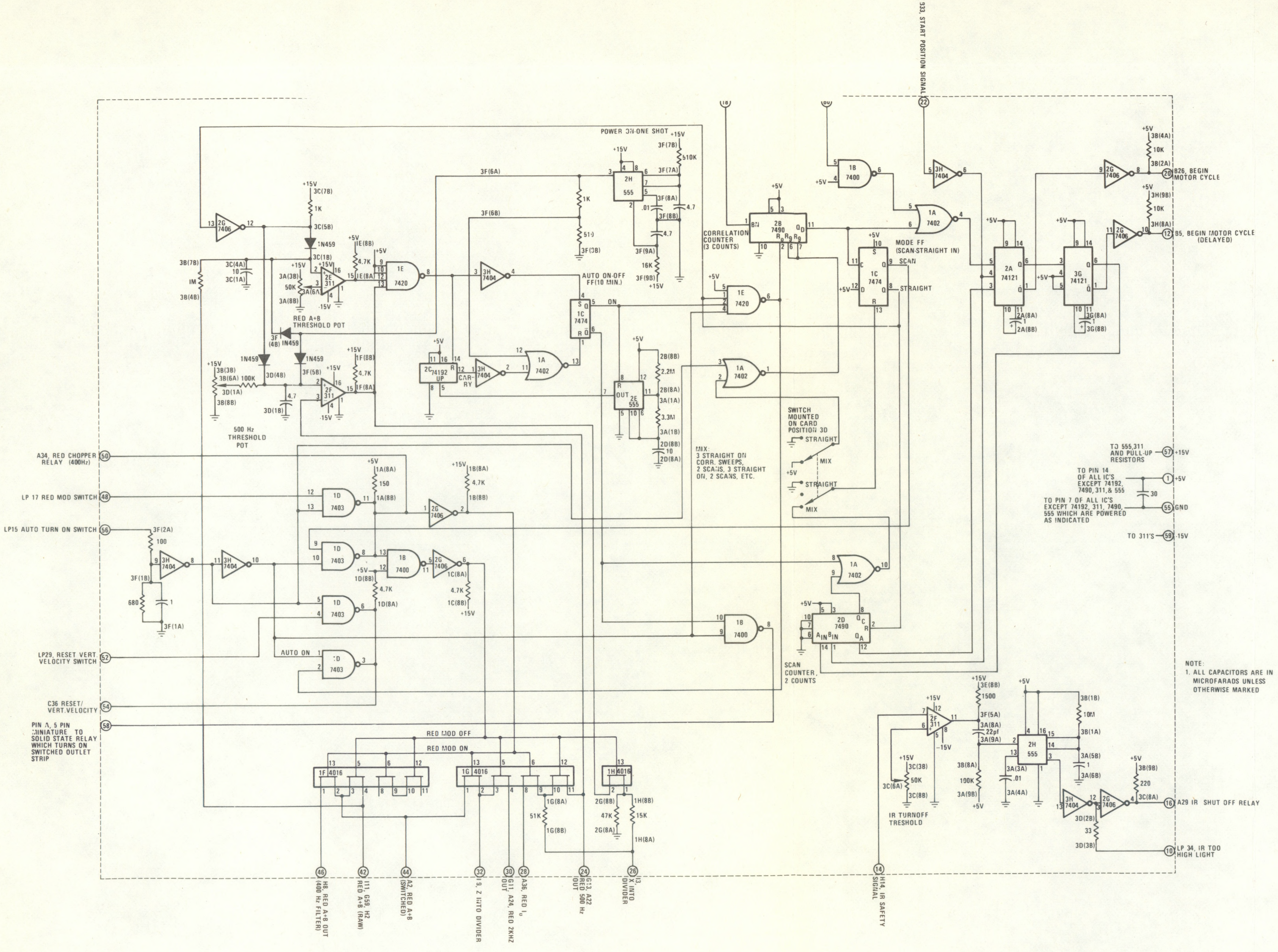


Figure 24. Automatic Turnon, Red Mod Switches, and IR Safety Circuits: Slot K.

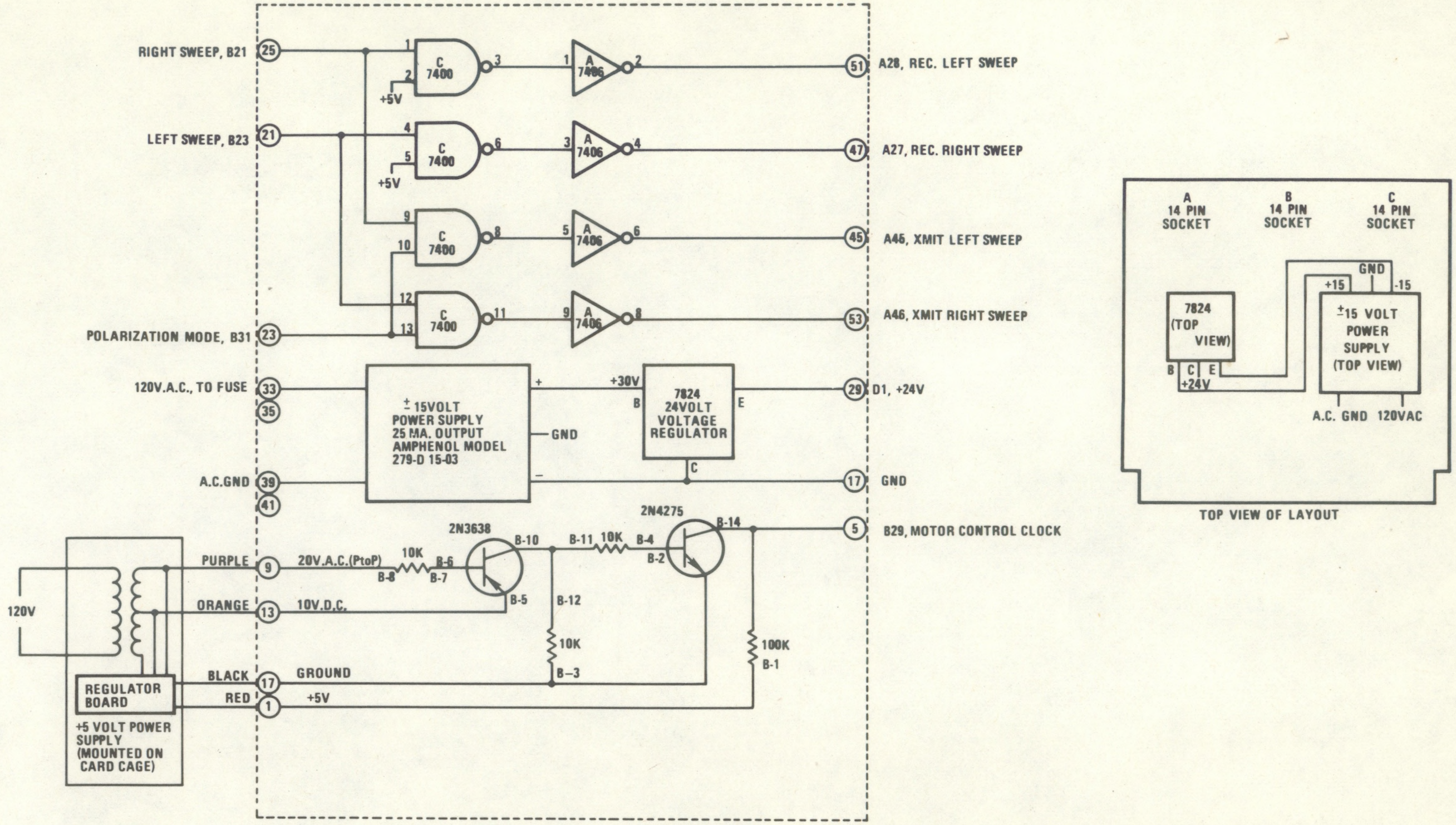


Figure 25. 24 Volt Power Supply and motor Interfaces: Slot L.

☆ U.S. Government Printing Office: 1977 — 777-045/1247 Region No., 8