NOAA Technical Memorandum ERL WPL-161

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

A REFRACTIVE-INDEX STRUCTURE PARAMETER PROFILING SYSTEM

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Wave Propagation Laboratory
Boulder, Colorado
February 1989

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Partial support for this project was provided by the Atmospheric Science Laboratory, White Sands Missile Range, NM, under MIPR No. ASL 86-8004.

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Gerard R. Ochs, James J. Wilson, and Scott Abbott

ABSTRACT

We describe an instrument that measures the refractive-index structure parameter over three segments of optical paths from 300 to 600 meters long.

1. INTRODUCTION

The line-averaged refractive-index structure parameter C_n^2 can be measured conveniently by observing the irradiance fluctuations of an incoherent light source with a receiver, where both the transmitter and receiver apertures are the same diameter and large compared to a Fresnel zone.[1] The measurement is most sensitive to C_n^2 in the center of the path, tapering to zero weight at the ends of the path. The incoherent apertures form broad spatial filters that have a peak response to refractive-index irregularities having a spatial wavelength slightly larger than the aperture diameter. A number of instruments have been designed and built that utilize this principle to obtain a path-averaged measure of C_n^2.

To profile C_n^2 along the light path, the weighting function can be shifted from the center of the path by using different diameter transmitters and receivers[2], and by taking the difference of two transmitting or two receiving aperture signals. To avoid the effects of scintillation saturation, however, each individual aperture must be sufficiently large[1], which restricts the filter complexity for an instrument of practical size. With these factors in mind, we have developed a compact profiling instrument that measures C_n^2 on three segments of an optical path between three-element transmitters and receivers.

2.DESCRIPTION OF THE SYSTEM

A brief overall view of the system is given here. The basis for the circuit calculation of C_n^2 is contained in Appendix A and the detailed circuit diagrams and calibration procedures are contained in Appendix B.

The transmitter and receiver are shown in Figs. 1 and 2, and a block diagram of the profiling system is shown in Fig. 3. Transmitters T_1 (14.6-cm dia), and T_2 and T_3 (both 4.4-cm dia) irradiate the receivers R_1,R_2 (both 4.4-cm dia), and R_3 (14.6-cm dia) with pulse-coded transmissions. All transmitters irradiate all receivers. The signals, which fluctuate in amplitude from refractive-index irregularities crossing the optical path, are preamplified and their long-term mean amplitudes are held constant by an automatic gain control (AGC). Gelatin optical filters are employed to limit the receiver optical bandwidth. However some background light is present and must be removed to

Fig. 1. Profiling system transmitter.

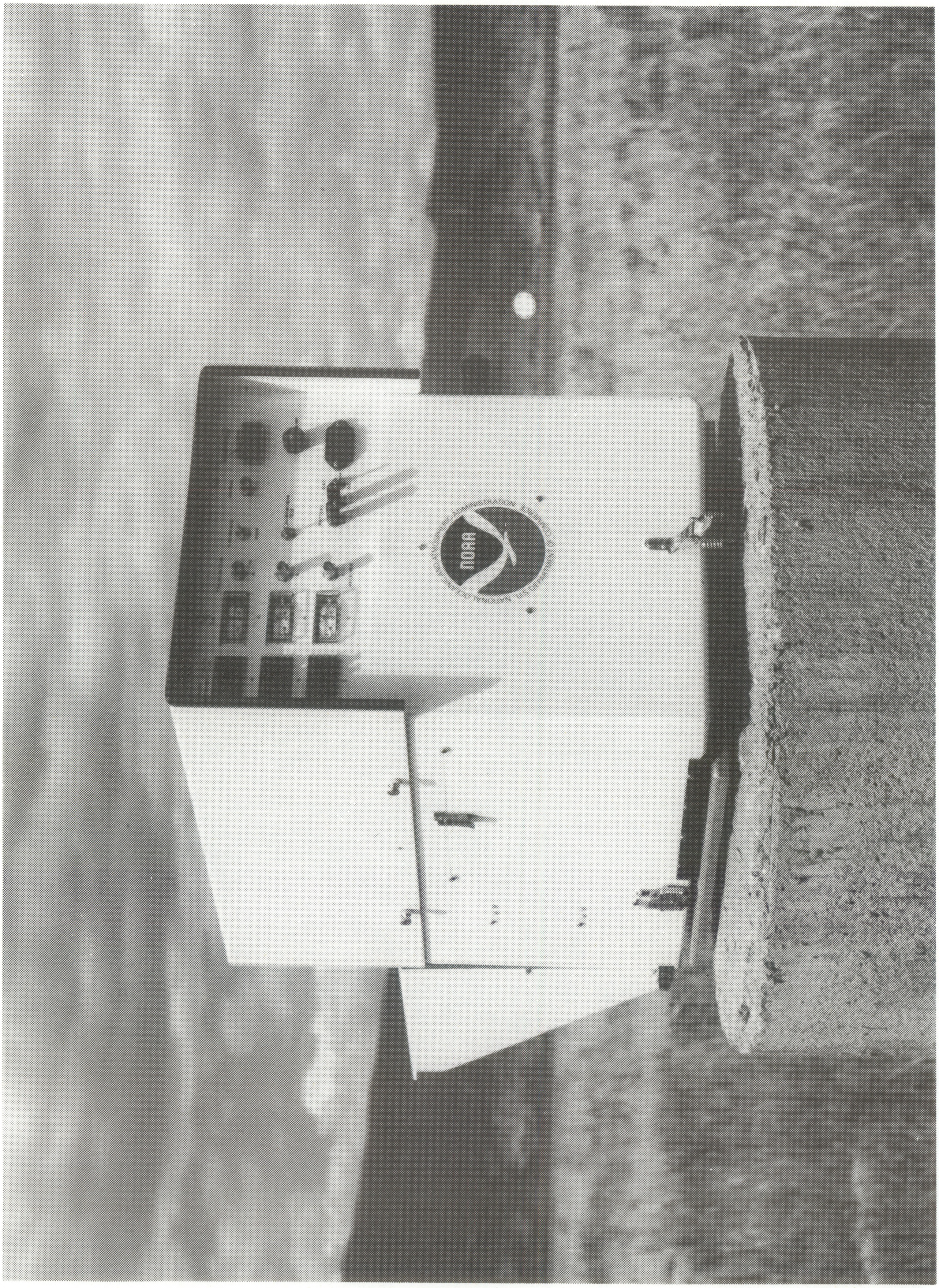


Fig. 2. Profiling system receiver.

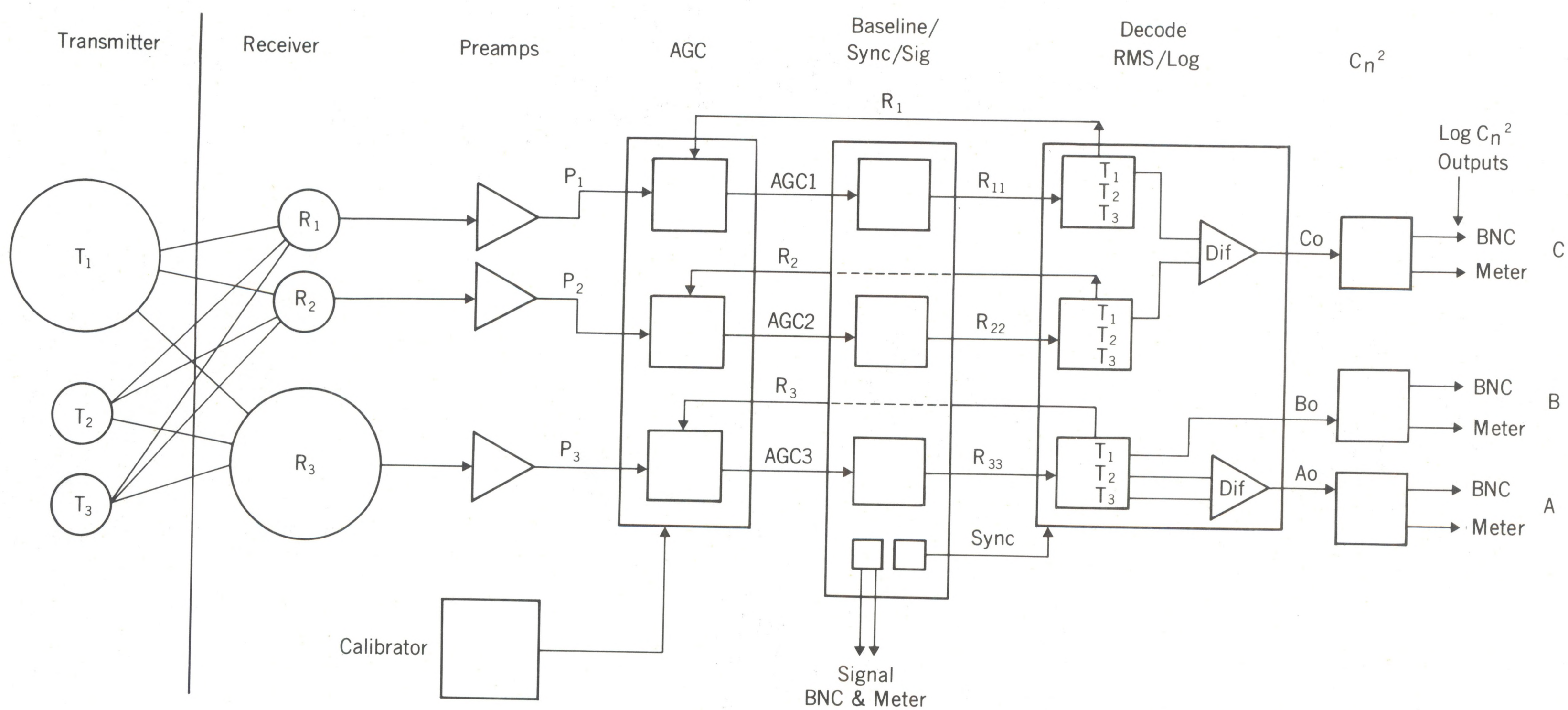


Fig. 3. Block diagram of system

prevent error in the log-intensity signal measurement. This background is removed by the baseline circuits which subtract the mean signal present between signal pulses from the pulse stream. A sync signal is developed from the pulse signals received by R_3. The decoding system uses this signal to time the sampling of the amplitude of each transmitter pulse. The sample and hold circuits then maintain the signal level between pulses and form a continuous fluctuating signal, which is the envelope of the amplitude fluctuations of the stream of pulses from each transmitter. We take the logarithm of these signals and then combine them in the following way.

$$A_0 = \text{path } T_3R_3 - \text{path } T_2R_3$$

$$B_0 = \text{path } T_1R_3$$

$$C_0 = \text{path } T_1R_2 - \text{path } T_1R_1$$

The signals are then bandpass filtered to improve the signal-to-noise and also to subtract the mean of the signal. The logarithm of the root-mean-square (RMS) of these signals is taken in the following stages. Digital pots on the panel control the gain of A_0, B_0, and C_0 to take into account path length, receiver-transmitter aperture diameter ratios, and RMS to mean square conversion.

Some other auxiliary circuits are present in the system. A signal strength indication is picked off from the sync signal before it is completely limited, since this signal, which is taken from the 15-cm aperture, does not have AGC. A calibration system that generates biased square waves of known log variance is built into the unit. This signal can be injected just after the preamps to check the operation and calibration of the circuits from this point.

The outputs A, B and C, representing, respectively, measurements of C_n^2 (in meters$^{-2/3}$) in approximately the first third of the path from the transmitter, the middle third, and the last third nearest the receiver, are related to the output voltage V as follows.

$$C_n^2 = 10^{(V-14)}$$

The weighting functions obtained by using these outputs directly are shown by the dashed curves in Fig. 4. Somewhat sharper weighting functions can be obtained by a linear combination and renormalizing of the A, B and C outputs having these weighting functions. If A, B, and C are combined to form new outputs

$$A1 = (B - .1A)/.9$$

$$B1 = (B - .3(A+C))/.6$$

$$C1 = (C - .1A)/.9$$

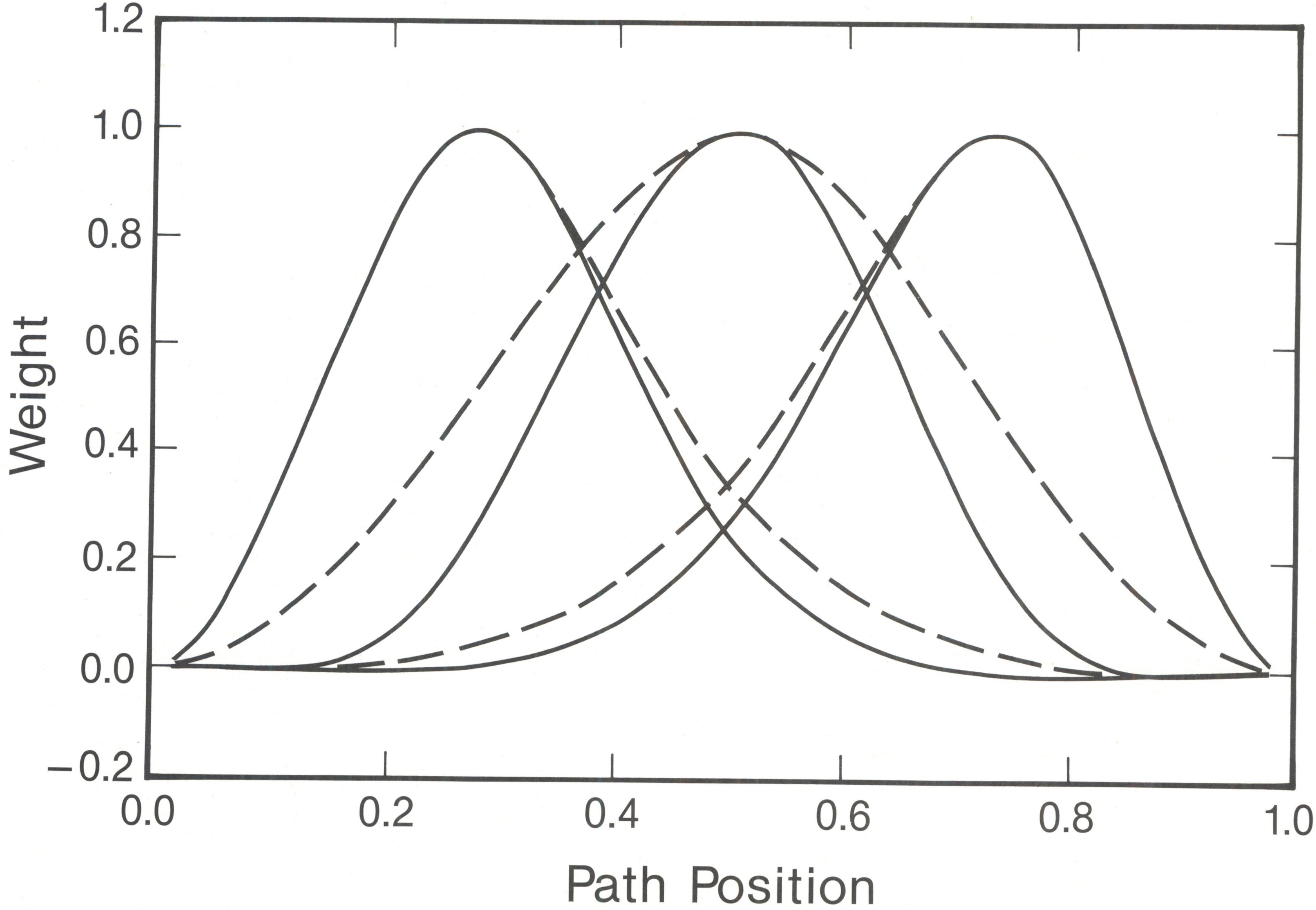


Fig. 4. Weighting functions for the three C_n^2 measurements. The transmitter is on the left. The dashed curves are the weights obtained using outputs A, B, and C directly from the instrument. The solid curves show the weights obtained by linear combination of outputs A, B, and C, as described in the text.

the resulting weighting functions are the solid curves in Fig. 4. The sharper weighting functions carry with them a signal-to-noise penalty but it is acceptable in practice.

3. OPERATING PROCEDURE

The transmitter and receiver should be mounted on solid, vibration-free mounts. A cover with a window is useful for weather protection and prevention of vibration due to wind. While window glass is satisfactory, Plexiglas is recommended as it has slightly greater transparency at 0.94 μm. It is also necessary to position the path so that sunlight doesn't shine directly into the optics.

The transmitter and receiver pointing accuracy should be better than 2 mrad so that the transmitting apertures appear uniformly illuminated and the receivers have uniform gain across their apertures. This is easy to do as long as the sighting telescopes are properly aligned. All of the optics including the telescopes have been aligned originally by using an infrared collimator. The receiver and transmitter alignment can be checked out in the field on operational paths by observing the received signal. For the transmitter, of course, this requires a communication link between the transmitter and receiver.

The system is optimized for path lengths of 400 to 500 m. It will operate with slightly reduced accuracy and dynamic range over 300 to 600 m. Shorter than optimum paths increase the minimum C_n^2 while longer paths reduce the maximum readable C_n^2.

The digital pots on the panel calibrate the system for a particular path length. The settings versus path length are listed in Table I.

TABLE I

Path Length Meters	Channel A and C	Channel B
200	164	61
210	177	68
220	189	75
230	202	83
240	214	90
250	226	98
260	238	105
270	250	113
280	262	120
290	274	128
300	285	135
310	296	143
320	307	150
330	318	158
340	329	165
350	340	173
360	350	180
370	360	188
380	370	195
390	380	202
400	390	210
410	399	217
420	408	224
430	417	231
440	426	238
450	435	245
460	444	252
470	452	259
480	460	266
490	468	273
500	476	280
510	484	287
520	492	293
530	499	300
540	506	306
550	514	313
560	521	319
570	528	326
580	534	332
590	541	338
600	547	344

Path Length Meters	Channel A and C	Channel C
610	554	350
620	560	356
630	566	362
640	572	368
650	578	374
660	584	380
670	589	386
680	595	391
690	600	397
700	606	402
710	611	408
720	616	413
730	621	419
740	626	424
750	631	429
760	636	434
770	640	439
780	645	444
790	649	449
800	654	454
810	658	459
820	662	464
830	666	469
840	670	473
850	674	478
860	678	483
870	682	487
880	686	492
890	690	496
900	693	500
910	697	505
920	700	509
930	704	513
940	707	517
950	711	522
960	714	526
970	717	530
980	720	534
990	723	538
1000	726	542

The output time constant, which varies somewhat with signal level, is approximately 1 sec. Since the outputs are logarithmic, C_n^2 should be computed, say from 1-sec samples, and these values used to obtain longer term averages.

The receiving system can be checked with the internal calibrator. To check, set the CALIBRATE-RUN switch to CALIBRATE. The MODULATION ON-OFF switch on the calibrator board should be in the ON position. Set all three calibration pots to 595. Then hold the CALIBRATE TEST switch first up and then down, and observe the A, B and C outputs. For the internal test signal settings suggested in the appendix, all outputs for either the up or down switch position should read 2.0 volts ($C_n^2 = 1x10^{(-12)}$.

An additional test of the circuit noise can be made by repeating this test with the MODULATION ON-OFF switch in the off position. In this case, the minimum possible C_n^2 reading for the path length calibration set in, will be read. For example, with the calibration settings for a 500-m path, the A, B and C outputs should be less than -3 volts.

The three transmitter LEDs should be set to approximately 200 ma average current as indicated on the meter. When set up on an actual path, the intensity of the three sets of pulses (this signal is available at the SIGNAL BNC) may not be the same at the receiver for the same current settings, however. If not, reduce the current of the appropriate LEDs below 200 ma until they are balanced. This balance is not critical and does not directly affect the calibration, but it does affect the S/N.

4. References

1. Ting-i Wang, G. R. Ochs, S. F. Clifford, Appl. Opt. 68, 334 (1978).

2. Ochs, G. R., and Ting-i Wang (1978): Finite aperture optical scintillometer for profiling wind and Cn-squared, Appl. Opt. 17, no. 23, 3774-3778.

3. Ochs, G. R., and R. J. Hill (1982): A study of factors influencing the calibration of optical C_n^2 meters, NOAA Tech. Memo. ERL WPL-106.

4. Ochs, G. R., D. S. Reynolds, and R. L. Zurawski (1985): Folded-path optical C_n^2 instrument, NOAA Tech. Memo. ERL WPL-123.

APPENDIX A: Derivation of Calibration

Pulse-code modulation is used in this instrument rather than the continuous 7 kHz carrier used in earlier systems. After demodulation, however, the signal processing circuitry is nearly identical to that used in the earlier systems. From Ref 1,

$$C_n^2 = K\,\sigma_x^2\,D^{7/3}\,L^{-3} \tag{1}$$

where o_x^2 is the log-amplitude variance of the irradiance, D is the larger transmitter or receiver aperture diameter, and L is the path length. By definition,

$$\sigma_x^2 = <\ln a - <\ln a>>^2$$

where a is the light amplitude. We measure irradiance I. Since I is proportional to a^2, and ln a = 2.3026 log a, we can write

$$\sigma_x^2 = \frac{2.3026^2}{4} <\log I - <\log I>>^2 \tag{2}$$

Refer to Fig 5. In the log unit, 2 volts = one decade and the bandpass unit subtracts off <log I> so that

$$\sigma_x^2 = \frac{2.3026^2}{4} (V_3/2)^2$$

$$\sigma_x^2 = 0.3314\,V_3^2 \tag{3}$$

Combining (1) and (3),

$$C_n^2 = 0.3314\,K\,D^{7/3}\,L^{-3}\,V_3^2 \tag{4}$$

Decide on the following instrument calibration

$$C_n^2 = 10^{-12}\,V_4^2 \tag{5}$$

Determine gain G as a function of path length L. From the circuit

$$V_4 = G\,V_3 \tag{6}$$

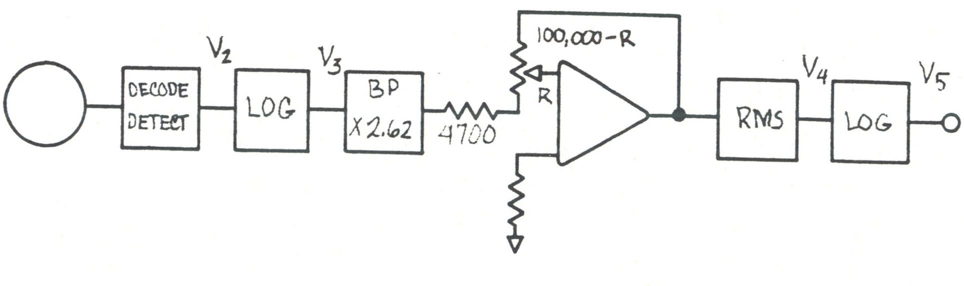


Figure 5. Simplified block diagram.

Combining (4), (5) and (6), to eliminate C_n^2, V_3 and V_4,

$$G = 5.757*10^5 K^{1/2} D^{7/6} L^{-3/2} \tag{7}$$

Decide on the following log output calibration (V_5):

$$C_n^2 = 10^{(V_5-14)} \tag{8}$$

Combining (5) and (8)

$$V_5 = 2 + 2 \log V_4 \tag{9}$$

Thus the log unit should be set so that

$$V_5 = 0 \text{ when } V_4 = 1$$

and

$$V_5 = 2 \text{ when } V_4 = 1 \text{ (i.e., 2 volts/decade)}$$

To determine the RMS voltage to be used to check the circuit gain, set $V_4 = 1$ volt ($V_5 = 2$ volts). Then from (7)

$$G = V_4/V_3 = 1/V_3 = 5.757 K^{1/2} D^{7/6} L^{-3/2} \tag{10}$$

Now calculate gain G as a function of pot position P. From the circuit

$$G = 2 \times 2.62 (100000-R)/(4700 + R)$$

Since

$$R = 100P$$

$$P = (5240 - 47G)/(G + 5.24) \tag{11}$$

where P is the digital pot setting. From (7) and (11) we can now calculate P as a function of K, D and L.

K depends upon the transmitter-receiver aperture geometry. We define K in (1) for D, the largest aperture in the system. Three configurations are used. One uses a 14.6-cm dia transmitter and receiver (output B). A second uses the difference of two 4.38-cm dia transmitter apertures spaced 6.7 cm on centers and one 14.6-cm dia receiver (output A). A third path uses one 14.6-cm dia transmitter and the difference of two 4.38-cm dia receivers spaced 6.7 cm on centers (output C). From Ref 1, one can calculate K = 4.474 for output B, and K=0.924 for outputs A and C. From (7) and (11), knowing D and K, we can calculate P as a function of path length L.

For K = 4.474, D = .146 m (output B),

$$P = (5240 - 6.068*10^6 L^{-3/2})/(1.291*10^5 L^{-3/2} + 5.24) \tag{12}$$

For K = 0.924,   D = .146 m (outputs A and C),

$$P = (5240 - 2.756{*}10^6\ L^{-3/2})/(5.863{*}10^4\ L^{-3/2} + 5.24) \qquad (13)$$

A tabulation of P for L from 200 to 1000 m appears in Table 1.

Derivation of Calibration Signal and Instrument Output Relationship

The calibrator generates a string of three pulses with the same timing as the sum of the three transmitter pulses normally received by each detector. These pulses are amplitude modulated by a 10 Hz square wave of adjustable amplitude. This calibration signal is processed in the circuit as follows. When switched into the receiver, the pulse train is decoded and demodulated, the logarithm is taken with 1 decade = 2 volts, and the mean is removed (V_3). Then in terms of the maximum to minimum square wave voltage ratio (a/b), the root mean square output voltage V_3 is then (see Fig. 6)

$$V_3 = [(\log (a/b))^2]^{1/2} \qquad (14)$$

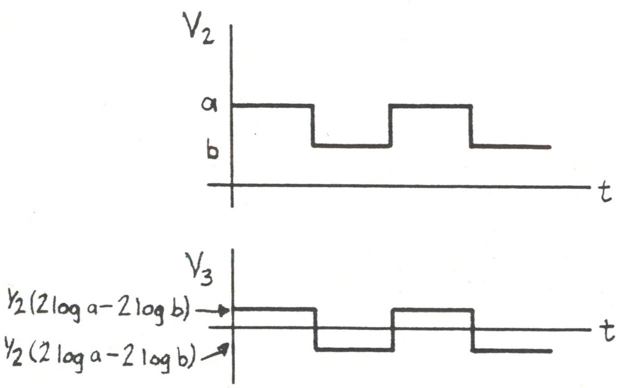


Fig. 6 Derivation of calibrator signal.

From (14), (9), (10) and (11) we can obtain the output voltage V_5 as a function of a/b and P.

$$V_5 = 2 + 2 \log [(5240 - 5.24\ P)(\log (a/b))/(P + 47)] \qquad (15)$$

If a/b = 2, as set up in the calibration procedure in Appendix A, and P is set to 594, then V_5 = 2.0 volts.

Saturation Criteria

The limits imposed by the saturation of scintillation have not been calculated for unequal aperture diameters from the most recent theory; however for equal diameters, the limiting expression is[3,4]

$$L < 0.54\ D^{5/8}\ \ {}^{1/8}\ (C_n{}^2)^{-3/8} \qquad (16)$$

Where L is the maximum path length for a given C_n^2, $\lambda = 0.94\ \mu m$ is the optical wavelength, and D is the aperture diameter. This geometry has a peak spatial wavelength response slightly larger than D. For the more complex three aperture system used for outputs A and C in the profiler, the mean response is to irregularities of spatial wavelength 8.9 cm. It seems reasonable to assign this value to D. Then (16) becomes

$$L < 0.0210\ (C_n^2)^{-3/8} \qquad (17)$$

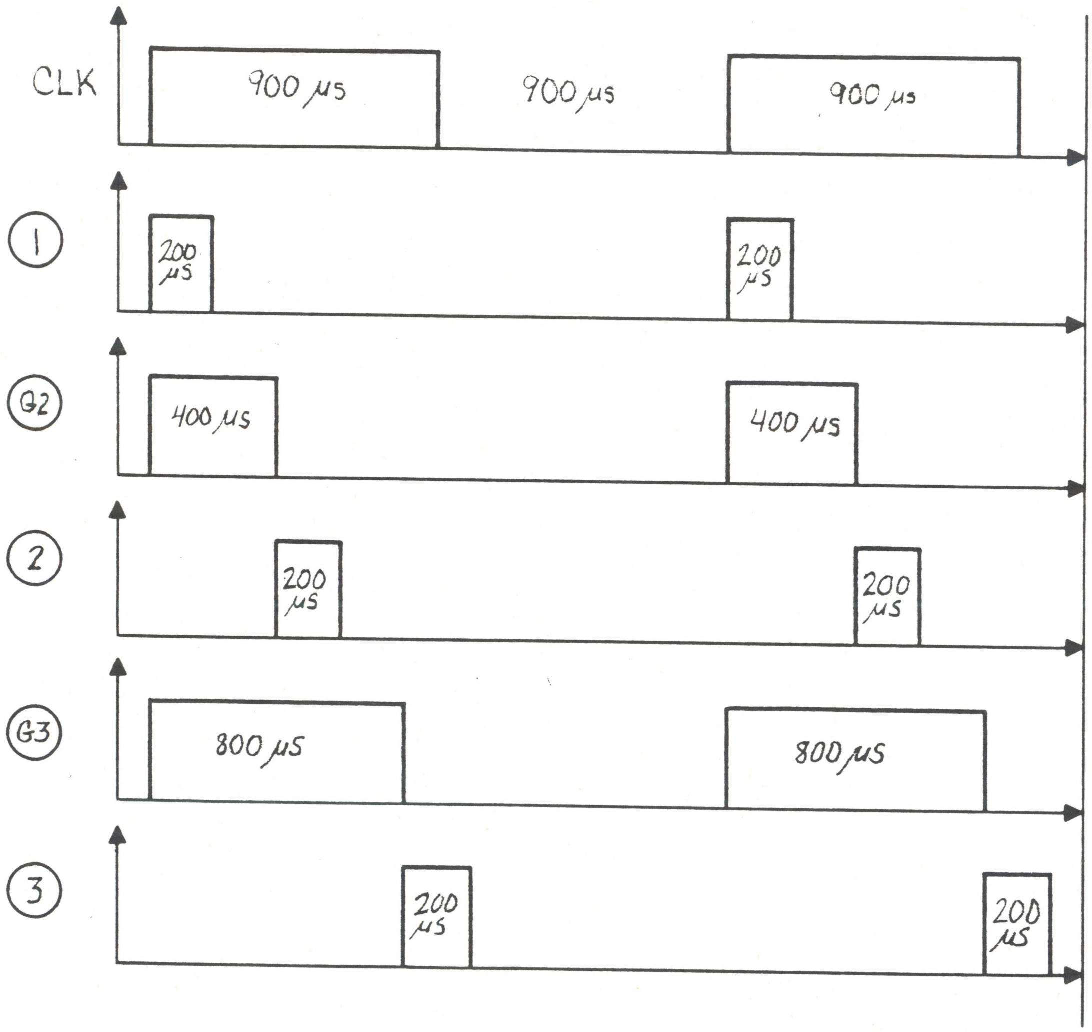
For $C_n^2 = 1*10^{-12}$, $L < 664$ M.

Experimental measurements verify that this is a reasonable estimate.

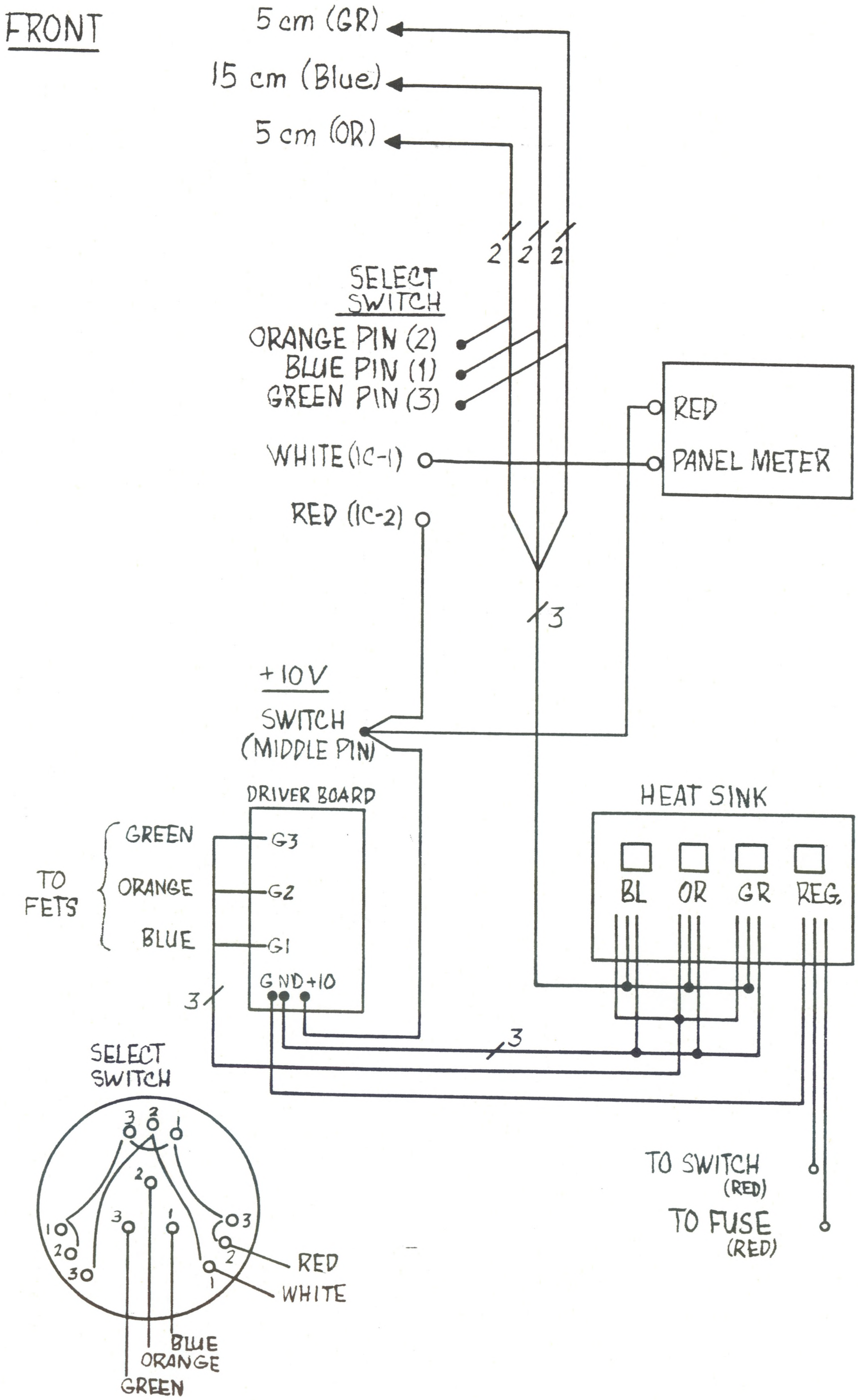
APPENDIX B: Circuit Diagrams, Alignment, and Layout

Transmitter

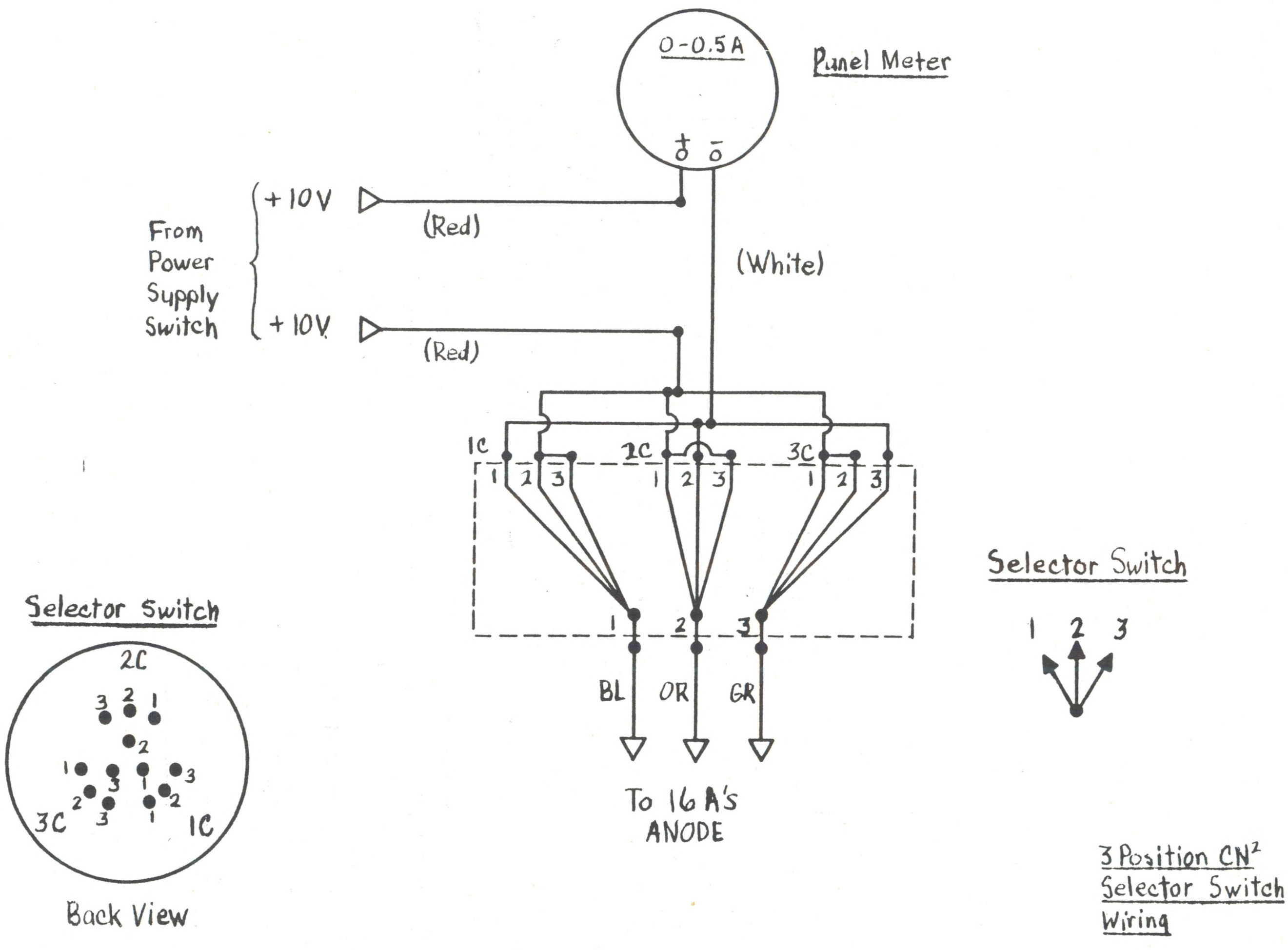
Receiver



Timing Diagram

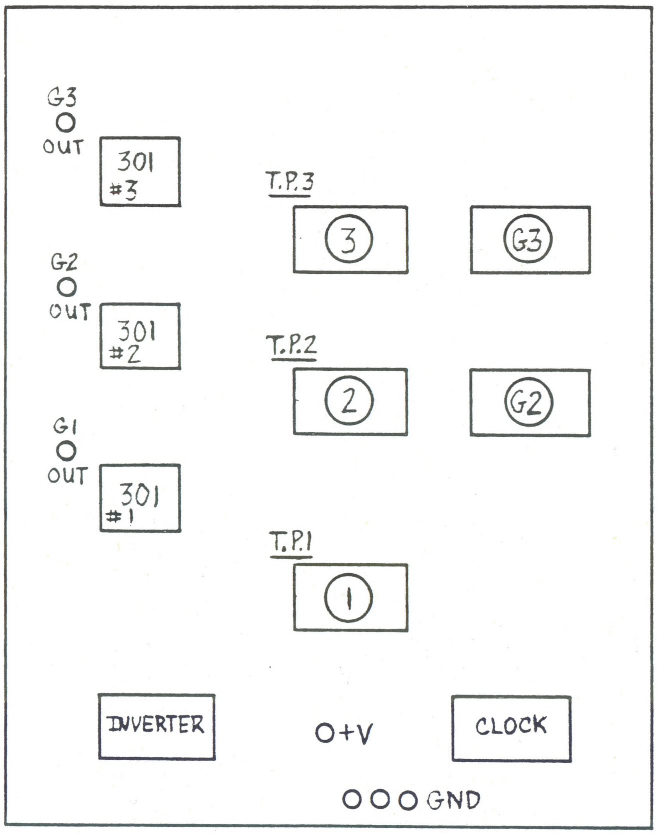


Block Diagram

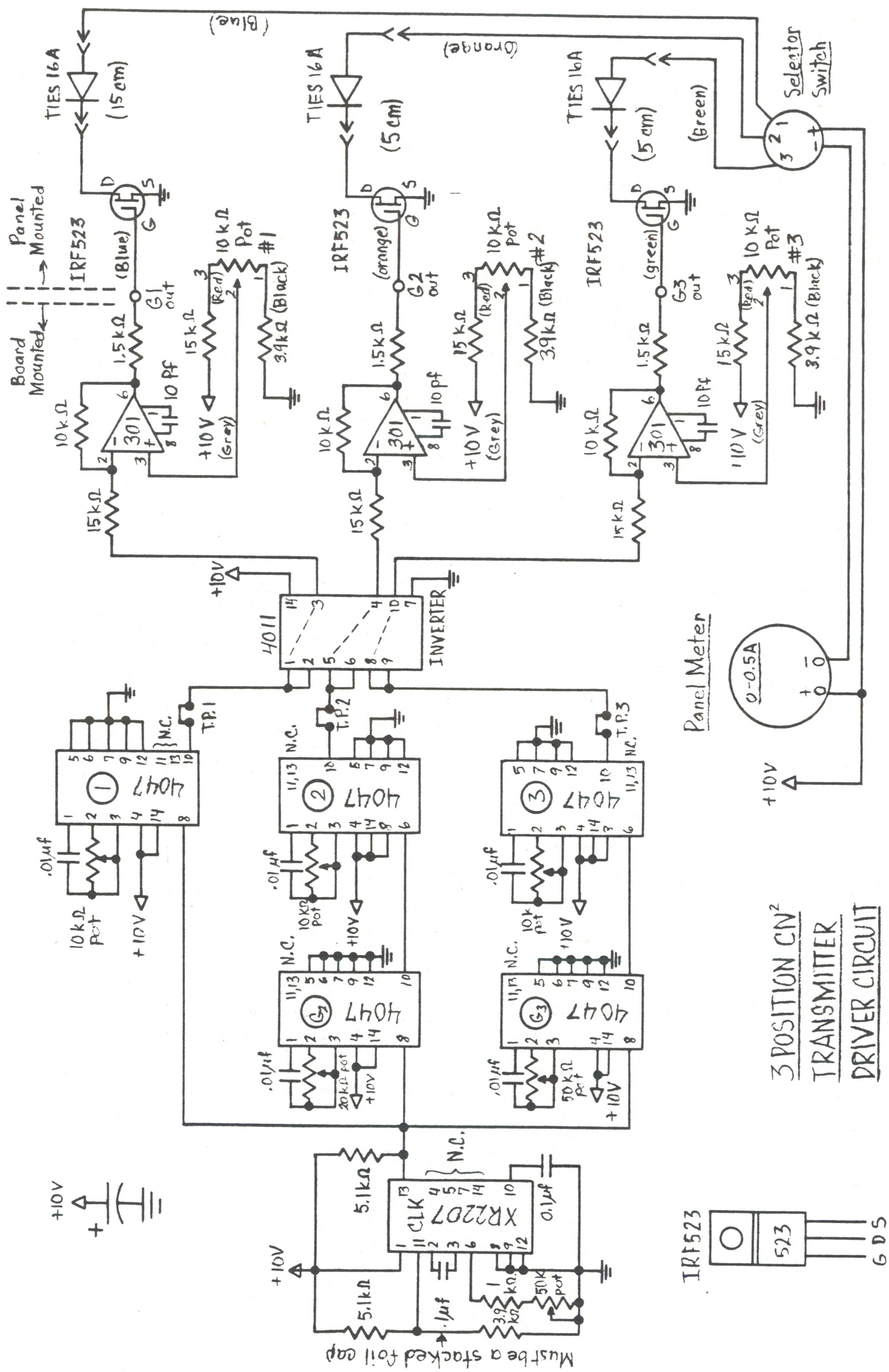


Selector Switch/Wiring

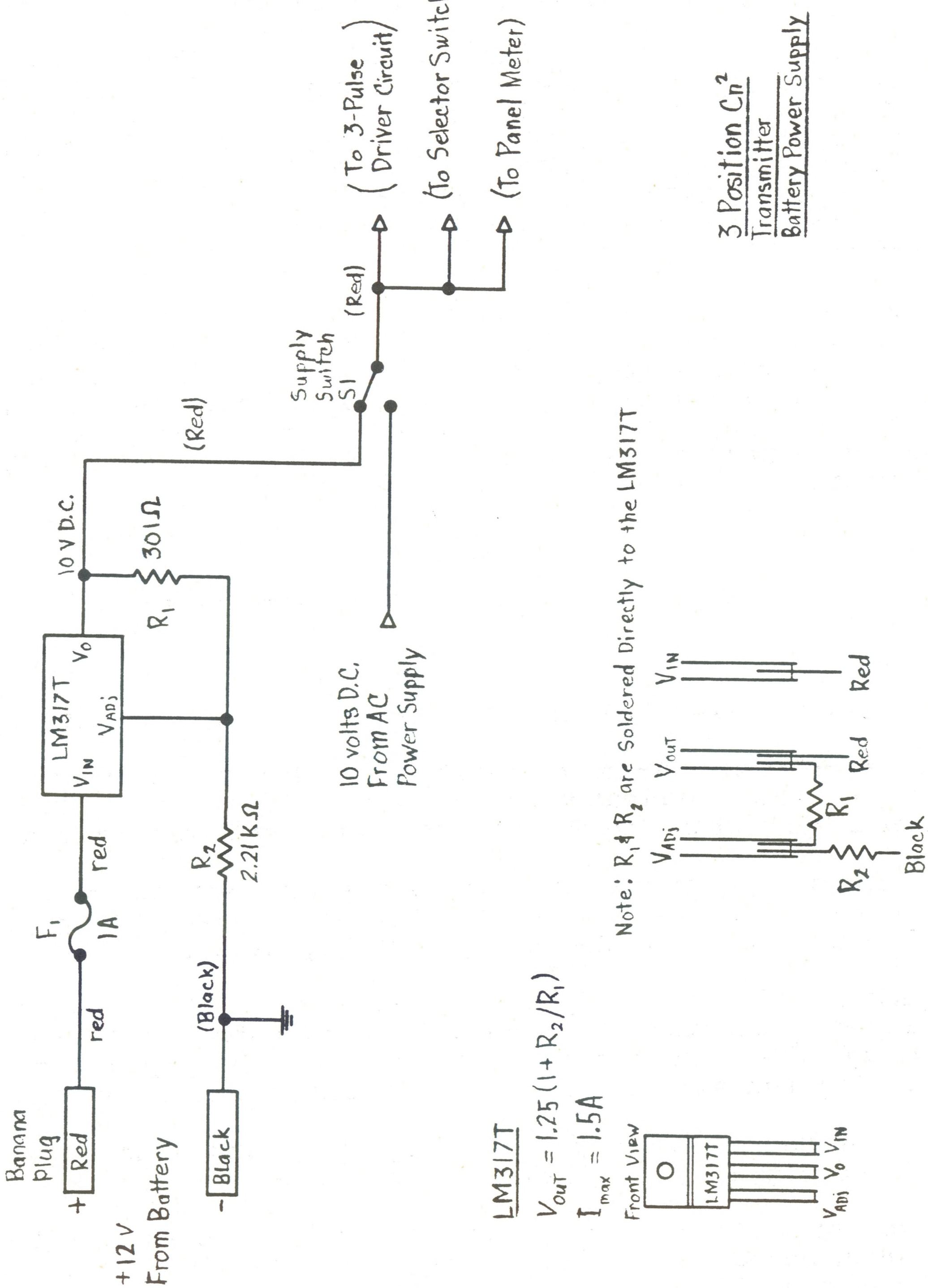
3 Position Cn^2
Transmitter



Three Pulse Driver Board



Driver Board Circuit



Banana plug
Red
Black
+
-
+12 V From Battery
red
F1
1A
red
LM317T
V_{IN}
V_{ADJ}
V_O
(Black)
R2
2.21 KΩ
R1
301Ω
10 V D.C.
(Red)
Supply Switch S1
(Red)
(To 3-Pulse Driver Circuit)
(To Selector Switch)
(To Panel Meter)
10 volts D.C. From AC Power Supply
LM317T
$V_{OUT} = 1.25 (1 + R_2/R_1)$
$I_{max} = 1.5A$
Front View
V_{ADJ} V_O V_{IN}
Note: R1 & R2 are Soldered Directly to the LM317T
V_{ADJ}
V_{OUT}
V_{IN}
R1
R2
Black
Red
Red
3 Position Cn^2 Transmitter Battery Power Supply

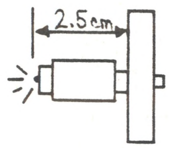
Alignment

1) Set power supply to 10.0 volts DC, with it disconnected. Reconnect.

2) Adjust timing signals in accordance with timing diagram. Start with the clock pulse first with diodes disconnected.

Note: The optical alignment procedure described below requires the use of a 20-cm diameter collimator. The collimator has an LED (0.94 um wavelength) at its focus. In addition to its normal use as an emitter, an LED will function as a narrow-band 0.94 µm wavelength detector and is used this way for some of the operations. While this description is specifically for the transmitter, a similar procedure is used for the receiver optical alignment.

3) Remove the 5 cm transmitter from the unit. Set it on a transit mount and use a C_n^2 driver box to power the transmitter. Connect an oscilloscope to the collimator detector output and move the transit mount until a signal is displayed on the scope. Adjust the focus for maximum signal and only one peak. (If there is a double peak it is out of focus.) Do the same for the second transmitter.



5-cm holder

Note: Make sure the diode holder is flat on both ends.

4) Reinstall the 5-cm transmitters. Mount the transmitter in front of the collimator on the transit mount. Connect the external sync probe to TP1 on the transmitter driver board.

5) Turn on the transmitter and adjust current #1 to 25-50 ma and #2 and #3 to 200 ma. Move the transmitter with the transit mount until one or more of the pulses are displayed on the scope.

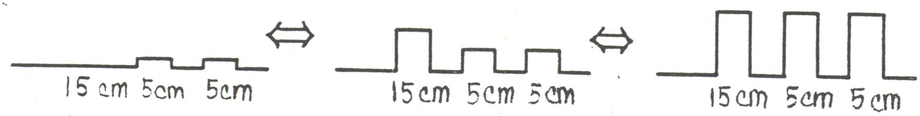
6) Adjust the 5-cm adjust plates until both 5-cm signals are displayed. Continue to adjust them so when the transmitter is moved up, down and sideways the signals both peak at the same time. Tighten all screws and check the alignment again.

7) Once the 5-cm units are aligned, adjust the 15-cm system until the signal is displayed on the scope.

8) Adjust the focus until you get maximum signal and only one peak when moved in and out of view. Double peaks indicate an out of focus condition.

9) Adjust the position of the diode until the signal peaks at the same time as the 5-cm signals. The 15-cm will rise and fall

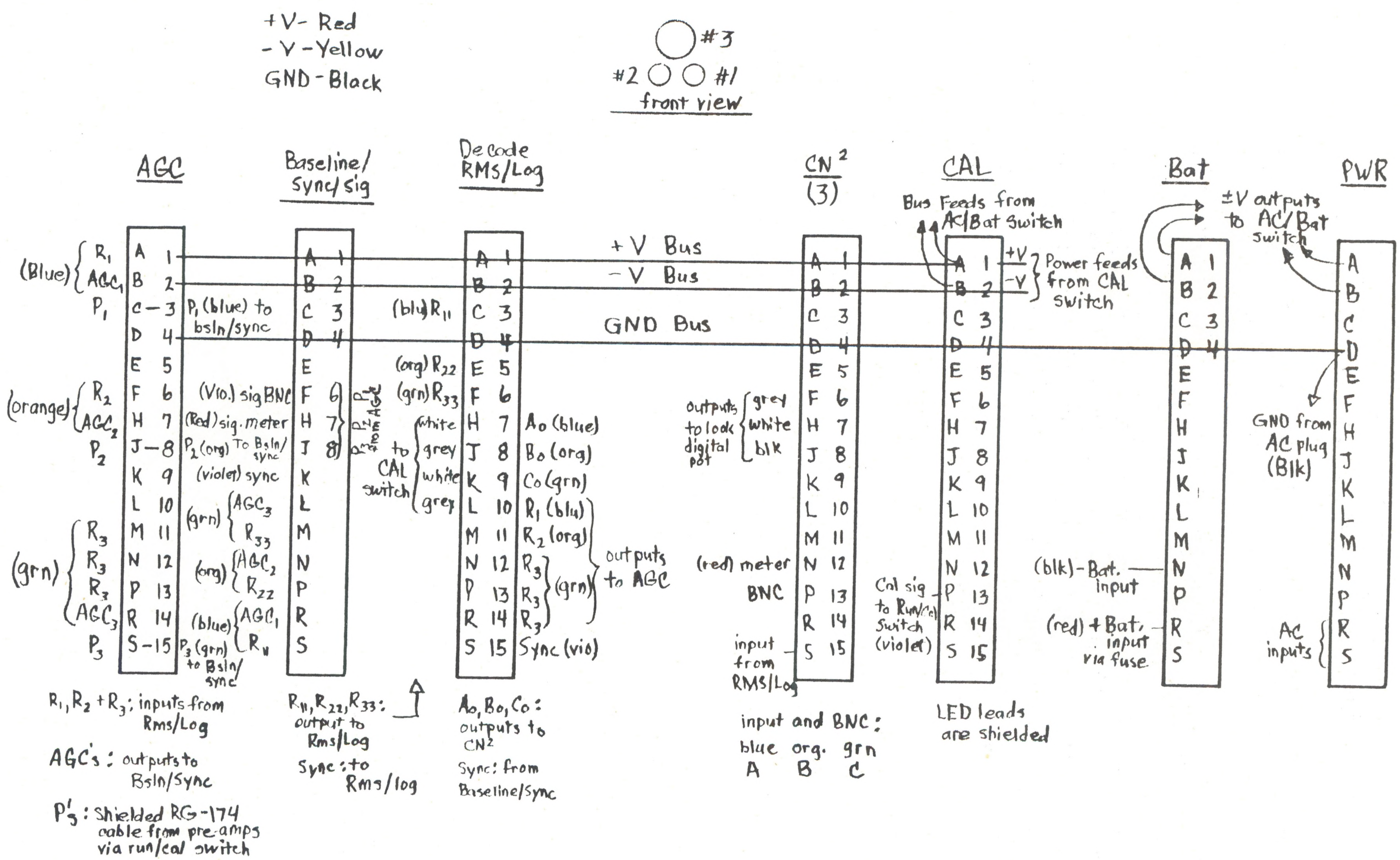
faster than the 5-cm units.



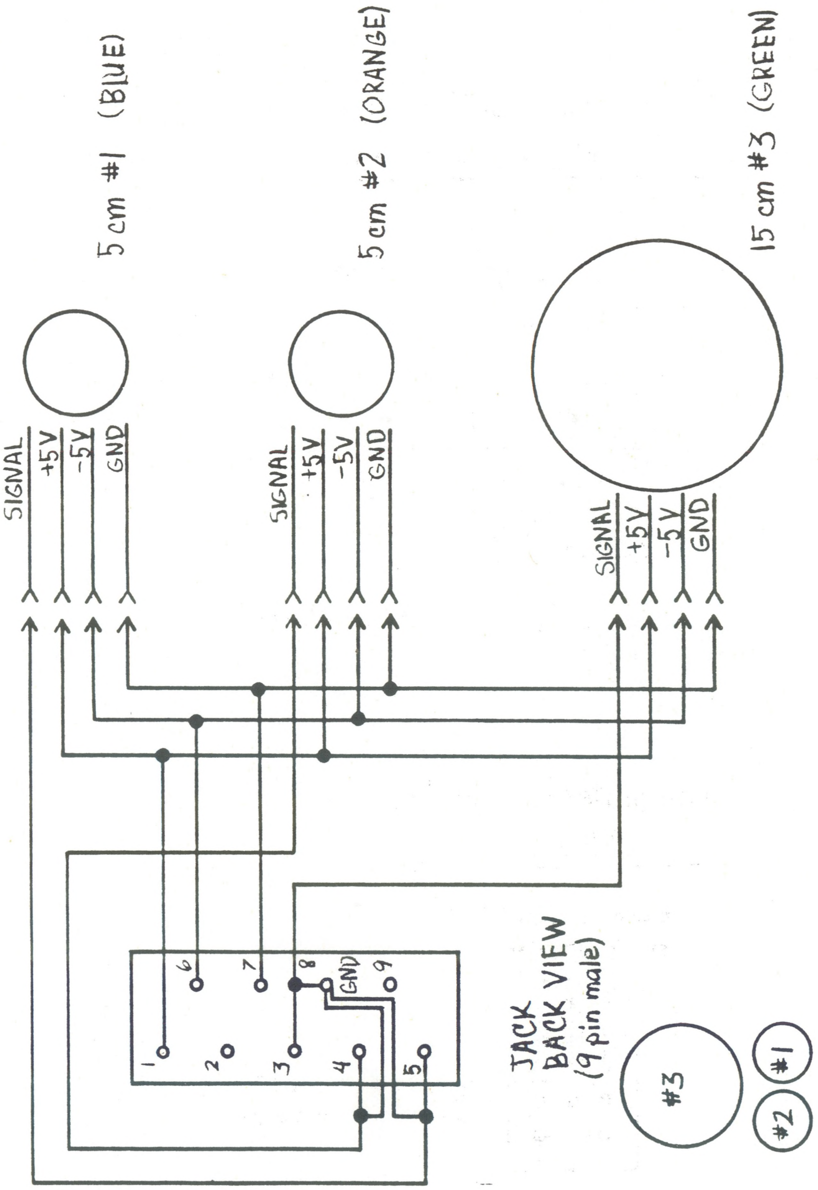
Note: The alignment of the 5-cm transmitters may have to be changed to get the 15 cm aligned to them.

10) Once all three signals peak at the same time, tighten all screws and check for proper alignment again.

11) Now align the rifle scope. Move the collimator up so the 15 cm signal is displayed and the rifle scope can see into the collimator. Place a light in front of the collimator so you can see the receiver diode when looking through the telescope. Adjust the transit mount until the maximum signal is displayed. Then adjust the riflescope crosshairs to line up on to the diode, and recheck the alignment.

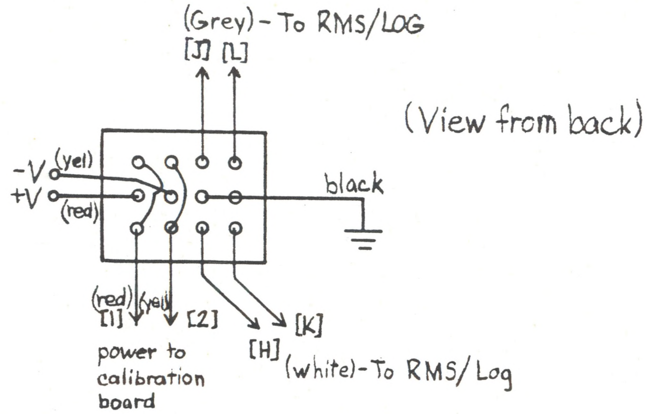


Connector Pinouts

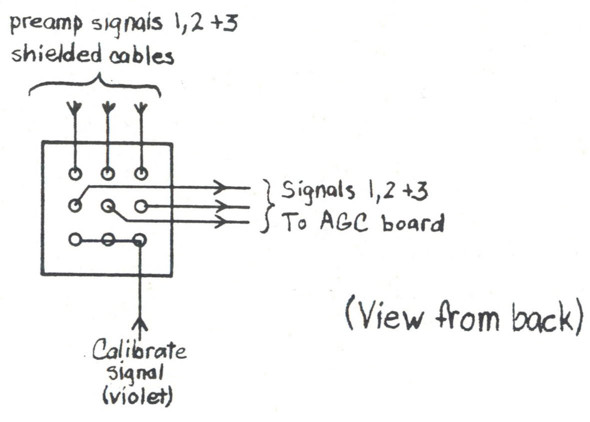


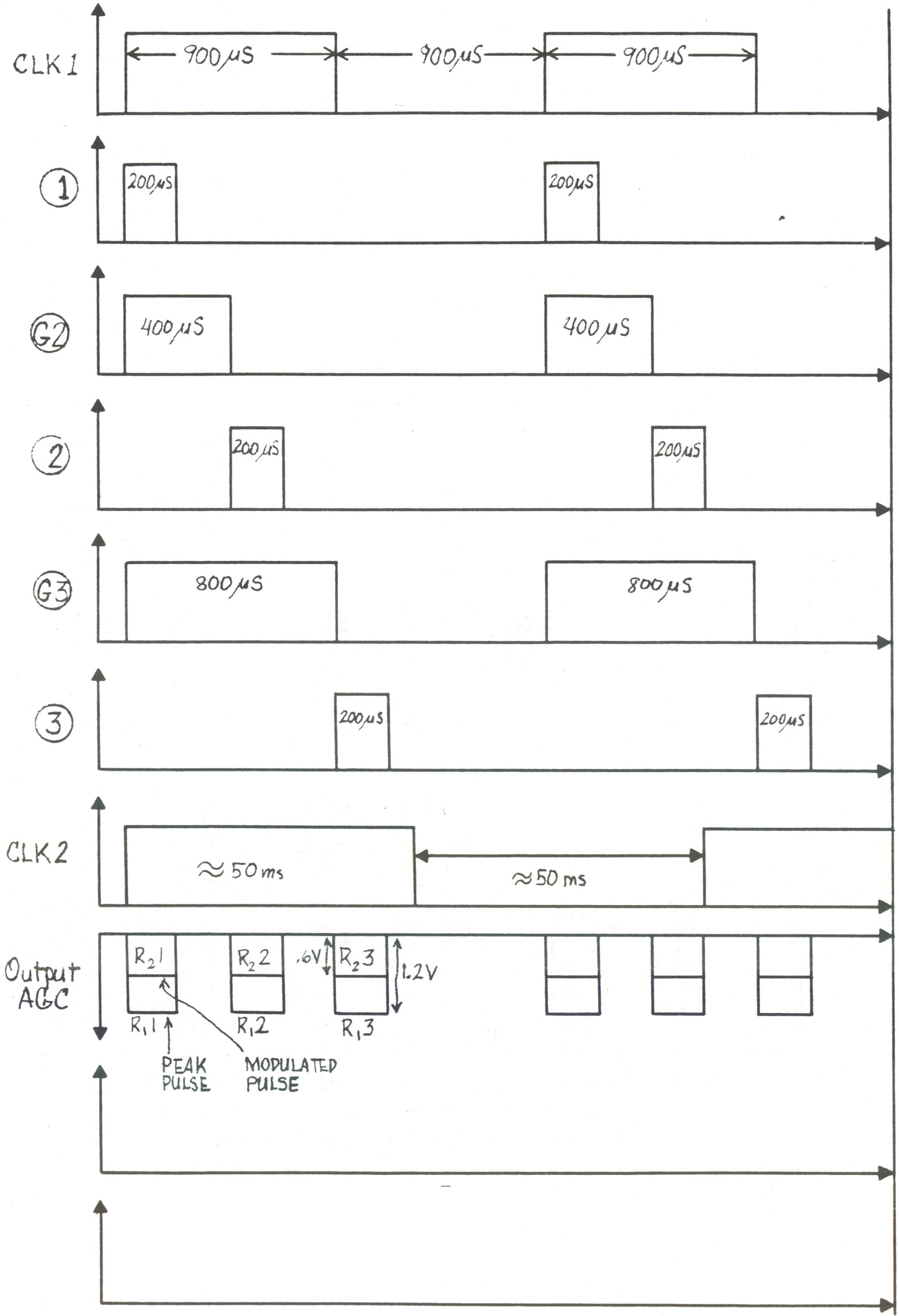
Wire Diagram

Calibration Test Switch
4 PDT (Momen.-off-Momen.)



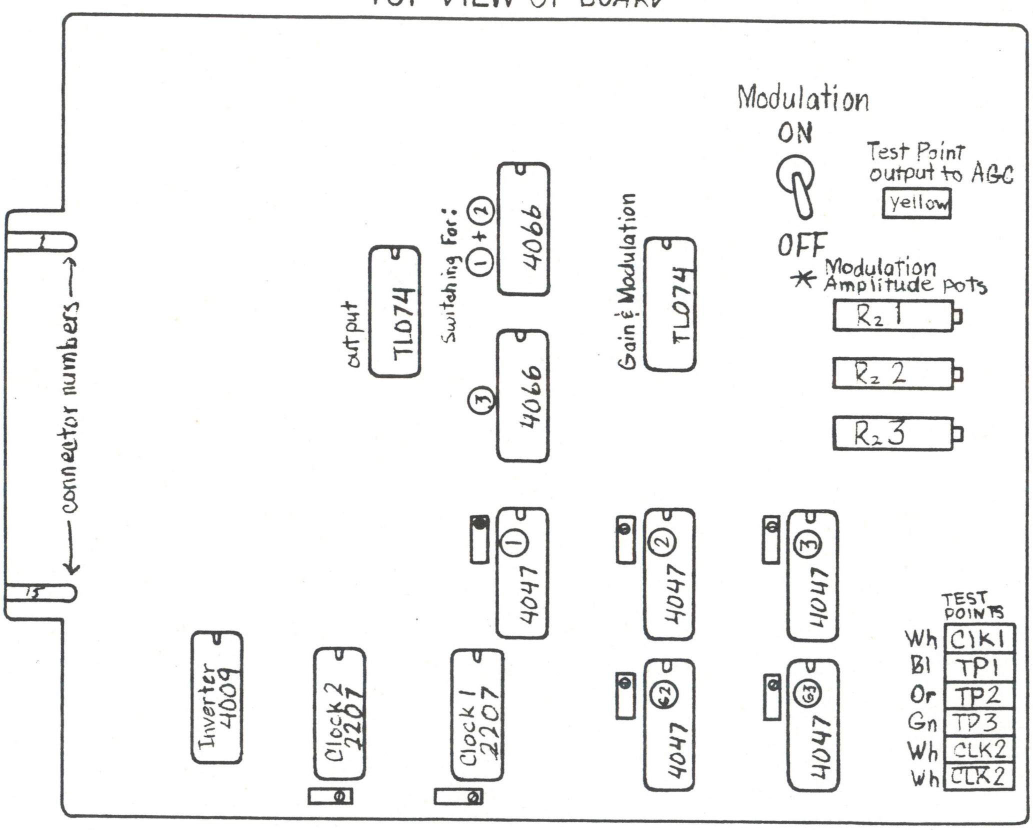
Calibrate/Run Switch
TPDT





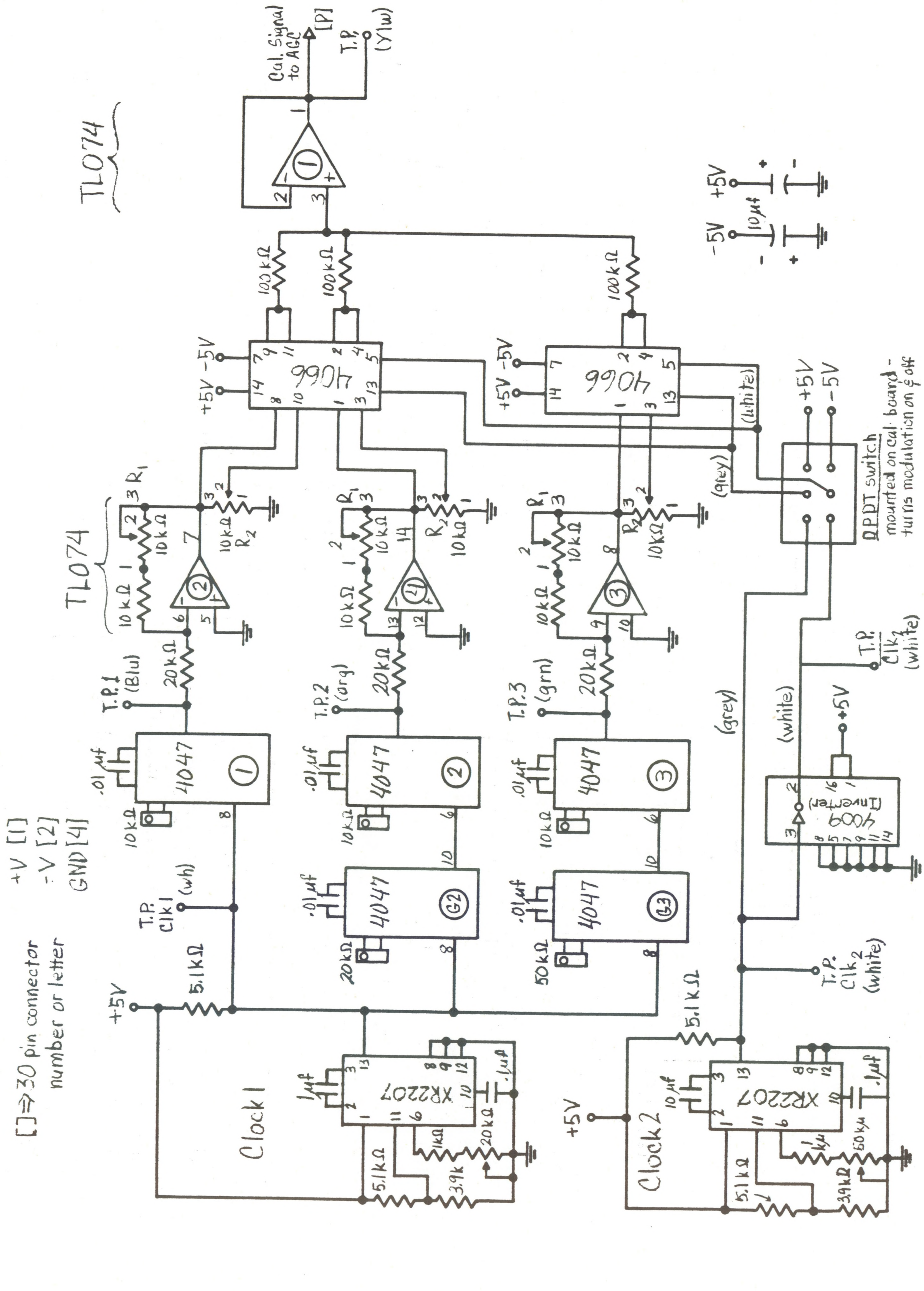
Calibration Board Timing Diagram

TOP VIEW OF BOARD

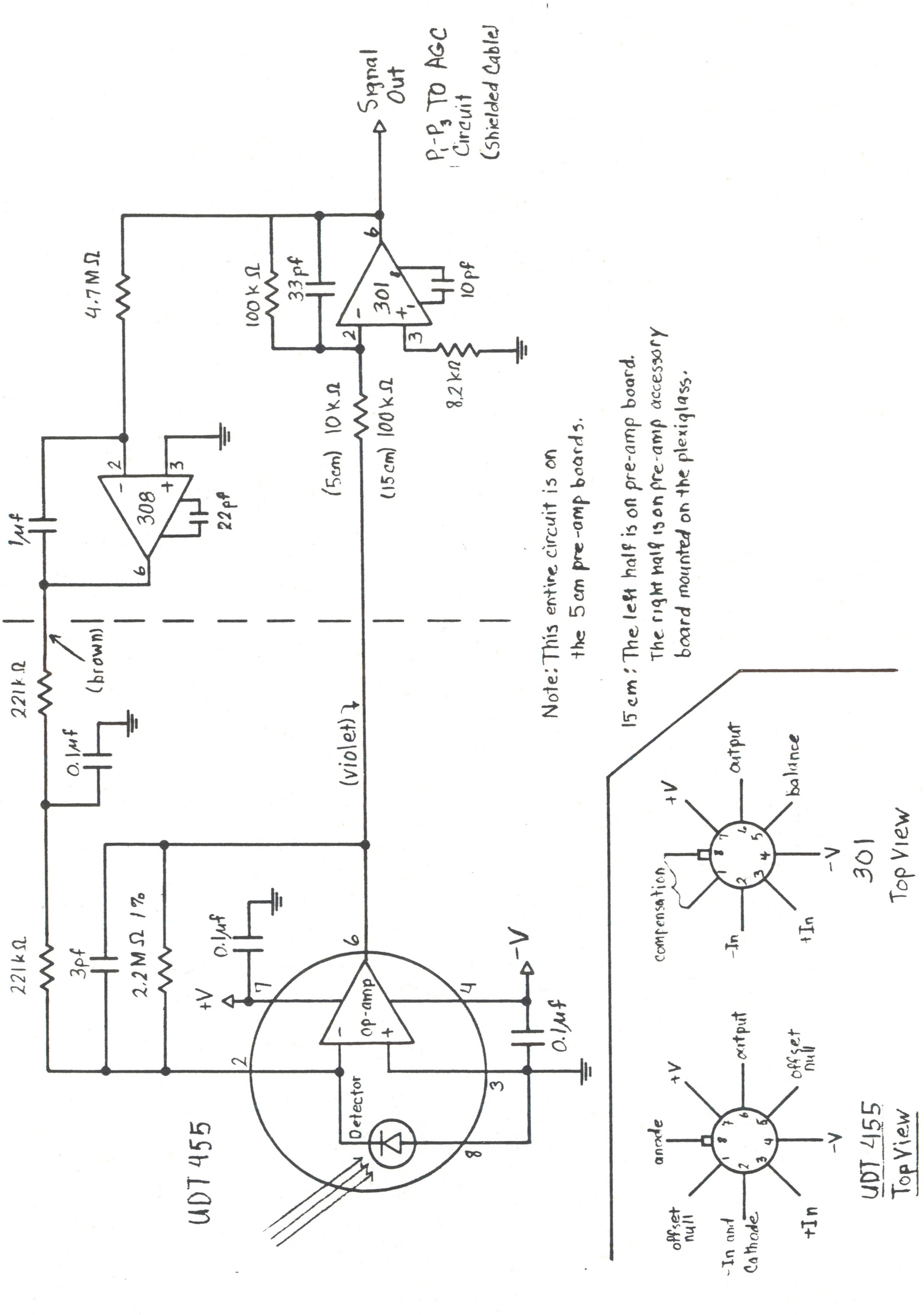


*Note: There are 3 pots mounted on the back of the board. These pots adjust the amplitude of the calibration pulses and are ordered $R_1 1$, $R_1 2$, $R_1 3$ (top to bottom).

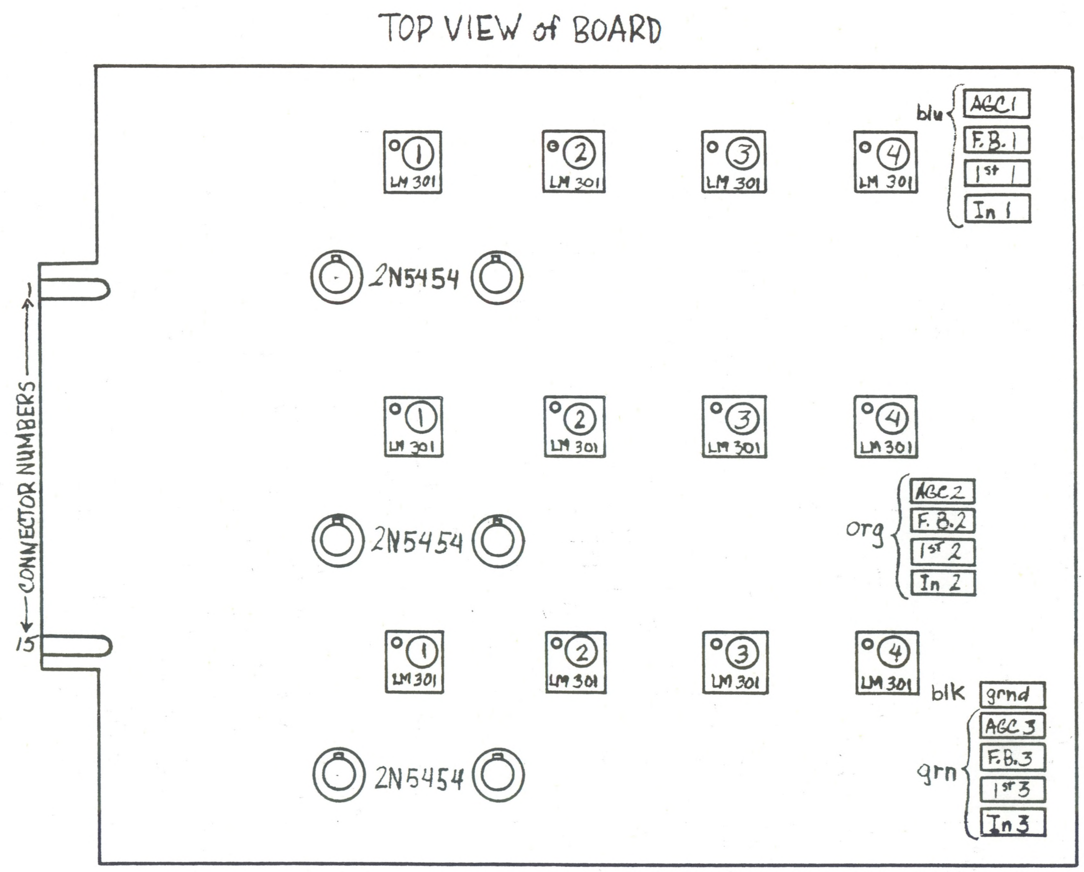
Calibration Board Layout



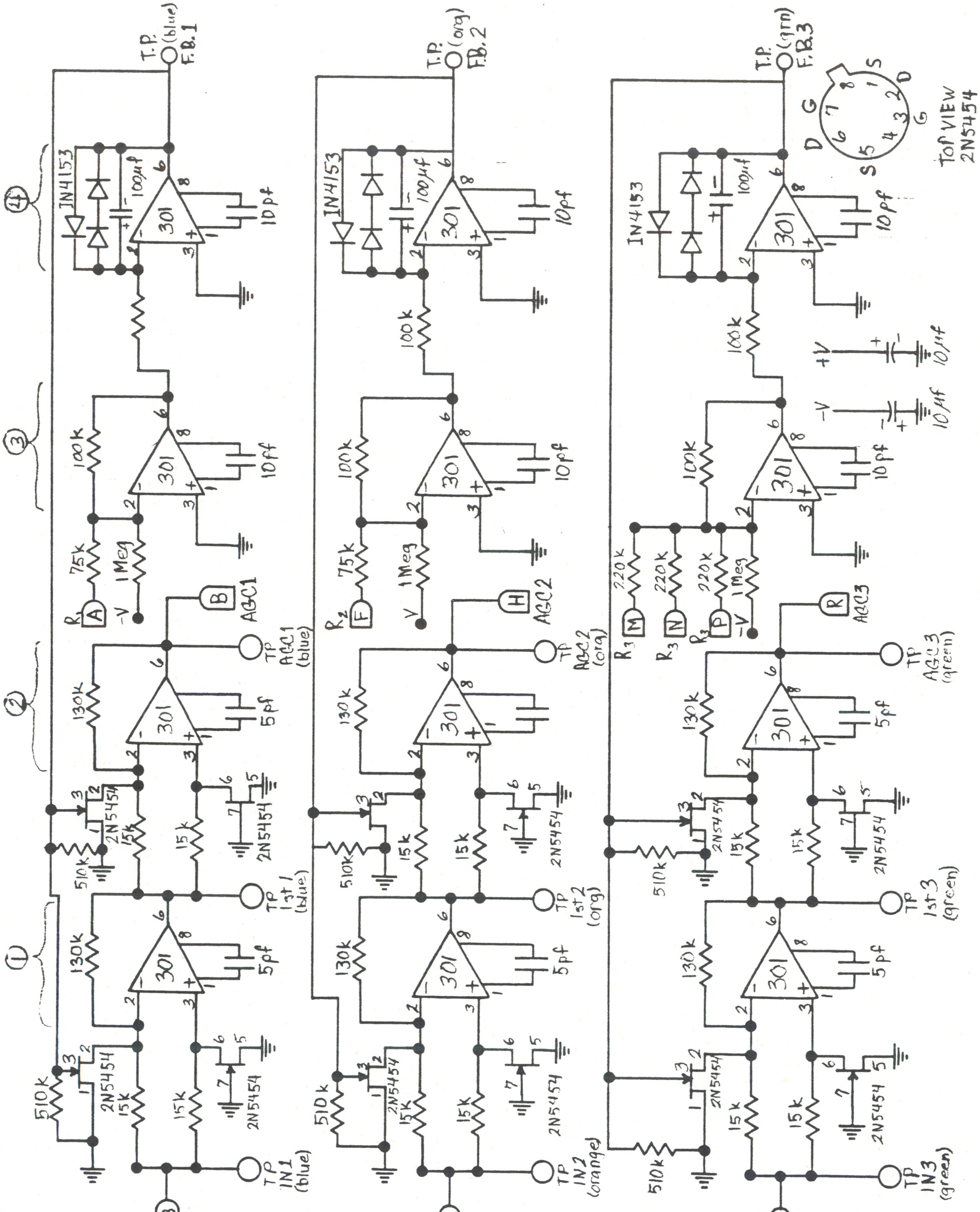
Calibration Board Circuit



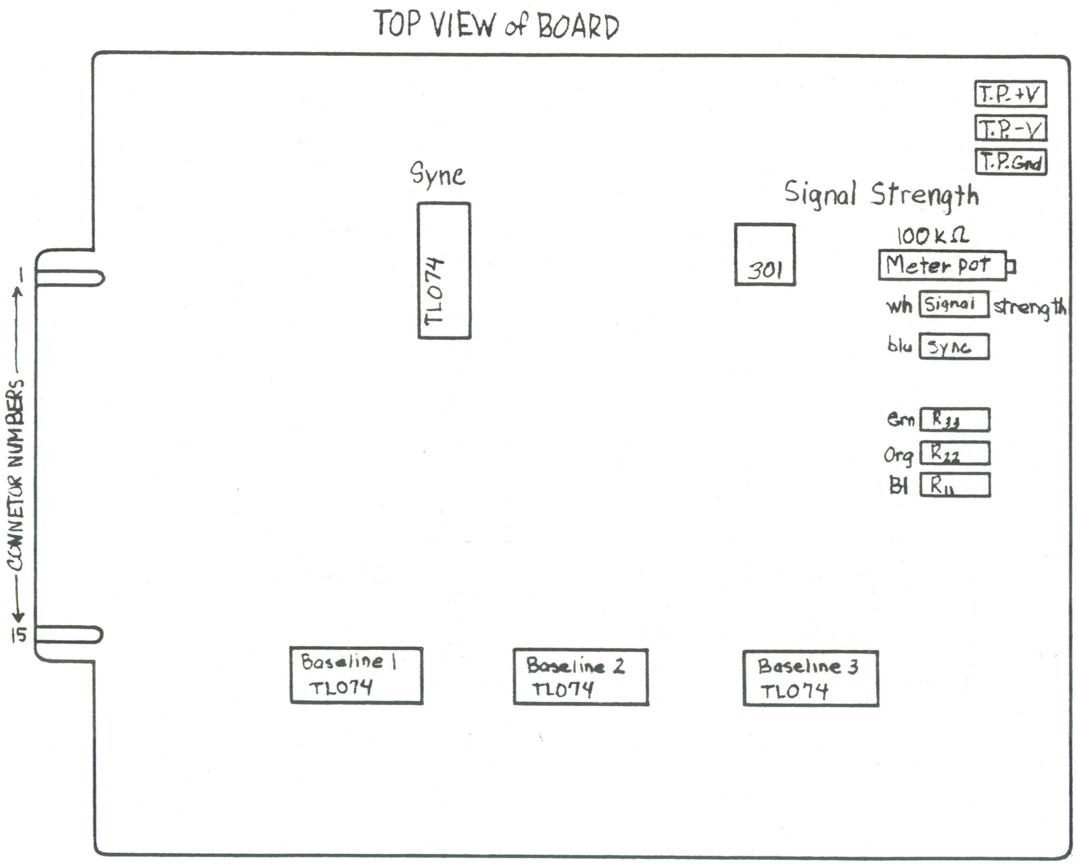
Preamplifier Circuit



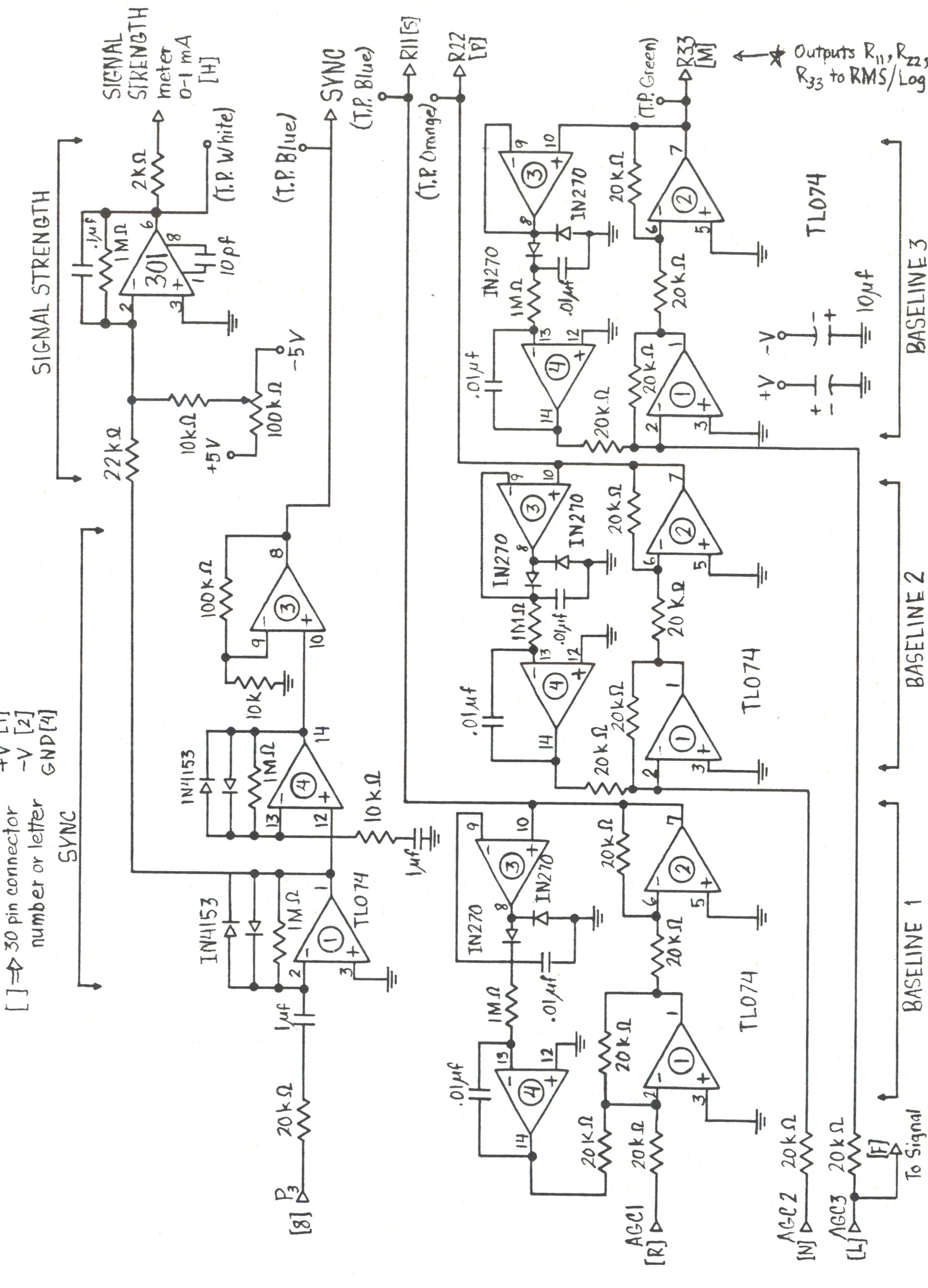
Automatic Gain Control Layout



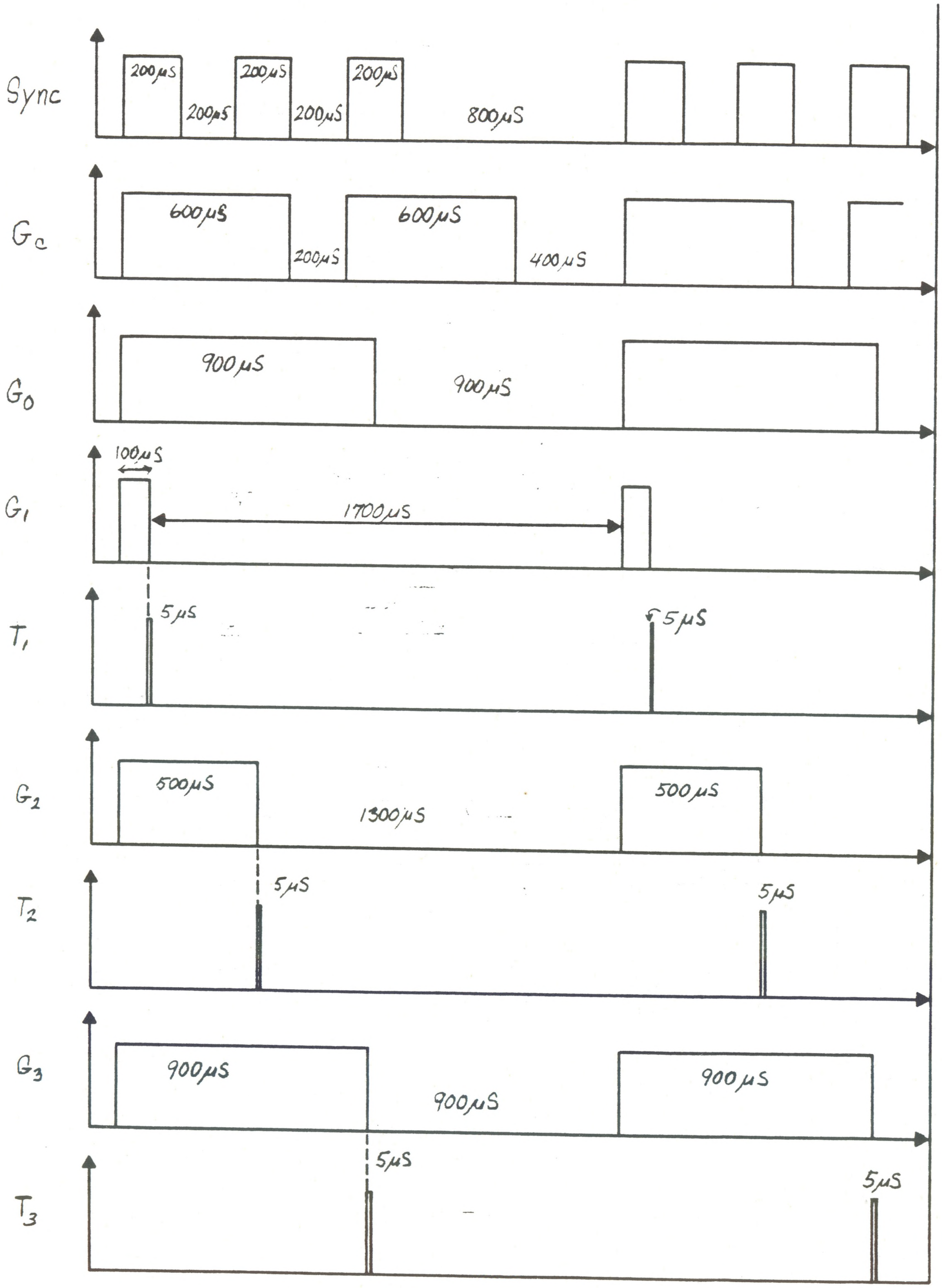
Automatic Gain Control Circuit



Baseline/Sync/Signal Strength Board Layout

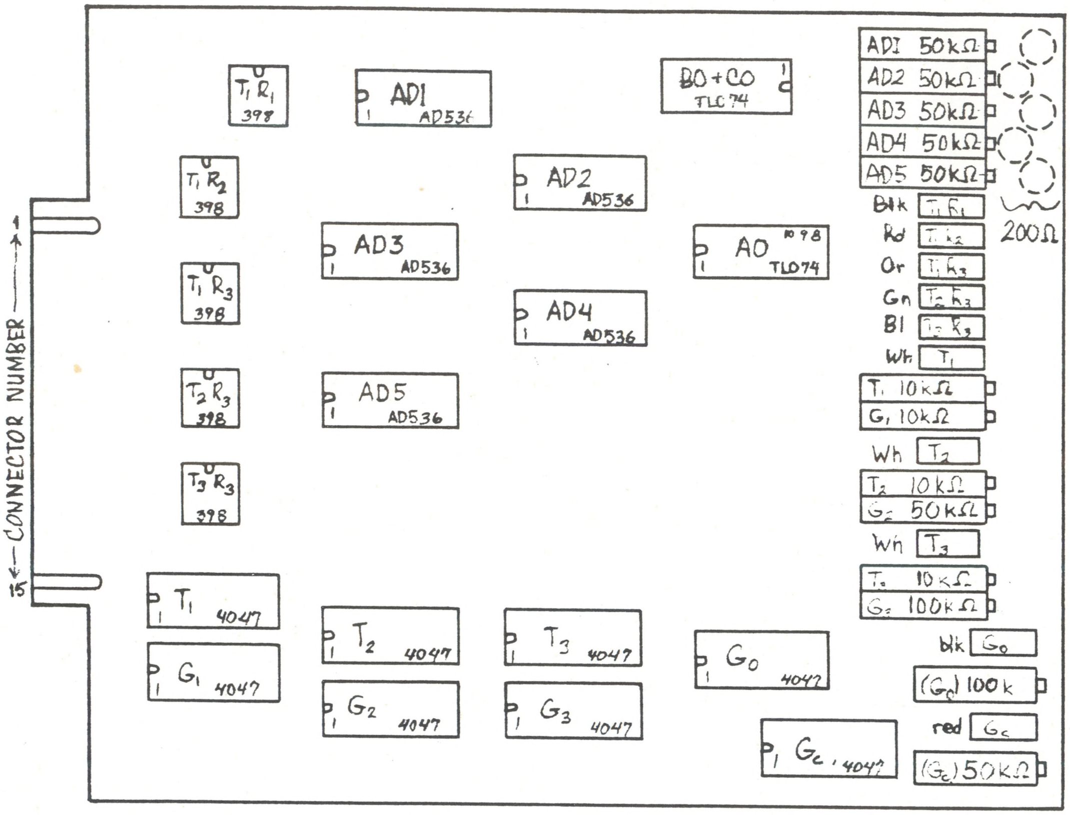


Baseline/Sync/Signal Strength Circuit

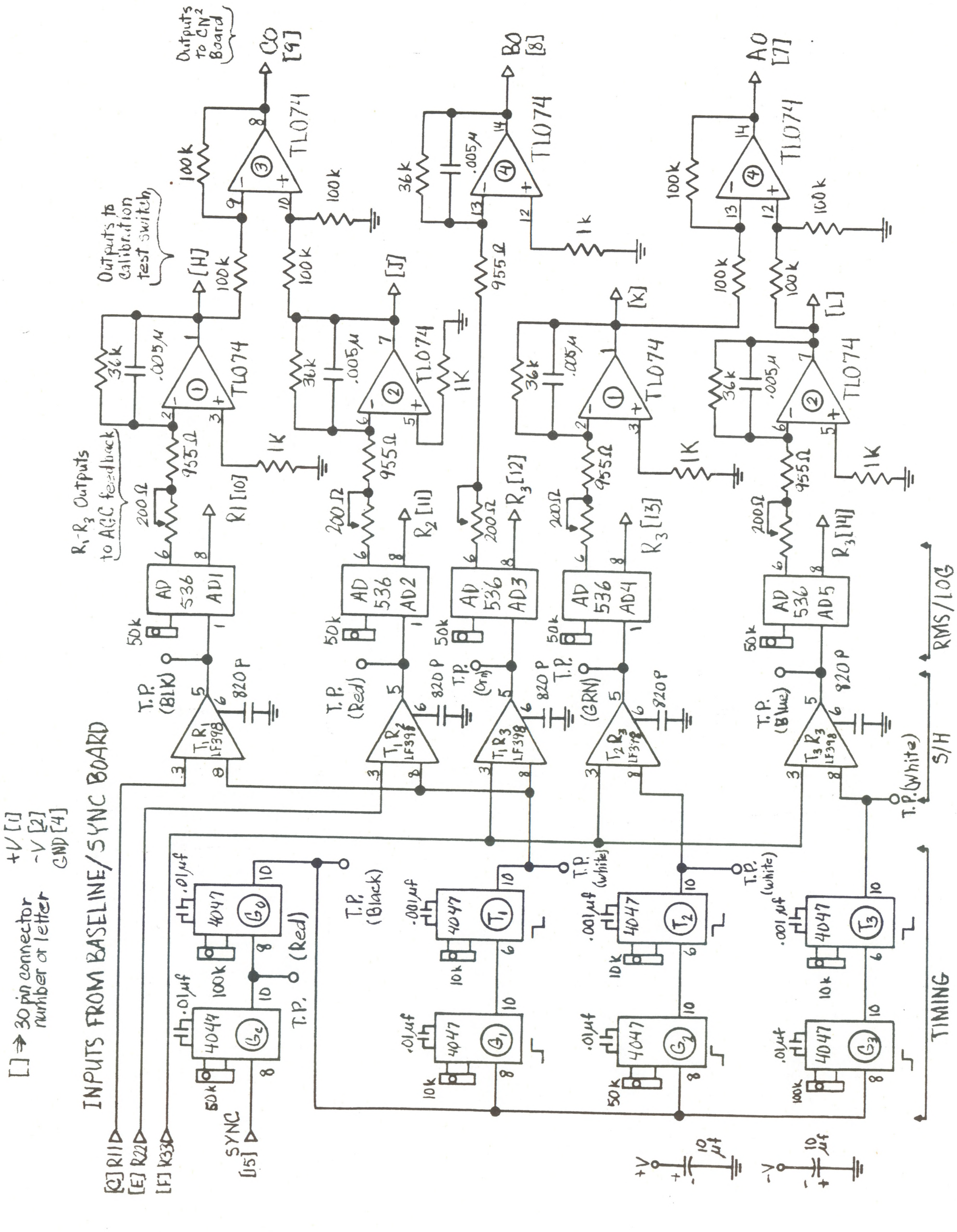


RMS/Log Board Timing

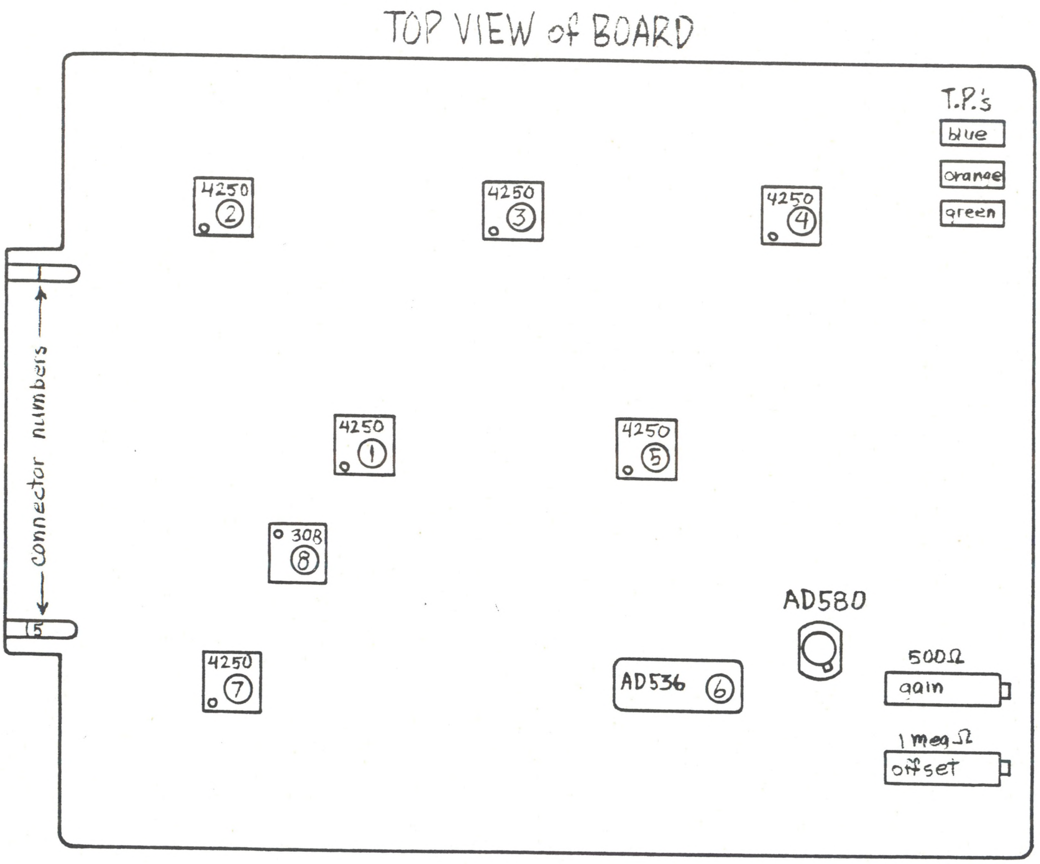
TOP VIEW OF BOARD



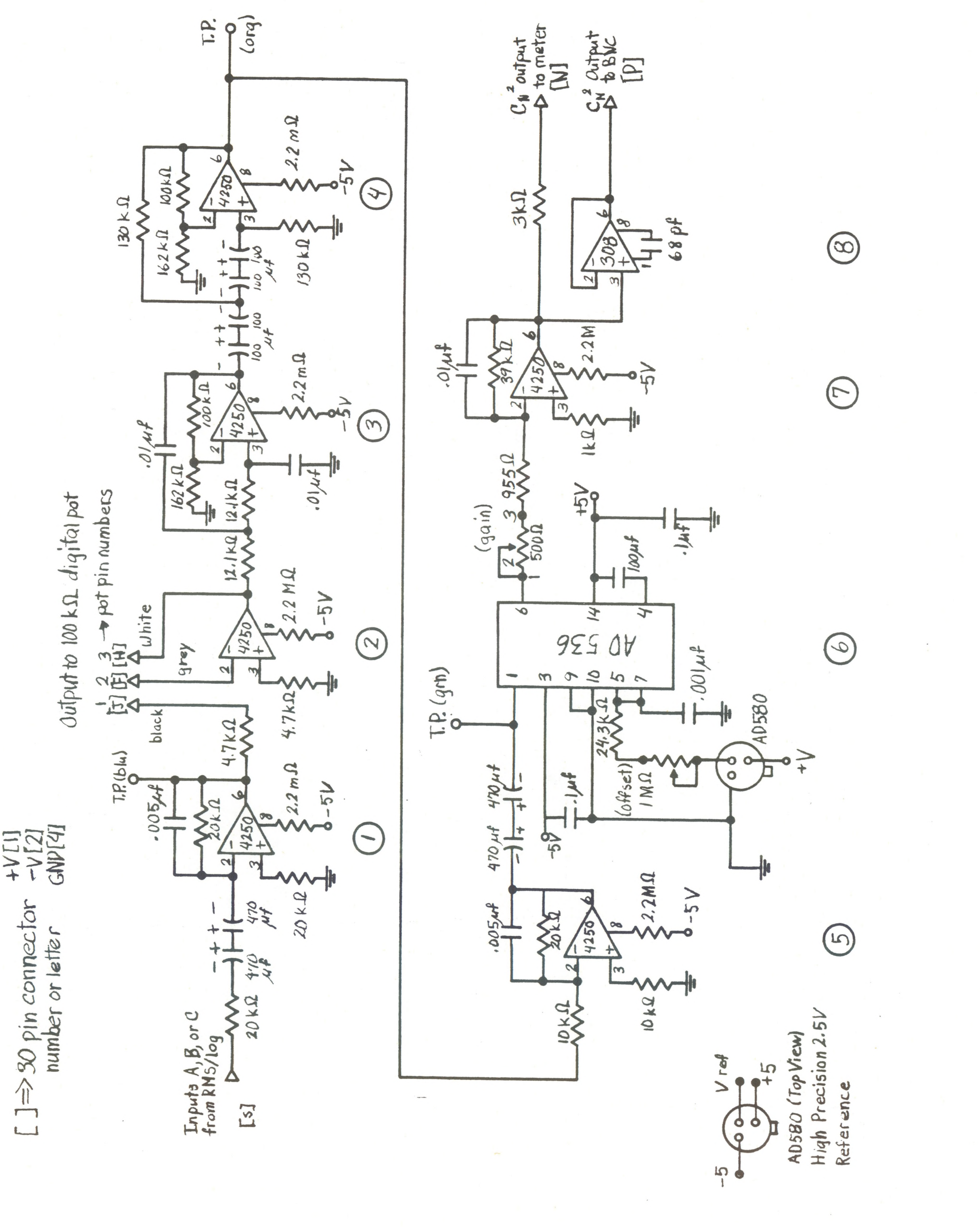
RMS/Log Board Layout



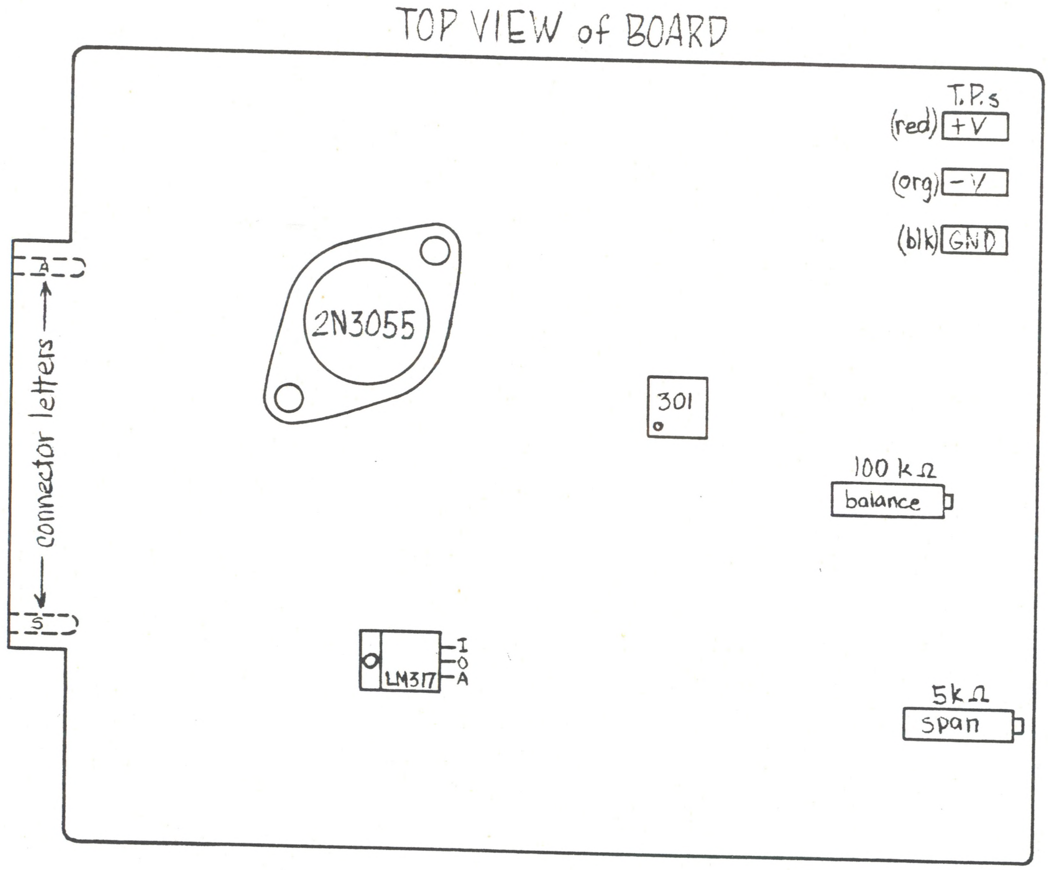
RMS/Log Circuit



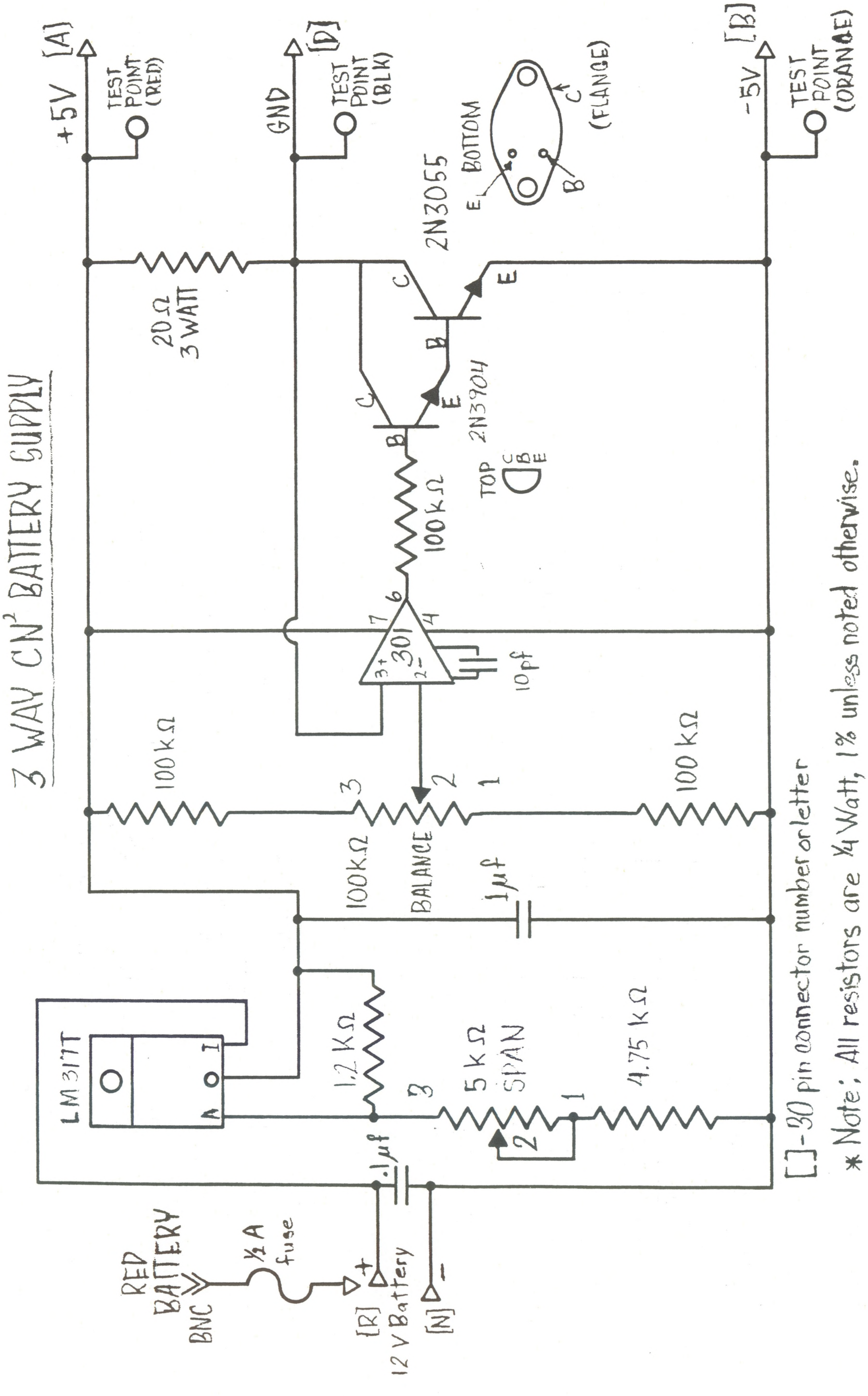
C_n^2 Board Layout


[ ] ⇒ 30 pin connector number or letter
+V [1]
−V [2]
GND [4]
Inputs A, B, or C from RMS/log
[s]
Output to 100 kΩ digital pot
pot pin numbers
black
grey
white
T.P. (blu)
T.P. (org)
T.P. (grn)
4250
308
AD 536
AD580
(gain)
(offset)
C_N^2 output to meter [N]
C_N^2 output to BNC [P]
V ref
AD580 (Top View)
High Precision 2.5V Reference
1
2
3
4
5
6
7
8

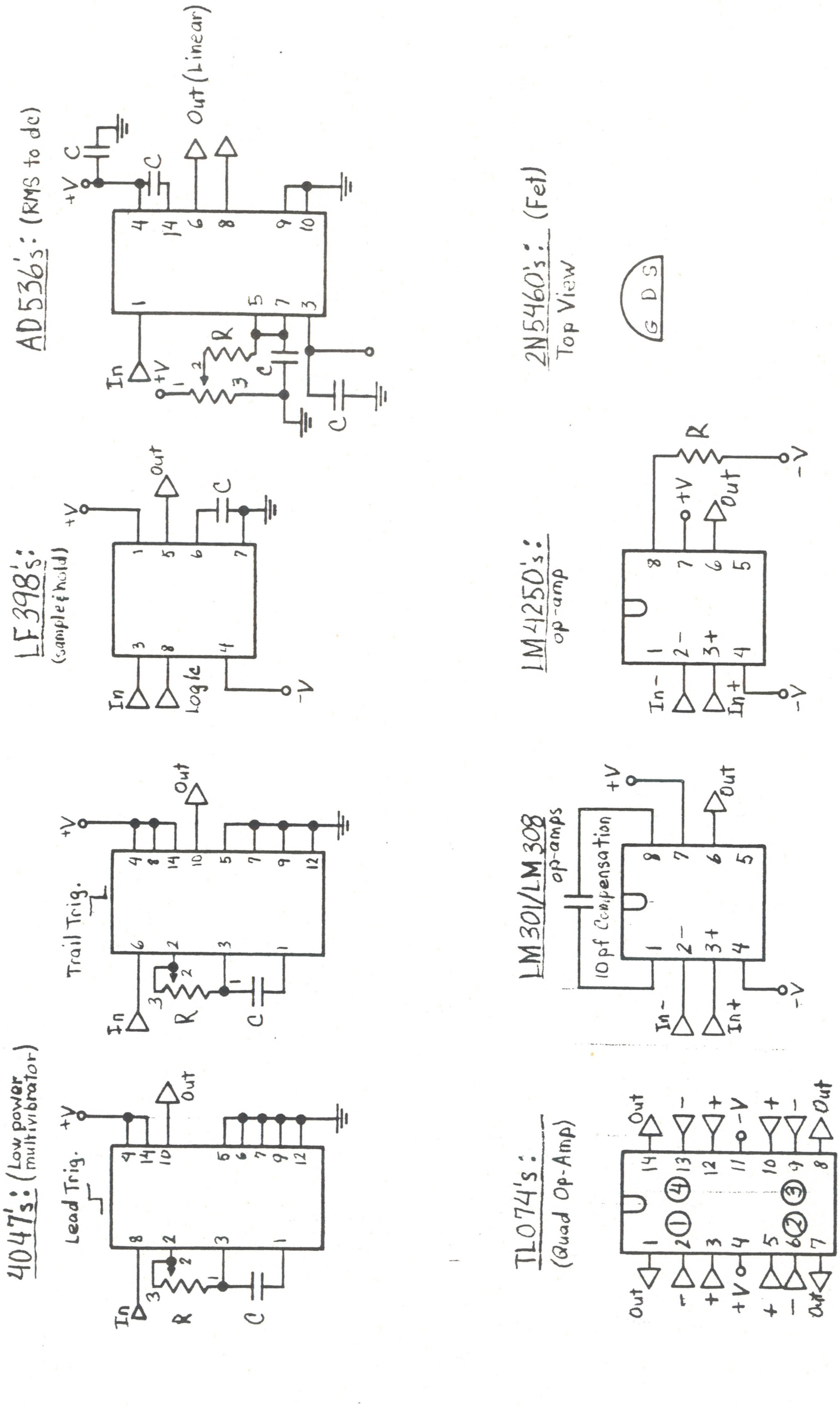
C_n^2 Circuit



Battery Power Supply Board Layout



Battery Power Supply Circuit



Chip Printout

Receiver calibration procedure

Place the RUN/CAL switch in the CAL position.

The CAL TEST switch must be held in either position (up or down) for the duration of the calibration procedure.

Refer to board layouts for location of pots and test points (TP).

Turn power off for removal or insertion of cards.

Calibration board

Refer to the calibration timing diagram and board layout.

1) Install the extender card.

2) Place the modulation ON/OFF switch in the ON position (The switch is on the calibration board). Note: For steps 3)-6) and 8), trigger the scope off of TP CLK1.

3) TP CLK1 (white).
   a) Adjust clock 1 pot to obtain a 900 µs pulse.

4) TP1 (blue).
   a) Adjust 1 for a 200 µs pulse.

5) TP2 (orange).
   a) Adjust 3 for a 200 µs pulse.
   b) Adjust G3 so the pulse begins 400 µs after the CLK1 pulse.

6) TP3 (green).
   a) Adjust 3 for a 200 µs pulse.
   b) Adjust G3 so the pulse begins 800 µs after the CLK1 pulse.

7) TP CLK2 (white) (trigger scope here also).
   a) Adjust clock 2 for a 50 ms pulse.

8) TP output (yellow).
   a) Adjust pulse gain pots ($R_1$1,$R_1$2 and $R_1$3 on rear of board) to obtain a 1.20 volt peak pulse.
   b) Adjust the modulation amplitude pots ($R_2$1,$R_2$2, $R_2$3 to obtain a modulated pulse of 0.60 volt (1/2 of peak pulse).

9) Remove the extender card.

AGC board

There are no adjustments possible on this board. The three AGC circuits should be tested, however, to assure proper operation.

1) TP's In1, In2 and In3.
   a) The three inputs should be identical to the output of the calibrator board.

2) TP's 1st1, 1st2 and 1st3.
   a) The signal at these points should be similar to the input but will be inverted with an amplitude modification and slight DC offset.

3) TP's FB1, FB2 and FB3.
   a) This is a feedback signal and should be a negative DC signal between -0.1 and -0.2 volts.

4) TP's AGC1, AGC2 and AGC3.
   a) These are the modified input signals with the gain adjusted.
   b) Place the RUN/CAL switch in the RUN position for several seconds and then switch back to CAL. The signal should start very large and gradually (5-10 sec) reduce to its steady state amplitude. (In the RUN position, the AGC receives no input signal and is attempting to increase the gain to produce a valid signal. Switching back to the CAL signal shows the increased gain and automatic adjustment back to steady state.)

Baseline/sync/signal strength board

1) TP's R_{11}, R_{22} and R_{33}.
   a) These signals should be similar to the AGC outputs (AGC1, AGC2, and AGC3 respectively) but the base of of each signal should be at zero volts. The base should be steady at zero and not bounce up and down.

2) TP sync (blue) (Refer to RMS/log timing diagram.)
   a) The sync signal should be 3 positive pulses, each approximately 200 μs in duration separated by 800 μs. Sets of pulses are separated by approximately 800 μs.

3) Place the RUN/CAL switch in the RUN position and wait several seconds for the needle to stabilize. Adjust the signal strength pot so the meter reads zero. Switch back to the CAL position. The meter should now read its maximum value.

RMS/log board

Refer to RMS/log timing diagram and board layout.

1) TP's G_c through T_3 (trigger scope off of sync pulse).
   a) G_c and G_o: Adjust pots to match timing diagram.
   b) T_1, T_2 and T_3: Adjust G_1, G_2 and G_3 to move the pulse to the proper time with respect to the first sync pulse. Adjust T_1, T_2 and T_3 for the proper

c) To test for proper adjustment, check pulses T_1, T_2 and T_3 against the sync signal. Each of these pulses should occur near the center of its corresponding sync pulse.

2) TP's T_1R_1 through Y_3R_3
   a) These signals should be approximately 0.4 volt peak to peak square waves with a period of 100 ms and a -0.5 volt offset.

3) Calibration of AD-536's.
   a) Turn power off and remove RMS/log board.
   b) Remove the five 398 IC's.
   c) Install extender card and RMS/log board.
   d) Turn off CAL test switch (place in center position).
   e) Turn power on.
   f) Apply a +0.10 volt DC input signal to TP T_1R_1 (pin 1 of the AD-536). Using a voltmeter, observe the voltage at pin 1 of the B0 and C0 TL074. Adjust the 50 kilohm pot for AD1 to obtain a reading of 0.0 volts.
   g) Change the input signal to +1.00 volt and adjust the 200 ohm AD1 pot for a +2.00 volt output.
   h) Repeat steps f) and g) for the remaining four AD-536 circuits using the following TP's and TL074 pin numbers for input and output.

AD-536	Input TP	TL074	Pin Number
AD1	T_1R_1	B0 & C0	1
AD2	T_1R_2	B0 & C0	7
AD3	T_1R_3	B0 & C0	14
AD4	T_2R_3	A0	1
AD5	T_3R_3	A0	7

   i) Remove the extender card.
   j) Replace the 398's and re-install the RMS/log card.
   k) Return the CAL test switch to the ON position.

C_n^2 boards (3)

1) Note the readings on the path length calibration digital pots (mounted on rear panel). Then set all three pots to 594.

2) Blue TP's.
   a) The signals should be 0.6 volt peak-to-peak with a period of 100 ms and zero offset.
   b) Check C_n^2 boards A, B and C.

3) Orange TP
   a) The signals should be approximately 1.04 volts peak-to-peak, of period 100 ms and zero offset.
   b) Check boards A, B and C.

4) Green TP
   a) The signals are approximately 2.1 volts peak-to-peak of period 100 ms with zero offset.
   b) Check boards A, B and C.

5) Calibration of AD-536's
   a) Turn power off and remove a C_n^2 board.
   b) Remove the 4250 opamps 1 - 5.
   c) Install the C_n^2 card and turn power on.
   d) Connect a voltmeter to the corresponding C_n^2 board.
   e) Apply a +0.10 volt signal to the green TP (pin 1 of the AD-536). Adjust the 1 megohm offset pot for a 0.00 volt output.
   f) Change the input signal to +1.00 volt and adjust the 500 ohm gain pot for a +2.00 volt output.
   g) Turn power off and replace 4250 opamps 1 - 5.
   h) Repeat the procedure for each card.

Post calibration tests

1) With all cards in place, modulation on, in CAL position with CAL test switch first up and then down, all 3 C_n^2 BNC readings should be +2.00 volts +-0.05.

2) The three BNC readings should remain approximately the same when the CAL test switch is placed in the opposite position.

3) Turn the modulation off. In CAL position with CAL test either up or down, the C_n^2 readings will gradually drop to -2.3 volts or less.

4) Return the path length calibration pots to the original settings.

Battery Supply Board

1) Important: Unplug all cards except battery board.

2) Using a 12 volt automotive battery or a power supply which supplies 12 to 30 volts DC at 2 or more amps, plug the supply into the battery banana plugs on the rear panel.

3) Switch the AC/BATTERY switch to BATTERY.

4) Place a voltmeter across the red (+5 volt) and orange (-5 volt) test points. Adjust the span pot for 10.0 volts.

5) Adjust the balance pot for a +5.0 volt reading across the red (+5 volt) and black (ground) TP's.

6) Check the voltage across the orange (-5 volt) and black (ground) TP's. It should read -5.0 volts. If not, then repeat steps 4), 5) and 6) until the outputs are +5.0 volts and -5.0 volts.

7) Unplug a battery lead and install all cards. Place the RUN/CAL switch in CAL position and the CAL TEST switch in either position. Reconnect the battery.

8) Repeat steps 4), 5) and 6) until proper voltage is achieved.