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FIVE-DAY RECORDER SEISMIC SYSTEM

by Ed Criley and Jerry Eaton

(with a section on the TIME CODE GENERATOR by Jim Ellis)

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I. INTRODUCTION

The 10-day recorder seismic system used by the USGS since 1965 has been modified substantially to improve its dynamic range and frequency response, to decrease its power consumption and physical complexity, and to make its recordings more compatible with other NCER systems to facilitate data processing. The principal changes include:

1. increasing tape speed from 15/160 ips to 15/80 ips (reducing running time from 10 days to 5 days with a 14" reel of 1 mil tape),
2. increasing the FM center frequency by a factor of 4, from 84.4 hz to 337.6 hz,
3. replacing the original amplifiers and FM modulators with new low-power units,
4. replacing the chronometer with a higher quality time code generator (with IRIG-C) to permit automation of data retrieval,
5. eliminating the amplifier/WWVB radio field case by incorporating these elements, along with the new TCG, in the weatherproof tape recorder box,
6. reducing the power consumption of the motor drive circuit by removal of a redundant component.

In the new system, the tape recorder case houses all components except the seismometers, the WWVB antenna, the 70 amp-hour 12 VDC battery (which powers the system for 5 days), and the cables to connect these external elements to the recorder box.

The objectives of this report are:

1. to describe the new 5-day-recorder seismic system in terms of its constituent parts and their functions,
2. to describe modifications to parts of the original system that were retained and to document new or replacement components with appropriate circuit diagrams and constructional details,
3. to provide detailed instructions for the correct adjustment or alignment of the system in the laboratory, and
4. to provide detailed instructions for installing and operating the system in the field.

II. DESCRIPTION OF THE FIVE-DAY RECORDER SEISMIC SYSTEM

a. Overview

The system is built around a modified version of the Precision Instrument PI 5100 7-track tape recorder. It consists of seismometers, seismic amplifiers and associated FM modulator/head drivers, a WWVB time code signal radio, a time code generator, reference frequency and bias signal generators, a mixer/head driver for the multiplexing and direct recording of the time signals and reference frequency, and the PI 5100 1/2 inch tape transport. Power for 5 days operation of the system is provided by a 70 amp hour 12 VDC automobile battery. All components except the seismometers, WWVB antenna, 12 VDC battery, and associated connection cables are housed in the tape recorder case and are powered by the same power supply as the tape recorder transport.

A schematic diagram of the electronics for recording seismic, timing, and reference signals is shown in Figure 1. Six of the 7 tape tracks are used to record seismic data in the FM mode. The 7th track is used to record a multiplexed timing and reference frequency signal in the direct record mode.

A block diagram of the system (excluding the tape drive control) is shown in Figure 2. The layout of the components in the recorder box is shown in Figure 3. In Figures 2 and 3, circuit boards are identified by the prefix B, symbols designating connectors are enclosed in parentheses and are identified by the prefix J, more complex control assemblies are also designated by the prefix J, but are not in parentheses, switches are identified by the prefix S, and fuses are identified by the prefix F.

b. Data channel electronics

The 6 FM data channels are laid out in pairs (both on one circuit board) to permit 2 modes of operation:

1. One input with separate Hi and Lo outputs.

2 Two separate inputs with separate Hi outputs.

The purpose of this configuration is to permit the system to be used with 3 seimometers, each recorded at 2 gain levels, or with 6 seismometers, each recorded at only 1 gain level. In the Hi/Lo configuration, the Lo channel is 30 db below the Hi channel. Both are driven by the channel 1 seismometer and are under the control of the channel 1 attenuator.

The Hi channel amplifiers consist of 3 RC-coupled IC amplifiers with a maximum total gain of 96 db. The gain of the second stage is adjustable in 6 db steps from 42 db to 0 db by an attenuator on the control panel. Coupling between stages 1 and 2 and between stages 2 and 3 is accomplished through identical passive 6 db/octave band pass filters whose cutoff frequencies can be changed by replacing the appropriate capacitors, which are mounted on "standoffs" on the circuit board. The overall amplifier response drops off at a rate of 12 db/octave at frequencies above and below the passband determined by these coupling filters. The amplifier output is RC coupled to the modulator input (low frequency cutoff at about 0.035 hz). The modulator center frequency is 337.6 hz and its sensitivity is ±135 hz per ±4.0 volts. The tape recorder heads are driven by the modulator output signals without further conditioning.

For the Lo output option, a separate low gain 3rd amplifier stage, which is driven by the same input as the Hi level 3rd amplifier stage, is switched (on the circuit board) to drive the modulator of the second seismic channel. In this mode, the seismic amplifier of the second channel is disconnected from its modulator, which is then driven by the Lo output of the first channel amplifier.

The input noise level of the preamp, "seen" through the normal 0.1 hz to 35 hz passband of the amplifier, is about 1.0 μVp-p. This noise appears at the output of the Hi level amplifier, operating at maximum gain, at a level of about 40 mV p-p.

The amplifier output is limited by the supply voltage to about ±4.5 V. Thus, the dynamic range of the amplifier when operated at maximum gain is about 46 db. This figure increases from 46 db to 64 db as attenuation is increased from 0 db to 18 db because the maximum output level remains fixed while the preamp noise is attenuated by a reduction of gain in the second stage. As the attenuation is increased beyond 18 db the dynamic range is limited by amplifier noise in the second stage. Because the second stage internal noise should decrease as second stage gain is decreased (the method employed to increase attenuation) the amplifier dynamic range should continue to increase with increasing attenuation. This improvement is of no practical consequence, however, because the system dynamic range is limited by the tape record/tape playback portion of the system to 42 db or less.

c. Multiplex channel electronics

Two time code signals and a compensation reference frequency are multiplexed together and recorded on the 7th tape track in the direct record mode. For this purpose signals from 3 VCO IC's and 1 frequency divider IC, and associated L-C sine wave shapers, are combined in a summing amplifier that serves as a multiplexer/head driver. The first VCO is modulated by the time code from the WWVB radio (272 $\pm$ 10 hz). The second VCO is modulated by the IRIG-C time code from the TCG (408 $\pm$ 10 hz). The frequency divider IC divides the 2.56 Mhz crystal frequency to the 625 hz compensation reference frequency. The third VCO, which is unmodulated, produces the high frequency bias signal (9 Khz) required for the direct mode recording of the three multiplexed information subcarriers.

d. Seismometers

The seismometers currently used with the system are Mark Products L-4C's, which have a natural frequency of 1.0 hz, a coil resistance of 5500 ohms, an open circuit damping constant of about 0.28, and a motor constant (open circuit) of about 2.8 volts/cm/sec. Prior to use, the seismometers are calibrated; and values of resistors for an L-pad network to adjust the seismometer damping to 0.8 and the effective motor constant (emf across the 10 Kohm amplifier input inpedance) to 1.0 volt/cm/sec are calculated. The resistors of the L-pad are soldered into a 4-pin connector at the (recorder) end of the seismometer leads.

Normally the system is set up with 3 seismometers (1 vertical and 2 horizontal components), which are connected to the recorder at connector J2 through a 3-pair shielded cable.

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The wiring guide for the seismometer cable and associated connectors is shown in Figure 18 and discussed in the appendix.

e. WWVB Receiver

The WWVB receiver currently used with the system is the True-Time Model 60-T. This receiver is used with the True-Time Model A-60 FS antenna, which employs a ferrite core antenna coil and a preamp/line driver. It operates at 60 khz (the WWVB transmission frequency) and has a sensitivity of 0.5 μV. For power, it requires a ±5VDC supply and draws 6 ma from each side of the supply.

The receiver circuit board is mounted on the side of the card cage. The antenna is located outside the recorder case and is connected to the system through connector J18 by a coax RG58A/U cable with male coax connectors on both ends.

An alternate WWVB receiver (used prior to the system modification) is the Develco Model 3202A, which employs a passive 5-foot-long ferrite core loop stick antenna (Model 1102AX). It operates at 60 khz, has a sensitivity of 10 μV, and draws 27 ma from a -10 to -16 VDC power source. It has a phone jack for monitoring the 2.5 khz IF. The detected (code) output is adjustable to 2.5 VDC.

The output signal from the WWVB receiver is fed to the multiplex board through connector J11-Y.

f. Time Code Generator - by Jim Ellis

The low power time code generator used with this system was designed specifically for this application. It consists of the following modules:

1. temperature compensated crystal oscillator,
2. minor time counter frequency divider chain,
3. major time counter frequency divider chain,
4. code generator,
5. display driver, and
6. control and display panel.

The TCG requires a nominal 12 VDC (11-15 VDC) power source and draws 20 mA with the display on and 8 mA with the display off. The main TCG assembly is mounted on the bottom of the tape recorder deck plate beside the recorder card cage, and its control and display panel is mounted on the recorder deck plate. The output of the TCG is fed to the multiplex board through connector J11-D.

Details of the individual components are as follows:

1. Temperature compensated crystal oscillator

   Frequency - fo = 1.0 Mhz

   Temperature stability - $\delta f_{max} = \pm 1 \times 10^{-7}, 0^{\circ}C < T < 50^{\circ}C$

   Aging rate - $\delta f_{max} = 1 \times 10^{-6}$ per year.

2. Minor time counter

   Divides 1 Mhz crystal output to 1 hz.

   Includes ADVANCE/RETARD circuitry with rates of 10 and 100 milliseconds/second. The 1 khz signal in the divider chain is interrupted when the generator is in HOLD.

3. Major time counter

   Counts the 1 hz signal out to hundreds of days. The days counter can be programmed by means of a wired plug for calendar or elapsed time, normal or leap years, or to count elapsed time to

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999 days. The "standard" configuration for the 5-day recorder is the Julian calendar.

4. Code generator

Sockets are wired for two code generators. Either generator can be programmed by wired plug to generate any one of three codes: IRIG-H, IRIG-C, or IRIG-E. If only one code is wanted, sockets for the second generator are left empty.

The codes are serial, DC level shift, pulse width modulated codes containing BCD time of day and day number information. One of the generators can be programmed by wired plug for 4 groups of 4 bits each of instrument identification. These bits are appended to the code immediately following the hundreds-of-days group of bits and are in the same format as the other code bits.

The "standard" configuration for the 5-day recorders is the IRIG-C code only.

5. Display driver

The L.E.D. display is driven by a circuit that time multiplexes the outputs of the nine major time counters to the appropriate display digit. Display is automatically turned off when units of minutes increments from nine to zero. This feature will reduce power if the display is left on by the operator.

6. Control and display panel (Figure 4)

HOLD pushbutton	- stops counting
RUN pushbutton	- starts counting

RESET pushbutton	- resets all counters to zero (disabled in RUN MODE)
ADV-OFF-RETARD toggle	- speeds up or slows down the counting rate
RATE toggle	- selects advance/retard rates of 10 or 100 milliseconds/second
Display	- nine digit L.E.D. displays units of seconds through hundreds of days
DISPLAY ON-OFF (center off)	- turns display L.E.D.'s on or off
Digit select rotary switch	- selects one of eight digits (tens of seconds through hundreds of days) for setting
SET pushbutton	- increments digit selected by digit select rotary switch (disabled in RUN mode)
Code and 1 hz jacks	- monitor points for serial codes and 1 hz signal
Run jack	- input for external start signal

g. Tape recorder

Type: Precision Instrument PI 5100 (modified) ½" tape recorder with stacked 14" reels.

Tape speed: 15/80 ips

Running time: 5 1/3 days per 7200' of tape (14" reel of 1 mil tape)

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Tape Track assignments:

1. 6 FM data channels (tracks 1, 2, 3, 4, 6, 7) with 337.6 hz center frequencies and ±40% deviation
2. 1 direct record channel (track 5) for a multiplexed timing and reference frequency signal consisting of WWVB (272 ± 10 hz), TCG (408 ± 10 hz), and Ref (625 hz)

Power requirements (entire system):

4 watts from a 12 VDC source.

Approximately 40 amp hours (at 12 V) for 5 days operation.

Input connectors:

1. power
2. seismic signals
3. WWVB antenna

Case: weatherproof, height 10", width 16½", length 20½", weight (with enclosed system components but without the full tape supply reel) 32 lbs.

Except for the specific changes to the running speed and power consumption noted below, the tape transport mechanism and electronics were not altered. The Precision Instruments manual on the PI 5100 is still the authoritative reference on those aspects of the recorder.

III. DOCUMENTATION OF CHANGES AND NEW COMPONENTS

In the previous section, the principal components of the system were described in terms of their general characteristics and functions. This section details modification of the tape recorder and describes the design, construction, and laboratory adjustment or alignment of the new power supply, amplifier/VCO's, and multiplex channel circuitry.

a. Tape recorder modifications

The FM modulator cards, their 18-pin connectors in the card cage, and associated wiring as well as the power supply card and associated wiring were removed. New 22-pin connectors for the new amplifier/VCO and multiplex cards were mounted in the card cage, and new wiring was provided for these components as well as for the new power supply card, tape heads, and test and control panels.

The tachometer limiter/frequency standard card (B7, Figure 5) was modified to increase the tape speed from 15/160 ips to 15/80 ips. C_1 and C_2 were changed to 0.15 μF 100 VDC, C_3 was changed to 0.54 μF, and R_1 was changed to 470Ω . A jumper wire was added to connect the junction of C_6 and R_{12} to pin M on card B7 so that the 540 hz reference frequency can be monitored at position 10 of switch S16 (on assembly J16). The reference frequency can be adjusted by varying R2 on card B7.

To permit use of the servo test push button on the tape deck panel to verify proper functioning of the servo system, the MDA card (B10, Figure 6) was modified slightly. C_1 was changed to 0.022μ F

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and R2 was removed. Q2 on card B10 was removed to reduce power consumption, and a jumper was added from the emitter of P1 to the base of Q3.

The fast drive motor and associated wiring to switch S3 (drive switch) were removed. The "fast" position on S3 is now used to permit the system to be operated in the "record" mode, but with the drive motor turned off, for monitoring the data and timing channel electronics. The revised wiring of switch S3 is indicated in Figure 14.

b. Power supply

Both regulated ±12 VDC and regulated ±5 VDC supplies are required for the 5-day-recorder seismic system. Because the old power supply provided only regulated ±12 VDC, it was necessary to build a new one.

The new power supply (B6) provides regulated ±12 VDC for the tape recorder drive train and regulated ±5 VDC for the seismic amplifiers and VCO's, for the multiplex board, for the TCG level shifter, and for the True-Time WWVB receiver. The unregulated 12 VDC is used for the TCG, the MDA board, and the Develco WWVB receiver when it is used.

The regulated ±12 VDC (at ±100 ma output) is provided by a Datel Systems, Inc., powermite series power supply modular DC-DC converter BPM 12/100-DIZ, Case I.

The regulated ±5 VDC is provided by a KGS Electronics KGS1447T 11-pin module network, with 12 VDC input and ±8.2 VDC output, driving a 2N3391 and LM4250 network for the regulated +5 VDC and an

LM 120H network for the regulated -5 VDC. RP1 and RP2 provide fine adjustment control for +5 VDC and -5 VDC, respectively.

Both regulators are powered by 12 VDC. The power supply card circuit diagram is shown in Figure 7 and the component layout and component values are shown in Figure 8.

c. <u>Amplifier/VCO</u>

The design of the amplifier/VCO was discussed in general terms in section II, above. Here, we shall present a more detailed description of the construction of this unit with the aid of the circuit diagram (Figure 9) and component layout diagram (Figure 10).

The amplifier/VCO specifications are as follows:

1. Noise referred to input: 1.0 microvolt peak to peak with a 10 K ohm impedance source and with the 0.1 hz to 35 hz amplifier passband.
2. Frequency response: bandpass, 6 db down at 0.1 hz and 35 hz, with 12 db/octave rolloff outside the passband.
3. Voltage gain: 96 db maximum on the high level output and 66 db maximum on the low level output, with 0 to 42 db attenuation in 6 db steps.
4. Input: differential input, with 10 K ohms input impedance.
5. Supply voltage: ±5 VDC, regulated
6. VCO thermal stability: 100 ppm/^{o}C
7. Carrier center frequency: 337.6 hz
8. Carrier deviation: ±40%, i.e. ±135 hz, limited to ±145 hz.
9. VCO sensitivity: ±135 hz for ±4.0 V at VCO input

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10. Amplifier/VCO sensitivity (adjustable):

    high level 2.1 to 0.017 hz/microvolt

    low level 67 to 0.53 hz/millivolt

11. Operating temperature range: $-30^{\circ}C$ to $50^{\circ}C$

Two amplifier/VCO's are laid out on each circuit board. Each amplifier (i.e., both channel 1 and channel 2) consists of a fixed gain preamplifier (A1 or A5), an adjustable gain intermediate amplifier (A2 or A6), a fixed gain output amplifier (A4 or A7), and a VCO/head driver (M1 or M2). The channel 1 amplifier also has a low gain output amplifier (A3) that operates in parallel with the high gain output amplifier (A4); and the channel 2 VCO/head driver (M2) can be disconnected by switch SA from the channel 2 high gain output amplifier (A7) and connected, instead, to the channel 1 low gain amplifier. Coupling between amplifier stages is through passive RC bandpass filters; and the output amplifier is coupled to the VCO through a passive RC high pass filter. The two channels can be operated independently with separate inputs, or the second channel can be "slaved" to the first to provide a low gain (-30 db) output of the channel 1 signal.

The seismic signal is direct-coupled to the preamplifier (A1) which has an input impedance of 10K ohms (R2 + R13). This amplifier stage has R-C feedback (C1, R1) to provide a fixed gain of 18 db and low-pass filtering with 6 db/octave roll-off above 85 hz. If a CD4250 IC amplifier is used in the preamp, its DC offset can be nulled with RP10. Normally, an OP-7 IC amplifier, which requires slightly more power than a LM 4250 but reduces the input noise level by a factor of 4, is used in the preamp section. The OP-7 does not require RP10 and R45 for DC offset adjustment.

The preamp and intermediate amplifier stages (A1 and A2) are RC coupled through a bandpass filter (R43, C21, C22), which has 3 db down points at 0.1 hz and 35 hz and a 6 db/octave roll-off outside the band. The coupling filter has a loss of about 1.2 db inside the passband.

The RC feedback circuit of the intermediate amplifier (A2) is variable (C2; J15 resistors R1 through R7). It provides for an adjustable gain from 0 db to 42 db in 6 db steps and a 6 db/octave roll-off above 85 hz. The layout of the attenuation control board, B15, is shown in Figure 11. The DC offset of this amplifier can be nulled with RP5.

The intermediate and high level output amplifiers (A2 and A4) are coupled through a bandpass filter (R24, C12, C13) which has 3 db down points at 0.1 hz and 35 hz and a 6 db/octave roll-off outside the band. The coupling filter has a loss of about 1.3 db inside the passband.

The high level ouput amplifier (A4) has an RC feedback circuit (R23, C14) to provide a fixed gain of 38.5 db and low pass filtering with 6 db/octave roll-off above 85 hz. The DC offset of this amplifier can be nulled with RP3.

The signal at the input to the high level output amplifier is also applied to the input of the low level output amplifier (A3), but after being attenuated 12.5 db by a voltage divider (R28, R30). This amplifier has RC feedback (R31, C20) to provide a fixed gain of 21 db and low-pass filtering with 6 db/octave roll-off above 85 hz. The DC offset of this amplifier can be nulled with RP4.

The high level output amplifier (A4) is coupled to the channel 1 VCO (M1) through a high-pass filter (R16, C11, RP2) with a roll-off of 6 db/octave below 0.035 hz. When the system is used in the 3 channel, Hi/Lo output, configuration the output of the low-level output amplifier (A3) is connected through switch SA and a high pass filter (R33, C15, RP7) with a roll-off of 6 db/octave below 0.035 hz to the channel 2 VCO (M2). When the system is operated in the 6 channel, high output only, configuration switch SA connects the channel 2 high level output amplifier (A7) to the channel 2 VCO (M2) through a highpass filter (R35, C16, RP7) with a rolloff of 6 db/octave below 0.035 hz. In this configuration, the output of A3 is left open and the amplifier/VCO consisting of A1, A2, A4, and M1 is identical to the amplifier consisting of A5, A6, A7, and M2.

When A2 is operated at 42 db gain (i.e. the 0 db attenuation setting), the response of the channel 1 amplifier with high level output (i.e., A1, A2, and A4), measured at the input to the VCO (M1) between pin S and COM is:

Total gain: 96 db

Frequency response: bandpass with 6 db down points at 0.1 hz and 35 hz, rolloff 12 db/octave below 0.1 hz increasing to 18 db/ocatve below 0.035 hz, rolloff 12 db/octave above 35 hz increasing to 30 db/octave above 85 hz.

When A2 is operated at 42 db gain (0 db attenuation), the response of the channel 1 amplifier with low level output (i.e. A1, A2, and A3) measured at the input to the VCO (M2) between pin J and COM is:

Total gain: 66 db

Frequency response: same as for the high level output.

Amplifiers A1 and A5 are OP-7 integrated circuit operational amplifiers that require about 1 ma at ±5 VDC. The LM 4250's (amplifiers A2, A3, A4, A6, and A7) require about 15 μa each at ±5 VDC.

The VCO utilizes only the VCO section of a COS-MOS phase locked loop integrated circuit (CD4046). The VCO center frequency (of M1) is determined by C7 and R3, with RP1 providing fine control adjustment. The VCO center frequency is temperature compensated by the circuit consisting of R8, R9, R11 and thermistor R10. The square wave output current of the VCO (M1) is limited by the resistor R15 and is capacity coupled through C5 to the record head. The voltage drop across the 10 ohm resistor R15 is monitored to check the square wave head current (80 mv peak to peak drop for the desired 8 ma head current).

The amplified seismic signal, which can be monitored at point S, is fed to the VCO (M1) through the potentiometer RP2. RP2 is used to adjust the VCO deviation (and amplifier/VCO sensitivity).

Amplifier Alignment

Attach power to the 5-day-recorder seismic system with all cards in it. Insert the extender card in place of the amplifier/VCO to be tested, and insert the latter in the extender card. Shunt the preamplifier inputs with 10 K ohm resistors. Turn on the power (S1) and record (S2) switches and turn the drive mode switch to "fast" position (note: the "fast" drive motor has been removed, and this switch position turns on the power to the amplifier/VCO's but not to the tape drive motor). Connect an oscilloscope to common (COM) and to TP1. Check the DC balance of A1. If an OP-7 is used in A1, there is no adjustment to be made. If a LM 4250 is used in A1, its DC output can be nulled by RP10. All DC adjustments should be made to ±40 mv. Next, move the scope lead to TP2, and adjust RP5 to null the DC output of A2. Continue this process to balance the rest of the amplifiers. The corresponding test points and balancing potentiometers are as follows: A4, TP4, RP3; A3, TP3, RP4; A5, TP5, RP11 (only if a LM 4250 is used); A6, TP6, RP9; A7, TP7, RP8.

After completing the DC balance adjustments, replace the 10K ohm shunts across the preamp inputs with a low-level sine wave signal generator. Connect the oscilloscope to common (COM) and to the output signal monitor point for the amplifier being monitored (pin S for the channel 1 high gain output amplifier and pin J for the channel 1 low gain output amplifier or for the channel 2 high gain output amplifier). Check the amplifier output signals to verify the proper gain at each attenuator setting. For a 5 hz input signal of

28 μV peak to peak (10 μV RMS) the output signal levels for the 0 db attenuator setting should be 1.77 Vp-p for the high gain amplifier and 0.055 Vp-p for the low gain amplifier. Measured output signal levels should be within 10% of the nominal values.

VCO Alignment

To set the center frequency of the channel 1 VCO (M1), connect a frequency counter and oscilloscope to the stand-off between pin 4 of M1 and R15 and to common and connect a resistor substitution box across the stand-offs for R3. The center frequency is determined by C7, whose value has already been fixed, and by R15, whose value must now be determined. Turn the channel 1 amplifier attenuator to 42 db. Center RP1, which has a total range of 20 turns, and set the resistance substitution box to a value that adjusts the center frequency to 338 hz. Select a resistor (from a supply of 1%, 100 ppm/^{o}C resistors) that is closest to the value determined by the resistor box and solder it onto the R3 stand-off in place of the resistance box. Use RP1 to adjust the center frequency to 338 hz. Wait 15 minutes for the resistor (R3) to cool, and readjust the frequency if necessary.

To set the $\pm$135 hz deviation, leave the frequency counter and oscilloscope connected as above and apply +4V DC between common and the monitor point, pin S. Use RP2 to set the deviated frequency to 473 hz. Reverse the voltage between COM and pin S to verify that the VCO deviates to 203 hz.

For M2, follow the same procedures using the appropriate points for the second VCO. Connect the frequency counter and oscilloscope to the stand-off between pin 4 of M2 and to common and connect the resistor substitution box across the stand-offs for R21. Center potentiometer RP6 (20 turns). Use RP6 for the fine adjustment after R21 has been selected and soldered into place. Check the frequency again after R21 has cooled. Apply +4V DC between pin J and common and set the deviated VCO frequency to 473 hz by adjusting RP7. Reverse the voltage between common and pin J and verify that the deviated frequency is 203 hz.

d. Multiplex board

The multiplex board is designed to generate a precise 625-hz reference frequency, to multiplex the reference frequency with two time-code-modulated audio fm subcarriers (272 hz for WWVB and 408 hz for IRIG-C from the TCG), and to record this multiplexed signal in the direct record mode on a single tape track (#5). The board also supplies the 9 Khz bias and the tape head driver amplifier required for this purpose.

The multiplex board employs five integrated circuits. They are, Figures 12 and 13:

IC1 CD4046 for the WWVB VCO

IC2 CD4046 for the IRIG-C VCO

IC3 CD4046 for the bias signal generator

IC4 CD4060 to divide the 2.56 M hz crystal frequency down to the required 625 hz reference

IC5 741 op amp for a summing amplifier (multiplexer) and head driver.

The WWVB code is fed to IC1 through connector J11, pin Y, and through RP1, the deviation control potentiometer. The IRIG-C code from the TCG is fed to IC2 through connector J11, pin D, and through RP8, the deviation control potentiometer.

The signal produced by each IC is passed through a potentiometer to adjust its amplitude (RP2, RP4, RP6, RP7, for IC1, IC2, IC3, and IC4, respectively) and through a tuned, moderately high Q L-C wave shaping circuit to convert the square wave IC output to a sine wave suitable for multiplexing. These separate sine wave signals pass through separate 36 K ohm resistors and then are summed by IC5, which also serves as a tape head driver. The 9 K hz unmodulated sine wave that is produced by IC3 and associated wave shaping circuit and is summed with the three other signals in IC5 provides the bias signal required for direct mode recording.

The output signal level from IC5 can be adjusted by RP9. This signal is coupled to the tape recorder head through C14 and passes through the 10 ohm resistor, R19, in series with the tape head to facilitate measurement of the head current.

Alignment of the multiplex board

With the recorder Power and Record switches turned on and the Drive switch in the Fast position, insert the multiplex board into an extender board that is inserted in connector J11. The output signals from WWVB radio and the TCG are square waves that alternate

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between common (0.0V) reference levels and a fixed DC offset level, positive for the True-Time WWVB radio and for the TCG and negative for the Develco WWVB radio. The undeviated frequencies of IC1 and IC2 are set so that the deviated frequencies swing across the nominal subcarrier center frequencies.

For IC1 (WWVB) short the WWVB output to ground (Wt banana plug to black banana plug on J16, Figure 15), connect the frequency counter and oscilloscope to TP1 and to common, and connect the resistor substitution box across the stand-offs for R29. Center RP3 (4 turns total range) and set the resistance substitution box to obtain a frequency of 262 hz if the True Time radio is used (282 hz if the Develco radio is used). Select a resistor closest to that indicated by the resistance substitution box from a supply of 1%, 100 ppm/oC resistors, and solder it onto the stand-offs for R29 in place of the substitution box. After R29 cools, adjust RP3 to bring the frequency back to 262 hz (or 282 hz if a Develco radio is used). Adjust RP2 to obtain a 40 mv pp subcarrier amplitude at TP5. The True Time radio has a fixed output level: the code alternates between 0.0 and 3.5 VDC. The Develco radio has an adjustable output level (between 0.0 and a maximum of -2.5 VDC) and it is adjusted so that the code alternates between 0.0 and -1.0 VDC.

To set the deviation of IC1 when the True Time receiver is used (+20 hz), disconnect the short between the WWVB output and ground, connect the frequency counter to TP1, and apply +4 VDC to jumper JM1 (Figure 13). Adjust RP1 to obtain 284 hz. To set the deviation of

IC1 when the Develco receiver is used (-20 hz), apply -4VDC to jumper JM1 and adjust RP1 to obtain 202 hz.

For IC2 (TCG), move the frequency counter and oscilloscope leads to TP2, center RP5 (4 turns total range), and connect the resistance substitution box across the stand-offs for R30. Interrupt the TCG signal to IC2 by depressing (and holding) switch S6 on the tape recorder drive control panel. Set the resistor substitution box to the value required to obtain a frequency of 398 hz. Select the 1%, 100 ppm 1°C, resistor closest to the value determined by the resistor substitution box, and solder it into the R30 stand-offs in place of the resistor substitution box.

After R30 cools, readjust the frequency to 398 hz by means of potentiometer RP5. Attach the oscilloscope lead to TP6 and adjust RP4 to obtain a subcarrier amplitude of 40 mv pp. Apply +4 VDC to TP10 and adjust RP8 to obtain a deviated frequency of 478 hz. Release switch S6 to reestablish the TCG signal to IC2. The TCG output level should be adjusted so the time code signal alternates between common (OV) and +1 VDC so that the subcarrier frequency produced by IC2 alternates between 398 hz and 418 hz.

The center frequency of IC3 should be 9000 ± 200 hz. Connect the frequency counter and oscilloscope to TP3 and to common, and connect the resistance substitution box across the stand-offs for R31. Determine the resistance required to produce a frequency of 9000 hz. Select the 1%, 100 ppm°/C resistor closest to that value and solder it to the R31 stand-offs in place of the substitution

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box. Attach the oscilloscope to TP7, and adjust RP6 to obtain an output level of 4.0 V pp for the 9000 hz bias signal.

The input to the binary divider chain IC4 is from a 2.56 Mhz crystal, and the output frequency depends on where the output signal is picked off of the divider chain. The output selected is the one that provides the required 625 hz reference frequency ($2.56 \times 10^6/2^{12} = 625$). Connect a frequency counter and oscilloscope to common and to TP8 to monitor the frequency (625 hz), sine-wave quality, and amplitude of the reference signal. Adjust the level of the reference signal to 60 mv pp by means of RP7.

The sine waves forms at TP5, TP6, TP7, and TP8 should be of good quality (not more than 2-3% distortion). If their signals are distorted, they can be improved by altering the capacitors (C9, C10, C11, C12, or C13) in the appropriate L-C wave shaping circuits.

Each of the four signals to be multiplexed passes through a 36 K ohm resistor to the input of the summing amplifier (IC5). The output level of the multiplexed signal, measured by the oscilloscope at TP11, is set to 1.25 V pp by adjusting RP9. It may be necessary to readjust the multiplex signal level by monitoring the head current (measured as a voltage drop across the 10 ohm resistor, R 19, between common and test point J5-E) through the track #5 tape head. RP9 on board B11 should be adjusted to produce a 70 mv pp signal at test point J5-E.

The voltage levels for the adjustments given above have been determined from a series of tests on bias and modulation levels required for low-noise playbacks from the 5-day-system tapes.

e. Connectors, control panels, and function monitor switches.

The relationships between the principal components of the 5-day-recorder system and the subcomponents and circuit boards of which they are composed are shown diagrammatically in Figure 2; and the location of these elements in the tape recorder case is shown in Figure 3. Because the connectors play an especially important role in the construction of the system, they are characterized more fully in terms of function, location, and associated circuit boards, if any, in Table 1.

Connectors J1 thru J14, J17, and J18 are simple sockets that are wired to receive circuit boards (board Bi plugs into socket Ji) or mating connectors on cables linking major components. J16 is the seismic amplifier control panel (wires from the amplifiers, etc., attach directly to lugs on switches, etc., mounted on it). B15 is the seismic amplifier attenuation card serving all 6 seismic channels, and J15-1, J15-2, and J15-3 represent the stand-off lugs on B15 to which wires from the three (dual) amplifiers are attached. B15 is mounted on J16.

J19 is the TCG panel. It is illustrated in Figure 4 and the functions of its components were discussed in Section IIg.

B20 is the True-Time radio circuit board and J20 represents the labelled wire attachments mounted on it.

The master connector wiring diagram, Figure 14, indicates the attachments made to each pin on all connectors and switches (except J19, which is an integral part of the TCG). It also indicates the input, output, or monitor functions served by those attachments.

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J16, the seismic amplifier control panel, is illustrated in Figure 15. This unit is mounted on the tape recorder deck plate. It carries the attenuator switches for the seismic amplifiers, banana plugs for monitoring various aspects of the WWVB radio time signal, and banana plugs and selector switch for monitoring the seismic amplifier output signals (at the VCO inputs) as well as the regulated +5 VDC and -5 VDC power supplies and the tachometer limiter signal (540 hz), which indicates whether the tape recorder is running at the correct speed. Figure 15 shows the selector switch (S16) wiring diagram and indicates the monitor functions associated with each position of the switch.

Connector J5 provides access to monitor points for many vital tape recorder drive and electronic functions. These functions include:

a. head currents for all 7 tape tracks

b. tachometer output, phase comparator, motor voltage, tachometer limiter, and frequency standard of the tape recorder motor drive system,

c. carrier signals for WWVB (272 hz), the TCG (408 hz) and the reference frequency (625 hz) on the multiplex board,

d. regulated power supplies of +5 VDC, -5 VDC, +12 VDC, and -12 VDC.

To facilitate access to these monitor points, a standard assembly consisting of a connector (mate to J5), cable, and channel selection box has been provided for use with the system. A sketch of the channel selection box as well as a schematic circuit diagram of the box showing the monitor functions associated with positions of the selector switches and pins on connector J5 are shown in Figure 16.

Twelve monitor points are selected by switch S1 (with toggle switch S3 pointing toward S1) and the remaining monitor points are selected by switch S2 (with toggle switch S3 pointing toward S2).The output from the box is accessible through a BNC connector, a pair of tip jacks, and a pair of banana plugs--all wired in parallel.

f. Electronic noise suppression

When the electronics package for the 5-day recorder seismic system was tested, it was discovered that the amplifier noise level was too high--about 5 μVpp at the amplifier input. The primary source of the noise was traced to the tape recorder drive motor and drive motor regulator card. Sharp, quasi-periodic transients generated in this part of the system appeared in the $\pm$12 VDC regulated power supply to the tape drive motor regulator. These were fed back through the $\pm$5 VDC regulator of the amplifier power supply and entered the first stage of the amplifier; so they were amplified and modified (filtered) by the amplifier system before appearing at the amplifier output.

By-pass filters to ground were attached to the +12 VDC regulated and -12 VDC regulated as well as to the -12 VDC unregulated leads at the tape drive regulator card.

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It was also discovered that strong high frequency "hash" from the multiplex board was being fed back through the 5V regulator and was present on the battery input and the 12 VDC regulated supply. Bypass filters were run to ground from the +5 VDC regulated, -5 VDC regulated, and modulator on/off control leads so as to isolate the X-tal controlled compensation frequency generator and the 9 K hz bias signal generator from the seismic channel modulators and the ±5 VDC regulator.

The by-pass filter used in all cases consisted of a 50 µF, 25 VDC, electrolytic capacitor in parallel with an 0.01 µF ceramic disc capacitor. The latter was required to pass the high frequency components of the noise signals.

The specific actions taken were:

Connector J10--motor drive amplifier socket

1. Tie pins K, L, E, F, H together (common)
2. Add by-pass filters between pins
    a. A, B and common — -12 VDC Reg to common
    b. C and common — +12 VDC Reg to common
    c. R and common — -12 VDC Unreg to common

Connector J11--multiplex board socket

1. Tie pins S and T together; tie pins U and V together.
2. Add by-pass filters between pins
    a. S, T to common — +5 VDC Reg to common
    b. U, V, to common — -5 VDC Reg to common
    c. P to common — mod. on/off control to common

TABLE 1

Function	Connector			Circuit Board	
	Desig./# of pins, location			Desig., location	
Power in	J1 /	3	Case	--	--
Seis signal in	J2 /	19	Case	--	--
#1 Head	J3 /	14	Deck plate	--	--
#2 Head	J4 /	14	"	--	--
Test connector	J5 /	21	"	--	--
Power board	J6 /	18	Card cage	B6	Card cage
Motor	J7 /	18	"	B7	"
drive	J8 /	18	"	B8	"
	J9 /	18	"	B9	"
boards	J10 /	18	"	B10	"
Multiplex board	J11 /	22	"	B11	"
Amp/VCO #3	J12 /	22	"	B12	"
" #2	J13 /	22	"	B13	"
" #1	J14 /	22	"	B14	"
Seis	J15-1/	4	B15(SACP)	B15	SACP*
ampl	J15-2/	4			
atten	J15-3/	4			
Monitor switch	J16-SW/	10	S16(SACP)		
Monitor jacks	J16-DP/	6	SACP		
TCG connector	J17 /	14	Side of card cage		
WWVB antenna in	J18 /	2	Case		
TCG control panel	J19		Deck plate		
True-Time radio	J20 /	11	B20	B20	Side of card cage

*SACP = seismic amplifier control panel (on deck plate)

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IV. FIELD OPERATING INSTRUCTIONS FOR THE FIVE-DAY-RECORDER SEISMIC SYSTEM

A. <u>Site selection and equipment layout</u>

1. Site selection

   a. Find a quiet location away from sources of cultural noise such as highways, railroads, factories, towns, electrical transmission lines, pipelines, cattle, etc.

   b. Hide the installation from view of passerby (vandalism).

   c. Place the recorder in the shade: under a tree, dense bush, or sunshade; or in a cave or tunnel, if available.

   d. Select a site for the seismometers that is 50 to 70 feet from the recorder (leave at least 10 feet of slack in the seismometer cable), that is free of large trees or structures that might be buffeted by the wind, and that will permit the seismometers to be placed on firm material as close to local bedrock as possible.

2. Layout of the recorder and supporting equipment

   a. Select a site for the recorder that is large enough for the recorder, two batteries, and working space. It may be necessary to clear and level such an area with a shovel.

      1) If the thermoelectric generator is to be used, clear off an area about 10 feet in diameter and remove all combustible materials from it. The TEG generator should be placed in the center of such a clean area to eliminate any possible fire hazard.

2) If the TEG is to be used, set it up and light it without any load attached. It requires 30 to 40 minutes warm-up time before the load is attached.

3. Installing the seismometers

a. Mark Products L4-C seismometers

These seismometers are moving coil, fixed magnet seismometers that do not interact with each other appreciably. In a 3-component installation, all 3 seismometers can be planted in one pit.

1) Record the serial numbers of the seismometers on the data sheet and indicate which seismometer is used for each component: N, E, and Z.

2) Dig a "pit" about 18 inches on a side and 18 inches deep.

3) Plant the vertical component seismometer in a 3-to-4-inch deep hole near the center of the pit, using a small carpenters test level to insure that it is level (i.e. the longitudinal axis is vertical, with the cable at the top).

4) The horizontals must be levelled very carefully or they will not function. (A very slight tilt drives the moving mass to an internal stop and it is immobilized).

a) to facilitate levelling, spread a layer of sand about 2 inches thick on the bottom of the pit.

b) Place the horizontal component seismometers on the sand in the pit, one oriented with its long axis N-S

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and the cable end pointing N (N-S component), the other oriented with its long axis E-W and the cable end pointing E (E-W component). The arrow on the case at the base of the horizontals must point upward. See Appendix 1 for instructions on use of a compass to establish the N-S and E-W reference lines for orienting the horizontals.

c) Nearly cover the horizontals with sand, but leave the upper edges exposed.

d) Use the carpenters test level to level the cases of the horizontals.

e) Use the horizontal seismometer level test box (Appendix 1) to refine the leveling of the horizontals.

(1). Connect the level test box (with VOM attached if the box has no meter) to one of the horizontals.

(2). Depress the red pushbutton switch on the level test box firmly, hold it down for about 5 seconds, release it abruptly, and monitor the subsequent deflection of the meter.

(3). Reverse the toggle switch (which reverses the seismometer leads).

(4). Repeat step (2).

(5). If the deflections for (2) and (4) are not equal, adjust the seismometer level slightly and repeat steps (2) through (5) until the two deflections are equal.

(6). When the seismometer is level, the "direct" and "reverse" deflections should both be about 1.0V.

(7). Repeat the foregoing process for the other horizontal component.

f) Connect the seismometers to the seismometer cable. The individual seismometer leads in the cable are identified by numbers and/or 1, 2, or 3 bands of electrical tape near their connectors: #1 = Z (vertical), #2 = N-S horizontal, #3 = E-W horizontal.

g) Complete covering the seismometers with sand, but avoid tamping in order not to disturb the level of the horizontals.

h) Cover the pit with a lid of plyboard, and put flat rocks and/or dirt on it to hold the cover down and to provide added insulation.

i) Cover the seismometer cable to the recorder with rocks, dirt or brush. It may be necessary to bury the cable to decrease its exposure to damage from chewing animals--cows, rabbits, squirrels, etc.

b. Electro-Tech EV-17 seismometers previously used with the 10-day-recorder system are moving magnet seismometers; and

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there can be intéraction between seismometers if they are too close together. Each seismometer should be in a separate pit 7 or 8 feet from the others.

1) The vertical is placed feet down, with the bubble centered. The quadrant target on the mass seen through the centering window should be bisected by the reference line on the window.

2) The horizontals should be placed feet down, with the carrying handle pointing north (for the N-S component) or east (for the E-W component). The bubble level should be centered, and the arrow on the mass seen through the leveling window should be centered in the window.

B. <u>Tape recorder set-up</u>

1. Check battery with hydrometer. The battery is fully charged if fluid level is in the green region (1250).

2. Cleaning recorder. Use cotton swabs soaked in freon.

   a. Use a small brush to brush dust from recorder.

   b. Clean rollers with freon swabs.

   c. Clean Pinch rollers (black). Black will always show on cotton swabs, but the roller should not look glazed.

   d. Clean heads with freon swabs paying special attention to the point (apex) at which the signal is put onto the tape.

   e. Clean clutch. (Clean only after being shown how to do so.) To remove:

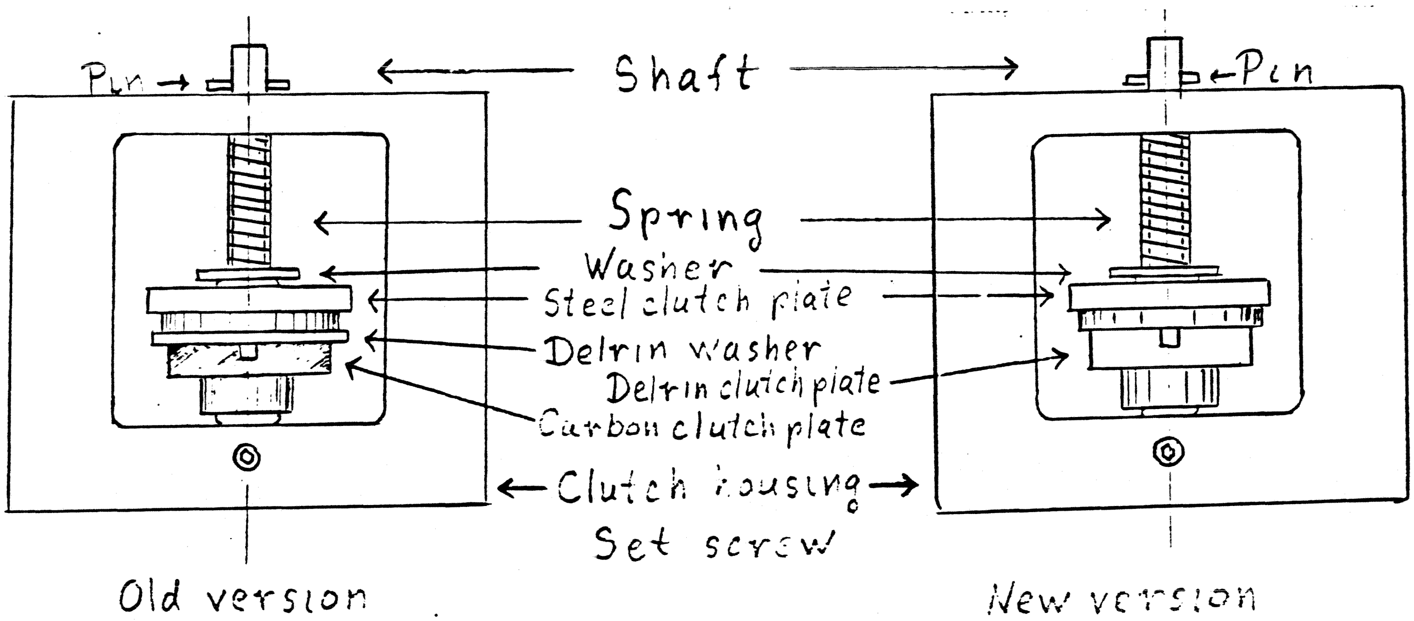
      1) Turn tape deck over so that clutch housing is exposed.

2) Loosen set screw.

3) Hold fingers on and around spring, washer, and clutch. With other hand, remove the shaft; then remove clutch, spring, and washer.

4) Clean surfaces with freon swabs.

f. Replace clutch; alignment as pictured:



1) Replace shaft, spring, and washer.

2) Slip a 90° longnose pliers under washer and grasp shaft firmly, but do not groove it.

3) Raise shaft and spring high enough to slip clutch plates in under short protrusion of shaft.

4) Let shaft down and slip pliers out, holding clutch plates in place with other hand.

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5) Wiggle shaft down through plates until pin in shaft rests on clutch housing. Hand tighten screw against flat side of shaft.

6) Replace tape deck to operating position in the box.

3. Record switch should be in "off" position. (Repeated surges of power to the heads with Record switch on will magnetize the heads).

4. Connect cables. Note that all sets of connectors are different, and hence it is very difficult, if not impossible, to hook the equipment up wrong.

   a. Slugs and slots in the connectors should line up.

   b. Threads should be clean.

   c. Do not force connectors.

5. Connect power

   a. Battery clips are color coded.

      1) Red to Positive terminal.

      2) Black to Negative terminal.

   b. The second set of battery clips are for:

      1) Replacing a used battery with a fully charged one without interrupting the power supplied to the recorder.

      2) When a TE Generator is used, remove one set of clips and connect wires to the power output of the TEG.

6. Turn Power switch on.

7. Installing magnetic tape.

   a. Remove the three discs on the tape hub spindle.

b. Place full reel on supply turntable (bottom).

   1) One of the three slots on the take-up reel should fit over the protruding pin of supply turntable.

c. Install supply reel hold-down disc. Use finger holes to tighten "finger" tight.

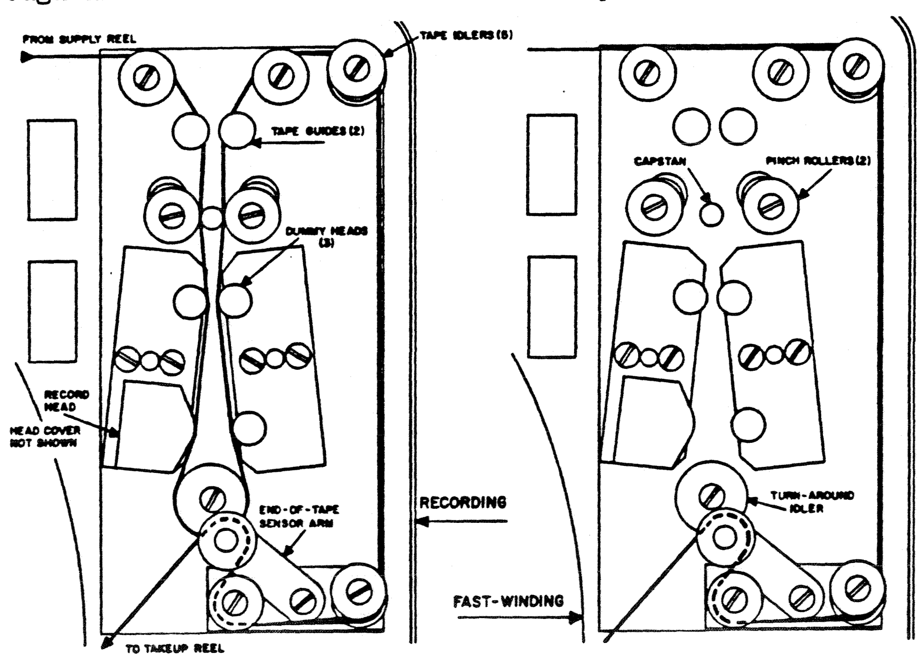
   1) Tape should come off the reel clockwise.

d. Install take-up turntable so that it seats over line-up pin and place take-up reel on it.

e. Finger tighten hold-down disc.

f. Make certain that reels or turntable do not wobble when rotated.

g. Pull off about 18 inches of tape from the supply reel and thread through and around rollers to the take-up reel. See drawing:



   1) Tape must be securely wound onto take-up reel. That is, when the take-up reel is rotated clockwise by hand, the

tape from the bottom reel must be wound onto the top reel without slipping.

2) Turn 10-15 turns of tape onto take-up reel.

3) End-of-the-tape-sensor-arm must be pulled to the left by the tape.

8. Turn Drive switch to Drive position.

a. Tape must be taut in order to move.

b. If tape doesn't move, check voltages and/or fuses, and end-of-tape-sensor-arm.

c. Push red Servo Test button. It will light up steadily while depressed if tape is running at correct speed.

C. Putting the system into operation

1. Set the Time code Generator (See Figure 4).

a. Turn on TCG display and verify that TCG is on power. Power should be turned on at least 10 minutes before TCG is set.

b. Depress and release "hold" button (stops counting).

c. Depress and release "reset" button (sets TCG at start of 001 day). TCG should not be advancing (counting) after steps 2 and 3.

d. Decide on the time at which the TCG is to be synchronized with WWV. A characteristic "tone return" occurs precisely at the start of each five-minute interval beginning on the hour. The synchronization time should be preset into the TCG (see step 5, below) so that the TCG can be started at the instant that the chosen synchronization time is signalled by

WWV. You will need a chart to determine the Julian day corresponding to the current calendar day.

e. Set digit select switch to HD. Use "set" pushbutton to increment "hundreds of days" digit to proper value. Set digit select switch to TD. Use "set" pushbutton to increment "tens of days" to proper value. Proceed in a similar manner to set the proper values for UD (units of days), TH (tens of hours), UH (units of hours), TM (tens of minutes), UM (units of minutes), and TS (tens of seconds).

f. At the voice announcement of the upcoming synchronization time, prepare to depress the "run" pushbutton. Depress the "run" pushbutton as close to the tone return (i.e. the onset of the short high-pitched tone following the voice announcement) as possible.

g. At the next minute (and before calibration), verify that the TCG is set correctly and that the zero second is synchronous with WWV to within ± 0.5 sec.

h. The display will automatically shut off after a 9th minute (e.g. after 17:49). To read the TCG, the display must be turned on manually.

2. Start the tape transport and verify that signals are being recorded on tape.

   a. Turn on the Record switch.

   b. Let the TCG run (and record) while you complete setting up the system. Obtain at least 10 minutes of TCG record before calibrating the seismic amplifiers (below).

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c. Use VIS-A-MAG to verify that the carrier signals are being recorded on tape. If the VIS-A-MAG bottle is dry, pour in a little freon. Shake the bottle each time before use. Dip a cotton swab into the solution and apply a small amount of it (by wiping) to the oxide side of the tape just beyond the last outside tape roller where the tape begins its upward-inclined path to the level of the take-up reel. All 7 tape tracks should appear as 1/16th inch stripes with a small separation between them. Track #5 will be very faint (direct rather than FM recording). Wipe off VIS-A-MAG completely before it reaches the next roller.

3. Tune the WWVB receiver

Note: The short white antenna is to be used with the True-Time receiver. This antenna draws ± 5 VDC through its leads to power a preamp contained in it. The longer stick antenna is to be used only with the Develco receiver.

a. Either antenna should be in a horizontal position about 10 to 20 feet from the recorder, off the ground, and oriented with its long axis perpendicular to a line toward Fort Collins, Colorado. Reception appears to be degraded if the antenna is put on the ground.

b. Adjust the antenna for best reception. Monitor the WWVB signal with an oscilloscope plugged into the black and white banana plug sockets on the seismic amplifier control panel. (J16, Fig. 15).

1) True-Time receiver

Adjust orientation of the antenna to optimize the signal monitored by the oscilloscope. The signal should be a "clean" square wave (VB code) with an amplitude of 3.4 to 4 VPP (DC scale). This signal is not adjustable. The 60 Khz RF carrier can be monitored across the black and green banana plug sockets, and the detected, but not limited, VB code can be monitored across the black and orange banana plug sockets.

2) Develco receiver

A 2 Khz IF audio signal can be monitored with an earphone plugged into the phone jack on the receiver. Adjust the antenna orientation to optimize the VB signal as detected by earphones or oscilloscope (across black and white banana plug sockets). Adjust the code output level monitored by the oscilloscope to 1 VPP (DC scale).

c. Fasten the antenna down to preserve its orientation.

4. Monitor record head signals and other internal functions available through connector J5.

Use the connector, cable, and channel select box described in Section IIIe and illustrated in Figure 16 for these measurements. Normal characteristics of the signals monitored through connector J5 are indicated below. The purpose of these measurements is to verify the proper adjustment and functioning of the recording and motor drive electronics.

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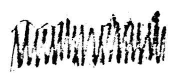
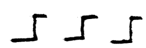
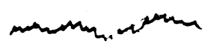
a. S3 toggle toward S1

	Head current				
S1 Position	3 seis	6 seis	Waveform	Voltage (pp)	Freq (hz)
1	Hi Z	Hi Ch1		80 mv	338 ± 10
2	Lo Z	Hi Ch2	"	"	"
3	Hi N-S	Hi Ch3	"	"	"
4	Lo N-S	Hi Ch4	"	"	"
5	MX time and comp.			70 mv	9K ± 200
6	Lo E-W	Hi Ch6		80 mv	338 ± 10
7	Hi E-W	Hi Ch5	"	"	"
	Function				
8	Tachometer output			1 V	540
9	Phase computer output*			12 V	540
10	Motor drive voltage			3 V	540
11	Tach limiter output			12 V	540
12	Reference oscillator limiter output			12 V	540

*Correct recorder speed is verified if peaks do not run together (Same info as from servo light button). Monitoring this point overloads some recorders and disturbs phase lock.

b. S3 toggle toward S2

S2 position	Function	Waveform	Voltage (pp)	Freq (hz)
1[a, b]	VB Mx subcarrier		40 mv True Time[c]	262
			40 mv Develco	282
2[d]	TCG Mx subcarrier		40 mv	398
3[a]	Reference frequency		60 mv	625
4	Regulated - 5VDC		Power for amplifier	
5	" - 5VDC		and VCO's	
6	" -12VDC		Power for tape drive	
7	" +12VDC		system	

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[a]Information 1 and 3 may be reversed

[b]Disconnect radio input (J18) while checking Mx subcarrier frequencies for WWVB.

[c]Short output between black and white banana plug sockets on J16 (amplifier control panel) to read 262 hz rather than 282 hz.

[d]Depress switch S5 on Tape Drive panel (between power and record switches) to interrupt TCG output in order to read 398 hz.

5. Monitor the seismic amplifier output signals and other internal functions available on the Seismic Amplifier Control panel (J16). This panel and selector switch S16 are described in Section IIIe and illustrated in Figure 15. Normal characteristics of signals monitored on J16 are indicated below. They are monitored between the black and red banana plug sockets on J16.

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	Component		
S16 position	3 seis	6 seis	Voltage (pp)
1	Hi Z	Hi Ch1	150 mv max
2	Lo Z /	Hi Ch2	5 mv max/150 mv max
3	Hi N-S	Hi Ch3	150 mv max
4	Lo N-S /	Hi Ch4	5 mv max/150 mv max
5	WWVB code output		3.5V TrueTime/1V Develco
6	Lo E-W /	Hi Ch6	5 mv max/150 mv max
7	Hi E-W	Hi Ch7	150 mv max
8	-5VDC	Amplifier/VCO	
9	+5VDC	regulated supply	
10	Tach limiter signal (540 hz)		1V

The other banana plug sockets on J16 are for monitoring the WWVB radio. Their funtions are as follows:

Black and White: VB "limited" output (True-Time or Develco)

Black and Orange: VB "detected" signal (True-Time only)

Black and Green: VB 60 khz carrier (True-Time only).

The principal purposes of the measurements made through J16 are 1) to verify that the seismic channels are functioning normally, and 2) to set the seismic amplifier attenuators at levels that establish appropriate levels of background noise modulation of the Hi level VCO's. The normal set-up procedure is outlined below.

a. Connect the oscilloscope leads to the red and black banana plug sockets on J16 (or to the BNC connector on the Tape Drive control panel near the servo light test button).

b. Set scope on 50 mv/division at a sweep rate of 0.2 sec/division.

c. Monitor the seismic signals at positions 1, 3, and 7 (Hi Z, Hi N-S, and Hi E-W for a normal 3 component set-up), and set the corresponding attenuator so that the signal (seismic background noise) is near but less than 150 mv pp.

   1. At normally quiet sites the attenuator settings will be 0 db to 12 db. If the settings are greater than 18 db, consider looking for a better site.

   2. Stamp on the ground to verify that the seismometers are responsive.

   3. If the site is very quiet (0 db) but the seismometer does not respond strongly to the stamping test, check for a possible faulty component: seismometer hung up, broken seismometer cable, insensitive amplifier, operator monitoring wrong channel?

d. Monitor positions 2, 4, and 6 (Lo Z, Lo N, and Lo E) to verify that these channels are active and that the background noise level on them is low--5 mv or less.

e. Monitor position 5 to check the True-Time receiver output level (3.5 to 4 VDC) or to set the VB output level (1 VDC)

f. Check positions 8 and 9 for ±5 VDC.

g. Check position 10 to check frequency (540hz) and wave form (/\/\/).

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6. Calibrate*

Tape should have run at least 10 minutes with Record switch on after TCG was set.

a. Turn Record switch off; Drive remains on.

b. Unplug seismometer cable and plug calibrator into J2.

c. Turn Record switch on.

d. Record time on data sheet.

e. Turn on calibrator starting at 10 μv.

f. Calibrate at each of the three levels for about 20 seconds each by moving red banana plug to each of the banana jacks on the calibrator.

1. Leave calibrator on while changing levels.

2. One can monitor calibration signal with scope at amplifier monitor points.

3. Put VIS-A-MAG on tape to verify that the calibration signal is being recorded; then wipe it off.

g. Turn calibrator off.

h. Turn Record switch off.

i. Remove calibrator plug and re-insert seismometer cable.

j. Turn Record switch on.

7. Final Checks

a. Make sure Record switch is on, calibrator is off.

b. Check the tape with VIS-A-Mag to verify that signals are being recorded.

---

*Calibrator circuit described in Appendix 1.

c. Depress servo light to verify that the recorder speed is correct.

d. Replace lid carefully so as not to stop tape.

   1. With lid resting on back ledge of recorder, depress servo button again.

e. Cover recorder with canvas and/or sticks and brush.

f. Clean up the area.

g. Cross your fingers and sneak away!

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D. Quick Set-up List

1. Locate in a quiet, remote and secure area.
2. Plant and level seismometers, away from trees, buildings, etc., close to bedrock.
3. Set up recorder and mount tape.
4. Connect cables, check battery.
5. Turn on power.
6. Set up WWVB, antenna perpendicular to the direction toward Fort Collins, Colorado. True-Time 3.5 v; Develco 1 v.
7. Set TCG after 10-15 minutes of power on.
8. Turn Record and Drive switches on.
9. Make Test Box checks (connector J5).

SW_1 positions 1-7) 338 ± 10 hz, except 5 (5 is 9K + 200 hz);
8-12) Tape Drive wave forms @ 540 hz.

SW_2 1) 625 hz or 262 hz True-Time / 282 hz Develco } short output to gd for Tru-Time; disconnect coaxial WWVB input cable for both True-Time and Develco.

2) 398 hz TCG — Depress button by Power switch.

3) The one that wasn't read at position 1.

4) -5v

5) +5v

6) -12v

7) +12v

11. Set attenuation levels of channels 1, 3, and 7 so that the signal at the amplifier output monitor is not greater than 150 mv pp.
12. Look at low gain (channels (2, 4, 6) for response and signal levels (<5 mv pp).
13. Record off, remove seismometer cable.
14. Calibrator in.
15. Record on, calibrate, and VIS-A-MAG.
16. Record off, remove calibrator.
17. Replace seismometer cable.
18. Close up carefully.

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E. Trouble Shooting Hints

1. Tape will not move, check:
   a. Proper tape winding
   b. End of tape-sensor-arm
   c. Battery voltage
   d. Fuses
   e. ±12 v regulated
2. Bad WWVB, check:
   a. Power to unit
   b. Antenna orientation
   c. Antenna cable for breaks
   d. Signal at board or unit
   e. Replace if no broken wires or bad connections found.
3. TCG
   a. Power to unit
   b. Broken wires
   c. Replace if necessary
4. No seismic signal, check:
   a. Seismometer cable hook-up
   b. ±5 v
   c. Resistances at seismometer end and then through the seismometer cable.
   d. All other cables
   e. If only on one seismometer and above OK, change boards.
   f. If still no signal go back to looking for broken wires and/or change seismometers.

5. No VCO signal or frequencies

    a. Record switch has to be on

    b. ±5 v

    c. Try another card.

F. <u>Procedure for Setting-up the Teledyne Thermoelectric Generator</u>

1. Setting up

a. Set the generator in an upright position, preferably above the ground, but at least slightly higher than the surrounding area (for air circulation).

1) Use some type of shade, under a tree or in an enclosed overhead shelter.

2) Attach the hose and regulator to the generator and gas suppy. The thread on the tank is left-handed.

3) Unless noted, the gas tank should be set so that the valve is at the top, otherwise moisture may interrupt the gas flow or possibly freeze.

b. To light

1) Set the pressure from 8 psi to 10 psi at the regulator on the tank and 3 psi on the gauge on the generator. Turning the screw under the red cap <u>in</u> increases the pressure.

2) Turn the gas valve on, open it all the way.

3) Hold a lighted match under each of the domes on top of the generator (except the one in front, closest to the door). A pop can be heard and the dome becomes hot almost immediately.

c. Use a pyrometer to check for the proper pressure setting by monitoring the hot junction temperature (260° to 290°). If the power required is obtained at a lower temperature, leave it. Monitor each thermocouple by switching to 1, 2, and 3 positions.

d. After 45-60 minutes, adjust the voltage limiter to 14.8 v without a power drain on the thermoelectric generator. Make sure all electrical connections are tight.

    1) Check the gas connections with leak detector.

e. The thermoelectric generator is ready for use.

    1) The limiter may be adjusted after a load is applied, so that the battery is being trickle charged (about 13.5 v).

2. Changing Gas Bottles

    a. Have a wrench and light ready. The thermoelectric generator door should be open to check the gas pressure and voltage.

    b. Turn the gas bottle valve off and loosen the regulator. Note the time. (The nut is reverse-threaded.)

    c. Put the regulator into the new gas bottle. Turn the gas bottle valve on all the way; light the thermoelectric generator.

    d. Check all gas lines with leak detector.

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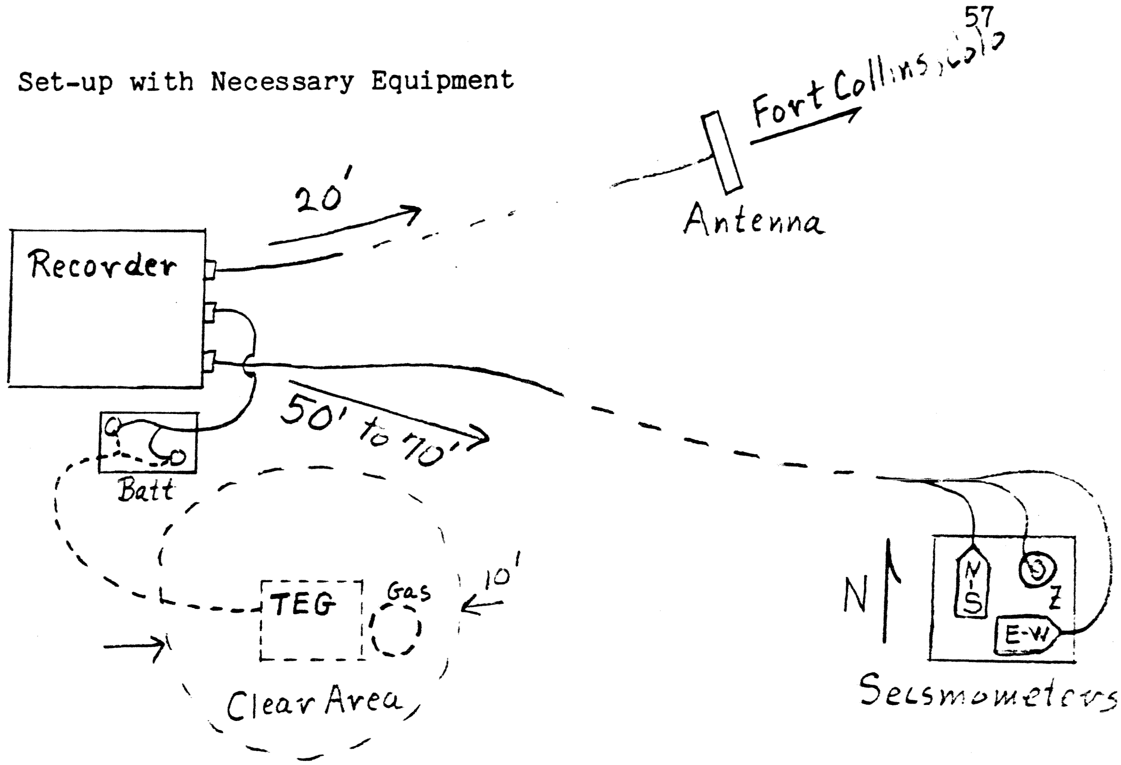
G. Typical Set-up with Necessary Equipment



1. Tape Recorder
2. 12v battery and cable
3. WWVB antenna and cable
4. Develco WWVB when used
5. Seismometers (L4-C - Mark Products) 1 Vertical, 2 Horizontals, and seismometer cable.
6. Full 14-inch tape reel and empty reel

    1. Compass
    2. Shovel and pick
    3. Scope
    4. VOM Meter
    5. Seismometer level box
    6. Freon and Q-tips

7. VIS-A-MAG
8. WWV radio
9. Data sheets
10. Calibrator and cable
11. Level
12. Counter
13. Test box (for monitoring J5)
14. 12v solder iron and solder
15. 12v GelCell
16. Long nose and side cutters, wire strippers, 90^{o} long nose
17. Screwdrivers (Phillips and blade)
18. Electrical tape
19. Test leads.

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V. APPENDIX: AUXILIARY EQUIPMENT

a. Horizontal seismometer level test circuit

The 1 hz L4C horizontal seismometer is not provided with an external level nor a mass-viewing-window in its case for levelling the seismometer. Thus, a simple method is required for determining whether the seismometer is level, or equivalently, whether the seismometer mass is "floating" freely and centered in its working range.

The method and a simple circuit employed for this purpose are illustrated in Figure 17. We assume that the seismometer is symmetrical in construction and performance and that the correct working position of the mass is midway between the "stops" at the two ends of the range of mass travel. If the seismometer is level (so the mass is centered), the seismometer release test signals produced when the seismometer is first held against one stop, then released, and then held against the opposite stop, then released, will be equal but of opposite sign. If the seismometer is out of level, the two "release" signals will be different.

The foregoing test is applied by the circuit outlined in Figure 17a. With switch S2 at D (direct), the pushbutton switch S1 is depressed to B (battery) to connect a sufficient voltage across the seismometer coil to drive the mass to the stop. When S1 is released abruptly to M (meter), the seismometer is simultaneously released from the stop (D) and its output is connected to the meter, which deflects an amount that depends both on the distance the mass moves from the stop to its resting point and on the speed with which it moves. Next, S2 is switched to R (reverse), and S1 is again depressed. With the current through the seismometer reversed, the mass is driven to the opposite stop. When S1 is now released, the deflection of the meter depends on the distance the mass moves from the stop (R) to its rest position. If the "direct" and "reverse" meter deflections are not equal, the level of the seismometer is adjusted to bring them into equality. The layout of the seismometer level test box is shown in Figure 17c.

b. Wiring guide for seismometer cable and connectors: seismometer to amplifier/VCO cards

It is extremely important that the seismometer signals be correctly introduced to the seismic amplifiers. The connectors and cables employed for this purpose are diagrammed in Figure 18. The resistors in connector 14S-2S on the end of the seismometer lead are the "S" and "T" resistors required to produce 0.8 critical damping of the seismometer and to adjust its output (across the 10 K ohm seismic amplifier input) to 1.0 V/cm/sec.

Each seismometer has its own lead, terminated in a 14S-2S connector. In the 3-component set-up illustrated in Figure 18, the seismometer cable (seismometers to recorder) contains 3 shielded pair cables in a single outer cover. On the "seismometer" end of the cable, each shielded pair is terminated with a 14S-2P connector that mates with the 14S-2S connector on the seismometer leads. On the "recorder" end of the cable, it is terminated with a single 22-14 P connector that mates with connector J2 (22-14S) on the recorder case.

Within the recorder case, six shielded pair cables are used to connect the appropriate pins of connector J2 to the seismic inputs of the 3 dual-channel amplifier/VCO cards in the card-cage sockets J12, J13, and J14.

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c. Calibrator

The circuit diagram and control panel of the calibrator used with the 5-day-recorder system are shown in Figure 19. The calibrator generates a 5 hz sine wave signal at levels of 10, 100, and 1000 microvolts rms. This signal is recorded in place of the seismometer signals under actual working conditions to determine the voltage sensitivity of the recording and playback system (exclusive of the seismometer). A method for combining the 5 hz-sensitivity of the system with the relative frequency response of the system (i.e. relative to 5 hz) and with the constants of the seismometer to determine the overall system frequency response has been described by Eaton (1975)*.

The calibrator consists of 1) a ±5V regulator (with a low voltage cutoff), 2) a 5 hz sine wave oscillator with adjustable output level, and 3) three voltage dividers to provide the required calibration signal levels.

The calibrator is quite stable, but it must be regarded as a 3rd order standard. Its output signals must be checked periodically against a calibrated oscilloscope. Remember that 10, 100, and 1000 μV rms are equal to 28.3, 282.8, and 2828 μV peak to peak, respectively. At TP2, the signal level should be 0.867 Vpp. The output signal levels can be adjusted by potentiometers RPO.

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*Eaton, J. P., Harmonic magnification of the complete telemetered seismic system from seismometer to film viewer screen, U.S. Geol. Survey Open-File Report No. 75-99, 1975.

The calibration signal is introduced to the recorder by means of a special cable with banana plugs on one end and an amphenol connector that mates with the seismometer input socket (J2) on the other. This cable is wired to apply the calibration signal to all channels simultaneously.

d. Compass

It is extremely important that the horizontal component seismometers be correctly oriented. Generally, the only reference available for this purpose is the compass. Since most of us use the compass infrequently, if at all, we should use it very thoughtfully to avoid gross errors. In particular, the difference between magnetic north and true north (the declination) must be understood and applied correctly, and the compass should not be read too close to ferromagnetic materials (e.g. the seismometers, etc.).

Declination is the angle between true north (Polaris) and the direction of the north-seeking end of the compass needle, measured E or W from true north. On 1/62,500 or 1/24,000 USGS Topo Maps, the declination is given, along with a diagram to eliminate any misinterpretation, at the bottom of the map. In central California, the declination, δ, is about 17° E. That is, the compass N points 17° E of true north. Also, remember that the small copper weight on the compass needle is on the south-seeking end in the northern (magnetic) hemisphere.

Figure 20 illustrates a Brunton Compass, with the declination set at 17° E, pointing toward true north. The north-seeking end of the needle points to N (i.e. 0°) on the Brunton scale, which has been rotated so

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that 17° E lies beneath the small index pointer on the line of sight axis. If the compass is rotated 45° counterclockwise so the line of sight points due NW, the needle remains fixed (toward magnetic north), while the compass body and affixed scale rotates to bring "N45° W" to the north-seeking end of the needle. Thus, with declination set correctly, the compass line of sight can be read off the compass scale at the point of the needle.

To avoid using the compass too close to the seismometers, it is convenient first to decide where the seismometers will be planted, then to establish a true N-S line across that location using the Brunton compass, and finally to record that direction by driving stakes into the ground along that line on opposite sides of the seismometer pit. When the pit is finished and the seismometers are to be planted, a string stretched across the pit between the stakes provides the needed reference for orientation of the seismometers.

However you proceed, do not place the compass on or near the seismometer case in order to orient the seismometer.

Figure captions

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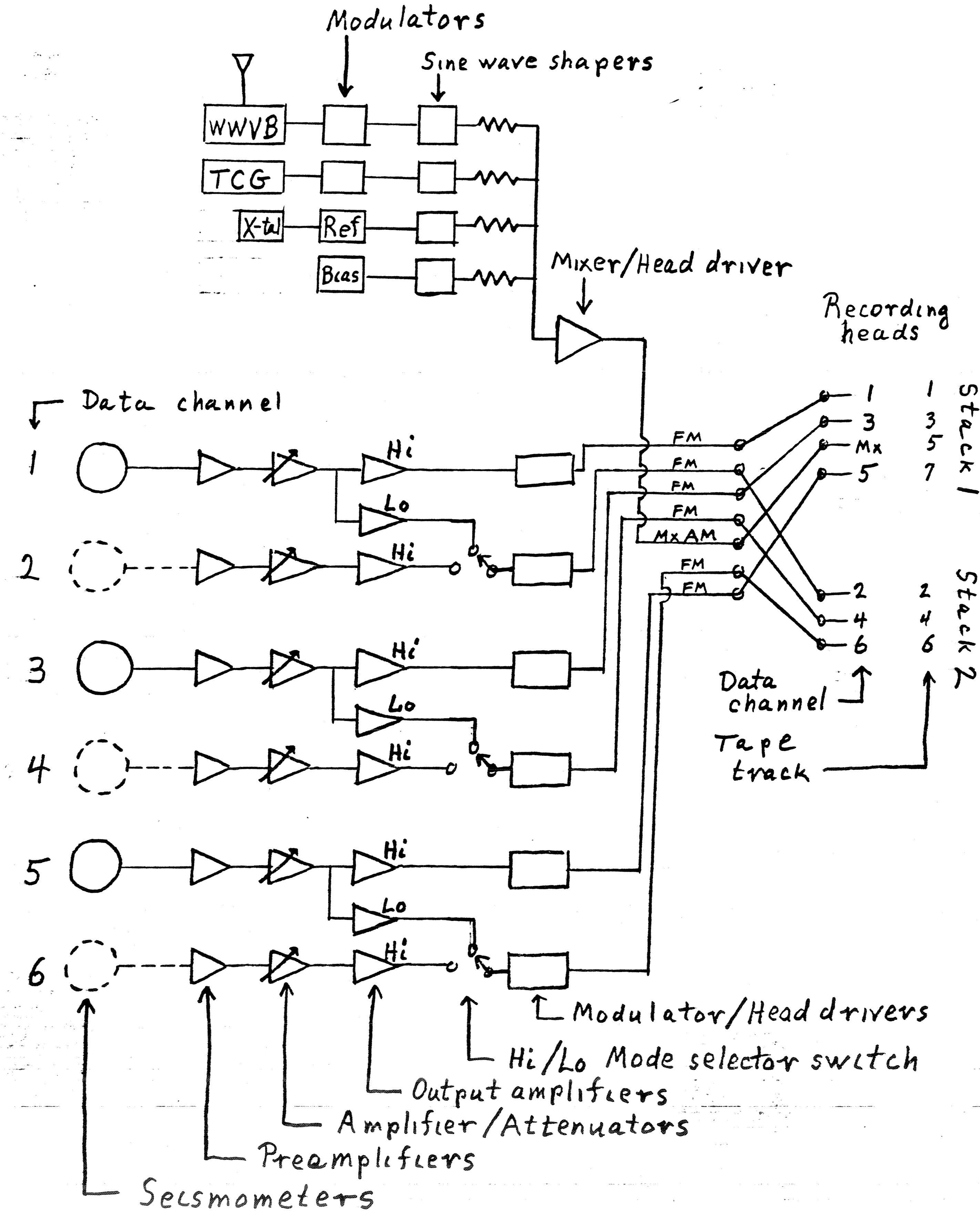
Figure 18. Seismometer cable wiring diagram---seismometer to amplifier input.

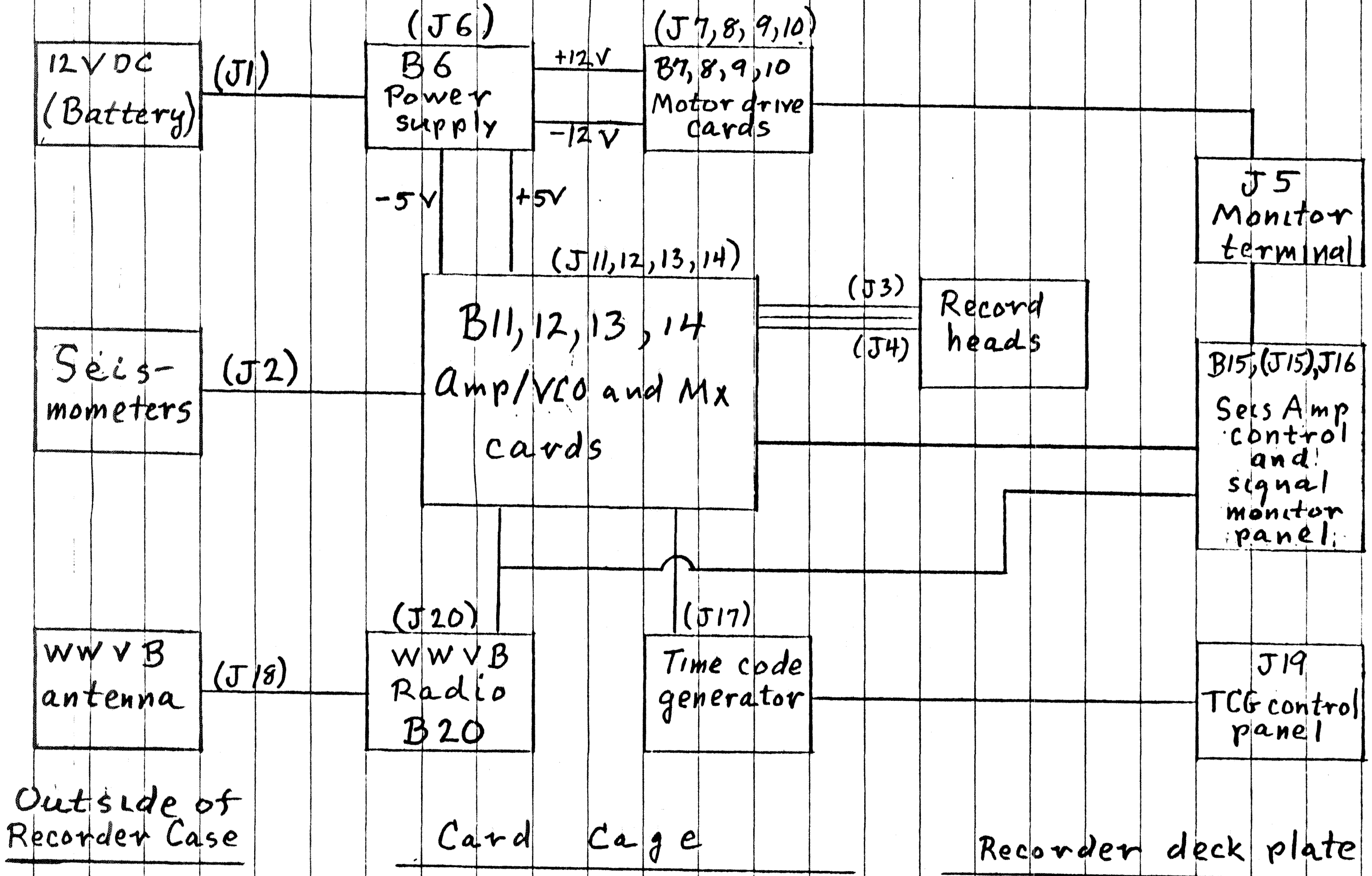
Figure 19. Five-hz sine wave calibrator circuit and control panel.

Figure 20. Diagram showing use of compass to orient horizontal seismometers.



Signal Block Diagram

Fig. 1



Five Day Seismic System Block Diagram (excluding tape drive control)

Fig 2

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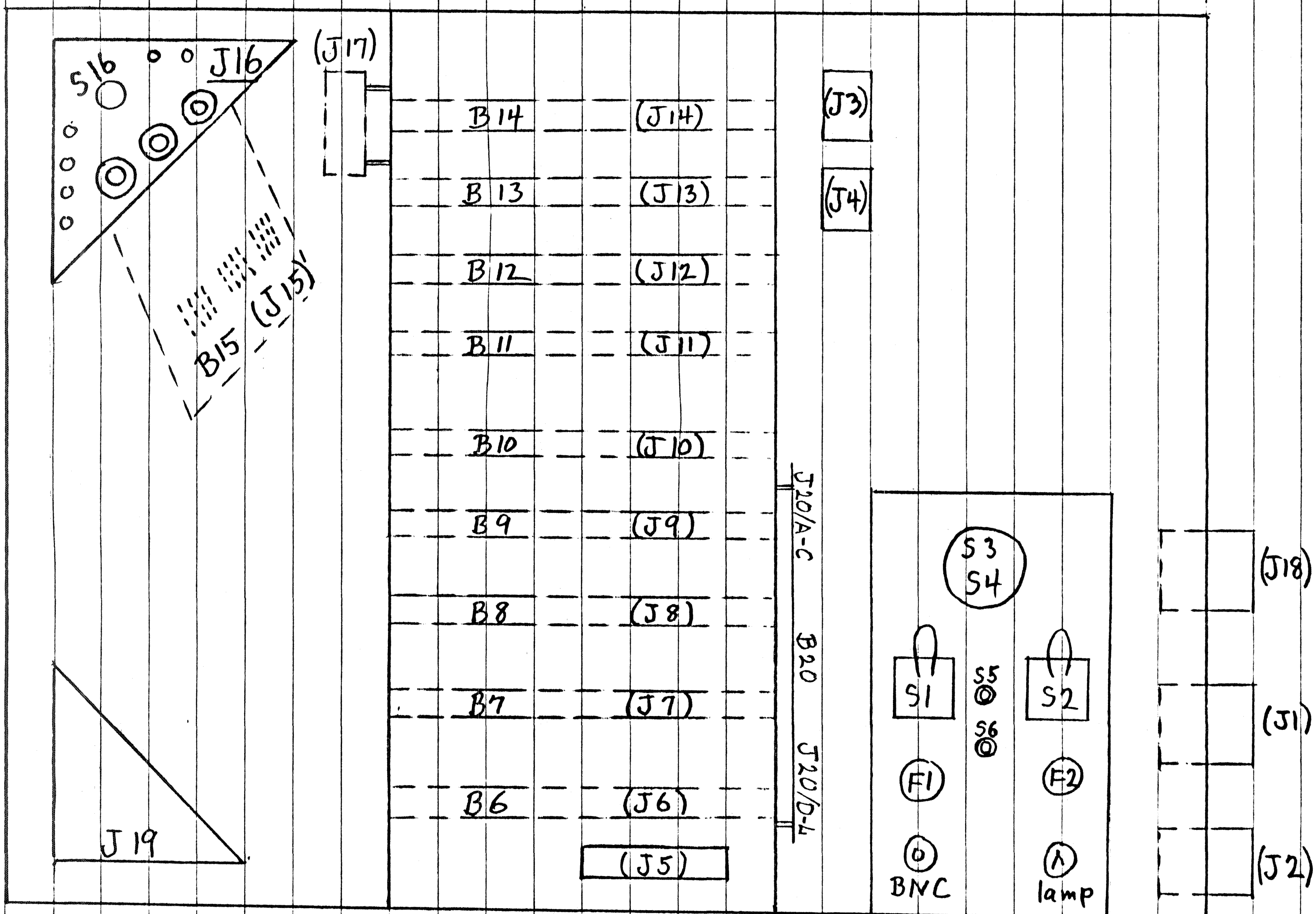
Fig 3



Connector and Card layout

PI 5100 5 Day Recorder

Top View

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Time Code Generator Control and Display Panel

J19

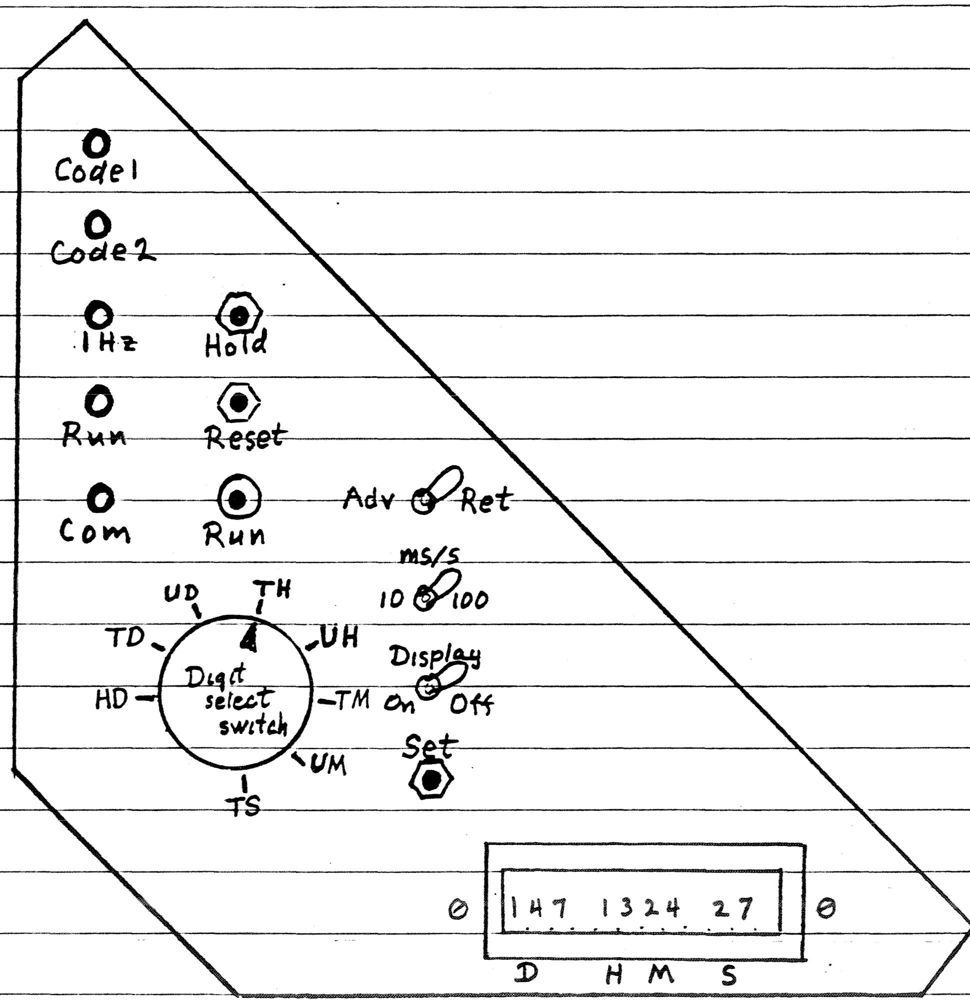
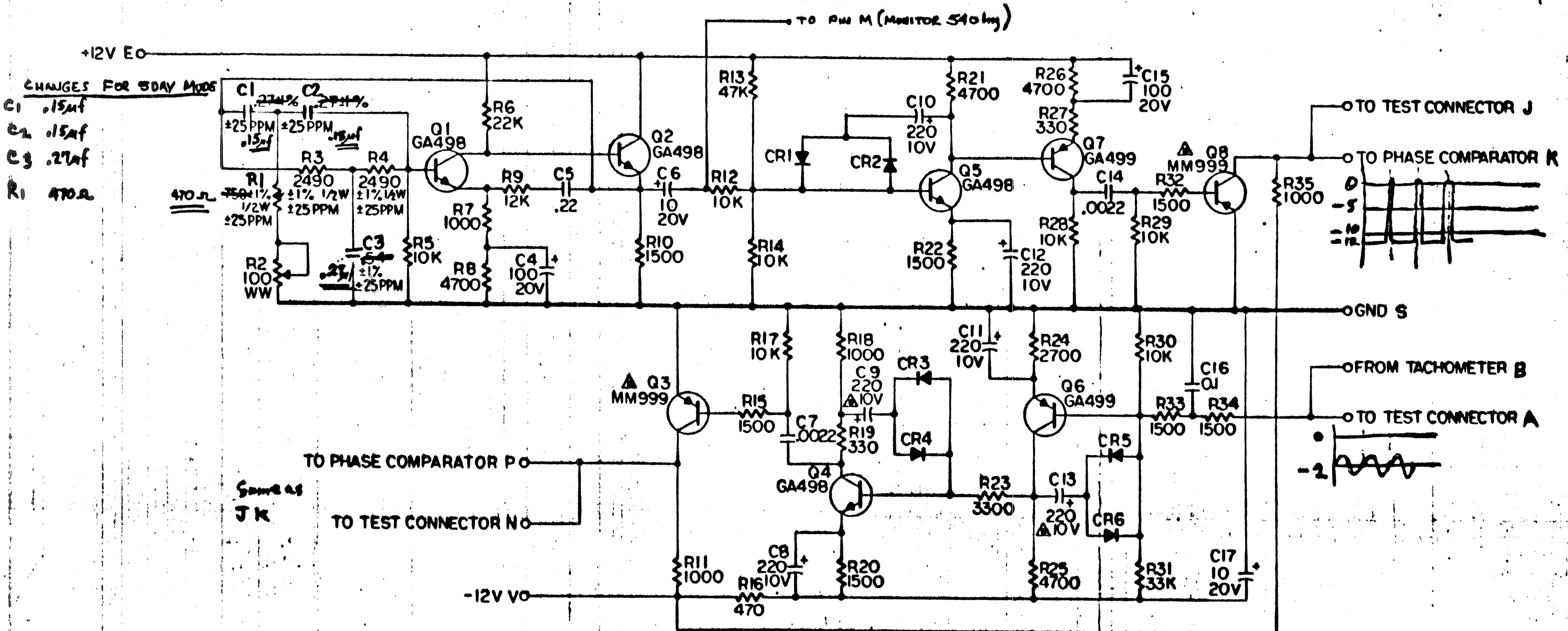


Fig 4

B7 Tach Limiter

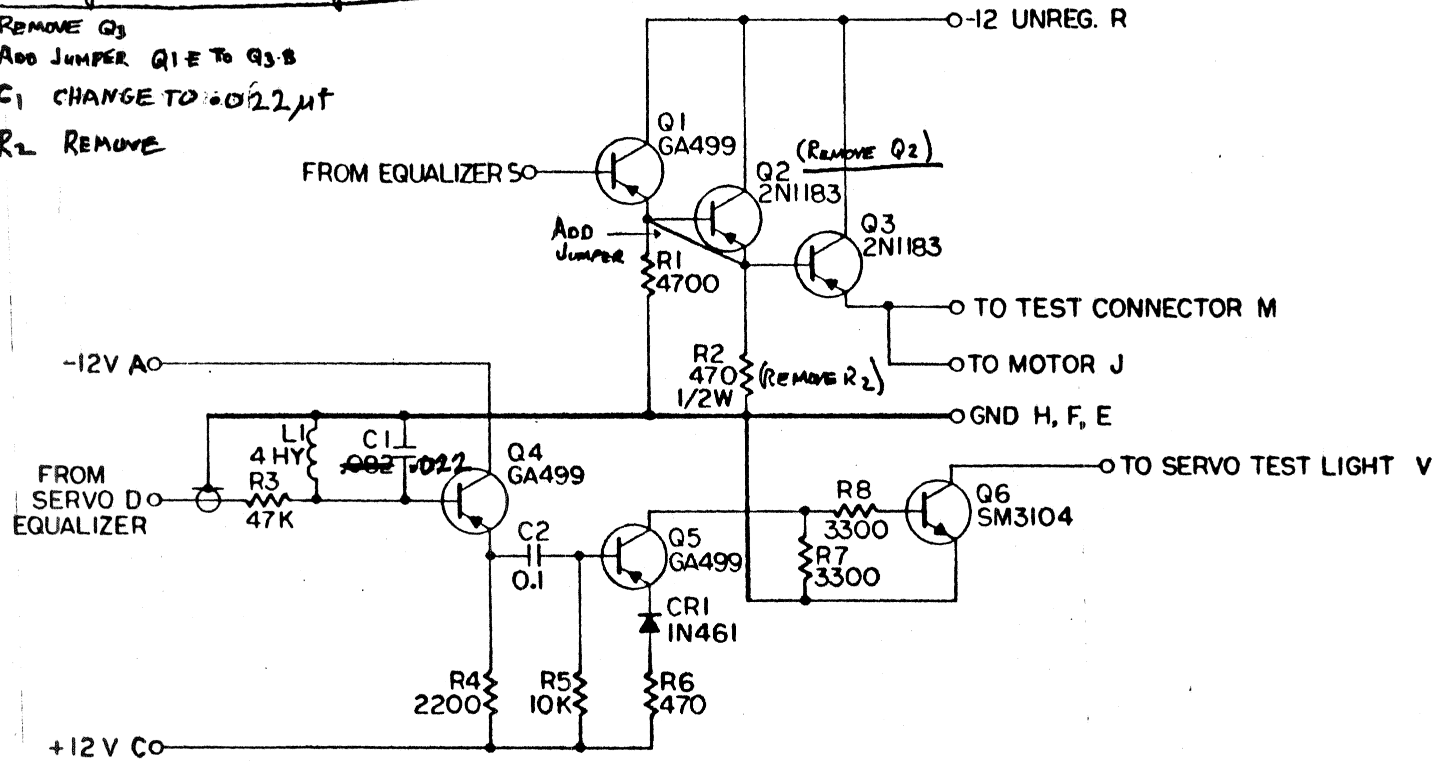


NOTES—UNLESS OTHERWISE SPECIFIED:
1. ALL RESISTOR VALUES IN OHMS, 1/4W, ±10%.
2. ALL CAPACITOR VALUES IN MICROFARADS.
3. ALL DIODES IN461.

Fig 5

Changes for 5-Day-Mode

REMOVE Q3
ADD JUMPER Q1-E TO Q3-B
C1 CHANGE TO .022 μf
R2 REMOVE



NOTES—UNLESS OTHERWISE SPECIFIED:
1. ALL RESISTOR VALUES IN OHMS 1/4 W ±10%.
2. ALL CAPACITOR VALUES IN MICROFARADS.

B10 **MOTOR DRIVE AMPLIFIER (J10)**
(DWG.NO. C20050650-B)

Fig 6

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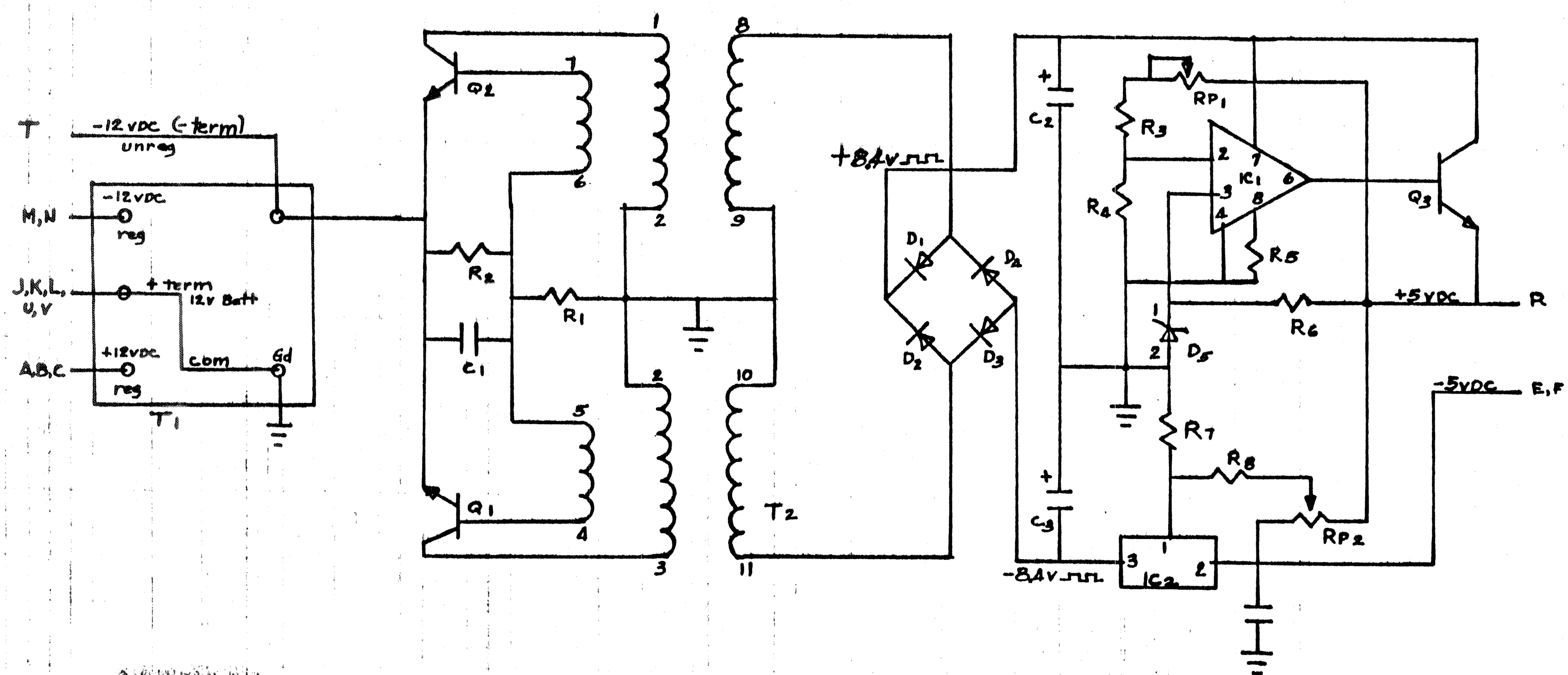


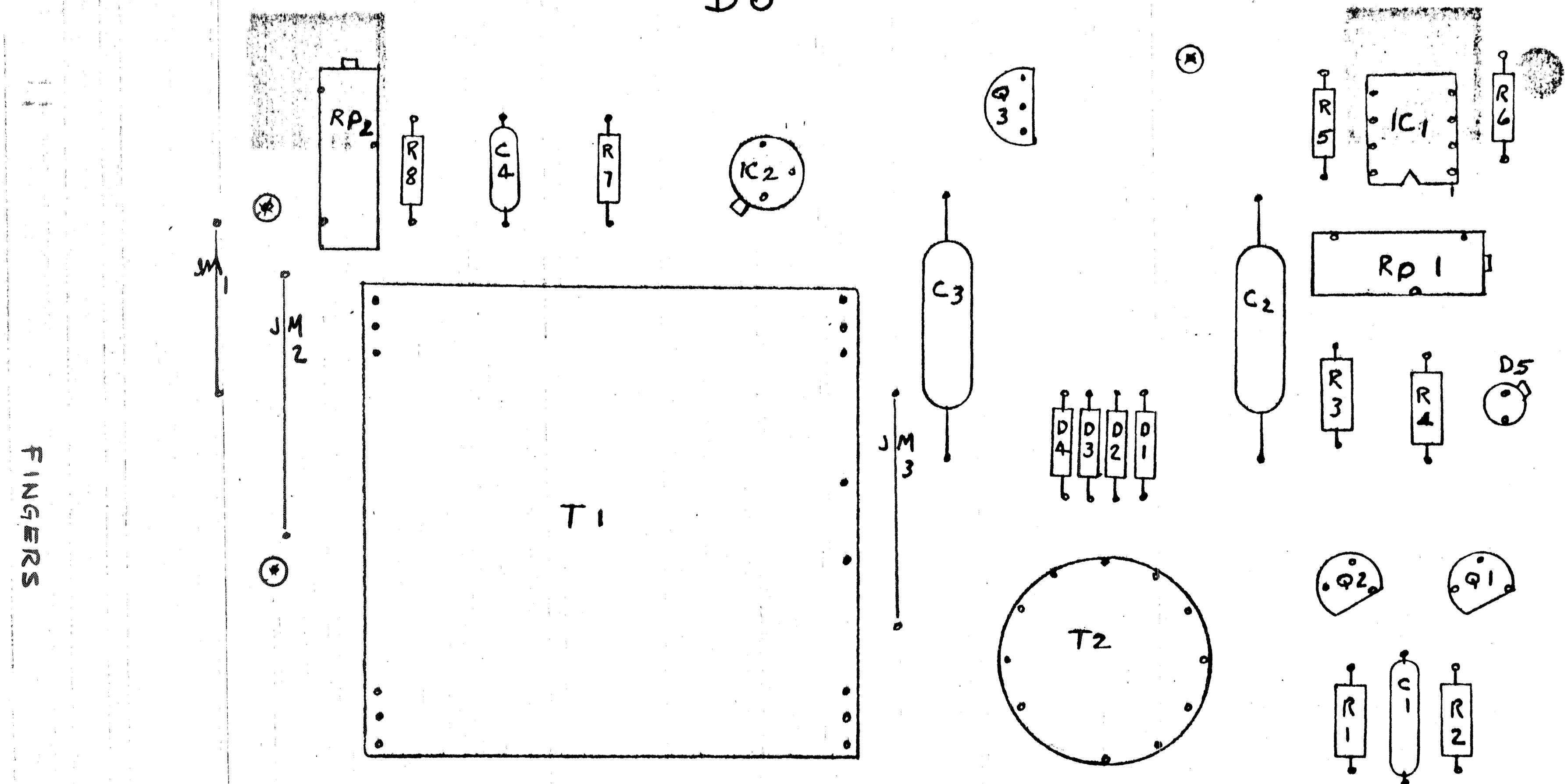
(B6) POWER BOARD

5-DAY RECORDER PI-5100

2-77 EC

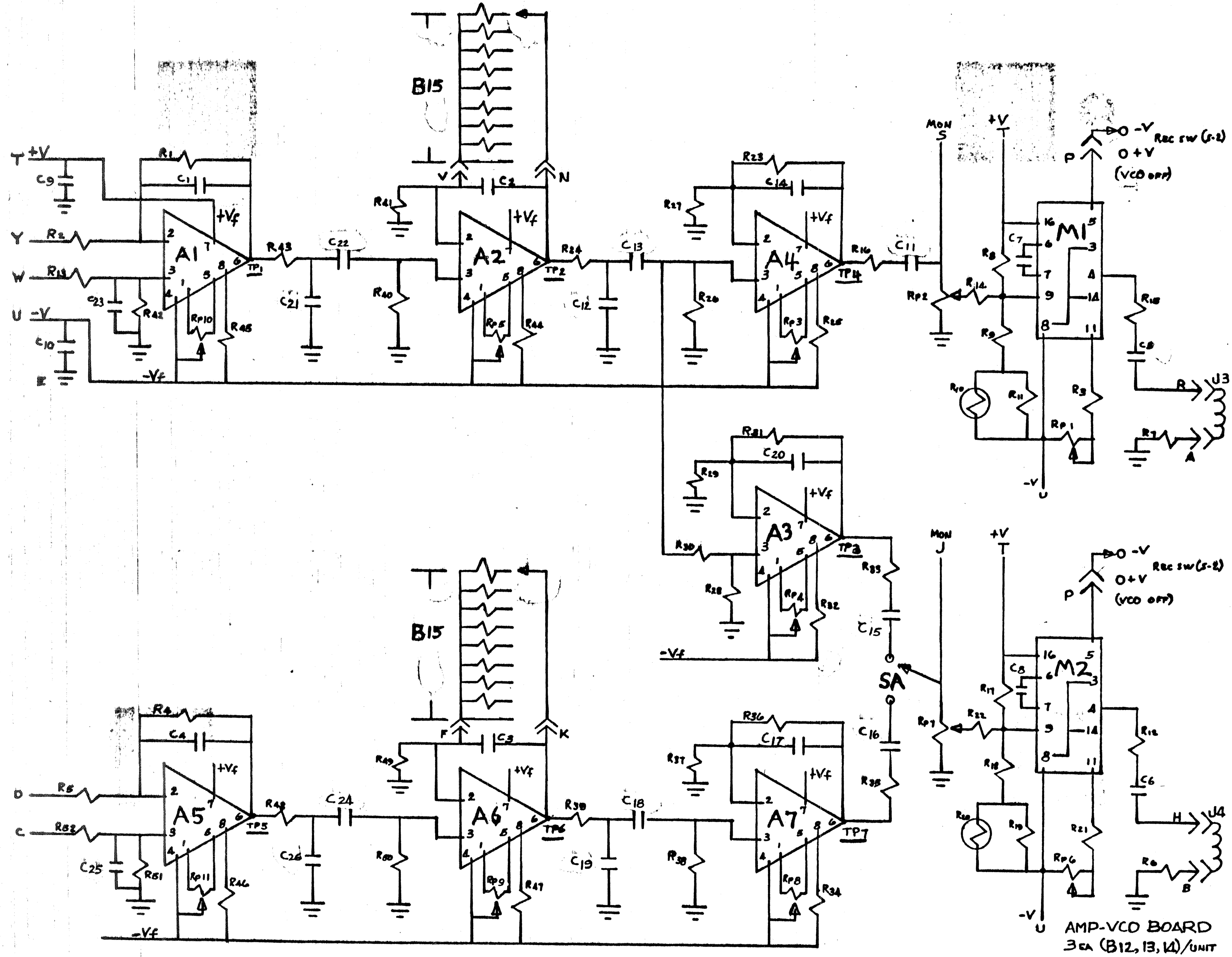
Fig 7

B6



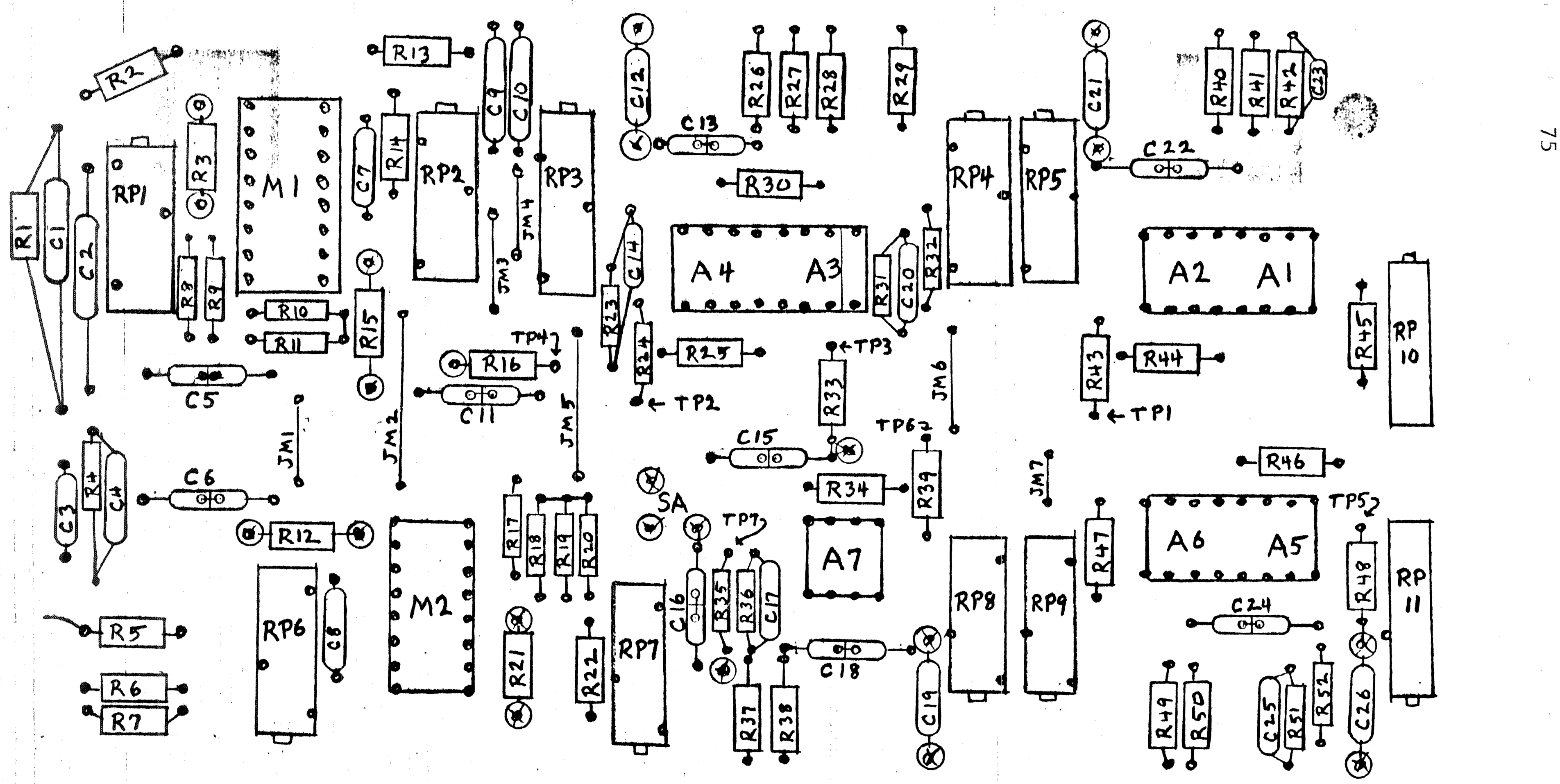
Q1,2	2N3569	C1	.01 μf	R1,4	2K	RP1,2	5K Pot
Q3	2N3391	C2,3	50 μf	R2	9.1K	JM1,2,3	JUMPER
T1	DATEL BPM 12/100 D12	C4	1 μf	R3	5.1K		
T2	KGS 1447T			R5	2 M		
IC1	8 Pin 4250	⊛	stand-off	R6	8.2K		
IC2	LM120H			R7	100Ω		
D1,2,3,4	1N270			R8	470Ω		
D5	LM113H						

Fig 8 POWER BOARD (B6)
5-DAY REC 2-77



AMP-VCO BOARD
3 ea (B12, 13, 14)/UNIT
5-DAY RECORDER
PI-5100

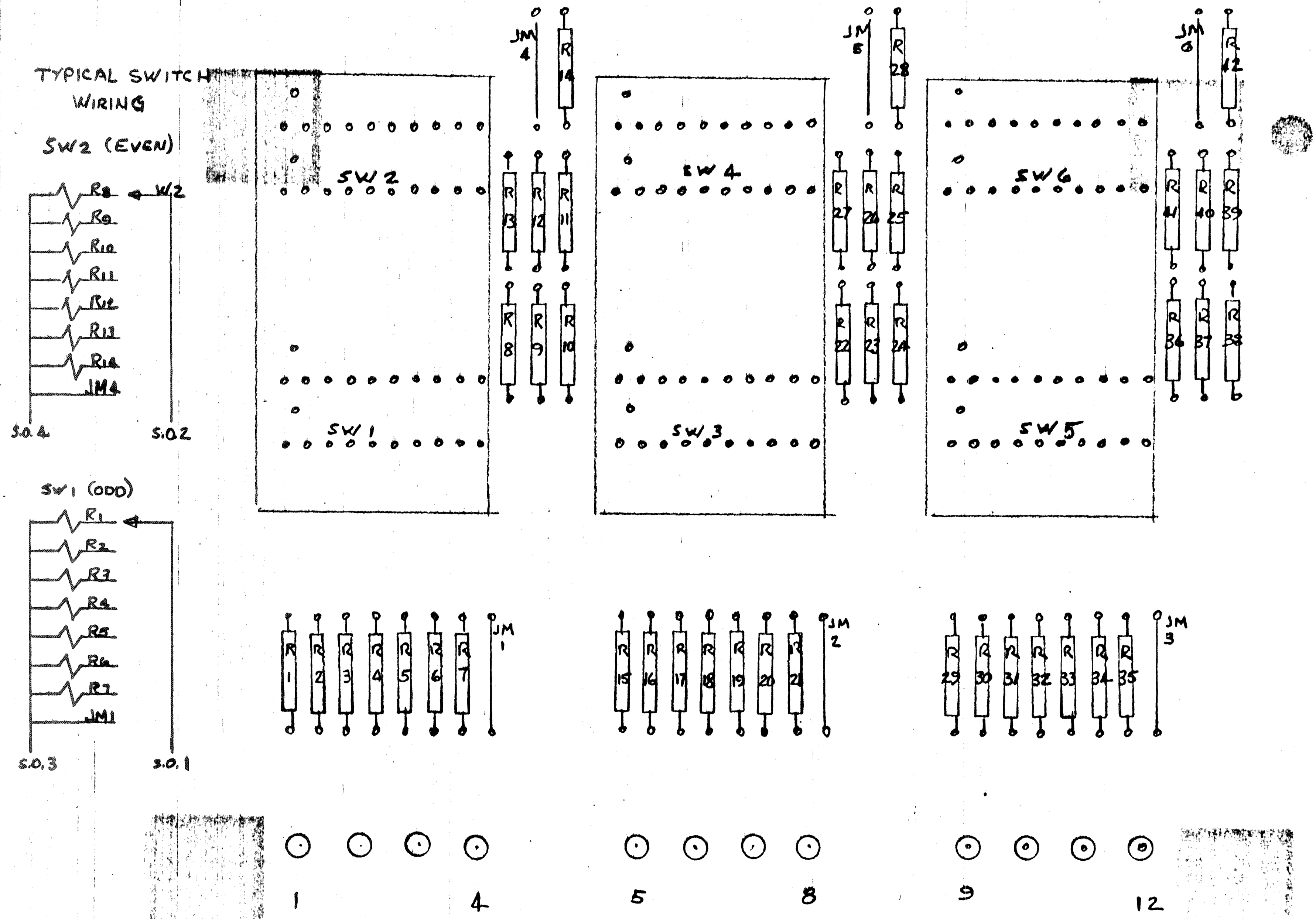
Fig 9



R6,7	10Ω	R14,22	150K	C 2,3	220pf	A1,5	OP-7
16,33,35	51Ω	11,19	300K	14,17	330pf	A2,3,4,6,7	LM4250
12,15	1.2K	31	340K	7,8	.0047µf	M1,2	CD4046
2,5,13,52	5 K	9,18	910K	20	.0056µf	⊕	STAND-OFF
24,39,43,48	10 K	8,17	1 M	9,10	.01 µf	JM1-7	JUMPER
28,29	30 K	25,32,34,44,45,46,47	4.7 M	1,4,23,25	.047µf		
1,4,42,51	39.2K	23,36	5.62M	12,19,21,26	.68 µf		
27,37,38,40,41,49,50	66.5K	10,20 (THERMISTER)	100K	11,13,15,16,18,22,24	25 µf (2×47µf)ϕ		
30	100 K	3,21	FREQUENCY *	5,6	75 µf (2×150µf)ϕ		
26	130 K	RP1-RP11	100K				

ϕ 2 ea are used to obtain small size Non-Polar caps.

B 12,13,14 Amp-VCO layout Fig 10



O 1-12	Standoff	
SW 1,2,3 4,6,5	Grayhill switch 71CY23537 (3ea)	
JM 1,2,3 4,5,6	JUMPER	

R1, 8, 15, 22, 29, 36
R2, 9, 16, 23, 30, 37
R3, 10, 17, 24, 31, 38
R4, 11, 18, 25, 32, 39

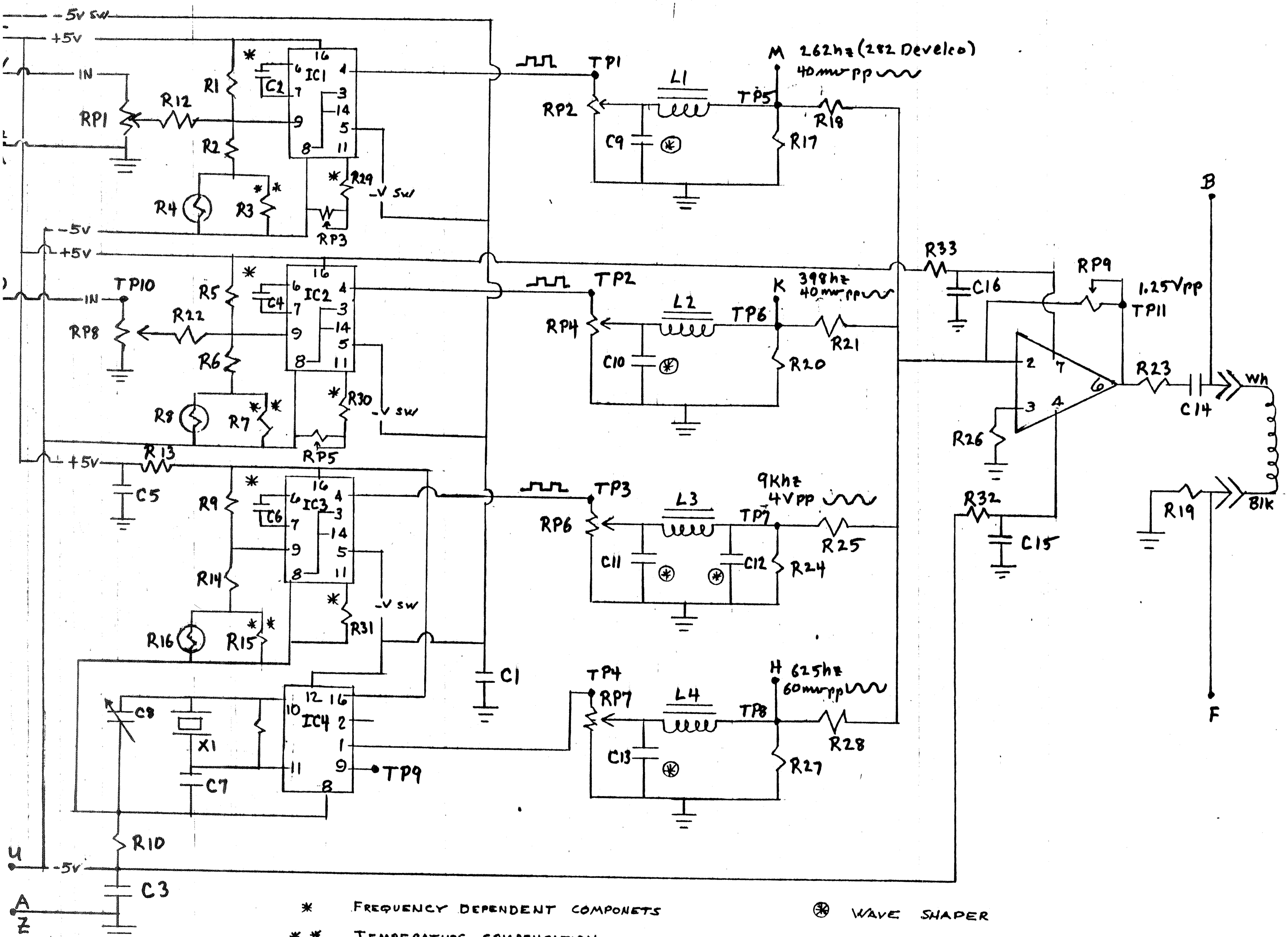
R5, 12, 19, 26, 33, 40
R6, 13, 20, 27, 34, 41
R7, 14, 21, 28, 35, 42

B15

P1-5100-5DAY
2-77 EC

B15 Amp-VCO Attenuator Board

Fig 11

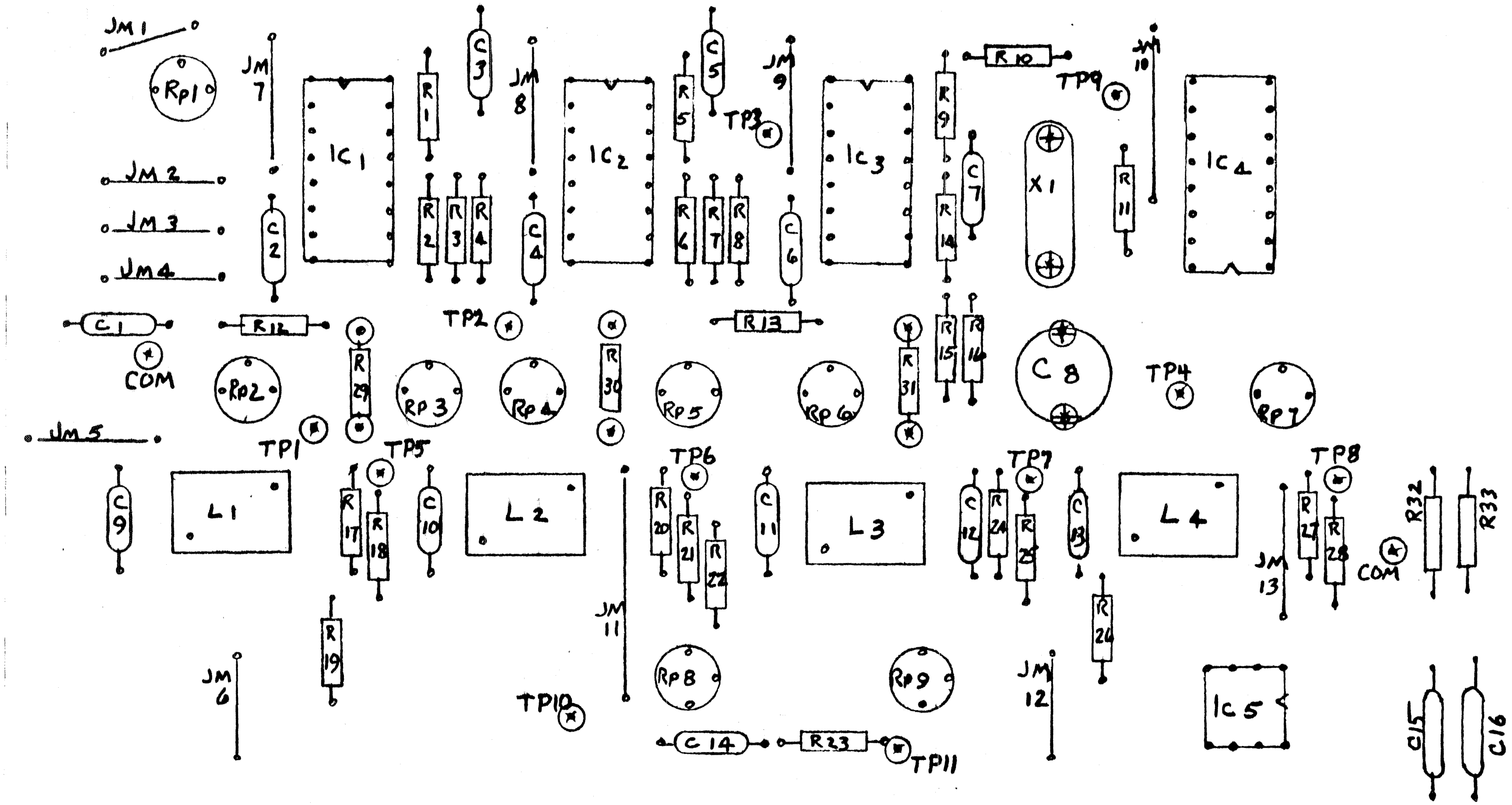


* FREQUENCY DEPENDENT COMPONETS

** TEMPERATURE COMPENSATION

⊛ WAVE SHAPER

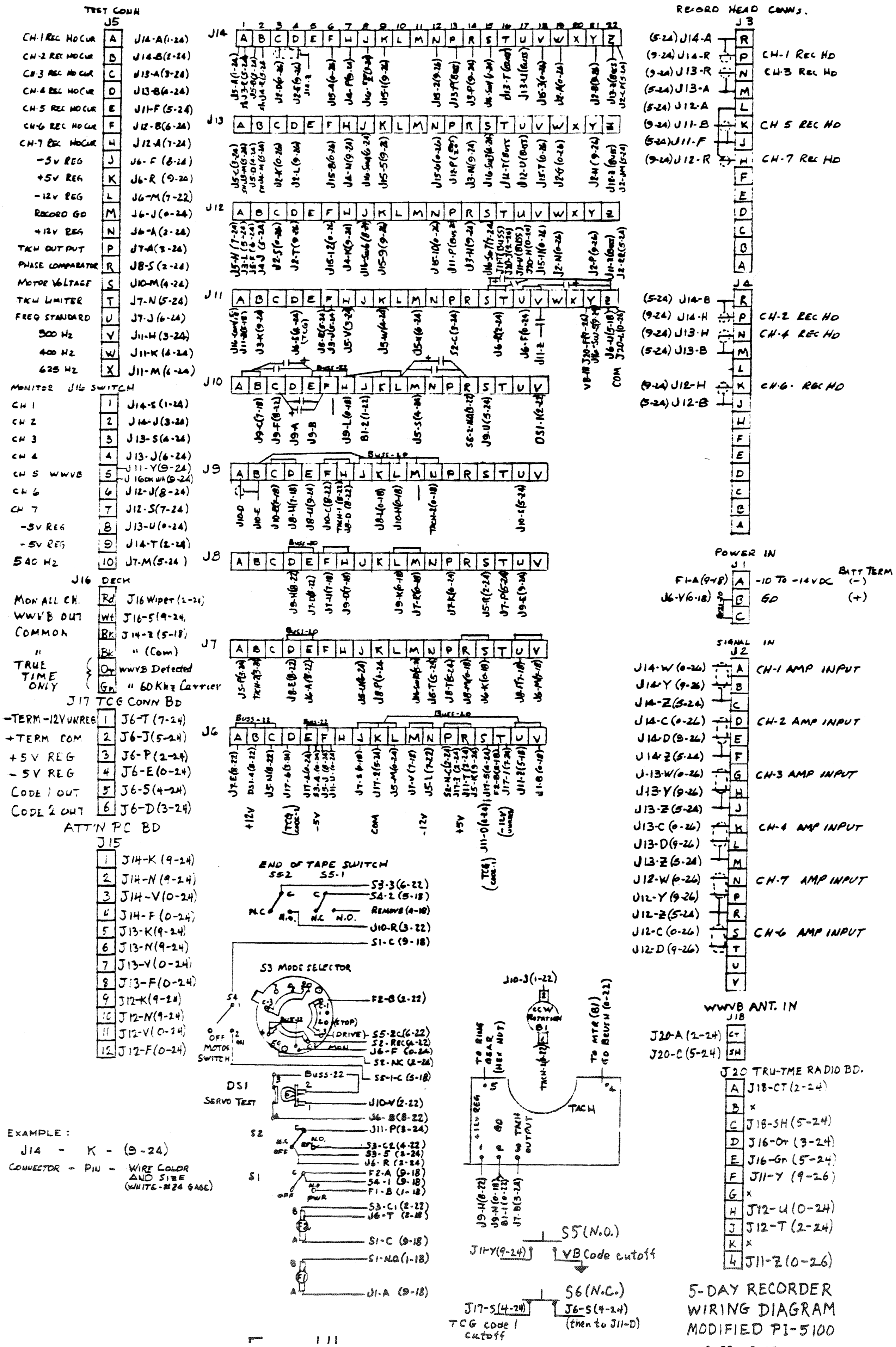
B11 Multiplex Board Fig 12



⊙ Stand-off (20ea)		Rp 1-9	100K Pot	R17,20,27	240 Ω	C1	.022 μf
⊕ .065 Holes (X1 & C8)		R1,5,9	1 meg	R18,21,25,26,28	36 K	C2,4	3300 pf K
IC 1,2,3,4	16 Pin	R12,22	150 K	R19	10 Ω	C3,5,14	150 μf
IC5 741	8 Pin	R2,6,14	910 K	R23	47 Ω	C6	330 pf K
L1,2,4	UTC ML6 4 hy	R3,7	open (Temp comp)	R24	51 K	C7	33 pf
X1	2.56mc Crystal	R4,8,16	100K UP51 J1	R29,30,31	open (freq set)	C8	.15-60 pf
JM 1-13	Jumper wires	R10,13	91 Ω	R32,33	910 Ω	C9,10,11,12,13	open (wave shaper)
L3	UTC-ML3 0.7 hy	R11	15 meg			C15,16	150 μf
IC1,2,3	4046	R15	300 K				
IC4	4060						

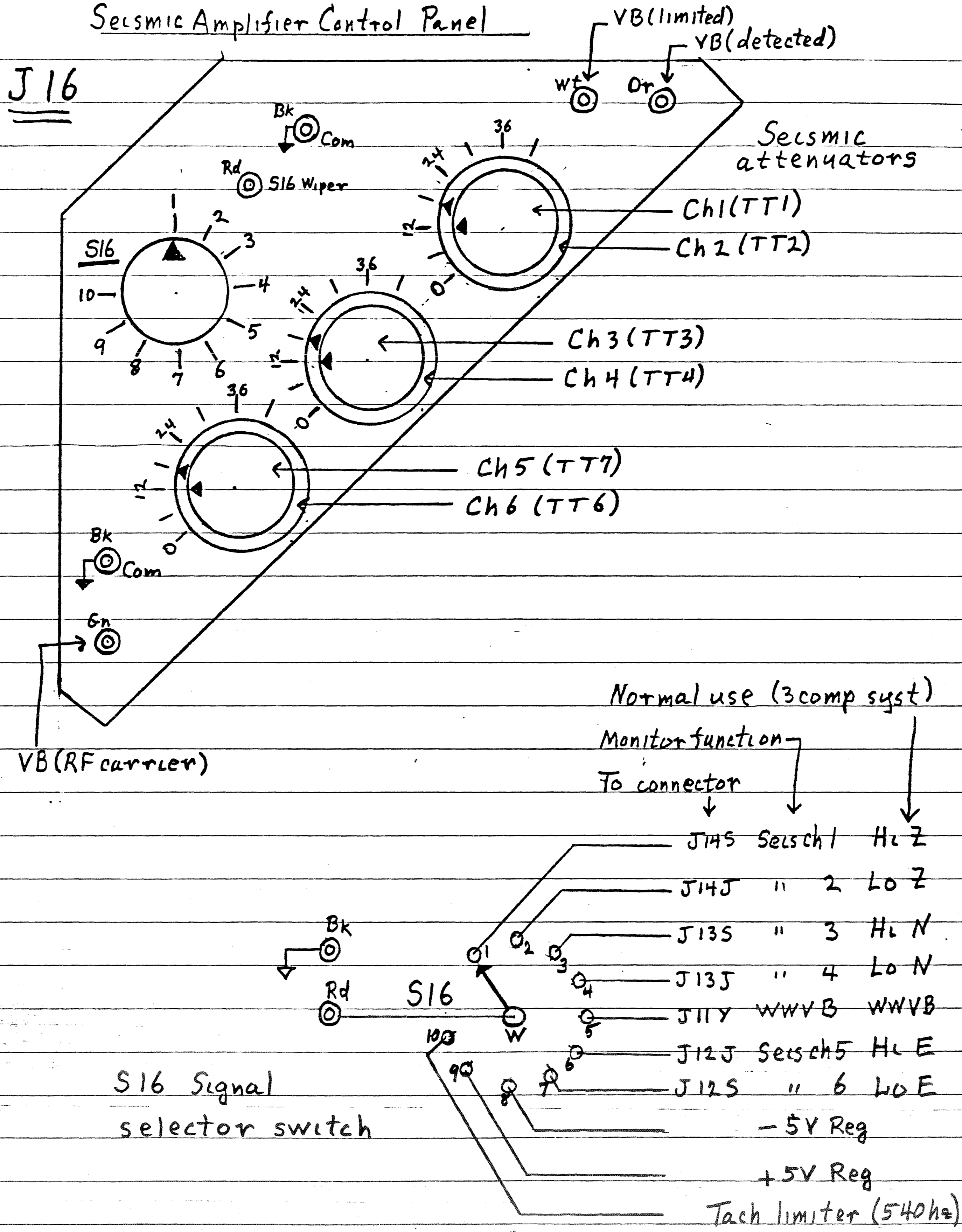
MULTIPLEX BOARD (B11)
5-DAY RECORDER
PI-5100 2-77 EC

Fig 13 B11 Multiplex Board layout


TEST CONN
J5
CH-1 REC HD CUR
CH-2 REC HD CUR
CH-3 REC HD CUR
CH-4 REC HD CUR
CH-5 REC HD CUR
CH-6 REC HD CUR
CH-7 REC HD CUR
-5V REG
+5V REG
-12V REG
RECORD GO
+12V REG
TACH OUTPUT
PHASE COMPARATOR
MOTOR VOLTAGE
TACH LIMITER
FREQ STANDARD
500 Hz
400 Hz
625 Hz
MONITOR J16 SWITCH
CH 1
CH 2
CH 3
CH 4
CH 5 WWVB
CH 6
CH 7
-5V REG
-5V REG
540 Hz
J16 DECK
MON ALL CH.
WWVB OUT
COMMON
TRUE TIME ONLY
WWVB Detected
60 KHz Carrier
J17 TCG CONN BD
-TERM -12V UNREG
+TERM COM
+5V REG
-5V REG
CODE 1 OUT
CODE 2 OUT
ATT'N PC BD
J15
J14
J13
J12
J11
J10
J9
J8
J7
J6
RECORD HEAD CONNS.
J3
CH-1 REC HD
CH-3 REC HD
CH 5 REC HD
CH-7 REC HD
J4
CH-2 REC HD
CH-4 REC HD
CH-6 REC HD
POWER IN
J1
-10 TO -14 VDC
GD
BATT TERM
SIGNAL IN
J2
CH-1 AMP INPUT
CH-2 AMP INPUT
CH-3 AMP INPUT
CH-4 AMP INPUT
CH-7 AMP INPUT
CH-6 AMP INPUT
WWVB ANT. IN
J18
J20 TRU-TME RADIO BD.
END OF TAPE SWITCH
S52 S5-1
S3 MODE SELECTOR
OFF MOTOR SWITCH
DS1 SERVO TEST
S2
S1
PWR
TACH
S5 (N.O.)
VB Code cutoff
S6 (N.C.)
TCG code 1 cutoff
(then to J11-D)
EXAMPLE:
J14 - K - (9-24)
CONNECTOR - PIN - WIRE COLOR AND SIZE (WHITE-#24 GAGE)
5-DAY RECORDER
WIRING DIAGRAM
MODIFIED PI-5100

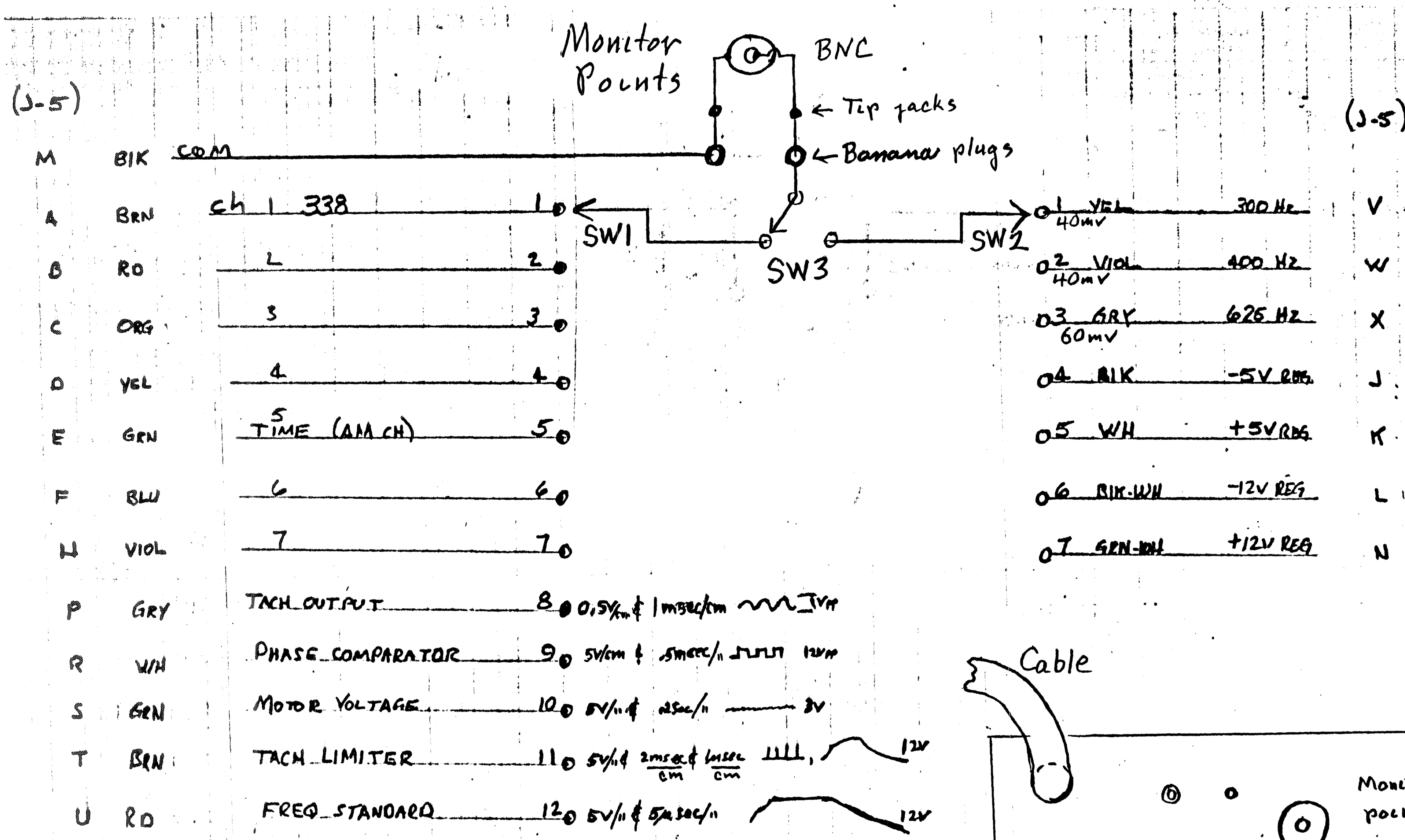
Seismic Amplifier Control Panel

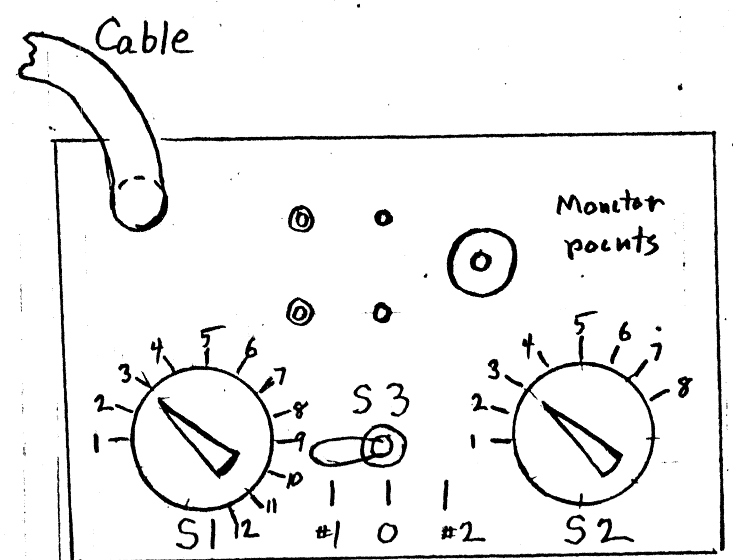
J16



S16 Signal selector switch

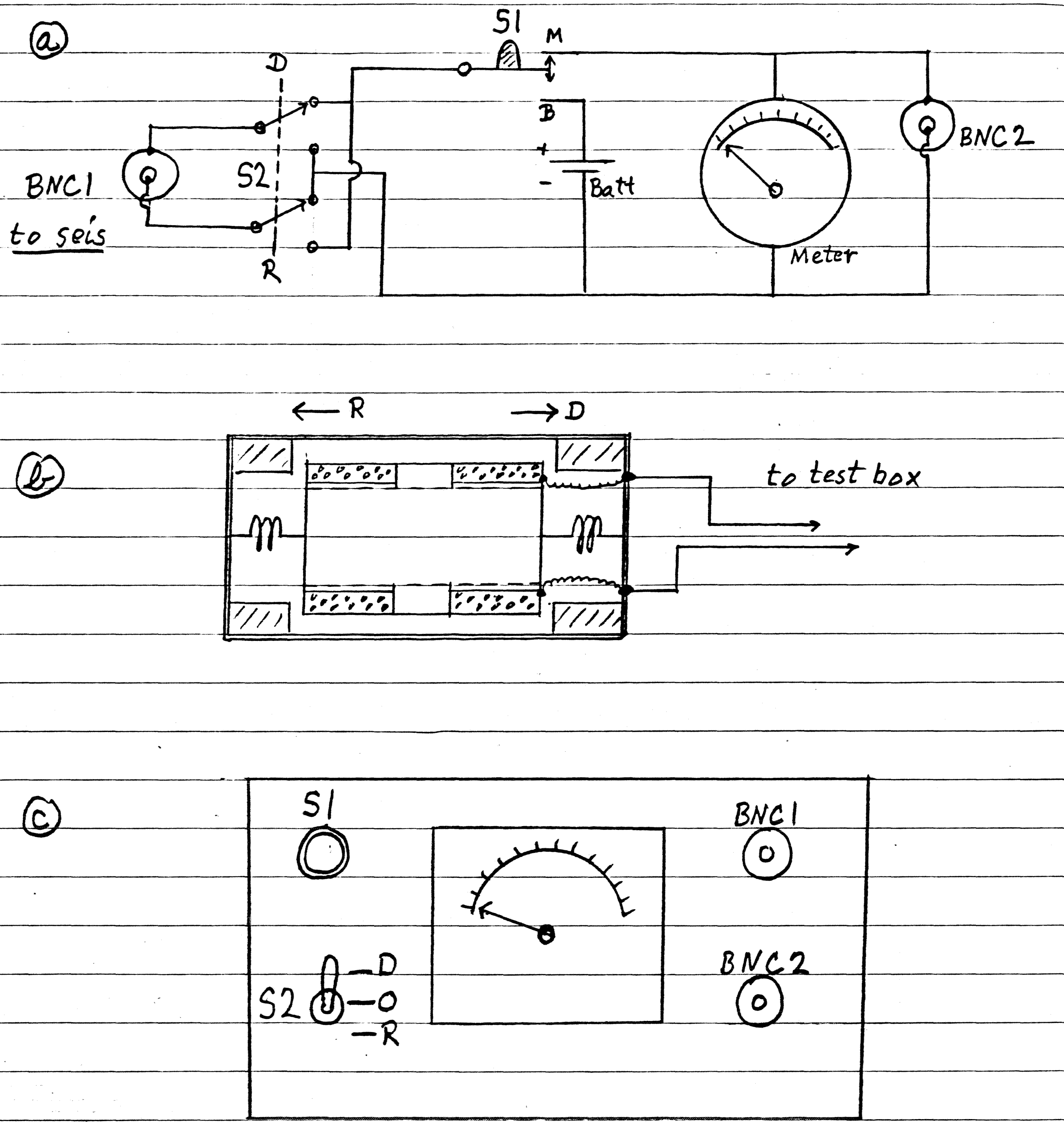
Fig 15





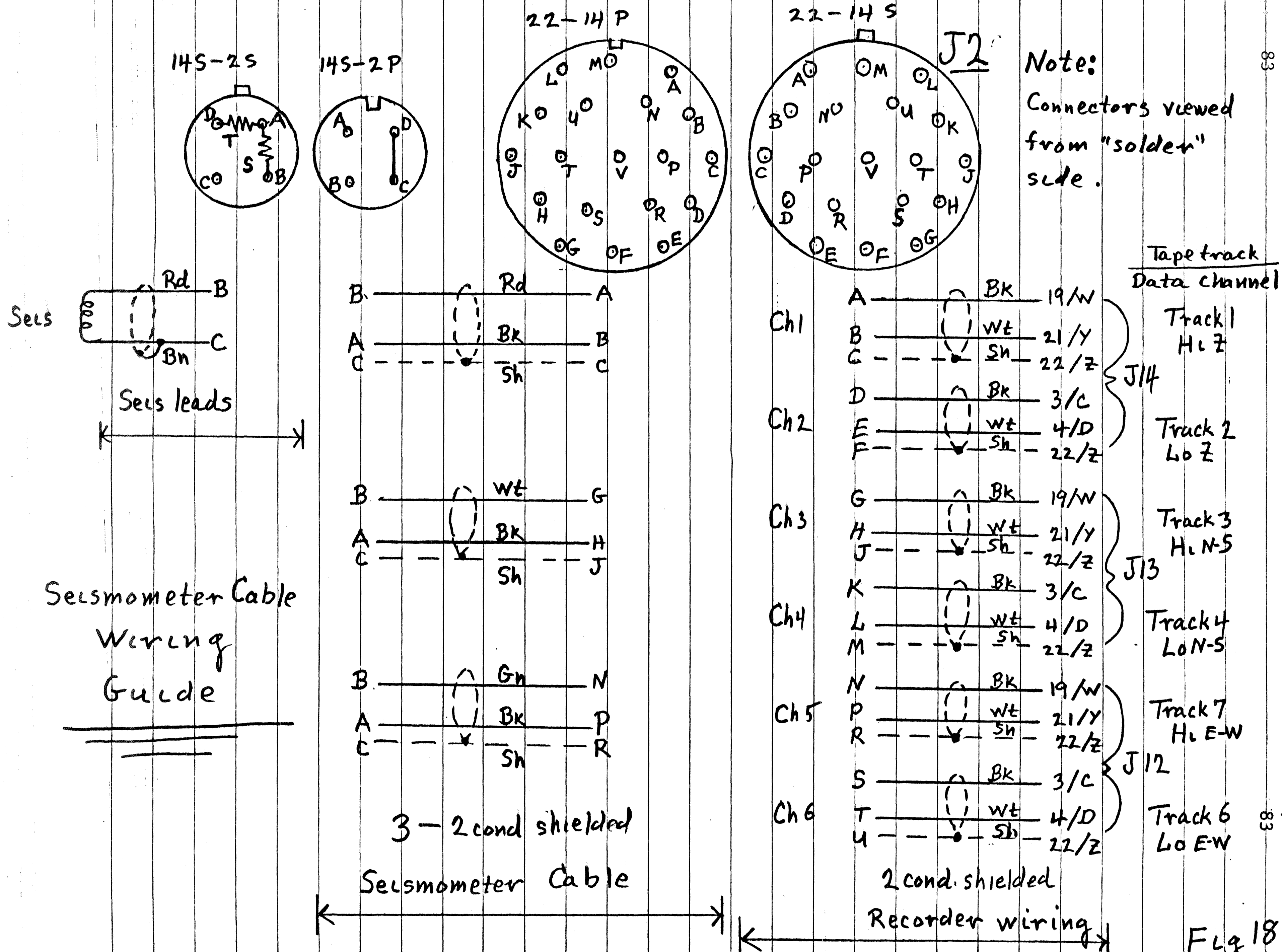
Connector, cable, and channel select box to facilitate use of master function monitor terminal J5

Fig 16



Horizontal seismometer level test box circuit and layout

Fig 17

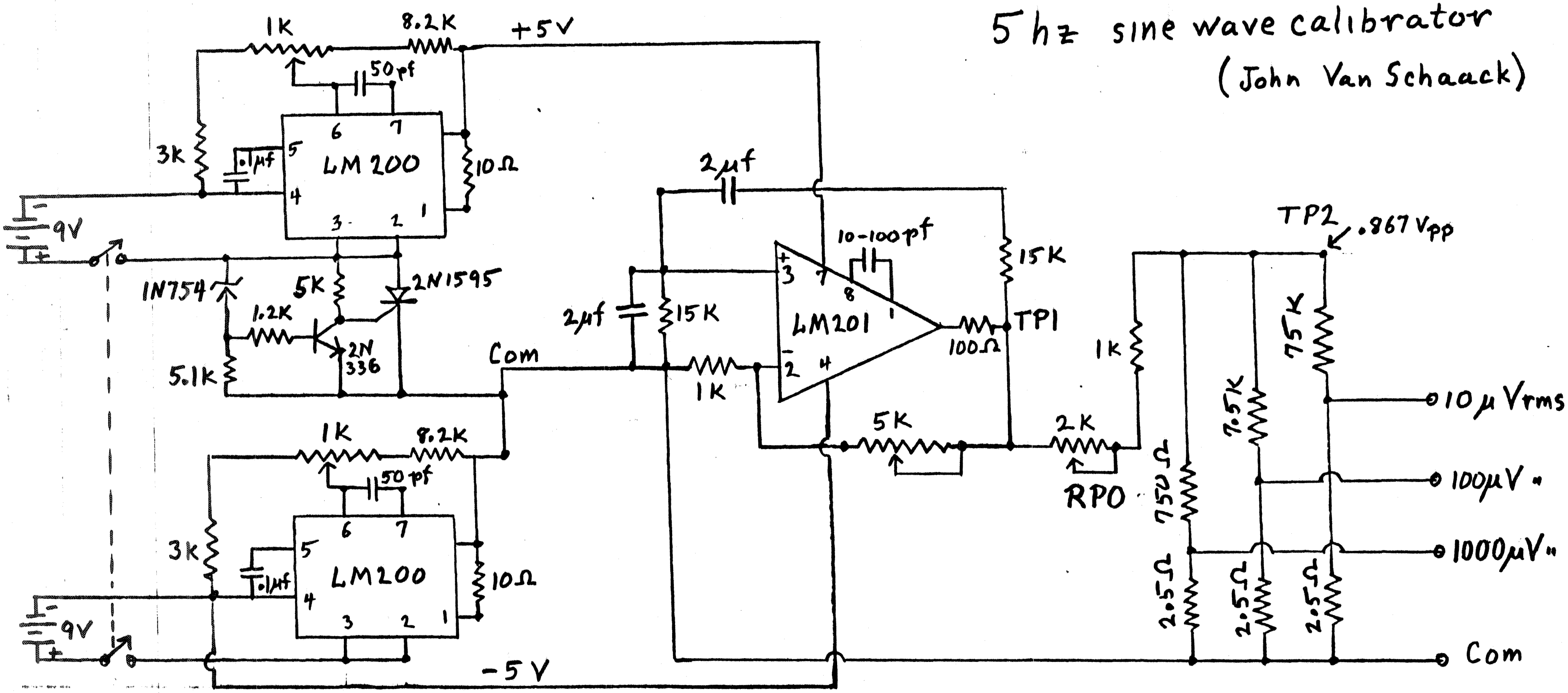


14S-2S
14S-2P
22-14 P
22-14 S
J2
Note: Connectors viewed from "solder" side.
Seis
Rd
B
C
Bn
Seis leads
Seismometer Cable Wiring Guide
B A
A B
C C
Rd
Bk
Sh
B G
A H
C J
Wt
Bk
Sh
B N
A P
C R
Gn
Bk
Sh
3 - 2 cond shielded
Seismometer Cable
Ch1
Ch2
Ch3
Ch4
Ch5
Ch6
A Bk 19/W
B Wt 21/Y
C Sh 22/Z
D Bk 3/C
E Wt 4/D
F Sh 22/Z
G Bk 19/W
H Wt 21/Y
J Sh 22/Z
K Bk 3/C
L Wt 4/D
M Sh 22/Z
N Bk 19/W
P Wt 21/Y
R Sh 22/Z
S Bk 3/C
T Wt 4/D
U Sh 22/Z
J14
J13
J12
Tape track
Data channel
Track 1 Hi Z
Track 2 Lo Z
Track 3 Hi N-S
Track 4 Lo N-S
Track 7 Hi E-W
Track 6 Lo E-W
2 cond. shielded
Recorder wiring

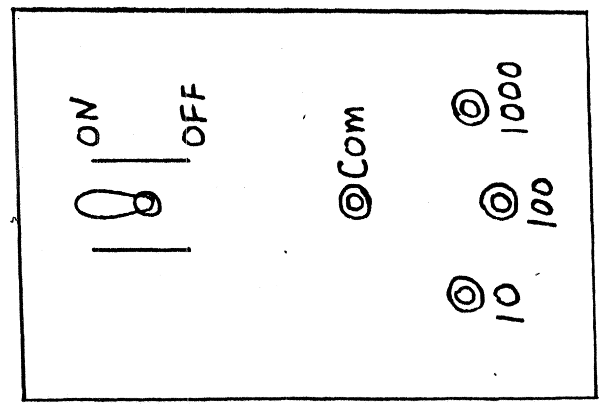
Fig 18

83

5 hz sine wave calibrator
(John Van Schaack)



Circuit



Top view of calibrator

Fig 19

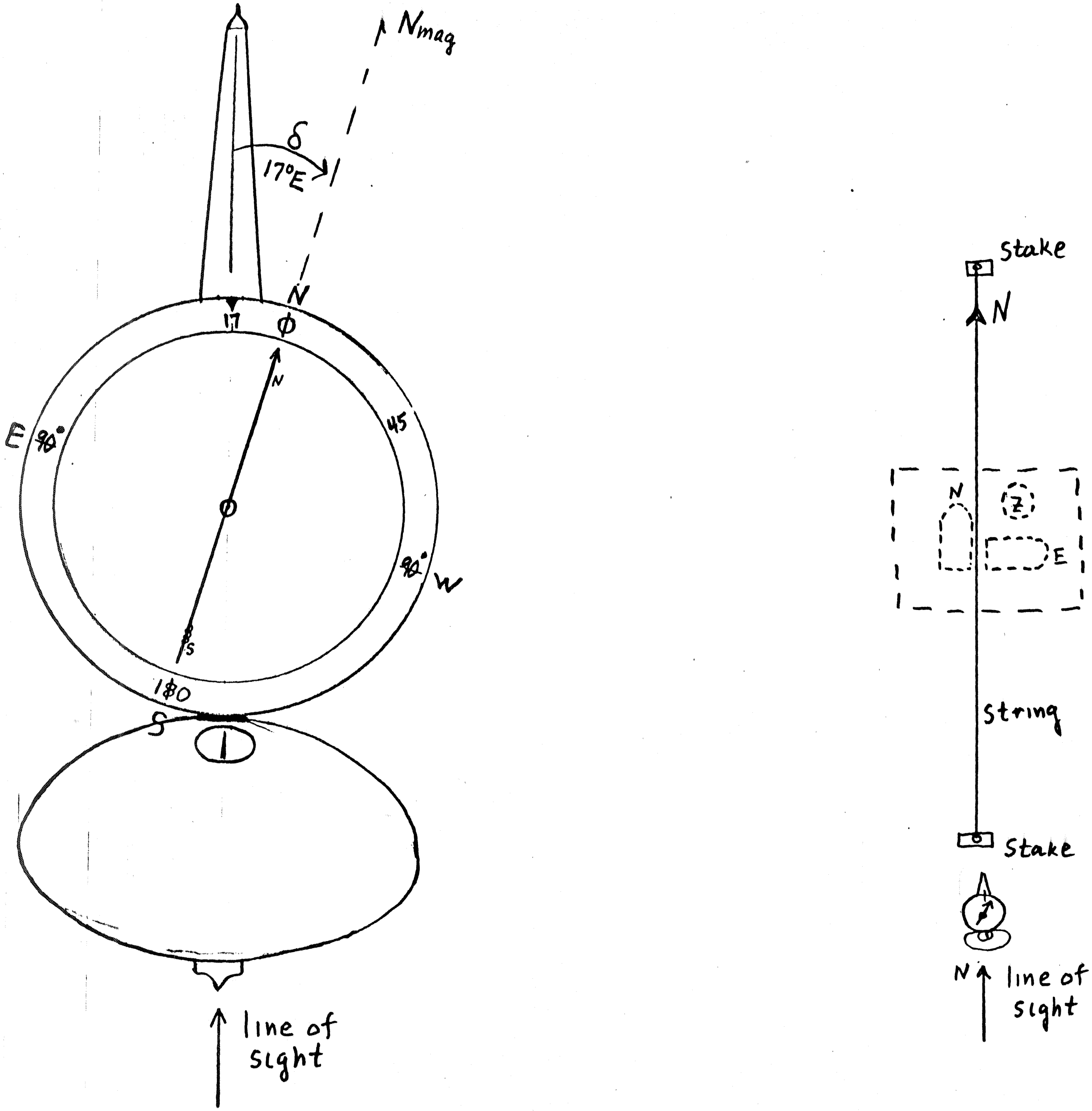

N mag
δ
17°E
17
N
Ø
45
E
90°
90°
W
180
S
line of sight
Stake
N
Z
E
string
Stake
N
line of sight

Fig 20

85