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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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THE CENTIPEDE SEISMIC RECORDING SYSTEM

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MAY 2 1977
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Open File Report 77-315
1977

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PREFACE

This field recording system was, by choice, based, in so far as possible, on existing equipment design and components used in the USGS Central California Micreoearthquake Network and telemetry system. By so doing, we believe we have maximized the compatibility of these systems, and minimized the confusion typically associated with new instrumment designs.

This report, then, brings together under one cover (as a system handbook) the individual write-ups on all of the principal equipment components used in this system. Some of these components are new and are described here for the first time. Other are modifications of pre-existing equipment. Still others have been used and described previously and are included herein for completeness.

INTRODUCTION

This report describes a portable seismic recording system known as Centipede, which is capable of recording vertical and or horizontal ground motion from up to 96 sensers. The sites may be arranged in any configuration as a network or an array, within the constrains imposed by telemetry. The instrumentation at each remote sensor site consists of a geophone, a preamplifier/voltage controlled oscillator (VCO), and, at some sites, a telemetry radio transmitter. The geophones are Mark Products, Ltd., Model L4-C (1-second period, horizontal and vertical). The amplifier and geophone combined frequency response is shown in Figure 1. This instrument response is identical to the response of the current USGS Central California Network instruments. All the remote site instrumentation is waterproof, battery operated, and self-contained, and my be operated unattended for periods up to one year. VHF radio links and/or hard-wire telemetry connects individual sensors, or clusters of sensors to the central recording site. The central recording site includes telemetry radio receivers, a crystal controlled clock/chronometer, a WWVB radio receiver, a signal conditioning/ monitoring (recording interface) unit, a 1-inch analog magnetic instrumentation recorder, and battery power supply. All data and timing (IRIG-E, IRIG-C, WWVB) are recorded on one analog magnetic tape, which runs 24 hours. All equipment at the central recording site derives power from two 12-volt car batteries. Attendance at the central recording site is required once every 24 hours to change tapes and batteries. The method of recording is FM multiplex. The multiplex structure and tape format (Table 1) is the same as that of the former USGS system. The tapes produced by Centipede are compatible with the USGS Central California Network Playback System (Open File Report No. 73-374 and 75-663) and with the USGS Centipede Analysis System.

SEISMOMETERS

The sensing elements in The Centipede system are Model L-4C geophones, manufactured by Mark Products, Ltd. These are dynamic (velocity sensitive) transducers with dual moving coil, humbuck wound. Coil resistance is 5500 ohm ± 5%. The suspended mass is nominally 1000 gram. The principal resonance is 1.0 Hz, nominal. The geophone looks into a resistive network composed of the damping ("S" and "T") resistors and the amplifier input resistors (Figure 5). This resistive network results in an effective load corresponding to damping of 0.8 critical. The geophone output (pins A-E, Figure 5) into this load is 3.6 volt-sec/inch, for frequencies above resonance. The voltage then presented to the amplifier input, after voltage divider (S,T) is nominally 1.0 volt-sec/cm. That is, ground motion (velocity) of 1 cm/sec produces 1.0 volt (nominal) across the amplifier input.

As stated above, the input circuit for the amplifier damps the seismometer to 0.8 critical, and divides the voltage output to a nominal value. The damping and voltage dividing are determined by the values of resistors "S" and "T" , which are in the form of an L-pad. Choice of values for these resistors is made with the aid of a Fortran program called NET CAL, written by J. P. Eaton and modified to its present form by E. Endo.
The L-pad resistors are physically located within the body of the electrical connector (Bendix PT06A-14-18P), potted in epoxy.

The geophones are packaged in sealed PVC vaults for electrical isolation.

J303 PREAMPLIFIER AND VOLTAGE-CONTROLLED OSCILLATOR UNIT

A. Description

The J303 Preamplifier and Voltage Controlled Oscillator (VCO) is designed as a seismic signal amplifier, conditioner and sub-carrier generator. The unit amplifies and filters seismic signals in the microvolt to millivolt range and bandwidth 0.1 to 30 Hz (Figure 1), and then frequency modulates an audio subcarrier with the amplified seismic signal. This method allows low level seismic signals to be telemetered by telephone line or by radio link to a recording site. The modulated subcarriers can be multiplexed so that as many as 8 seismic signals can be transmitted over one voice grade telephone line or radio link.

B. Specifications

1. Noise (referred to input): 1.0 microvolt peak to peak with a source impedance of 10,000 ohms over bandwidth 0.1 Hz to 30 Hz.
2. Bandwidth (-3 dB points): 0.1 Hz to 30 Hz with 12 dB/octave roll-off.
3. Gain: Voltage gain 90 dB max., with 42 dB attenuation in 6 dB steps.
4. Input: Differential, 10,000 ohms input impedance.
5. Supply voltage: ±4.05 VDC at 200 microamps with output level at -10 dBm.
6. VCO frequency stability
    - 6.1 Temperature coefficient: 0.01%/°F max. over range 0°F to 90°F.
    - 6.2 Maximum drift: ±15 Hz (3060 Hz C.F.), ±3 Hz (680 Hz C.F.) over range 0°F to 90°F.
7. Output distortion: Harmonic power content less than 1% of fundamental.
8. VCO output level: Adjustable, up to -5 dbm (1.2V, p-p) into 600 ohm load.
9. Output impedance: 600 ohm, balanced.

10. Carrier deviation: ±125 Hz nominal, adjustable to ± 135 Hz max.

11. Deviation sensitivity*. The output frequency deviation per microvolt input to the preamplifier is given below as a function of attenuator switch position:

Attenuation	Sensitivity
0 db	1.25 Hz./microvolt
6	.63
12	.31
18	.16
24	.078
30	.039
36	.020
42	.010

12. Operating temperature range: 0°F to 120°F.

C. Principles of Operation

The J303 (Figures 2,3) consists of a preamplifier (A1), an amplifier (A2), and a voltage-controlled oscillator (VCO), and associated filtering circuitry. The seismic signal is direct-coupled to the preamplifier which has an input impedance of 10,000 ohms. This amplifier stage has resistance and capacitance feedback to provide a fixed gain of 48 dB and low-pass filtering with 6 dB per octave roll-off above 30 Hz. The D.C. offset of this amplifier can be nulled with R7.

The preamplifier and amplifier stages are resistance-capacitance coupled through C3 and R8, resulting in high-pass filtering with 6 dB per octave roll-off below 0.1 Hz. Series resistors R25 through R32 provide 42 dB of attenuation in 6 dB steps.

*Within the passband (0.1-30 Hz), and when alligned as described in section D, below.

The amplifier stage also has resistance and capacitance feedback with a fixed gain of 42 dB and low pass filtering with 6 dB per octave roll-off above 30 Hz. The D.C. offset of this stage can be nulled with R13. Both A1 and A2 are micropowered integrated circuit operational amplifiers that require about 15 μa each at ± 4 VDC.

The output of the amplifier stage is resistance-capacitance coupled through C5, R14 and R15 to the VCO stage to produce 6 dB per octave roll-off below 0.1 Hz. The result is an amplifier system with a maximum voltage gain of 90 dB and a passband 0.1 Hz to 30 Hz with 12 dB per octave roll-off outside these frequencies.

The VCO utilizes only the VCO section of a COS MOS phase-locked-loop integrated circuit (CD4046). The amplified seismic signal is fed into the VCO through potentiometer R15, which functions as deviation sensitivity control. The center frequency of the VCO is determined by C6 and R22 with potentiometer R21 being a fine adjustment control for the center frequency. The center frequency of the VCO is temperature compensated by the circuit consisting of R17, R18, R19, and thermistor R20. The output of the VCO is fed through potentiometer R23, the output level control, into I1, C8, and C7, the wave shaping network, and then into the output transformer T1. The center frequencies given in Table I have become standard in the transmission of seismic data by constant bandwidth methods. All frequencies are operated in a constant bandwidth system, each having a maximum deviation of $\pm$ 125 Hz..

D. Alignment Procedures

1) Amplifier Section

Insert integrated circuits A1, A2, and VCO into their respective sockets (Figures 2, 3). Shunt the prepamplifier input with a 10 K ohm resistor,

TABLE 1

SIGNAL LEVELS FOR AMPLIFIER SET-UP PROCEDURE

Input signal: 100 V, p-p, 5Hz sine wave.

Attenuator Switch	Signal Level at TP1	Signal Level at TP2
0 db	120 mV p-p	clipped
- 6 db	"	clipped
-12 db	"	2.35 V, p-p
-18 db	"	1.17 V, p-p
-24 db	"	.60 V, p-p
-30 db	"	.30 V, p-p
-36 db	"	.15 V, p-p
-42 db	"	.075V, p-p

TABLE 2

FREQUENCY DEPENDENT COMPONENT VALUES
IN VCO SECTION

Frequency	C6 uf	C7 uf	C8 uf	L1	R 34 (ohms)
680 Hz	.0015	.018	.01	ML-6	300
1020 Hz	.0015	.01	.082	ML-6	270
1360 Hz	.001	.015	.0082	MOT	240
1700 Hz	.001	.0068	.0050	MOT	200
2040 Hz	.001	.0047	.0039	MOT	180
2380 Hz	.001	.0056	.0033	ML-3	150
2720 Hz	.00068	.0047	.0027	ML-3	130
3060 Hz	.00068	.0039	.0022	ML-3	100

R22 varies with individual VCO Ics. Minimum value for R22 should not be less than 240 K ohms. Maximum value may be 3 Meg ohms.

and apply ±4VDC power. Connect an oscilloscope to common and tie-point 1 (TP1) and adjust R7 for 0 VDC ±5 mV. Next, connect the oscilloscope to tie-point 2 (TP2) and adjust R13 for 0 VDC ±5 mV. Last, connect the oscilloscope to the amplifier monitor (AMP MON) and remove the 10 K ohm shunt from the input to A1. Connect an AC signal source (100 μV, 5 Hz) across the inputs to A1 and monitor the amplifier output for proper gain at each attenuator setting. Gains may vary a maximum of 10%. (Table 1)

2) VCO Section

To align the VCO to the proper center frequency, determine the resistor (R22) and capacitor (C6) values from Table 2, and install them. These values are only approximate and some trimming may be required. R21, the center frequency adjust pot, provides about 2% adjustment of the center frequency.

Load the secondary of output transformer T1 with 600 ohms and connect a frequency counter and an oscilloscope across the load. Set the attenuator switch to -42 dB to minimize amplifier noise. Set center frequency as desired, using resistor substitution box across R22. Adjust output to -10 dbm (0.69 V, p-p). Reset center frequency to nominal value. Check output wave form at wiper of R23 without C7 and C8 in circuit. Note phase shift (tilt at top and bottom of square wave). With decade capacitance box, set C8 for zero phase shift. With C8 installed check for -10 dbm (0.69 V, p-p) output level and nominal center forequency (adjust if necessary). With decade capacitance box, adjust C7 for best sine wave shape. Reset center frequency to nominal value and output to -10 dbm.

To set the deviation sensitivity of the VCO, apply +3.0 VDC to the point labeled "AMP MON", and adjust R15 for 125 Hz increase of the carrier frequency. Reverse the polarity of the 3.0 VDC and check for 125 Hz decrease of the carrier frequency.

E. Tests

1) VCO voltage-frequency stability tests.

Some VCO chips are very sensitive to supply voltage changes. The acceptable level of change is 5Hz per KHz with a 4% change in supply voltage. The following screening test can be used to find acceptable VCO chips.

Install a VCO chip in its socket, connect the battery supply and measure the VCO frequency. Disconnect one side of the battery supply voltage, insert a germanium diode in series and reconnect the battery. Measure the new VCO frequency and the voltage drop across the diode. Compute the Hz per KHz change of the VCO frequency as follows:

$$\text{(Hz/Khz) per 4\% supply voltage change} = \frac{\text{(frequency change in Hz)}}{6 \times \text{(center frequency in kHz)} \times \text{(voltage change in volts)}}$$

If the anwer is greater than 5, reject the chip.

2) Temperature compensation tests

Individual VCO chips should be tested in circuit operating with batteries. The temperature compensating circuit consists of R17, R18, R19, and R20. Changing the value of R19 will change the amount of temperature compensation provided to the VCO chip. The nominal value of R19 is 30K ohms but may vary between 18K ohms and 43K ohms for typical VCO chips.

The VCO center frequency should be measured at 0°, 30°, 60° and 90°F. To find the correct value for R19, the following procedure should be used.

Replace R19 with a resistor substitution box that has values from 18K ohms to 43K ohms. At 0°, 30°, 60°, and 90°F, connect a frequency counter to the VCO and record the frequency at each resistor value from 18K ohms to 43K ohms. Place the VCO in the controlled temperature vaule and wait 30 minutes. Again measure and record the VCO frequency at each reeistor value from 18k ohms to 43K ohms. The resistor value (Allen Bradley 1% CC type) that results in the smallest change in frequency over the temperature range should be installed in the circuit (R19). If the VCO frequency can not be compensated within the range of 18K ohms to 43K ohms, the chip should be replaced. This test should be repeated on the new chip. If the test indicates a center frequency change greater than .01% per °F a new chip should be installed and test repeated. If the center frequency at 0°F or at 90°F differs from that at 60°F by more than 0.5 percent, install a new chip and repeat the test.

C6 CALIBRATOR

A. Description

The C6 calibrator is a modification of the C5 calibrator, described by Van Schaack (Open File Report No. 75-64), and is intended to operate with the J303 amplifier/VCO inside the seismic station. Most of the C6 circuitry is located on the printed circuit board opposite the J303 amplifier/VCO (Figure 4). A few components of the C6 are located on the J303 board. The C6 calibrator automatically provides all the signals and switching necessary to produce a calibration sequence in the J303 amplifier. This sequence includes the application of fixed voltage steps to the amplifier and amplifier-geophone combination. The response of the amplifier and geophone to these steps modulates the VCO and thus may be telemetered and recorded. An analysis of the calibration sequence response can then provide checks on the geophone free period, the motor constant, the frequency response of the geophone-amplifier combination, and the system noise. In addition to calibrating the amplifier and geophone, the C6 produces a header code at the beginning of the calibration sequuence, consisting of a train of pulses encoded with the seismic station identification number and the step-attenuator switch position. The C6 calibrator contains a crystal controlled clock which provides the timing to control the calibration sequence and to trigger the start of the sequence once every 24 hours. Thus, the calibration sequence, which lasts approximately 40 seconds, occurs automatically once each day. The time of day that the calibration occurs is preset during the initial setup.

B. Principles of Operation

The calibration sequence is composed of four sequential phases. Figure 5, depicts the waveform at the "CODE IN" test point of the J303 amplifier during the four-phase sequence. Phase 1, lasting 5 to 7 seconds, consists of the coded pulse header. Approximately one second after the beginning of the calibration sequence, a series of 13 to 15 evenly spaced pulses are seen. Each pulse has height 0.3 V or 0.5 V, corresponding to logical "zero" or "one", respectively. The first eight pulses are the binary-coded ID number, with the least significant bit first. The next three pulses give the step-attenuator switch position, in binary. The remaining bits are not programmed. Phase 2, which follows the code, lasts 2 to 3 seconds. The test point signal is the amplifier noise with a resistive input termination substituted for the seismometer. During phases 1 and 2, the seismometer mass is offset by a fixed DC current (relay 1A). Phase 3 is the "release test" in which the amplifier is reconnected to the seismometer, the current offsetting the seismometer mass is removed, and the mass swings freely back to equilibrium. The resulting output signal produced by the seismometer and amplifier is shown in Figure 5. This wave-form is the combined amplifier-seismometer response to a step in "ground acceleration". Phase 3 lasts 10 to 12 seconds. In phase 4, known as the "step test", the seismometer is disconnected from the amplifier and a fixed voltage step is applied to the amplifier input (relay 3). The resulting waveform is the response of the amplifier alone to a step input voltage. Phase 4 lasts 18 to 22 seconds. At the end of phase 4, the seismometer is reconnected to the amplifier and the waveform returns to normal (background seismic noise).

The clock circut (Figure 6) provides a square wave with one negative-going edge per day, which innitiates the calibration sequence by triggering a chain of three monostable multivibrators (Figure 1). Multivibrator 1 (duration 8 to 10 seconds) closes relays 1A and 1B (Figure 5) which apply a fixed current to the seismometer coil, terminate the amplifier input with 698 ohms (R20), and turn on the code generation circuit (Figure 8). The oscillation of the seismometer mass caused by the injection of the current step dies out during this 8 to 10 second interval. Multivibrator 2 (duration 10 to 12 seconds) closes relay 2 approximately 3 milliseconds before relays 1A and 1B are released. The release of relays 1A and 1B begins the "release test" phase of the sequence, during which the seismometer mass is allowed to freely return to equilibrium. Relay 2 introduces a 24 dB attenuator (R22, R23) to reduce the effect of background seismic noise during this phase. When multivibrator 2 turns off, relay 2 is released and multivibrator 3 is triggered (duration 18 to 22 seconds), closing relay 3. This is the "step test". Relay 3 applies a voltage step across the amplifier input. When multivibrator 3 turns off, relay 3 is released, restoring the station to its normal state (seismometer and damping resistors connected to amplifier) for another 24 hours.

C. Power Supplies

A 1.35 volt mercury battery is used as the voltage standard for the seismometer mass offset and amplifier voltage step. A 5.4 volt mercury battery powers the clock and multivibrator circuits. These batteries have high capacity and stable voltage. Even in extremely cold environments, the mercury batteries provide enough power to operate the clock and multivibrator circuits for one year. A 9-volt alkaline transistor battery, used to close the relays, has both adequate shelf life and capacity to provide power for one year. Only fresh battery replacements should be used.

D. Testing

All tests are made with a properly alligned VCO and seismometer attached. All measurements are made with respect to common (COM).

1. Clock. The cyrstal oscillator frequency may be adjusted at room temperature with trimmer capacitor C_1 (Figure 6) while monitoring pin 15 of the CD4045AE chip. A 25-pf capacitor must be used in series with a scope probe to minimize loading effects of scope and frequency counter. Adjust C_1 with a non-conductive tool for a reading of 397.662 KHZ. If unable to adjust the frequency this low, replace the crystal. The frequency is intentionally adjusted low to compensate 9 Hz for loading and 4 Hz for temperature. The crystal is not temperature compensated; stability is approximately 1.5 ppm per degree Centigrade.

2. Triggering. Monitor the CODE IN tie point on the J303 board with an oscilloscope or strip chart recorder. Connect the trigger terminal (TR) on the C6 calibrator to ground terminal (COM) while clock (CK) is in high (+5V) state and disconnect it after clock goes low. Observe the full calibration sequence illustrated in Figure 5. Triggering the C6 calibrator manually does not affect the timing circuit (IC2) which automatically triggers the calibrator once every 24 hours.

3. Code Generation (Figure 8) When gate IC4 receives two low inputs (from the clock and IC3), it energizes relay RY4, which connects 9 VDC power to the code circuit (IC5, IC6 and IC7). After the one second delay introduced by R26 and C13, the code circuit begins to generate the square wave train. Two sections of IC5 comprise the oscillator which generates the clock rate for the code pulses. Resistor R30 determines the pulse width. There should be 13 pulses produced during the 6 to 7 seconds (interval is determined by C15 and R36) that this circuit is on. IC6 and IC7 are cascaded parallel shift bit

registers which encode the pulses to logical "one" or "zero" (0.5 V and 0.3 V, respectively). The coded pulse train is connected to the VCO through capacitor C12 and relay 4. Code generation terminates when relay 4 is released.

4. Relay control circuit (Figure 7). The relay control circuit consists of a CD4049AE hex inverter (IC3) which triggers a chain of three one-shot multivibrators. In each multivibrator circuit, an RC time constant determines the length of time one or more relays are energized. Relays 1A and 1B are energized 8 to 10 seconds (C4 and R6). Relay 2 is energized 10 to 12 seconds (C6 and R8). Relay 2 is energized 10 to 12 seconds (C8 and R15). The timing of these relays defines the strucutre of the calibration sequence. Adjustments in these resistors may be made to achieve the correct timing.

5. Resetting 24-hour timer. Normally the C6 calibrator automatically innitiates a calibration sequence once every 24 hours. The time of day that the triggering occurs may be manually reset to the present time as follows. Observe the clock signal on terminal CK. While the clock is in the high (+5 volt) state, momentarilly connect the reset terminal (R) to the +5V terminal. The calibrator will trigger 24 hours later.

6. Setting the 24-hour timer. A simple external circuit, developed by Van Schaack, may be used to "jam" a partial count into the counter IC2, thereby setting the 24-hour timer to any desired triggering time.

TELEMETRY

A. Description.

Telemetry literally means measuring, transmitting and receiving data over a distance. In this section, the term telemetry refers only to the transmission and reception of data, beginning with the frequency-modulated subcarriers generated by the VCO's and ending at the Recording Interface Unit. Two methods of telemetry are available with the Centipede system: VHF radio, and hard-wire (telephone type) transmission. In either method, from one to eight data subcarriers may be carried over a single telemetry link. The data subcarriers are in the audio frequency range (680 Hz to 3060 Hz). The term multiplex refers to the complex signal produced by combining (simple sum) two or more data subcarriers of different frequencies. The multiplex signal is formed either by direct connection, or with an active summing amplifier. When two VCO signals are directly connected, the signal level of the resulting multiplex is less than that of either subcarrier due to mutual loading. Subsequent addition of other subcarriers further reduces the multiplex level. Table 3 shows the multiplex signal level produced by directly connecting up to 8 subcarriers, each initially having signal level -10 dbm. Since the summing amplifier provides amplification, it may be used to bring a multiplex signal up to the nominal -10 dbm level.

The multiplex signals are directly recorded on the magnetic tape recorder; each multiplex signal is recorded on one tape track. Because the multiplex signal is a complex wave form consisting of several frequency-modulated subcarriers, the data it contains are not resolvable without some electronic processing called discrimination. Discrimination of the multiplex signal is normally done when the tapes are played back in the analysis system, at which time the tape recorded multiplex signals are transformed back to simple waveforms. However, discrimination of the multiplex signals way also be done in the field, using, The Recording Interface Unit. Thus, seismic waveform data may be monitored at the recorder before and during the recording.

TABLE 3

When two or more VCO subcarriers, each having signal level -10 dbm, are directly connected, the resulting multiplex (sum) signal level is, approximately, as follows:

Number of subcarriers	Multiplex level
1	-10 dbm
2	-11
3	-12
4	-13
5	-14
6	-15
7	-16.5
8	-17.5

B. Radios

The radios used in Centipede are modified FM transceivers manufactured by Motorola (Model HT-200). The modificaiton consists of seperating the transmitter and receiver sections, lowering the RF power output, and repackaging the two sections. The transmitter is crystal controlled. The receiver is a superheterodyne type.

TRANSMITTER SPECIFICATIONS

Frequency range	150.8 - 174.0 MHz
Frequency stability	± 0.0005 %, -30°C to +60°C
FR power output	100 milliwatt
Antenna impedance	50 ohm
Modulation	
signal amplitude	1.0 V, p-p (max)
carrier devaition	± 1000 Hz with 1.0 Volt, p-p input at 5 kHz.
Power requirement	11.5 - 16.5 VDC 45 ma @ 12.5 VDC
Dimensions	3" x 3" x 5"

RECEIVER SPECIFICATIONS

Frequency range	150.8 - 170.0 MHz
Frequency stability	± 0.0025 % - 30°C to +60°C
Antenna impedance	50 dhm
Sensitivity	0.5 microvolt, rms for 20 db quieting
Audio output level	Adjustable to greater than 0 dbm.
Output impedance	500 ohm
Power requirement	11-5 - 16.5 VDC 12 ma @ 12.5 VDC
Dimensions:	3" x 3" x 5"

C. Antennas.

The antennas used are Scala horizontal yagis, model CA5-150 VHF, with balun feed.

ANTENNA SPECIFICATIONS

Forward gain:	+9 db
Impedance:	50 ohm
Frequency range:	162 - 174 MHz

TABLE 4

VHF Radio Frequency Allocations currently assigned to the U.S. Geological Survey

5F2 (Narrow band emission)	10F2 (Wide band emission)
163.609375 MHZ.	163.606250 MHz.
163.796875	163.793750
164.009375	164.006250
164.846875	164.843750
165.809375	165.806250
166.421875	166.418750
166.659375	166.656250
167.196875	167.193750
167.809375	167.806250
	171.406
	173.194

Emission type	Allowable subcarriers
5 F2	680,1020, 1360, 1700 Hz.
10F2	680, 1020, 1360, 1700, 2040, 2380, 2720, 3060 Hz.

D. RADIO LINK EFFECTIVE RANGE.

By making an assumption, the theoretical range of the radio links can be calculated. The assumption is that the propagation of the radio signal, from the transmitting antenna to the receiving antenna, is governed only by the free-space (geometrical spreading) attenuation relation. This relation strictly applies only between two antennas in free space. No account is taken of the attenuation introduced by air, weather, folliage and ground effects. These signal losses are variable and can be estimated and introduced later. The free-space calculation is presented here to provide a convenient frame into which the real life attenuation conditions may be placed. In the example presented below, the power unit "dbm" is used. Zero dbm is defined as 1 milliwatt. The frequency 170 MHz., and the distance 60 miles are arbitrary, typical values. The free space attenuation is obtained from the relation presented in Reference Data for Radio Engineers, 6th Edition, page 28-19:

$$\alpha = 36.6 + 20 \log f + 20 \log d$$

where α is the free-space attenuation in decibels, f is frequency in MHz., and d is distance in miles.

Free-space example:

Transmitter power (100 mW)	+20	dbm
Transmitter antenna gain	+ 9	db
Receiver antenna gain	+ 9	db
Free-space transmission loss at 170 MHz. over 60 miles	-117	db
Power delivered to receiver	- 79	dbm
Power needed at receiver for 20 db quieting	-113	dbm
Power margin	34	db

From our experience, we have some knowledge of the attenuation actually introduced by the signal path losses and by fixed losses in an actual radio link. Fixed losses in the radio link amount to approximately 5 db. Signal path losses vary, of course, with the wetness of the terrain, atmospheric moisture, folliage, proximity of the ground, etc. A typical dry line of site signal path introduces attenuation 0.05 db/mile. Perhaps a reasonable assumption is that for adverse conditions such as a signal path encountering folliage and precipitation, this figure may become 0.5 to 1 db/mile. Using these values, the effective range of a 100 mW radio link (assuming a power margin at the receiver of 10 db) is 180 miles in the case of dry clear line of site, and 30-40 miles when precipitation or folliage are in the signal path.

RECORDING INTERFACE UNIT

A. Description.

The Recording Interface Unit (RIU) serves as an interface between the telemetry system and tape recorder (Figures 10-12). Its primary function is to generate, control and monitor the FM - subcarrier multiplexes, which are recorded on the tape. The RIU also serves to de-modulate and monitor any subcarrier in any of the incoming multiplexes using eight FM discriminators. And, the RIU generates and monitors the timing and tape speed compensation signals recorded, by means of a crystal clock-chronometer.

The FM-multiplex structure is shown in Table 5. Each of the twelve data tracks (tracks 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, and 14) may contain up to 8 subcarriers, with center frequencies given by

$$f_i = 340\ (i+1)\text{Hz}, \quad i = 1,2,\ldots, 8.$$

Frequency modulation of these subcarriers is effected by the J303 preamp/VCO. The deviation limits of each subcarrier are ± 125 Hz. The frequency limit to the data is 30 Hz, corresponding to a modulation index of $\frac{125}{30} \approx 4$.

The multiplex for track 13 contains 3 subcarriers, generated by the RIU, at center frequencies 680 Hz, 1020 Hz and 1360 Hz. These subcarriers, which carry the DC level shift time codes, are deviated ±25 Hz.

Track 8 is dedicated to a single unmodulated carrier, at 3125 Hz which is derived from the clock crystal and is used as a reference signal for subtractive tape speed compensation at the playback discriminators.

TABLE 5

FM MULTIPLEX COMPOSITION

Track	Subcarrier Center Frequencies	Deviation	Signal Content
1,2,3,4,5, 6,7,9,10,11,12,14	680 Hz	± 125 Hz	seismic data (0.1 - 30 Hz)
	1020	± 125	
	1360	± 125	
	1700	± 125	
	2040	± 125	
	2380	± 125	
	2720	± 125	
	3060	± 125	
13	680	± 25	WWVB
	1020	± 25	IRIG-E
	1360	± 25	IRIG-C
8	3125	unmodulated tape speed compensation	

B. AGC Circuits and signal path

Twelve identical automatic gain control (AGC) circuits (Figure 13), described by Jensen (U.S.G.S. Open File Report, in preparation), are used to automatically adjust the incoming multiplex signals to a constant amplitude level suitable for undistorted tape recording. An incoming multiplex signal, from either a wire or radio telemetry source, is plugged into one jack in the Line Receiving Unit (Figure 14). It is carried from there, through a short cable and a matching transformer to an AGC circuit. Provided the incoming multiplex signal level remains within the operating range of the AGC, the AGC will amplify or attenuate it to the preset constant output level (0 dBm, nominal). This output signal travels directly to the appropriate tape recorder input. Two LED indicators, located on the front panel, are connected to each AGC and indicate when the input multiplex level is above or below the operating range of the AGC'S. The output of each AGC (which is the signal presented to the tape recorder) appears on a BNC jack (J1 to J12) for monitoring. When correctly set up; the AGC circuits will accept an incoming multiplex signal levels from -30 to -10 dBm (0.24 to 0.024 VRMS) and present the tape recorder with a constant 0 dBm (0.77 VRMS)level.

C. Timing

Timing is based upon two independent sources: a crystal controlled clock/chronometer within the RIU, and an external radio receiver tuned to radio station WWVB (National Bureau of Standards, Ft. Collins, Colorado). The crystal chronometer, designed by Ellis, (U.S.G.S. Open File Report, in preparation) generates two standard serial time codes (IRIG-C and IRIG-E) in DC level shift form (Appendices A, B). The maxiumum drift rate of the crystal reference is ±0.5 ppm per year.

The signal from WWVB is a serial time code (broadcast at 50 kHz) of

Universal Time Coordinated (Greenwich Mean Time), and is derived from a Cesium frequency standard. The WWVB time code is a 1-minute frame of pulses (1 pulse per second) encoding days, hours and minutes in BCD.

The two IRIG time codes and the WWVB time code each modulate a VCO in the RIU to produce three subcarriers (center frequencies 680, 1020 and 1360 Hz.) These subcarriers are deviated ± 25 Hz by their respective codes, and are combined in the summing amplifier (Figure 15) to produce the timing multiplex on channel 13.

The reference carrier at 3125 Hz used for subtractive tape speed compensation is derived from the 100 kHz crystal clock in the chronometer by means of a divide-by-32 digital circuit on the chronometer board. The resulting 3125 Hz Square wave is transformed to a sine wave by a tuned circuit amplifier in the RIU (Figure 16), and this signal comprises channel 14 in the RIU. (Note that channel 14 is the tape speed compensation signal in the RIU, but is recorded on track 8 in the tape recorder. Similarly, the data multiplex on channel 8 in the RIU is recorded on track 14 on the tape. All other channles in the RIU correspond directly with the tape track number on which they are recorded.)

D. Discriminators

A set of eight FM discriminators allows one to monitor the data on any subcarrier in the array at any time, including during a recording. The discriminators are essentially the same as the USGS Model J101 (U.S.G.S. Open File Report No. 75-64). Any one of the 13 multiplex channels (channel 1-13) may be selected (switch S1) as input to all eight discriminators. Each discriminator data output appears at a separate BNC jack (J15-J22). Two LED indicators (D25-D40) are associated with each discriminator. The brightness of the LED's indicate when the subcarrier frequency is approaching the upper or lower band edges. The eight individual subcarriers which are demultiplexed by the discriminator bank are available for monitoring and level checking. Switch S2 is used to select the desired VCO subcarrier. VCO 1 is 680 Hz; VCO 8 is 3060 Hz. The selected subcarrier appears at J24 and its level in dBm (0 dbm=0.77 V, rms) going to the tape is shown on the level meter, M1. An oscilloscope, AC volt-meter or frequency meter may be attached at J24.

The discriminators (Figure 17) should be adjusted (R33) to have deviation sensitivity 2.5V/125 Hz. When the subcarrier input for a particular subcarrier is absent or too weak that discriminator output goes low (approx. -5 VDC) and the low LED indicator goes on.

E. Power

Power for the RIU is derived from two 12-volt car batteries connected in series. The normal power comsumption is 7.3 Watt (410 ma @ +12V; 200 ma @ -12V). The unit is protected against reversed polarity, and by two 1 amp fuses. The circuits within the RIU require ±12 volts, unregulated, ±6 volts. regulated, provided by an internal dual regulator circuit (Figure 15). Monitoring of battery voltages is done with meter M2 and switch S3, on the front panel. The unit will operate with battery voltage from 11 to 14 volts.

F. Operating Procedure

1. Connect incoming multiplex lines (600 ohms, balanced) from telemetry radio reveivers and/or land lines to desired pairs of input jacks on the Line Receiving Unit; connect power cable and tape recorder signal cable.

2. Check power supply voltages with S3 and meter.

3. Set Switch S2 to MUX.

4. Check each channel for presence of multiplex signal with S1 and level meter should read 0 dBm ± 2 db.

5. Check the timing multiplex (channel 13) for a signal level of 0 dBm, bouncing rythmically about 1 db.

6. Check the tape speed compensation (channel 14) for a steady signal level of + 4 dBm.

7. Check the frequency of individual subcarriers by selecting the desired channel (S1), and desired subcarrier or VCO (S2) and connecting a frequency meter to J24.

8. Check the data waveforms by selecting the desired channel (S1) and connecting an oscilloscope or strip chart recorder to the output jact (J15-J22) corresponding to one of the eight traces on that channel.

9. Set the clock-chronometer.

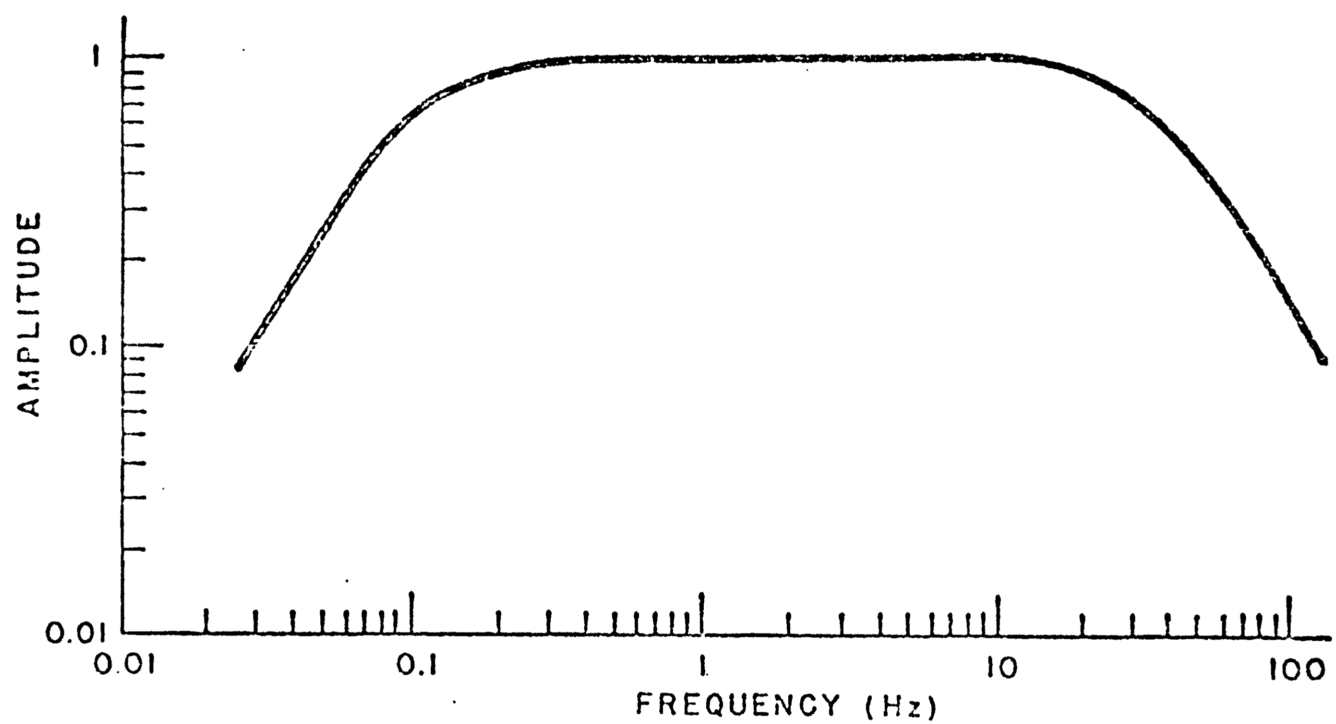

Figure 1 Relative Frequency Response of the J303 Seismic Amplifier

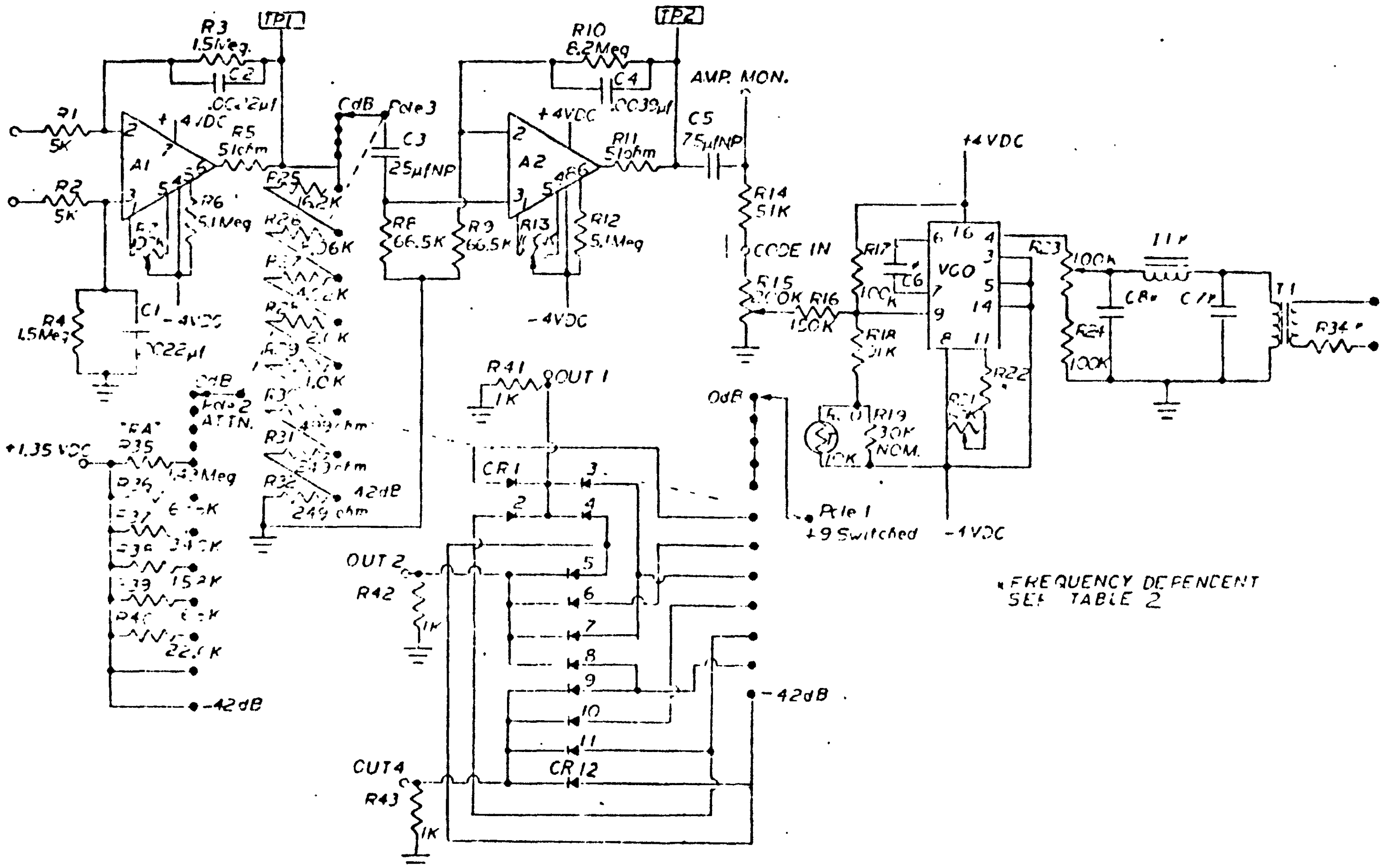

Figure 2 J-303 SEISMIC AMPLIFIER/VOLTAGE CONTROLLED OSCILLATOR, SCHEMATIC diagram

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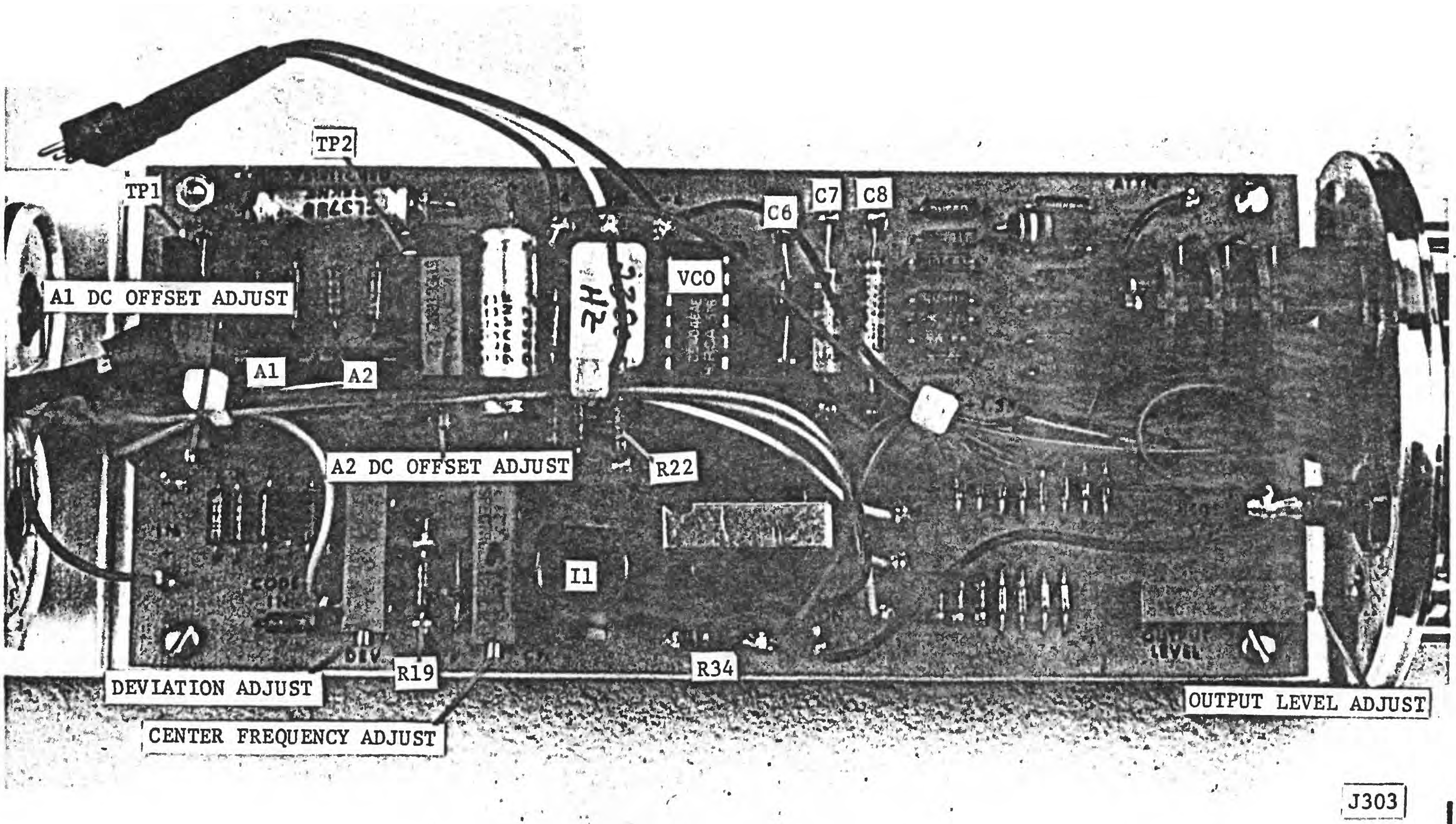


FIGURE 3 J303 SEISMIC AMPLIFIER/VCO
Electronic component layout

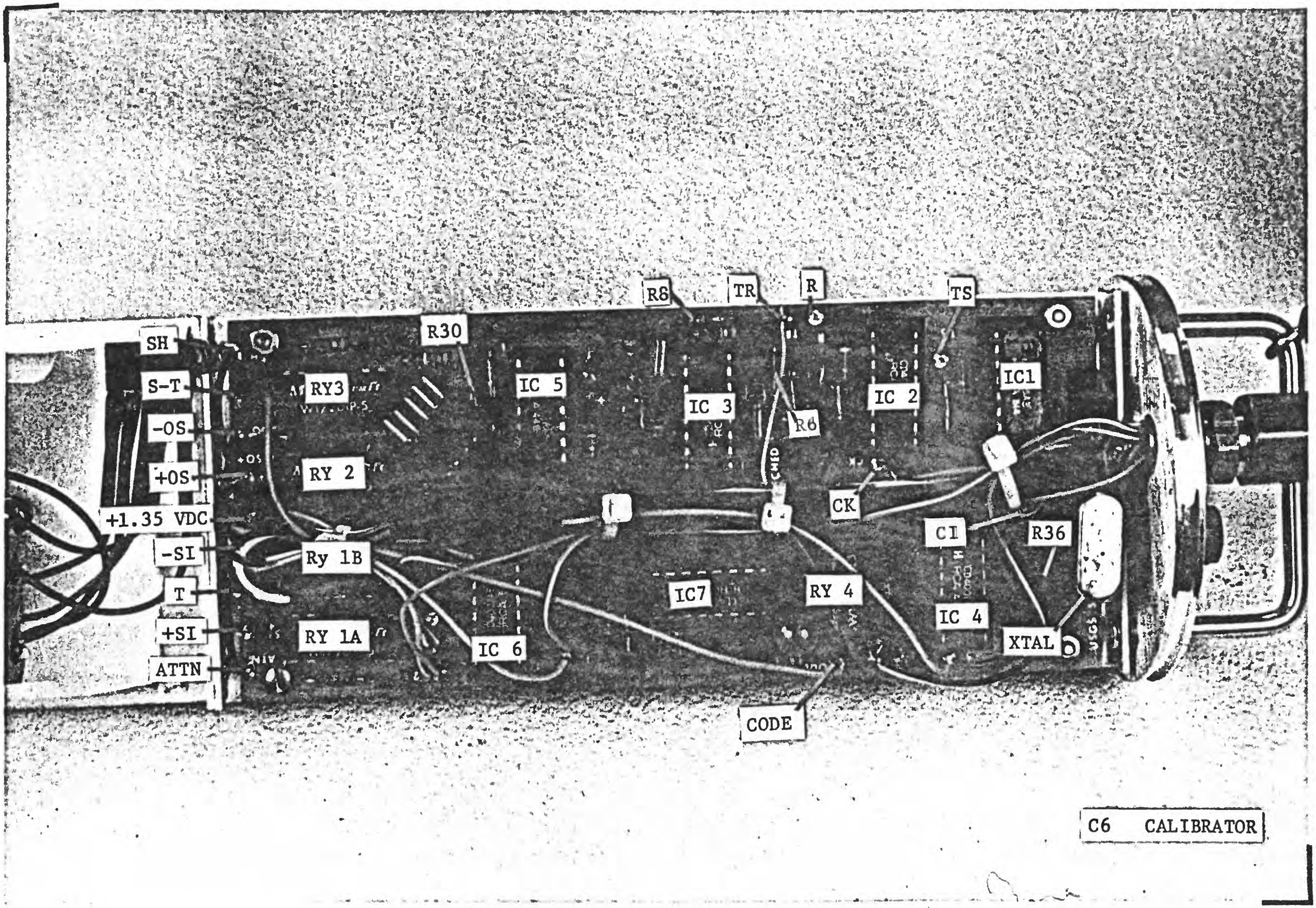
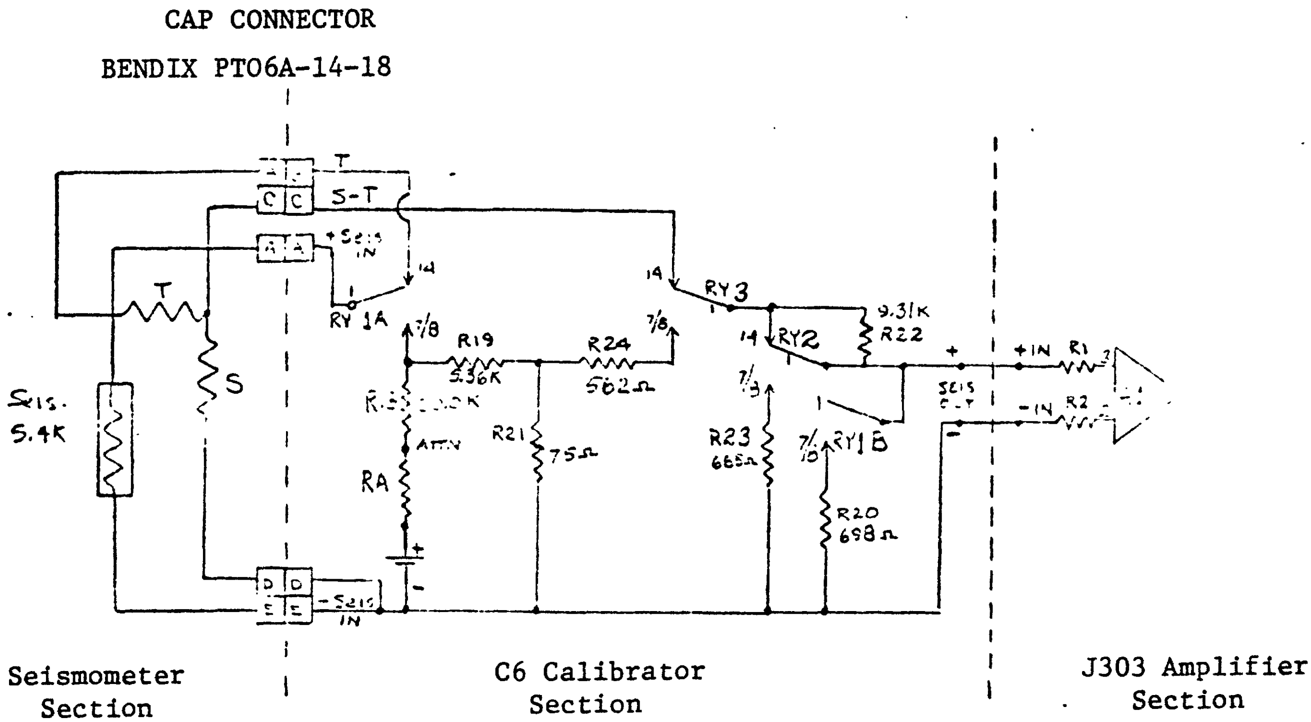


FIGURE 4 C6 CALIBRATOR
Electronic component layout



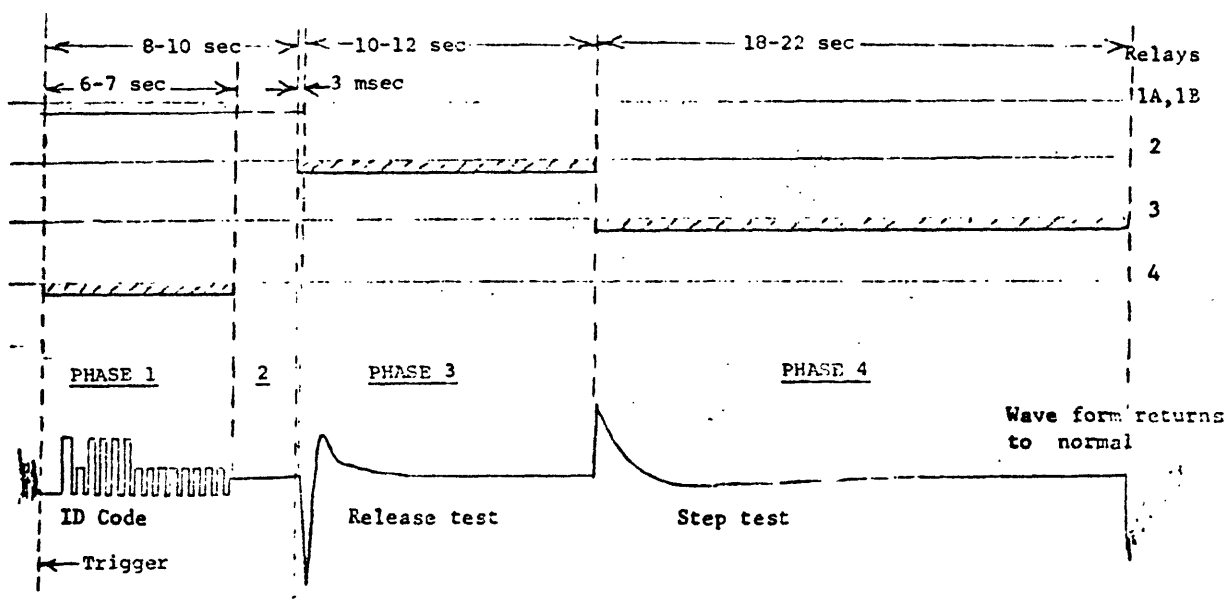


Figure 5 C6 CALIBRATOR

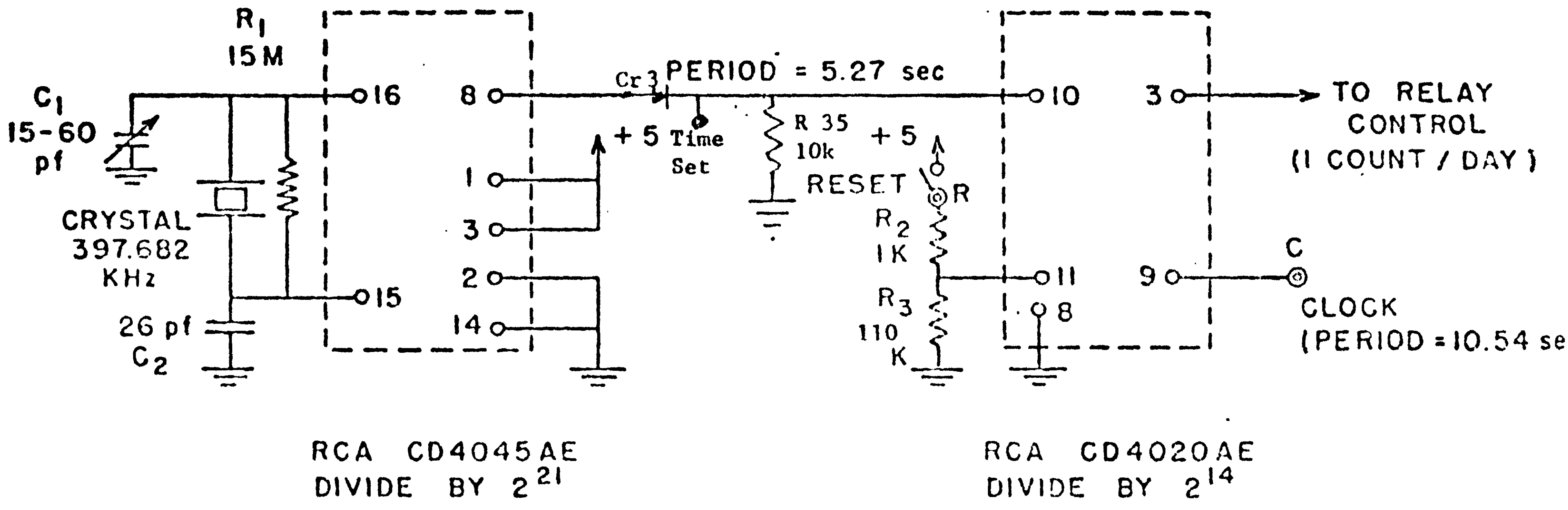
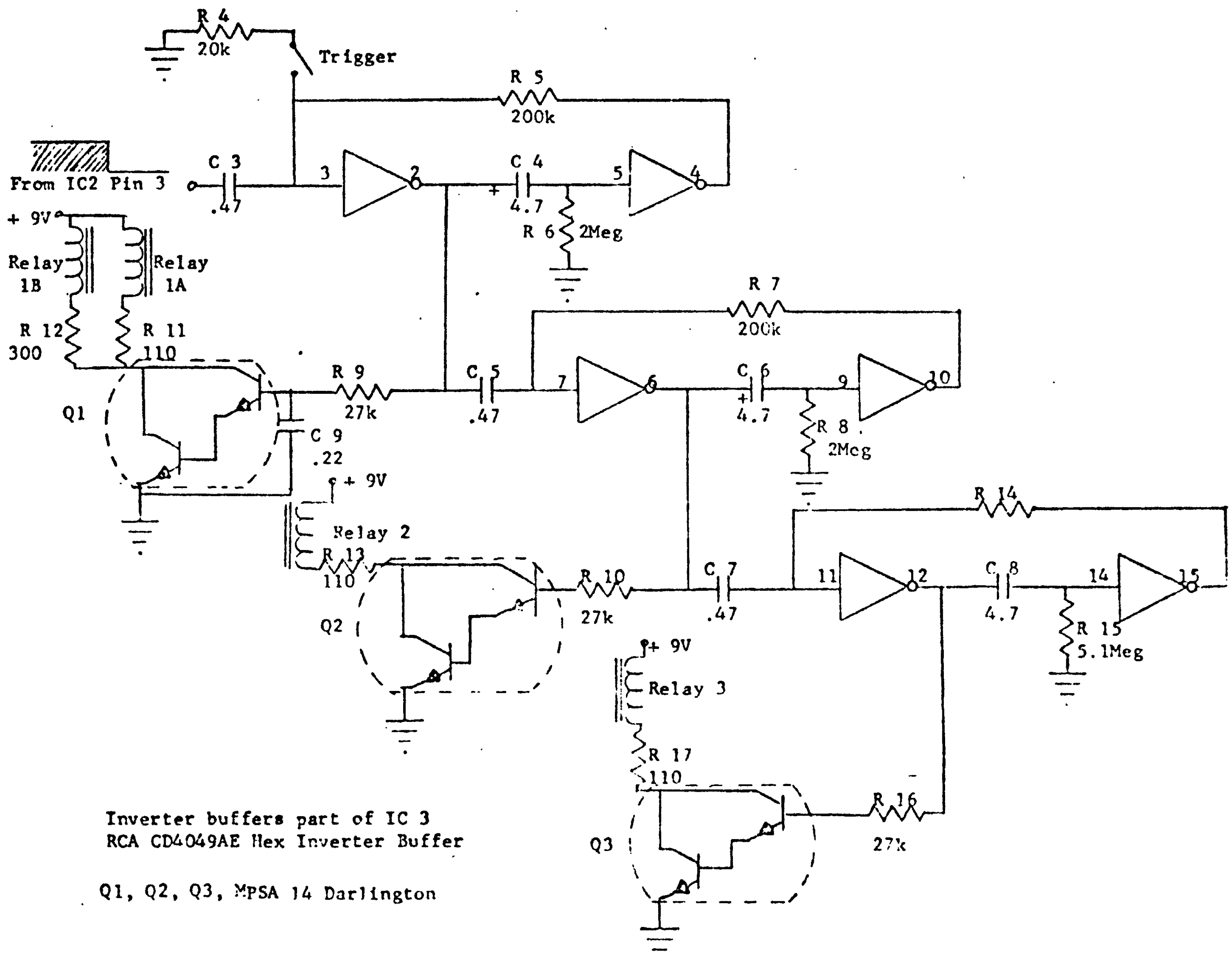


Figure 6 C6 CALIBRATOR - Clock Circuit



Inverter buffers part of IC 3
RCA CD4049AE Hex Inverter Buffer

Q1, Q2, Q3, MPSA 14 Darlington

Figure 7 C6 CALIBRATOR - Relay Control Circuit

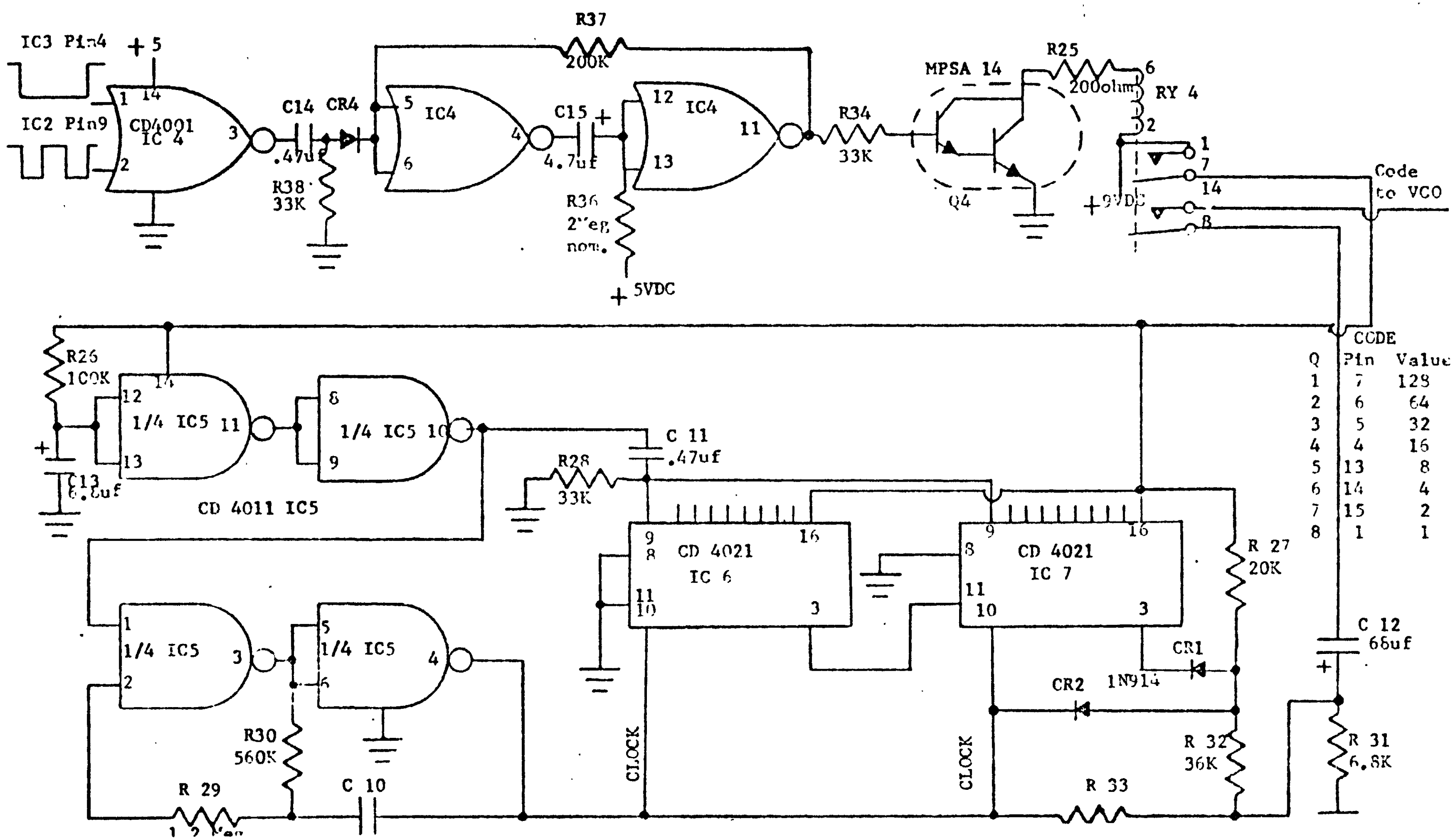


Figure 8 C6 CALIBRATOR - Code Generation Circuit

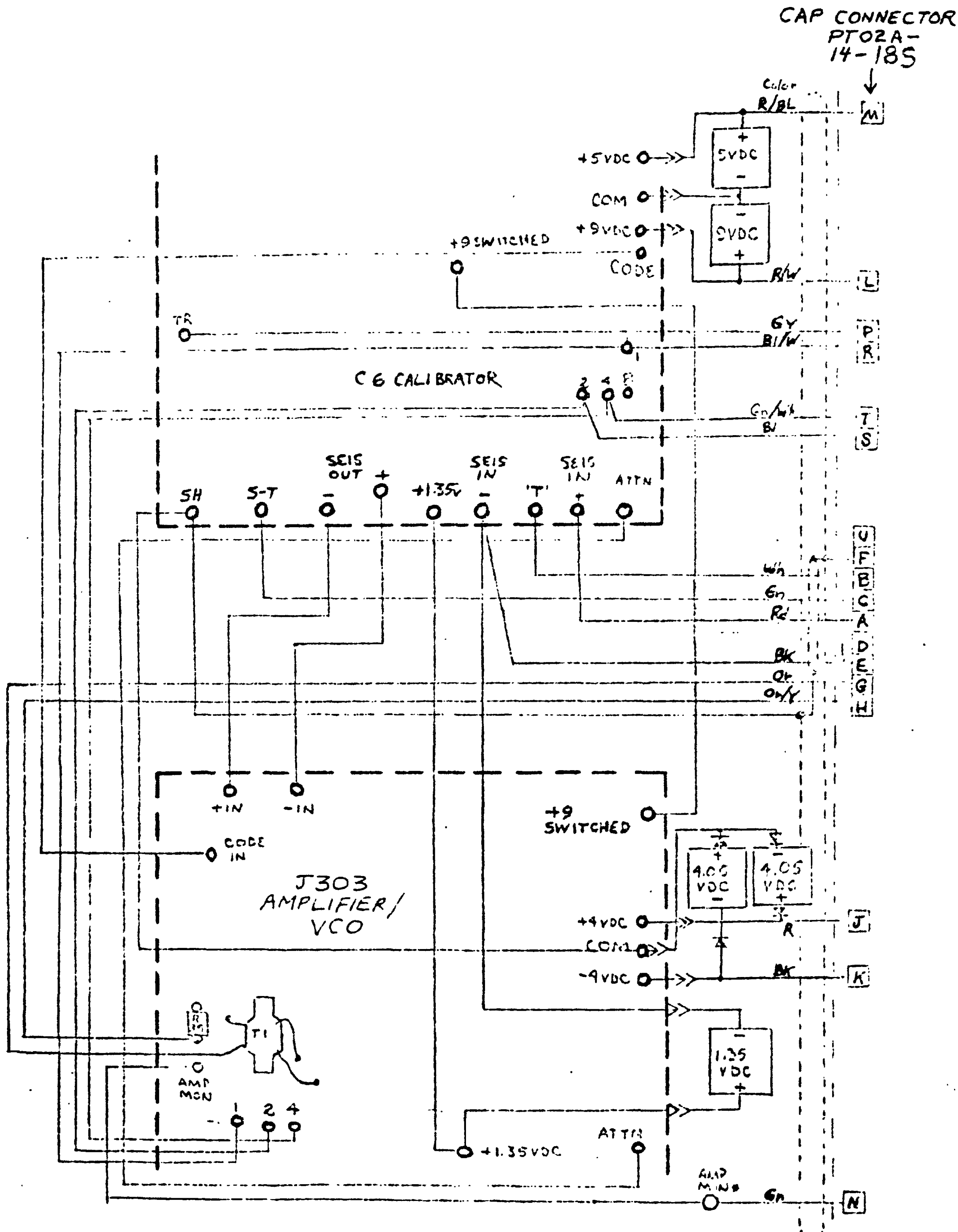


Figure 9 J303 - C6 Board Interconnections

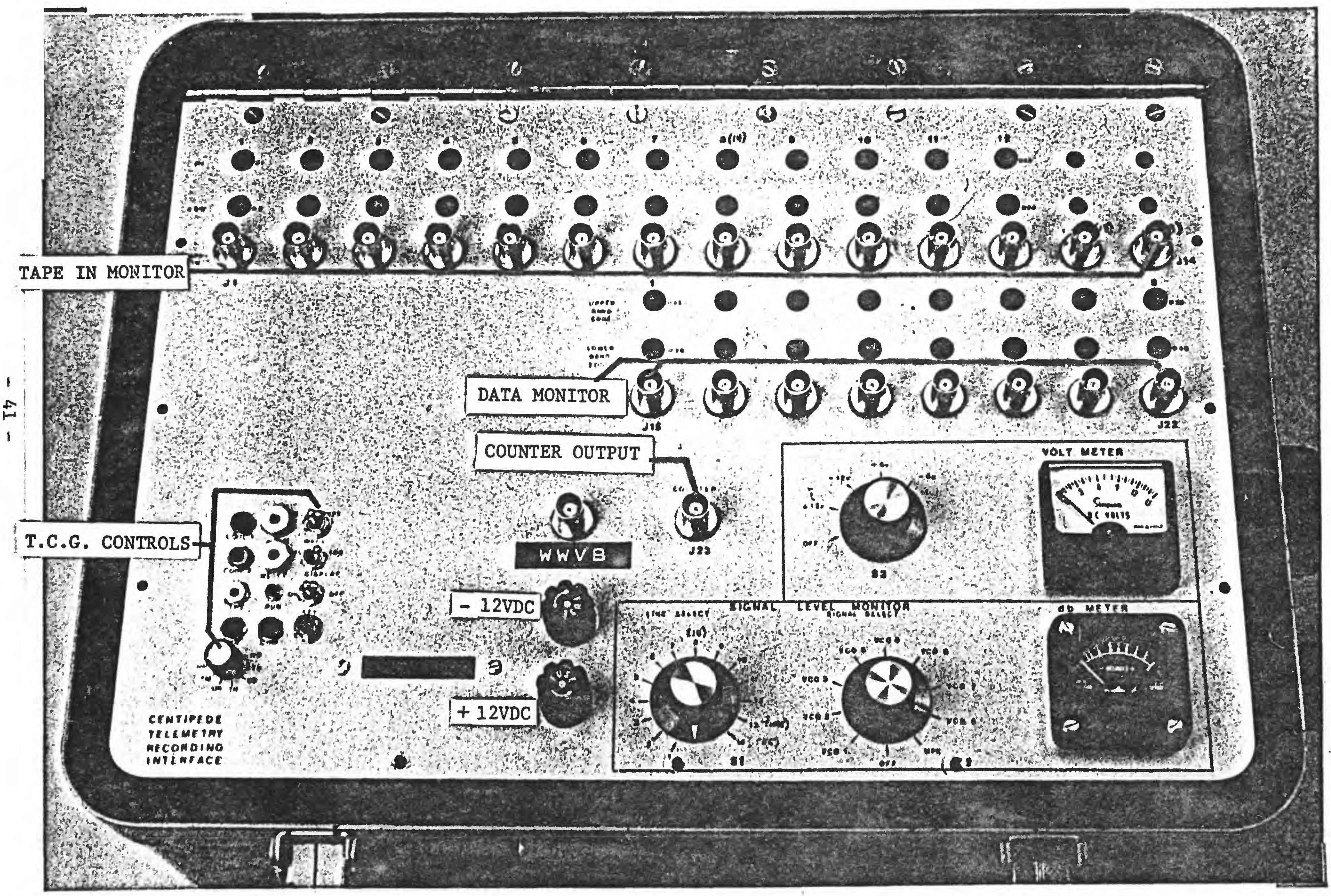


FIGURE 10 RECORDING INTERFACE UNIT
Front panel

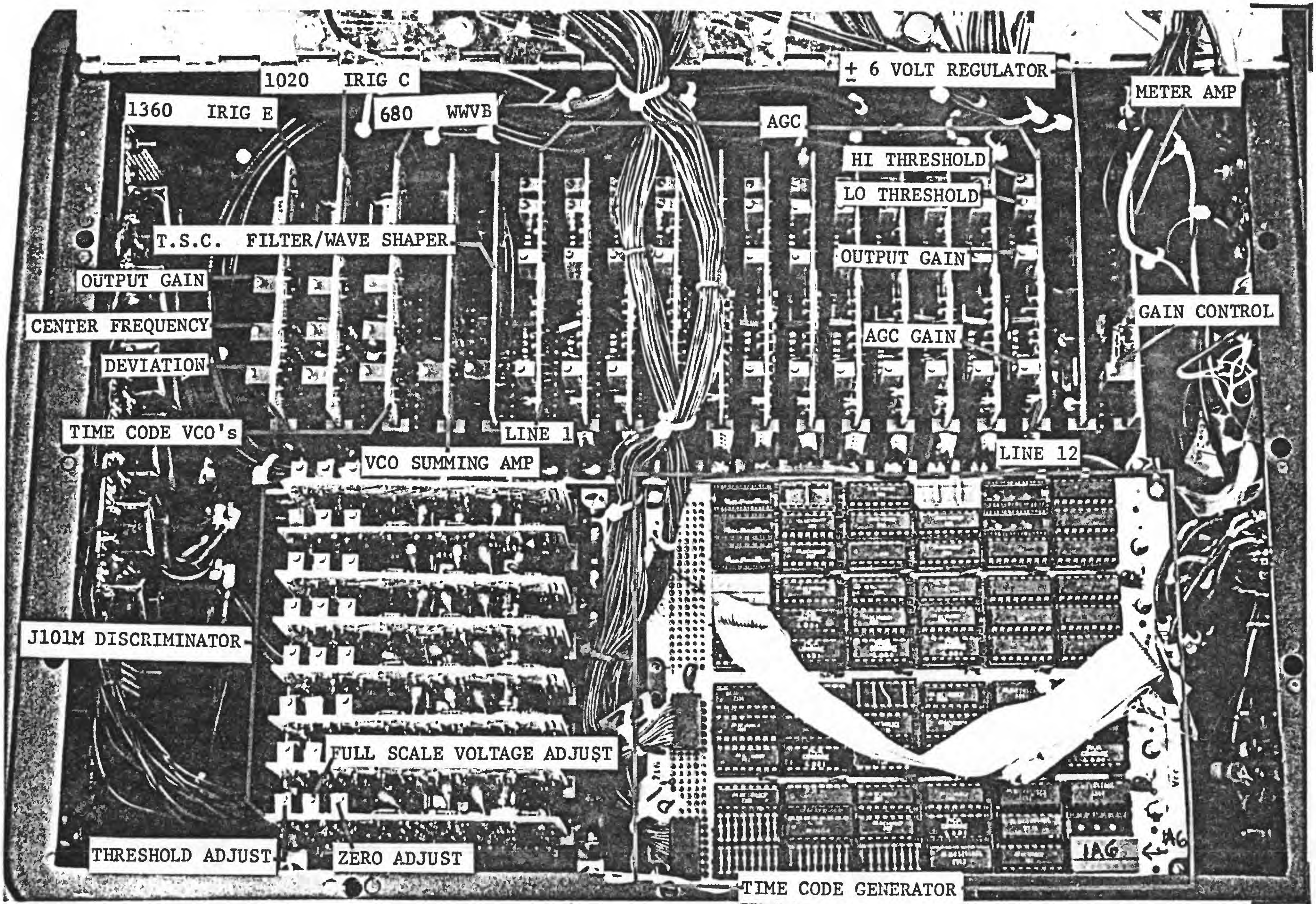


FIGURE 11 RECORDING INTERFACE UNIT
Inside view of electronics subassemblies

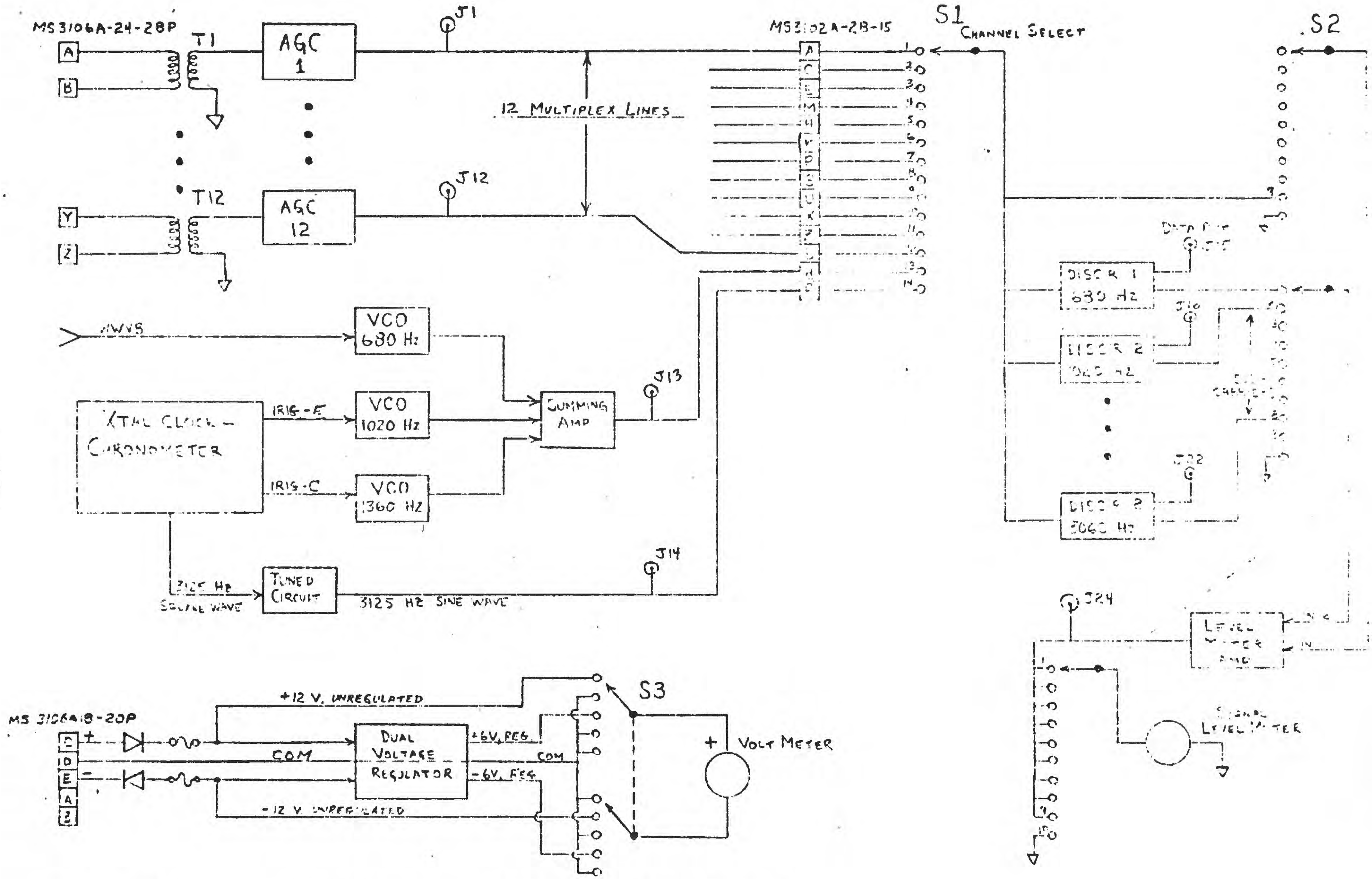


Figure 12 RECORDING INTERFACE UNIT - Block Diagram

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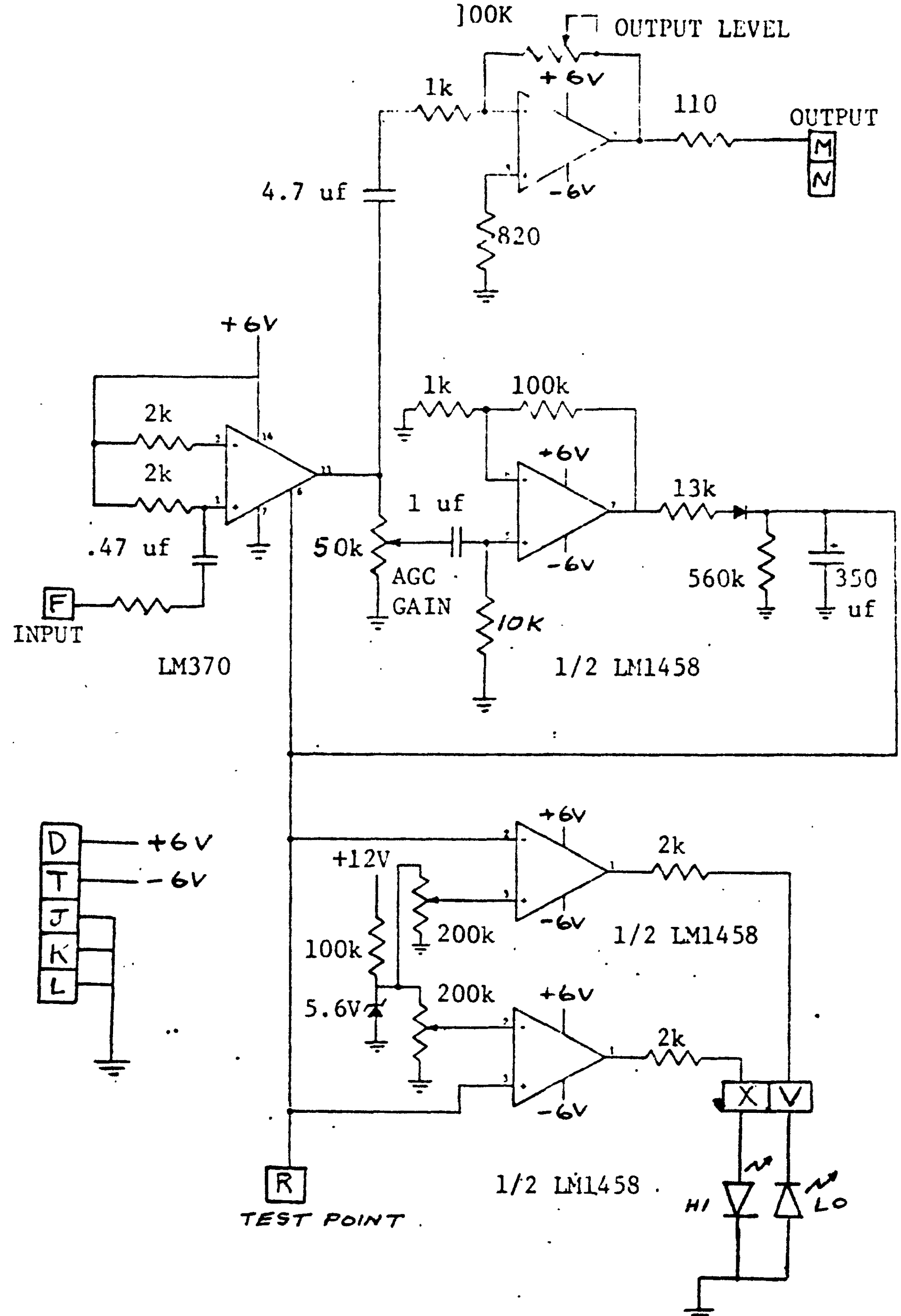

Figure 13 AUTOMATIC GAIN CONTROL - Schematic diagram Recording Interface Unit

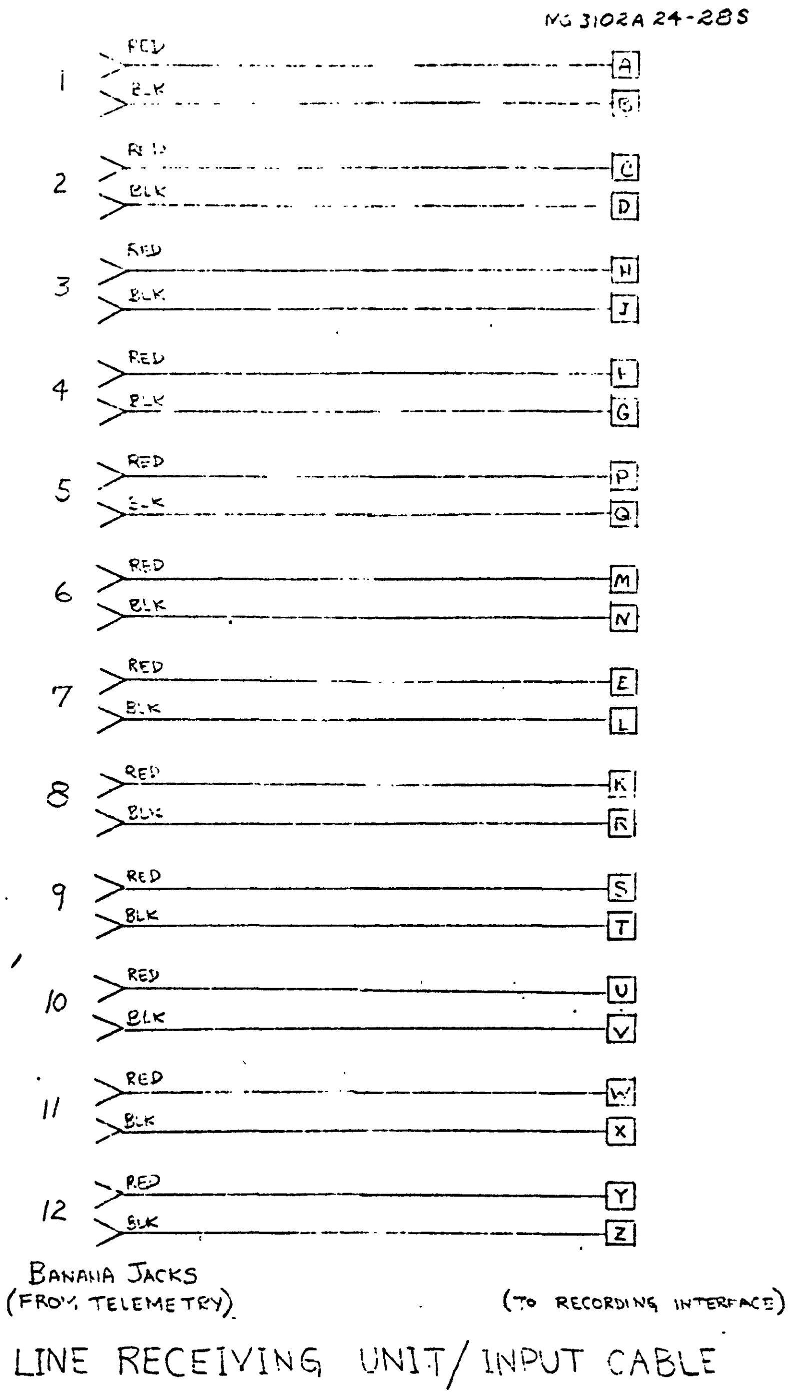

Figure 14 Input signal wiring
Recording Interface Unit

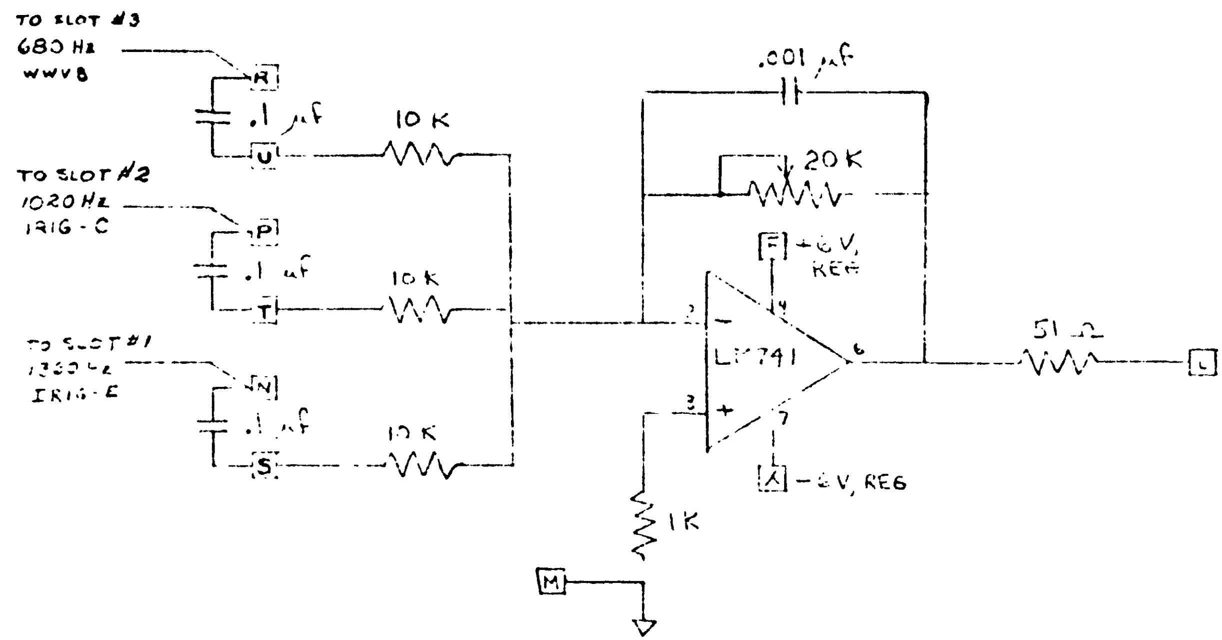

Figure 15 SUMMING AMPLIFIER-Schematic diagram
Recording Interface Unit Timing Multiplex

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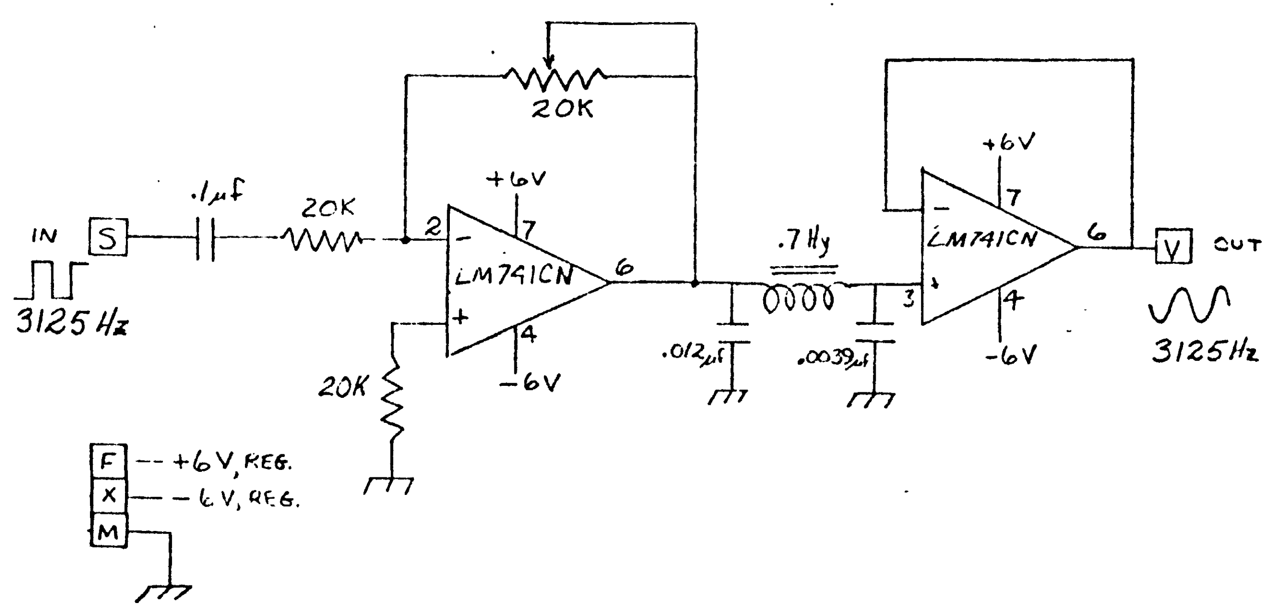


Figure 16 TAPE SPEED COMPENSATION SIGNAL FILTER
Recording Interface Unit

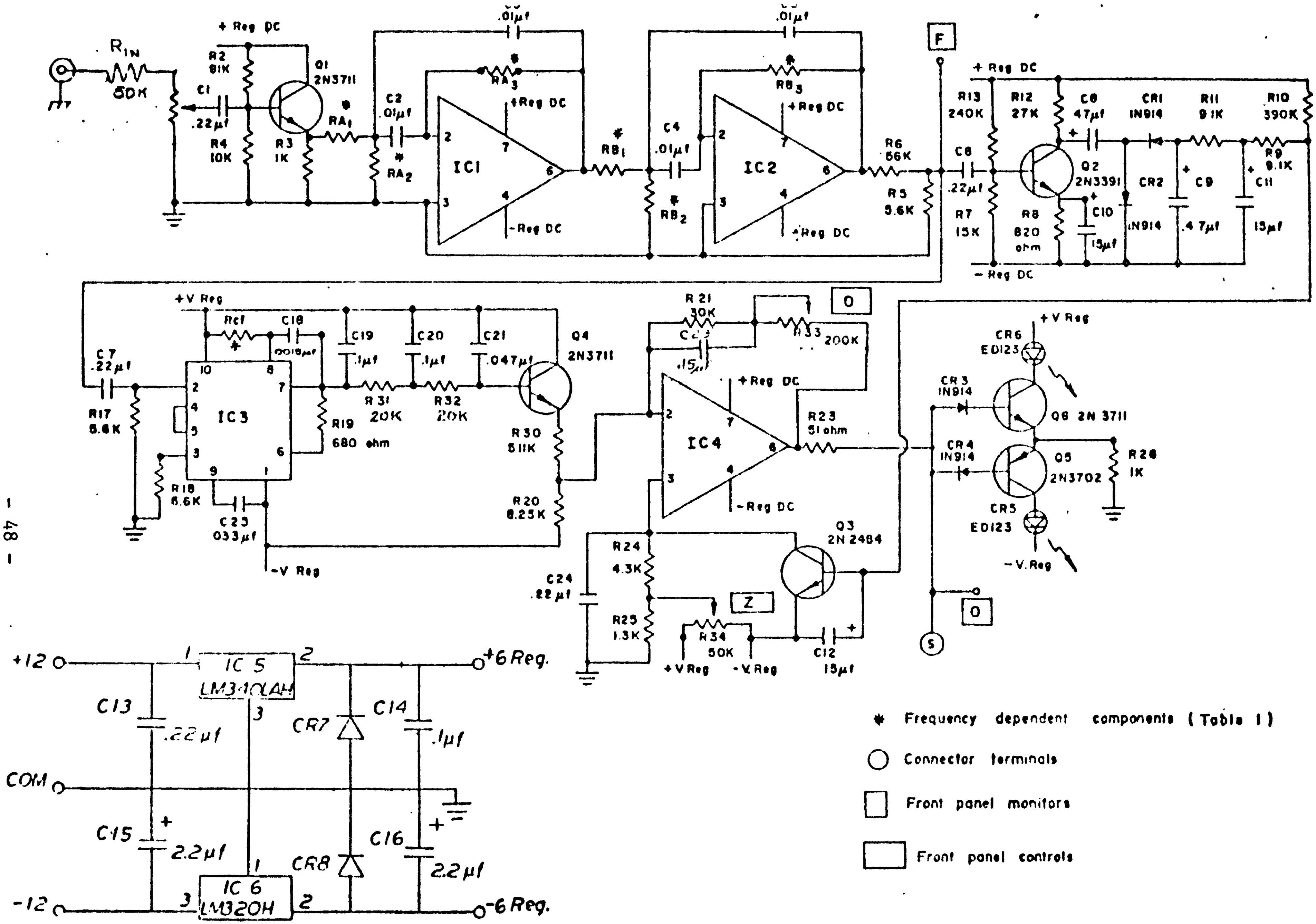


Figure 17 DISCRIMINATOR-Schematic diagram
Recording Interface Unit

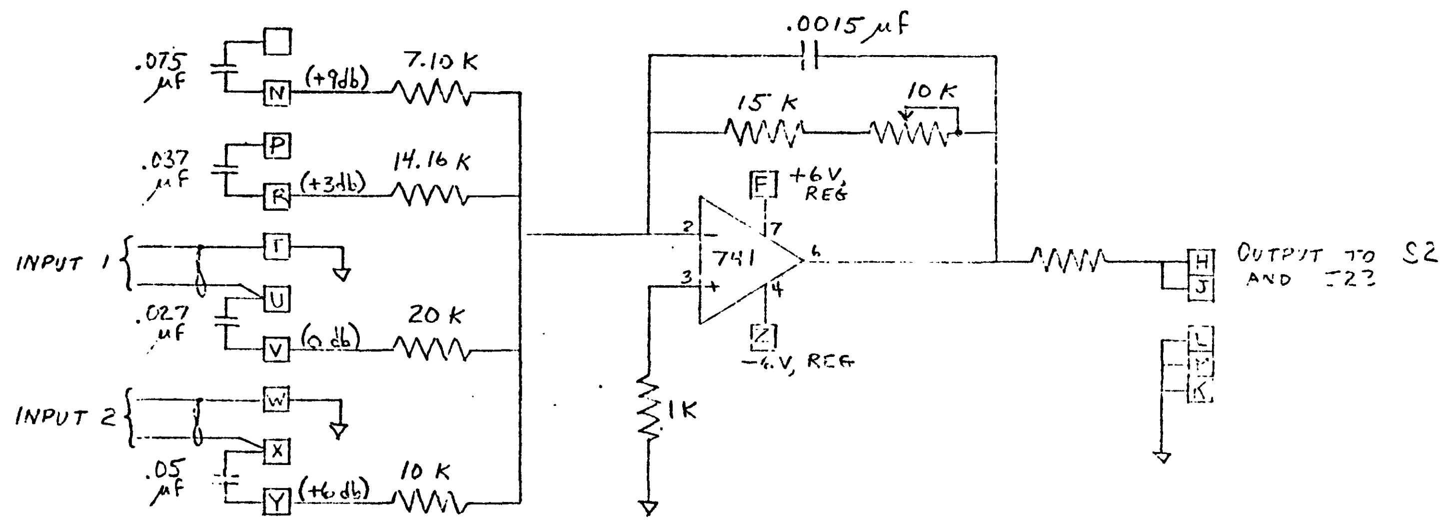


Figure 18 METER AMPLIFIER-Schematic Diagram
Recording Interface Unit

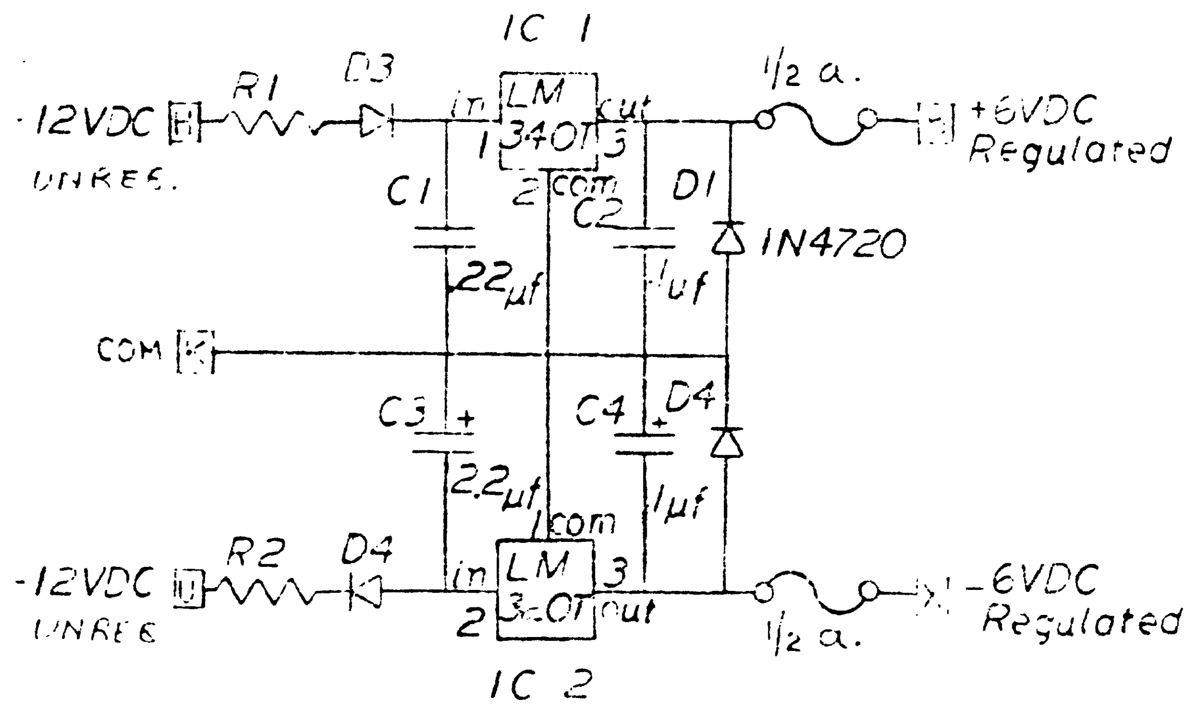


Figure 19 DUAL VOLTAGE REGULATOR-Schematic diagram Recording Interface Unit

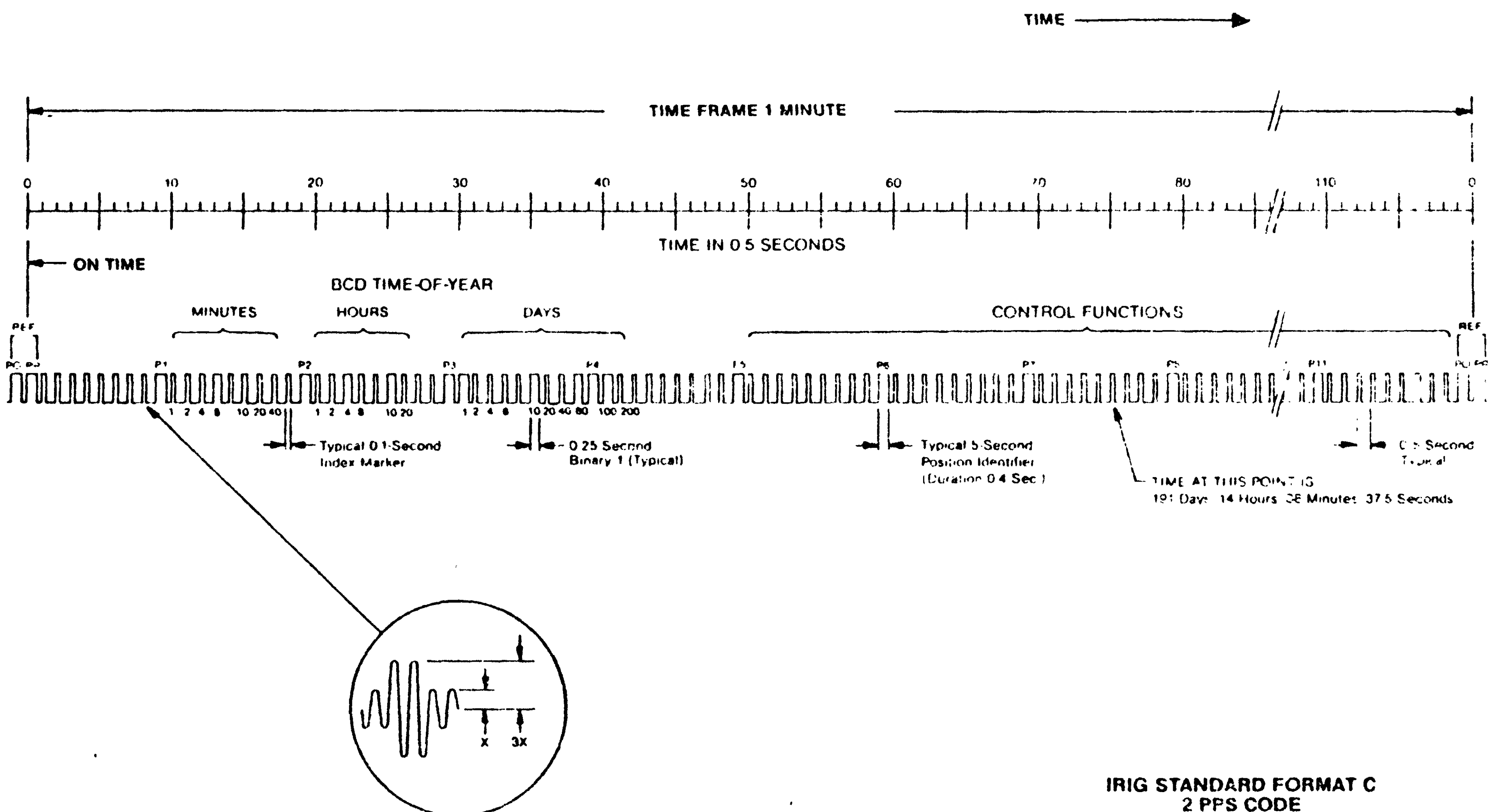
APPENDIX A

TIME CODE FORMATS AND GENERAL INFORMATION

The material in this Appendix was taken directly from the pamphlet entitled "The New Handbook of Time Code Formats", (1973), published by Datum, Inc., Timing Division, Anaheim, California.

IRIG FORMAT 'C' — GENERAL (OBSOLETE) HISTORICAL

1. **TIME FRAME:** 1 minute
2. **CODE DIGIT WEIGHTING OPTIONS:** Binary Coded Decimal Time-of-Year CODE WORD only — 23 binary digits Minutes, hours and days; recycles yearly
3. **CODE WORD STRUCTURE:** BCD: Word begins at INDEX COUNT 10. Binary-coded Elements occur between POSITION IDENTIFIER Elements (seven for minutes; six for hours; ten for days) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT.** Occurs first
5. **ELEMENT RATES AVAILABLE:**
   a. 2 per second (basic Element rate)
   b. 1 per 5 seconds (POSITION IDENTIFIER Rate)
   c 1 per minute (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a "On-Time" reference point for each Element is its leading edge.
   b. INDEX MARKER duration 0.1 seconds (Binary zero or uncoded Element)
   c CODE DIGIT duration: 0.25 seconds (Binary one)
   d. POSITION IDENTIFIER duration: 0.4 seconds (Refers to the leading edge of the succeeding Element)
   e. REFERENCE MARKER Two consecutive POSITION IDENTIFIERS.
   (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 0.5 seconds (unmodulated); 0.01 seconds (modulated 100 Hz), 0.001 seconds (modulated 1000 Hz).
8. **CARRIER FREQUENCY:** 100 or 1000 Hz when modulated.



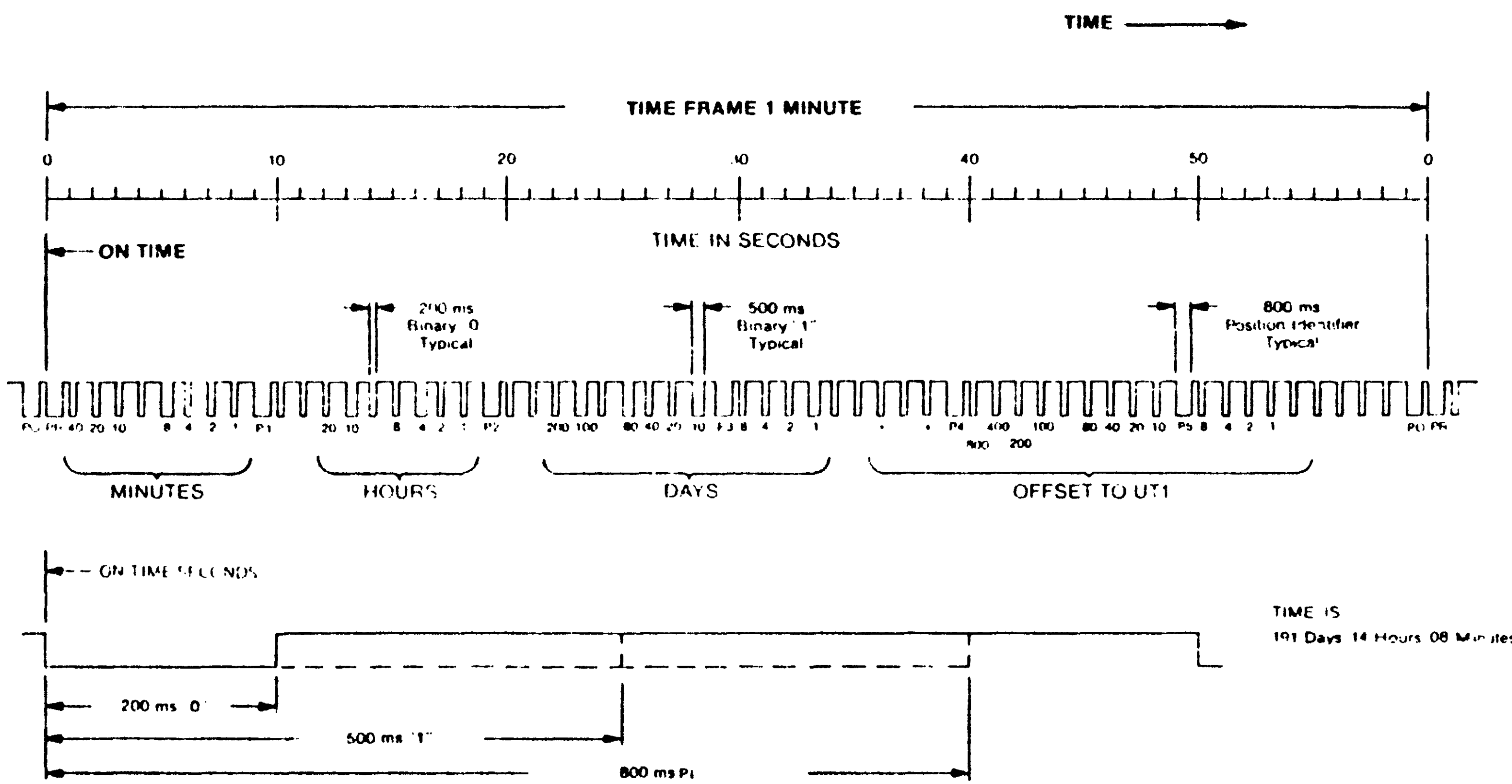
TYPICAL MODULATED CARRIER
(RECOMMENDED FREQUENCY 1000 Hz or 100 Hz)

IRIG STANDARD FORMAT C
2 PPS CODE
(DISCONTINUED)
REFERENCE IRIG DOCUMENT 104-60

WWVB TIME FORMAT

1. **TIME FRAME:** 1 minute
2. **CODE DIGIT WEIGHTING:** BCD Time-of-Year CODE WORD — 35 binary digits.
   a. Minutes, hours, days, UT correction 0.1 seconds, 0.01 seconds, 0.001 seconds.
3. **CODE WORD STRUCTURE.** BCD Word begins at INDEX COUNT 1. Binary coded elements occur between POSITION IDENTIFIER ELEMENTS (seven for minutes, six for hours, ten for days, 12 for UT corrected) till the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** (Minutes) occurs first — UT correction occurs after days.
5. **ELEMENT RATES AVAILABLE:**
   a. 1 per second (Basic Element Rate)
   b. 1 per 10 seconds (POSITION IDENTIFIER Rate)
   c. 1 per minute (Frame rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each element is its leading edge.
   b. INDEX MARKER duration: 0.2 seconds (Binary zero or uncoded element)
   c. CODE DIGIT duration: 0.5 seconds (Binary one)
   d. POSITION IDENTIFIER duration: 0.8 seconds
   e. REFERENCE MARKER — 1 per minute. Two consecutive POSITION IDENTIFIERS

      (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER).
7. **RESOLUTION:** 1 second (unmodulated)
8. **CARRIER:** 60 kHz (1:10 modulation ratio) suppressed carrier.
9. **TIME SCALE:** Universal Time Coordinated with coded correction to UT1.

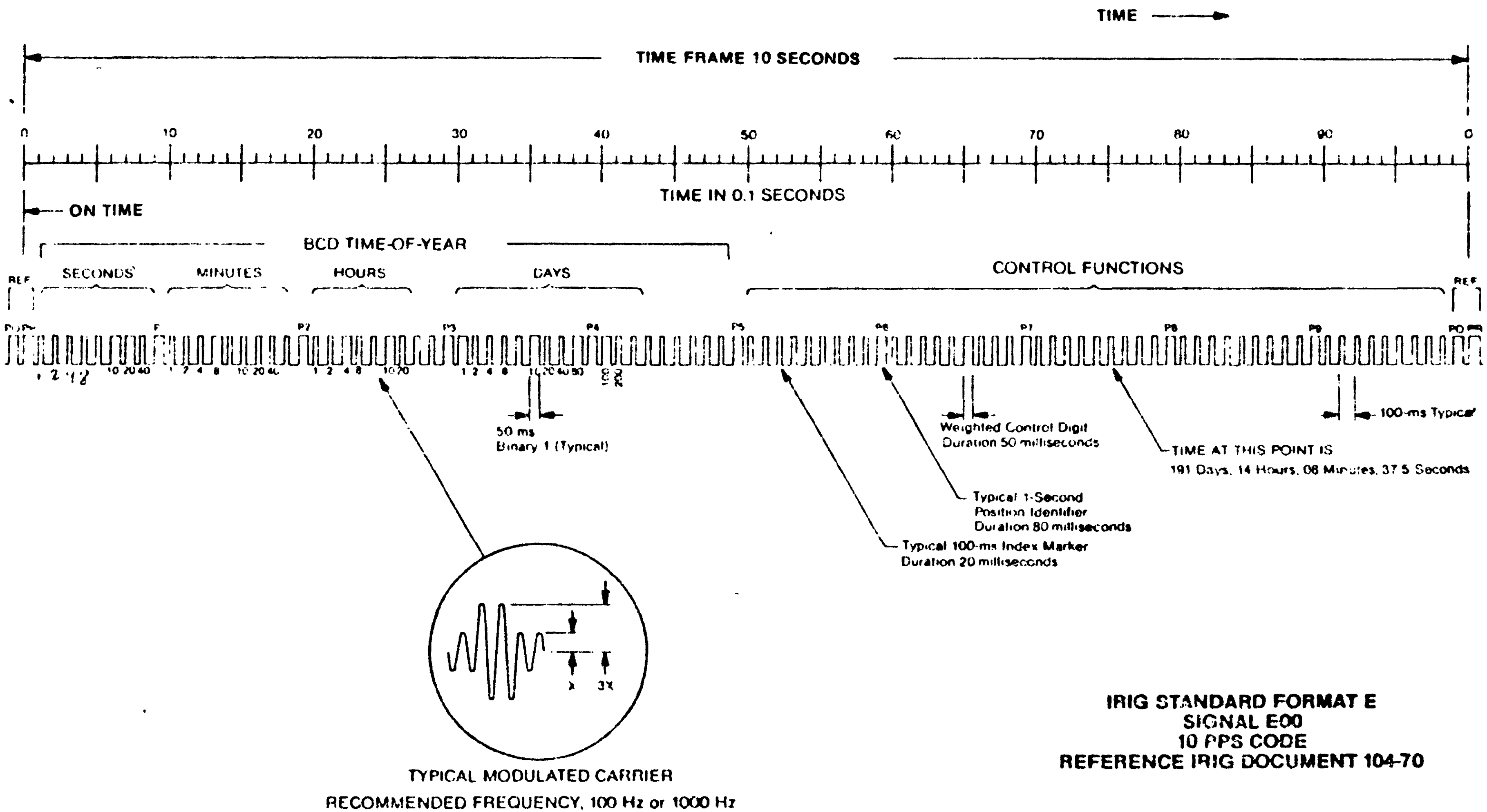


NATIONAL BUREAU OF STANDARDS
WWVB TIME CODE
ONE-PPS CODE ENVELOPE

IRIG FORMAT 'E' — GENERAL

1. **TIME FRAME:** 10 seconds
2. **CODE DIGIT WEIGHTING:** BCD: Time-of-Year CODE WORD — 26 Binary Digits. Seconds, minutes, hours and days: recycles yearly
3. **CODE WORD STRUCTURE:**
   BCD: Word begins at INDEX COUNT 6. Binary-coded Elements occur between POSITION IDENTIFIER ELEMENTS (three for seconds, seven for minutes; six for hours, ten for days) until the CODE WORD is complete. A POSITION IDENTIFIER occurs between decimal digits in each group to provide separation for visual resolution.
4. **LEAST SIGNIFICANT DIGIT:** Occurs first.
5. **ELEMENT RATES AVAILABLE:**
   a. 10 per second (basic Element rate)
   b. 1 per second (POSITION IDENTIFIER Rate)
   c. 0.1 per second (Frame Rate)
6. **ELEMENT IDENTIFICATION:**
   a. "On-Time" reference point for each Element is its leading edge
   b. INDEX MARKER duration: 20 milliseconds (Binary zero or uncoded Element)
   c. CODE DIGIT duration: 50 milliseconds (Binary one)
   d. POSITION IDENTIFIER duration: 80 milliseconds (Refers to the leading edge of the succeeding Element).
   e REFERENCE MARKER (one per 10 seconds): Two consecutive POSITION IDENTIFIERS.

   (The "On-Time" point, to which the CODE WORD refers, is the leading edge of the second POSITION IDENTIFIER.)
7. **RESOLUTION:** 100 milliseconds (unmodulated); 1 millisecond (modulated).
8. **CARRIER FREQUENCY:** 1 kHz or 100 Hz when modulated.

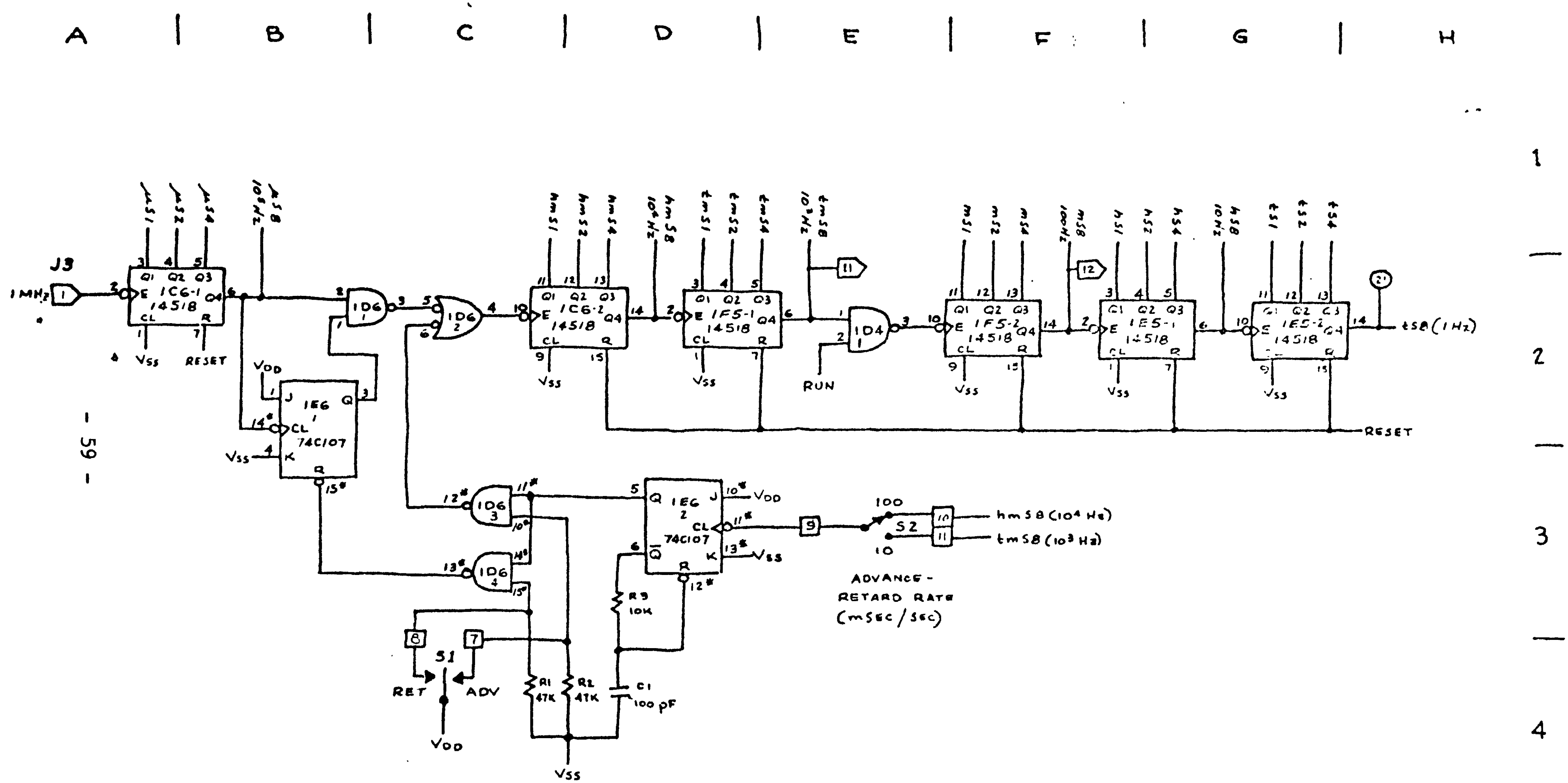


IRIG STANDARD FORMAT E
SIGNAL E00
10 PPS CODE
REFERENCE IRIG DOCUMENT 104-70

APPENDIX B

CHRONOMETER - TIME CODE GENERATOR
CIRCUIT DIAGRAMS

This chronometer / time code generator was designed, built and documeted by J. Ellis, U.S.G.S., and was incorporated into the Centipede System with only minor modification.

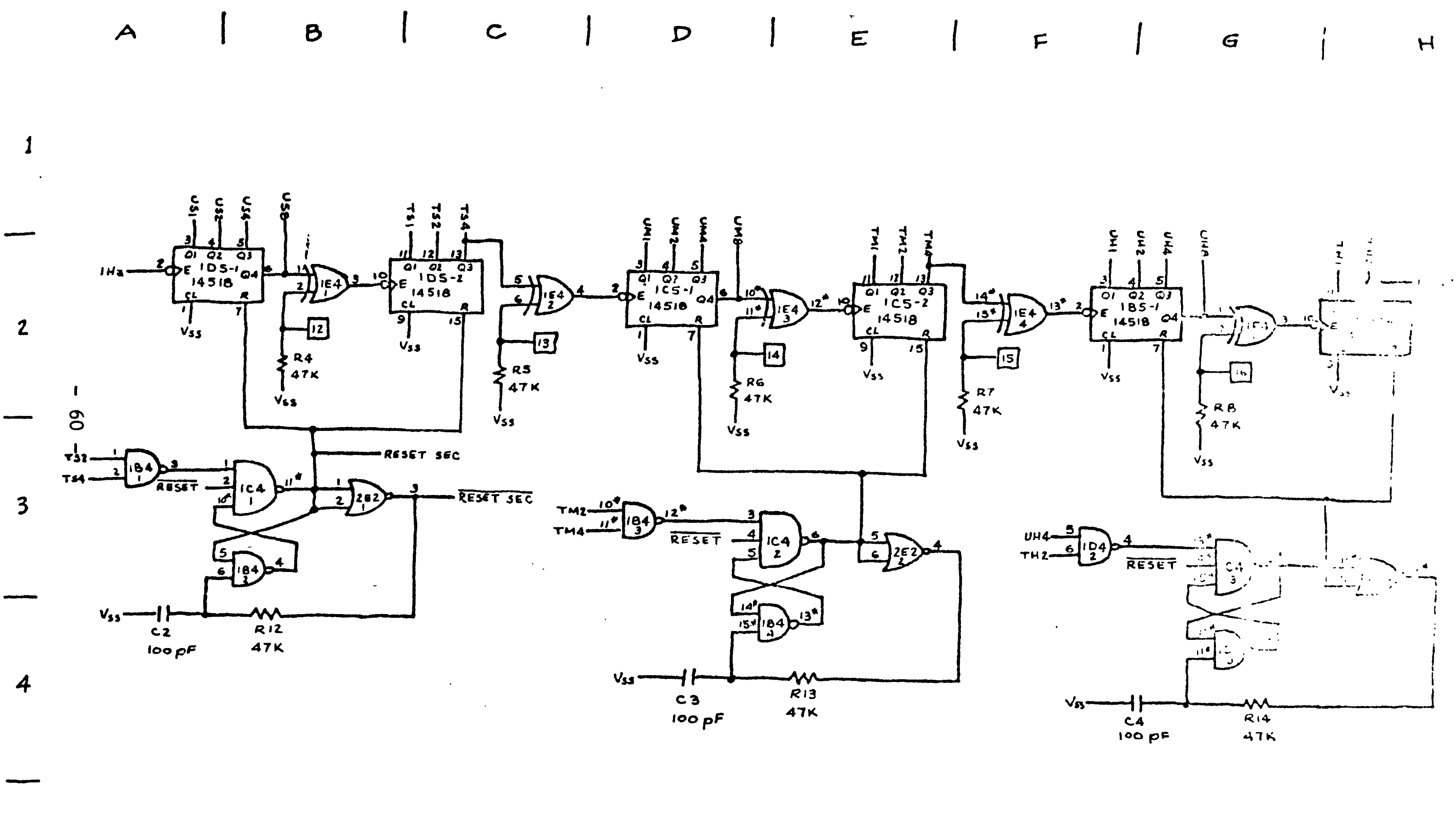


5

CLOCK-GENERATOR

MINOR TIME COUNTER WITH
ADVANCE-RETARD

DWG. NO. 1



- 60 -

CLOCK-GENERATOR

MAJOR TIME COUNTER
SHEET 1 OF 2

DWG. NO. 2

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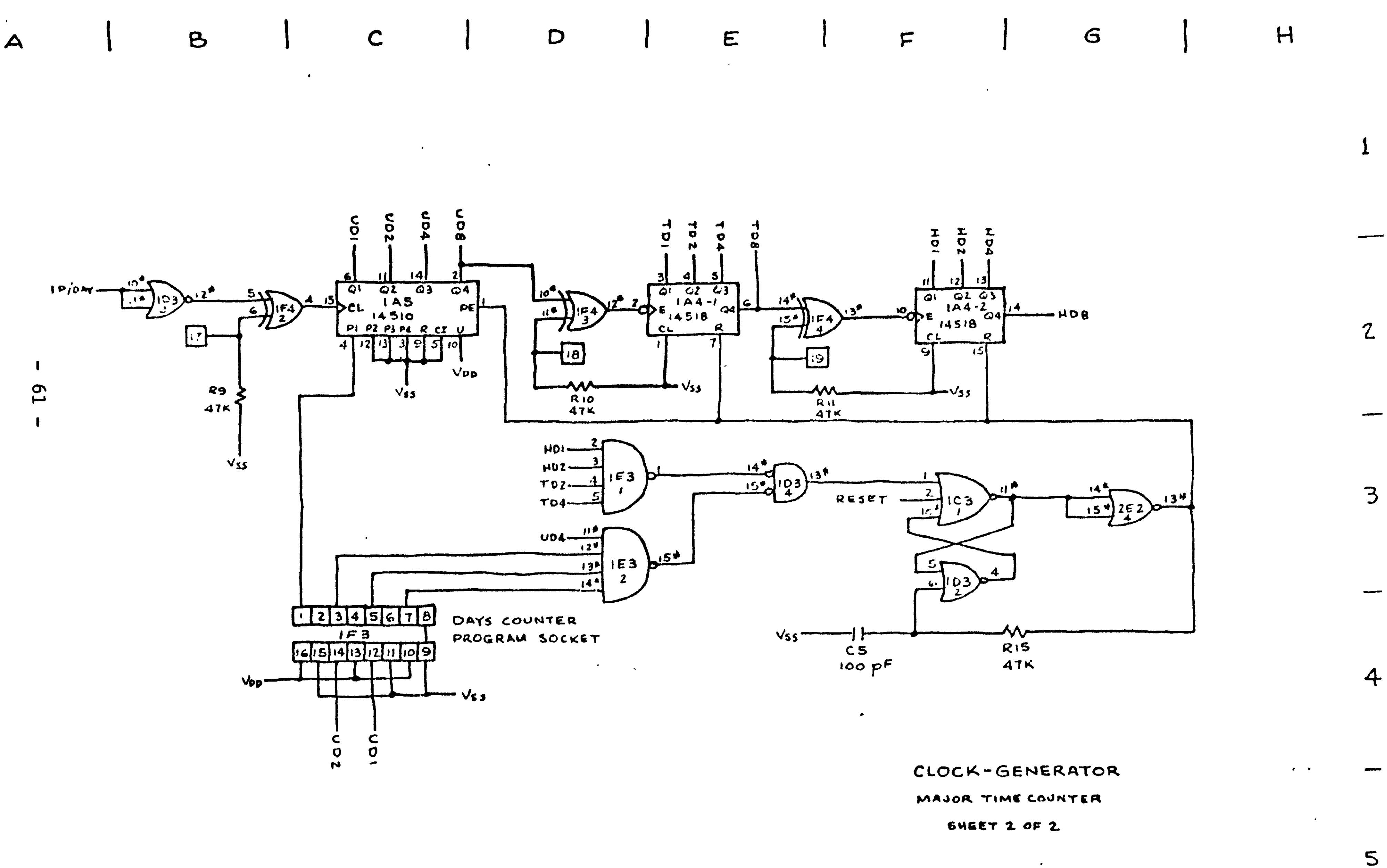
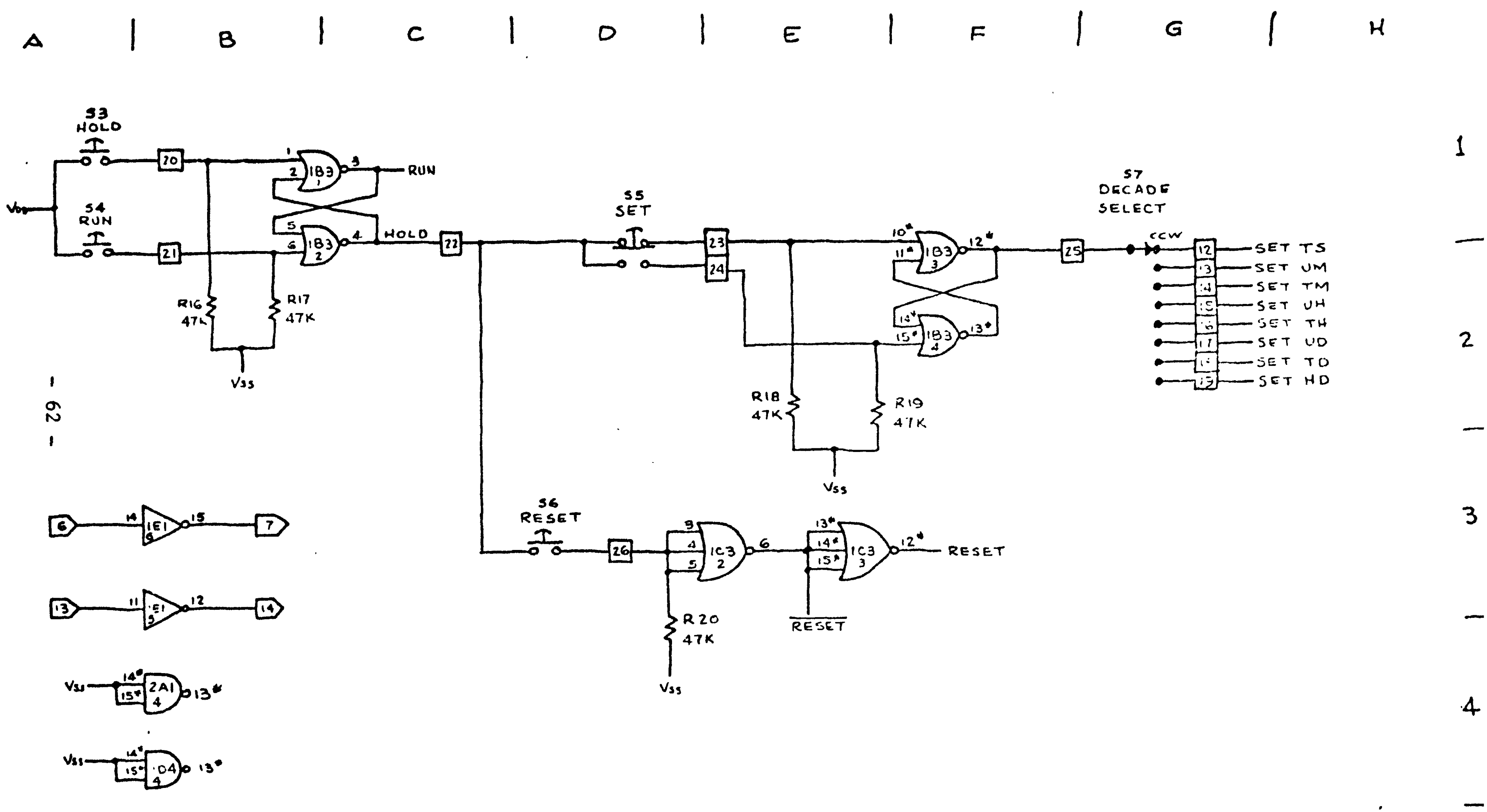


CLOCK-GENERATOR

MAJOR TIME COUNTER

SHEET 2 OF 2

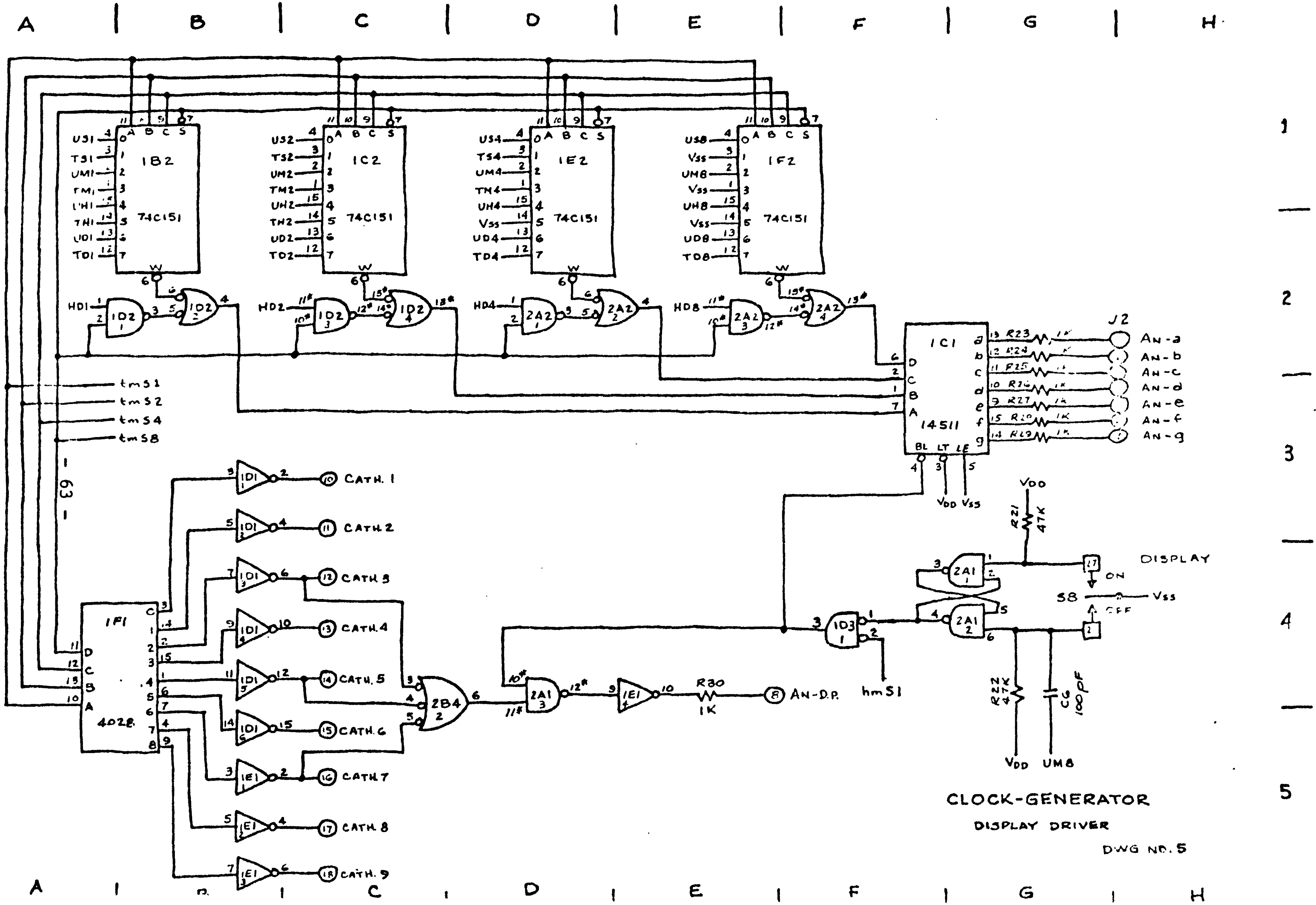
DWG. NO. 3



CLOCK-GENERATOR

CONTROL CIRCUIT
OUTPUT BUFFERS
UNUSED GATES

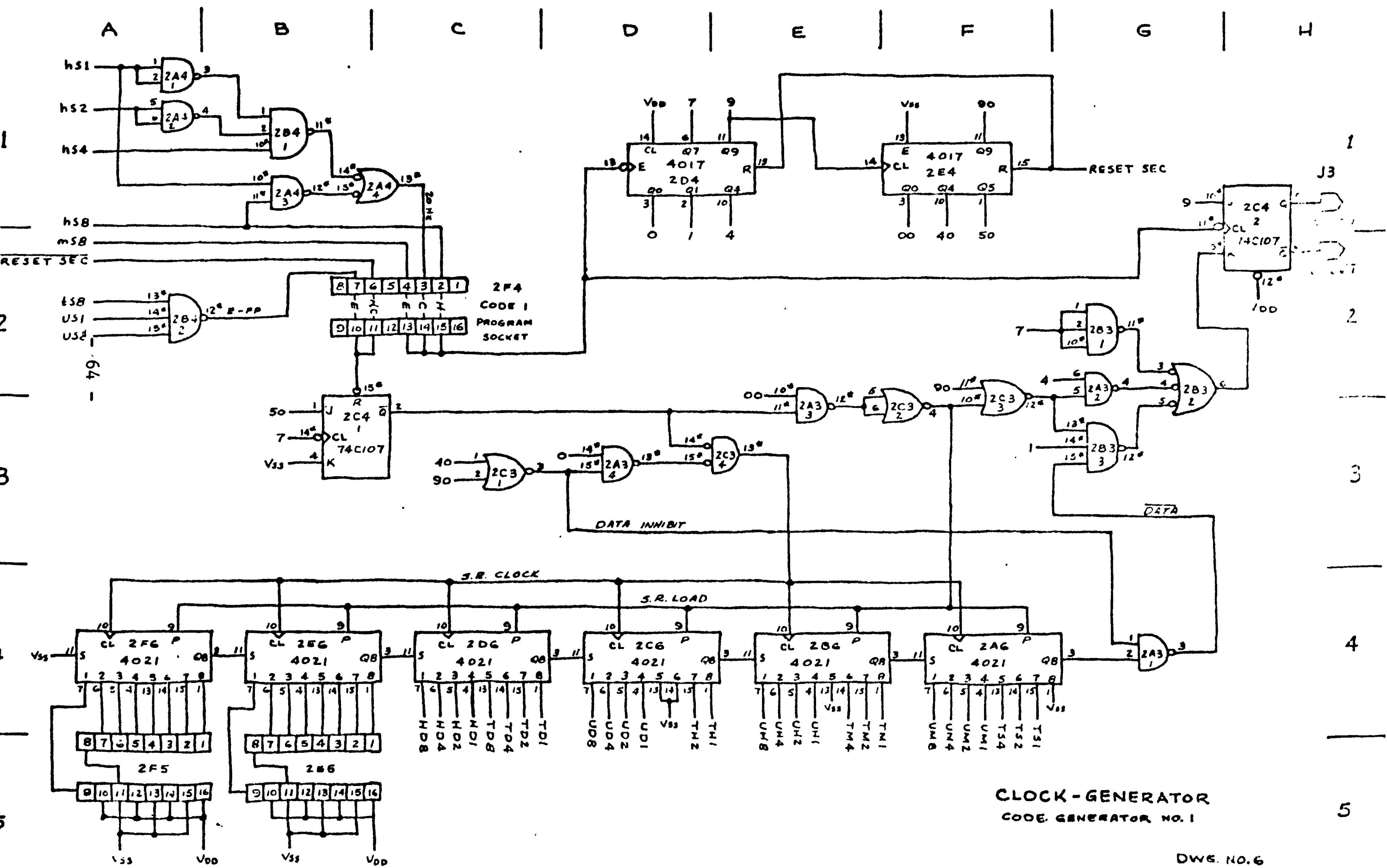
DWG. NO. 4

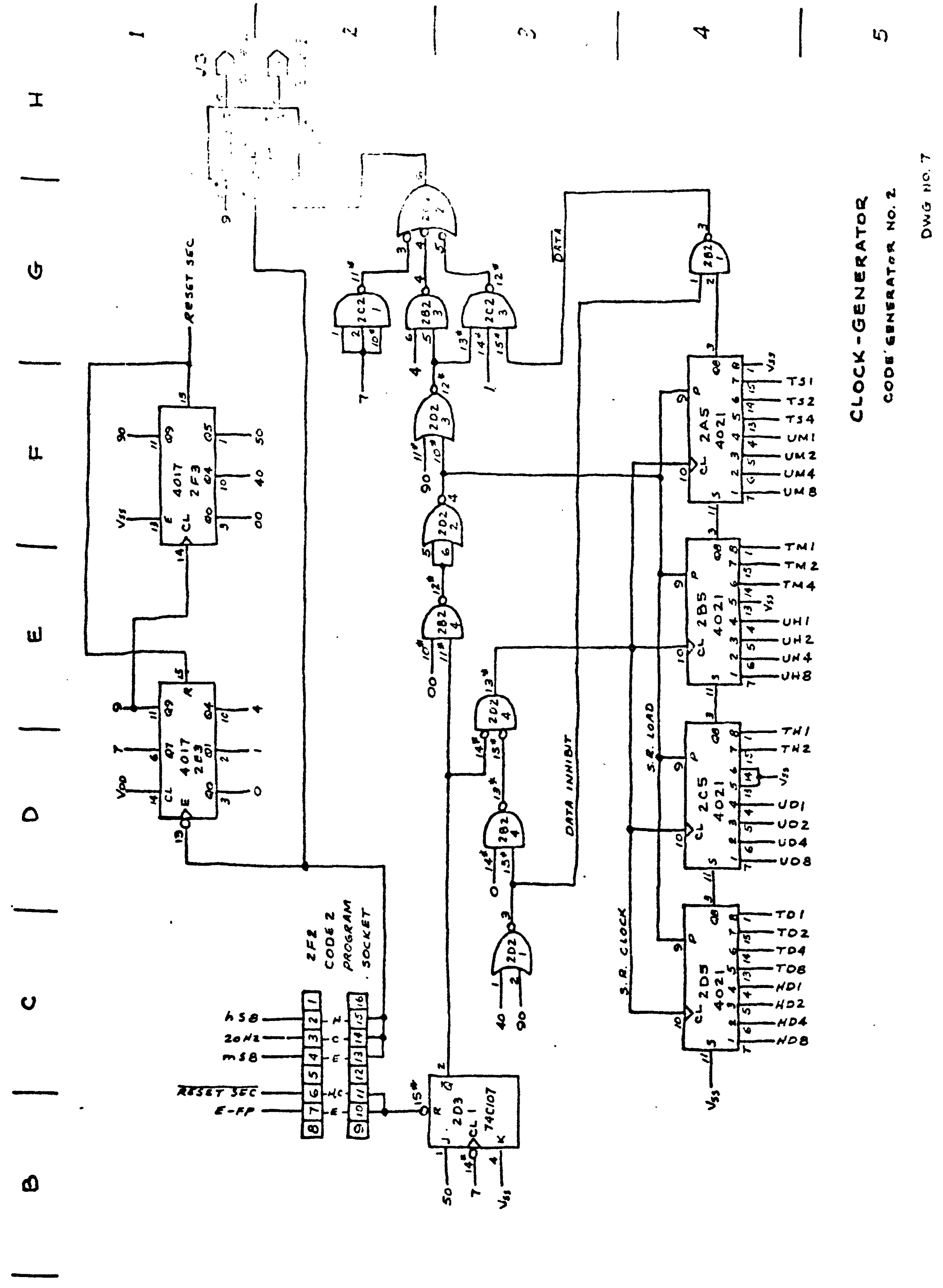


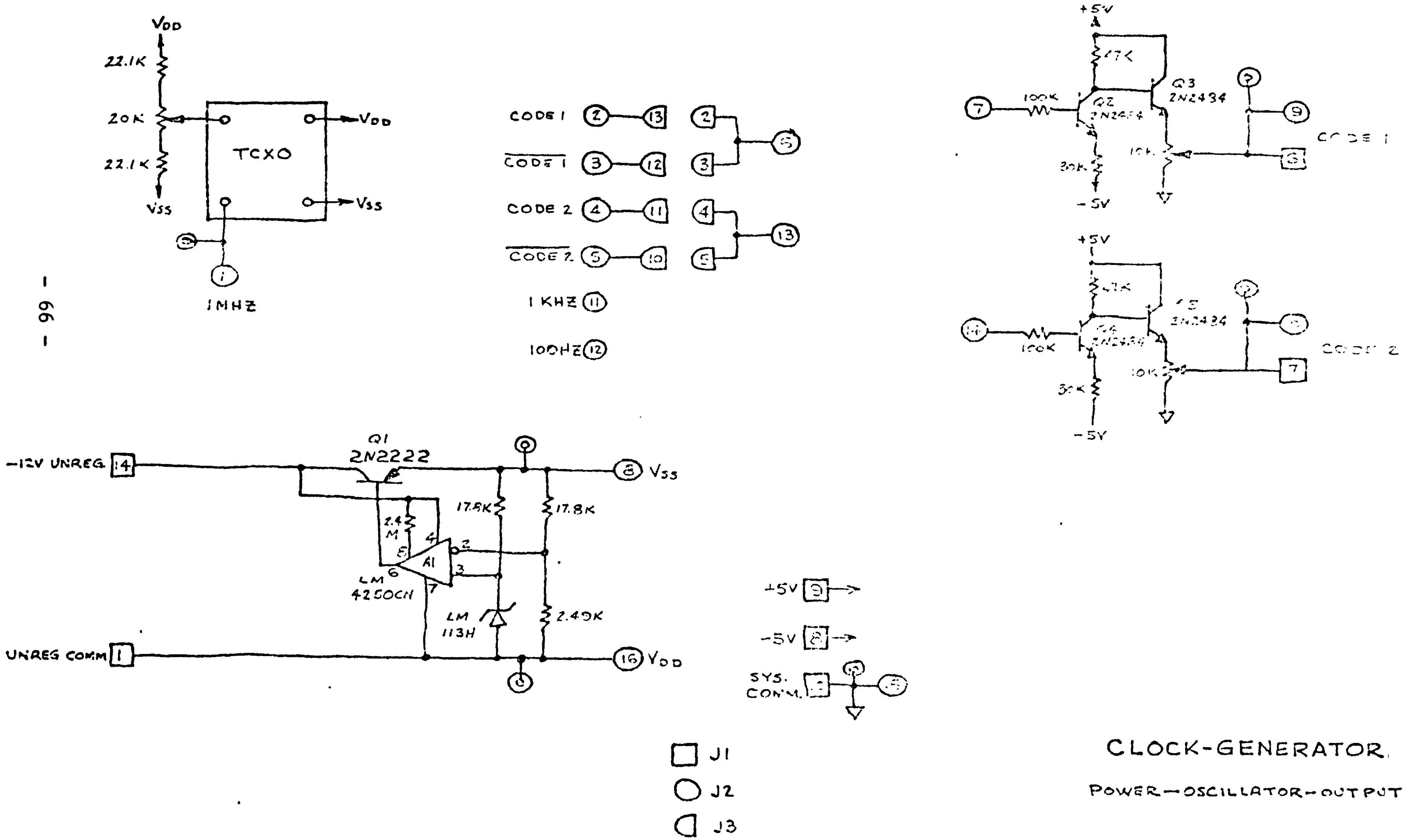
CLOCK-GENERATOR

DISPLAY DRIVER

DWG NO. 5


CLOCK - GENERATOR
CODE GENERATOR NO. 1
DWG. NO. 6
RESET SEC
DATA INHIBIT
S.R. CLOCK
S.R. LOAD
2F4
CODE 1
PROGRAM
SOCKET


CLOCK-GENERATOR
CODE GENERATOR NO. 2
DWG NO. 7
RESET SEC
DATA
DATA INHIBIT
S.R. LOAD
S.R. CLOCK
2F2
CODE 2
PROGRAM
SOCKET
4017
2F3
2E3
74C107
2D3
4021
2AS
2BS
2CS
2DS



CLOCK-GENERATOR

POWER—OSCILLATOR—OUTPUT

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APPENDIX C

ELECTRONIC PARTS LISTS
FOR MAJOR CIRCUITS

J303 PREAMP/VCO Parts List

C1, C2	Capacitor .0022 uf	Aerovox CK05BX222K
C3	Capacitor 25 rf 6VNP	GE 29F538
C4	Capacitor .00039 uf	Aerovox CK05BX391K
C5	Capacitor 7.5 uf 6VNP	Sprague 151D755X9006X2
C6	Capacitor .00068-.0015 uf	Aerovox 3419-100A series
C7, C8	Capacitor .0027-.033 uf	CD WMF Series (frequency dependent)
R1, R2	Resistor 4.99K ohm	RN55D 1%
R3, R4	Resistor 1.50 meg ohm	A-5 type CC 1%
R5, R11	Resistor 51 ohm	1/4W 5%
R6, R12	Resistor 5.1 meg ohm	1/4W 5%
R7, R13, R23	Resistor 100K ohm Pot.	Spectrol 43W104
R8, R9	Resistor 66.5K ohm	RN55D 1%
R10	Resistor 8.25 meg ohm	A-B type CC 1%
R14	Resistor 51K ohm	1/4W 5%
R15	Resistor 200K ohm Pot.	Spectrol 43W204
R16	Resistor 150K ohm	1/4W 5%
R17	Resistor 100K ohm	A-B type CC 1%
R18	Resistor 91K ohm	A-B type CC 1%
R19	Resistor 30K ohm	1/4W 5% nominal(varies with VCO chip)
R20	Thermistor 10K ohm	Fenwal KP41J2
R21	Resistor 50K ohm Pot	Spectrol 43W503
R22, R34	Resistor	1/4W 5% frequency dependent
R24	Resistor 3.6K ohm	1/4W 5%
R25	Resistor 16.2K ohm	RN55D 1%
R26	Resistor 8.06K ohm	RN55D 1%
R27	Resistor 4.02K ohm	RN55D 1%
R28	Resistor 2.00K ohm	RN55D 1%
R29	Resistor 1.00K ohm	RN55D 1%
R30	Resistor 499 ohm	RN55D 1%
R31, 32	Resistor 249 ohm	RN55D 1%
R35*	Resistor 1.43 meg ohm	A-B type CC 1%
R36*	Resistor 698K ohm	A-B type CC 1%
R37*	Resistor 340K ohm	RN55D 1%
R38*	Resistor 158K ohm	RN55D 1%
R39*	Resistor 68.1K ohm	RN55D 1%
R40*	Resistor 22.6K ohm	RN55D 1%
R41, 42, 42	Resistor 1K ohm	1/4W 5%
L1	Inductor .7Hy	UTC/TRW ML-3
	Inductor 4Hy	UTC/TRW ML-6
	Inductor 1.5Hy	Motorola 25B82751D01
T1	Transformer	UTS/TRW SSO-14
A1, A2	Micropower Op Amp	National LM4250CN
VCO	C MOS Phase lock loop	RCA CD4046AE
SW1	Switch, 12 position 3 pole	Grayhill 71ASF30-03-1-12S-C
S1, S2	Socket, 16 pin DIP	Amphenol 821-25011-164
	Battery, 4 ea, 4.05V	Mallory TR233R
	Diodes 4 ea	IN34A in series with batteries
Cr1-Cr12	Diodes	1N914
	Terminals 23 ea	USECO 2003B
	PC Board	
	Connector, Power 3 pin	W.S. Deans 3 pin pair

* Indicates components used in the calibrator circuit

C6 CALIBRATOR PARTS LIST

C1	Capacitor 15-60pf	Erie 0538011F15-60
C2	Capacitor 25pf	Sprague 10TCC-Q25 NPO
C3,5,7,11,14	Capacitor .47uf	Erie 8131-050-475M
C4, 6, 8, 15	Capacitor 4.7uf	Sprague 196D475X9010HA1
C9	Capacitor .22uf	Erie 8131-050-651-224M
C10	Capacitor .27uf	Aerovox CK06BX274K
C12	Capacitor 68uf	Kemet T362C686K015AS
C13	Capacitor 6.8uf	Sprague 196D685X9010HA1
R1	Resistor 15 meg ohm	1/4W 5%
R2	Resistor 1K ohm	1/4W 5%
R3	Resistor 91K ohm	1/4W 5%
R4, 27	Resistor 20K ohm	1/4W 5%
R5, 7, 14, 37	Resistor 200K ohm	1/4W 5%
R6, 8, 36	Resistor 2 meg ohm	1/4W 5% Nominal (Optimize timing)
R9, 10, 16	Resistor 27K ohm	1/4W 5%
R11, 13, 17	Resistor 110 ohm	1/4W 5%
R12	Resistor 330 ohm	1/4W 5%
R15	Resistor 5.1 meg ohm	1/4W 5% Nominal (Optimize timing)
R18	Resistor 20.0K ohm	RN55D 1%
R19	Resistor 5.36K ohm	RN55D 1%
R20	Resistor 698 ohm	RN55D 1%
R21	Resistor 75 ohm	RN55D 1%
R22	Resistor 9.31K ohm	RN55D 1%
R23	Resistor 665 ohm	RN55D 1%
R24	Resistor 562 ohm	RN55D 1%
R25	Resistor 200 ohm	1/4W 5%
R26	Resistor 180K ohm	1/4W 5%
R28, 34, 38	Resistor 33K ohm	1/4W 5%
R29	Resistor 1.2 meg ohm	1/4W 5%
R30	Resistor 560K ohm	1/4W 5%
R31	Resistor 6.8K ohm	1/4W 5%
R32	Resistor 36K ohm	1/4W 5%
R33	Resistor 75K ohm	1/4W 5%
R35	Resistor 10K ohm	1/4W 5%
Cr1, 2, 3, 4	Diode	1N914
Q1, 2, 3, 4	Transistor, Darlington	Motorola MPS A 14
IC1	Digital Integrated Circuit	RCA CD4045AE
IC2	Digital Integrated Circuit	RCA CD4020AE
IC3	Digital Integrated Circuit	RCA CD4049AE
IC4	Digital Integrated Circuit	RCA CD4001AE
IC5	Digital Integrated Circuit	RCA CD4011AE
IC6, 7	Digital Integrated Circuit	RCA CD4021AE
RY1A, 2, 3	Relay	Magnecraft W172DIP5
RY1B	Relay	Magnecraft W171DIP7
RY4	Relay	Magnecraft W171DIP25
X1	Crystal	Monitor Products 397.682khz
	IC Socket 2 ea	Amphenol 821-25011-144
	IC Socket 5 ea	Amphenol 821-25011-164
	Battery 5.6V	Mallory TR234
	Battery 9V	Mallory MN1604
	Battery 1.35V	Mallory TR233R (use 1 cell with cover)
	Connector 5 pin	W. S. Deans 5 pin
	Terminal 22 ea	USECO 2003 B1
	PC Board	
	Spacer 8 ea	H. H. Smith 8880

J101 DISCRIMINATOR PARTS LIST

R1	5K Variable	Spectrol #43W502
R2	91K	1/4 W 5% carbon
R3, R26	1K	" "
R4, R9, R11	9.1K	" "
R5, R17, R18	5.6K	" "
R6	56K	" "
R7	15K	" "
R8	820Ω	" "
R10	392K	" "
R12	27K	" "
R13	243K	" "
R19	680Ω	" "
R21	30K	" "
R23	51Ω	" "
R24	4.3K	" "
R25	1.3K	" "
R31, R32	20K	" "
R20	8.25K	1/4W 1% RN55D
R33	200K Variable	Spectrol 43W-204
R34	50K Variable	Bourns 3006W-1-503
RIN	50K	1/4W 5% CARBON
R30	5.11K	1/4W 1% RN55D
C1, C6, C7, C13	.22μf ceramic 50WVDC	Erie #8131-050-651-224M
C2, C3, C4, C5	.01μf polyester	Cornell-Dublier #WMf-151
C8	4.7μf solid-tantalum	Sprague #196D 475X9035JA1
C10, C12, C11	15μf " "	Sprague #196D156X9015JA1
C9	.47μf ceramic	Erie #8131-050-651-474M
C21	.047μf ceramic	Erie #8121-050-651-473M
C23	.15μf ceramic	
C18	.0015 f ceramic	AVX #CK05BX152K
C14, 19, 20	.1μf ceramic	Erie #8121-050-651-104M
C25	.033μf Ceramic	Erie #8121-050-651-333M
C15, C16	2.2μf Solid tantalum	Sprague #196D225X9025HA1
Q4, Q6, Q1	Transistor	National #2N3711
Q2	"	" 2N3391
Q3	"	" 2N2484
Q5	"	" 2N3702
CR1, 2, 3, 4, 7, 8	Diode	1N914
CR5, 6	LED	Sprague #ED123
IC1, 2, 4	I Cop amp	National LM 741CH
1C 5	1C regulator	National LM 340 CAH
IC6	" "	" LM 320H
IC3	1C phase lock loop	" LM 565CH
IC Sockets	8 pin	Augat #8058-1G49
IC Sockets	10 pin	Augat #8058-1G34

± 6 VOLT DUAL REGULATOR PARTS LIST

R, R2	OPTIONAL	2 Watt resistor
C1	.22 μf ceramic	Erie 8131-050-651-224M
C2	.1 μf ceramic	Erie 8 121-050-651-104M
C3	2.2 μf Solid Tantalum	Sprague 196D225X9035JA1
C4	12 μf " "	Sprague 196D105X9035HA1
D1,D2,D3,D4	1N4270 Diode	National
ICI	LM340T +6V Regulator	National
IC2	LM320T -6V Regulator	National

APPENDIX D

WIRING LISTS FOR CABLES AND CONNECTORS

TABLE 6

RECORDING INTERFACE UNIT - OUTPUT CABLE WIRING

(CONNECTING RIU WITH TAPE RECORDER)

Signal	Connector Pins (MS3102A-28-15)		Connector Pins (Airborn K-50)		Geotech Track #
	Hot	Shield	Hot	Shield	
MUX 1	A	B	A	C	1
MUX 2	C	D	K	H	2
MUX 3	E	F	P	S	3
MUX 4	M	N	Y	W	4
MUX 5	H	J	c	e	5
MUX 6	K	L	n	K	6
MUX 7	P	R	t	v	7
MUX 8	S	T	u	w	14
MUX 9	U	V	L	J	9
MUX 10	X	Y	R	T	10
MUX 11	Z	a	Z	X	11
MUX 12	b	c	d	f	12
MUX 13 (Timing)	d	e	p	m	13
TSC	f	g	B	D	8

TABLE 7

Recording Interface Unit - Power Cable Wiring

Connector: Amphenol MS3102A-18-20P

Pin	Use
A	N/C
B	N/C
C	+ 12 VDC
D	Power common
E	-12 VDC

TABLE 8

Telemetry Radio Receiver connector pin designation

Connector: Bendix MS3102E-14S-5S

Pin	Use
A	Power ground
B	Power (+ 12.5 VDC)
C	N/C
D	Audio output
E	Audio output

TABLE 9

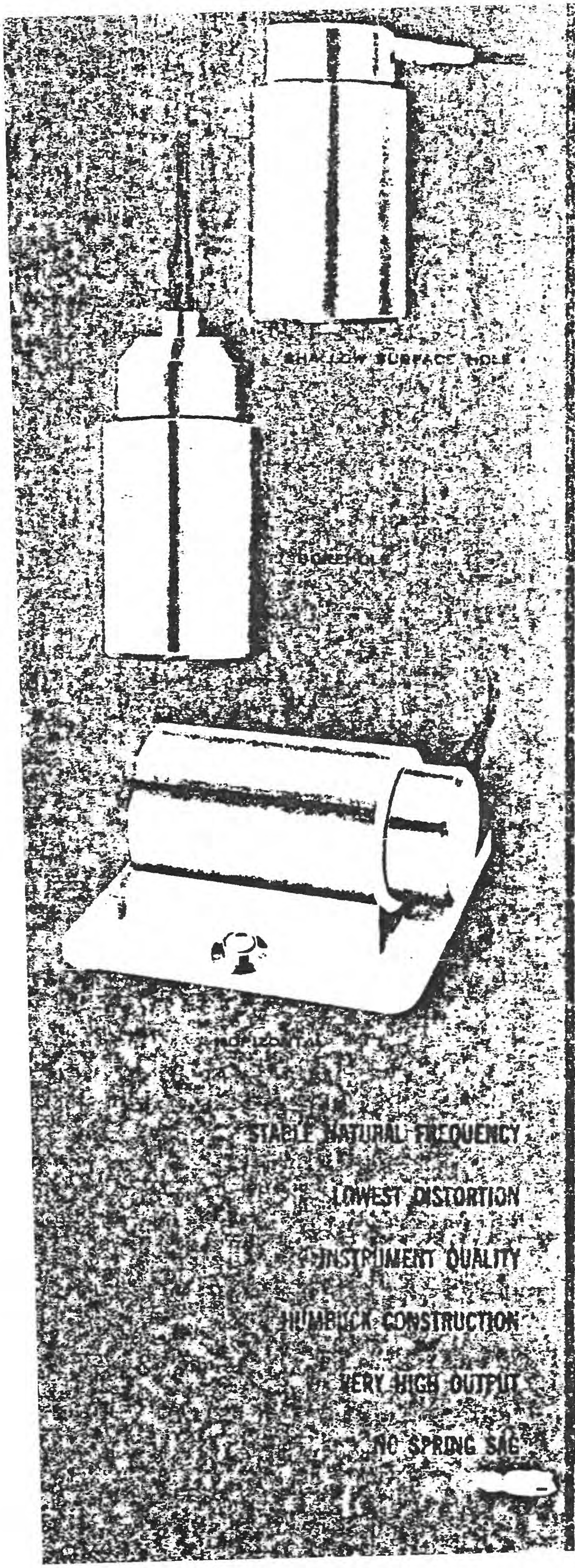
Telemetry Radio Transmitter connector pin designation

Connector: Bendix MS3102E-14S-5S

Pin	Use
A	Power ground
B	Power (+12.5 VDC)
C	Case ground
D	Modulation input
E	Modulation input

APPENDIX E

SPECIFICATIONS FOR MARK L-4C GEOPHONES



The L-4 is an INSTRUMENT QUALITY ONE Hz or TWO Hz multi-purpose geophone, that is small, light, and economical. It is designed to yield the performance needed for scientific studies, yet has the ruggedness required for petroleum exploration work.

The L-4 design ELIMINATES the usual causes of FAILURE in VERY LOW FREQUENCY geophones, such as SPRING FATIGUE, OVERSTRESS and INSTABILITY. This geophone maintains a close frequency tolerance with tilt and temperature, and is TRANSPORTED WITHOUT CLAMPING the moving element.

The L-4 is available with or without calibration coils, and may be obtained as VERTICAL OR HORIZONTAL elements. A variety of fittings are available for custom application.

U.S. PATENT 3,451,040
FRENCH AND NETHERLANDS PATS. PEND.

1.0 Hz AND 2.0 Hz LAND OR BOREHOLE GEOPHONE

L-4

1.0 Hz BASIC UNIT GUARANTEED FOR ONE YEAR ON PRORATED BASIS
2.0 Hz BASIC UNIT GUARANTEED FOR TWO YEARS ON PRORATED BASIS
EXTERNAL VOLTAGE AND HIGHLINE DAMAGE NOT INCLUDED IN WARRANTY

SPECIFICATIONS

L-4A 2.0 Hz GEOPHONE

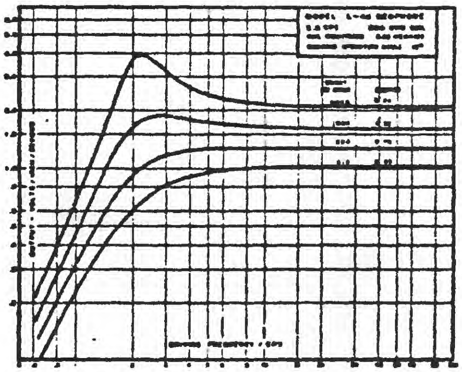
TYPE	Moving dual coil, humbuck wound
FREQUENCY	2.0 ± 0.25 Hz measured on 200 pound weight at 0.09 inches/second.
FREQUENCY CHANGE WITH TILT	Less than 0.10 Hz at 10° from vertical.
FREQUENCY CHANGE WITH EXCITATION	Less than 0.10 Hz from 0 to 0.18 inches/second
SUSPENDED MASS	500 grams
STANDARD COIL RESISTANCES	See Table
LEAKAGE TO CASE	100 megohm minimum at 500 volts
TRANSDUCTION POWER	8.8·10⁻³ watts/inch/second or 13.6 watts/meter/second
OPEN CIRCUIT DAMPING	$(b_o) = 0.28$ critical
CURRENT DAMPING	$(b_c) = \frac{1.1\,R_c}{R_s + R_c}$ where: R_c = coil resistance - ohms, R_s = shunt resistance - ohms
COIL INDUCTANCE	$(L_c = 0.0011\,R_c$; L_c in in henries.
ELECTRIC ANALOG OF CAPACITY	$C_c = \frac{36{,}500}{R_c}$ (microfarads)
ELECTRIC ANALOG OF INDUCTANCE	$L_m = 0.17R_c$ (henries)
CASE HEIGHT	5⅛ inches — 13 cm.
CASE DIAMETER	3 inches — 7.6 cm.
TOTAL DENSITY	2.9 grams/cm³
TOTAL WEIGHT	3¾ pounds — 1.7 kilograms
OPERATING TEMPERATURE	Range: −20° to 140°F or −29° to 60°C.
OPERATING PRESSURE	500 PSI.

L-4C 1.0 Hz GEOPHONE

TYPE	Moving dual coil, humbuck wound
FREQUENCY	1.0 ± 0.05 Hz measured on 200 pound weight at 0.09 inches/second
FREQUENCY CHANGE WITH TILT	Less than 0.05 Hz at 5° from vertical.
FREQUENCY CHANGE WITH EXCITATION	Less than 0.05 Hz from 0 to 0.09 inches/second
SUSPENDED MASS	1000 grams
STANDARD COIL RESISTANCES	See Table
LEAKAGE TO CASE	100 megohm minimum at 500 volts
TRANSDUCTION POWER	8.8·10⁻³ watts inch second or 13.6 watts meter second
OPEN CIRCUIT DAMPING	$(b_o) = 0.28$ critical
CURRENT DAMPING	$(b_c) = \frac{1.1\,R_c}{R_s - R_c}$ where: R_c = coil resistance - ohms, R_s = shunt resistance - ohms
COIL INDUCTANCE	$(L_c = 0.0011\,R_c$; L_c in in henries.
ELECTRIC ANALOG OF CAPACITY	$C_c = \frac{73{,}500}{R_c}$ (microfarads)
ELECTRIC ANALOG OF INDUCTANCE	$L_m = 0.345R_c$ (henries)
CASE HEIGHT	5⅛ inches — 13 cm.
CASE DIAMETER	3 inches — 7.6 cm.
TOTAL DENSITY	3.7 grams cm³
TOTAL WEIGHT	4¾ pounds — 2.15 kilograms
OPERATING TEMPERATURE	Range: −20° to 140°F or −29° to 60 C.
OPERATING PRESSURE	500 PSI

L-4A 2.0 Hz GEOPHONE

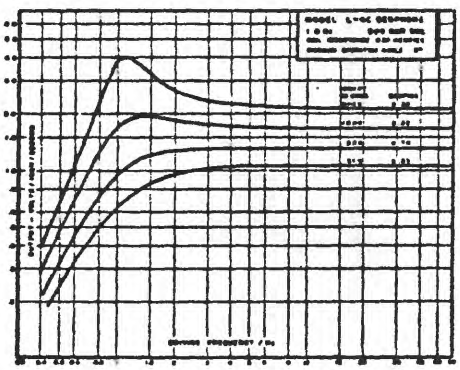
Coil Resistance (ohms	84	134	206	320	500	870	1280	2000	3500	5500
Transduction (volts/inch/sec)	0.87	1.11	1.36	1.70	2.1	2.8	3.4	4.2	5.6	6.9
Coil Inductance (henries)	0.092	0.15	0.23	0.35	0.55	0.96	1.4	2.2	3.9	6.0
Analog Capacity Equivalent (microfarads)	435	272	177	114	73	42	29.5	18.3	10.4	6.65
Analog Inductance Equivalent (henries)	14.5	23.1	35.5	55.2	86.3	150	221	345	604	950
Shunt For 0.83 Critical Damping	84	134	206	320	500	870	1280	2000	3500	5500
Shunt For 0.70 Critical Damping	136	218	335	520	810	1410	2080	3250	5700	8900
Shunt For 0.60 Critical Damping	180	297	440	690	1070	1860	2750	4300	7500	11800



Open Circuit Damping $(b_o) = 0.28$ Critical

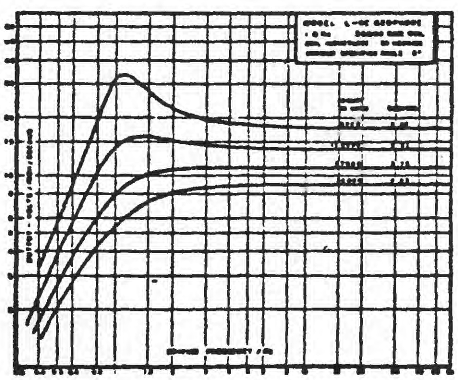
Coil Current Damping $(b_c) = \frac{1.1\,R_c}{R_c + R_s}$

Total Damping $(b_t) = b_o + b_c$



L-4C 1.0 Hz GEOPHONE

Coil Resistance (ohms)	84	134	206	320	500	870	1280	2000	3500	5500
Transduction (volts/inch/sec.)	0.87	1.13	1.34	1.7	2.1	2.8	3.5	4.2	5.55	6.9
Transduction (volts/meter/sec.)	34.2	43.5	53	67	83	110	136	165	220	273
Coil Inductance (henries)	0.092	0.147	0.230	0.35	0.55	0.95	1.40	2.20	3.85	6.05
Analog Capacity (microfarads)	875	550	356	230	147	85	58	37	21	13.4
Analog Inductance (henries)	29	46.4	71	110	173	300	440	690	1200	1900
Shunt For 0.70 Critical Damping	133	215	333	520	810	1400	2070	3250	5650	8900
Shunt For 0.60 Critical Damping	205	325	500	780	1220	2120	3100	4900	8500	13400



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