UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

A description of an extremely low frequency loop-loop geophysical system

by

J. Cooke, J. Bradley, C. Mitchell, R. Lescelius

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Project Collaborators

Management

National Science Foundation grantee and Antarctic expedition leader - Anthony England

Project director, scientific and engineering consultant - Frank Frischknecht

Project engineer - James Cooke

Project administrator and expediter - Charles Mitchell

Equipment Design

Transmitter Controller and Receiver

Designers - Jerry Bradley (Digital); James Cooke (radio frequency (RF) and analog)
Lead Technician - Jerry Bradley
Technicians - Edward Cushman, Mark Patton, Duane Meade and Steve Trostorff

Power switcher and DC supply

Designers - Roger Lescelius (switcher and supply); Charles Mitchell (supply)
Technicians - Robert Krizman (supply); Donald Rohret (switcher)

Power Unit and Battery Charger

Designers - Roger Lescelius (alternating current (AC) voltage control); Orville McKim (mechanical); Charles Mitchell (Lead designer, speed control, direct current (DC) voltage control, AC and DC electrical generator); Charles Roubique (charger)
Mechanical engineering consultant - Rutledge Mills
Lead Technician - Charles Mitchell
Technicians - Orville McKim, Charles Tippens

Specifications

Transmitter	
Loop	1 turn, Area = 10^6 m^2
Current maximum (square wave)	20 amperes
Voltage maximum	500 volts
Dipole moment (Fundamental)	1.8×10^7 Ampere-turn-m^2
Frequency Range	0.02 Hz to 2 kHz
Frequency Steps	10/decade - logarithmic
Phase Lock (receiver to transmitter)	RF Link (3.35 MHz, AM, 10W)
Power	
Current Switcher	208V-3 phase-400Hz-12 kW
Transmitter Controller	Batteries
Receiver	
Loop	8 turn 4×10^4 m^2
Sensitivity (20 decibel (DB) signal/ noise ratio at 0.02 Hz)	4×10^{-6} Ampere/m (5 mgammas)
Dynamic Range (Preamplifier Gain of 300)	105 dB
Detector	Synchronous
Band-Pass Filter	4 pole Butterworth
Low-Pass Filter (min. noise bandwidth)	1.14×10^{-4} Hz
Power	Batteries

Purpose of Development

The extremely low frequency loop-loop system was designed specifically for the investigation of the Dufek Massif pluton in western Antarctica. Properties to be determined were the pluton's depth beneath the ice, its thickness and eastern boundary and its electrical properties. Because of the ice overburden a loop-to-loop, amplitude- and phase-measuring induction system was the best approach for obtaining the desired information.*

Weight and volume restrictions were severe because the equipment had to be air shipped to a field site in Antarctica. This, along with the desirability of generating the maximum possible dipole moment, dictated the development of a smaller, lighter, and higher power transmitter and power generator than were commercially available. In addition it was anticipated that travel and communication between the transmitter and receiver sites (maximum separation of 10 km) would be difficult and time consuming. Consequently, a radio link was designed to phase-lock the receiver oscillator to the transmitter oscillator and automatic resetting circuitry was designed into the transmitter and receiver frequency-generating circuits. These two features insured that the transmitter and receiver phase detection circuits maintained a known phase relationship. An extended frequency range of 0.02 Hz to 2 kHz gave the system a good probability of penetrating both the ice and the pluton.

This system was designed and developed in four and a half months and worked very well in the field with the exception of the electronic governor on the power generator.

*For additional information on this geophysical method see: Keller, G. V. and Frischknecht, F. C., (1966), Electrical Methods in Geophysical Prospecting: New York, Pergamon Press, 517 p.

In order to determine the effect of the geology on the transmitted signal, the following parameters must be known:

1. The amplitude, phase, and frequency of the transmitted magnetic dipole field.
2. The amplitude and phase of the received signal, in order to normalize it to the transmitted signal.

A brief description of the instruments used to obtain these parameters is given in the following section.

System Description

INTRODUCTION

The system block diagram is shown in figure 1. Two major elements of the system, the transmitter and receiver, physically separated, must generate identical timing waveforms that provide the basis for comparing transmitted current with received voltage. The phase-lock AM link provides synchronism. The other elements of the transmitter generate, control, and measure the transmitted current. The other elements of the receiver amplify, filter, and measure the received voltage.

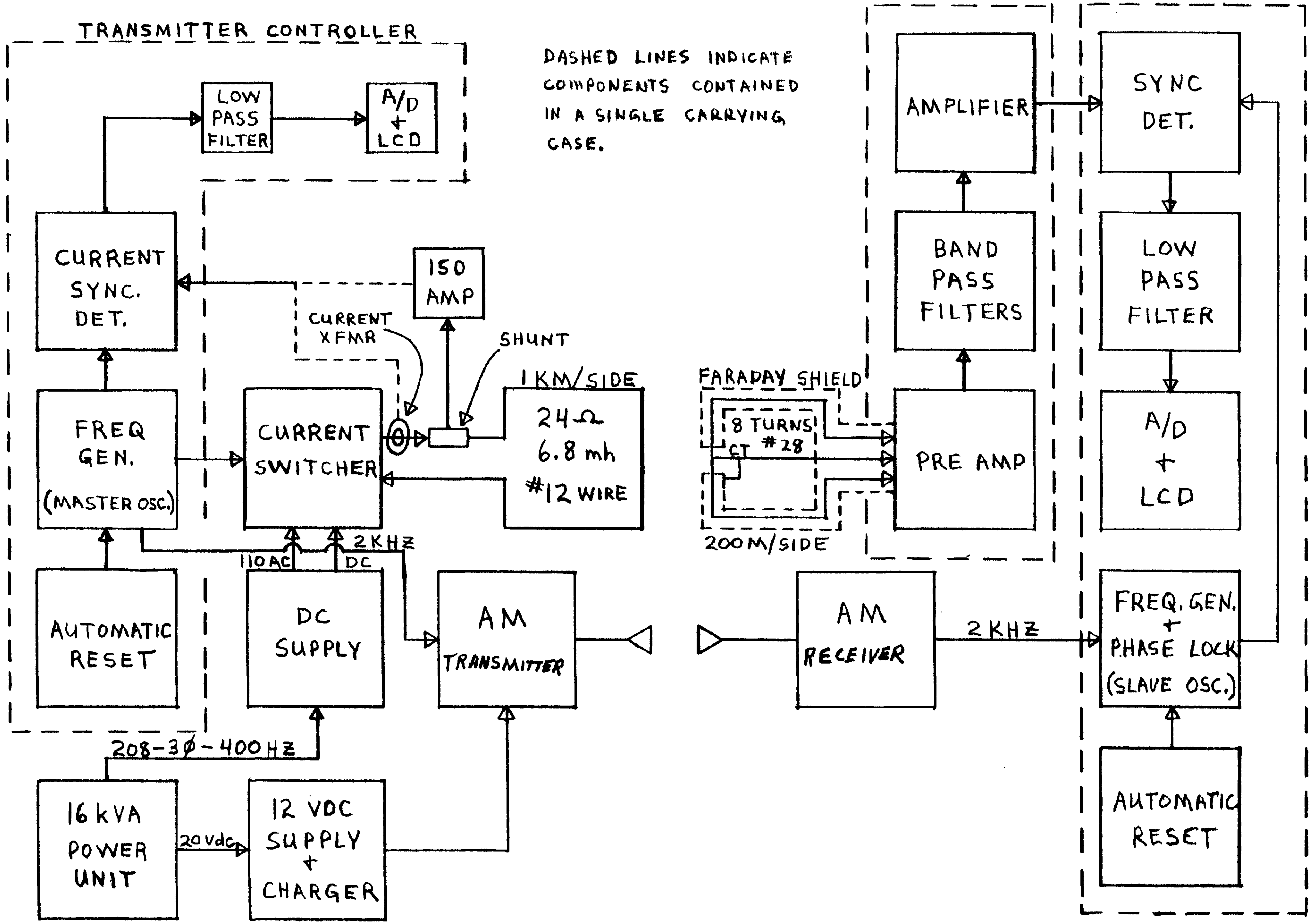
The frequency generator determines the frequency of the transmitted magnetic field whereas the DC power supply voltage determines the dipole moment. In order to measure a signal proportional to the amplitude and phase of the transmitted dipole field, either a current shunt and isolation amplifier or a current transformer is required. Both are required in this system because the isolation amplifier works well below 100 Hz and the transformer works well above 100 Hz and neither will cover the entire frequency range satisfactorily. The fundamental of the signal derived by either one of the two devices is synchronously detected, low-pass filtered, and the real and quadrature components of the signal are converted to digital form for display and manual recording. The frequency, dc voltage level, and low-pass filter time constant are switch selectable.

The frequency generator modulates the AM transmitter carrier signal with a 2-kHz signal to enable the slaving of the receiver oscillator to the transmitter oscillator. The AM-transmitted 2-kHz is demodulated at the receiver site and is used to phase lock a 2-kHz signal derived from the slave oscillator.

The signal induced in the receiver loop is amplified, band-pass filtered, amplified again, synchronously detected, low-pass filtered and then the real and quadrature components are converted from analog to digital form and liquid crystal displayed for manual recording. The preamplifier gain, bandpass frequency, amplifier gain, detection frequency, and the low pass filter time constant are switch selectable.

The main counter chains in the transmitter controller and receiver frequency generators are hard wire synchronized prior to data collection and the counters that generate the operating frequencies are automatically reset with each frequency change.

A system calibration procedure, given later in the report, determines the transfer functions of the conditioning and detection circuitry of the transmitter and receiver at each frequency. System calibration removes purely instrumental amplitude and phase variations, leaving only variations due to electrical structure in the survey area. Interpretation of the amplitude and phase measurements is done by curve matching or computer interpretation of the residual amplitude and phase curves.



SIGNATURES		BLDG.	RM.	PHONE	ELF SYSTEM BLOCK DIAGRAM FIGURE 1	U.S. GEOLOGICAL SURVEY
DESIGNED JC	DRAWN [signature]					DIVISION
SCALE	DATE 3-28-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

86608

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Transmitter

Transmitter Controller

The block diagram is shown in figures 2, 3 and 4 and a panel photograph is shown in figure 5. The frequency and multiplier switches determine the operating frequency. Eleven frequencies/decade are provided. Nine of these are unique, but the highest and lowest provide data overlap for repeatability checking between decades. The four phases of the selected operating frequency (f_0) required for the synchronous detectors and the single phase required by the current switcher are derived by binary and decade division from the 10 MHz oscillator as shown in figure 2.

The movement of any one or more of the frequency, multiplier, or operate/standby switches causes the reset of all digital circuits past the frequency and multiplier switches as shown in figure 3. One of twelve reset frequencies is selected automatically depending upon the frequency and multiplier switch positions. The reset frequency selected always contains a whole number of cycles of the selected operating frequency.

Because the reset frequency is derived from the main counter chains in the receiver and the transmitter controller, and because these counter chains are hard wire synchronized or reset prior to data collection, synchronism of the transmitter controller and the receiver is maintained at the operating frequency regardless of when the next frequency is selected at either site. The reset signal is delayed for two seconds to allow the operator time to complete switch movements. A light emitting diode (LED) indicated a reset operation is in progess.

The isolated shunt signal or the current transformer signal is buffered and inverted and fed into the square wave synchronous detector. Because the current signal is a square wave and is synchronously detected as such, a portion of the dc output of the signal of interest, is due to odd order harmonics. A tunable, multi-pole, low-pass filter can be used to remove the current signal harmonics, or an f_o sine wave can be generated and multiplied with the current signal. The first way requires considerable electronics and causes some error due to incidental attenuation of the fundamental frequency. The second way uses a multiplier which contributes dc offset errors to the output and causes additional errors due to distortion in the generated sine wave. The means herein employed to eliminate the harmonic response is to step-wise synchronously attenuate the detector outputs (see schematic on p. 41). This effectively multiplies the detector outputs by a unit amplitude, full-wave rectified sine wave or cosine wave. (Bench tests showed negligible error introduction).

Then the signals are low-pass filtered, buffered, and routed via the meter function switch to the digital panel meter (DPM) for analog-to-digital (A/D) conversion and display. A manually operated heater switch provides heat to the liquid crystal display during low temperature operation. A mode switch enables grounding the signal input for offset recording during data collection. A self calibration is obtained when the mode switch is in the calibrate position.

5-MHz and 1.65-MHz sine waves are derived from the 10-MHz oscillator in order to provide ultra stable intermediate frequency and carrier signals to the AM transceivers. This proved to be unnecessary because the transceivers used generate internal signals with adequate stability.

A connector for using external power is provided, along with an operate/standby switch to reduce battery drain when data is not being taken, although the oscillator main counter chains remain powered to maintain synchronism between the transmitter controller and the receiver.

Current Switcher and DC Supply

The block diagrams are shown in figure 6. The switches used are power transistors with maximum ratings of 600 volts (V), 20 amperes (A) continuous, 40 A peak and 350 watts. They are capable of switching up to 10 kilovolt-ampere (kVA) in this application. Switches 2 and 4 are closed when the input square wave is high. When the square wave goes to its low level switches 2 and 4 are opened and, after a short delay, switches 1 and 3 are closed, thus reversing the current flow in the loop.

The inductive switching transient (kick) of the loop is returned to the 210 microfarad (μF) snubbing capacitors via reversed biased diodes across each power transistor. The base-emitter junction of each power transistor is protected by a forward-biased diode in the emitter leg. Further protection is provided by voltage and current sense circuits which inhibit turn on of a pair of transistors whenever voltage or current conditions would allow a short circuit across the dc power supply. (See schematics on pages 44, 45, and 46.)

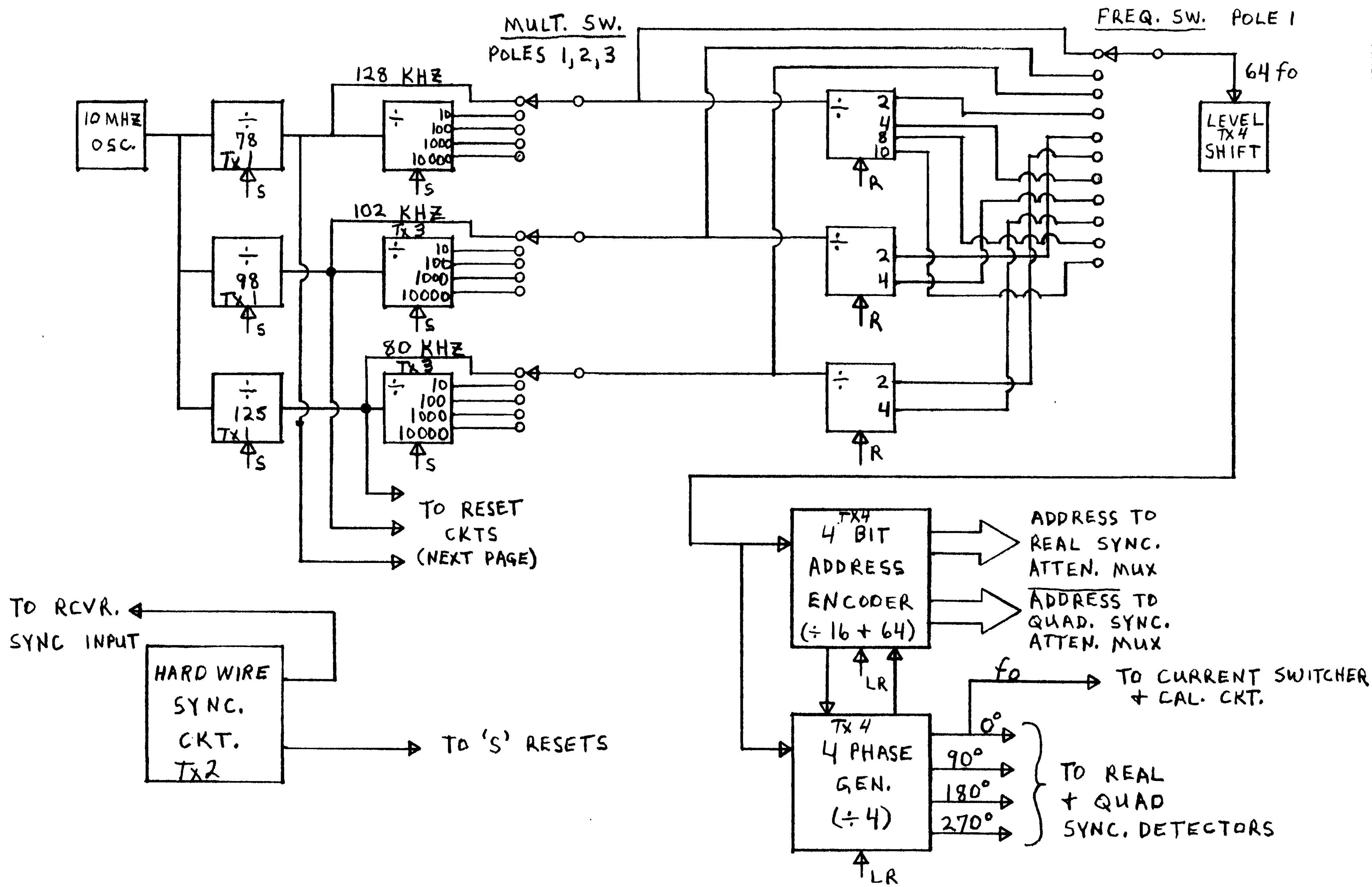
The drive circuits and sense circuits for each power transistor and the switching logic are powered by isolated ±5V dc supplies. The voltage-and current-sense signals, the drive signal and the input square wave are all optically isolated from the switching logic.

The tapped dc supply provides one of 5 dc levels to the current switcher. These levels, under no load conditions, are 507, 375, 247, 123 and 52 dc. The current switcher and dc supply are fan cooled.

Power Unit and Battery/charger

The block diagram and a photograph of the unit are shown in figures 7 and 8, respectively. The power unit is a skid mounted, 350 lb, 400 Hz, 3 phase, WYE connected, 208 volt generating system. The generator is an 8000 RPM aircraft generator driven by a 640 cubic cm, 58 HP snowmobile engine turning at 4900 RPM. The generator is driven by a toothed belt from the engine. Power output capacity is approximately 16 kVA. An automotive 70 A, 20 V dc alternator is incorporated into the unit for charging the instrumentation batteries and to supply power to the AM transmitter.

Several sets of diodes, connected in series with the anodes and cathodes tied to banana jacks, serve as current limiters for charging batteries. An ammeter, temporarily connected into the circuit with jumper cables, serves as a current monitor.



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JAB	DRAWN [signature]			
SCALE	DATE 3-28-80	ASSEMBLY DWNG. NO.		
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED				

TRANSMITTER CONTROLLER
FREQ. GEN. BLOCK DIA.
FIGURE 2

U.S. GEOLOGICAL SURVEY
DIVISION
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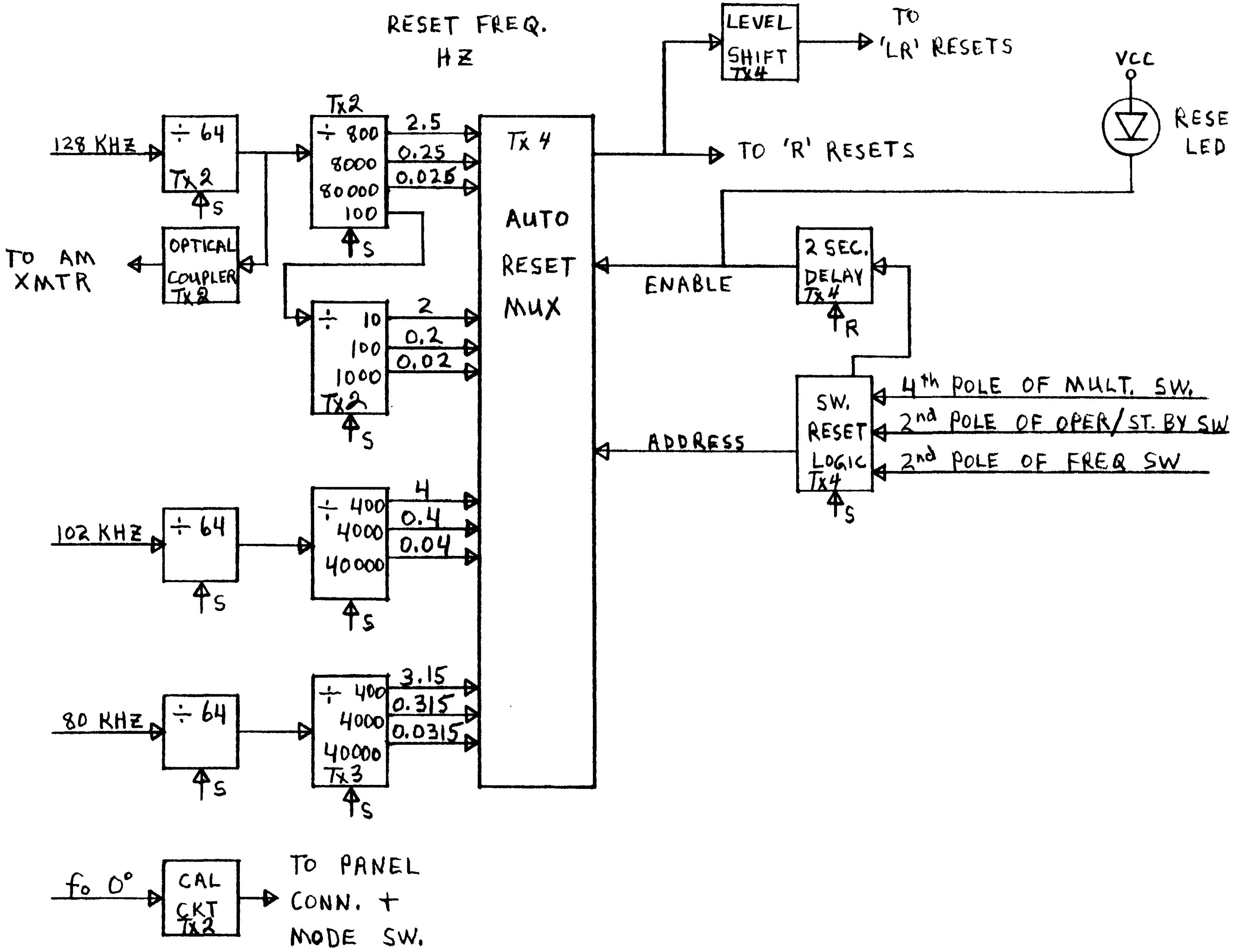

SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JAB	DRAWN [signature]			
SCALE	DATE 3-31-80	ASSEMBLY DWNG. NO.		

TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED

TRANSMITTER CONTROLLER
AUTOMATIC RESET BLOCK DIA.
FIGURE 3

U.S. GEOLOGICAL SURVEY
DIVISION
DWNG. NO.
SHEET OF

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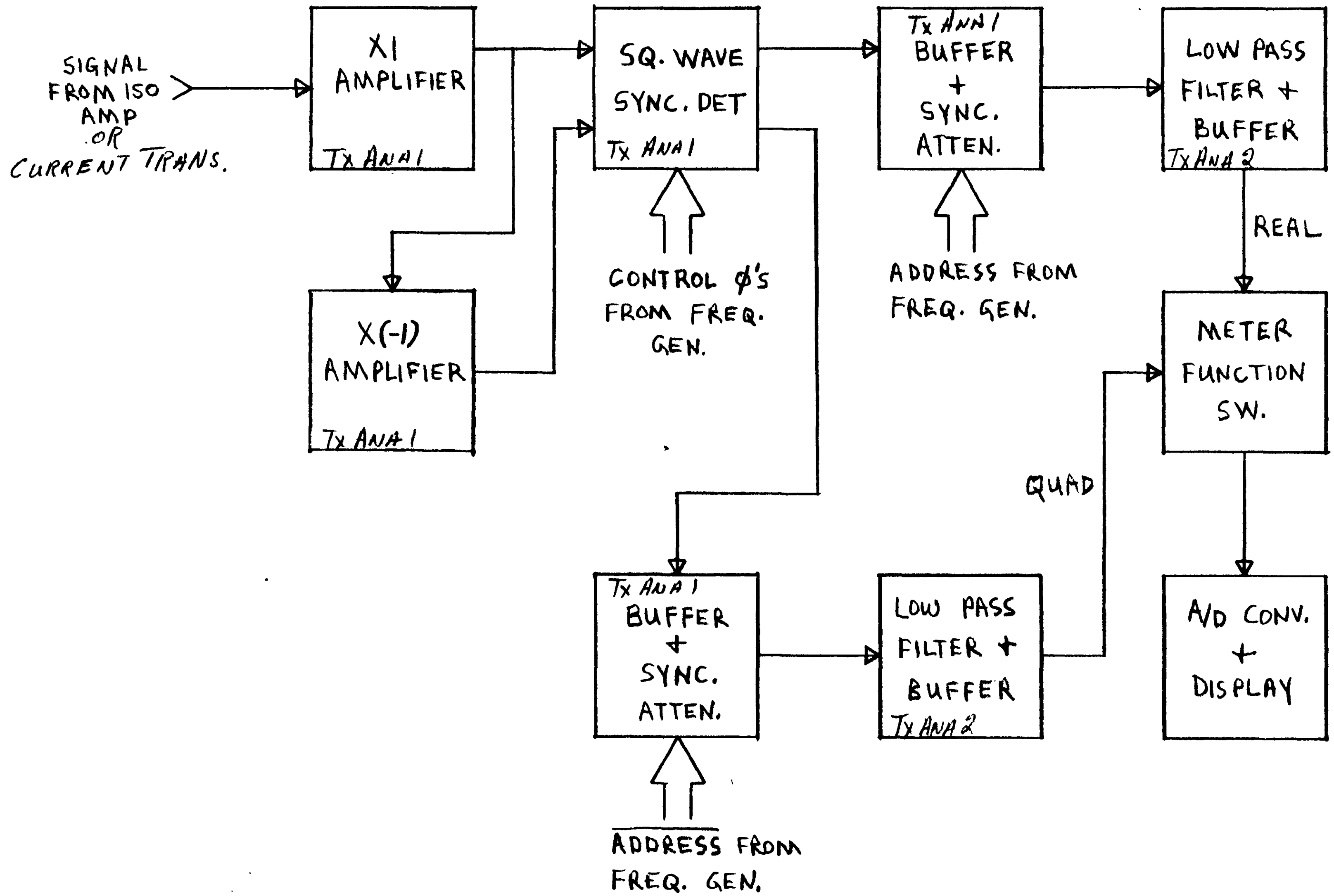

SIGNATURES		BLDG.	RM.	PHONE	TRANSMITTER CONTROLLER, SYNC. DET. LP FILTER + DISPLAY BLOCK DIA, FIGURE 4	U.S. GEOLOGICAL SURVEY
DESIGNED JC	DRAWN [signature]					DIVISION
SCALE	DATE 3-31-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ±2° UNLESS OTHERWISE SPECIFIED						SHEET OF

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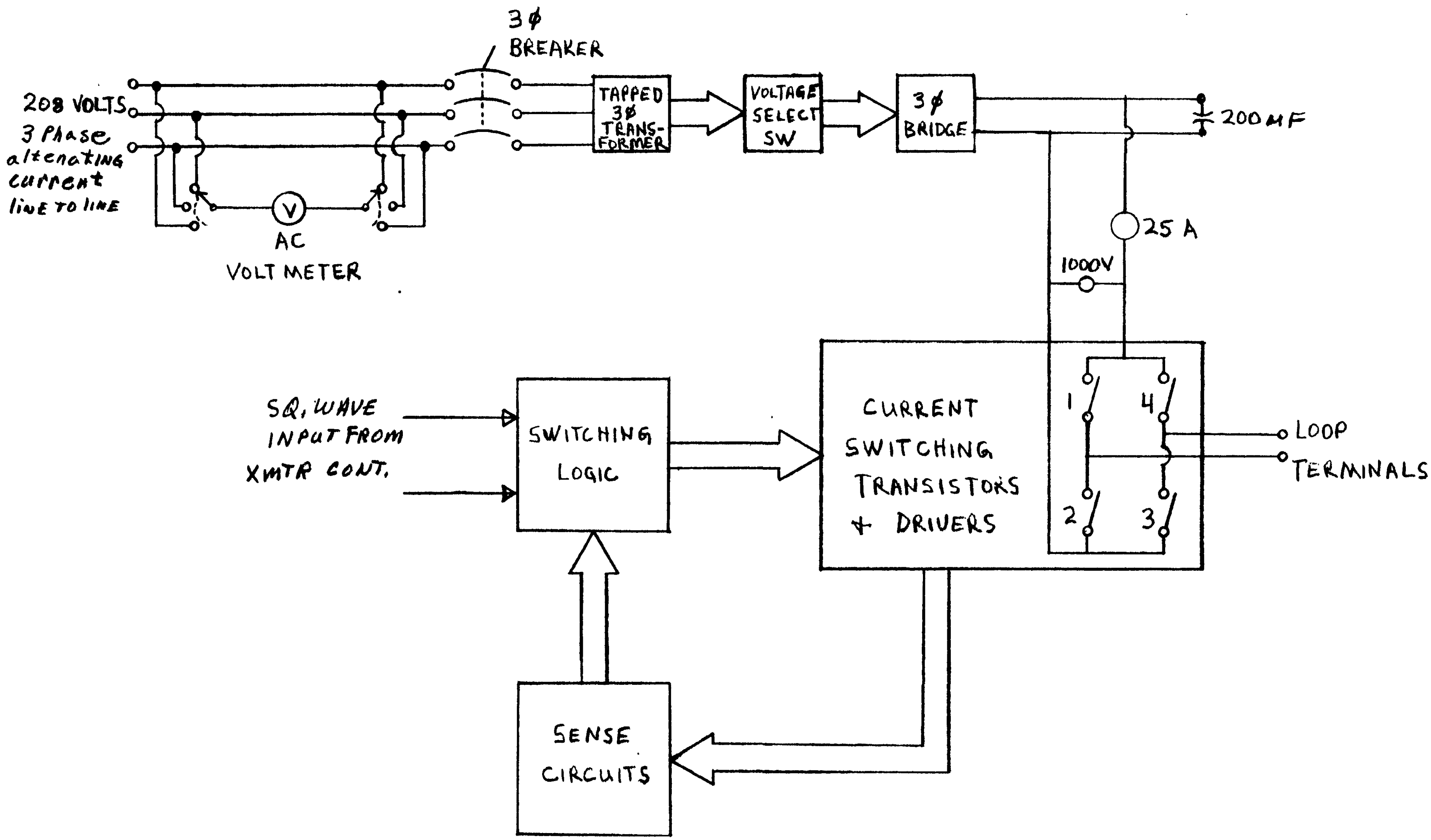
FIGURE 5
EXTERNAL POWER
CHG / OPERATE
OPERATE
STAND-BY
SYNC ENAB.
2 KHZ
PHASE CHECK
SHUNT IN
MEAS. TIME
RESET
GROUND
EXTERNAL
CAL
REAL
QUAD
METER EXPAND
HEATER
KHZ
HOLD
DISPLAY TEST
SYNC
FREQ



SIGNATURES		BLDG.	RM.	PHONE	DC POWER SUPPLY AND CURRENT SWITCHER FIGURE 6	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED R. L.	DRAWN Kevin P. Kreutzer					
SCALE	DATE 3-31-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

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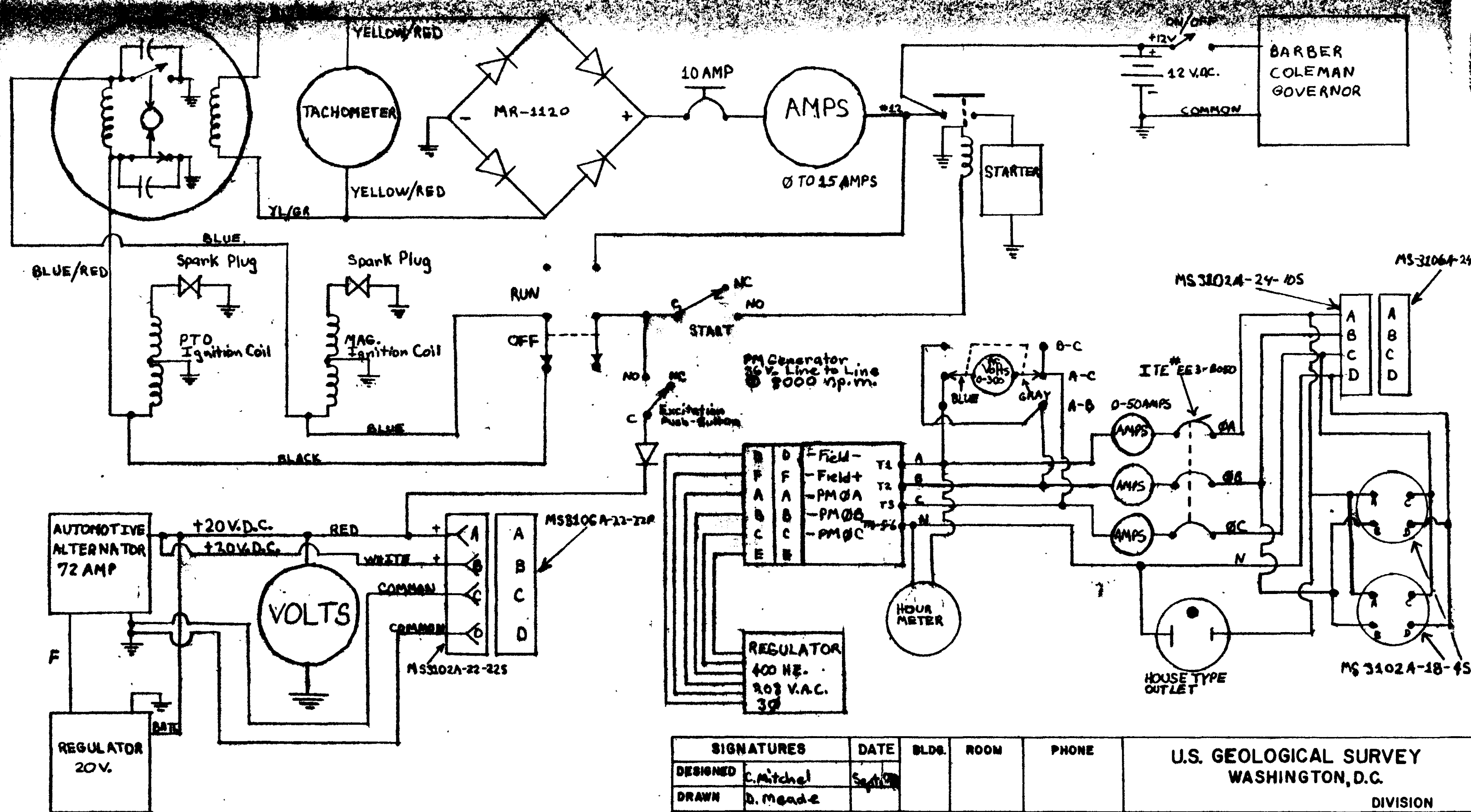

SIGNATURES		DATE	BLDG.	ROOM	PHONE
DESIGNED	C. Mitchel	Sept.			
DRAWN	D. Meade				
APPROVED	R. Lescelius				

U.S. GEOLOGICAL SURVEY
WASHINGTON, D.C.

DIVISION

TOLERANCES
UNLESS OTHERWISE SPECIFIED
DECIMAL DIMENSIONS = ±.005
FRACTIONAL DIMENSIONS = ±1/64
ANGLE DIMENSIONS = ± 2°

16 KVA POWER UNIT
(Snowmobile engine)

FIGURE 7 PAGE 18

SCALE: | ASSEMBLY DRAWING NO. | DRAWING NO.

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FIGURE 8

Receiver

The receiver consists of two separate boxes, one containing the signal conditioning amplifiers and filters and the other containing the frequency generator, synchronous detector, and display.

Preamplifier, Filter, and Amplifier

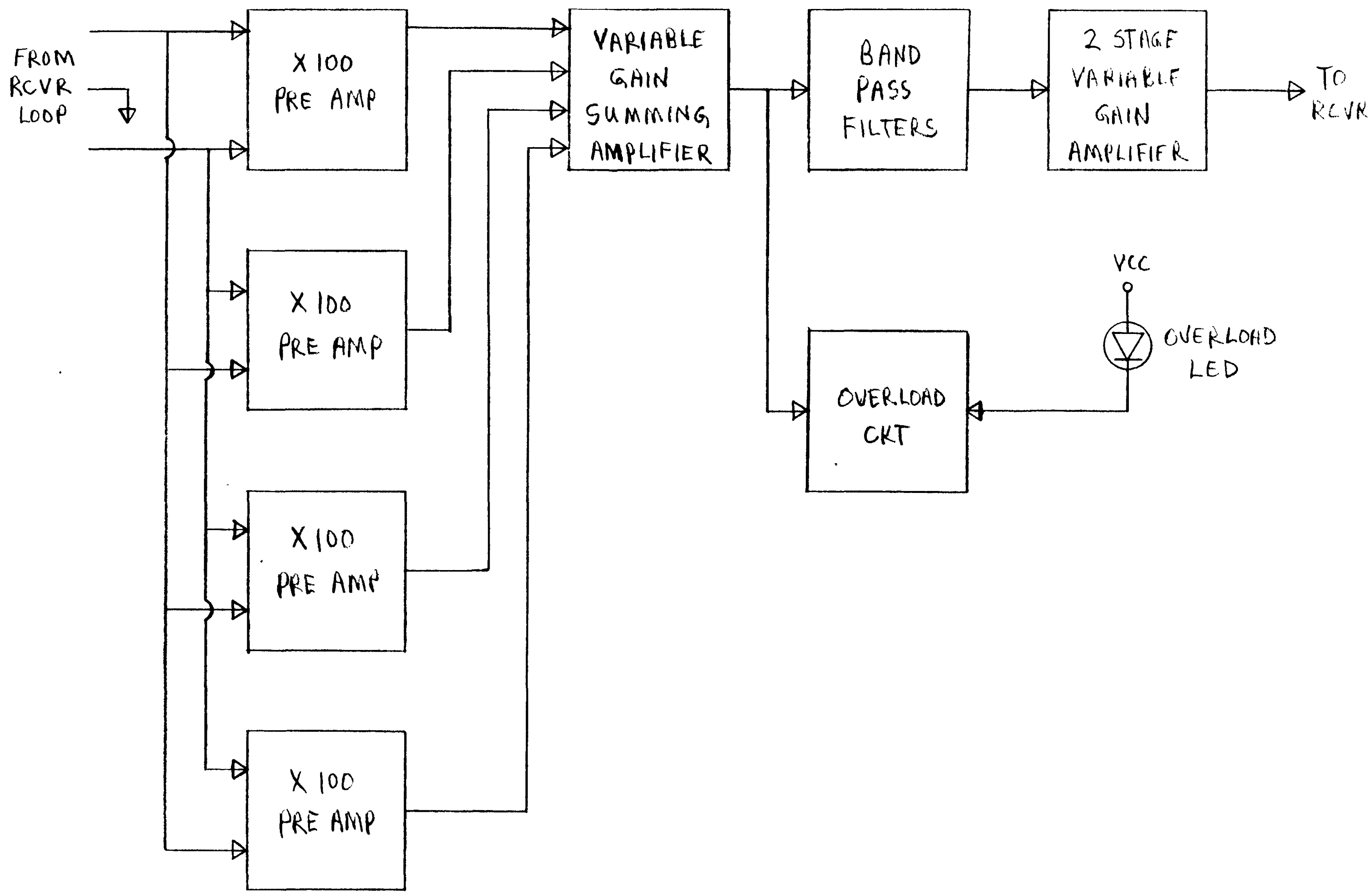
The block diagram and panel photograph are shown in figures 9 and 10. The signal from the receiver loop is amplified by four parallel, X100, low-noise, instrumentation amplifiers. The outputs are summed, giving a total signal gain of 400 and an instrument noise gain of 200 (due to the non-coherent nature of the noise) resulting in a 6 db signal to noise (S/N) increase. The signal is then further amplified according to the preamplifier gain switch setting and then band limited by a four-pole, variable-frequency, Butterworth bandpass filter. A signal overload circuit located at the input to the filter activates a panel mounted LED when the broadband signal amplitude is in the limit region.

The signal is further amplified in two variable-gain stages according to the amplifier gain switch setting. Multi-turn potentiometers and test points are provided on the front panel for offset adjustment. All of the above electronics are contained in a single carrying case. Panel test points are provided for battery and regulated voltages and a plug is provided for operation on external power.

Synchronous detection, display, and frequency generation

The block diagrams and panel photograph are shown in figures 11, 12, 13 and 14, respectively. The amplified and filtered signal is fed into the receiver via a coaxial cable for a final X10 amplification and square wave synchronous detection. Signal clipping activates a front panel LED. Then the signal is filtered by a two-pole low-pass filter with a switch-selectable time constant, amplified by X1 or X10 and routed to the digital panel meter via the meter function switch for A/D conversion and liquid crystal display.

The 10-MHz oscillator is phase-locked to the transmitter via the AM radio link. This is accomplished by passing the demodulated 2-kHz signal through a bandpass filter, shaping the output and then comparing its phase to a 2-kHz signal derived from the 10-MHz oscillator. The dc error signal from the phase comparator is amplified and used to electronically tune the 10-MHz oscillator until phase-lock is achieved. An "unlock" condition is indicated by an LED on the front panel. The frequency generation circuits are similar to those in the transmitter controller.



SIGNATURES		BLDG.	RM.	PHONE	RECEIVER	U.S. GEOLOGICAL SURVEY
DESIGNED JC	DRAWN Kim P. Kerfoot				PRE AMP, FILTER, AMPLIFIER, BLK. DIA,	DIVISION
SCALE	DATE 4-7-80	ASSEMBLY DWNG. NO.			FIGURE 9 PAGE 22	DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

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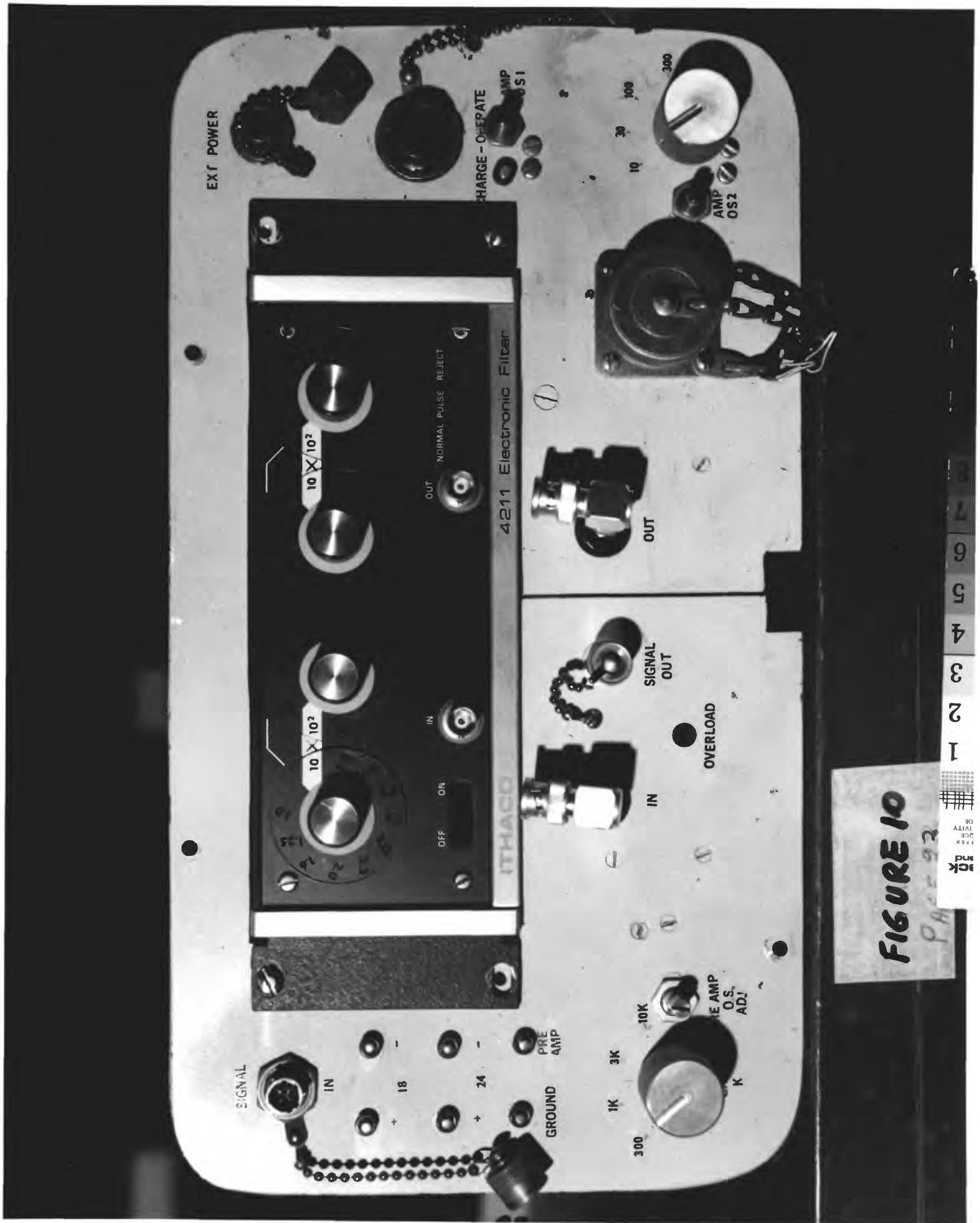
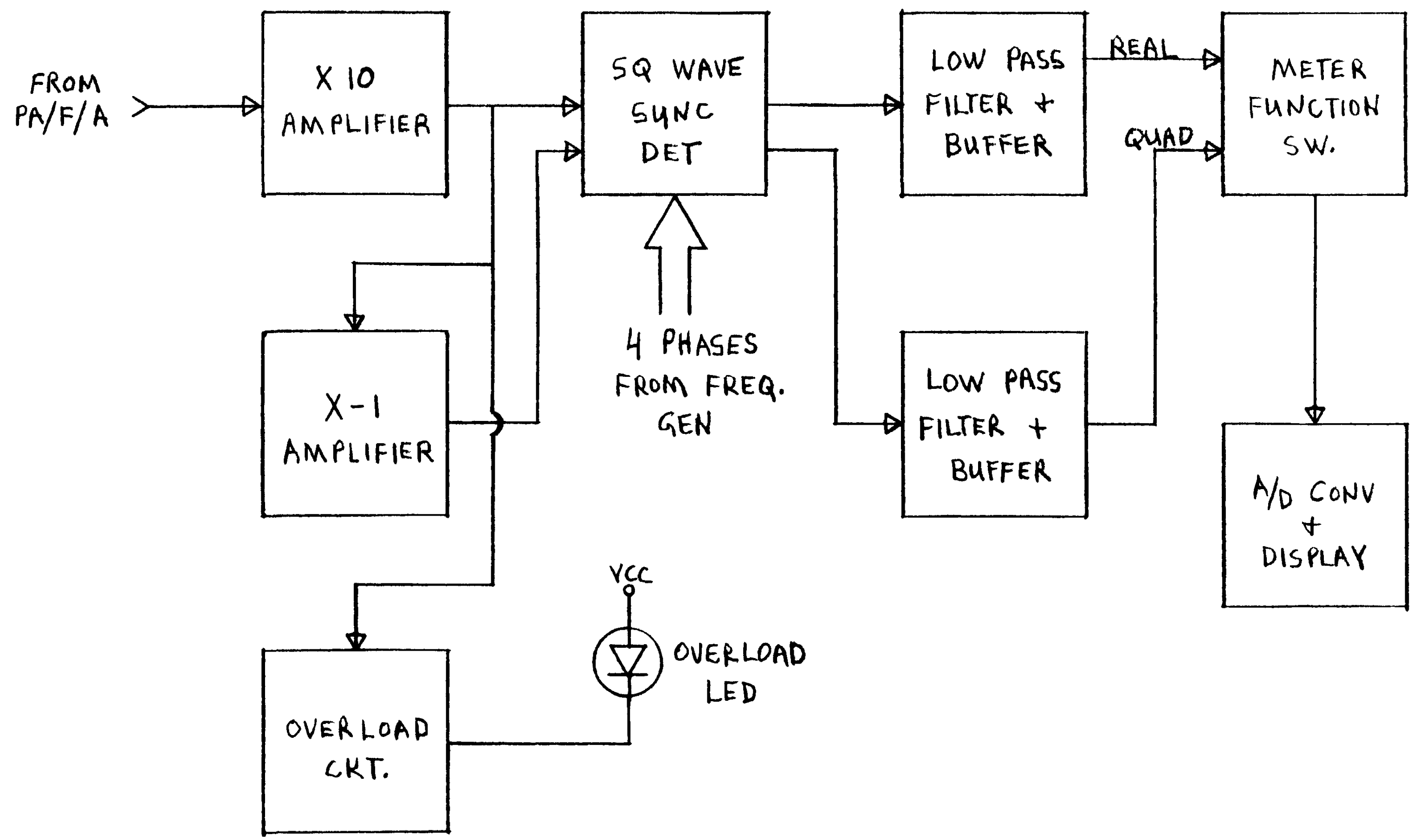

EXT POWER
CHARGE - OPERATE
AMP OS1
10
30
100
300
AMP OS2
4211 Electronic Filter
ITHACO
NORMAL PULSE REJECT
OUT
IN
OFF
ON
OUT
SIGNAL OUT
OVERLOAD
IN
SIGNAL
IN
18
24
PRE AMP
GROUND
300
1K
3K
10K
O.S. ADJ
FIGURE 10



SIGNATURES		BLDG.	RM.	PHONE	RECEIVER, SYNC, DET., LP FILTER + DISPLAY BLK. DIA. FIGURE 11 PAGE 24	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED JC	DRAWN Kevin P. Kreutzer					
SCALE	DATE 4-1-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						SHEET OF

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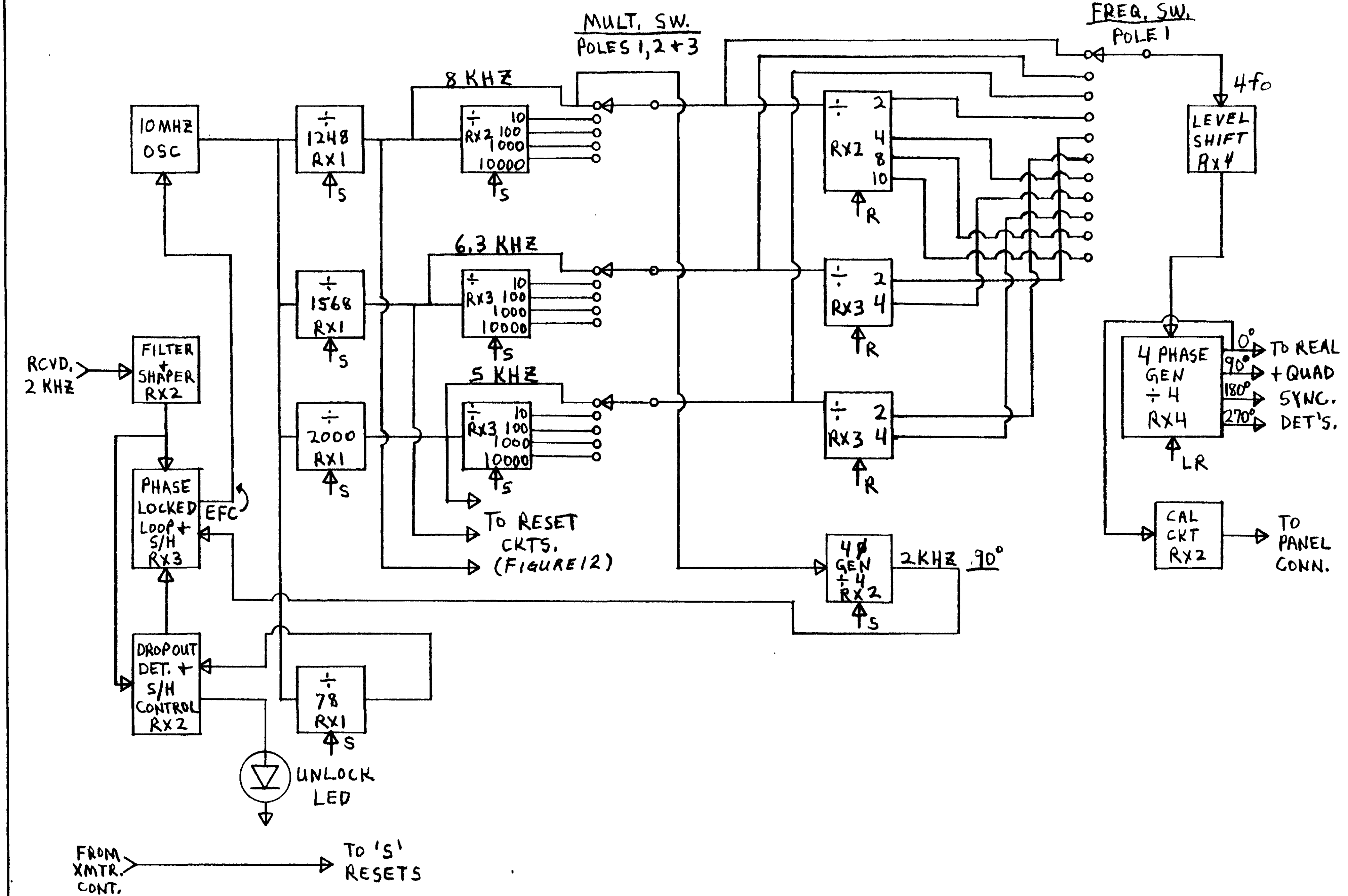

SIGNATURES		BLDG.	RM.	PHONE	RECEIVER FREQ. GEN. + PHASE LOCK FIGURE 12 PAGE 25	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED JAB	DRAWN [signature]					
SCALE	DATE 3-31-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

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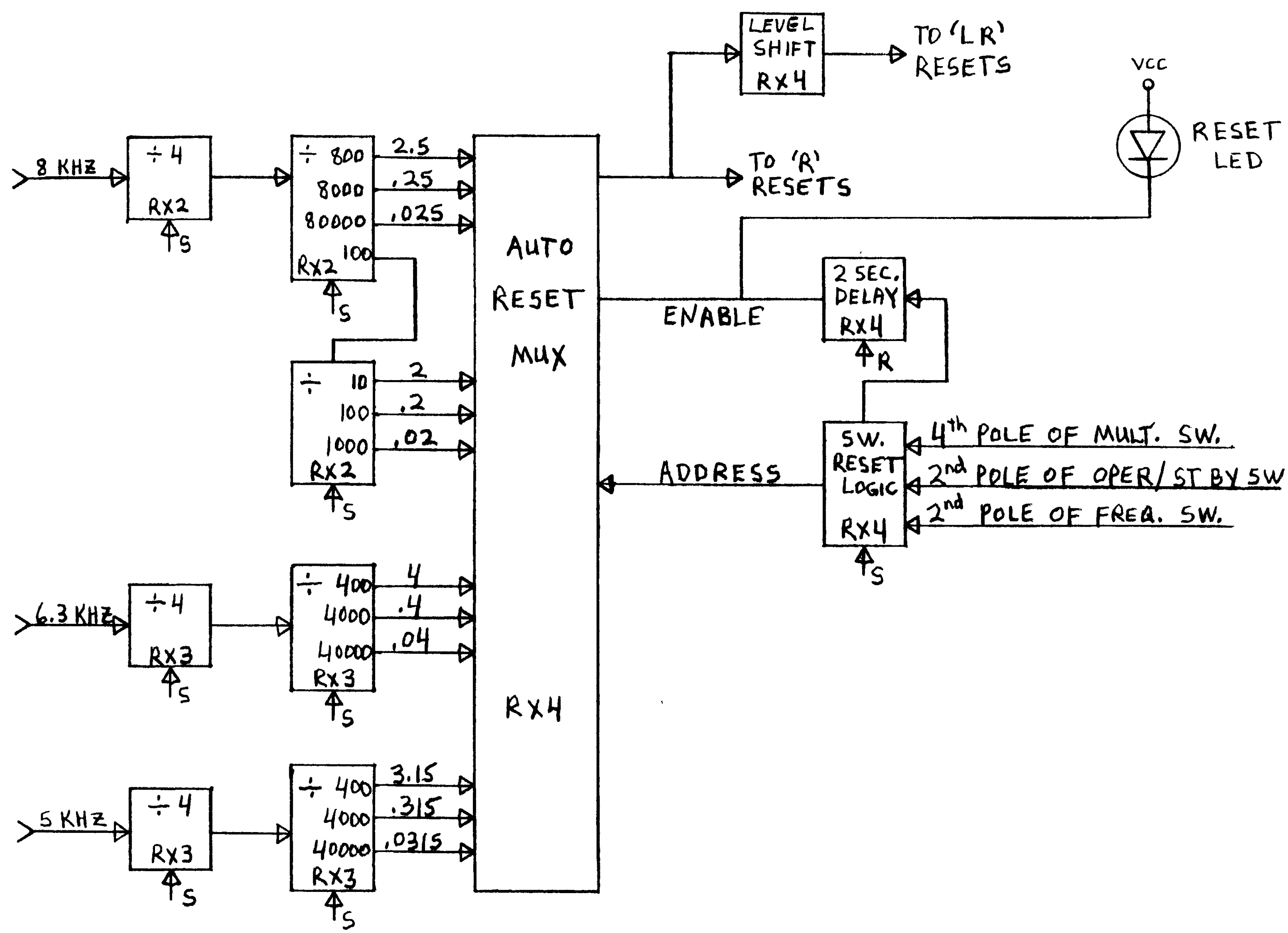

SIGNATURES		BLDG.	RM.	PHONE	RECEIVER AUTOMATIC RESET BLK. DIA. FIGURE 13 PAGE 26	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED JAB	DRAWN [signature]					
SCALE	DATE 4-1-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

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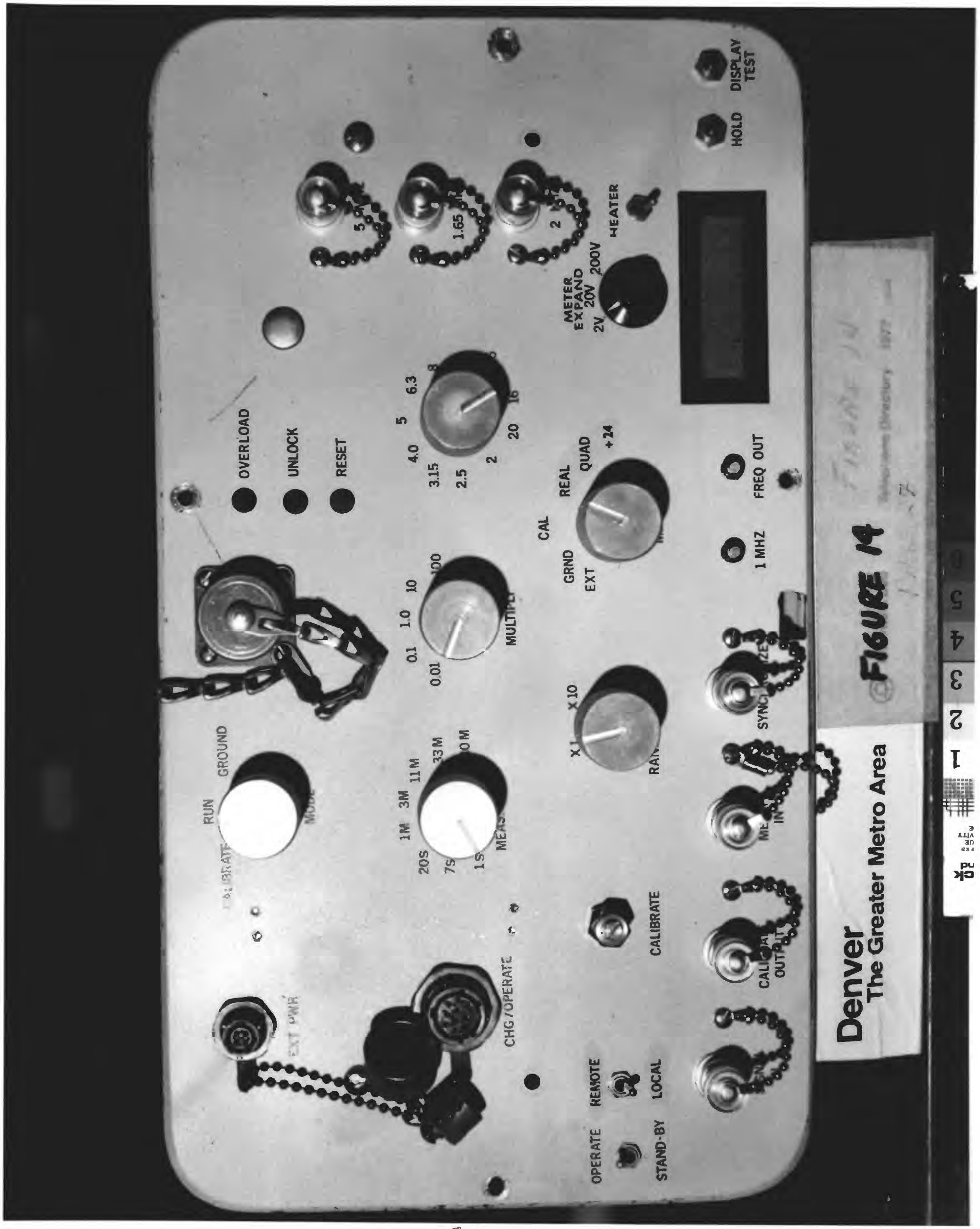


FIGURE 14
Denver
The Greater Metro Area
OVERLOAD
UNLOCK
RESET
METER
EXPAND
2V
20V
200V
HEATER
HOLD
DISPLAY
TEST
CAL
REAL
QUAD
GRND
EXT
+24
1 MHZ
FREQ OUT
RUN
GROUND
CALIBRATE
CHG/OPERATE
OPERATE
STAND-BY
REMOTE
LOCAL

System Calibration

The calibration setup is shown in figure 15. This method, suggested by Raymond Watts of the USGS, allows the use of transmitter current levels and receiver gains near those used during data collection because most of the generated flux lies inside the receiver loop. The equation for the voltage, V, induced in the receiver loop is shown below.

$$V = \frac{n\pi\sqrt{\pi\mu_o IAf}}{D}$$

where I = current in transmitter loop in amperes

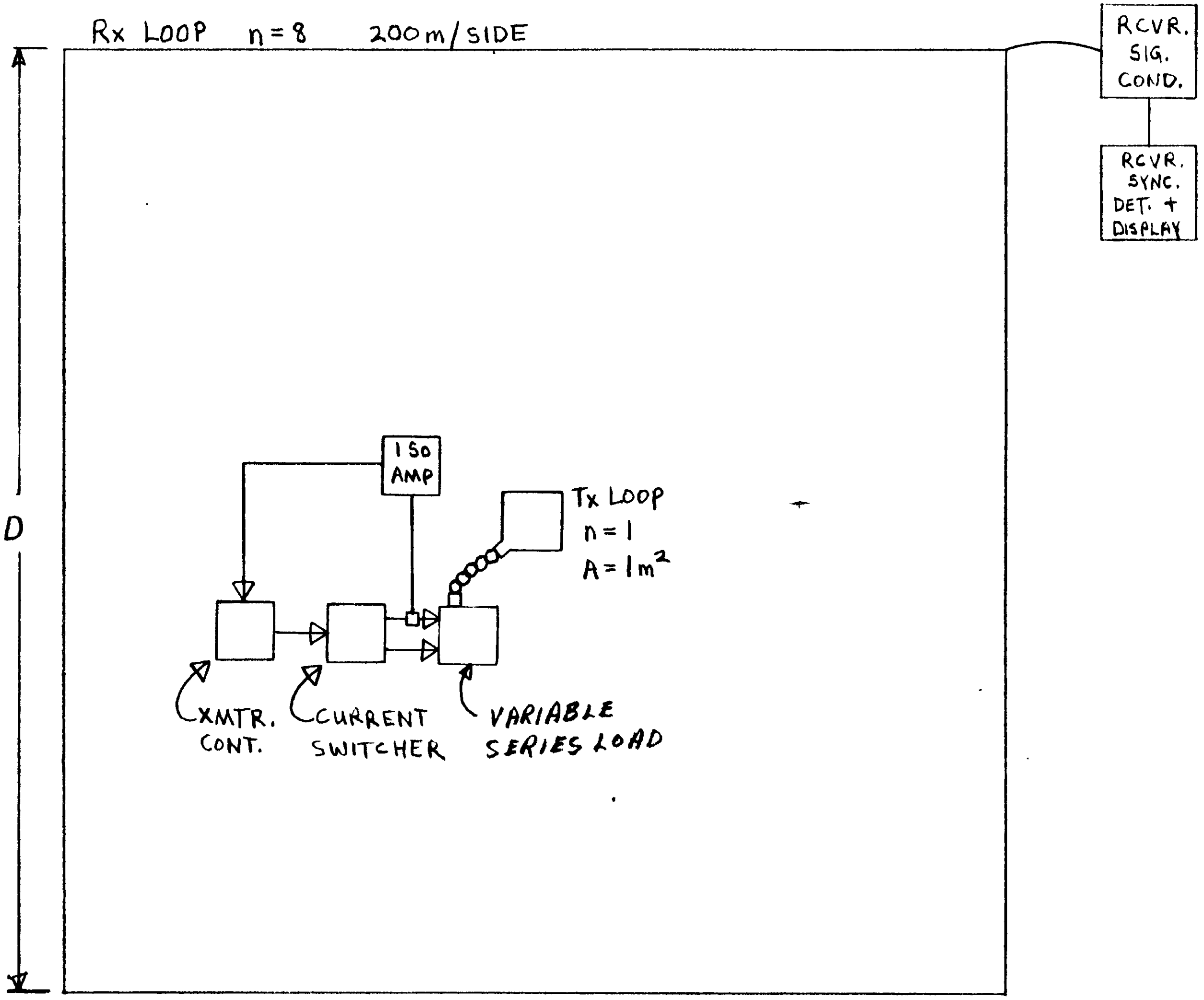
A = area of transmitter loop in meters (single turn)

f = frequency

D = dimension of receiver loop in meters

n = number of turns in receiver loop

μ_o = magnetic permeability of free space



SIGNATURES		BLDG.	RM.	PHONE	SYSTEM CALIBRATION	U.S. GEOLOGICAL SURVEY
DESIGNED	DRAWN					DIVISION
SCALE	DATE 4-3-80	ASSEMBLY DWNG. NO.			FIGURE 15 PAGE 29	
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						DWNG. NO.

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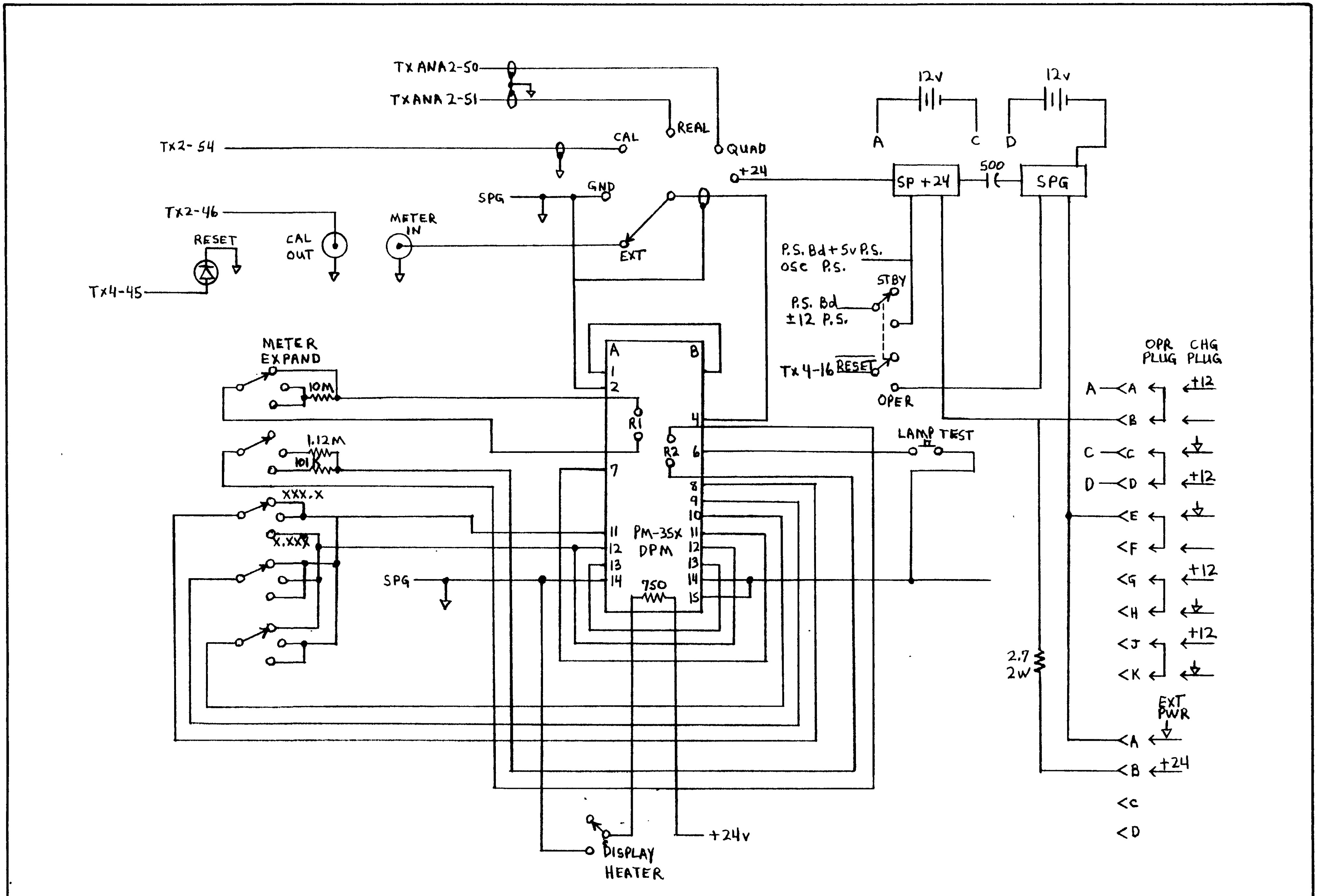
Commercial Subassemblies

Item	Manufacturer and Part No.	Usage
AM Transceiver	Stoner Comm. SSB-40MA	Phase Link
Alternator 25 KVA	Bendix Corp. 28 B135-5C	Power Unit
Band Pass Filter	ITHACO 4211	Receiver
Batteries	Eagle-Picher CF6V8 + CF6V2.6	Transmitter and Receiver
Carrying Cases	Zero Manuf. 116-X	Transmitter and Receiver
Carrying Cases	TA Manufact. Corp. KBP10-05-10 AC NBP39-05-08 AC	Current Switcher and dc Supply
Current XFMR	Pearson Electronics 110A	Transmitter and Receiver
DC-DC Converters	Semiconductor Devices LD24-5S600 (5V), DTD24-120-165(±12V)	Transmitter Controller Receiver
Digital Panel Meter	Textron PM-35X	Transmitter Controller Receiver
Engine	Bombardier (snowmobile) Type 640E	Power Unit
Generator	Motorola 72 AMP (Automotive Type)	Power Unit
Governor	Barber Coleman Controller P/N DYN1-10006-12 Actuator P/N DYNC-11000-12	Power Unit
Isolation Amplifier	Burr-Brown 3650 KG	Transmitter
Muffin Fans	Optional 120V, 400 Hz	Current Switcher and dc Supply

Commercial Subassemblies (Cont)

Oscillator, 10 MHz	Hewlett-Packard 10544A	Transmitter Controller Receiver
Power Supplies, 5 VDC	Optional 120V, 400 Hz	Current Switcher & dc Supply
Voltage Regulator, DC	Motorola 12V automotive	Power Unit
Wire Reels	Precision Specialities 321-BP	Transmitter Receiver Loops



SIGNATURES		BLDG.	RM.	PHONE	Tx FRONT PANEL	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED	DRAWN					
SCALE	DATE 4-1-80	ASSEMBLY DWNG. NO.				
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						DWNG. NO.

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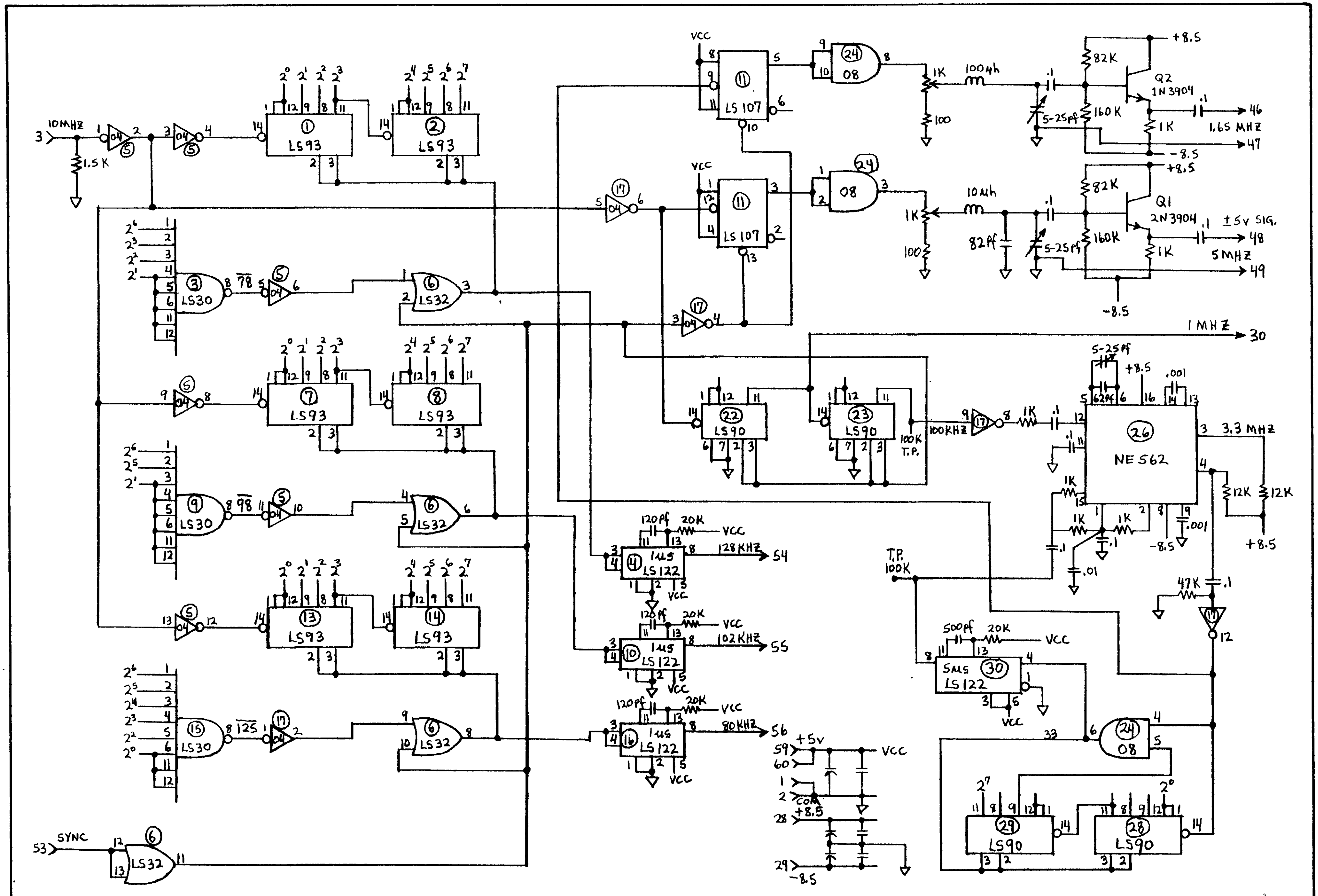

SIGNATURES		BLDG.	RM.	PHONE	Tx 1 MAIN COUNTER CHAIN	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED JAB	DRAWN Kevin P. Krautzer					
SCALE	DATE 4-3-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

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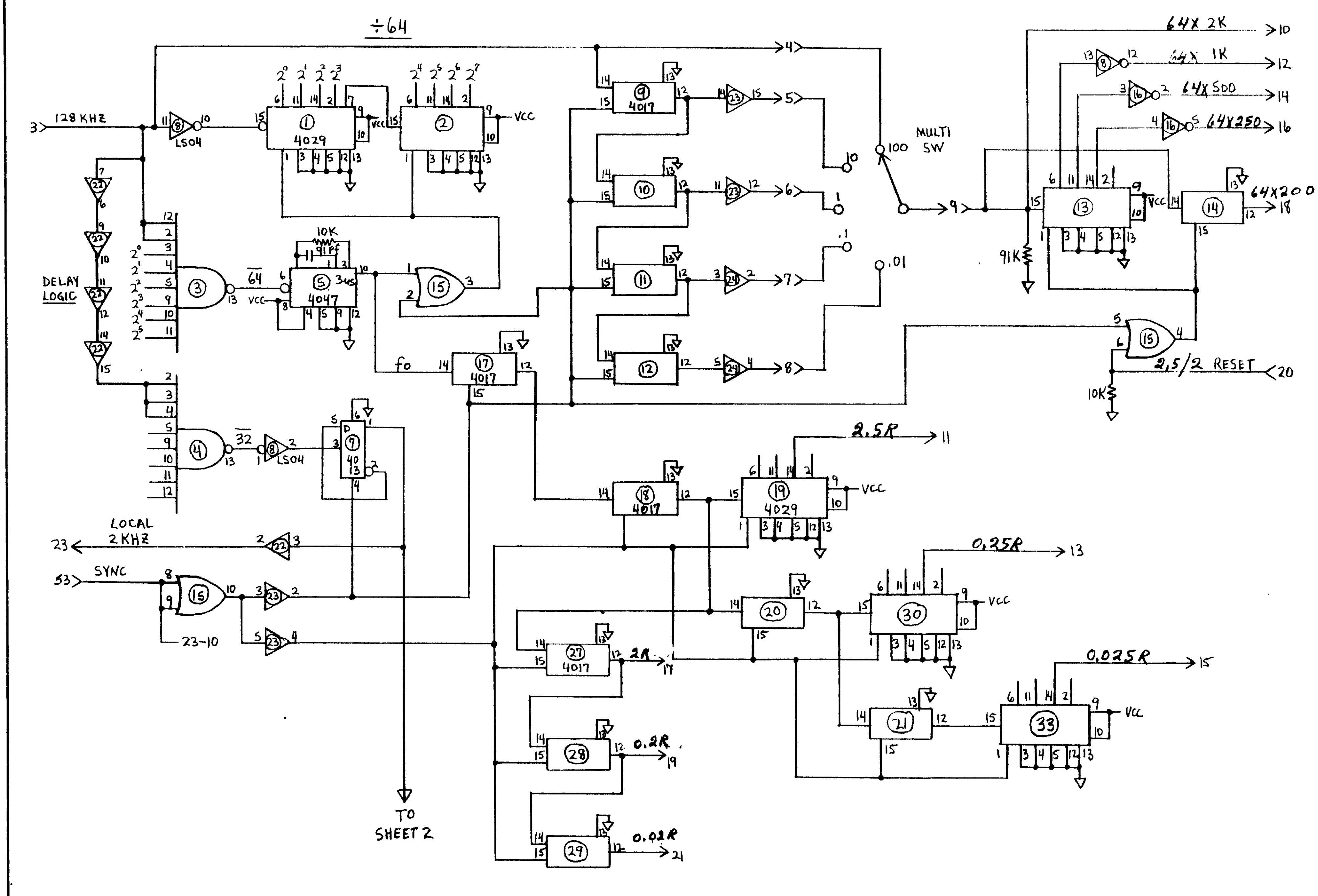

SIGNATURES		BLDG.	RM.	PHONE	Tx 2 / 64fo 2K COUNTER AND 2.5/2R RESET CKT / PAGE 34 / 1 OF 2
DESIGNED JAB	DRAWN Kevin P. Kaufman				U.S. GEOLOGICAL SURVEY
SCALE	DATE 4-4-80	ASSEMBLY DWNG. NO.			DIVISION
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED					DWNG. NO.

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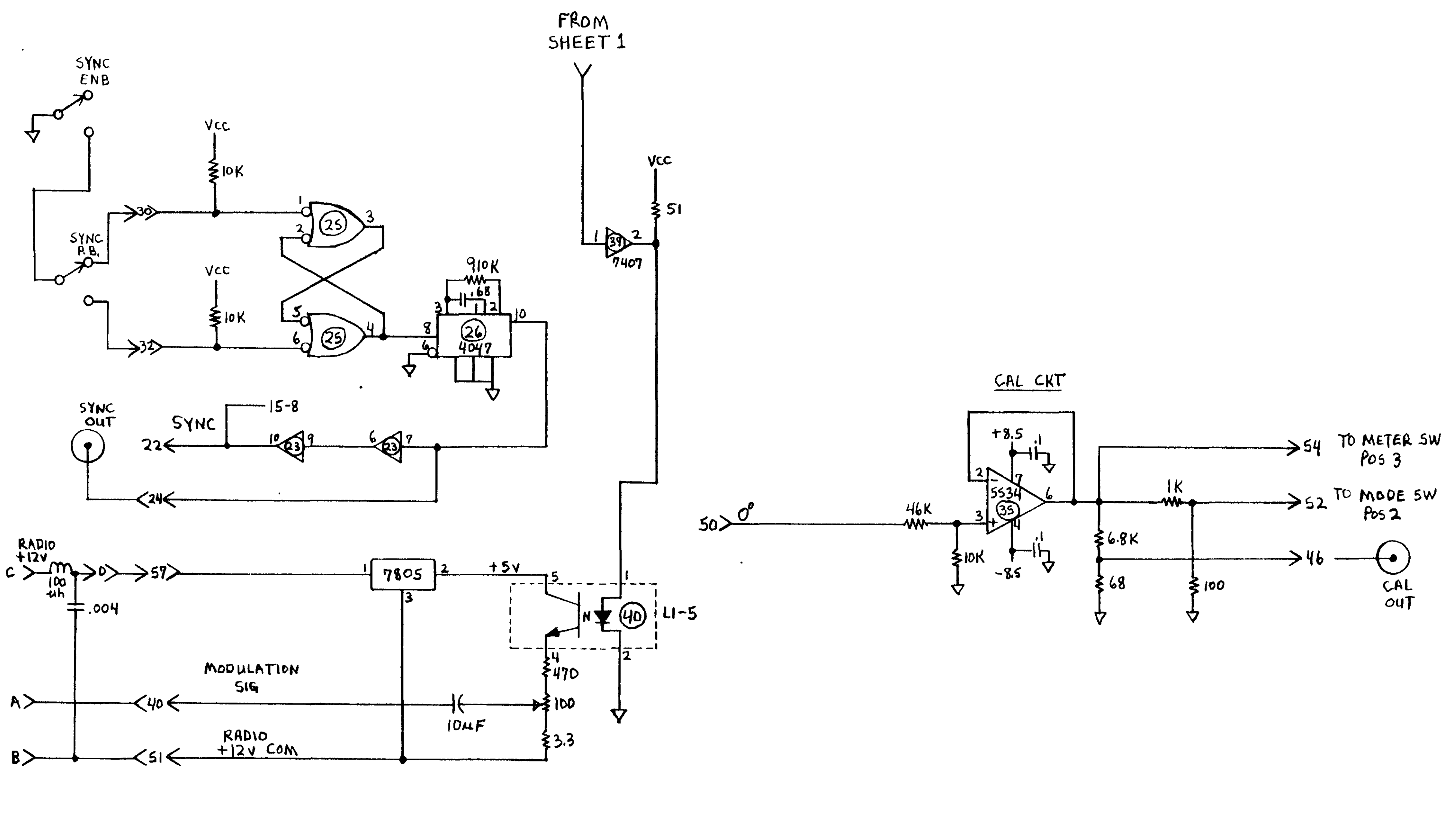

SIGNATURES		BLDG.	RM.	PHONE	Tx 2 SYNC. CKT, AM RADIO OPTICAL COUPLER AND CAL. CKT.	U.S. GEOLOGICAL SURVEY
DESIGNED JAB	DRAWN Kevin P. Kreutzer					DIVISION
SCALE	DATE 4-4-80	ASSEMBLY DWNG. NO.			2 OF 2	DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

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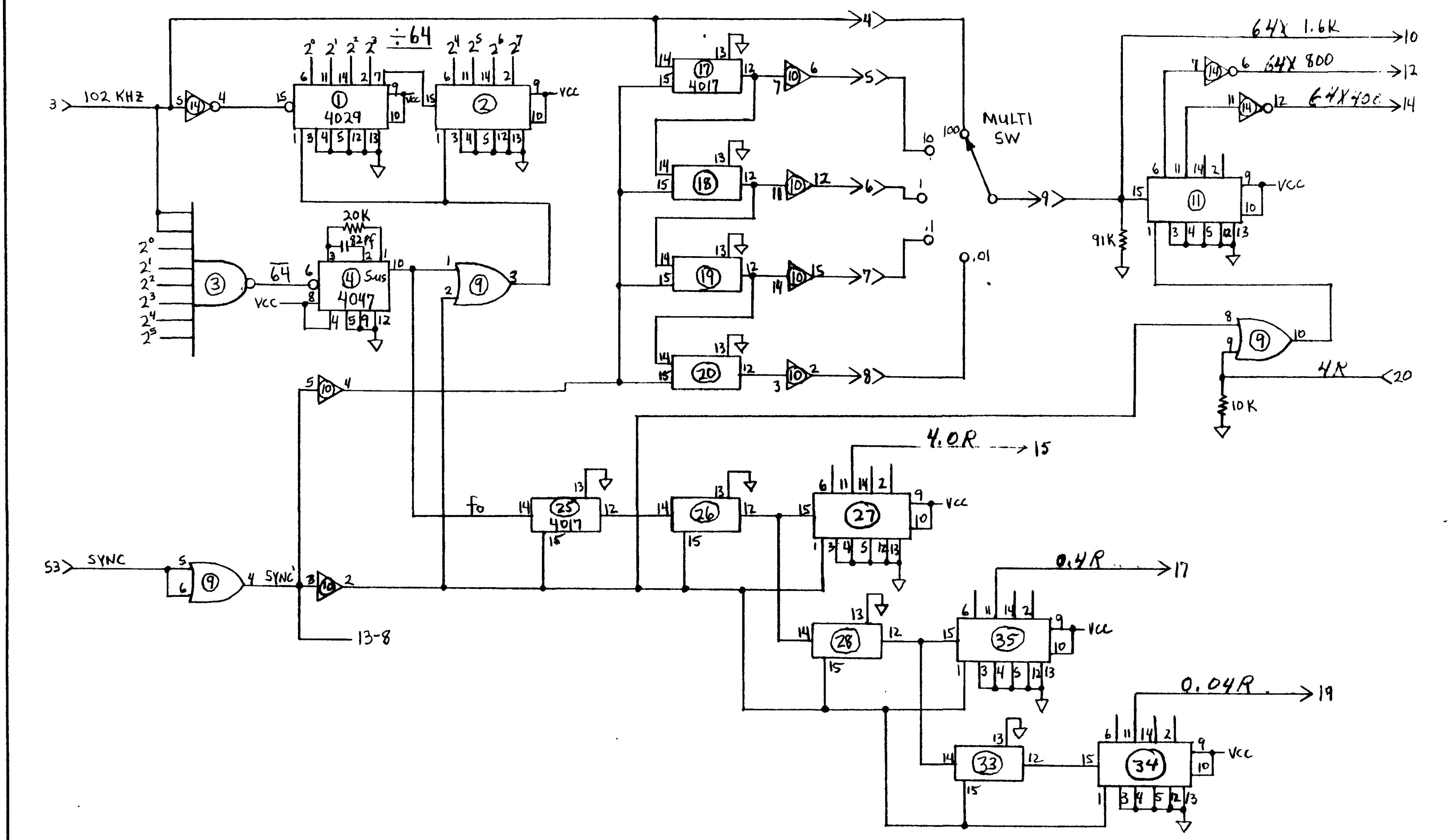
SHEET OF

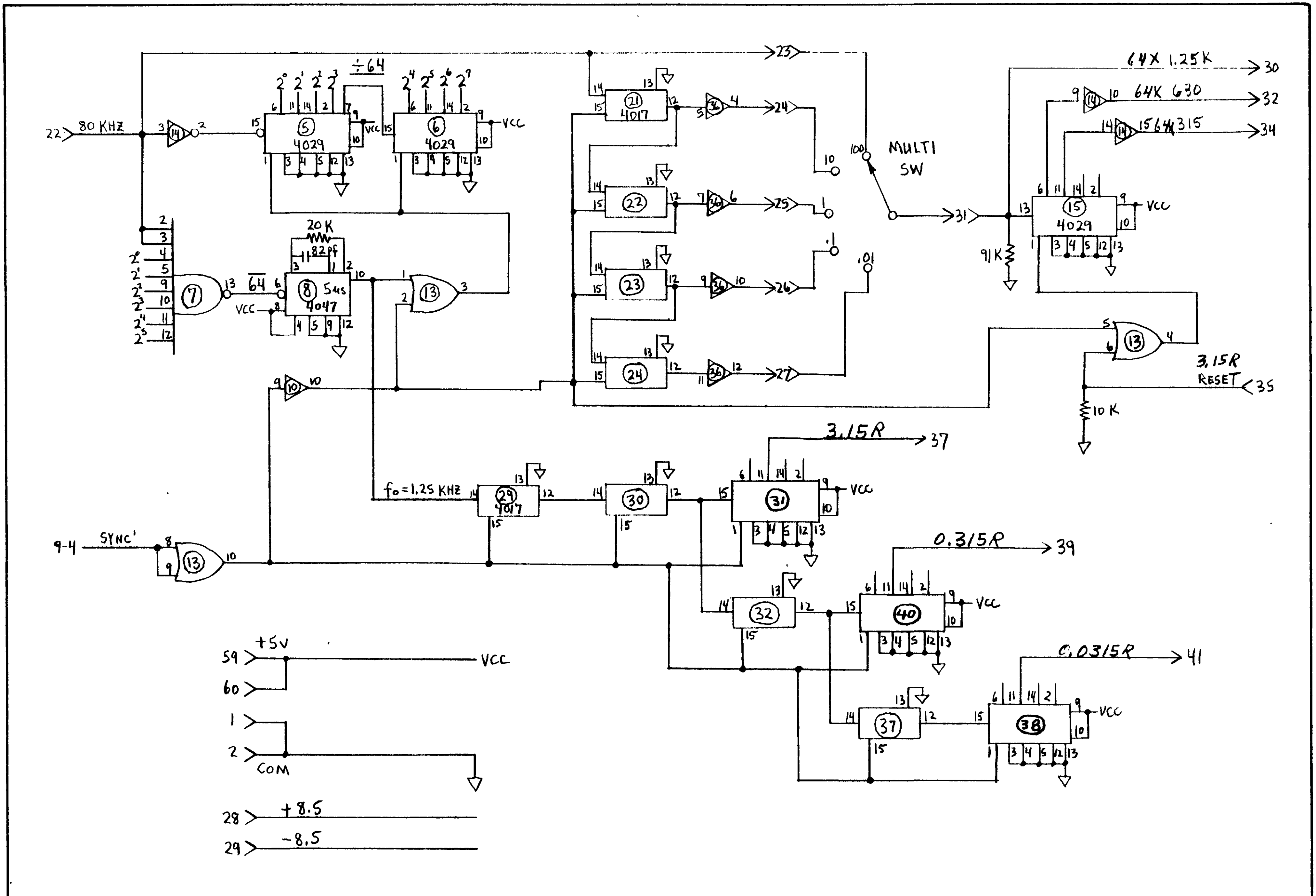


SIGNATURES		BLDG.	RM.	PHONE	Tx 3 (1 of 2) 64f0 1.6K COUNTER AND 4R RESET CKT	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED JAB	DRAWN Kevin P. Kreutzer					
SCALE	DATE 4-7-80	ASSEMBLY DWNG. NO.				DWNG. NO.

TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED

86608

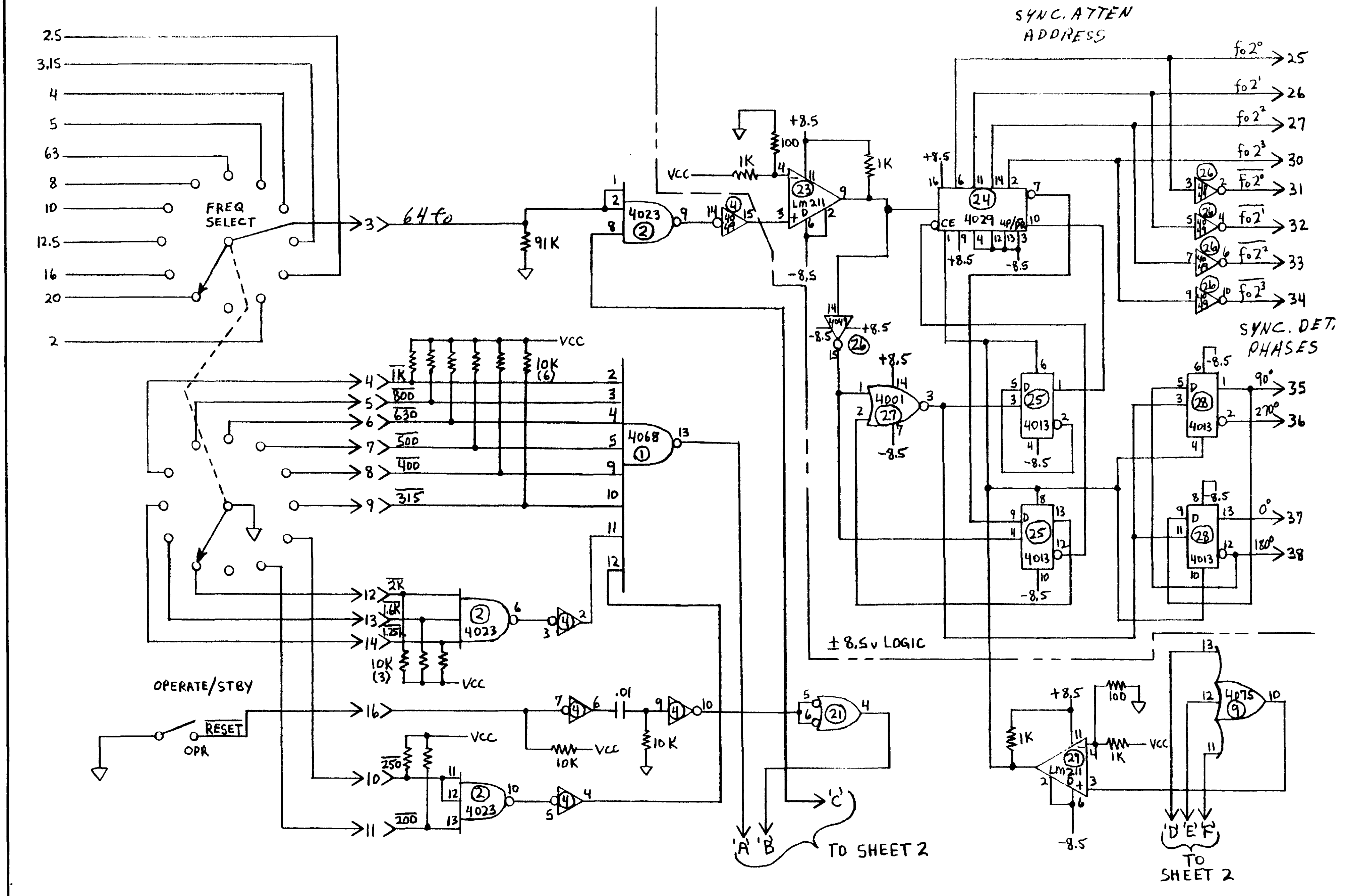
SHEET OF



SIGNATURES		BLDG.	RM.	PHONE	Tx 3 (2 of 2)	U.S. GEOLOGICAL SURVEY
DESIGNED JAB	DRAWN Kenneth Kreiger				64fo 1.25K COUNTER	DIVISION
SCALE	DATE 4-8-80	ASSEMBLY DWNG. NO.			AND 315R RESET CKT	
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						DWNG. NO.

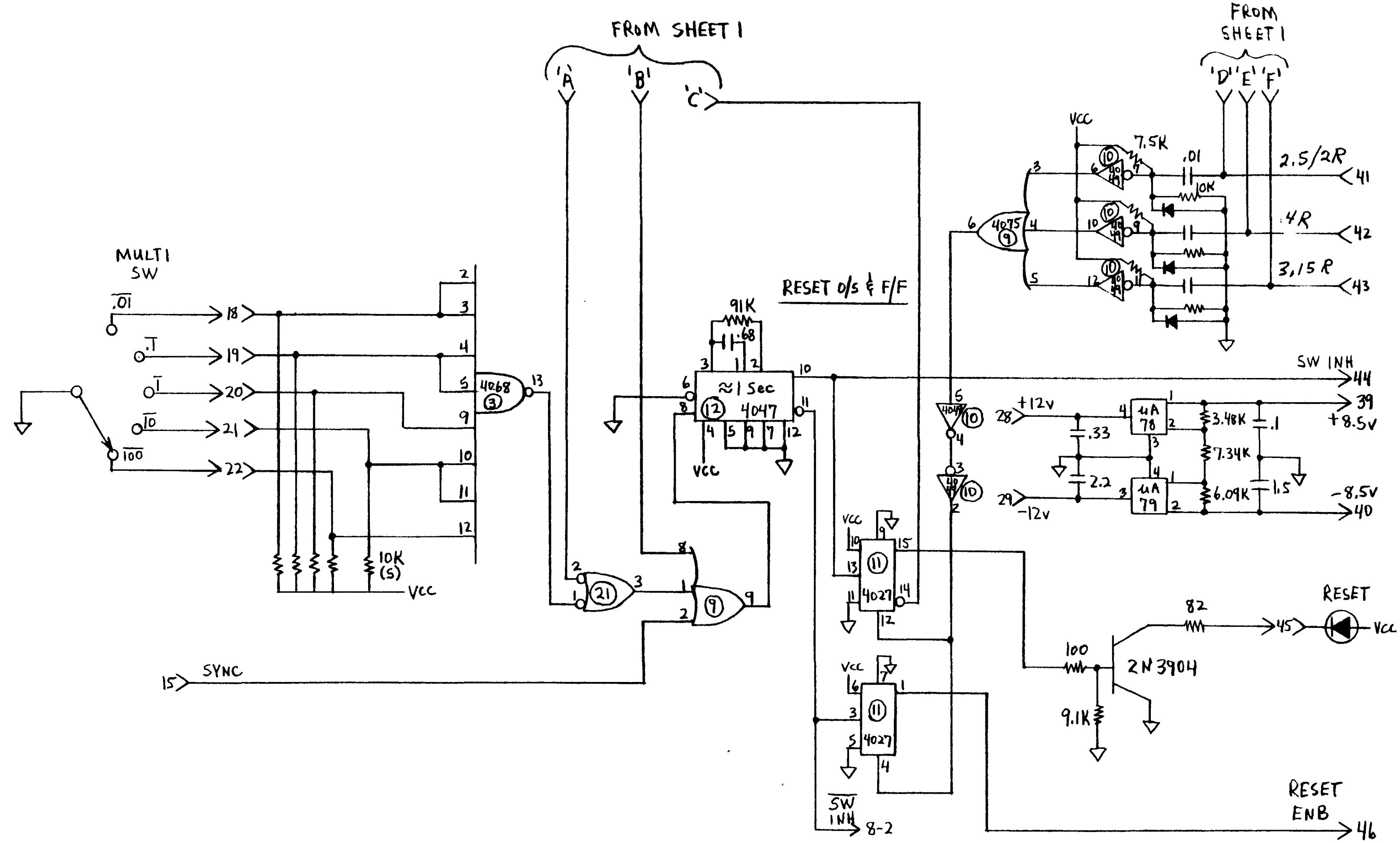
86608

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE	Tx 4 (1 of 3) SW RESET, SYNC ATTEN ADDRESS AND SYNC. DET. PHASES	U.S. GEOLOGICAL SURVEY
DESIGNED JAB	DRAWN [illegible]					DIVISION
SCALE	DATE 4-10-80	ASSEMBLY DWNG. NO.			1 OF 3	DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						SHEET OF

86608



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JAB	DRAWN Kenneth Kreutzer			
SCALE	DATE 4-11-80	ASSEMBLY DWNG. NO.		
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED				

Tx 4 (1 of 3)
SW RESET AND RESET INDICATOR
CKT 2 OF 3.

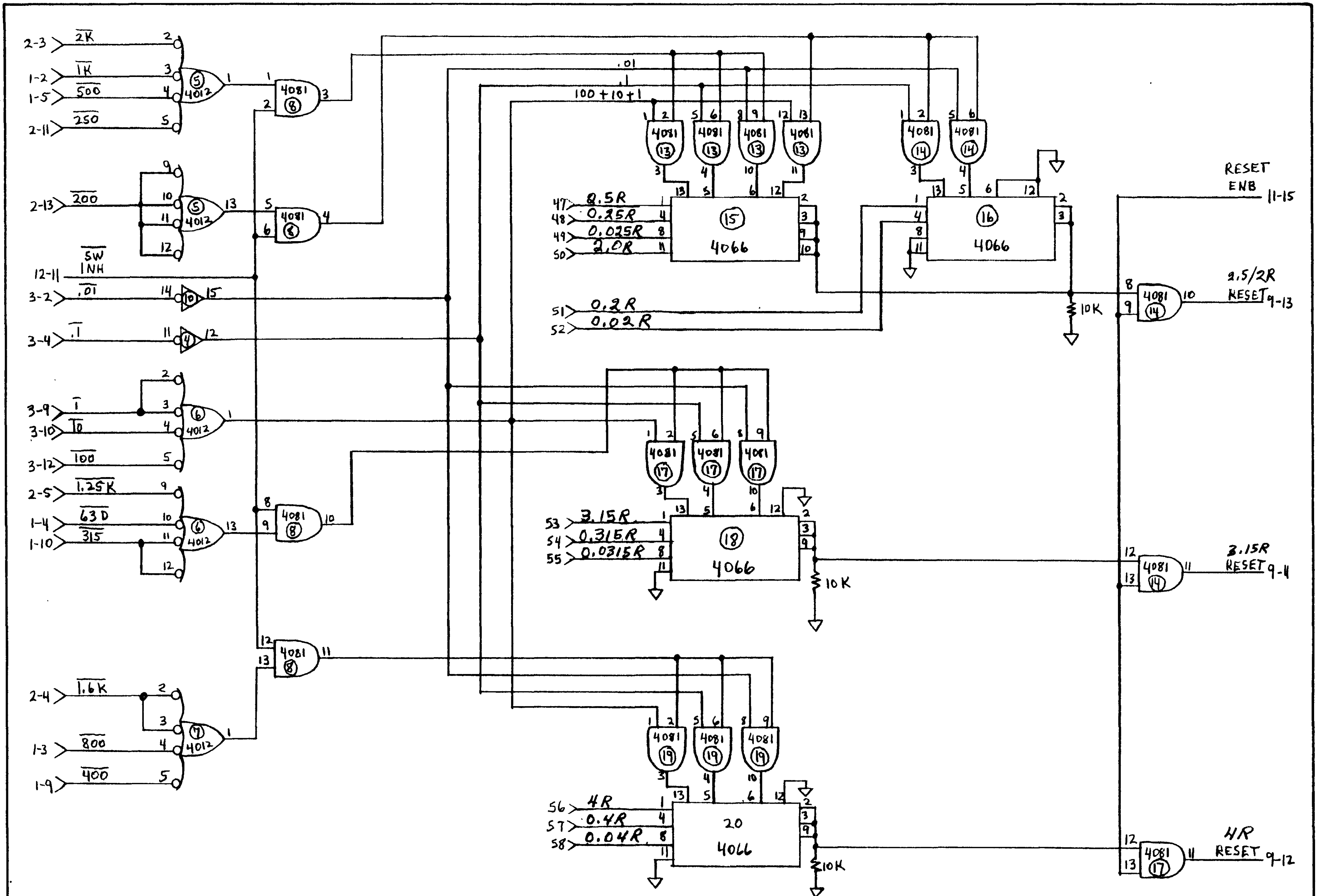
U.S. GEOLOGICAL SURVEY

DIVISION

DWNG. NO.

86608

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JAB	DRAWN Kevin P. Kraeger			
SCALE	DATE 4-22-80	ASSEMBLY DWNG. NO.		

TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED

86608

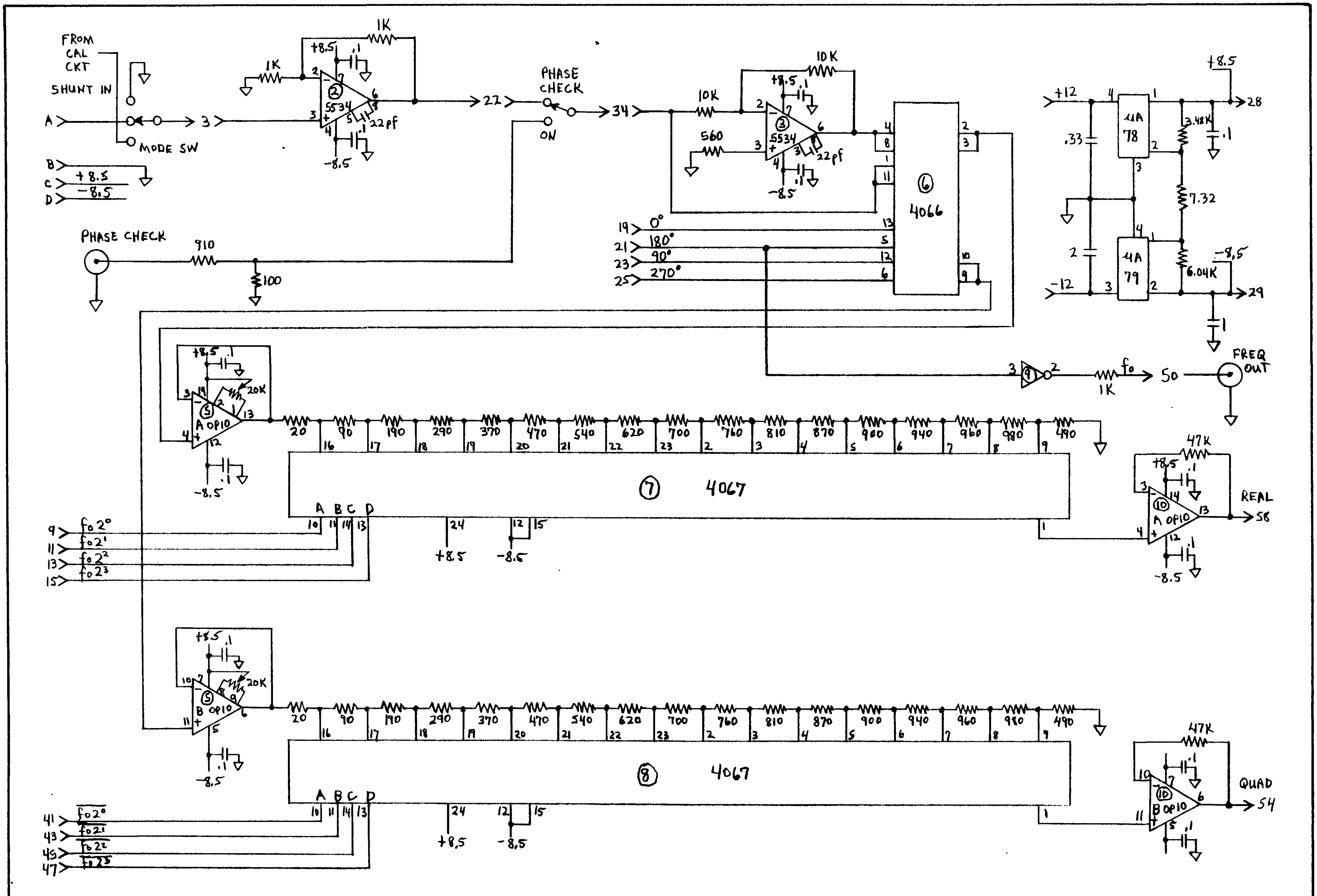
Tx 4 (3 of 3)
RESET MUX CKT

U.S. GEOLOGICAL SURVEY

DIVISION

DWNG. NO.

SHEET OF

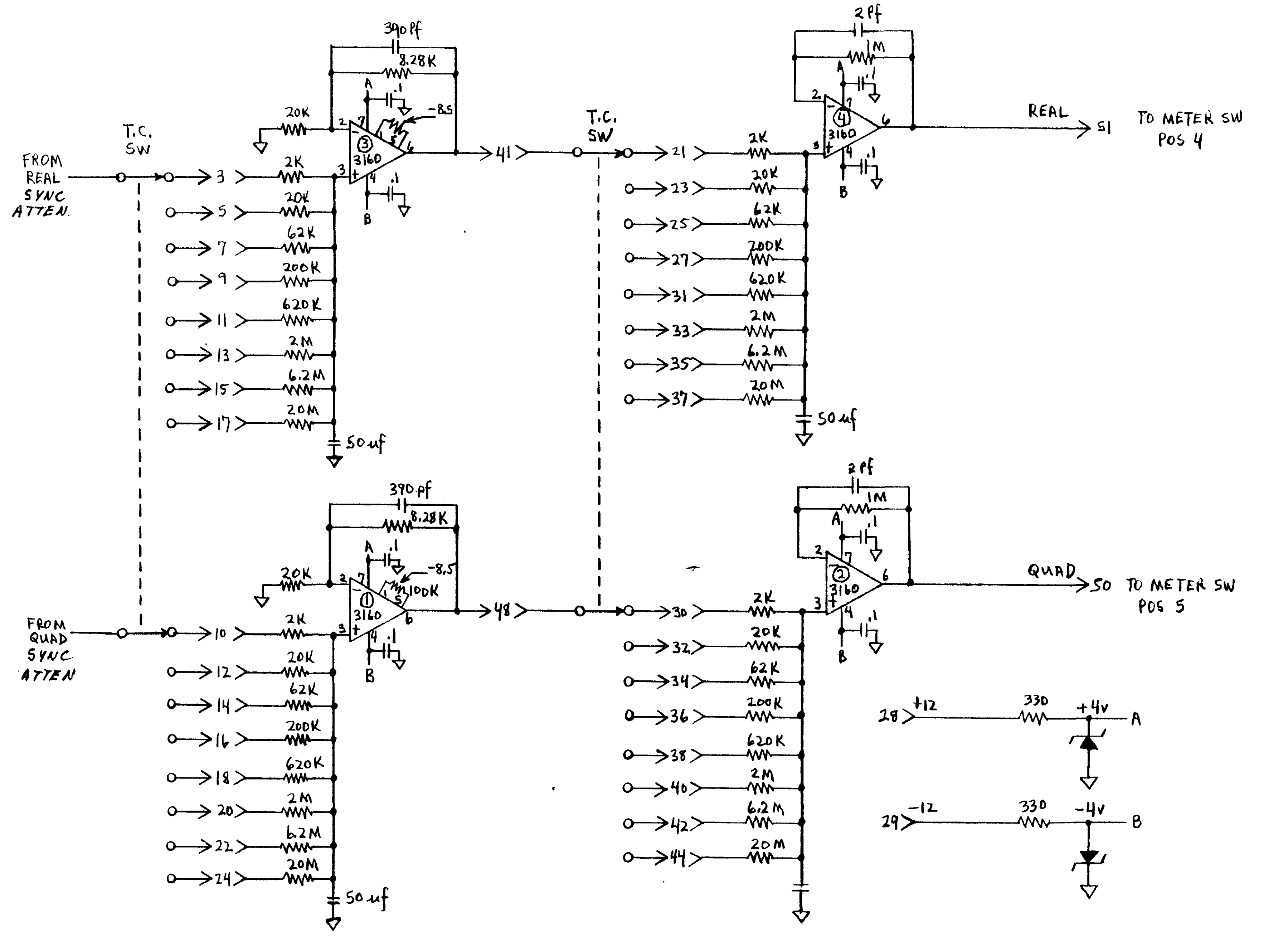


SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JC	DRAWN			
SCALE	DATE 4-24-80	ASSEMBLY DWNG. NO.		
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED				

Tx ANA 1
SHUNT AMP AND SWA

U.S. GEOLOGICAL SURVEY
DIVISION
DWNG. NO.
SHEET OF

86608



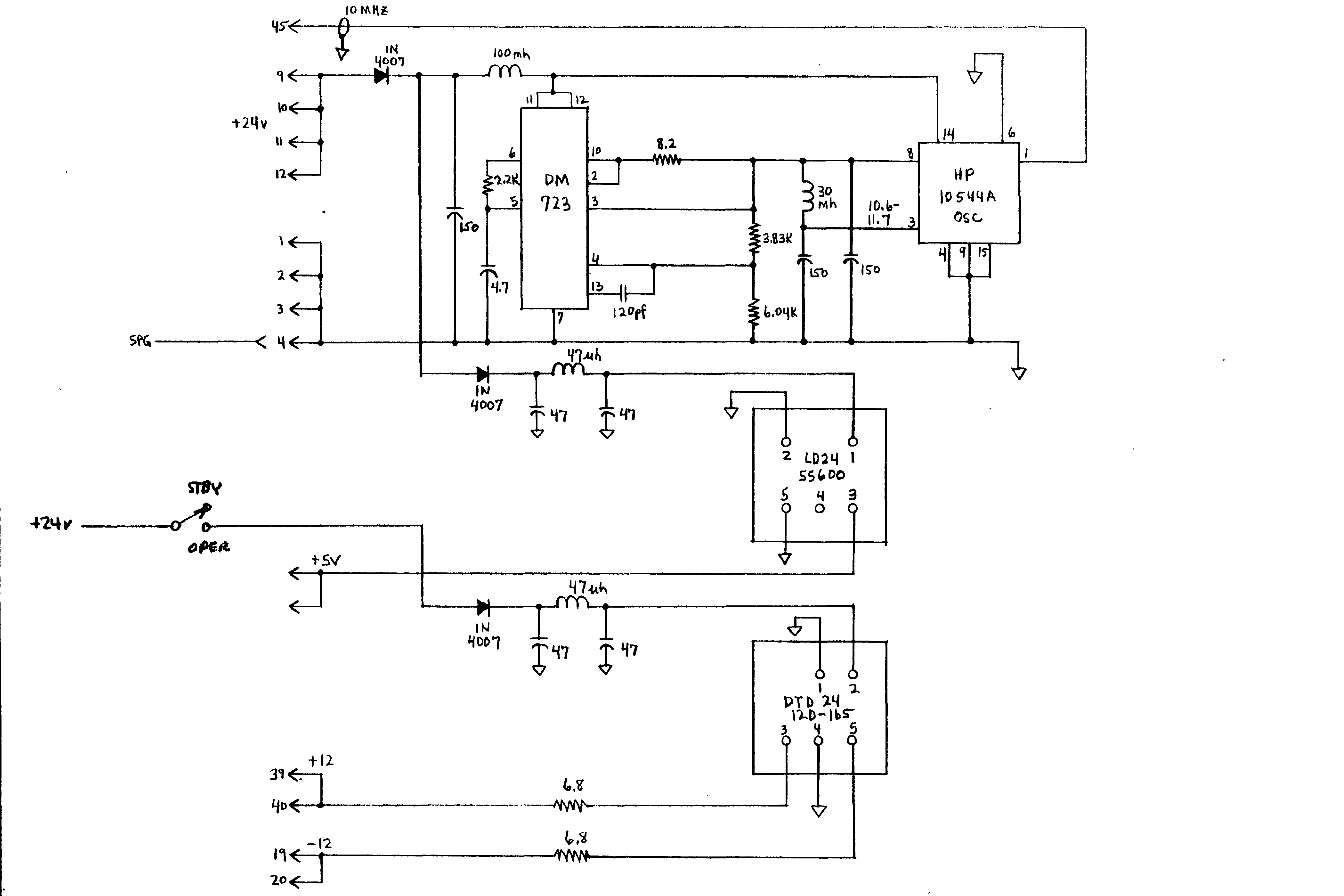
SIGNATURES		BLDG.,	RM.	PHONE
DESIGNED JC	DRAWN [signature]			
SCALE	DATE 4-25-80	ASSEMBLY DWNG. NO.		
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED				

Tx ANA 2
LOW PASS FILTER

U.S. GEOLOGICAL SURVEY
DIVISION
DWNG. NO.

86608

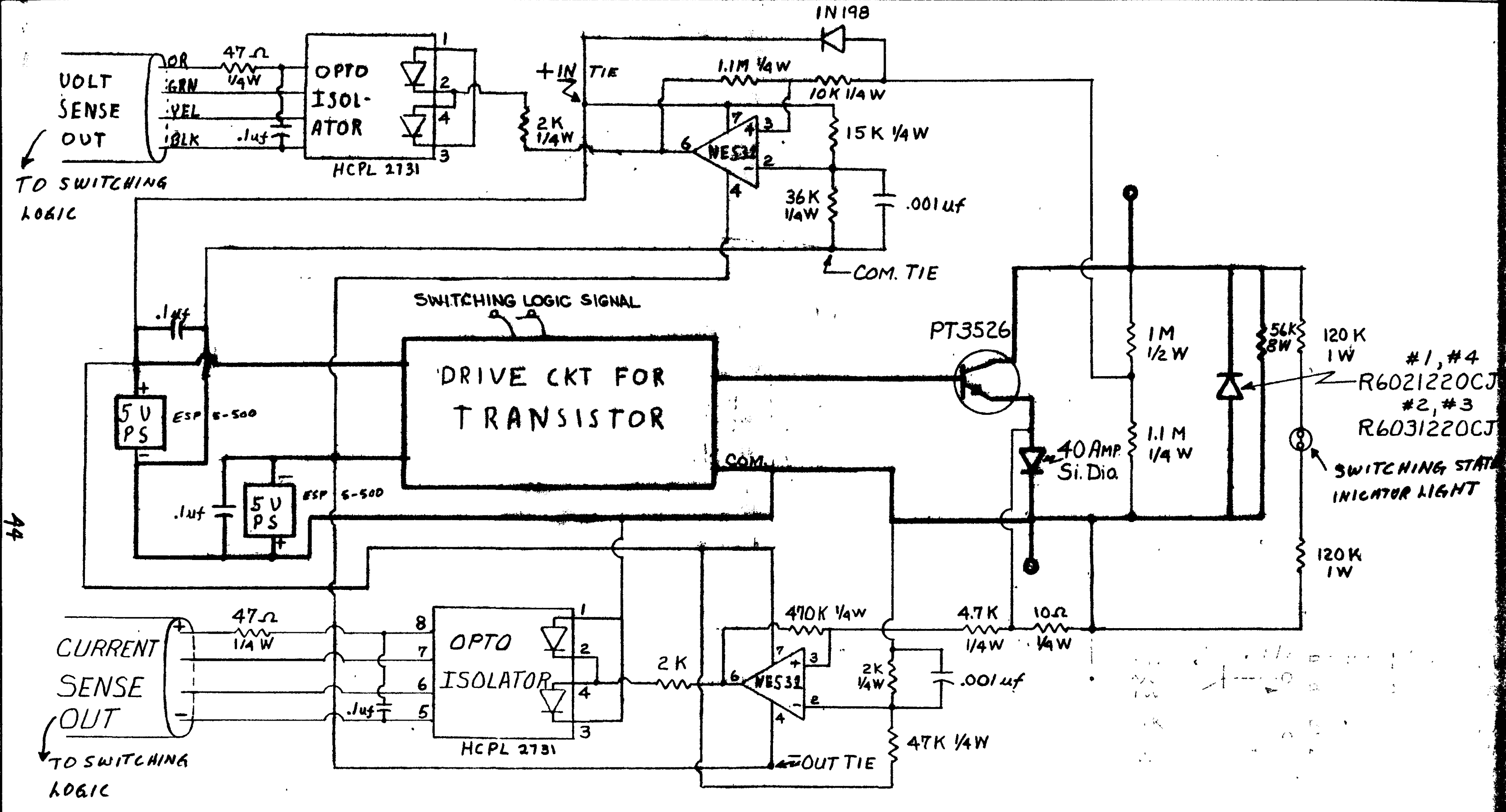
SHEET OF



SIGNATURES		BLDG.	RM.	PHONE	Tx 5 POWER SUPPLY BD.	U.S. GEOLOGICAL SURVEY
DESIGNED JAB	DRAWN Karl P. Kuenzer					DIVISION
SCALE	DATE 4-22-80	ASSEMBLY DWNG. NO.				
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						DWNG. NO.

86600

SHEET OF



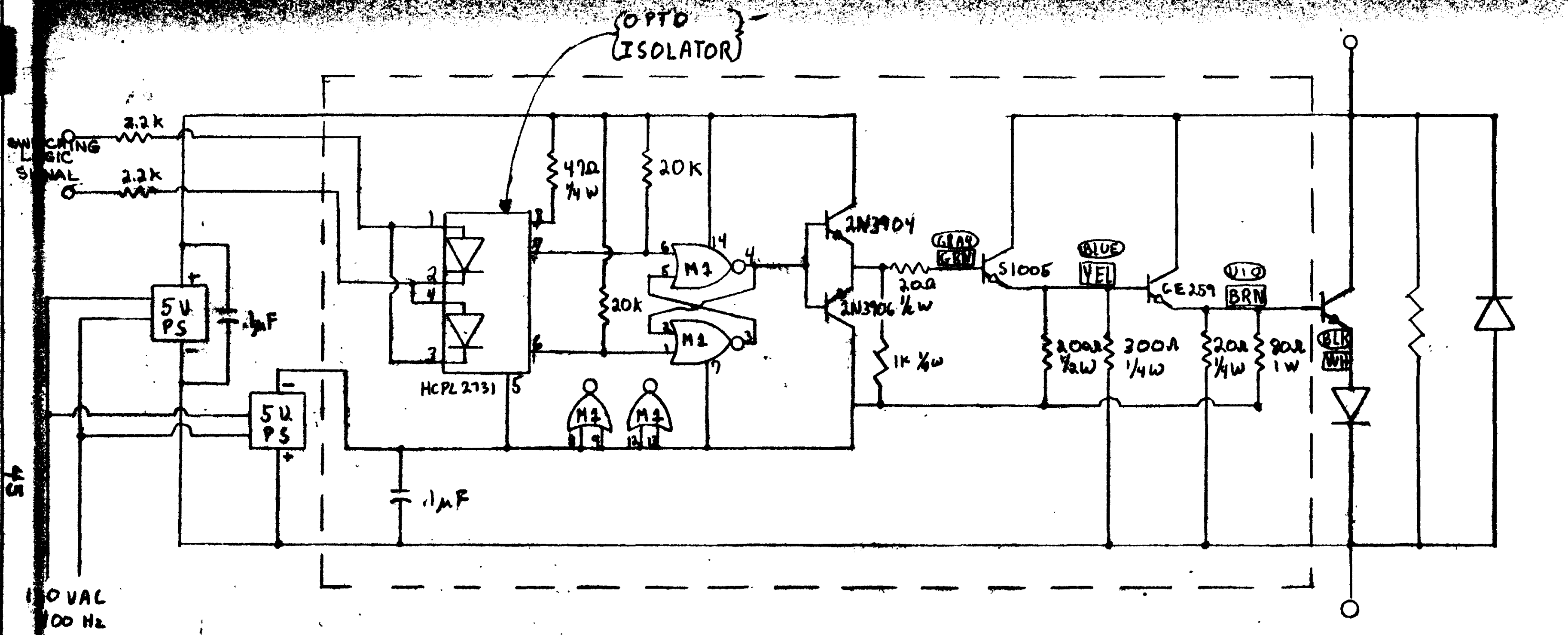
SIGNATURES		DATE	BLDG.	ROOM	PHONE	U.S. GEOLOGICAL SURVEY
DESIGNED	RHY	10-16-78				GEOLOGIC DIVISION
DRAWN	DBS	10-11-78				
APPROVED						

TOLERANCES
FRACTIONAL DIMENSIONS: ±1/64
ANGLE DIMENSIONS: ± 2°

SENSE CIRCUITRY FOR EACH TRANSISTOR CURRENT SWITCHER

SCALE: | ASSEMBLY DRAWING NO. | DRAWING NO. PAGE

SHEET OF



○ TRANSITORS 2+3
▭ " 1+4
M1 CD4001 BE

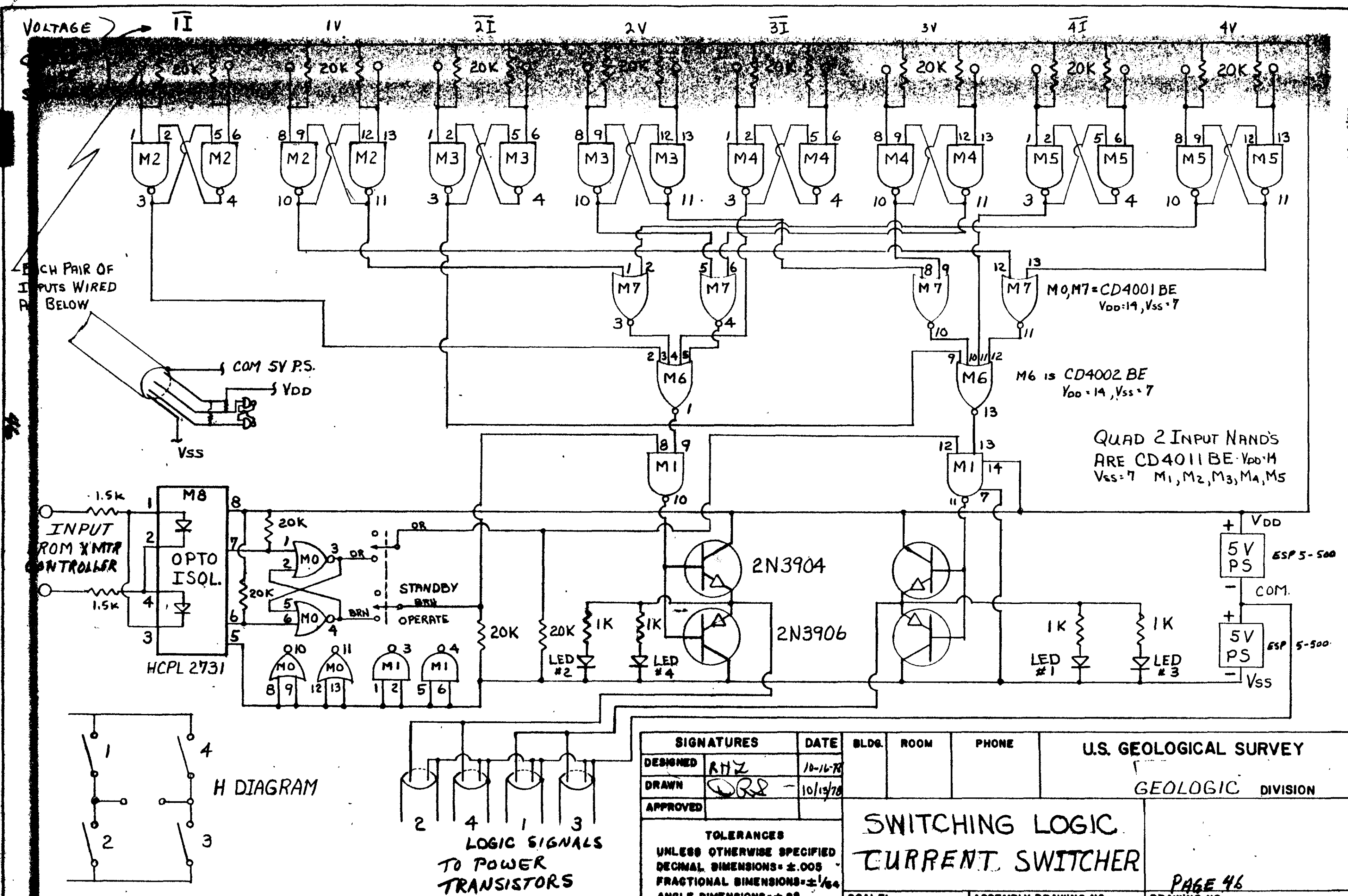
SIGNATURES		DATE	BLDG.	ROOM	PHONE	U.S. GEOLOGICAL SURVEY
DESIGNED						GEOLOGIC DIVISION
DRAWN	John Kuiper	7-28-78				
APPROVED						

TOLERANCES
UNLESS OTHERWISE SPECIFIED
DECIMAL DIMENSIONS = ±.005
FRACTIONAL DIMENSIONS = ±1/64
ANGLE DIMENSIONS = ±2°

DRIVER CIRCUIT FOR
1 of 4 TRANSITORS
CURRENT SWITCHER

SCALE: | ASSEMBLY DRAWING NO. | DRAWING NO. PAGE 45

SHEET OF



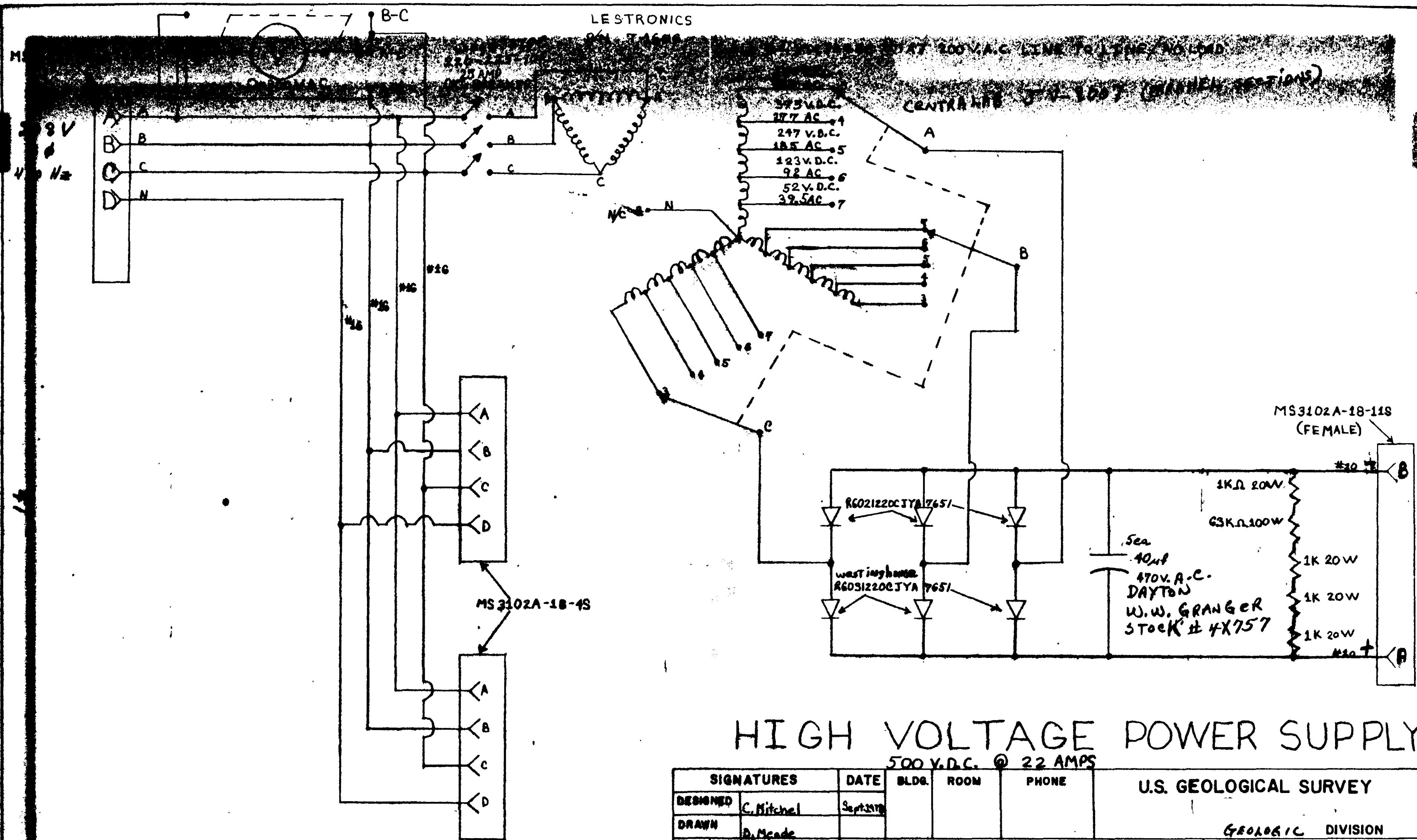
SIGNATURES		DATE	BLDG.	ROOM	PHONE	U.S. GEOLOGICAL SURVEY
DESIGNED	RHZ	10-16-78				GEOLOGIC DIVISION
DRAWN	QRL	10/19/78				
APPROVED						

TOLERANCES
UNLESS OTHERWISE SPECIFIED
DECIMAL DIMENSIONS = ±.005
FRACTIONAL DIMENSIONS = ±1/64
ANGLE DIMENSIONS = ± 2°

SWITCHING LOGIC CURRENT SWITCHER

SCALE: | ASSEMBLY DRAWING NO. | DRAWING NO. PAGE 46

SHEET OF



HIGH VOLTAGE POWER SUPPLY

500 V.D.C. @ 22 AMPS

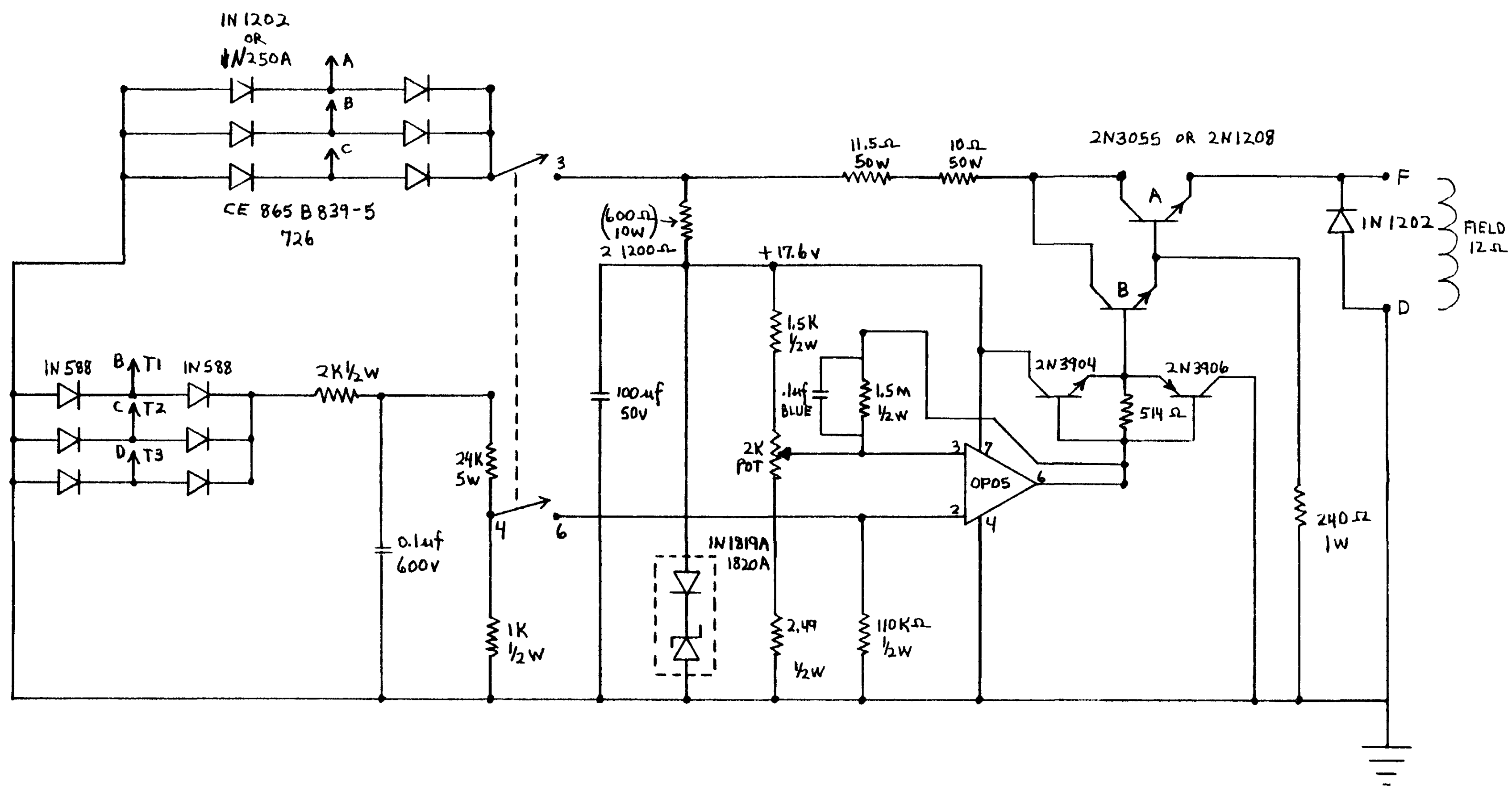
SIGNATURES		DATE	BLDG.	ROOM	PHONE	U.S. GEOLOGICAL SURVEY
DESIGNED	C. Mitchel	Sept 1978				GEOLOGIC DIVISION
DRAWN	D. Meade					
APPROVED	R. Lescelius					

TOLERANCES
UNLESS OTHERWISE SPECIFIED
DECIMAL DIMENSIONS = ±.005
FRACTIONAL DIMENSIONS = ±1/64
ANGLE DIMENSIONS = ±2°

DC VOLTAGE SUPPLY

SCALE: | ASSEMBLY DRAWING NO. | DRAWING NO. PAGE 47

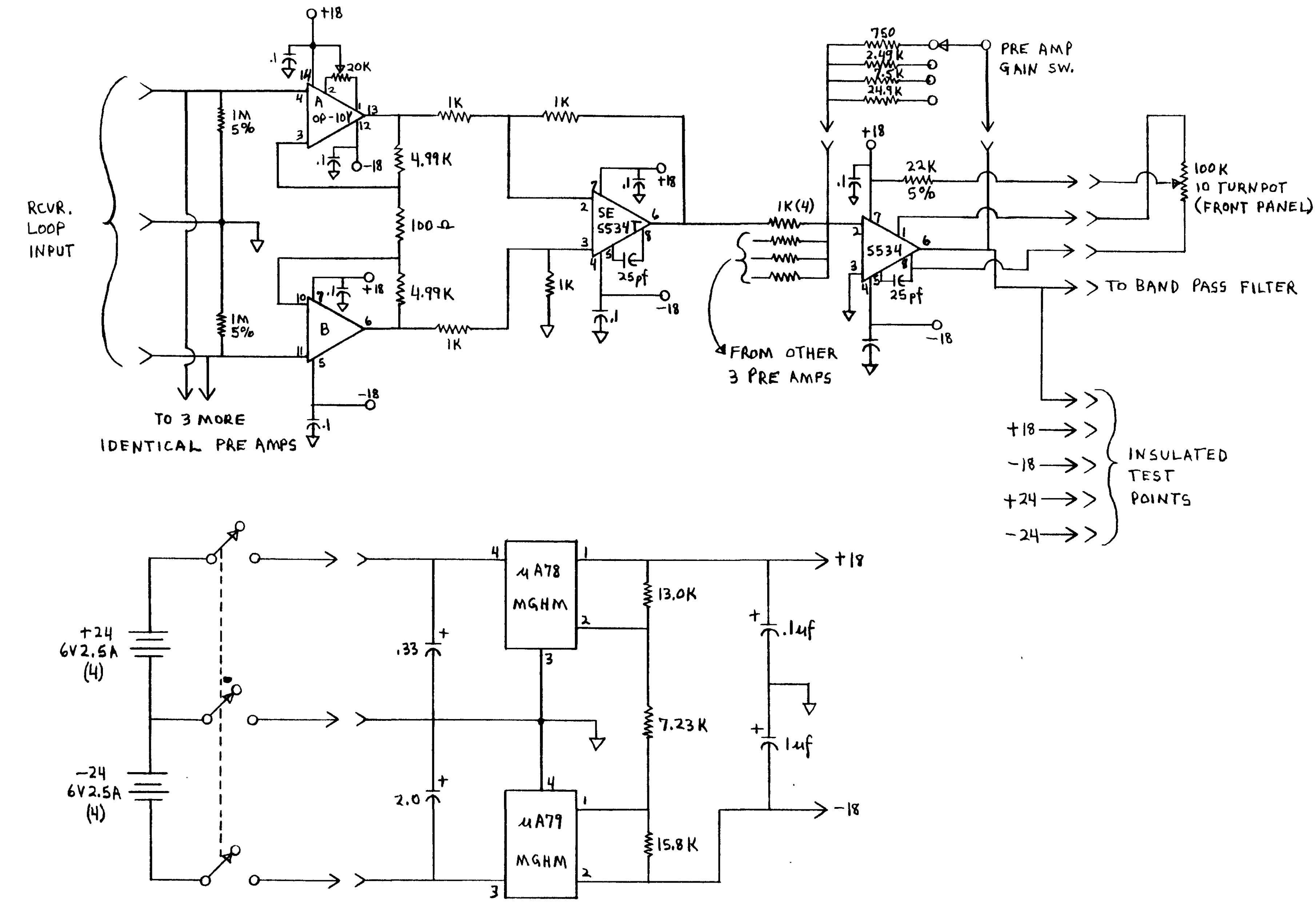
SHEET OF



SIGNATURES		BLDG.	RM.	PHONE	208 V REGULATOR	U.S. GEOLOGICAL SURVEY WASHINGTON, D.C. DIVISION
DESIGNED	DRAWN					
SCALE	DATE 6 AUG 1980	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

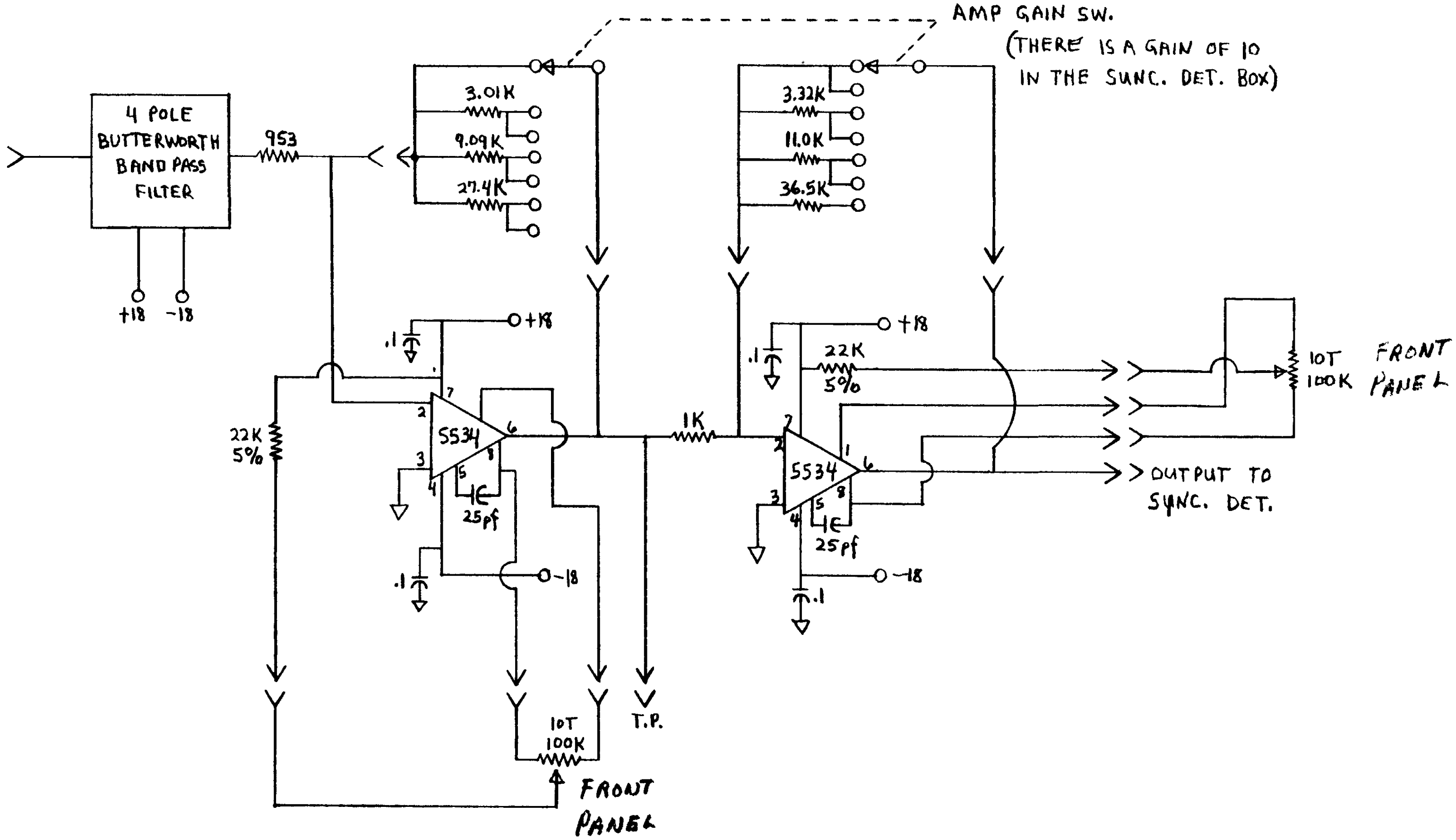
86608

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE	PRE AMP, FILTER, AMPLIFIER 1 of 2	U.S. GEOLOGICAL SURVEY WASHINGTON, D.C. DIVISION
DESIGNED JC	DRAWN Kemp, Kemp					
SCALE	DATE 5 AUG 1980	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64 ± 2° UNLESS OTHERWISE SPECIFIED						SHEET OF

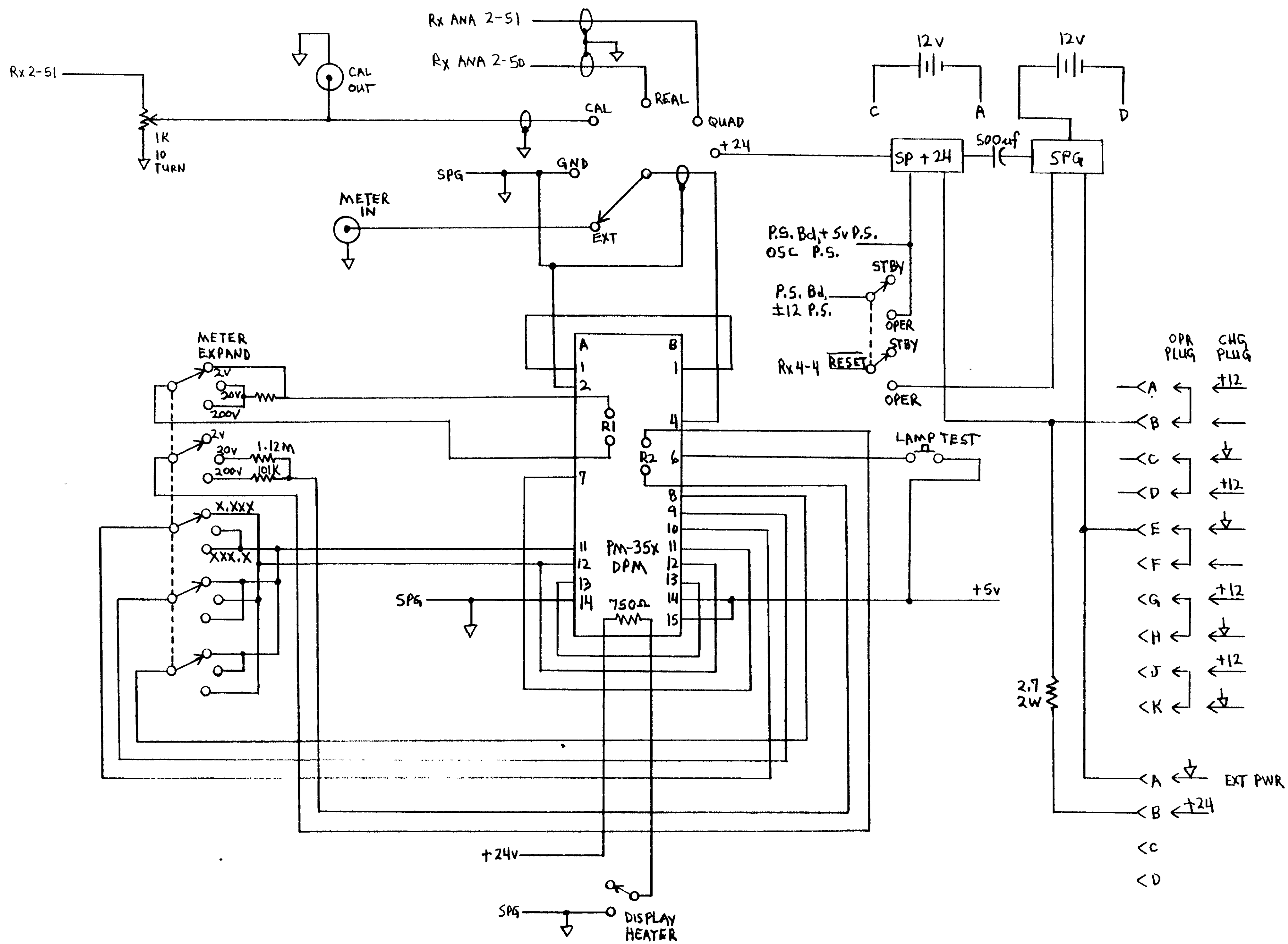
86608



SIGNATURES		BLDG.	RM.	PHONE		U.S. GEOLOGICAL SURVEY WASHINGTON, D.C. DIVISION
DESIGNED JC	DRAWN [signature]				PRE AMP, FILTER, AMPLIFIER	
SCALE	DATE 5 AUG 1980	ASSEMBLY DWNG. NO.				
TOLERANCES ARE ±.005, ±1/64 ± 2° UNLESS OTHERWISE SPECIFIED					PAGE 50 2 of 2	DWNG. NO.

86608

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED	DRAWN			
SCALE	DATE 5-20-80	ASSEMBLY DWNG. NO.		

TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED

Rx

FRONT PANEL

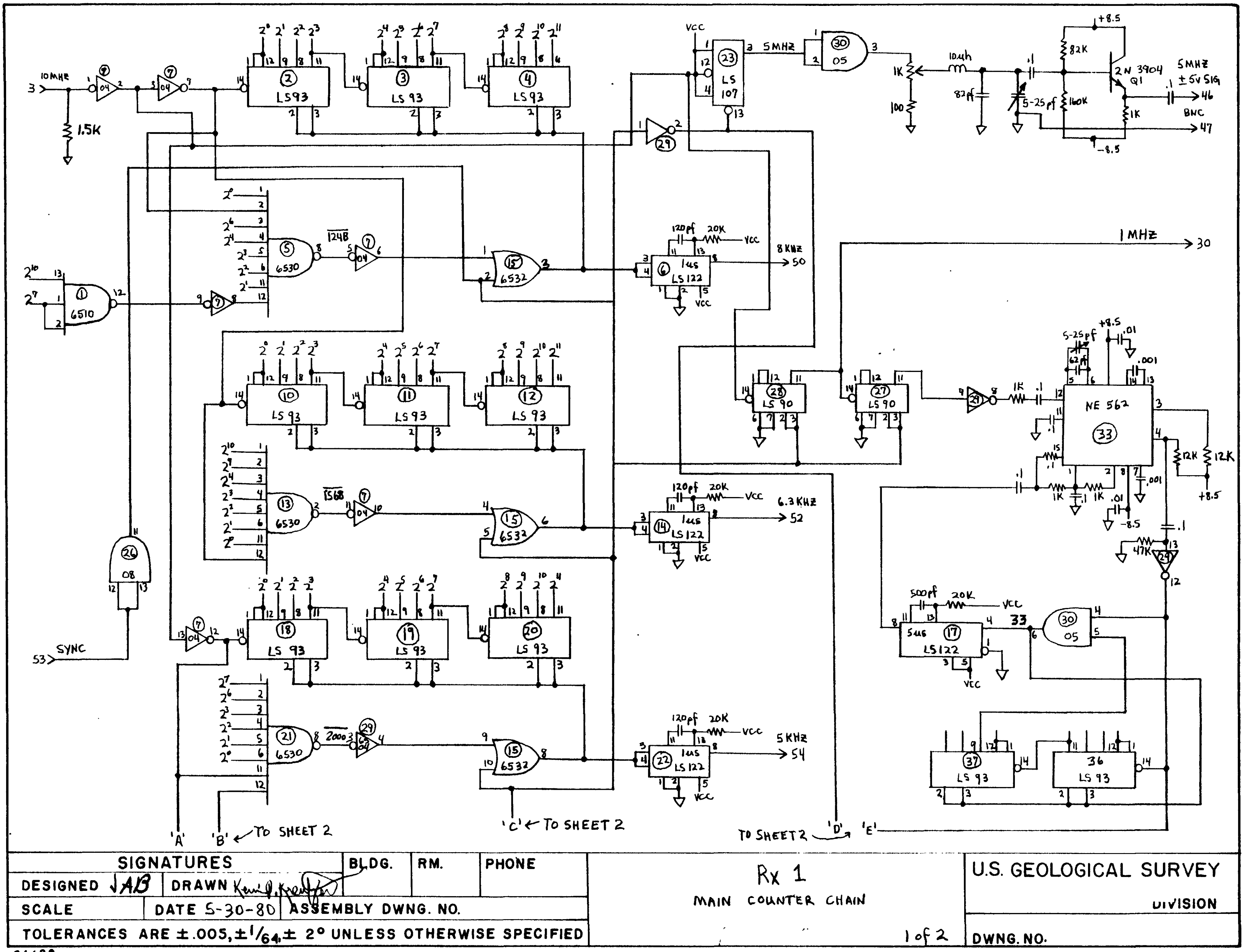
U.S. GEOLOGICAL SURVEY

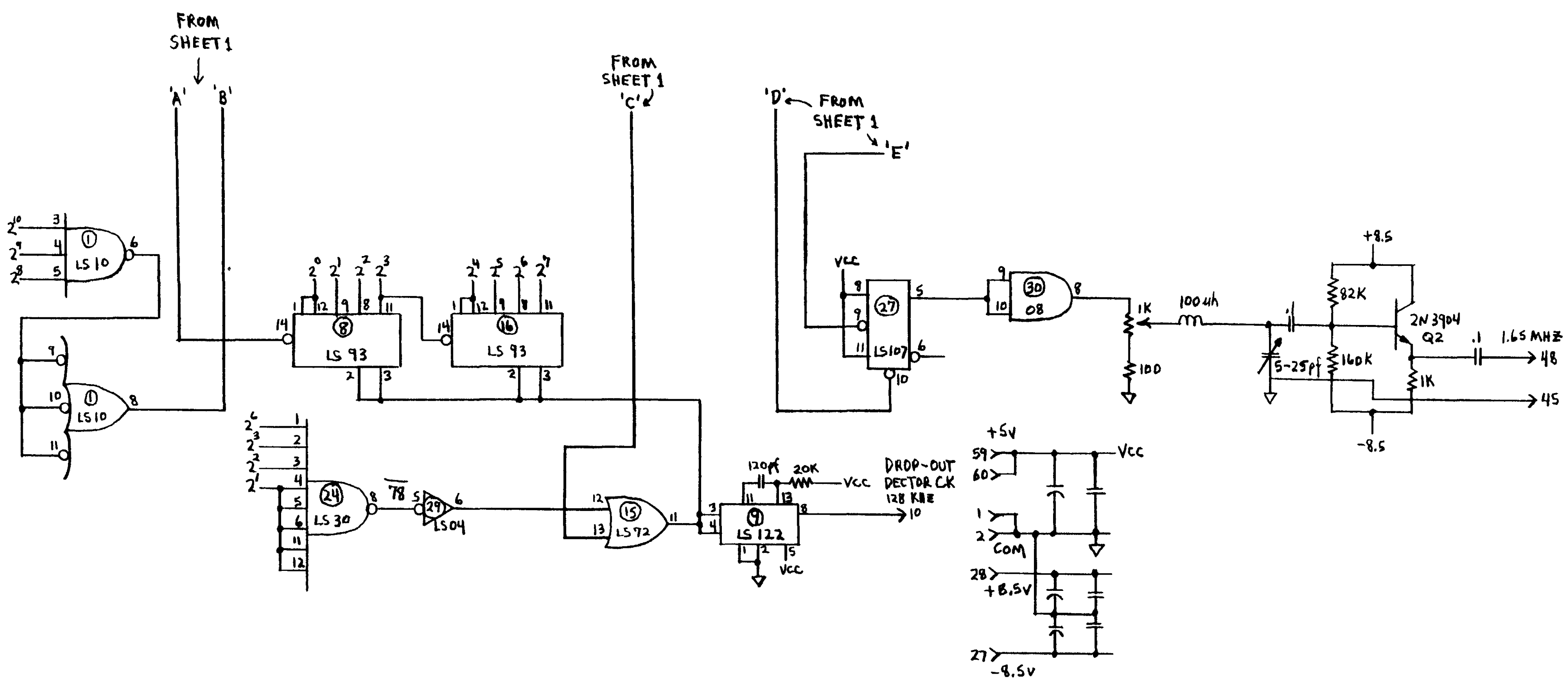
DIVISION

DWNG. NO.

SHEET OF

86608

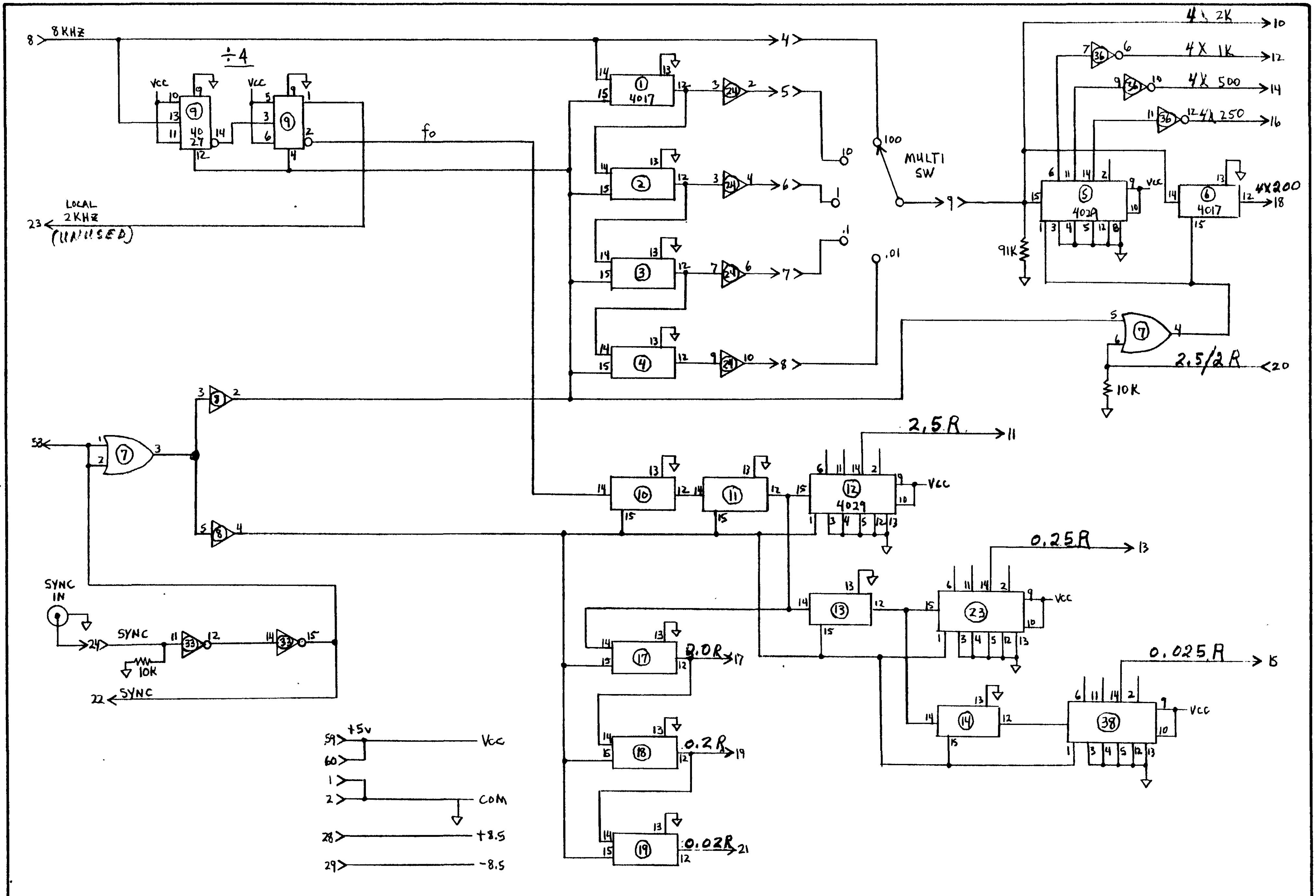

SIGNATURES
DESIGNED JAB
DRAWN
BLDG.
RM.
PHONE
SCALE
DATE 5-30-80
ASSEMBLY DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED
Rx 1
MAIN COUNTER CHAIN
1 of 2
U.S. GEOLOGICAL SURVEY
DIVISION
DWNG. NO.
SHEET OF
86608



SIGNATURES		BLDG.	RM.	PHONE	Rx 1 MAIN COUNTER CHAIN 2 of 2	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED JAB	DRAWN Kemp K.					
SCALE	DATE 6-3-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

86608

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED AB	DRAWN			
SCALE	DATE 6-9-80	ASSEMBLY DWNG. NO.		

TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED

Rx2 (1 of 4)
4fo 2K COUNTER
AND 2.5/2R RESET CKT

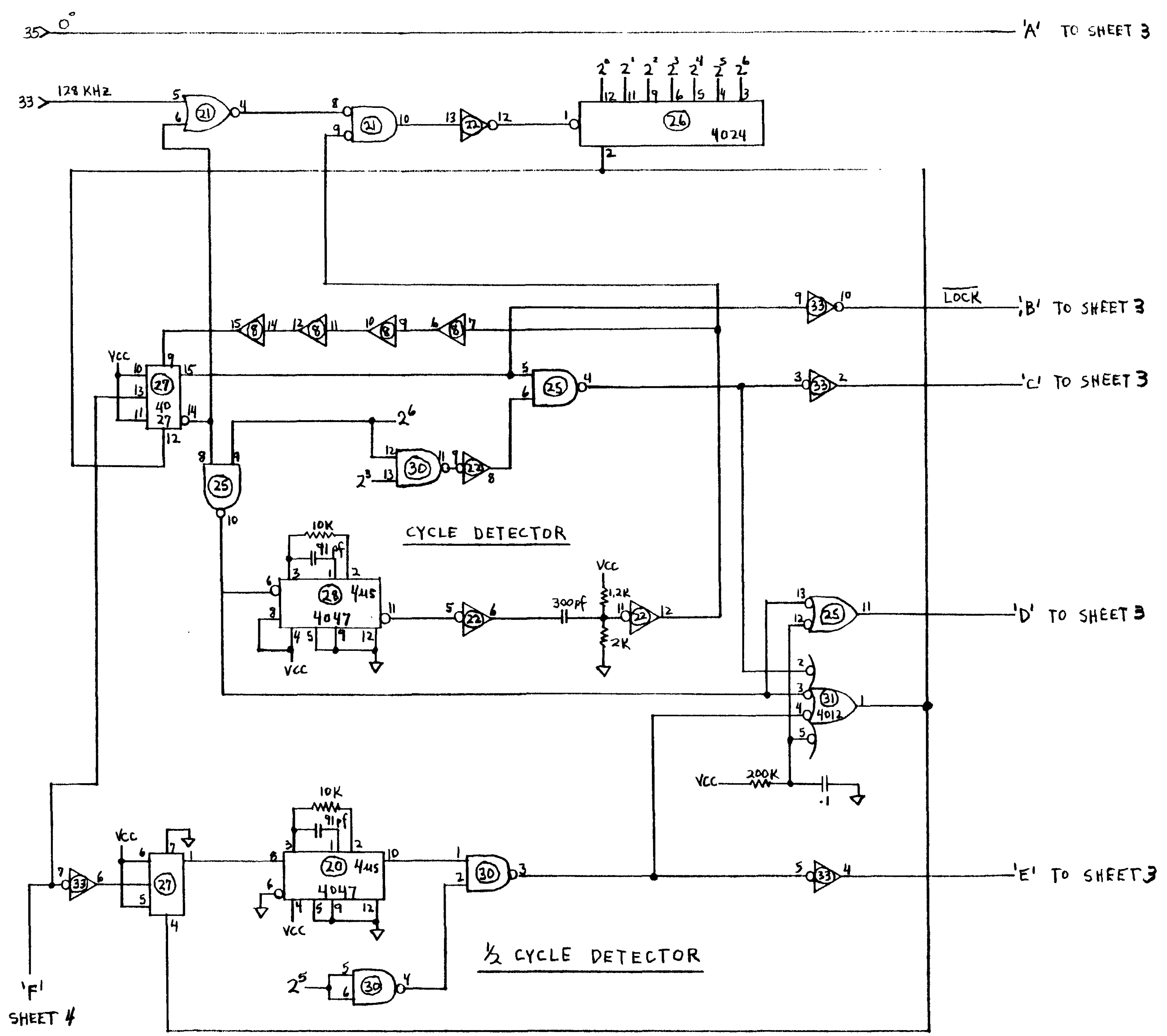
U.S. GEOLOGICAL SURVEY

DIVISION

DWNG. NO.

SHEET OF

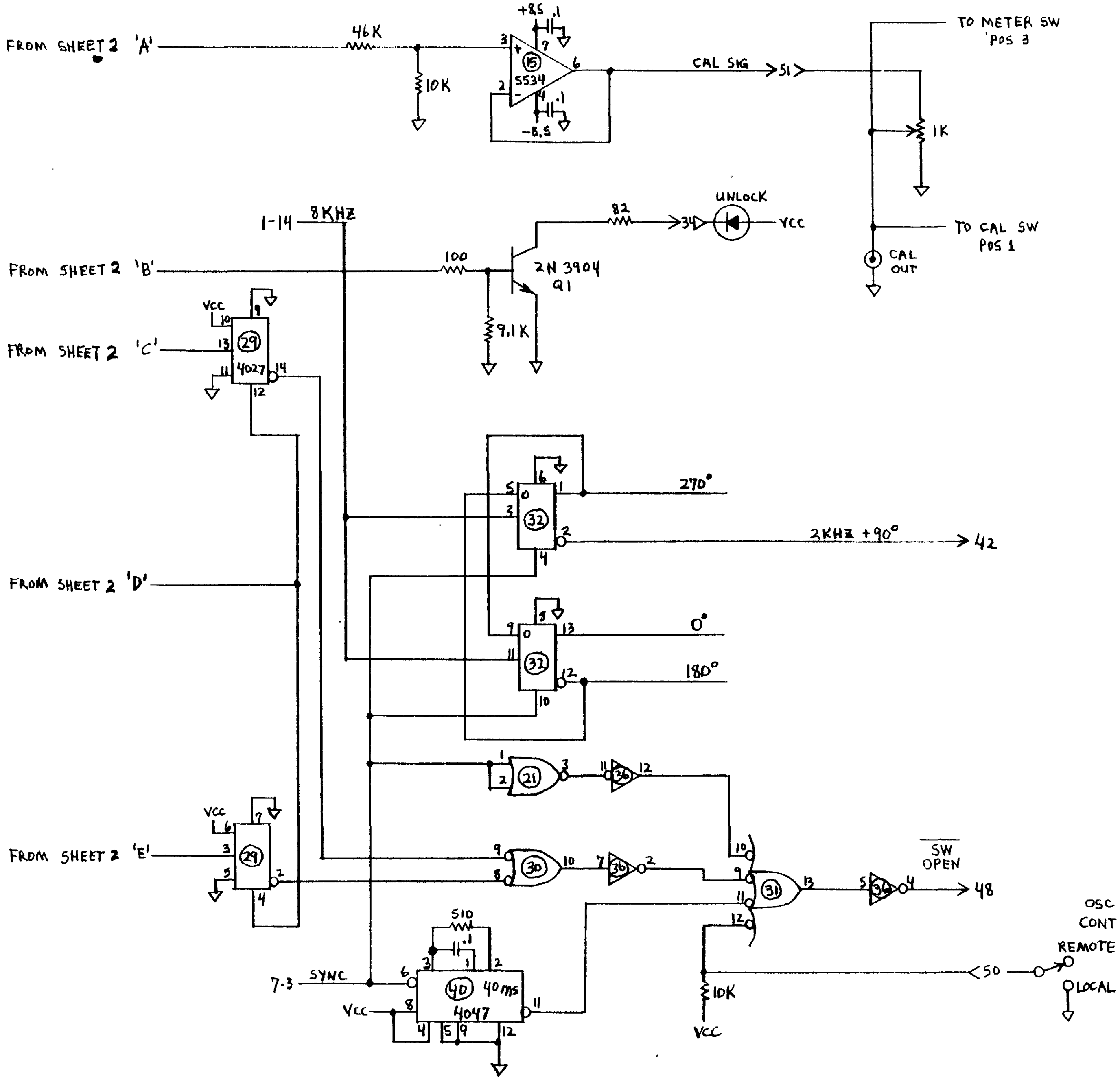
86608



SIGNATURES		BLDG.	RM.	PHONE	Rx 2 (2 of 4) PHASE LOCK DETECT CKT	U.S. GEOLOGICAL SURVEY
DESIGNED AB	DRAWN Kevin J. Kreutzer					DIVISION
SCALE	DATE 6-10-80	ASSEMBLY DWNG. NO.				
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						DWNG. NO.

86608

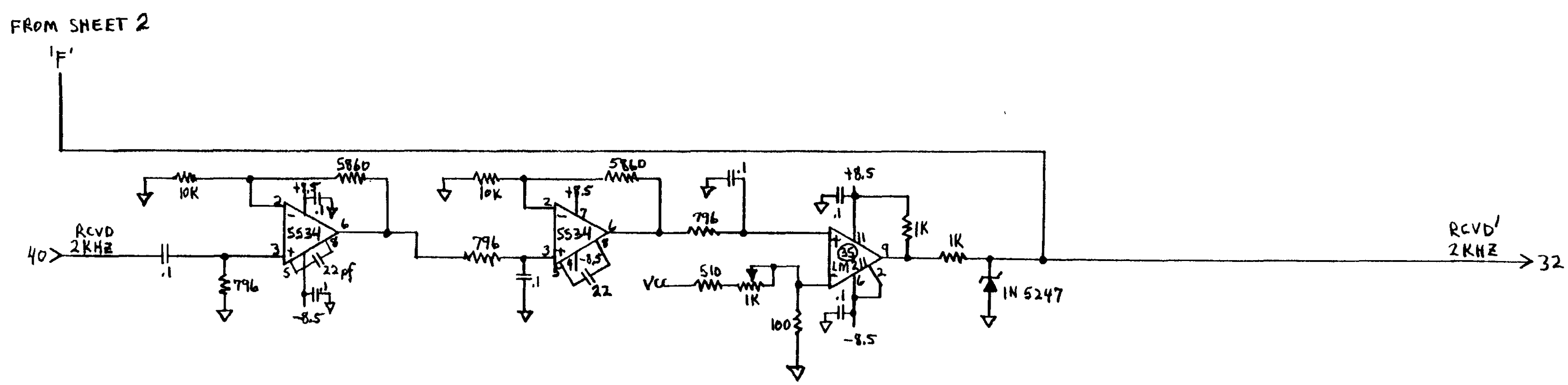
SHEET OF



SIGNATURES		BLDG.	RM.	PHONE	Rx 2 (3 of 4) CAL. CKT., LOCK INDICATOR CKT.	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED JAB	DRAWN					
SCALE	DATE 6-11-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

86608

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JC	DRAWN			
SCALE	DATE 6-11-80	ASSEMBLY DWNG. NO.		

TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED

Rx 2 (4 of 4)

AM RCVD 2 kHz SHAPING CKT.

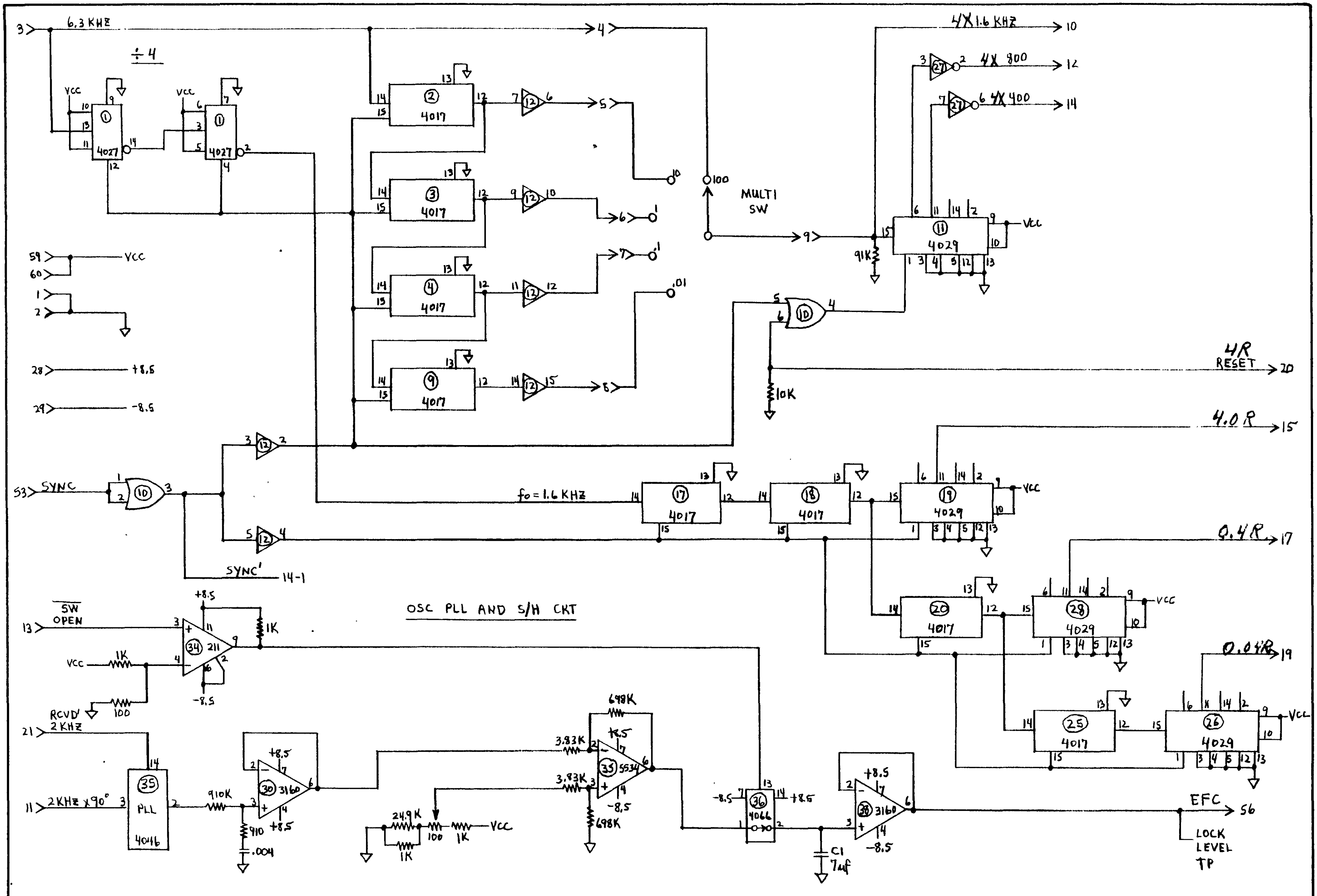
U.S. GEOLOGICAL SURVEY

DIVISION

DWNG. NO.

SHEET OF

86608

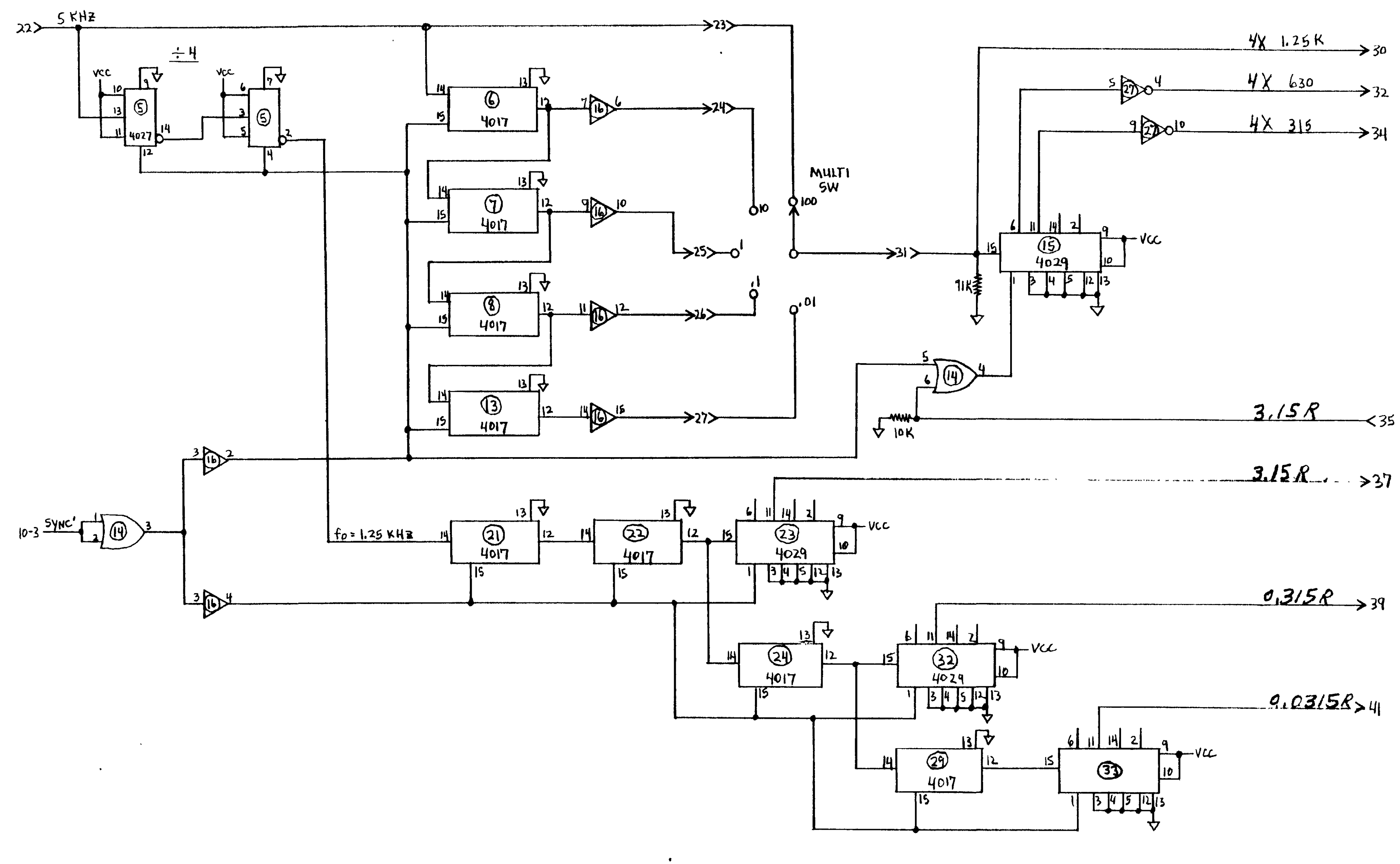


SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JAB	DRAWN			
SCALE	DATE 6-12-80	ASSEMBLY DWNG. NO.		
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED				

Rx 3 (1 of 2)
4 f0 1.6K COUNTER
AND 4R RESET CKT

U.S. GEOLOGICAL SURVEY
DIVISION
DWNG. NO.
SHEET OF

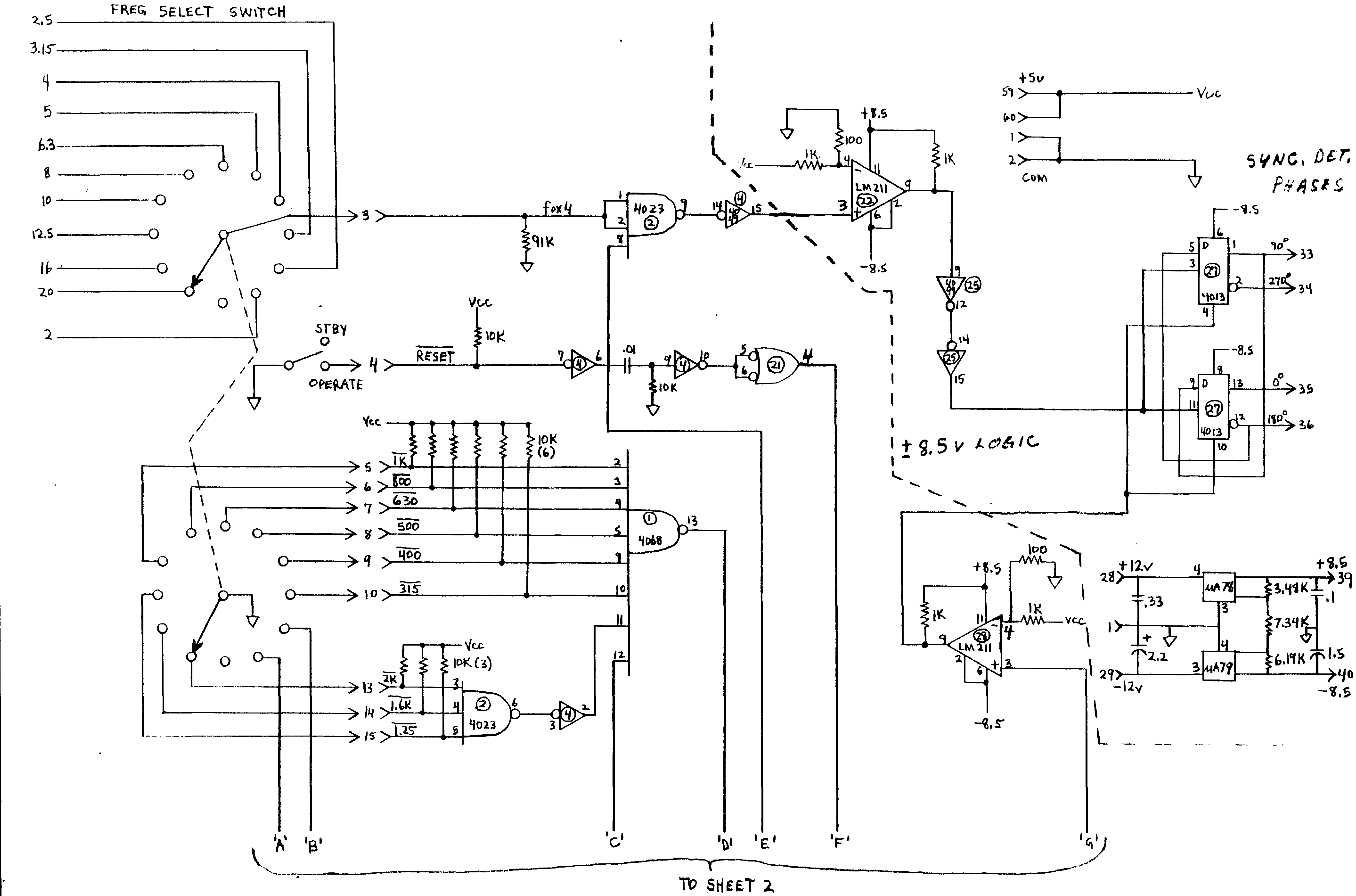
86608



SIGNATURES		BLDG.	RM.	PHONE	Rx 3 (2 of 2) 4f0, 1.25 KHZ COUNTER AND 315R RESET CKT	U.S. GEOLOGICAL SURVEY DIVISION
DESIGNED JAB	DRAWN Kenneth Kre[illegible]					
SCALE	DATE 6-17-80	ASSEMBLY DWNG. NO.				DWNG. NO.
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						

86608

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JAB	DRAWN [signature]			
SCALE	DATE 18 AUG 80	ASSEMBLY DWNG. NO.		
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED				

Rx 4

SWITCH RESET AND SYNC DET PHASE CKT.

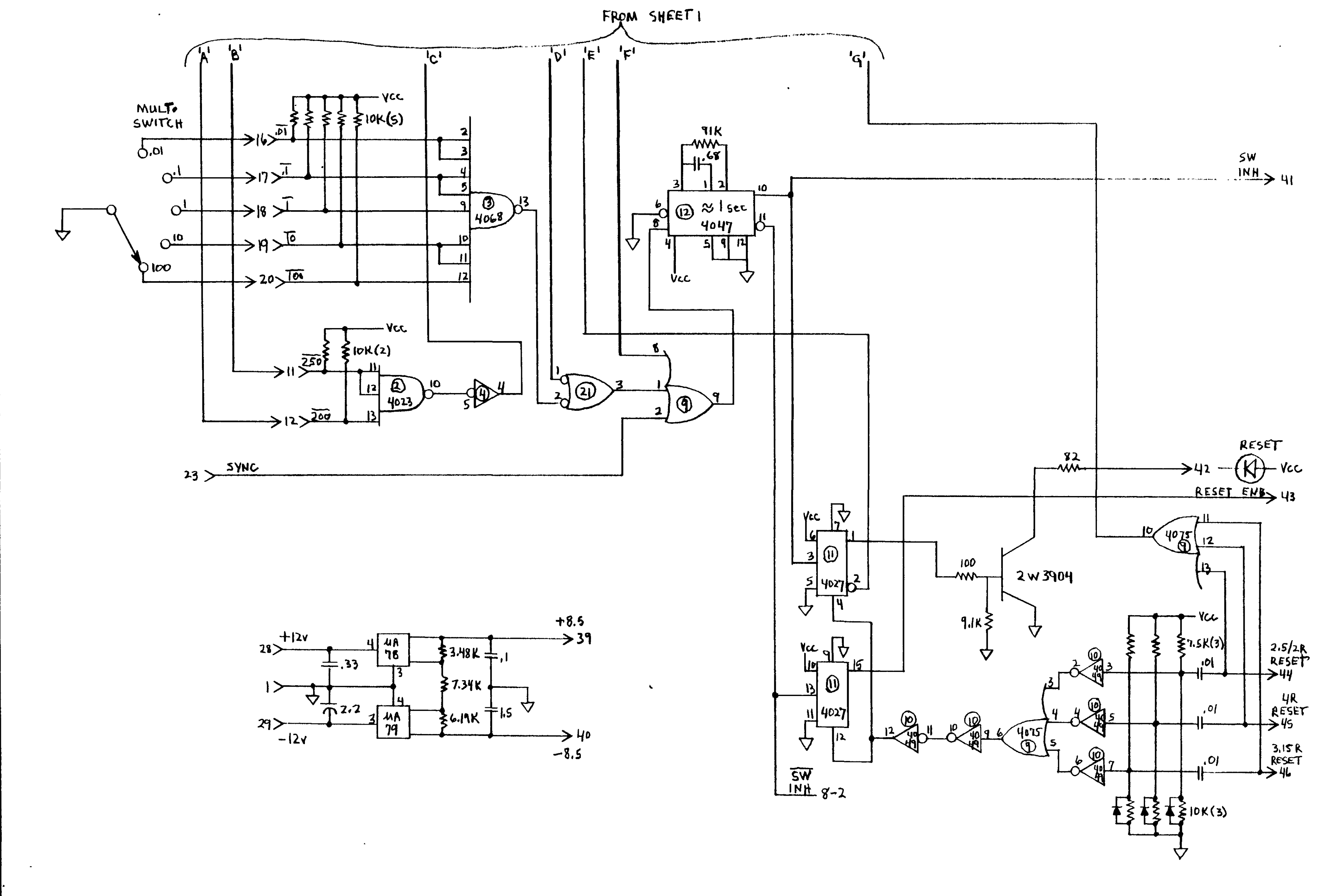
1 of 3

U.S. GEOLOGICAL SURVEY
WASHINGTON, D.C.
DIVISION

DWNG. NO.

86608

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JAB	DRAWN [signature]			
SCALE	DATE 18 AUG 80	ASSEMBLY DWNG. NO.		

TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED

Rx 4

SWITCH RESET AND SYNC DET PHASE CKT.

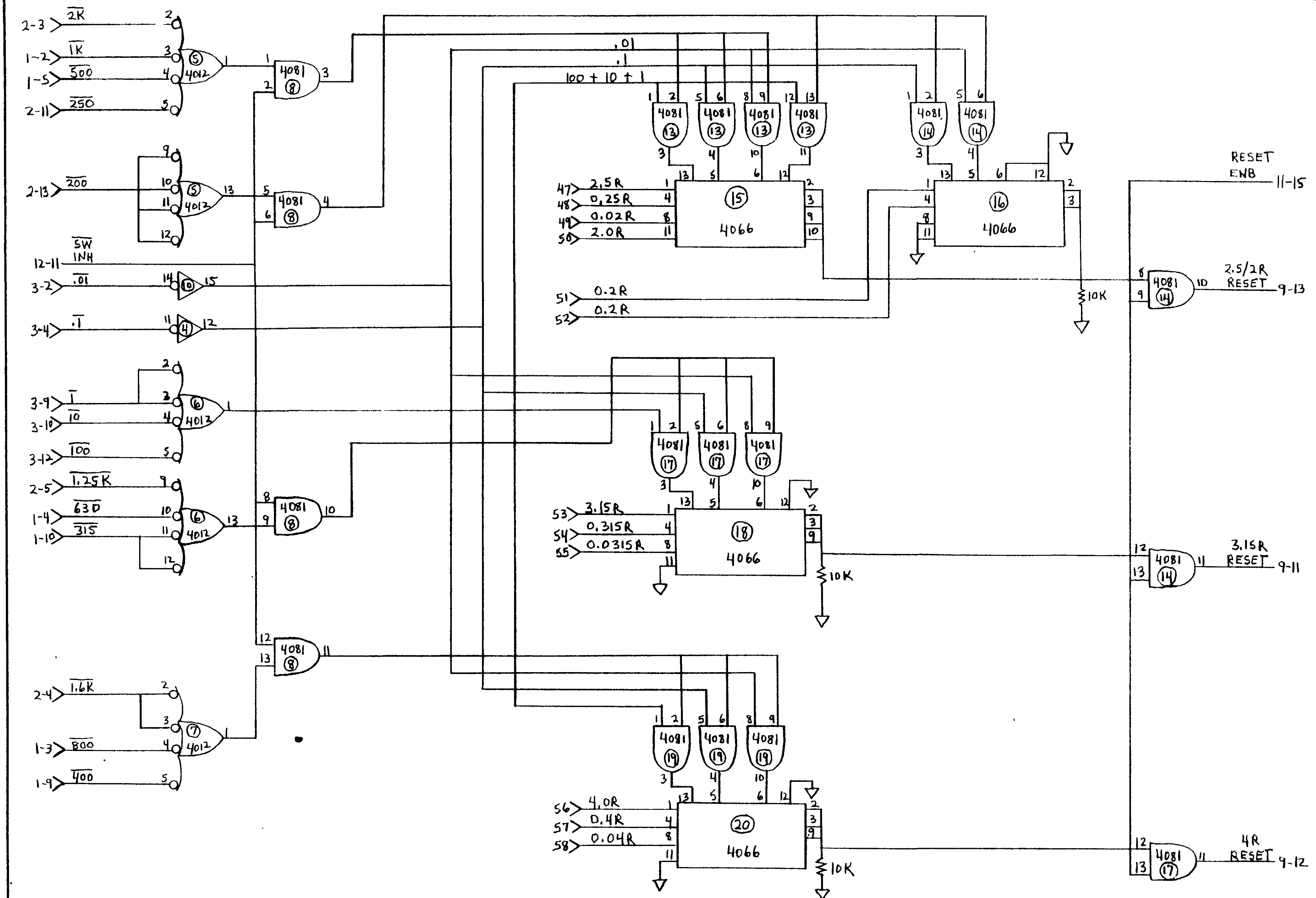
2 of 3

U.S. GEOLOGICAL SURVEY
WASHINGTON, D.C.
DIVISION

DWNG. NO.

86608

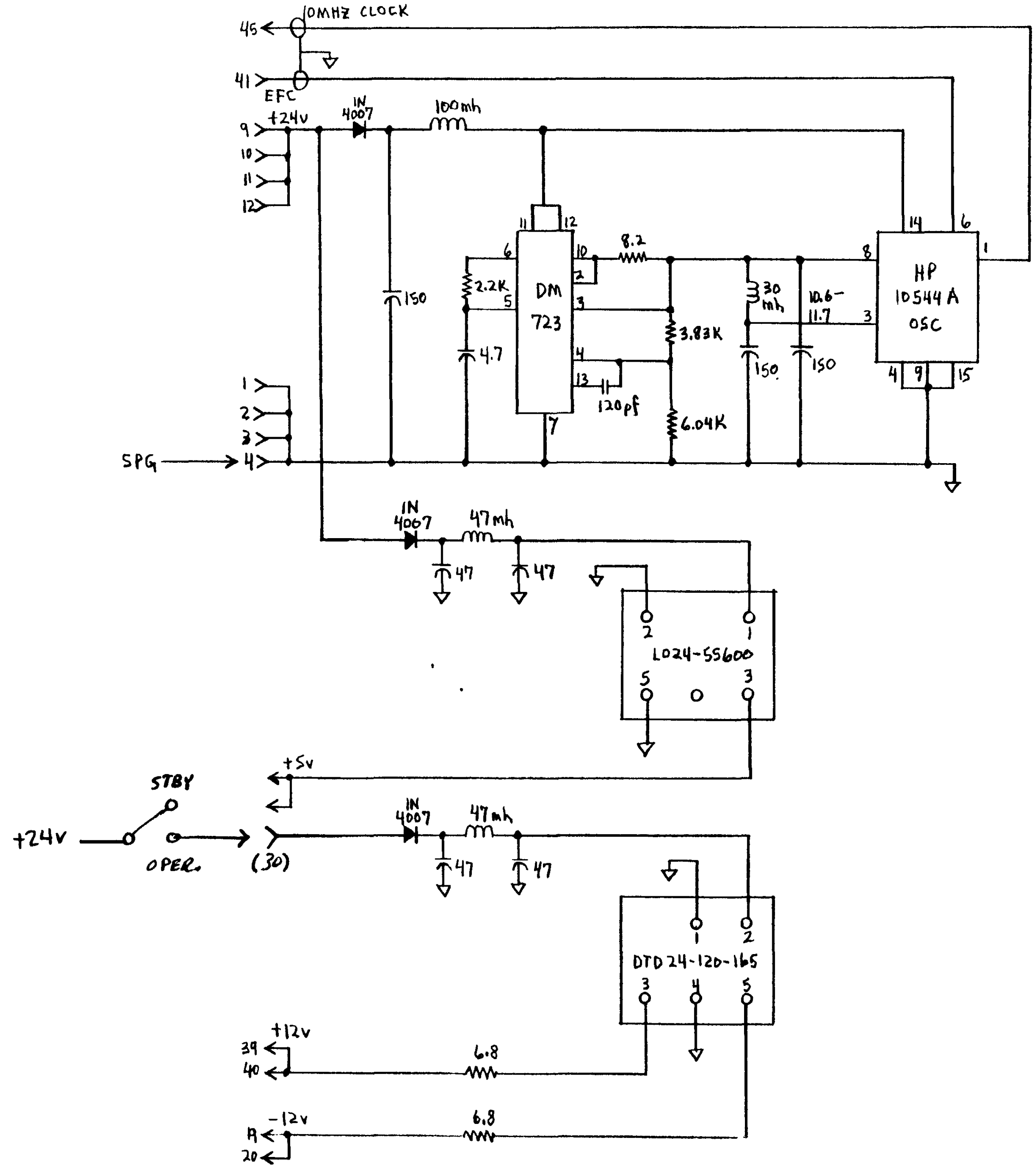
SHEET OF



SIGNATURES		BLDG.	RM.	PHONE	Rx 4 (3 of 3)	U.S. GEOLOGICAL SURVEY WASHINGTON, D.C. DIVISION
DESIGNED JAB	DRAWN Kenneth Kaufman				RESET MUX CKT	
SCALE	DATE 12 AUG 1980	ASSEMBLY DWNG. NO.				
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED						DWNG. NO.

86600

SHEET OF



SIGNATURES		BLDG.	RM.	PHONE
DESIGNED JAB	DRAWN [signature]			
SCALE	DATE 6-17-80	ASSEMBLY DWNG. NO.		
TOLERANCES ARE ±.005, ±1/64, ± 2° UNLESS OTHERWISE SPECIFIED				

Rx 5
POWER SUPPLY
BOARD

U.S. GEOLOGICAL SURVEY
DIVISION
DWNG. NO.
SHEET OF

86608