UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY
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# AN ANALOG DATA TELEMETRY SYSTEM FOR REMOTE MONITORING APPLICATIONS, VERSION II

by

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Open-File report 79-946

1979

## INTRODUCTION

The data telemetry transmitter described herein, developed for use in volcanic gas monitoring experiments, has evolved from, and thus is similar to, a previously described system (McGee and Sato, 1979). In these systems, the output from various sensors implanted in volcanic fumaroles must be converted to a form convenient for transmission to a data collection site. Since fumaroles are by their nature located in remote areas, the most important consideration is to design a system with extremely low power requirements. As in the previous system, low power CMOS integrated circuits have been utilized to meet that design goal. Typical current drain for this system (excluding the radio transmitter) is 5 mA. The present system also incorporates several significant improvements over the earlier system. An audio frequency harmonic filter, 8-channel input, a wheatstone bridge/amplifier circuit, and increased timing flexibility are among those improvements. A complete functional block diagram is shown in figure 1.

## DESCRIPTION

The clock circuit consists of two sections of a 4001 quad 2-input NOR gate (U6) and an RC network. The basic sensor period (i.e. the length of time the multiplexer spends at each of its inputs) is determined by the selection of values for R1 and C1 (see table 1). The clock signal, after passing through a 4520 divide-by-16 counter (U1), triggers the 4522 decimal divide-by-N counter (U2). The number of sensors to be scanned (1 to 8) is programmed by jumper wires in BCD code (see table 2) to the four inputs of the 4522 [Refer to the CMOS Cookbook (Lancaster, 1977) for details about the individual integrated circuits]. The unused inputs are grounded. A complete schematic is shown in figure 2.

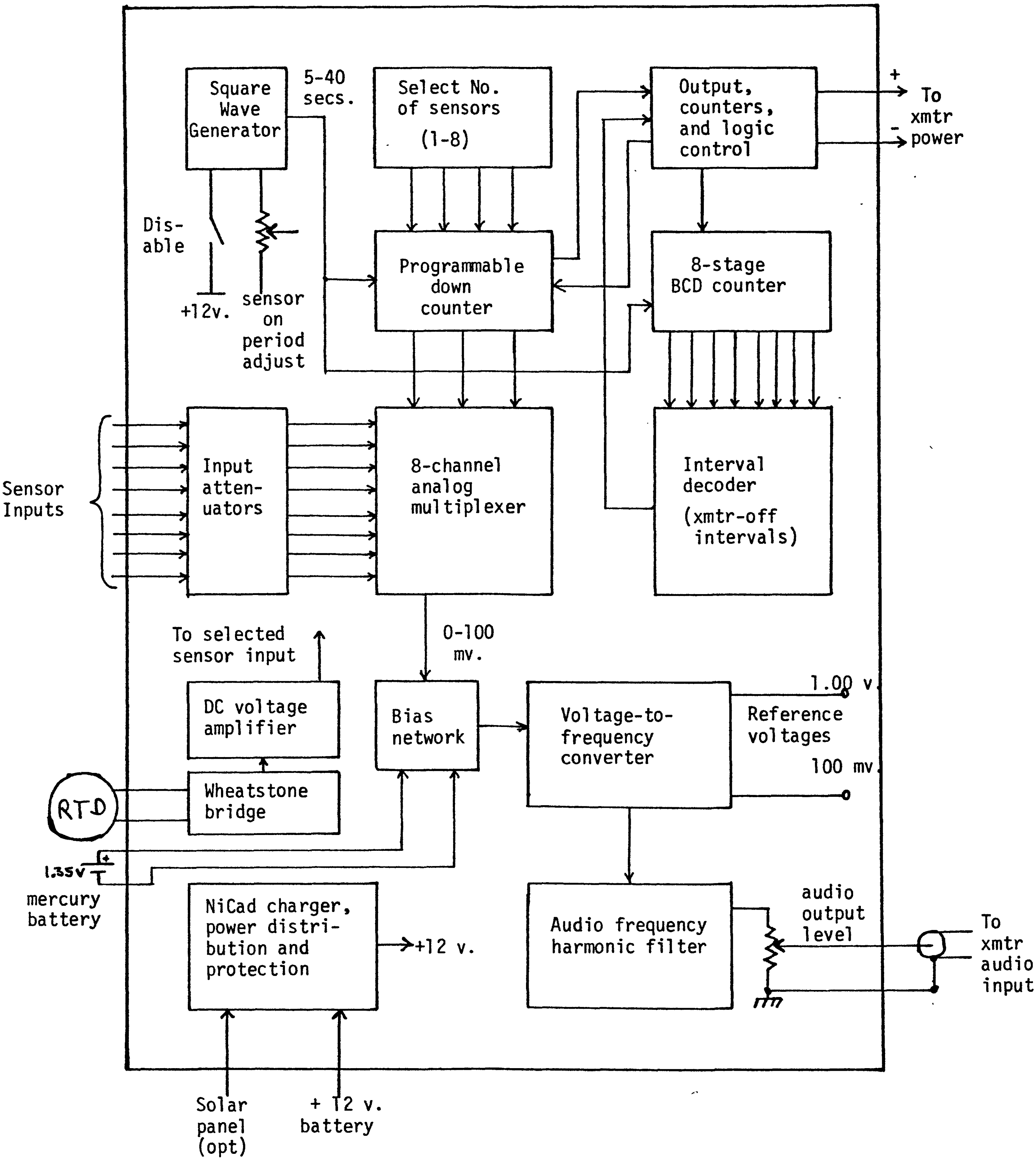


Figure 1. Block diagram

Table 1

R1 Select for
Basic Sensor Period

| Sensor Period (secs) | C1 (μfd) | R1 (MΩ) |
|---|---|---|
| 2 | .1 | 1.0 |
| 5 | .1 | 2.0 |
| 10 | .1 | 3.9 |
| 15 | .1 | 5.6 |
| 20 | .1 | 6.8 |
| 25 | .1 | 8.0 |
| 30 | .1 | 9.1 |
| 35 | .1 | 10.2 |
| 40 | .2 | 6.8 |
| 45 | .2 | 7.5 |
| 50 | .2 | 8.0 |
| 55 | .2 | 8.6 |
| 60 | .2 | 9.1 |

Table 2

Programming for
No. of Sensors

| No. of Sensors | Install Jumpers |
|---|---|
| 1 | J3 |
| 2 | J2,J3 |
| 3 | J4 |
| 4 | J2,J4 |
| 5 | J3,J4 |
| 6 | J2,J3,J4 |
| 7 | J1 |
| 8 | J1,J2 |

Table 3

Programming No. of
Sensor "off" periods

| No. "off" Periods | Insert Jumper From Z to: |
|---|---|
| 1 | U |
| 2 | T |
| 4 | S |
| 6 | M |
| 8 | R |
| 12 | N |
| 16 | Y |
| 20 | P |
| 24 | Q |
| 32 | X |
| 64 | W |
| 128 | V |

Table 4

Select R22, R23, C3, C4, & C5 for Audio Channel Used

| Channel | $f_0$(Hz) | R22(Ω)* | R23(Ω) | R22+R23(Ω) | C3(μfd)** | C4(μfd)** | C5(μfd)** | C3+C4+C5 |
|---|---|---|---|---|---|---|---|---|
| 1 | 680 | 510 | 270 | 780 | 0.068 | 0.068 | None | 0.1280 |
| 2 | 1020 | 820 | 300 | 1120 | 0.068 | 0.018 | 0.0027 | 0.0892 |
| 3 | 1360 | 1200 | 260 | 1460 | 0.068 | 0.0005 | 0.00025 | 0.0685 |
| 4 | 1700 | 1500 | 300 | 1800 | 0.047 | 0.005 | 0.0039 | 0.0556 |
| 5 | 2040 | 1800 | 340 | 2140 | 0.047 | None | None | 0.0467 |
| 6 | 2380 | 2200 | 280 | 2480 | 0.022 | 0.018 | None | 0.0403 |
| 7 | 2720 | 2700 | 120 | 2820 | 0.022 | 0.01 | 0.0039 | 0.0355 |
| 8 | 3060 | 3000 | 160 | 3160 | 0.022 | 0.01 | None | 0.0316 |

*1% or better, low temperature coefficient, **2% or better, polystyrene

Table 5

Platinum RTD Characteristics

| Temp (°C) | RTD ohms |
|---|---|
| 0 | 100.0 |
| 25 | 109.7 |
| 50 | 119.4 |
| 75 | 129.0 |
| 100 | 138.5 |
| 125 | 147.9 |
| 150 | 157.3 |
| 175 | 166.6 |
| 200 | 175.8 |
| 250 | 194.1 |

Table 6

Programming the
U9 Reference Voltage

| Output Voltage U9 pin 1 | Jumper J15 Installed Between |
|---|---|
| 10.0 | Omit |
| 7.5 | 44 & 46 |
| 5.0 | 40 & 44 |
| 2.5 | 40 & 46 |

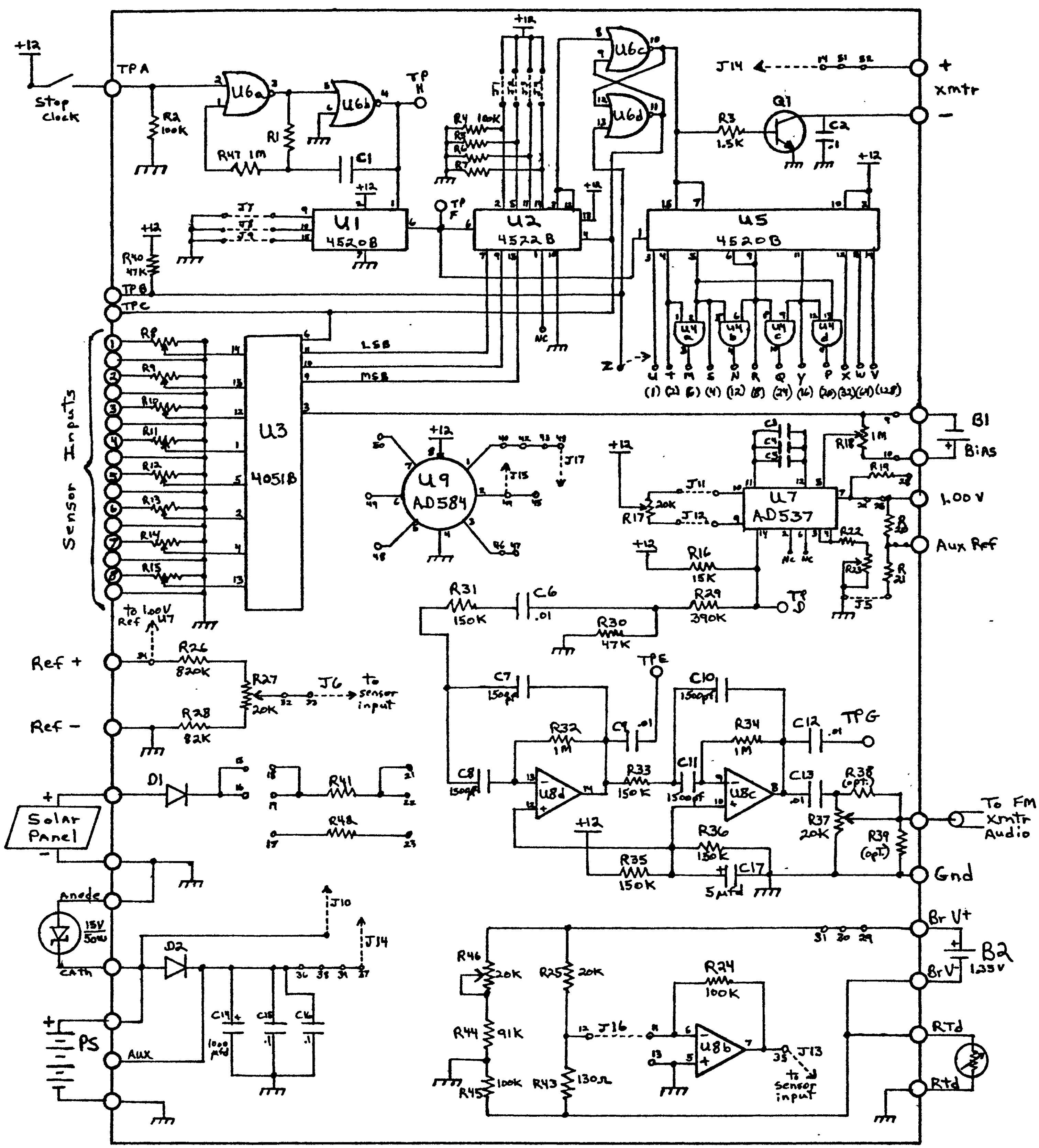


Figure 2. Complete schematic of the analog data telemetry transmitter

A radio transmitter can be turned on and off by transistor Q1 driven by a flip-flop composed of the other two sections of the 4001 NOR gate (U6) which is in turn controlled by the combination of a 4522 (U2) and another 4520 divide-by-16 counter (U5). The number of basic sensor periods that the transmitter is off can be programmed by a jumper wire (see table 3) from point Z (see schematic) to the appropriate output of U5 or the 4081 quad 2-input AND gate (U4). If point Z is jumpered to an output other than points M, N, Q, or P, then U4 is not necessary. The output signals from U2 control the channel selection of the 4051 8-channel multiplexer (U3). Since U2 counts backwards, the inputs of the 4051 are read in reverse order. For example, if U2 is jumper programmed to scan 4 sensor inputs, channels 4-3-2-1 of the 4051 multiplexer will be scanned in that order.

Sensors or reference voltages are connected to the appropriate inputs of U3 through low-temperature coefficient trimmer resistors (if necessary) to attenuate the sensor signals to appropriate levels. The standard input range after trimming is 0 to 100 mv. As each sensor input is scanned, the corresponding signal is routed to the Analog Devices AD537 V/F converter (U7). There, the voltage from each sensor is converted into a corresponding audio frequency. A bias potential is provided at the input of U7 to boost the resulting frequency output into standard seismic audio channels (see table 4). For example, to utilize the 1700 Hz seismic audio channel, a bias voltage of 1.700 volts would be required at the input of U7 to produce an output frequency range of 1700 Hz to 1800 Hz for a sensor input range of 0 to 100 mv.

Capacitor C3 is the timing capacitor for the AD537 and its value is chosen by the relationship, $freq_{out} = V_{in}/10RC$. Therefore, using the recommended 1 mA of drive current, a 0.001 μf timing capacitor will give a 100 kHz full scale frequency and a 0.01 μf value will give 10 kHz, etc. If needed, C4 and C5 can be added in parallel with C3 to achieve non-standard values of capacitance. The combination of R22 and R23 is the scaling resistance for U7. In this case,

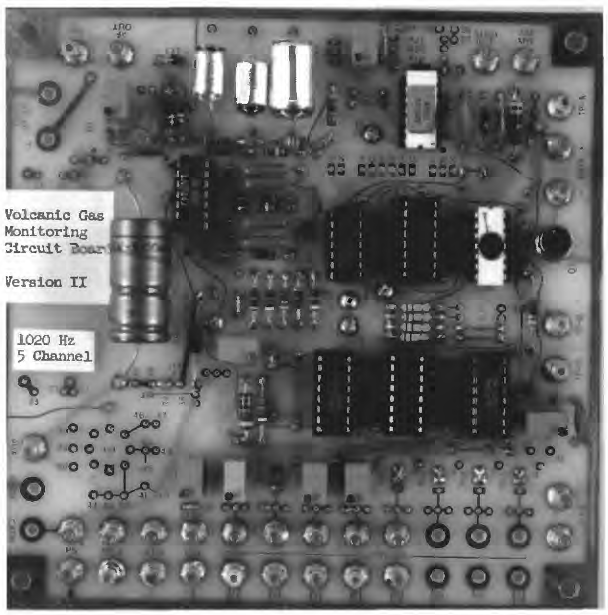


Figure 3. Photograph of the circuit board layout

R = V/I, where V is the full-scale input voltage to pin 5 of U7 and I is the full-scale current (1 mA). Therefore, a 10 volt range would require a 10k ohm resistor, etc. All of the frequency determining components used with the AD537 should be of the low temperature coefficient variety. The frequency output from U7 is routed through two successive sections of a LM124 quad operational amplifier (U8) to transform the waveform from square into sinusoidal and act as a harmonic filter. The LM124 was selected because it can be operated from a single voltage supply and it has a low current drain (typically 0.8 mA). The output level from the final section of the LM124 is adjusted by means of a resistor network to accomodate the input requirements of a variety of radio transmitters. The value of resistor R29 can be decreased to increase the output level.

A wheatstone bridge and amplifier (using the unused section of the LM124 quad op amp) combination is provided in the circuit to be used with a platinum RTD temperature sensing device. The bridge is driven by a 1.35 volt mercury battery and the output from the bridge/amplifier can be jumpered to any of the sensor inputs. The temperature measuring circuit is typically configured to operate in the 75°-220°C range (130-180 ohms, see table 5). The output, however, operates in reverse (if temperature goes up, voltage/frequency output goes down).

Also provided for in this system is a full scale (100 mv) reference signal using the 1.00 volt reference signal from U7 with R26, R27, and R28. The 100 mv signal can be connected to any of the 8 sensor inputs using jumper J6 (see schematic). A 0 mv (or ground) reference signal is generated by grounding one of the sensor inputs. Other reference voltages can be generated by installing the optional AD584 monolithic multiple voltage reference (U9) and connecting its output through a resistance dividing network to the appropriate sensor input terminal.

As in the previous system, the provision for solar panel operation has been included. If a zener diode is used to regulate the output from a solar panel, R41 and R42 can be used for the required limiting resistance. D1 should be installed in that case.

In the normal configuration of this circuit, the audio output is connected to a VHF FM radio transmitter for transmission of the data (either direct or via a repeater) to a convenient receiving and recording site. However, it is possible to use a long two-wire cable to relay the data by taking the output directly from U7 at TP-D. It is also possible to configure the circuit to continuously transmit data (no off periods). In that case, the connection between U6c-8 and U2-3 is broken and U6c-8 is grounded. In addition, there would be no jumper at point Z while Q1, U4, and U5 would not be necessary.

This system is designed to be used with a standard constant bandwidth seismic discriminator, such as the U.S.G.S. Model J101 or the Develco Model 6203, at the receiving site. When using the U.S.G.S. Model J101, the recommended zero reference frequency can be set below the standard constant bandwidth frequency (for example: 970 Hz rather than 1020 Hz) to ensure good capture when frequency multiplexing with other carrier signals. A small chart recorder (i.e., a Rustrak DC recorder) that prints a series of dots on pressure-sensitive chart paper can be used at the discriminator output to record the data. The output from each of the channels appears as a continuous line on the chart paper.

## REFERENCES CITED

Lancaster, Don, 1977, CMOS Cookbook: Howard W. Sams & Co., Inc., 414 p.

McGee, K.A., and Sato, M., 1979, An Analog Data Telemetry System for Remote Monitoring Applications, Version I, U.S.G.S. Open-File Report No. 79-276, 11 p.

PARTS LIST

C1 - see Table 1
C2 - 0.1 uf disc ceramic
C3 -
C4 - polystyrene timing capacitors
C5 - see note 1 and Table 4
C6 - 0.01 uf disc ceramic
C7 - 1500 pf mica
C8 - 1500 pf mica
C9 - 0.01 uf disc ceramic
C10 - 1500 pf mica
C11 - 1500 pf mica
C12 - 0.01 uf disc ceramic
C13 - 0.01 uf disc ceramic
C14 - 1000 uf, 25v, electrolytic
C15 - 0.1 uf disc ceramic
C16 - 0.1 uf disc ceramic
C17 - 5 uf, 10v, electrolytic

R1 - see Table 1
R2 - 100k ohm, 1/4 watt
R3 - 1.5k ohm, 1/4 watt
R4 - 100k ohm, 1/4 watt
R5 - 100k ohm, 1/4 watt
R6 - 100k ohm, 1/4 watt
R7 - 100k ohm, 1/4 watt
R8-
R15- trimmer resistor, 22 turn, Helitrim
R16 - 15k ohm, 1/4 watt
R17 - 20k ohm, Helitrim (opt) see note 2
R18 - 1 Megohm, Helitrim resistor
R19 - (opt)
R20 - (opt) see notes 3 & 4
R21 - (opt)
R22 - see Table 4 and note 5
R23 - 500 ohm Helitrim, see note 5
R24 - 100k ohm, 1/4 watt, 2%, tin oxide
R25 - 20k ohm, 1/4 watt, 2%, tin oxide
R26 - 820k ohm, 1/2 watt, 2%, tin oxide
R27 - 20k ohm, Helitrim
R28 - 82k ohm, 1/4 watt, 2%, tin oxide
R29 - 390k ohm, 1/4 watt, see note 6
R30 - 47k ohm, 1/4 watt, see note 6
R31 - 150k ohm, 1/4 watt
R32 - 1 Megohm, 1/4 watt
R33 - 150k ohm, 1/4 watt
R34 - 1 Megohm, 1/4 watt
R35 - 150k ohm, 1/4 watt
R36 - 150k ohm, 1/4 watt
R37 - 20k ohm, Helitrim
R38 - divider resistor (opt)
R39 - divider resistor (opt)
R41 - 10 watt, see note 7
R42 - 10 watt, see note 7
R43 - 130 ohm, 1/4 watt, 2%, tin oxide
R44 - 91k ohm, 1/4 watt, 2%, tin oxide
R45 - 100k ohm, 1/4 watt, 2%, tin oxide
R46 - 20k ohm, Helitrim
R47 - 1 Megohm, 1/4 watt

Q1 - 2N2102A transistor

D1 - 1N4001 silicon diode
D2 - 1N4001 silicon diode
D3 - 1N2813, 50w, 15v zener diode (opt)

B1 - mercury battery, see note 8
B2 - 1.35 volt mercury "D" cell

U1 - 4520B CMOS IC
U2 - 4522B CMOS IC
U3 - 4051B CMOS IC
U4 - 4081B CMOS IC
U5 - 4520B CMOS IC
U6 - 4001B CMOS IC
U7 - AD537 V/F Converter
U8 - LM124J Linear IC
U9 - AD584 Voltage Reference (opt)

Misc: binding posts, transistor socket, gold-plated IC sockets, etc.

Note 1 - C3 is the timing capacitor and its value is chosen by the relationship, $freq_{out} = V_{in}/10RC$. Therefore with 1 mA of drive current, a 0.001 uf timing capacitor will give a 100 kHz full scale frequency and a 0.01 uf will give 10 kHz (maximum frequency is 150 kHz). If needed, C4 and C5 can be added in parallel with C3 to achieve non-standard values of capacitance.

Note 2 - R17 is an optional 20k ohm pot used only when trimming the input amplifier offset. If used, jumpers J11 and J12 should be installed.

Note 3 - With a 91k ohm, 5%, resistor installed at R19 and a jumper from hole 28 to one of the sensor inputs, a value of 10k ohm resistance from a thermistor will develop 100 mv at that sensor input. Similarly, 5k ohms will develop 52.1 mv and 1k ohms will develop 10.9 mv. A calibration curve can then be drawn relating temperature in °C to the developed millivoltage.

Note 4 - Should a specific voltage be desired at one of the sensor inputs for ID or some other purpose, a 91k, 5%, resistor can be installed at R20 and a jumper connected from hole 27 to one of the sensor inputs. Then a 10k ohm resistor at R21 would develop 100 mv at the sensor input, 5.6k ohms at R21 would develop 58 mv, 2k ohms at R21 would develop 21.5 mv, and so on.

Note 5 - The combination of R22 and R23 is the scaling resistance for the AD537. In this case, R = V/I, where V is the full-scale input voltage to pin 5 of the AD537, and I is the full-scale current (1 mA). Therefore, a 10 volt range would require a 10k ohm resistor, and so on. R23 should have a low temperature coefficient such as a Helitrim trimmer.

Note 6 - Output circuitry depends on the specific telemetry or radio system being used. The values listed are compatible with a Repco Model 810-041 transmitter. The Repco unit requires 5 - 10 mv of audio. To raise the audio level decrease the value of R29.

Note 7 - If a solar panel and zener diode are used, the value for the limiting resistor (R41) is calculated by:

$$R = \frac{E_{in} - E_{out}}{I_{load} + I_{zdl}},$$

where $E_{in}$ is the unregulated source voltage, $E_{out}$ is the regulated output voltage of the zener, $I_{load}$ is the maximum current load, and $I_{zdl}$ is the nominal current through the zener (normally 10% of $I_{load}$). Space is provided for another resistor (R42) for series or parallel connection to R41.

Note 8 - B1 is a source of bias voltage to the AD537 and serves to raise the audio output into standard seismic audio channels. For example, to utilize the 2380 Hz seismic channel, a bias voltage of 2.38 volts would be required at the input of U7 to provide an output frequency range of 2380 Hz to 2480 Hz for a sensor input of 0 to 100 mv. R18 is provided to trim the voltage from B1.