Technical Manual for the Experimental Acoustic Flow Monitor

By Kevin C. Hadley and Richard LaHusen

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Abstract

A debris flow detection system that monitors ground vibrations has been developed by the U.S. Geological Survey (USGS) in Vancouver, WA. The acoustic flow monitor (AFM) uses a non-contact method of flow detection for high reliability. Prototype AFM systems were installed at several locations for evaluation, including Redoubt Volcano, Alaska; Mount Saint Helens, Washington; and Pinatubo Volcano, Philippines. The AFM hardware consists of a microprocessor based field module and a geophone sensor. The field module analyzes signals from the sensor and radio transmits data to a base station computer. Electronic circuitry of the AFM consists of the sensor pre-amplifier, signal conditioning, analog to digital conversion, and microprocessing sub-circuits. Circuit descriptions, schematic diagrams, and parts lists are provided in this technical manual to assist scientists and technicians using the prototype AFM to maintain their systems. A troubleshooting guide is provided for the electronic technician.

INTRODUCTION

A debris flow detection system that monitors in-ground acoustic vibrations has been developed by the U.S. Geological Survey (USGS) in Vancouver, Washington. The Acoustic Flow Monitor (AFM) experimental model was first built in 1989 and tested during the 1990 eruptions of Redoubt Volcano, Alaska (Brantley, 1990). Since 1990, the AFM system has been installed for evaluation purposes at Mount St. Helens and Mount Rainier in Washington, Jiangjia Ravine in China, Cotopaxi Volcano in Ecuador and Pinatubo Volcano in the Philippines (Hadley and LaHusen, 1991).

The AFM has several features that give it versatility and durability. The non-contact method of flow detection eliminates the need for repetitive and hazardous maintenance of equipment after each debris flow, unlike a trip wire detection system. The AFM equipment is weatherproof, rugged, and has been proved to operate at remote sites under extreme temperature and humidity conditions. Two-way radio communications enable automatic, real-time data transmissions from remote instrument sites to a base station receiver. Users have the ability to query the AFM field units from a base station computer to obtain data or modify system operating parameters.

Purpose and Scope

In support of cooperating scientists and technicians who are currently utilizing the AFM experimental model, this manual is intended to provide the necessary technical information for persons with a working knowledge of electronics to maintain the AFM hardware. Schematic diagrams, component layouts and parts lists are provided, as well as guidelines for troubleshooting the circuitry.

Acknowledgments

The authors would like to acknowledge those persons who have provided assistance to install, maintain and provide evaluation comments on the hardware,

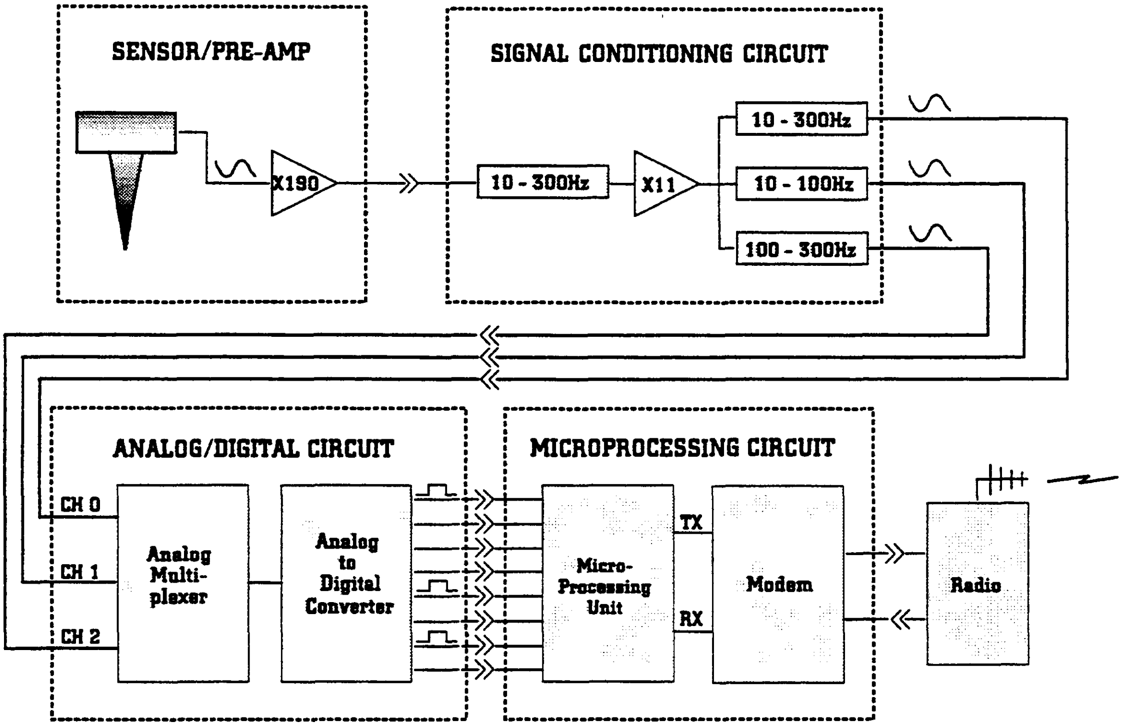

Figure 1. Acoustic Flow Monitor system simplified functional block diagram.

software and performance of the experimental AFM systems. In particular, individuals who have provided exceptional support include: Joe Dorava of the Alaska Volcano Observatory, Jinfan Duan and Ye Mingfu at the Dongchuan Debris Flow Observation Center in China, Patricia Mothes and Wilson Enriques of the Instituto Geofisico-Escuela Politecnica Nacional in Quito, Ecuador and Sergio Marcial and Arnoldo Melosantos of the Philippine Institute of Volcanology and Seismology.

THEORY OF OPERATION

The AFM is a micro-powered field computer programmed to continuously analyze the amplitude, frequency and duration of ground vibrations. The AFM reads and transmits digital data via UHF radio back to a base station receiver at timed intervals. If debris flow activity is detected a data set is sent immediately.

The AFM is designed to analyze the frequency spectrum, 10 to 100 Hz, where acoustic ground signals generated by debris flows are known to occur (Okuda and others, 1979). A geophone sensor converts ground motion to input signals for the AFM module. Input peak amplitude values are compared with a 'threshold' value stored in the AFM memory. If input signal levels exceed the threshold the AFM begins tracking the elapsed time that input levels remain above threshold and compares the elapsed time with a 'duration' value stored in memory. If the elapsed time value exceeds the duration the AFM jumps to an alert mode resulting in an immediate data set transmission that is flagged to indicate a debris flow alert status. The AFM will remain in alert mode and continue to send flagged data at 1 minute intervals while input levels remain above threshold. When the signal level drops below threshold the AFM resumes normal operation sending unflagged data transmissions at preset timed intervals, typically every 30 minutes. The threshold, duration and frequency band values define the criteria for debris flow detection by the AFM. These parameters may vary depending on desired sensitivity of the unit at each field site.

SYSTEM OVERVIEW

The AFM circuitry is composed of several functional subsystems (fig. 1). The geophone sensor converts vertical ground velocity to an analog signal. A signal preamplifier located near the geophone sensor maximizes the input signal-to-noise ratio to the AFM

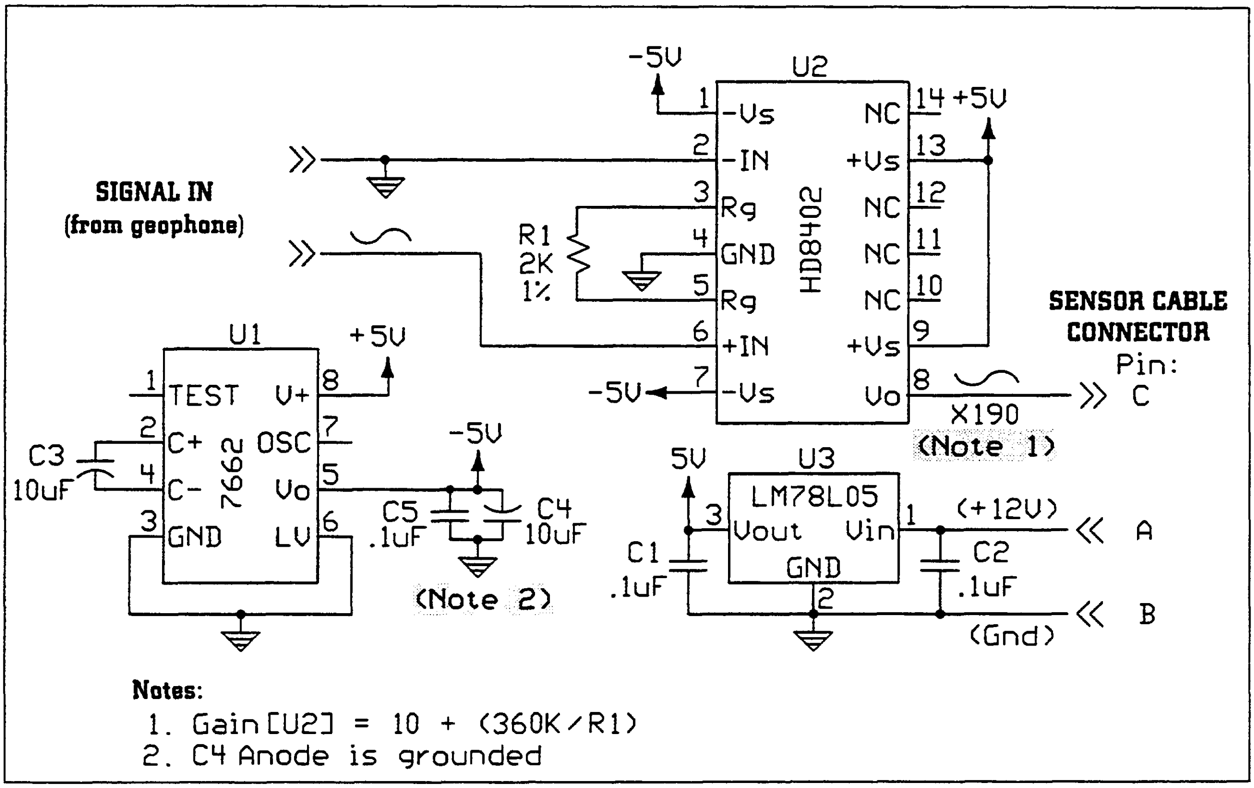

Figure 2. Signal preamplifier schematic diagram.

from the sensor cable. The amplified signal is filtered into 3 frequency components by the signal conditioning circuit of the AFM module. An analog multiplexer (MUX) consecutively selects the 3 input channels to be digitized by the analog-to-digital converter (ADC). The micro-processing unit (MPU) controls input channel selection and analog-to-digital conversions. The MPU also controls radio communications. Radio transmissions are activated by the push-to-talk (PTT) circuit and data are modulated by the 300 baud modem and passed to the radio transmitter. The AFM, while analyzing acoustic data, monitors radio communications for commands from the base station or other AFM units.

CIRCUIT DESCRIPTIONS

Appendixes in this report include complete schematic diagrams, component layout diagrams, hardware connectivity diagram, and parts lists for circuits discussed. Sub-circuit diagrams are included in this section for quick reference.

Sensor and Preamplifier

The AFM system uses a Mark Products model L10-AR geophone as the vibration sensor. The geophone is inexpensive, waterproof and rugged. It has a specified -3db frequency response of 10-250 hertz with no spurious responses. The sensor is operated critically damped (0.7 damping) to provide a flat frequency response and prevent overshoot at the 10 hertz resonant frequency.

The signal preamplifier (fig. 2) is a low offset, low power consumption circuit. The printed circuit board (PCB) is cast in epoxy resin for protection against moisture and physical damage. Therefore, the circuit is unserviceable and must be replaced if faulty.

Power to the preamplifier board is provided by the primary +12VDC battery supply and regulated to +5VDC by U3. C1 and C2 decouple transient signals from the DC supplies.

U1 provides -5VDC to U2 by inverting the output from U3. C3 and C4 function as a charge pump/reservoir for U1. C5 is a decoupling capacitor for the output of U1.

Signal gain of U2 is controlled by the value of R1 with the relation $\{\text{Gain}U_2 = 10 + (360K/R1)\}$. R1 is fixed at 2K giving a gain of 190. The output from U2 is applied to the signal conditioning circuit via the geophone cable.

Signal Conditioning Circuit

The signal conditioning circuit (Fig. 3) consists of an amplifier and an array of low pass and high pass filters with associated peak detectors. The signal from the geophone cable is passed through a 300 Hz low pass filter and then amplified (X11). Three parallel filters split the signal into 3 frequency bands: 1) 10-300 Hz, 2) 10-100 Hz and 3) 100-300 Hz. Frequency responses are shown in figure 4. The 10 Hz lower limit is a-function of the geophone frequency response. Peak detectors on the output of each filter track peak signal amplitudes for analysis.

Power to the signal conditioning PCB is derived from the +5VDC power bus on the A/D PCB, discussed in a later section. U1 provides a -5VDC to U2 and U3 by inverting the +5VDC. C4 and C5 are charge pump and reservoir capacitors respectively for U1. AC decoupling capacitors (.1 uF) are used throughout the circuit to eliminate transients on the power supply bus. The 300 Hz low pass filter on the input consists of one-fourth U2, R1 and C6. C8 and C9 are AC coupling capacitors with biasing resistors R2 and R5 respectively. The filtered signal is amplified by one-fourth U2, R3 and R4. The signal is filtered by 3 parallel filter circuits consisting of one-fourth U2, R6 and C12 (300 Hz low pass); one-fourth U3, R8, C13 and one-fourth U3, R9, C14 (2-stage 100 Hz low pass); and one-fourth U3, C16, R11 and one-fourth U3, R12, C20 (2-stage 100 Hz high pass). Diodes D1, D2 and D3 and their corresponding operational amplifiers U2 and U3 function as amplitude rectifiers. Capacitors C11, C15 and C19 with resistors R7, R10, and R13 respectively provide an envelope output of peak amplitude levels for each frequency band on J1. The outputs are applied to the mux input channels on the Analog/Digital circuit.

Analog/Digital Circuit

The Analog/Digital (A/D) PCB contains 5 subcircuits: 1) the analog multiplexer (MUX), 2) -5VDC power supply, 3) peripheral interface adapter (PIA), 4) 12 bit analog-to-digital converter (ADC), and 5) address decoder circuits.

Signal inputs are coupled to the A/D PCB through connector P2 and appear on MUX U3 pins 13, 14, and 15 (fig. 5). Channel selection is controlled by logic levels applied to U3, pins 9, 10, and 11 from PIA U1 pins 4, 3, and 2 respectively (see Appendix 4). The MUX output on U3, pin 3 is buffered by U9 and applied to ADC U2, pin 3 (fig. 6).

An analog to digital conversion is initiated by a write cycle to U2 that toggles U2, pin 9 and 10 to a low logic level. A 2 millisecond software pause allows completion of the conversion before the first byte is read. A read cycle occurs when U2, pin 11 is toggled low via inverter U5. The high byte (bits 0 through 7) is read on the first read cycle and the low byte (bits 8 through 12) on the second. The conversion and read steps are repeated for each input signal channel.

Power to the A/D PCB on P3, pin 36 is derived from the +5VDC regulated supply of the MPU PCB, discussed later in this section. U10 inverts the +5VDC supply producing a -5VDC supply output to U2, U3 and U4. U8 provides a stable +5VDC reference to U2. L1 and D1 operate as a one way charge pump and C18 as a reservoir for U10.

Chip selection for the A/D PCB is controlled by U6 which decodes addresses appearing at U6, pins 1, 2 and 3.

Microprocessor Unit Circuit

Subcircuits on the MPU PCB include: 1) the microprocessor unit (MPU) and memory, 2) address decoder, 3) real-time clock, 4) 300 baud modem, and 5) regulated power supply circuits.

MPU U1 is an 8-bit CMOS microprocessor. The instruction code for U1 is stored in U3, UV-erasable read-only memory (EPROM) (see Appendix 4). Random access memory (RAM) for MPU U1 is provided by U4. Upon power-up, the inputs on U1, pins 8, 9, and 10 are latched to set the MPU mode of operation (fig. 7). The mode of operation is set for a multiplexed A0-A7 address/D0-D7 data bus and an externally derived serial communications clock. Address lines A0-A7 are latched to the address bus by U2 and controlled by the address strobe at U1, pin 39 (see Appendix 4). The serial communications interface (SCI) of U1 is set at 300 baud by the pulse rate from U7, pin 13 which is gated through U8 and applied to U1, pin 10. The system clock frequency (E) appearing at U1, pin 40 is equal to 614 KHz or

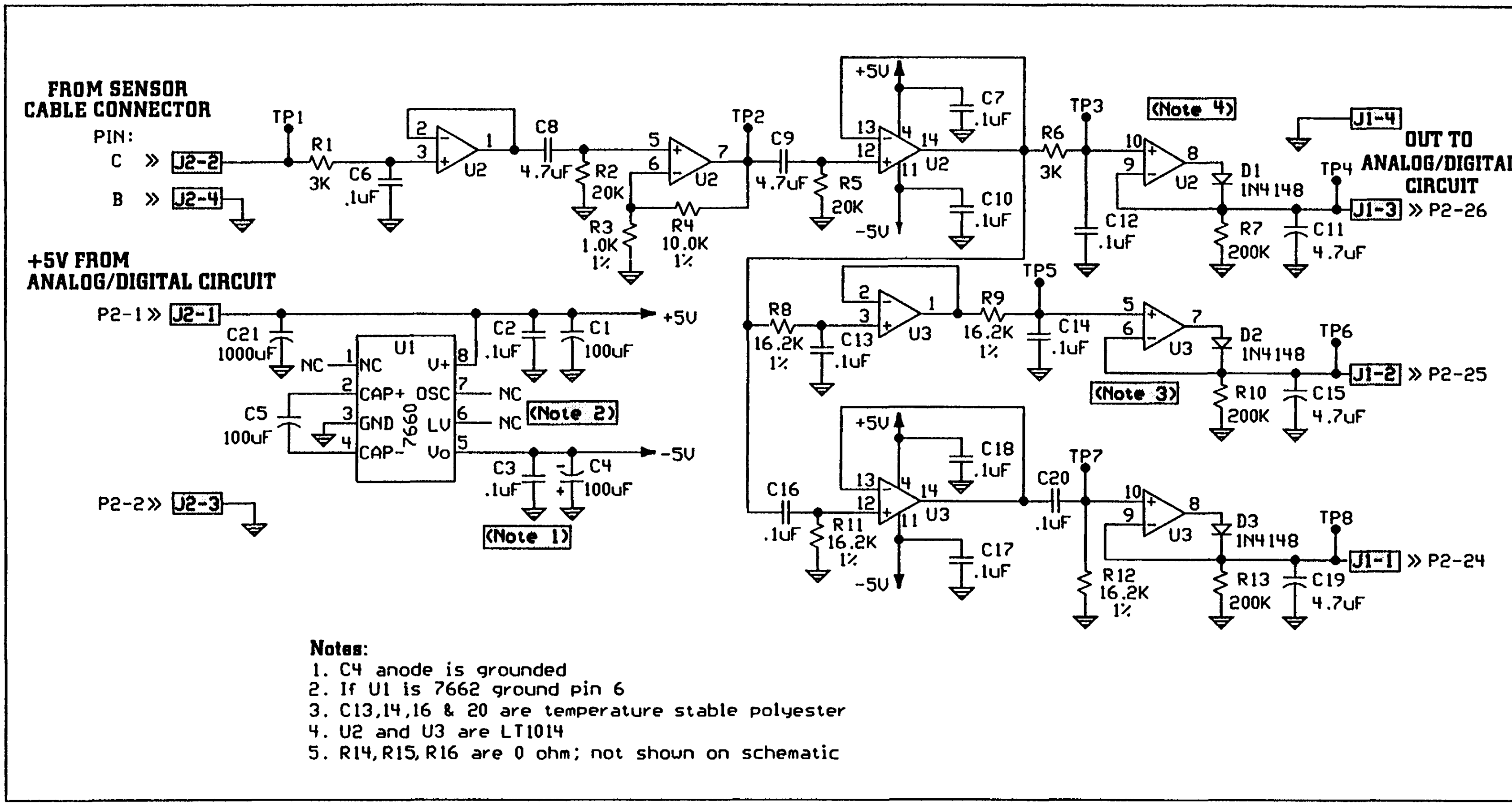

Figure 3. Signal conditioning circuit schematic diagram.

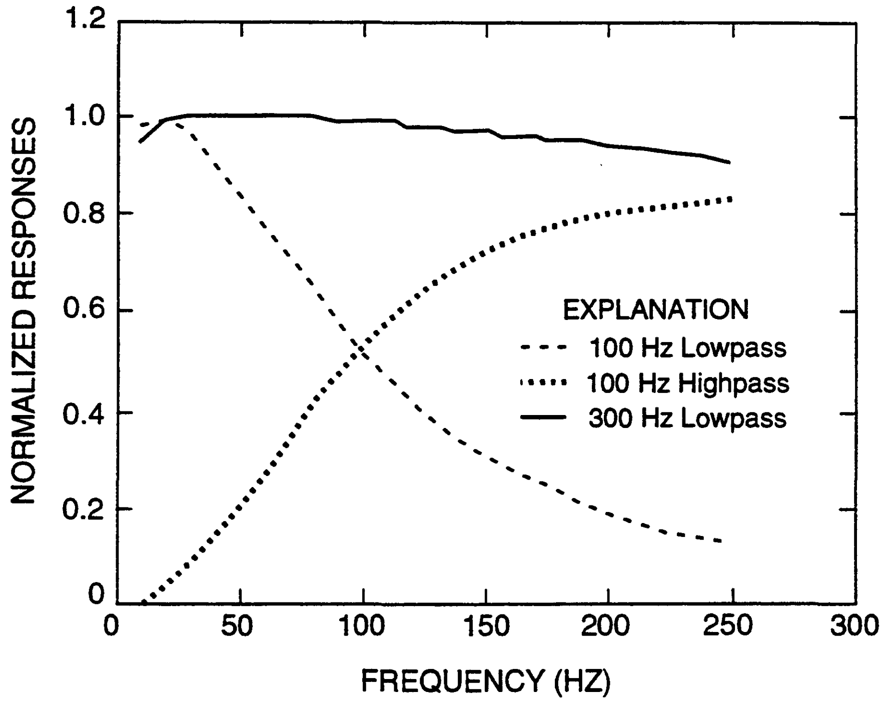

Figure 4. Frequency response of the Signal Conditioning Circuit.

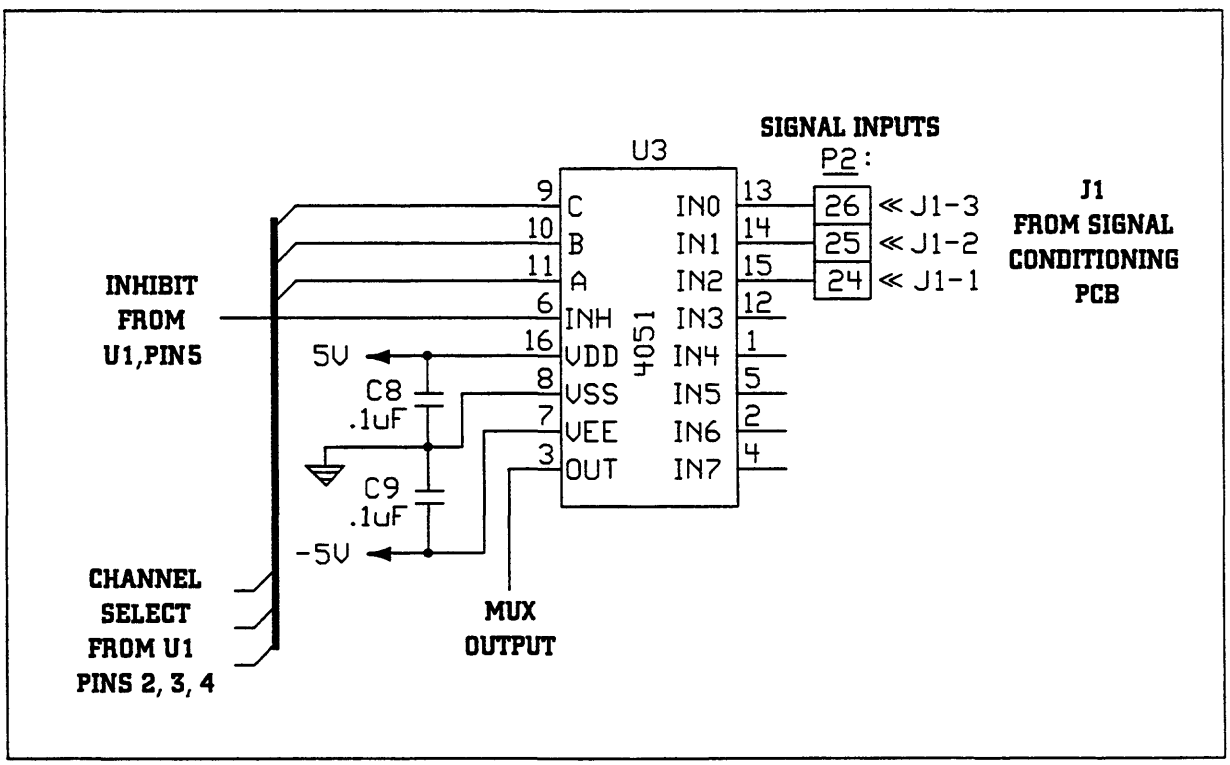

Figure 5. Analog multiplexer subcircuit schematic diagram.

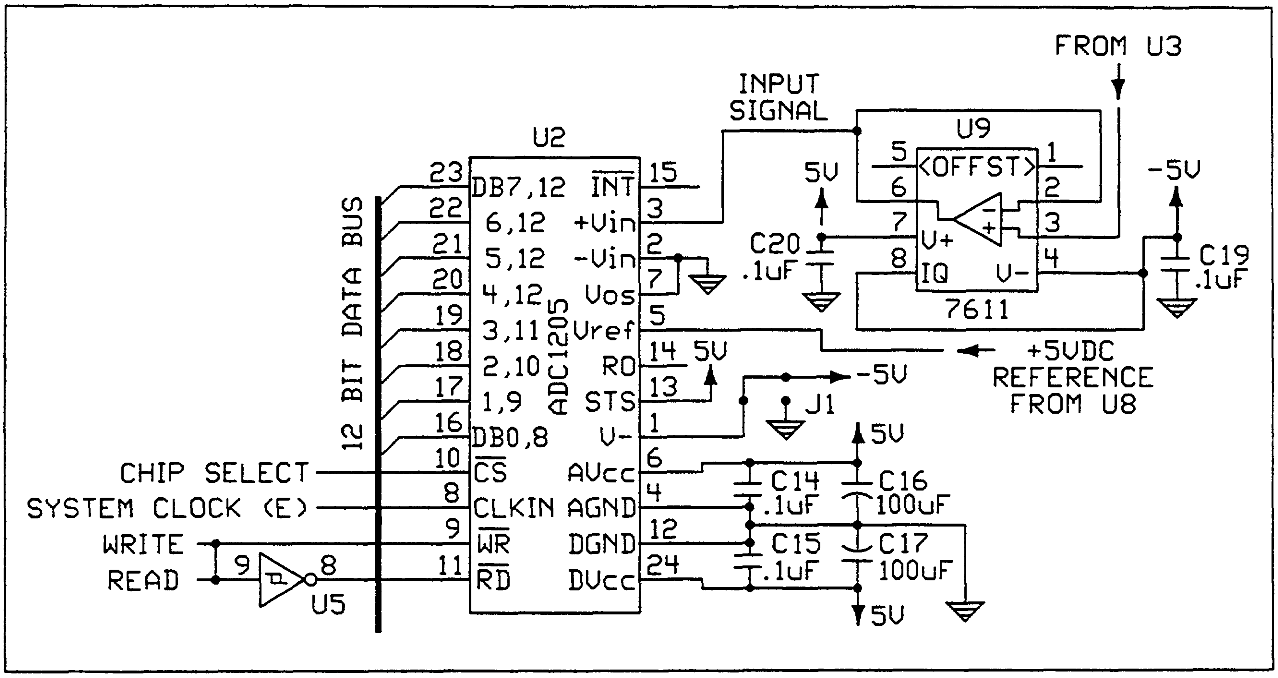

Figure 6. Analog to Digital converter subcircuit schematic diagram.

one-fourth the oscillating frequency of Y1. In addition to setting modes of operation, U1 also establishes the AFM station identification (ID) number by reading the inputs on U1, pins 16, 17, and 18 which are manually set with switch SW2.

A restart of the AFM will occur with a restoration of power to the unit or by resetting the MPU with SW1. Upon restart operating parameters including: 1) threshold, 2) duration and 3) transmit interval are set to default values in the instruction code stored in U3.

U10 is a real time clock/calendar that interfaces directly with U1 and has programmable operation modes (fig. 8). Upon restart, U1 writes to the U10 command register setting the clock operation modes to a 24 hour cycle with an oscillator frequency of 32.768 KHz provided by Y3, C20, and C21. If primary power to U10 is removed backup power from battery BT1 will maintain clock operation and settings.

Modem U5 interfaces the MPU SCI I/O ports (U1, pin 11 & 12) to the UHF transceiver (fig. 9). U5 has originate and answer modes of operation that are controlled by the logic level appearing on U5, pin 13. A logic high from U1, pin 19 simultaneously sets U5 to originate mode and activates the push-to-talk (PTT) circuit (Q1) enabling the radio transmitter. Data transmitted from U1, pin 12 appears on U5, pin 11. The modulated data output on U5, pin 17 is sent to the transmitter. On the receive side, data from the receiver appears on U5, pin 16. The demodulated digital data on U5, pin 5 is applied to U1, pin 11. Transmit and receive digital data appear at TP3 and TP2 respectively for test purposes. T1 and T2 provide impedance matching between the modem and transceiver. The transmit level of U5 (-9 dbm) is set by R7. Carrier detect timing and carrier detect threshold circuits internal to U5 are set by C14 and C15 on U5, pins 4 and 7 respectively.

Address decoder U11 decodes U1 address bus lines A13, A14, and A15 on U11, pins 1,2, and 3 respectively for chip selection on the MPU PCB (see Appendix 4).

Power to the MPU, A/D, and signal conditioning PCB's is provided by a +5VDC regulating supply circuit including U6 and Q3 (fig. 10). D1 and R11 form a voltage reference to amplifier U6. U6 drives transistor Q3 and feedback from the emitter of Q3 is applied to U6, pin 2. U6 adjusts the base current of Q3 to maintain a regulated +5VDC supply. R10 sets the quiescent operating current of U6.

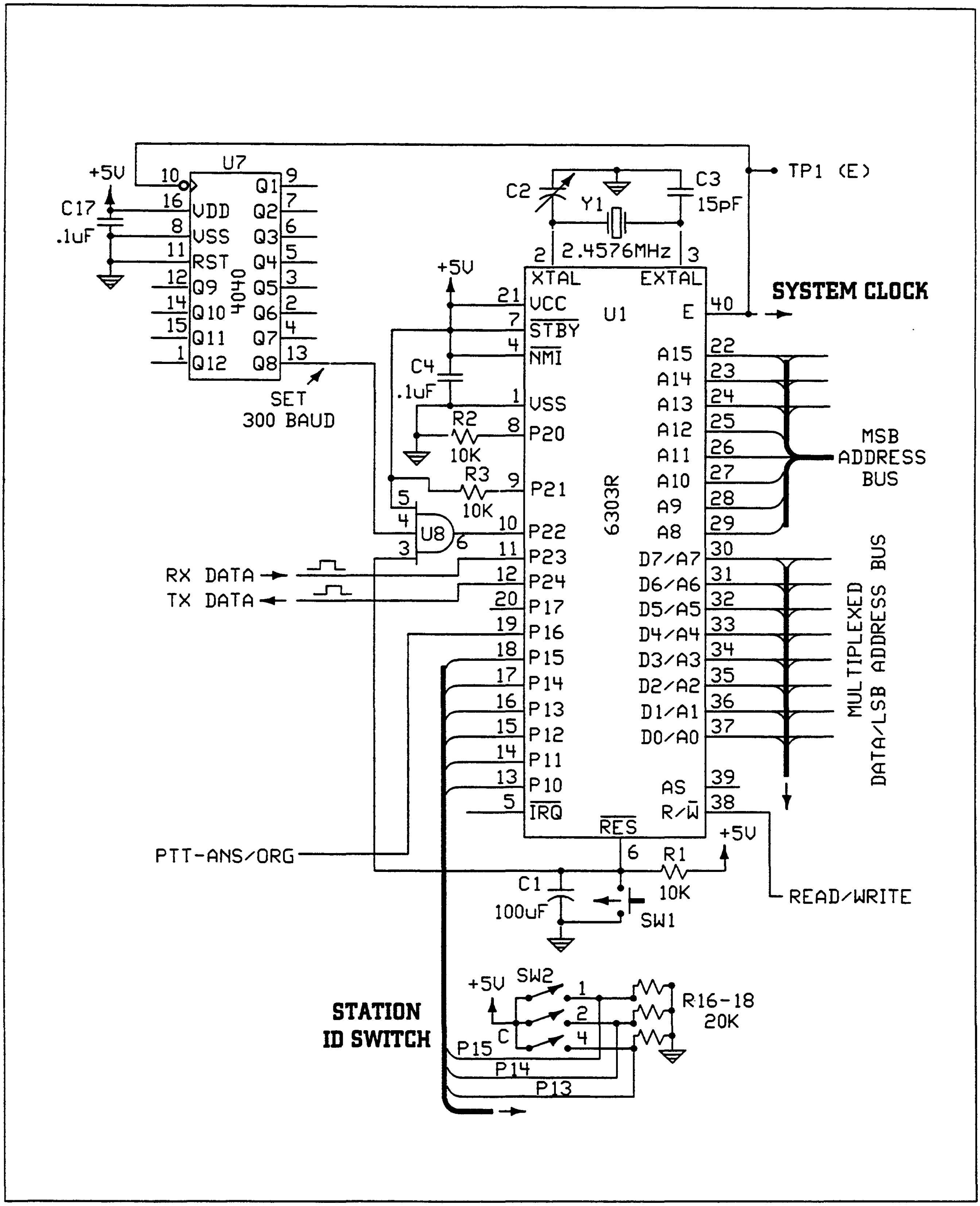

Figure 7. Microprocessor unit sub-circuit schematic diagram.

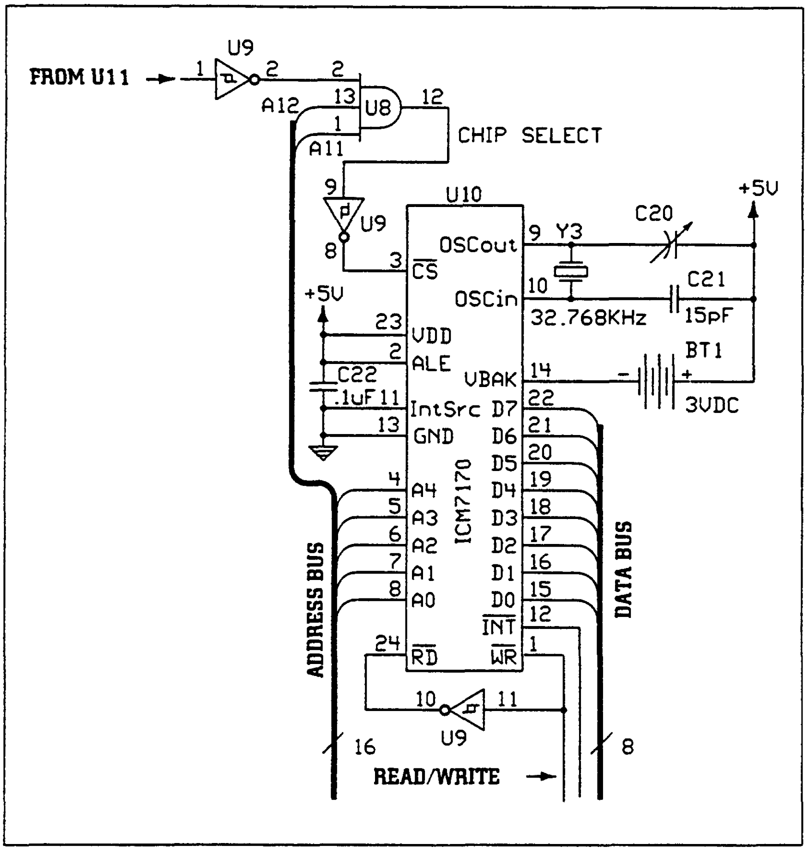

Figure 8. Real time clock/calendar sub-circuit schematic diagram.

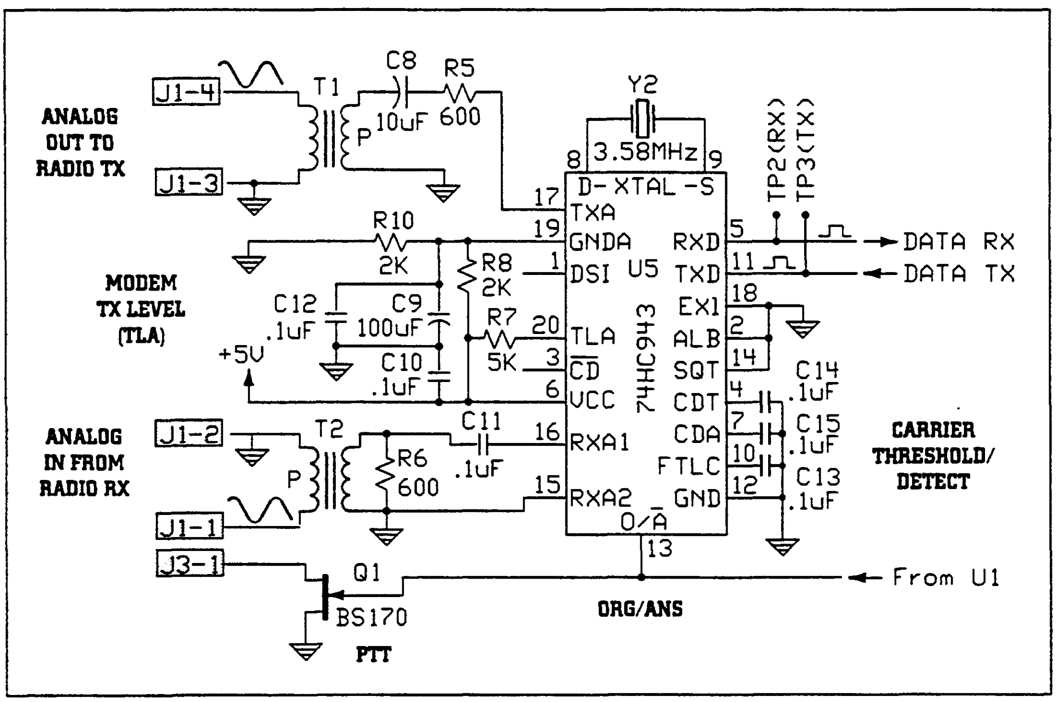

Figure 9. Modem subcircuit schematic diagram.

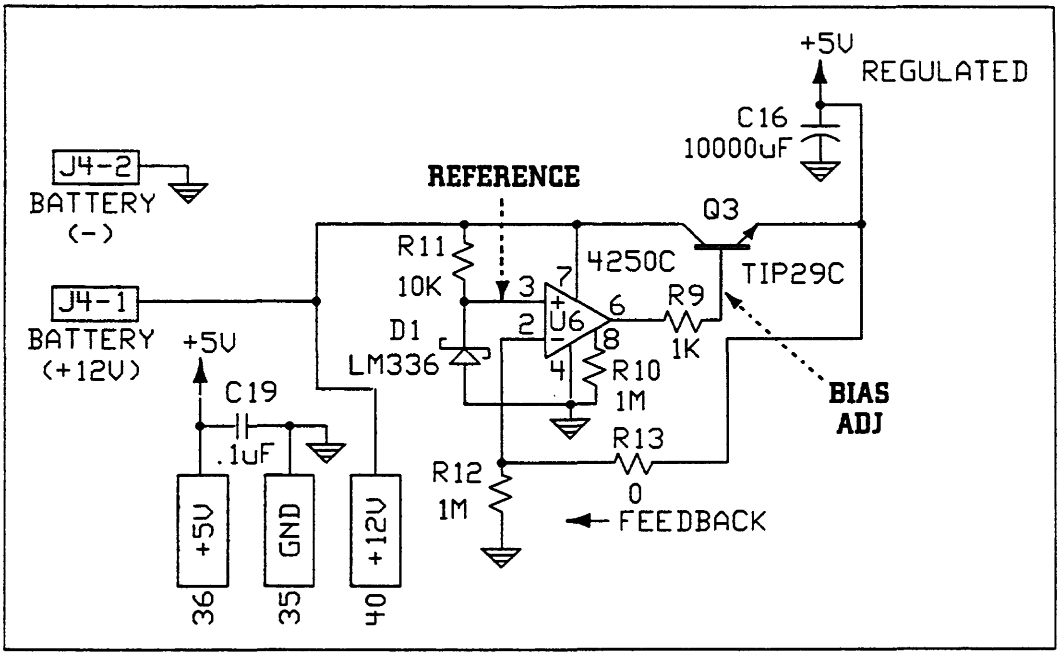

Figure 10. +5VDC regulated supply subcircuit schematic diagram.

SYMPTOM ANALYSIS AND TROUBLESHOOTING

Troubleshooting and repairing of the AFM electronics requires a trained technician who has a solid understanding of electronic principles, both analog and digital, and proper test/repair procedures. The following guide will assist the technician in isolating a problem area on the circuit board. Knowledge of the test equipment and theory of operation of the circuits is imperative to effectively troubleshoot problems to the component level.

Equipment needed: 1) multimeter, 2) oscilloscope, 3) signal generator, 4) watt meter, 5) frequency counter and 6) radio scanner.

Regulated supply (+5VDC)

Symptom: +5VDC supply absent from all or part of circuit.

Areas to check:

1) +12VDC primary power input to the PCB - using a multimeter measure the voltage across J4 on the MPU PCB (see Appendix 1). (12 - 14.5 volts = ok).

2) The +5VDC regulated supply circuit - measure the voltage at TP4 (4.8 - 5.2 volts = ok).

3) The +5VDC supply bus - verify continuity of the +5VDC supply bus to problem areas.

Symptom: Excessive current consumption.
Normal maximum current consumption (not including radio):

Total, all PCBs (< 35mA = ok).

MPU and A/D only (< 30mA = ok)

MPU only (< 20 mA = ok)

Areas to check:

1) PCB solder side - inspect the solder side of the PCB for solder bridges or shorted leads (applies primarily to newly constructed or reworked boards). If corrosion is present on older boards, remove it and recheck current consumption.

2) Component side; integrated circuit (IC) or discrete component - Visually look for signs of a faulty component such as discolored, chipped, or broken component cases. Check for bent component leads or IC pins and pins not fully inserted into a socket.

3) IC removal - If component failure is suspected power down the circuit and remove all IC's. Never insert or remove IC's from a powered circuit. Discharge C16 before removing or inserting IC's. With all IC's removed, power up the circuit and recheck supply current consumption (< 10mA = ok). If current consumption is still high then a defective discrete component exists. Capacitors generally have a higher

failure rate than resistors. If an IC is suspected insert IC's one at a time, with the MPU inserted last, and recheck current consumption, looking for a considerable increase. Replace IC's drawing high current. Electrical characteristics for IC's can be found in manufacturers data books.

Operation of circuit

Symptom: No data is transmitted from AFM
Areas to check:

1) Radio transceiver - with a watt meter and frequency counter, verify that the radio transmitter is functioning properly by measuring the output power and carrier frequency. (refer to the manufacturers radio specifications for tolerances).

2) Modem/PTT interface - with the radio connected to the AFM and power on, perform the following tests:

a) Use a scanner tuned to the transmit frequency to listen for a modem tone (2225Hz) while keying the transmitter. No tone indicates a problem in the modem interface circuit.

b) Initiate an AFM restart with reset switch SW1 of the MPU PCB located on the outside of the PCB enclosure and listen for data being transmitted immediately after restart. Frequency shift keying (FSK) from modem U5 should be clearly heard. No FSK indicates no data being modulated by U5.

c) Verify the PTT circuit is operating. If, upon restart of the AFM, there is no radio carrier present then a problem in the PTT circuit exists. Ground J3, pin 1 on the MPU board. This should activate the transmitter; otherwise, a problem in the cabling to the radio is likely.

3) MPU PCB - with an oscilloscope check the system clock signal (E) from U1 at TP1 (614KHz, 5V pk-pk, square wave = ok). Monitor TP3 on the oscilloscope while initiating a MPU reset with SW1. Look for digital data being transmitted immediately after reset (+5VDC, square wave = ok).

Symptom: Digital data values not consistent with analog input.
Areas to check:

1) Geophone/pre-amp sensor - view the amplified output of the sensor at TP1 on the signal conditioning PCB with an oscilloscope while gently vibrating the geophone (max. 2-3 volts pk-pk, sine wave = ok).

2) Signal conditioning PCB - using a signal generator inject a sine wave (max. 4-5 volts pk-pk) to the input of the signal conditioning circuit on TP1. J2-3 is signal ground. Perform the following tests: (Refer to fig. 3)

a) Sweep the generator frequency from 10 to 300Hz while observing the 100Hz high pass output on TP8. The output should increase to a maximum at 300Hz.

b) Sweep back from 300 to 10Hz while observing the 100Hz low pass output on TP6. The output should increase to a maximum at 10Hz.

c) The 300Hz low pass dc output level on TP4 should have a flat response over the full 10 to 300Hz range.

3) A/D PCB - check the voltage reference to ADC U2 on pin 5 (+5.00 +/- .05VDC = ok). If an AFM base station system is available to receive and view data perform the following tests:

a) Apply +5VDC to MUX input channel IN0, IN1, and IN2 on P2, pins 26, 25, and 24 respectively.

b) Measure the voltage on the analog input to ADC U2, pin 3 (+5VDC = ok).

c) Restart the MPU and check data values received at the base station (approx. 4095 all channels = ok).

Erroneous data indicate problems with the MUX input channel selection circuitry, which includes PIA U1, or with ADC U2. Note, a constant digital value of 1285 on all channels indicates the MPU does not acknowledge ADC U2 on the data bus. Check continuity between the MPU and A/D PCBs.

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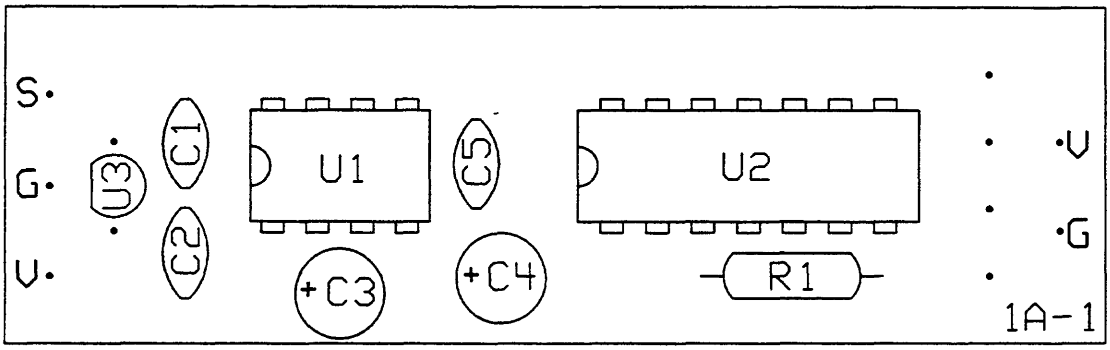
Okuda, S., Suwa, H., Okunishi, K., Yokoyama, K., Ogawa, K., and Hamana, S., 1979, Synthetic observation on debris flow, Annals of Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan, Volume 22 B-1, pp 157-204 (in Japanese).

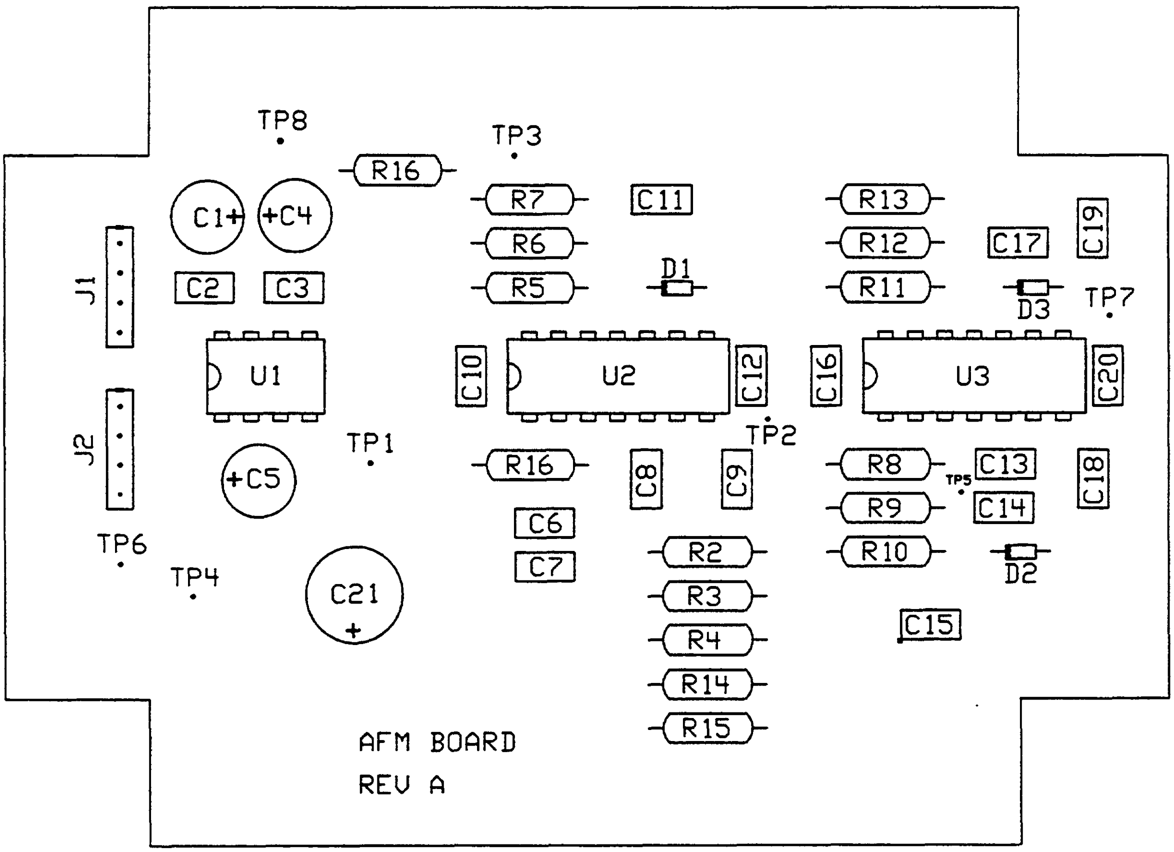
APPENDIX 1

Printed Circuit Board (PCB) component layouts

APPENDIX 1

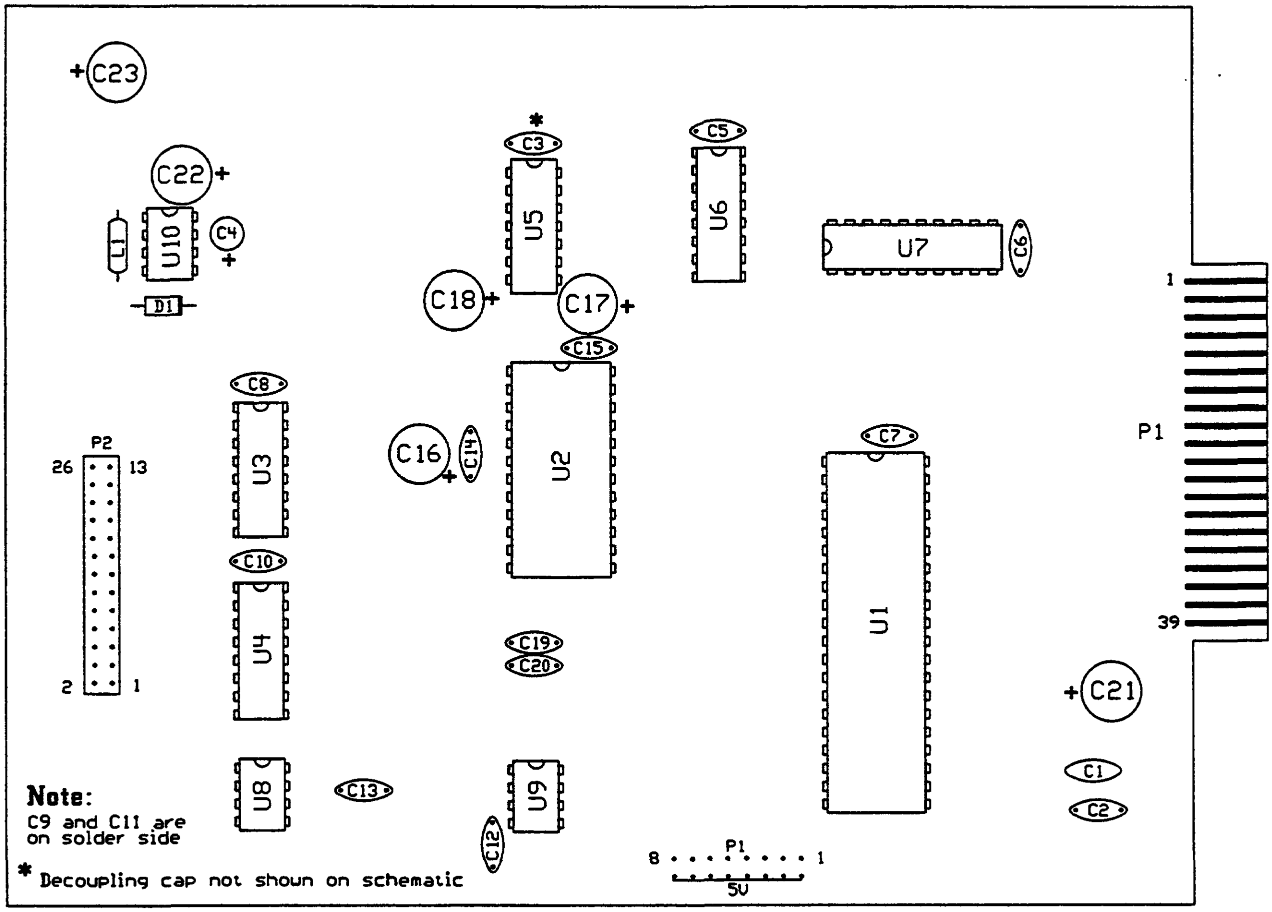


Sensor pre-amplifier PCB component layout.



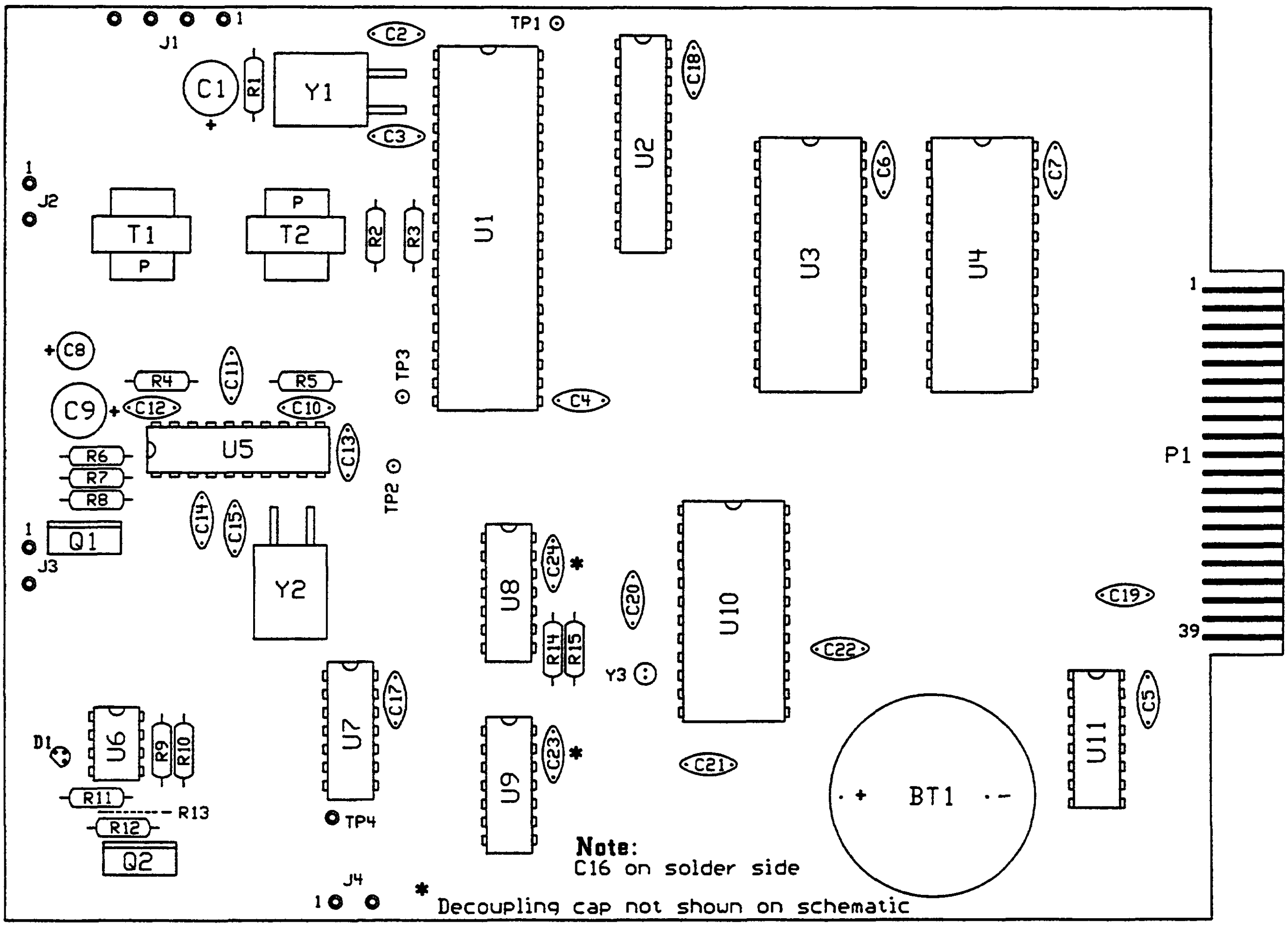
Signal conditioning PCB component layout.

APPENDIX 1



Analog/Digital (A/D) PCB component layout.

APPENDIX 1



Microprocessor unit (MPU) PCB component layout.

APPENDIX 2

Printed Circuit Board (PCB) parts list

APPENDIX 2

	Pre-amplifier PCB:	
Ref.No.	Description	MFR's
C1	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C2	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C3	Capacitor, elect., 10uF, 16V, +/- 20%	Multiple
C4	Capacitor, elect., 10uF, 16V, +/- 20%	Multiple
C5	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
R1	Resistor, met. film, 2.0K Ohm, 1/4W, +/- 1%	Multiple
U1	IC, C-MOS, voltage inverter, ICL7662	Multiple
U2	IC, amplifier, instrumentation, HD8402	Hydelco
U3	IC, +5V regulator, 3-terminal, 78L05	Multiple

APPENDIX 2

Signal conditioning PCB:		
Ref.No.	Description	MFR's
C1	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C2	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C3	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C4	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C5	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C6	Capacitor, poly. film, .1uF, 63V, +/- 10%	Multiple
C7	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C8	Capacitor, elect., NP, 4.7uF, 50V, +/- 10%	Multiple
C9	Capacitor, elect., NP, 4.7uF, 50V, +/- 10%	Multiple
C10	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C11	Capacitor, elect., NP, 4.7uF, 50V, +/- 10%	Multiple
C12	Capacitor, poly. film, .1uF, 63V, +/- 10%	Multiple
C13	Capacitor, poly. film, .1uF, 63V, +/- 10%	Multiple
C14	Capacitor, poly. film, .1uF, 63V, +/- 10%	Multiple
C15	Capacitor, elect., NP, 4.7uF, 50V, +/- 10%	Multiple
C16	Capacitor, poly. film, .1uF, 63V, +/- 10%	Multiple
C17	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C18	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C19	Capacitor, elect., NP, 4.7uF, 50V, +/- 10%	Multiple
C20	Capacitor, poly. film, .1uF, 63V, +/- 10%	Multiple
C21	Capacitor, elect., 1000uF, 16V, +/- 20%	Multiple
D1	Diode, silicon, signal, 1N4148, or 1N914	Multiple
D2	Diode, silicon, signal, 1N4148, or 1N914	Multiple
D3	Diode, silicon, signal, 1N4148, or 1N914	Multiple
R1	Resistor, carbon, 3K Ohm, 1/4W, +/- 5%	Multiple
R2	Resistor, carbon, 20K Ohm, 1/4W, +/- 5%	Multiple
R3	Resistor, met. film, 1.0K Ohm, 1/4W, +/- 1%	Multiple
R4	Resistor, met. film, 10.0K Ohm, 1/4W, +/- 1%	Multiple
R5	Resistor, carbon, 20K Ohm, 1/4W, +/- 5%	Multiple
R6	Resistor, carbon, 3K Ohm, 1/4W, +/- 5%	Multiple
R7	Resistor, carbon, 200K Ohm, 1/4W, +/- 5%	Multiple
R8	Resistor, met. film, 16.2K Ohm, 1/4W, +/- 1%	Multiple
R9	Resistor, met. film, 16.2K Ohm, 1/4W, +/- 1%	Multiple
R10	Resistor, carbon, 200K Ohm, 1/4W, +/- 5%	Multiple
R11	Resistor, met. film, 16.2K Ohm, 1/4W, +/- 1%	Multiple
R12	Resistor, met. film, 16.2K Ohm, 1/4W, +/- 1%	Multiple
R13	Resistor, carbon, 200K Ohm, 1/4W, +/- 5%	Multiple
R14	Jumper, 0 Ohm	
R15	Jumper, 0 Ohm	
R16	Jumper, 0 Ohm	
U1	IC, C-MOS, voltage inverter, ICL7662	Multiple
U2	IC, quad op. amp., low power, LT1014	Linear Techn.
U3	IC, quad op. amp., low power, LT1014	Linear Techn.

APPENDIX 2

Analog/Digital (A/D) PCB:		
Ref.No.	Description	MFR's
C1	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C2	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C3	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C4	Capacitor, elect., 10uF, 16V, +/- 20%	Multiple
C5	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C6	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C7	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C8	Capacitor, monolith., 10uF, 50V, +/- 20%	Multiple
C9	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C10	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C11	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C12	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C13	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C14	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C15	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C16	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C17	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C18	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C19	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C20	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C21	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C22	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C23	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
D1	Diode, silicon, signal, 1N4148 or 1N914	Multiple
L1	Choke, 330uH, 100mA, Q min = 60, 43LS334	Mouser Elect.
P1	Switch/connector, 16-pin dip, 8-pin sip (May be omitted depending on application)	Multiple
P2	Header, shrouded, 26-pin, for IDC connector	3M, AMP
U1	IC, CMOS, peripheral interface adaptor (PIA)	Hitachi
U2	IC, CMOS, ADC, 12-bit + sign, ADC1205CCJ-1	National Semi.
U3	IC, analog multiplexer, 8-channel, 4051	Multiple
U4	C, analog multiplexer, 8-channel, 4051	Multiple
U5	IC, C-MOS, Schmitt trg., hex inv., 74HC14	Multiple
U6	IC, C-MOS, 3-to-8 line decoder, 74HC138	Multiple
U7	IC, C-MOS, magnitude comparator, 74HC688	National Semi. Harris
U8	IC, precision reference, 5V, LT1021	Linear Techn.
U9	IC, C-MOS, op-amp, low power, ICL7611	Intersil
U10	IC, C-MOS, regulator, inverting, MAX635	Maxim

APPENDIX 2

Microprocessor unit (MPU) PCB:

Ref.No.	Description	MFR's
BT1	Battery, lithium coin, 3V	Multiple
C1	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C2	Capacitor, ceramic, 15pF, 50V, +/- 20%	Multiple
C3	Capacitor, ceramic, 15pF, 50V, +/- 20%	Multiple
C4	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C5	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C6	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C7	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C8	Capacitor, monolith., 10uF, 16V, +/- 20%	Multiple
C9	Capacitor, elect., 100uF, 16V, +/- 20%	Multiple
C10	Capacitor, elect., .1uF, 50V, +/- 20%	Multiple
C11	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C12	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C13	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C14	Capacitor, ceramic, 15pF, 50V, +/- 20%	Multiple
C15	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C16	Capacitor, elect., 10000uF, 16V, +/- 20%	Multiple
C17	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C18	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C19	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C20	Capacitor, ceramic, 15pF, 50V, +/- 20%	Multiple
C21	Capacitor, ceramic, 15pF, 50V, +/- 20%	Multiple
C22	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C23	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
C24	Capacitor, monolith., .1uF, 50V, +/- 20%	Multiple
D1	Diode, reference, LM 336-5.0, 5.0V	National Semi.
Q1	Transistor, power, mosfet, IFR511, 60V, 4A	Multiple
Q2	Transistor, power, NPN, TIP29	Multiple
R1	Resistor, carbon, 10K Ohm, 1/4W, +/- 5%	Multiple
R2	Resistor, carbon, 10K Ohm, 1/4W, +/- 5%	Multiple
R3	Resistor, carbon, 10K Ohm, 1/4W, +/- 5%	Multiple
R4	Resistor, carbon, 620 Ohm, 1/4W, +/- 5%	Multiple
R5	Resistor, carbon, 620 Ohm, 1/4W, +/- 5%	Multiple
R6	Resistor, carbon, 2K Ohm, 1/4W, +/- 5%	Multiple
R7	Resistor, carbon, 5K Ohm, 1/4W, +/- 5%	Multiple
R8	Resistor, carbon, 2K Ohm, 1/4W, +/- 5%	Multiple
R9	Resistor, carbon, 1K Ohm, 1/4W, +/- 5%	Multiple
R10	Resistor, carbon, 1M Ohm, 1/4W, +/- 5%	Multiple
R11	Resistor, carbon, 10K Ohm, 1/4W, +/- 5%	Multiple
R12	Resistor, carbon, 510K Ohm, 1/4W, +/- 5%	Multiple
R13	Jumper, 0 Ohm	Multiple
R14	Resistor, carbon, 10K Ohm, 1/4W, +/- 5%	Multiple

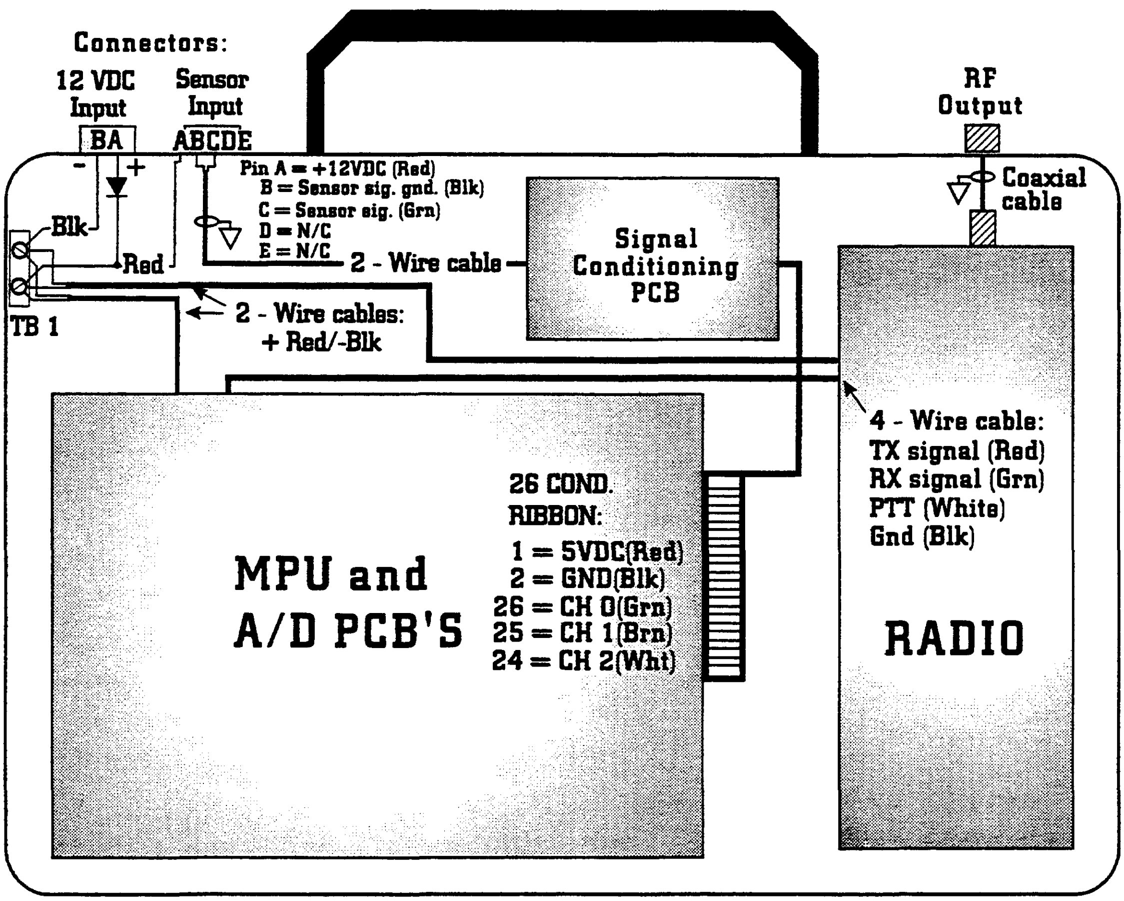
APPENDIX 2

	Microprocessor unit (MPU) PCB cont...	
Ref.No.	Description	MFR's
R15	Resistor, carbon, 10K Ohm, 1/4W, +/- 5%	Multiple
R16	Resistor, carbon, 20K Ohm, 1/4W, +/- 5%	Multiple
R17	Resistor, carbon, 20K Ohm, 1/4W, +/- 5%	Multiple
R18	Resistor, carbon, 20K Ohm, 1/4W, +/- 5%	Multiple
SW1	Switch, push button, momentary, N.O.	Multiple
SW2	Switch, thumbwheel, binary coded, EECO 1400	Multiple
T1	Transformer, audio, 4K - 600 ohm, TL021	Mouser Elect.
T2	Transformer, audio, 4K - 600 ohm, TL021	Mouser Elect.
U1	IC, C-MOS, MPU, HD6303RP	Hitachi
U2	IC, C-MOS, Octal D-type latch, 74HC373	Multiple
U3	IC, C-MOS, Eprom, 64K, UV erase, 27C64	Multiple
U4	IC, C-MOS, Static RAM, 64K, 6264	Multiple
U5	IC, C-MOS, Modem, 300 baud, 74HC943	National Semi.
U6	IC, Op-amp, programmable, LM4250	National Semi.
U7	IC, Binary counter, 12-stage 4040	Multiple
U8	IC, C-MOS, AND gate, triple 3-input, 74HC11	Multiple
U9	IC, C-MOS, Schmitt trg., hex inv., 74HC14	Multiple
U10	IC, C-MOS, Real time clock, ICM7170	Intersil/Harris
U11	IC, C-MOS, 3 to 8 line decoder, 74HC138	Multiple
Y1	Crystal, quartz, 2.4576Mhz	Multiple
Y2	Crystal, quartz, 3.579545Mhz	National Semi.
Y3	Crystal, quartz, 32.768Khz	Multiple

APPENDIX 3

Acoustic Flow Monitor module hardware connectivity diagram

APPENDIX 3

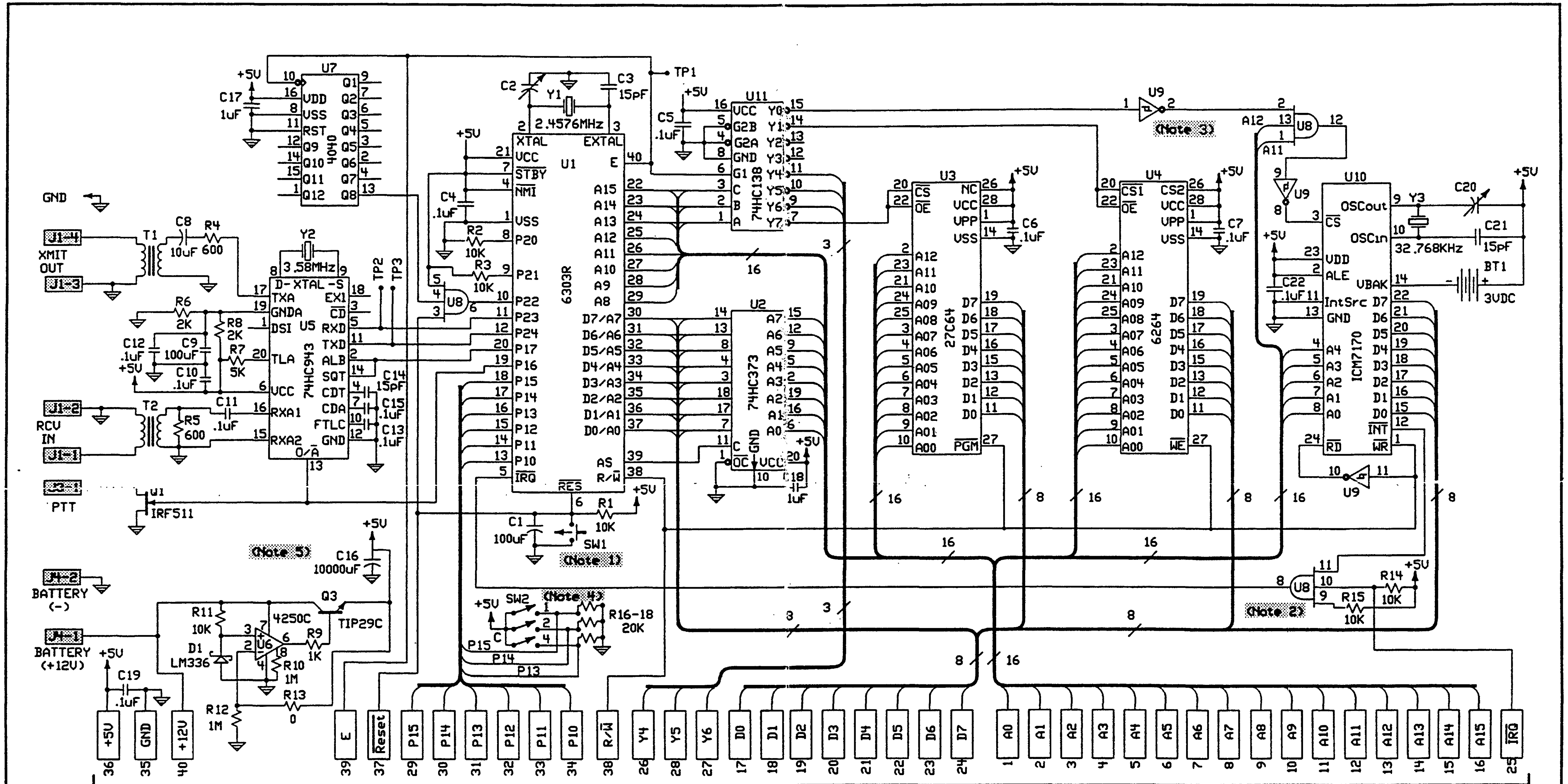


Acoustic Flow Monitor hardware connectivity diagram.

APPENDIX 4

Schematic diagrams

APPENDIX 4

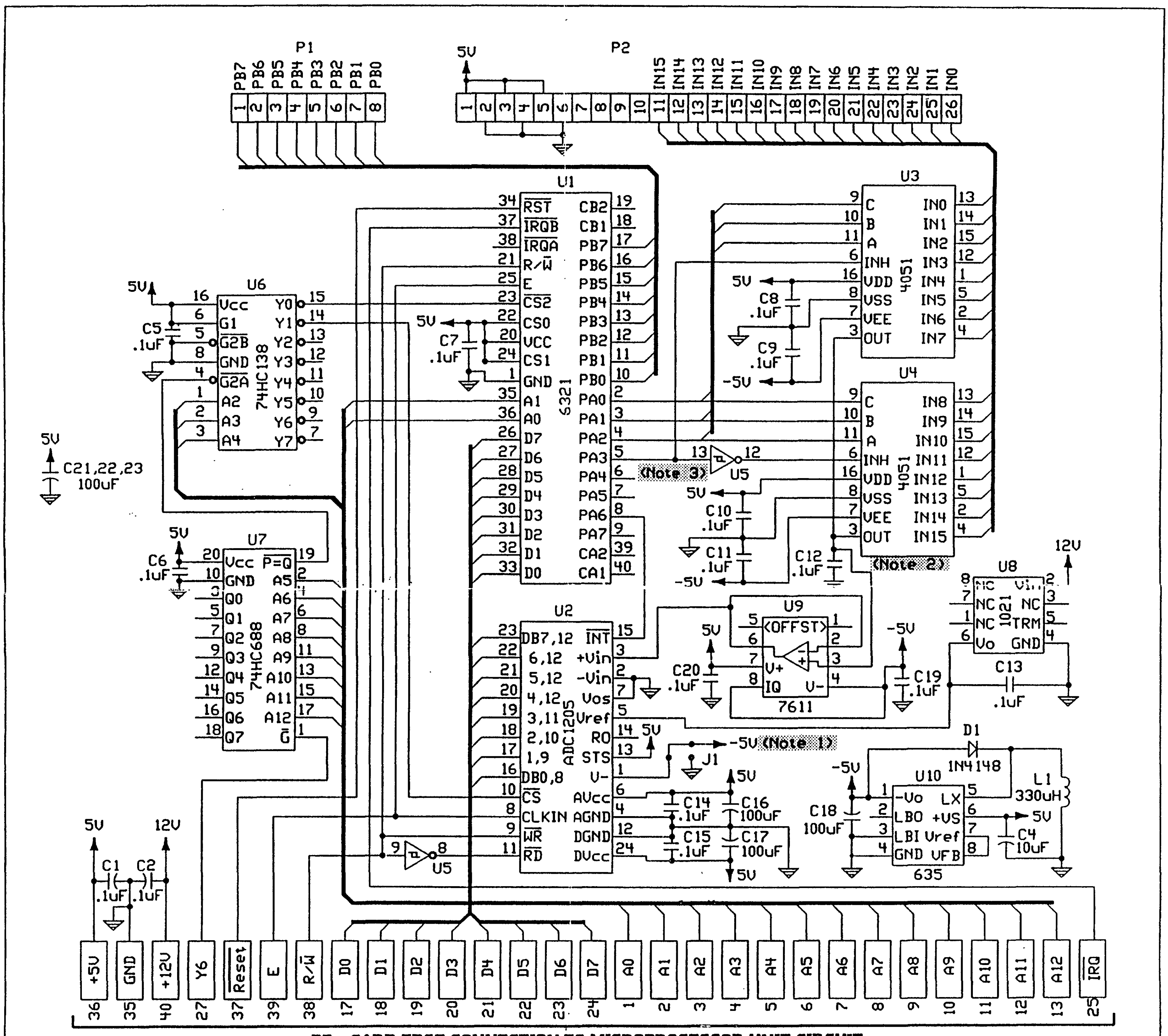


P1-CARD EDGE CONNECTION TO ANALOG/DIGITAL CIRCUIT

Notes:
1. SW1 is located on enclosure
   Connection to PCB is via J2
2. U8 is 74HC11
3. U9 is 74HC14
4. SW2 is located on enclosure
5. C16 located on solder side

Microprocessor Unit (MPU) Circuit schematic diagram

APPENDIX 4



Notes:

1. J1 to -5V for bi-polar; J1 to Gnd for uni-polar
2. U4 optional for additional analog inputs
3. U5 is 74HC14

Analog/Digital (A/D) Circuit schematic diagram