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A Filter Circuit Board for the Earthworm Seismic Data Acquisition System

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THE EARTHWORM FILTER
BOARD

Introduction

The Earthworm (EW) system [1, 2] is a seismic network data acquisition and processing system developed by the U. S. Geological Survey, Earthquake Hazards Team (USGS, EHZ) and Dr. Carl Johnson during the 1990's. It is used by the Northern California Seismic Network (NCSN) as well as many other networks including the Hawaiian Volcano Observatory, the Alaska Volcano Observatory, the Southern California Seismic Network, and others. The input to the EW system is comprised of many realtime electronic seismic waveforms fed to a multi-channel digitizer on a PC platform. For systems with more than 16 channels, the digitizer consists of one, two or four 64-channel multiplexer boards (National Instruments Corp. AMUX-64T) [3] attached to an A/D converter board located in the computer.

When the system was initially developed the multiplexer boards were modified by adding passive filter circuits to each channel in order to eliminate electronic noise picked up in cabling. It was later discovered that a small amount of crosstalk occurred between any given channel and the channel immediately following it in the digitizing sequence. This crosstalk was measured at a ratio of approximately 49dB (280:1). Though small, during digitization of large amplitude signals it will cause what appear to be small earthquake arrivals at the wrong time on some channels. This can result in erroneous calculation of earthquake arrival times, particularly by automated algorithms, unless recognized by human analysts. Furthermore, even when crosstalk doesn't cause miscalculated arrival times, it still distorts the recorded data.

Tests were performed to determine the best way to eliminate the crosstalk. It was discovered that two changes were necessary. First, the sample interval between successive channels in a scan needed to be increased from 4 microseconds to 10 microseconds. This is easily accomplished by changing the Earthworm configuration file. Second, the source impedance driving the input to the multiplexer channels needed to be lowered dramatically. The passive filters that were added to the boards had introduced an inherent impedance of 24 kilohms between the source (discriminator outputs) and the inputs. In order to provide a low impedance signal to the inputs while at the same time providing filtering to prevent cable noise, we developed the Earthworm Filter Board to replace the passive filters. This report describes that board.

Description

The following design criteria were used to design the Earthworm Filter board. It had to provide low output impedance, a low-pass filter of at least one pole, preferably it should use low power so that no external power would be necessary, and it should integrate well with the existing wiring and metal rack-mount housing for the multiplexer. Since a two-pole, low-pass active filter can be formed using a single non-inverting operational amplifier (see schematic in Appendix E) and since such a configuration provides a low impedance output without altering the passband signal, this circuit was adopted as a replacement for the existing passive filters. Bench tests were performed with an EW system to determine the optimum operational amplifier integrated circuit (opamp I.C.). It was found that the TL064 quad opamp provided the needed low impedance while having a low power consumption. Furthermore, the quad device has four opamps in a single I.C. package which makes layout and assembly efficient.

The two-pole low-pass filter requires two capacitors and two resistors for each channel to determine the filter characteristics. This one was designed to produce a 60 Hertz cutoff frequency and a Butterworth response. In our application these filters are not intended as the main anti-aliasing filters for the digitizer. The analog input signals are filtered before they reach the EW Filter board with 20Hz anti-aliasing filters. The EW filters are needed only to eliminate noise picked up in the intervening cabling. This noise is typically high frequency. So a filter cutoff frequency somewhat higher than the anti-aliasing frequency eliminates any high-frequency noise pickup while having a minimal effect on the tranfer function of the signal. For other applications the EW filter cutoff frequency can be adjusted as needed to allow different sample rates or even to serve the anti-aliasing function. To adjust the cutoff frequency, the filter resistors can be changed in inverse proportion to the frequency change.

The EW digitizers used in the NCSN in Menlo Park are all wired in a standard way using two 34-pin ribbon cables to bring the seismic signals to the input terminals of the multiplexer board. Conductors 1 and 34 of both ribbon cables are tied to ground. Conductors 2 through 33 are connected to channels 0 through 31 sequentially in the first cable and channels 32 through 63 in the second cable. The EW Filter board is designed with 34-pin ribbon cable connectors mounted on the circuit board for both the inputs and the outputs using this same pin assignment. This permits retrofitting the multiplexer with the new filter boards by simply cutting the existing ribbon cables, crimping on additional ribbon connectors, and inserting the board inline (see Appendix D1). Any previously installed passive filters on the multiplexer must also be removed and 0 ohm jumpers put in their place.

The EW Filter board has the same dimensions as the AMUX-64T multiplexer board and has the same mounting hole locations. This allows it to be mounted on standoffs in the same rackmount housing as the multiplexer board. It could even be stacked with the multiplexer board. Also, the filter board can get the +5 volt, 170 ma power it needs from the multiplexer. By soldering a jumper across the outer pins of the multiplexer external power switch (see Appendix D2), the internal 5 volt power of the multiplexer can be routed to the "external" power connector (this now makes it the internal power connector). An identical connector is mounted on the filter board. Two wires can be used to join these two connector and thus bring power to the filter board. All this allows for integration of the filter board with the multiplexer in an efficient manner. For EW systems which do not use the ribbon cable input arrangement described above, an adaptation for that input wiring to the filter boards ribbon connectors would be necessary.

Appendix B contains images of waveforms gathered during tests which show the effect of the Earthworm Filter board on crosstalk. Without the board and sample rate change, a crosstalk signal of 14 digital counts (17 mv) peak-to-peak results from a 5 volt p-p source (Appendix B fig. B). With the changes, the crosstalk signal is not detectable over the typical digitizer noise of 2 counts (2.4 mv) p-p (Appendix B fig. E). This is an improvement of greater than 17dB (7:1). The overall crosstalk ratio then becomes greater than 66 dB (2000:1). Since the crosstalk signal is below the digitizer noise, the actual ratio is unknown.

Included in the various appendices is all the information needed to build and install the Earthworm Filter board. The entire schematic on one page is shown on the first page of Appendix E. It is difficult to read in full page view or when printed, but onscreen it can be magnified to see every detail. The second page is a segment of the schematic which is easier to read. Since most of the circuit is simply duplication of this segment it can be used as a guide to the whole circuit. Appendix H is not a page but is rather a computer file that bundles ten files together in compressed format. These are the files necessary to have a printed circuit board manufacturer produce additional blank circuit boards.

Acknowledgements

References

[1] Johnson, Carl E., Alex Bittenbinder, Barbara Bogaert, Lynn Dietz, Will Kohler, Earthworm: A Flexible Approach to Seismic Network Processing, Incorporated Research Institutions for Seismology (IRIS) Newsletter, V14 N2, p1-4, 1995.

[2] Council of the National Seismic System, Earthworm Web Pages, *http://www.cnss.org/EWAB/*, 2000.
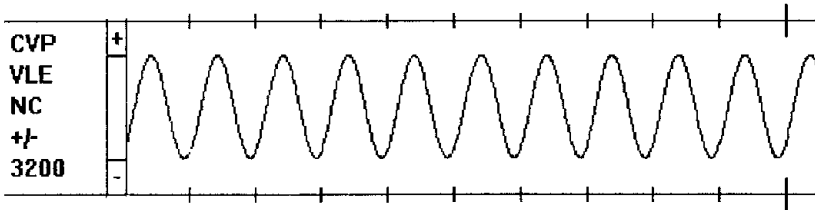
[3] National Instruments Corp. *AMUX-64T User Manual.* National Instruments Corp., 1992.
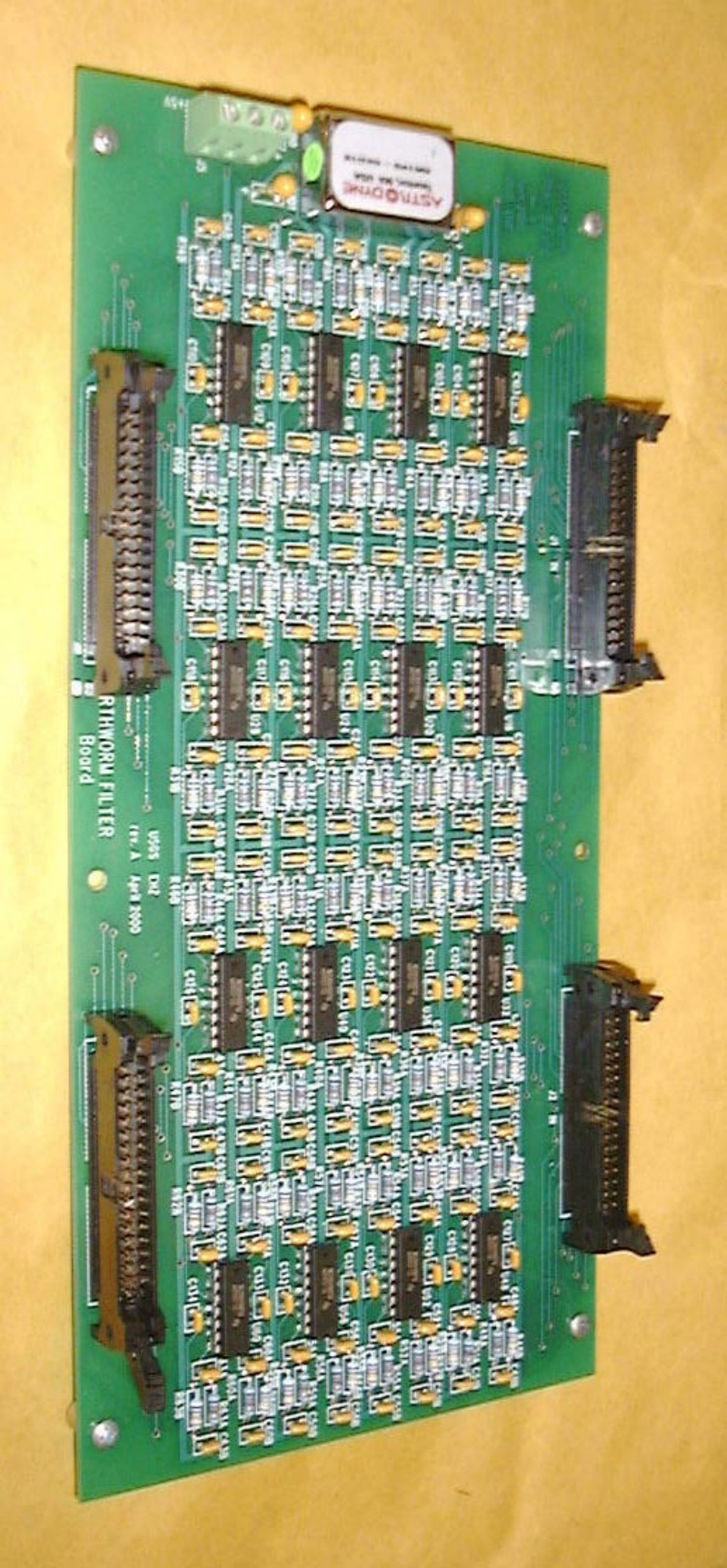
Appendix A

Appendix B

Plot A below is a source signal, a sinewave of 10 Hz and +/- 2.5 volts, plotted at a scale of +/-3200 counts edge-to-edge. Plots B - D are of the channel immediately following the source under various conditions plotted at a scale of +/-13 counts edge-to-edge.


A. Typical source signal for each of the following plots. This signal is put on the channel preceding the ones shown in the following plots. The scale is 246 times greater for this plot.
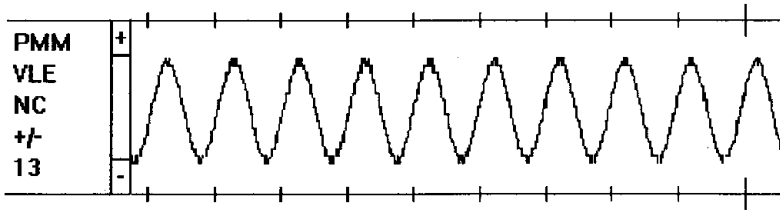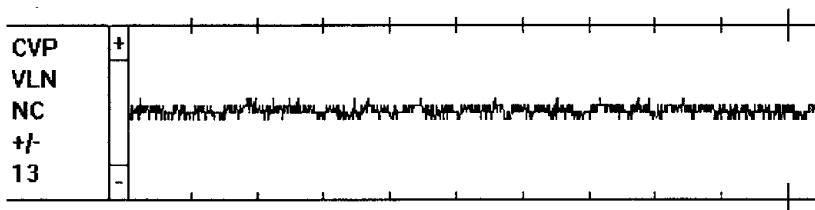

B. Crosstalk signal with unmodified multiplexer board and 250KHz sample clock. (Amplitude 14 counts or 17 mv)
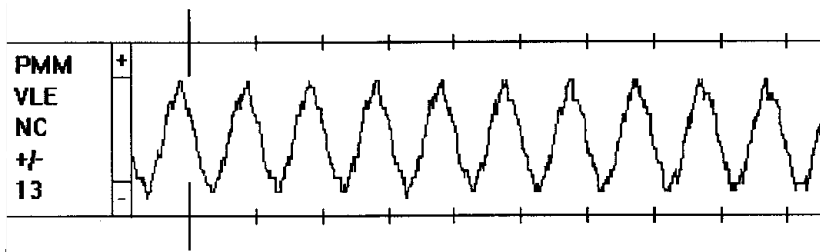
C. Crosstalk signal with unmodified multiplexer board and 100KHz sample clock.
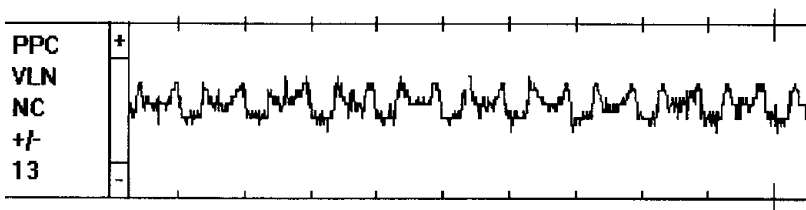
D. Crosstalk signal with EW Filter board added and 250KHz sample clock.

E. Crosstalk signal with EW Filter board added and 100KHz sample clock. (Amplitude <2 count or <2.4 mv)

Appendix C

Earthworm Filter Board
Specifications

Number of channels	64
Filter cutoff frequency (-3dB)	60 Hz
Filter type	2-pole Butterworth lowpass
Filter pole coordinates (no zeroes)	$-266 \pm 266i$ rad/sec
Gain (in passband)	1.00 (0 dB)
Input impedance (DC)	10^9 ohms
Input connector	Two 34-pin ribbon headers
Output connector	Two 34-pin ribbon headers
Power	5 volts, 170 ma
Power connector	Wire clamp terminal
Size	12.5 x 26.9 cm (4.9 x 10.6")

EarthWorm Filter Board Installation

BEFORE

Ch. 0-31 → AMUX-64T BOARD

Ch. 32-63 → AMUX-64T BOARD
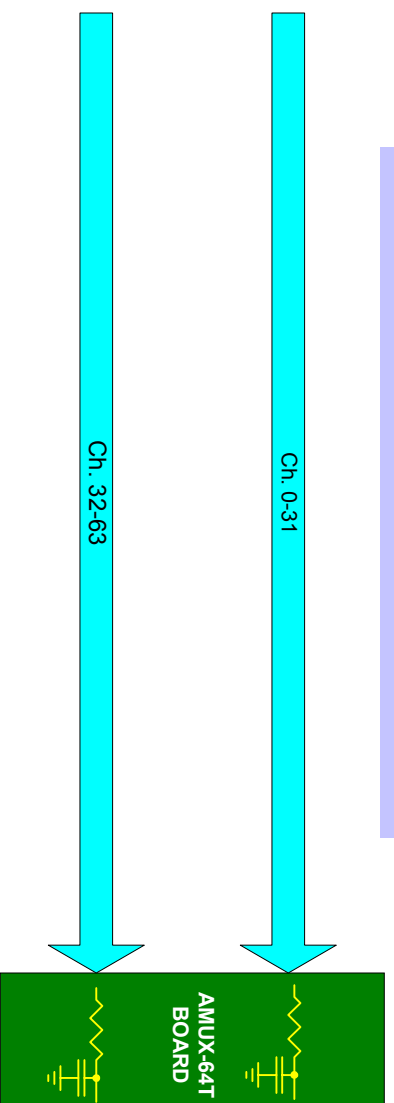
Inputs are connected to the AMUX-64T board by two 34-pin ribbon cables. The input end has an IDC connector and the other end has the individual wires of the ribbon clamped in the M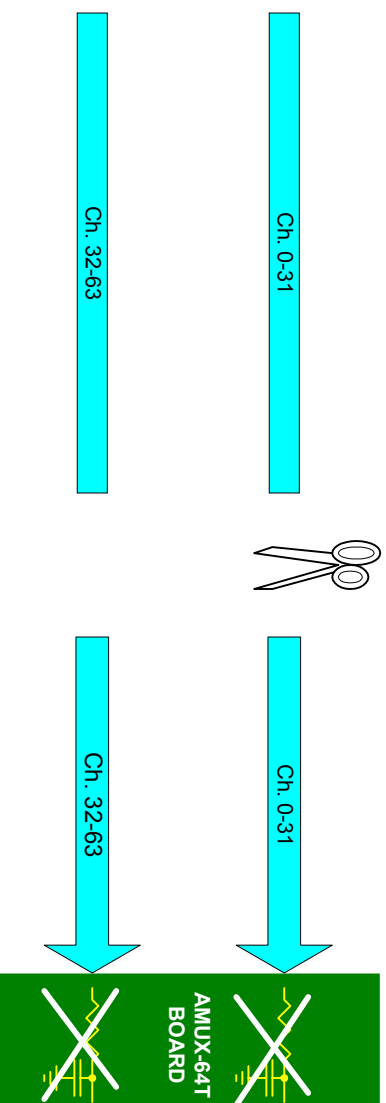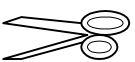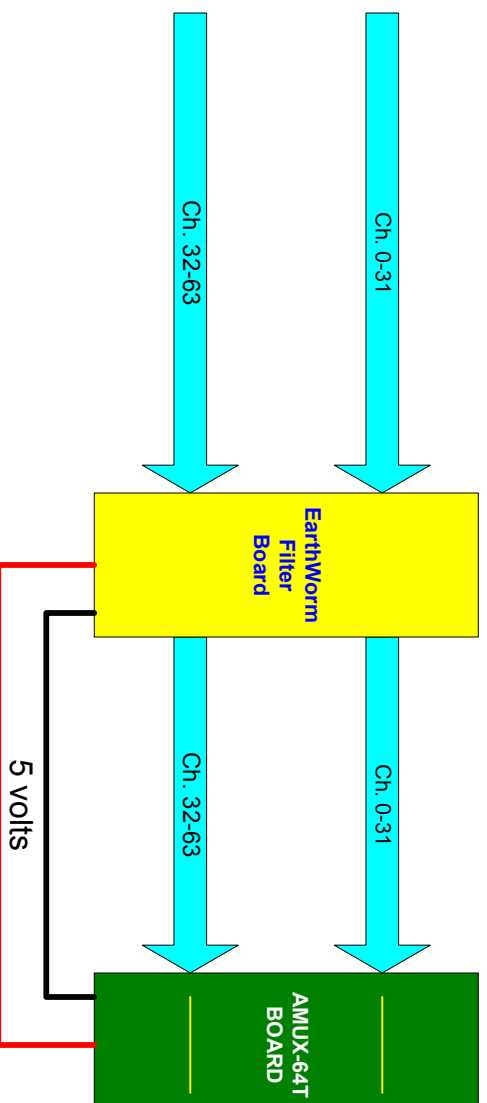UX barrier strip connectors. Ribbon cable wires 1 & 34 are ground. Wires 2 through 33 are channel 0 (32) through 31 (63) respectively.

(middle section)

Ch. 0-31

Ch. 32-63

Ch. 0-31 → AMUX-64T BOARD

Ch. 32-63 → AMUX-64T BOARD

Any previously added passive filtering is removed from the MUX board and original jumpers are restored. The two ribbon cables are cut about 1 foot from the MUX board. IDC connectors are attached to both sides of the cut. Also a small jumper is soldered to the MUX board power switch to permit use of the power barrier strip as a source of 5 volts for the EW Filter board.

AFTER

Ch. 0-31 → EarthWorm Filter Board → Ch. 0-31 → AMUX-64T BOARD

Ch. 32-63 → EarthWorm Filter Board → Ch. 32-63 → AMUX-64T BOARD

5 volts

The EW Filter board is mounted in the rack shelf below the MUX board. The new IDC connectors are connected to the EW Filter board and 5 volt power is connected from the MUX board. The guide channel (ch. 0) input, as well as any timing channels, can be wired to bypass the filter board or the filters for those channels can be modified for higher cutoff frequencies.

Appendix D 2

AMUX-64T board jumper modification

Jumper goes under here

add jumper here
Solder a wire across the 2 outer pins

12
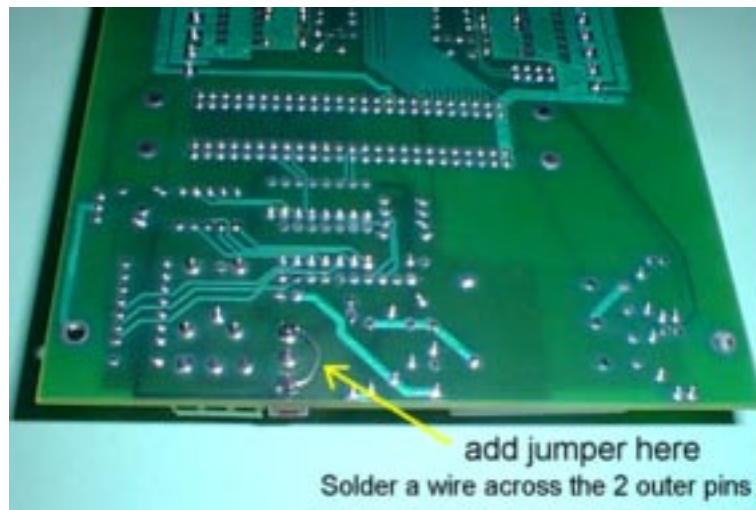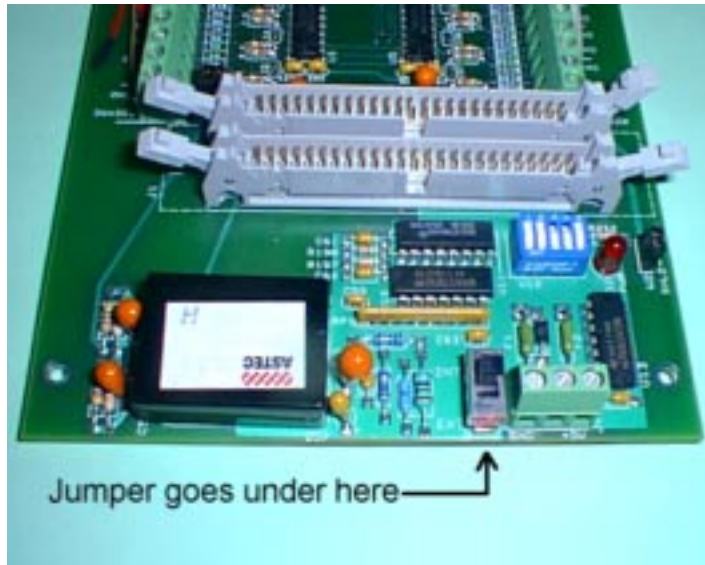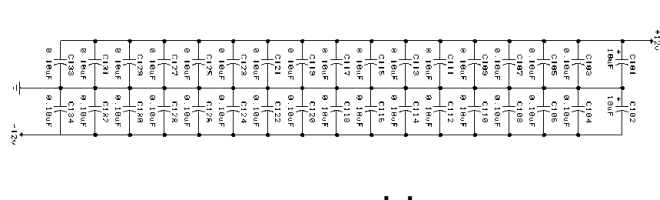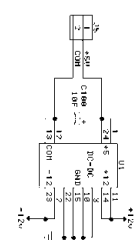
U.S. Geological Survey, O.E.V.E.
345 Middlefield Rd, Menlo Park CA 94025

TITLE: Earthworm Filter Board

FILE NAME	REF	NUMBER
DATE 2000 Jan 18	DRN BY E Jensen	
DATE 2000 May 26	REV BY E Jensen	

PAGE 1 OF 1 REV A SIZE D

J1

18 R16a 13.0K
19 R17a 13.0K
20 R18a 13.0K
21 R19a 13.0K
22 R20a 13.0K
23 R21a 13.0K
24 R22a 13.0K

C16a 0.22uF C17a 0.22uF R16b 24.3K C16b 0.10uF C17b 0.10uF R17b 24.3K R18b 24.3K R19b 24.3K C18a 0.22uF
C20a 0.22uF C21a 0.22uF R20b 24.3K C20b 0.10uF C21b 0.10uF R21b 24.3K R22b 24.3K C22b 0.10uF

J3

2 3 4 5 6 7 8 9

+12v U+ 4 U0 TL064 U- 11 -12v
1 7 8 14
2 3 6 5 9 10 13 12

+12v U+ 4 U4 TL064
1 7 8 14
2 3 6 5 9 10 13 12

C0a 0.22uF C1a 0.22uF R0b 24.3K C0b 0.10uF C1b 0.10uF R1b 24.3K R2b 24.3K C2b 0.10uF C3b 0.10uF R3b 24.3K C3a C2a 0.22uF
C4a 0.22uF C5a 0.22uF R4b 24.3K C4b 0.10uF C5b 0.10uF R5b 24.3K R6b 24.3K C6b 0.10uF

R0a 13.0K R1a 13.0K R2a 13.0K R3a 13.0K R4a 13.0K R5a 13.0K R6a 13.0K

J1

2 3 4 5 6 7 8

Appendix F
Earthworm Filter Board
Parts List

Qty/bd	Description	Value	Manufacturer	Part #	Reference Designator
96	Capacitor	0.10uF, X7R, .1"	Kemet	C320C104K5R5CA	C0-63b, C103-134
64	Capacitor	0.22uF, X7R, .1"	Kemet	C320C224K5R5CA	C0-63a
2	Capacitor	10uF,25v, tant., .2"	Kemet	T352E106K025AS	C101-102
1	Capacitor	47uF,20v, tant., .2"	Kemet	T354K476K020AS	C100
1	DC-DC convert	5v to +/-12v	Astrodyne	DR1P5-05D12	U1
16	I.C.	Quad opamp	Texas Instr.	TL064ACN	U0,U4,U8,U12, … U56,U60
64	Resistor	13.0K 1%, 1/4W,metal film	Multicomp	MFR1/4W-1%-13K0	R0-63a
64	Resistor	24.3K 1%, 1/4W,metal film	Multicomp	MFR1/4W-1%-24K3	R0-63b
64	Resistor	1.0 ohm 5%, 1/8W, carbon film	Multicomp	CR1/8W-5%-1R	For AMUX -64T board
4	Connector	34-pin ribbon header straight-up			J1-4
4	Connector	34-pin ribbon IDC			J1-4
1	Connector	3-pin barrier conn.	Phoenix Contact	MKDS 1.5/3-5.08	J5
1	PCB	EW Filter Bd. (rev. A)	Martex Circuits		
6	Standoff	1/2" 4-40 int. thread both ends			
12	Screw	1/4" 4-40 w/ star lockwasher			
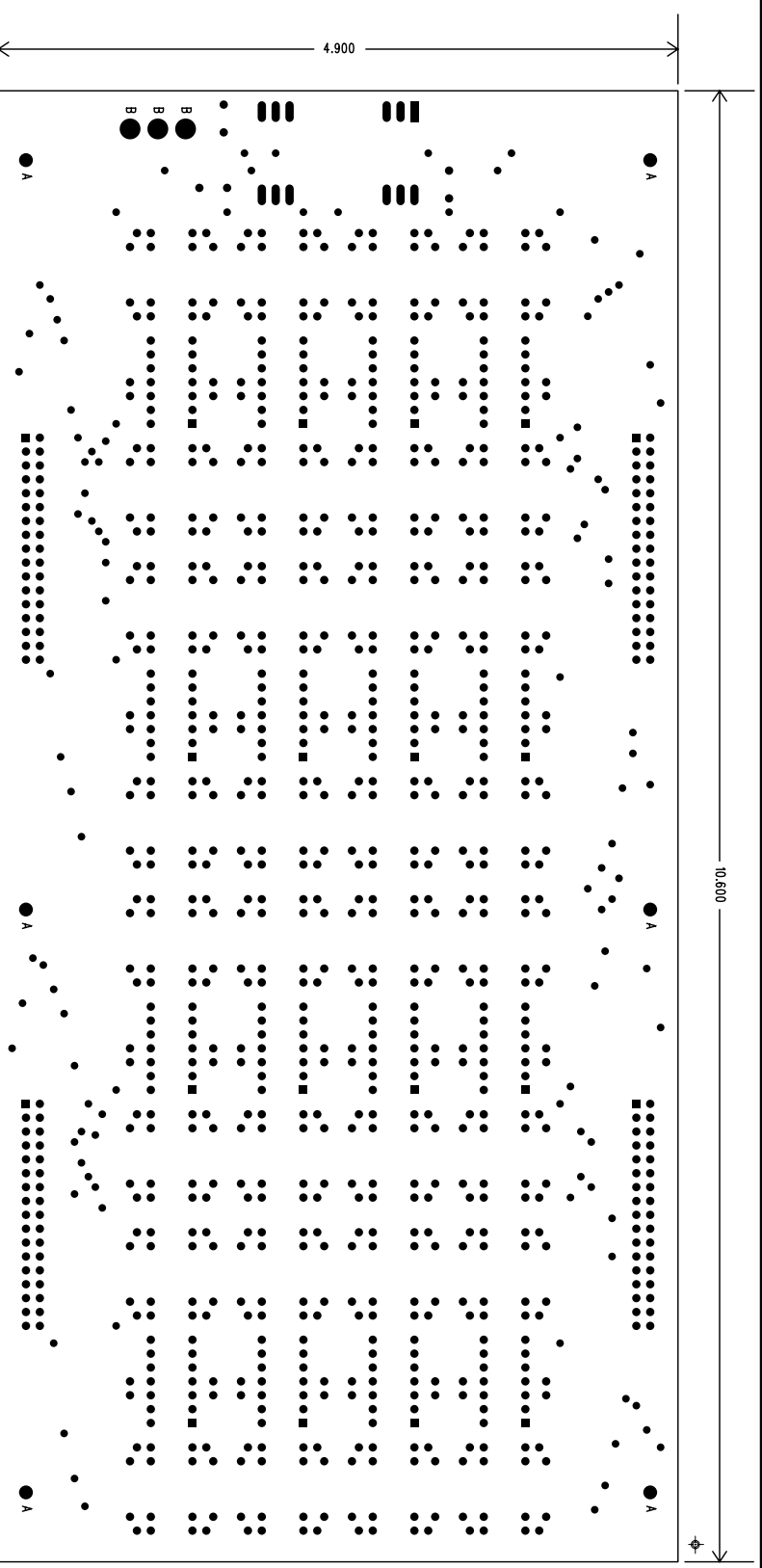
Scale not 1:1

ALL DIMENSIONS ARE INCHES

4.900

10.600

MATERIAL

TYPE: EPOXY GLASS
GRADE: FR-4
THICKNESS: .062 IN.
COLOR: NATURAL
CLAD: 2 SIDES
COPPER WT.: 1 OZ.
SOLDER MASK: GREEN, BOTH SIDES
SOLDER PLATE: 40% Pb / 60% Sn
LEGEND: WHITE

DRILLING SCHEDULE

CODE	HOLE SIZE	QTY
A	.125 IN.	6
B	.052 IN.	3
ALL OTHERS	.037 IN.	1065

ALL HOLE PLATED-THRU
WITH MIN. .0014 IN.
COPPER THICKNESS

FINISHED HOLES TOL. +.005, −.000 IN.

U. S. GEOLOGICAL SURVEY

MS 977, 345 MIDDLEFIELD RD, MENLO PARK, CA 94025

TITLE		SIZE
EARTHWORM FILTER / BUFFER BOARD FAB. DRAWING		A

FILE NAME	REF. NUMBER	
EWFILTER		

DATE: 2000 MAR 14	DWG BY:	PAGE 1 OF 1	REV B
DATE:	REV BY: E. G. JENSEN		

Appendix G 1

EarthWorm Filter Board
Assembly Drawing

EarthWorm
Filter Board
rev. A
April 2000
USGS EHZ

U1
Astrodyne
DRTP5-05D12

C100
47uF +
C102
10uF

GND
+5V
Phoenix Contact
MKDS 1.5/3-5.08
J5

C101
10
uF +

C103

34-PIN RIBBON CONNECTOR (Typical 4 places)

J1 IN

TL064
U0

TL064
U4

TL064
U8

TL064
U12

EARTHWORM FILTER
Board
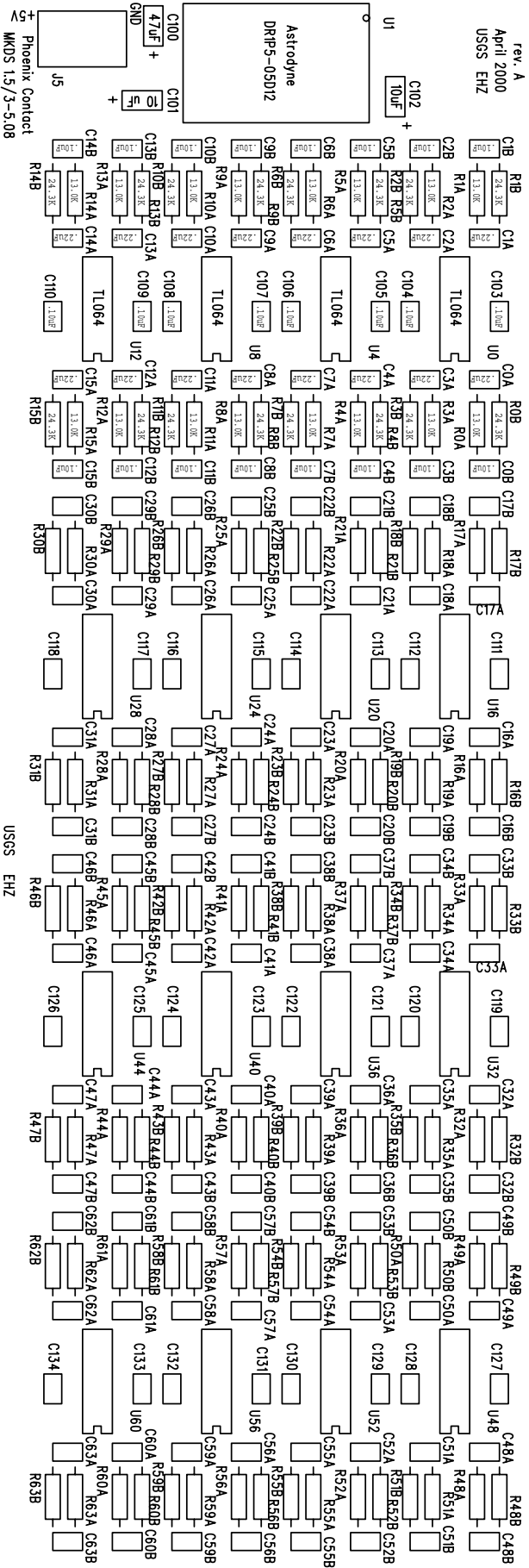
USGS EHZ
rev. A April 2000

J3 OUT

J2 IN

J4 OUT

Appendix H

Appendix H comprises the computer file EWFILTER.EXE. This file contains ten more computer files which can be used to produce the Earthworm Filter printed circuit board. The files can be extracted by running the EWFILTER.EXE. The file README.TXT is one of the files that will be extracted. It is a text file which provides a description of the other files. It can also be editted to provide manufacturing instructions to a printed circuit board manufacturer. The files with names ending in .PHO are Gerber Photoplotter files used to generate the film layers needed in manufacturing. GEN0127.PHO is the board fabrication drawing in photoplotter format. The file APERTURE.TXT provides data needed to create each of the photoplots correctly. The files beginning with DRL01 are used to control drilling of the boards.