

Creative Control Concepts

HAL-4

EEG Biofeedback Brainwave Analyzer

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The Hemispherical Activation Level Detector (HAL-4) is presented as an engineering example of the design techniques used in acquiring brainwave signals. The HAL-4 ***is not a medically approved device***, no medical claims are made for this device, and it should not be used for any medical diagnostic purposes. Furthermore, the ***safe use of HAL-4 requires that the electrical power and communications isolation described in its design not be circumvented***. HAL-4 is designed to be battery operated only: ***Do not substitute plug-in power supplies***.

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An Introduction to Brain Function

It has long been supposed that human beings use two major modes of thought. A common sense view is that there are two ways of thought that occasionally conflict, the way of "reason" and the way of "emotion". Some writers conceptualize the differences as "analytic" versus "synthetic", "successive" versus "simultaneous", or even "digital" versus "analogical."

Paralleling the conceptualization of two modes of thought have been the results of research on the two hemispheres of the brain. Psychobiologist Roger Sperry of the California Institute of Technology won the 1981 Nobel Prize for Physiology and Medicine for his "split brain" studies on the functions of the two hemispheres of the brain. Essentially, Sperry and his colleagues studied individuals who had a commissurotomy, an operation which severed the main bundle of nerve fibers which support the bulk of neural communication between left and right hemispheres. They found that each of the two hemispheres seem somewhat specialized for different tasks. For about 95% of the population (right-handed individuals and two-thirds of left-handed individuals), it appears that the left hemisphere of the brain is better organized for the following tasks:

Left Hemisphere Strengths

- **Verbal:** language skills, speech, reading and writing, recalling names and dates, spelling
- **Analytical:** logical, rational evaluation of factual material
- **Literal:** Literal interpretation of words
- **Linear:** sequential information processing
- **Mathematical:** numeric and symbolic processing
- **Contralateral movement:** controls movement on the right side of the body.

Right Hemisphere Strengths

- **Non-verbal:** uses imagery rather than words
- **Holistic:** processes information simultaneously, in "parallel"
- **Visuospatial:** functions involving perceptions of location and spatial relationships
- **Emotional:** experiencing feelings
- **Dreaming:** imaginative, metaphoric visual image making
- **Contralateral movement:** controls movement on the left side of the body.

The Problem: Digging into the Waves

The brain is a source of many electrical signals. An EEG (short for electroencephalogram) is a recording (usually a strip chart) of the electrical potential differences between pairs of electrodes fastened to the scalp.

Silver-silver chloride electrodes are used to pick up the signals. Some care must be taken to clean the area of the scalp with alcohol and perhaps use a mild abrasive conducting cream to ensure good electrical contact. Ideally, there will be less than 10K ohms impedance between any two electrodes, but anything under 25K ohms is acceptable.

It takes a trained eye to determine specific information about a person from an EEG. At the present, we can only generalize as to what these recordings mean and we are unable to correlate specific waveforms with "intelligence". The observable electrical activity however, does offer some clues.

According to medical and psychological research, by monitoring this activity, we could, in a gross way, investigate how the brain functions in a variety of circumstances. For example, if we monitor the two hemispheres while a person is problem solving, the type of problem could be indicated by the relative preponderance of one hemisphere's activity as compared to the other. Sometimes, even the activity (sleep vs. reading: relaxed vs. agitated) can be determined.

The electrical signals that we are currently able to monitor and identify from the brain are categorized as follows:

Alpha - Research has already indicated that in an awake person, the presence of alpha waves indicates a relaxed person with an absence of problem oriented brain activity. (Alpha wave activity describes electrical activity in the range of 8-12 Hertz, nearly sinusoidal signal at a voltage level of between 5 and 150 μ V, typically 20 to 50 μ V.)

Beta - When a person is attending to some stimulus or thinking, alpha wave activity is replaced by beta wave activity (14 to 25 Hz activity of a lower amplitude).

Theta - Theta wave activity (4 to 8 Hz, 20 μ V. and higher) usually appears during sleep, but has been associated with deep reverie, mental imagery, creativity, dreaming, and enhanced learning ability.

Delta - Delta wave activity from 0.5 to 4 Hz is seen in the deepest stages of sleep.

In addition, we must remember that we are attempting to correlate cerebral electrical activity with subjectively observed events (types of cognitive tasks). While brain waves may be varying tens of times per second, our subjective experience varies more slowly. It may take a second or two to change concentration and to focus on a new task. We need to integrate the readings over a short period of time. Previous research in this area suggests that .25 to .50 seconds is reasonable.

A Noisy Environment

Circuitry sensitive enough to detect hemispheric activity will also detect artifactual signals: muscle activity from the forehead, eye and head movements, heart rate activity, brainwave "spikes" or irregular slow wave activity, and if we are not careful, 60 cycle power line hum. To eliminate this unwanted "noise", a bandpass filter is used, which eliminates frequencies under 4 Hz and over 20 Hz. While compromising delta wave acquisition, the benefit is that it filters out most of these undesired signals.

Detecting 4-20 Hz signals with a minimum amplitude of 5 μ V. from a source with approximately 10-20K ohm impedance is not an insignificant task. Ideally, the bandpass filter section should have a flat (\pm 1 dB) response across the pass band; it should provide at least -18 dB per octave attenuation of signals outside the pass band; the frequency response of the amplifier should be at least 50-60 dB down at 60 Hz; an equivalent input noise level of 0.5 μ V. or less would be good; and, finally, input DC current should be less than 50 na (nanoamps).

The Hemispheric Activation Level Detector

The Hemispheric Activation Level detector (HAL, for short) graphically displays the relative amounts of brainwave activity in each brain hemisphere.

The HAL can distinguish among grossly different conscious states such as concentrated mental activity and pleasant daydreaming. For example, if you are analytically debugging a program, HAL should show a predominance of left hemispheric activity. If you are listening to some light music and daydreaming, HAL should show a predominance of right hemispheric activity.

HAL is a relatively sophisticated low-cost standalone fully isolated four-channel EEG brainwave monitor. The analog brain wave voltages gathered from four sets of scalp contacts are filtered, converted to digital values, and transmitted via serial RS-232 (making HAL compatible with any computer) for recording or analysis. HAL includes a 2 channel Fourier Transform analysis and display routine for an IBM PC (HAL's PC software is intended only as a graphic display demo, so it only displays two channels even though HAL sends data on four channels). We hope to have a windows based monitor program available soon.

When running this special analysis and display package, the PC separates out various amplitudes and frequencies of alpha, beta, and theta waves as well as phase differences between the hemispheres. The result is a graphically representation of what is going on in your brain in real time!

Analyzing HAL's circuitry illustrates practical design techniques including: differential amplifiers for low level signal detection in a high background noise level environment, low frequency band-pass filtering-rectifying-integrating detector, opto-isolation for safety, and analog to digital conversion.

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HAL's Circuitry

HAL's hardware circuitry is divided into two sections: preamplifier/filter and digitizer/control. The preamps and filters acquire and boost the μV level analog signals to useful levels. The digitizer section does the signal conditioning, analog to digital conversion, and sends the data through an optocoupler to the host computer for analysis.

A special preamplifier/filter amplifies the specific EEG signals picked up from the scalp of the subject and amplifies them a level high enough for A/D conversion. Each HAL preamplifier/filter channel takes 6 op-amps. Four op-amps provide amplification and impedance matching and two others provide 60 Hz rejection filtering.

The amplifiers and active filters, shown in the schematic, were designed around the TL-084 quad op-amp and use as many common values as possible. The TL-084 provides JFET inputs with pico-amp bias currents, low power consumption, and adequate input noise level (another type of op-amp **should not be substituted** if you are building this project). The bandwidth of the analog section is approximately 16 Hz (-3dB at 20 Hz). The equivalent input noise is calculated by integrating the noise voltage as a function of frequency over the bandwidth. This 180 nV equivalent noise combined with the noise from the differential input stage multiplied by the system gain yields a calculated output noise level of approximately 2.5 mV (actual measurements of the noise output of the four channel prototype were 3.5 mV RMS with a source impedance of 13k ohm impedance per input. This was considered acceptable for the system with a 10 mV per bit A/D sensitivity).

Three sections of U1A are used to make a differential input instrumentation pre-amplifier (note that all six op-amps associated with channel A are labeled U1A and U2A. Channel two's op-amps are labeled U1B and U2B respectively, etc.). An ideal difference amplifier will only amplify the voltage difference between the two inputs. Voltages, which appear on both inputs when referenced to the ground lead, are called common mode voltages. For example, if the voltage on one input were +50 μV and the other input were +15 μV , the difference signal would be 35 μV while the common mode signal would be 15 μV . In HAL it is the difference signal between the two electrode positions that is to be measured. The difference amplifier accomplishes this by applying one signal to the inverting input of the op-amp and the other signal to the non-inverting input.

The ability of the op-amp to amplify only the difference is specified as the common mode rejection ratio. In HAL, this common mode rejection was experimentally measured by shorting the inputs, applying an input signal between the shorted inputs and ground, and comparing the output with that obtained by applying the same signal across the two inputs. The common mode output was 43 dB down below the differential output.

With HAL it is expected that the major component of common mode voltages will be induced by the 60Hz power line. Resulting rejection of 60Hz signals will be discussed after the following description of the filtering used.

The voltage gain of the pre-amplifier was set at 5800. AC coupling was incorporated between the stages to eliminate DC offset voltages and to provide some low frequency roll-off. Feedback capacitor C3 provides high frequency roll-off with the gain down 9 dB at 60 Hz. The third order active filter stage has a -3 dB frequency of 22 Hz and is 30 dB down at 60 Hz. The same third-order filter is used at the input of each final-amp to the A/D converter, thus providing another 30 dB, for a total of 69 dB attenuation at 60 Hz.

The interstage coupling capacitors set the low frequency pass band of the amplifiers. The low frequency roll-off is 24 dB per octave with the -3 dB point at 6 Hz. This is well above muscle activity and other "noise".

A 2.5 volt reference diode sets the analog references to the A/D at 1.75 and 3.25 volts, or +/- 1.25 volts of half the power supply. The last amplifier stage is DC offset to one half the power supply voltage with the AC signals having a permissible peak value of 1.25 volts. The overall gain of the amplifier stage was set to 12,500 so that a 100 μ V signal would be the maximum input. This amounts to about .8 μ V per bit sensitivity.

Since the ADC0808 is generally thought of as a DC converter and we are measuring AC signals, offsetting the reference to the A/D converter allows it to measure signals that swing above and below some point which is designated as "zero" (offset binary converter). When 0V is applied to the A/D its output will be 80H.

A voltage gain of 12,500 corresponds to 82 dB ($20 \cdot \log A_v$). The 60 Hz rejection of 69 dB results in a 60 Hz gain of 13 dB (82 dB - 69 dB). The common mode rejection of 43 dB reduces the 60 Hz gain to a loss of -30 dB (13 dB - 43 dB). This all means that a 60 Hz common mode signal at the inputs is reduced by a factor of .03 in getting to the A/D converter. To show up as a +/- one-bit ripple on the data, the common mode input signal would have to have an amplitude of 300 mV peak to peak. This 300 mV would be reduced by a factor of .03 to become 10 mV at the A/D.

The Digitizer and Control Section

The signals from the four amplifier/filter channels go to four of the eight analog inputs of the ADC0808. Channel selection and transmission to the host CPU is performed by an 8031 CPU (while it is possible to duplicate the amplifier/filter section to ultimately produce an 8 channel version of HAL, the current level of software for the 8031 is designed for 4 channels).

Schematic 1 shows the microcontroller part of the headset circuitry. The 80C31's Port 1 connects to the ADC0808's data outputs, with all the control and status bits handled by Port 3. Bits from Port 1 also drive the serial output line and the two switches. Because Port 2 is dedicated to the upper half of the program address and Port 0 is the EPROM data bus, there are no port bits left for anything else!

The timing requirements are so simple that the code doesn't even need interrupts. It samples the two switches, reads the left and right hemisphere voltages from the ADC0808, and sends the results out serially. Each data sample consists of a 5 byte transmission. The data sequence is: first byte, 2 switch position codes with 6 bits of leading zeros; followed by 4 bytes of sequentially sampled A/D channels.

HAL is battery powered. Four Alkaline C cells provide plus six volts and 4 AA cells provide a negative six volts (+/- 6V) for the op-amps. The CMOS digital circuitry runs from the 6 volt supply. Current drain with all CMOS components is 225 mA @ 6V and 50 mA at -6V. (yes, we know that most chips like 5 volts, but CMOS digital chips will work fine in this application at 6V). An additional 9V battery (10 mA) is used for the serial communication.

The two pushbutton switch inputs (J6) are provided to allow operator signaling to the host computer. Serial data output drives the TIL111 optocoupler by means of a BS-170 FET. A MAX232 (U6) converts the opto-coupler's output to RS-232 levels compatible with the serial input of the PC host computer. It is powered by a separate 9V battery so that when it is connected to the PC, isolation between HAL and the PC will be maintained (Do not try to use the 6V C cells which power the main HAL circuit to power U6!).

BIO-31 8031 Firmware

BIO-31 is a simple "READ/TRANSMIT/WAIT" loop (shown in figure 1). The read portion of the loop simply samples the switches and the analog to digital (A/D) converter. The samples are placed into the output buffer and transmitted at 4800 bps to the host PC as binary data. The transmission is a 5 byte sequential string: switch data/sync, channel 1, channel 2, channel 3, and then channel 4.

Program Flow

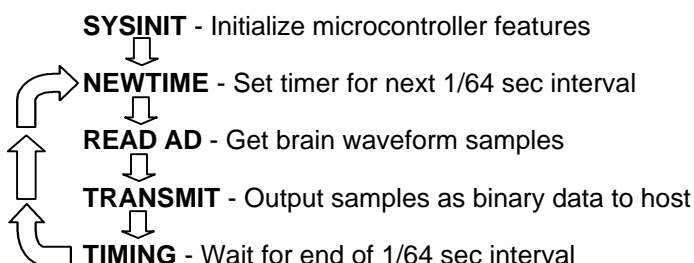


Figure 1 - BIO-31 Program Flow Diagram

Once transmission is complete, the program waits for the processor's internal timer to time out. This precise time delay is what provides the host program with data samples that can be successfully analyzed by an FFT.

HAL's firmware control program (main loop shown in Listing 1), contained in a 2764 EPROM, U9, is called BIO-31. Nearly all of the BIO-31's time is spent in line waiting for Timer Flag 0 (TFO) to become a logic 1. Whenever that happens, the code reloads Timer 0 to produce the next 1/64 second delay and clears the flag again.

While the five bytes in each sample take only 6.25 ms to transmit at 4800 bits/sec and there's lots of idle time on the link (the PC code needs 64 samples per second. We don't send it faster because the PC analysis program would choke.), the Fourier Transform software in the PC presumes that all the data points are sampled at the same instant in time. As a requirement then, BIO-31 runs the ADC as fast as possible between samples. We used in-line code to eliminate the overhead of subroutine calls and returns, although I'll be the first to admit that the few microseconds probably don't make any difference at all. Listing 2 shows what's needed to grab Channels 0 and 1 from the ADC0808.

Throughout the conversions the Accumulator holds a copy of Port 3, so that changing the ADC channel address is simply a matter of adding 1 to the right ACC bit and reloading Port 3. The code sets the ADCready bit to a 1 to make sure that the bit is always an input; writing a zero to that bit would turn it into an output!

toggling the ADC's start bit using a pair of CLR/SETB instructions provides a one microsecond pulse on that output. One of the nice things about the 8031 is that you can tell exactly how long each instruction will take, so generating precise time intervals is quite simple.

The ADC0808 takes a few microseconds to drop the line that signals the end of conversion before starting the next one, so the code includes a loop to wait for that bit to go away before continuing. This is one of those cases where the computer can outrun the peripheral!

Listing 1 -- 80C31 main loop

```
ADCdata EQU P1           ; data inputs
ADCctls EQU P3           ; control I/O
start EQU 2              ; + to start conversion
ready EQU 3              ; + on end of conversion
switches EQU 81H         ; switch bit locations
ADC0 EQU 10H             ; low order address bit
ADCaddr EQU 70H          ; address bit location
sync EQU P3.0            ; sync out of switch input!

; Setup Code Omitted

;--- wait for Timer 0 to run out, then reload it
again EQU $
      JNB TF0,again      ; loop until timer tick
      CLR sync           ; blip scope sync down
      NOP
      SETB sync          ; ... and back up again
      CLR TR0
      MOV TH0,#HIGH -Toperiod ; reload
      MOV TL0,#LOW -Toperiod
      CLR TF0            ; clear end flag SETB
      TR0                ; restart counter

;--- read the channels in a great rush

      CALL getADC

;--- read the switches and send them out

      MOV A,ADCctls      ; grab input bits
      ANL A,#switches   ; strip switches
      RLA                ; move to bits 1-0

Lsw   JNB TI,Lsw         ; will set every time!
      MOV SBUF,A         ; send byte
      CLR TI ; reset ready flag ;--- send analog data

L0    JNB TI,L0         ; wait for trans ready
      MOV SBUF,R0        ; drop in the value
      CLR TI            ; reset trans ready

L1    JNB TI,L1         ; repeat for channel 1
      MOV SBUF,R0
      CLR TI
      JMP again
```

Listing 2 -- read analog-to-digital converter

```
;-----  
; Get channels from the ADC input  
; Values are stashed in registers  
  
getADC  PROC  
  
        MOV    A,ADCctls           ; reset address  
        ANL    A,#NOT ADCaddr  
        SETB   ACC.ready           ; ensure this bit is a 1  
        MOV    ADCctls,A  
  
; --- grab channels  
  
        SETB   ADCctls.start       ; blip start line  
        CLR    ADCctls.start       ; ... with 1 us pulse  
Lw0r    JB     ADCctls.ready,Lw0r   ; wait for EOC to go away  
Lw0e    JNB    ADCctls.ready,Lw0e   ; now wait for EOC active  
        MOV    R0,ADCdata          ; save data in reg  
        ADD    A,#ADC0             ; tick channel number  
        MOV    ADCctls,A  
        SETB   ADCctls.start       ; repeat for channel 1  
        CLR    ADCctls.start  
Lw1r    JB     ADCctls.ready,Lw1r   ;  
Lw1e    JNB    ADCctls.ready,Lw1e   ;  
        MOV    R1,ADCdata  
  
        RET  
  
getADC  ENDPROC  
  
        END
```


Software Overview

The overall operation of HAL is relatively straightforward. HAL samples four channels of analog brainwave data 64 times per second and transmits this data serially to a host computer. There, two channels of the data are analyzed to determine frequency components, and then the results are displayed on the PC's monitor.

The frequency range of interest in brainwave detection is 4-20 Hz, which includes alpha, beta, and theta waves. HAL could have been designed with many independent bandpass filters to separate each channel's complex waveform into discrete sinusoidal components but this would have involved at least an order of magnitude more hardware. Instead, HAL transmits its raw digitized analog data to a host computer which runs a Fast Fourier Transform (FFT) on the data.

An FFT is like a mathematical screwdriver that makes sense out of what often looks like random data. In this case, using an FFT will break down whatever waveform it analyzes into its sinusoidal components. This way we can extract amplitude and phase values for any given frequency in our target spectrum -between 4 and 16 hertz.

The system software coordinates four major tasks (graphically outlined in figure 2). The Intel 8031 microcontroller's task is precise sampling of hemispherical data and transmission via opto-coupled RS232 link to the host PC (the 8031 firmware is called BIO31). The task called COMMO is an interrupt driven communications program that receives data independent of the activities of FFT analysis and video display. As data is received by the host, it is loaded into both of the 1024 byte sample queues for left brain and right brain data.

The FFT algorithm reads this incoming data at will, calculates amplitude and phase values per frequency, then updates integer arrays. The last task is for BIO to use these arrays to continually update the bar graphs on the video display.

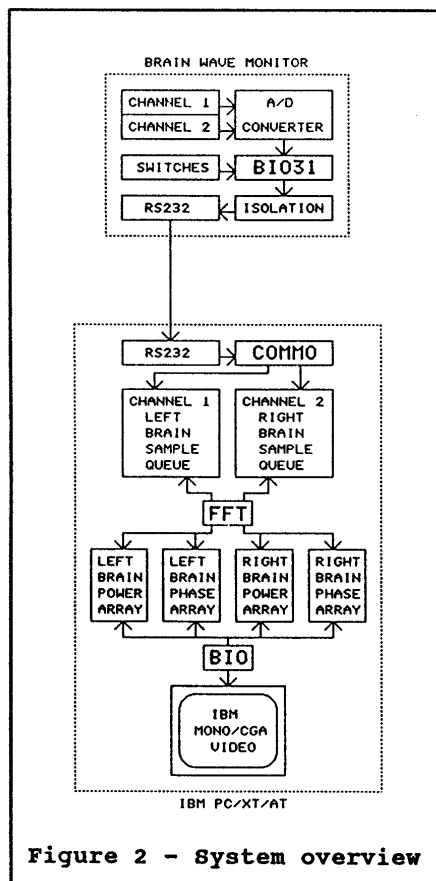


Figure 2 - System overview

Simple - Right? Just like using a hammer to make gravel out of a boulder. Simple in theory at least.

While HAL is technically host computer independent by virtue of its serial interface, the demonstration software was developed for display on an IBM PC for convenience (conversion for, use on other computers is left as an exercise to the individual. Any conversions made available to CCC will be offered to all through the Creative Control Concepts website at <http://www.cc-concepts.com/>). Because HAL is supposed to be an educational as well as functional presentation, the fundamental goal for the PC software was, "Keep it simple and keep it fast", and to that end BASIC was used wherever possible. However, to maintain processing speed, certain assembly level routines were incorporated which are called from BASIC (QUICK BASIC compiler).

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Referring to the system overview (Figure 2), the blocks called COMMO and FFT are written in assembly language. COMMO is really a group of subroutines, of which only the initialization code is actually called from BASIC. The actual communications interface with the opto-coupled HAL headset electronics is interrupt driven.

The FFT block was written in assembly language for optimum speed in the Fourier Transform calculations. Note that on today's PCs you can probably use a high level language to calculate the transform and display the data in real-time. If you come up with something, let us know and we'll share it with other users via our Open Source web site.

COMMO - The PC Communications Interface

COM port 1 is configured as the headset interface port. Data is transmitted from the headset at 4800 bps with no parity and 1 stop bit. The data from the headset is expected in a rather simple format (see figure 3). The headset transmits 5 bytes of data 64 times a second. The first byte is a switch configuration on the headset transmitter.

A switch/sync byte value of 00000011 indicates that both the left and right switches are closed and all zeros indicates that they are both open. The maximum value the switch position/sync byte can be is 3. BIO31, as one of its functions, tests all outgoing data and limits the lowest A/D channel data to a value of 4. Since any incoming data of 3 or less must therefore be the switch position/sync byte, it is possible for COMMO to "Sync-up" on the incoming data stream and put the data in the correct place.

COMMO's service routine uses a state machine to synchronize itself with the incoming data. It reads the data byte from the DATA RECEIVE register and stores it according to which state the routine is in. If state zero, it saves the switch bits and advance to the next state. If state = 1, it loads the sample data into the left brain input queue. If state = 2, it loads into the right brain data queue, etc. If a value of 3 or less is encountered, the state will automatically change to state zero and it will save the data as switch parameters.

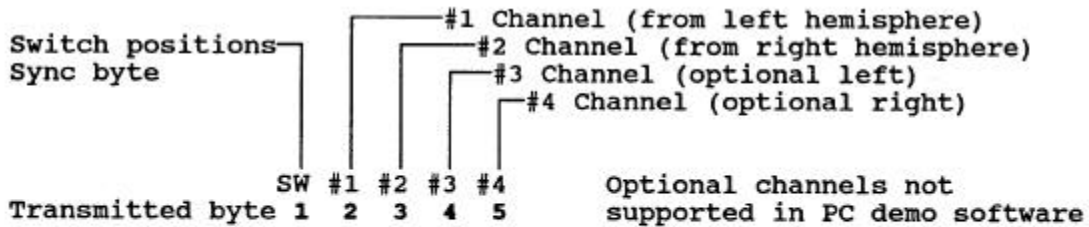
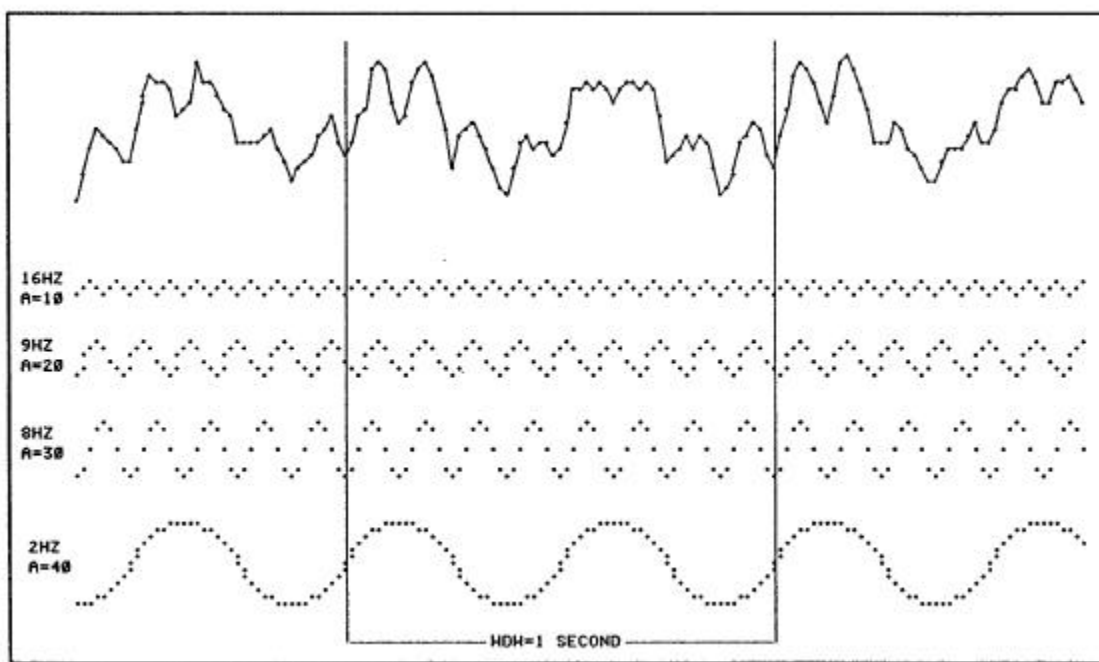


Figure 3 -- Transmission protocol from HAL to the PC

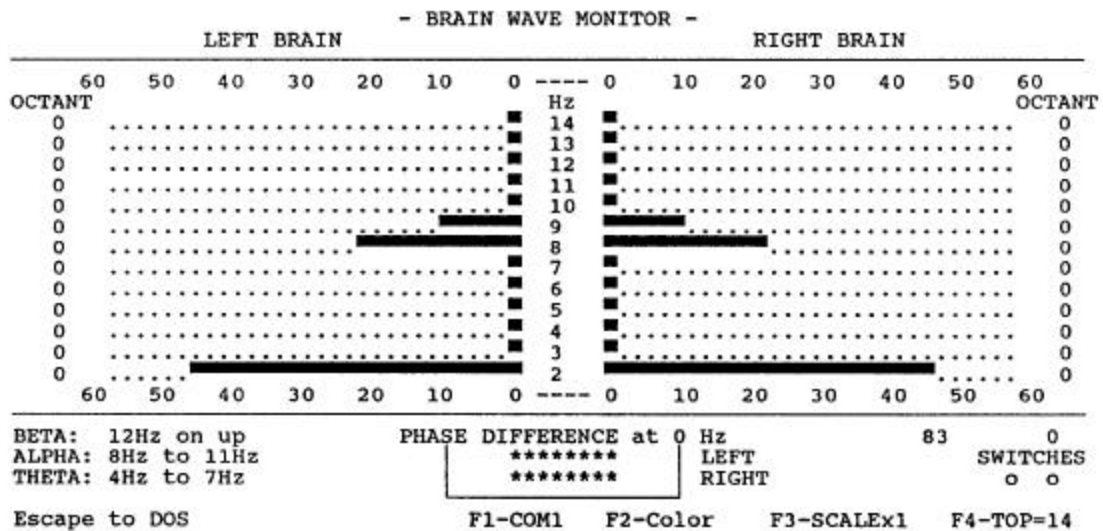
FFT - The Fast Fourier Transform

After the data is received, the next major function is the FFT where whatever data we have collected is transformed into something more useful. In this application, we want to see what frequencies are active in our brains, and how powerful they are.

What does the FFT do for us here? Consider figure 4. The four sine waves on the bottom represent energy levels at four different frequencies plotted with respect to time. The vertical bars represent our one second sample window (if you really want to count them, there are 64 dots on each graph between the two vertical lines that represent precisely 1/64 second intervals). The top squiggle is an integrated waveform, that is the sum of the four waveforms below it at any given point in time.



This integrated waveform is similar to what we find in the real world. Values generated from this integrated waveform were used to test HAL's software. The results of the FFT on this generated data appears on the screen in figure 5. The bars are read side to side with their respective frequencies labeled in the middle. Energy levels are defined both above and below the bar graphs. The same test data was applied to both the left brain and right brain sample queues and the result is what you see. The display will be discussed in greater detail later.



There is a little more to structuring an FFT than just using an algorithm out of a book. Listing 3 is a section of the file FFT.BAS, the FFT code written in ZBASIC. The initial lines of code are configuration data and only the last 11 lines perform the actual Fourier Transform on RAWDATA.

There are three major factors that must be addressed when building a simple FFT algorithm: the duration of the sample window, the sample rate, and the actual frequencies desired for output. These factors are identified as:

WDW - The sample window:

The time period over which the sample is taken will affect the resolution you can expect in your output. A period of one second will yield one hertz intervals of frequency. This is the way the program is set up now. If the sample window is cut to 1/2 second, your resolution is halved. Your frequency output will be in 2 hertz increments. By increasing the sample window to 2 seconds, you get .5 hertz intervals back.

PT - The sample rate:

The number of points taken during the sampling period determines the range of frequency increments (dependent on window period) you can calculate. According to the Nyquist sampling theorem, you must sample more than twice as fast as the greatest frequency you expect to encounter. If your high end is 40 Hz, you must take at least 81 samples during that sample window. HAL takes 64 samples during a one second window. We should be able to evaluate frequency output up to 30 Hz.

MIN and MAX - The output frequencies:

The counter variable HZ need only be the frequencies desired. The Fast Fourier Transform algorithm is really a speeded up version of what is called a Discrete Fourier Transform (DFT). The DFT calculates frequency output from 0 to the number of points taken. But, this output includes something called negative frequencies. These mathematical monkeyshines can be ignored for the purpose of understanding this project. However, FFT.BAS can be easily tweaked to graphically display this also.

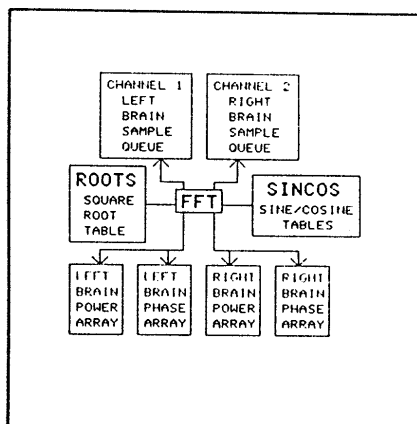
Listing 3 - FOURIER TRANSFORM ALGORITHM IN BASIC

```
REM -----
REM FREQUENCY(Hz)   AMPLITUDE           PHASE(Radians)
FREQ(0)=16:         A(0)=10:             P(0)=0:   REM Channel 1
FREQ(1)=9:         A(1)=20:             P(1)=0:   REM Channel 2
FREQ(2)=8:         A(2)=30:             P(2)=0:   REM Channel 3
FREQ(3)=2:         A(3)=40:             P(3)=0:   REM Channel 4
WDW = 1.0:   REM Sample period in seconds
PT = 64:     REM Number of sample points
MIN = 2:     REM Minimum frequency to be evaluated (1 - 25)
MAX = 16:    REM Maximum frequency to be evaluated (MIN - 25)
SM = 040:    REM Offset to start of sample period
REM -----
FOR HZ = MIN TO MAX:REM Calculate frequencies MIN Hz to MAX Hz
  REAL = 0:      REM Clear the real and imaginary components
  IMAG = 0
  FOR X=0 TO PT-1: REM Begin the frequency analysis loop
    G = 2*PI*HZ*X/PT: REM reference angle
    REAL = REAL + RAWDATA(X)*COS(G)/PT: REM real component
    IMAG = IMAG - RAWDATA(X)*SIN(G)/PT: REM imaginary component
  NEXT X
  FFT(HZ,0) = 2*SQR(IMAG*IMAG + REAL*REAL): REM Power
  FFT(HZ,1) = ATN(IMAG/REAL): REM Phase
NEXT HZ
```

The array called FREQ(4) represents the sinusoidal frequencies to be integrated into the squiggle we talked about earlier. Array A(4) represents the peak amplitude of these sine waves. And P(4) is there to introduce a phase offset in a single channel. The variable SM specifies the start of the PT points of data to be analyzed by the FFT. Graphically, SM locates the vertical bars on the display.

An FFT Optimized for Speed

Speed was a key issue in the HAL-4 DEMO programs. For a visual display to be of any value to a user, the brainwave data had to be analyzed and displayed as quickly as possible. Ideally, we should be able to see changes in hemispherical activity every 1/2 second or less. Unfortunately, FFT.BAS takes about five minutes to run with 64 points of data even in compiled BASIC. (At least it did when this board was designed and 'AT' style computers were the latest thing.)



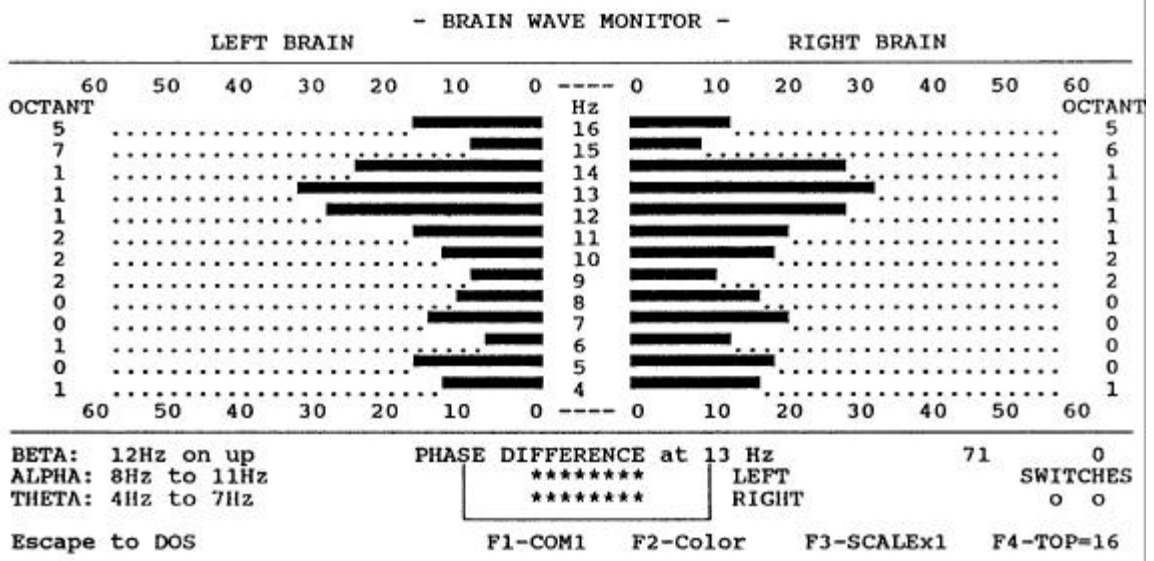
Clearly, a high level language was not going to do the trick. Ultimately, a machine language version of the FFT algorithm described in FFT.BAS was implemented in the PC software for HAL. Figure 6 shows the flow of sample data from the left and right brain sample queues through the algorithm, and into the power and phase arrays defined in the BASIC program. A 64 point analysis of both hemispheres takes about 240 milliseconds using this algorithm. On the IBM PC/XT, it takes about 2 seconds to complete the entire feedback cycle. On the AT the feedback cycle can be done in about 1/2 second.

NOTE – The times above were measured using XT and AT style PCs when this board was originally designed. Given the raw power of today's PCs with math processors on the CPU, etc. you would easily be able to perform the FFT in a high level language and display the information in Windows.

BIO - The IBM PC Video Display Driver

The BIO module takes calculated output from the power and phase arrays just loaded by FFT, converts this output into character strings, and writes them to the display. This is the part of the software that displays the window opened by HAL into your brain.

Figure 7 below shows a typical HAL display. It can be displayed in either CGA color or monochrome. The horizontal bars represent the relative energy levels found in the frequencies evaluated. The bars that lead to the left represent the energy in the left hemisphere (channel #1), and the bars to the right of center are the right hemisphere (channel #2). Respective frequencies are labeled down the middle of the display under the heading "Hz". The numbers 0 to 60 located in rows above and below the energy bars represent relative energy levels only (pressing F3 changes the scale). They do not necessarily indicate absolute voltage levels that a much more expensive EEG machine might provide.

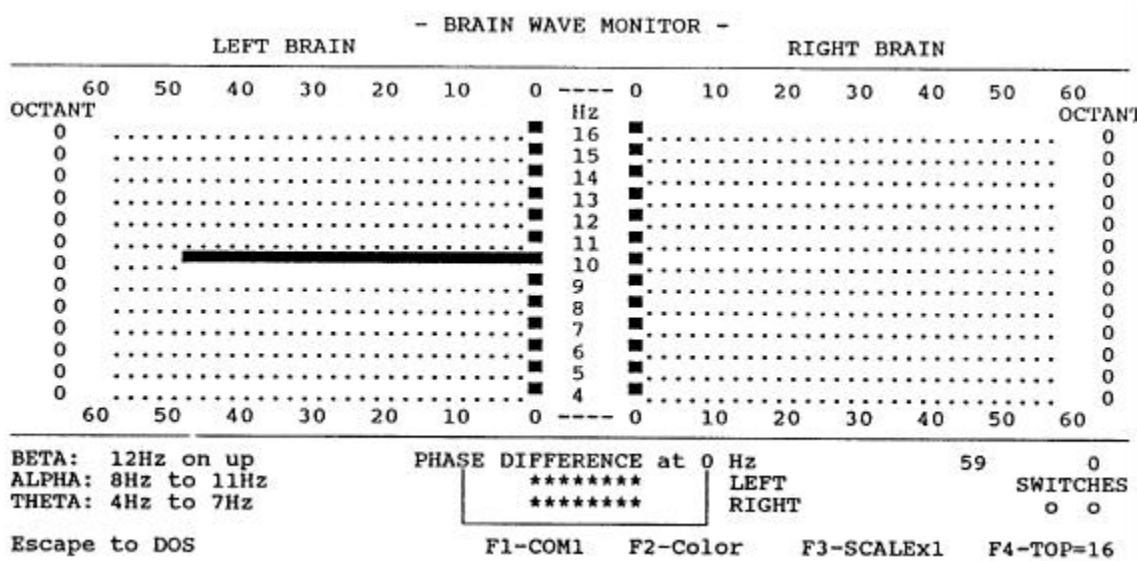


The phase angle of any given frequency is shown under the heading of "OCTANT" for its respective hemisphere. An Octant is nothing more than 1/8th of a cycle. Octant 0 means the waveform is within the first 45 degrees of its cycle. A value of 1 puts it between 45 and 90 degrees, and so on. Relative phase is also indicated in a box at the bottom center of the screen under the heading of "PHASE DIFFERENCE". This feature selects the frequency from the left hemisphere with the greatest energy level, and compares its phase angle with the phase of the corresponding frequency in the right hemisphere. The two rows of asterisks (*****) represent the position of the right hemisphere relative to the left. If the right hemisphere is 1 octant ahead of the left, the right hemisphere indicator will be advanced 1 column in front of the left hemisphere indicator.

Confidence in the System

How do we know that what we see on the display is really what is going on in our heads? What makes data from HAL's electronics different from a string of random data? Testing, of course.

The first test we have already discussed (figure 5). A known waveform was built from several known sinusoidal waveforms into integrated data. When the FFT does its thing on that data, we saw that the frequencies and energy levels we put in are indeed what we got back out.



The next level of confidence comes by using a sine wave generator and force-feeding the hardware with real data. The generator's output is put through a transformer for isolation. HAL's common ground connects directly to the generators ground. Signal levels at the isolated side of the transformer will overpower HAL's differential inputs unless a resistor divider network is used to reduce it by a factor of about 1 million. The inputs of channel 1 go across the last resistor of the divider. Figure 9 is a sample of a 10 Hz sine wave being introduced into the headset electronics channel #1 input. Note that all other frequency bands are null.

Once we know how the FFT algorithm works, and we have the confidence that the hardware will deliver the data correctly, the rest is up to the interpretation by the users. A sample session using the complete system seems to indicate that many frequencies are active. There also appears to be a difference between the right and left hemispheres in both amplitude and phase. However, just what that means will have to be left to a person more involved with Biofeedback.

Using The HAL-4

HAL is one of the few Creative Control Concepts projects in which the circuitry and software is relatively simple in comparison to its application. While the basic EEG apparatus has been in use for 60 years, we are just beginning to understand the "circuitry" and "software" operating within our own heads. There are many hundreds of volumes devoted to clinical and research electroencephalography. Several references have been included at the end of this manual, which may be of interest in exploring this complex and fascinating field.

HAL can provide an effective demonstration of how our gross behavior is in some way mirrored in the electrical activity of the brain. However, to view this behavior, you must learn how to connect HAL to your head.

Disposable EEG electrodes with adhesive pads and conductive gel can be purchased from medical supply houses (see Electrode Cables.) Re-usable silver/silver-chloride electrodes are also available. The re-useable electrodes are more expensive initially, but can be used almost indefinitely if properly cared for.

Five wires are involved in a 2-channel HAL connection: Common reference, Left channel differential pair (J1A and J2A), and Right differential input pair (J1B and J2B). Each of the differential pair wires should be made with shielded cable. Standard shielded microphone cable with a male RCA connector at one end and snap that would mate with the electrode at the other end is quite sufficient (see Electrode Cables.) The shield is of course only grounded at the RCA jack on HAL. Be careful not to accidentally short the shield to the differential input electrodes or erroneous results will occur.

The common reference electrode may be placed on the mastoid, the bony projection just behind the ear. The site should first be cleaned with soap and water to remove oils from the hair and scalp. Next, the area should be lightly rubbed with a piece of alcohol-dampened gauze. Finally, peel off the adhesive from a disposable electrode, fill the well with conductive gel (but do not over-fill), and finally place the electrode on the previously selected spot. Note that some electrodes come pre-filled with gel allowing you to skip this step.

A similar procedure is, followed for the placement of the differential pair electrodes on each hemisphere. One wire (J2A or J2B) goes over the frontal lobe - directly above the eye and just below where your hairline was before it started receding! The second electrode (J1A or J1B) is more difficult to place (unless you happen to be completely bald). This electrode should be placed over the occipital lobe, which in most people is covered with hair.

On the back of your head there is a ridge where your skull begins to bend inward toward your neck. Find a spot about one third from the midline of your head to the common electrode placed on the mastoid, and just on or below the ridge. Again, the scalp is prepared, as before, though care should be taken to ensure that the hair is carefully held away from the site. A sweatband may be used to hold the electrode in better contact with

the scalp, and several small holes may be made in the headband to allow easier access to the electrode connector.

Figure 8 shows the general location and nomenclature for commonly used electrode placements. If you build a multi-channel model of the HAL, you will need to refer to more detailed literature about electrode placement, monopolar and bipolar placement, and other esoteric subjects.

If you have successfully placed both channels of electrodes appropriately, it is time to fire up the PC software, which is supplied with HAL. **REMEMBER, to retain its electrical isolation, HAL should only be operated on batteries, EXACTLY as presented.**

Attach the electrode wires to the electrode connectors, connect HAL to the PC's COM1 port, turn on HAL, load BIO.EXE into the PC and watch your monitor. The sample display illustrated previously will allow you to see your own brain activity as you produce it. Actually, due to sampling and processing time, you will see it delayed by about half a second.

You may not see much high amplitude activity at all, and the dominant frequency may drift quite a bit (pressing F3 will change the amplitude range). Nevertheless, if you close your eyes and make your mind more blank than usual, your "lab partner" should see a dominant frequency appear somewhere in the alpha range. Of course, if you open your eyes to see it, it will immediately disappear. Somehow, this is reminiscent of the old question about a tree falling in a forest making a sound or not. Of course, since HAL's data is serial, a secession could be stored to disk so that you can view it "off-line" later.

The display also shows the condition of the two optional switches which can be attached to HAL. The intent here was to provide a way for you to monitor either some external condition or internal state in order to correlate it with your brain wave activity. Two momentary contact switches could be used, one for each hand perhaps, and you could see if you can correctly identify from internal cues some aspect of brain functioning, e.g., what band you are producing a dominant frequency in, whether left or right hemisphere is showing greater power output for different mental tasks, etc. Alternatively, the switches could be triggered by some external variable such as the presence or absence of music, a strobe light, or other stimulus. Since you have two switches, four different conditions could be coded.

The BIO code can also be modified to turn HAL into a standard biofeedback device. In this case you would want to add threshold "controls". That is, the program could provide audio feedback only when you had achieved certain minimum values of relative amplitude within a certain frequency band. Different feedback could be provided for each channel, or feedback could be tied into both channels meeting the same (or different) criteria.

To prevent battery drain when not in use, turn off the power switch and remove the serial cable from the HAL-4. The power switch disconnects the 6-volt batteries and the serial cable disconnects the 9-volt battery.

Assembling the HAL-4

1 - Check the parts list to become acquainted with the components and to verify that you have all that are needed. Read through the rest of the assembly steps without putting anything together to become familiar with the assembly procedure. Once you have done this, you may want to gather the following tools:

- Low wattage soldering iron
- Rosin core solder
- Small wire cutters
- Needle nose pliers
- Lead bending jig (optional)
- IC insertion tool (optional)

Note that the side of the board with the silkscreen outline is the component side and the opposite side is the circuit side. All components should be mounted on the component side and all soldering should be done on the circuit side.

2 - Because of the number of resistors on the board, it is best to install only a few at a time. Using the guide provided, check off each resistor as it is installed. Use the silkscreen to help locate the resistor location and remember to check your work as you go along.

All the resistors are installed in the following manner: Bend the leads on .4 inch centers. Insert the resistor into the circuit board, bending each lead slightly to prevent the resistor from falling out. Solder each lead on the circuit side and then clip each lead as you go along.

1% Resistors (Blue Body)

4	<input type="checkbox"/>	16K	(BRN-BLU-BLK-RED)	R1A,R1B,R1C,R1D
12	<input type="checkbox"/>	470K	(YEL-VIO-BLK-ORG)	R2A,R2B,R2C,R2D
				R3A,R3B,R3C,R3D
				R16A,R16B,R16C,R16D
8	<input type="checkbox"/>	5.1K	(GRN-BRN-BRN-BRN)	R4A,R4B,R4C,R4D
				R5A,R5B,R5C,R5D
8	<input type="checkbox"/>	510K	(GRN-BRN-BRN-ORG)	R6A,R6B,R6C,R6D
				R7A,R7B,R7C,R7D
4	<input type="checkbox"/>	10K	(BRN-BLK-BLK-RED)	R8A,R8B,R8C,R8D
24	<input type="checkbox"/>	100K	(BRN-BLK-BLK-ORG)	R9A,R9B,R9C,R9D
				R10A,R10B,R10C,R10D
				R11A,R11B,R11C,R11D
				R13A,R13B,R13C,R13D
				R14A,R14B,R14C,R14D
				R15A,R15B,R15C,R15D
4	<input type="checkbox"/>	4.7K	(YEL-VIO-BLK-BRN)	R12A,R12B,R12C,R12D
4	<input type="checkbox"/>	1M	(BRN-BLK-BLK-YEL)	R17A,R17B,R17C,R17D

2	□ 51K	(GRN-BRN-BLK-RED)	R18,R19
2	□ 240Ω	(RED-YEL-BLK-BLK)	R20,R21

5% Resistors (Tan Body)

2	□ 100K	(BRN-BLK-YEL)	R22,R23
1	□ 8.2K	(GRY-RED-RED)	R24
1	□ 47Ω	(YEL-VIO-BLK)	R25
1	□ 2.2K	(RED-RED-RED)	R26

3 - All the IC sockets have a notch in one end to indicate the pin 1 end of the socket. Check the circuit board and match the notches when you insert the sockets. Insert all the sockets into the board and verify that all the socket leads protrude through the board and then solder them in place.

1	□ 8 pin DIP socket	SK5
7	□ 14 pin DIP sockets	SK1A, SK1B, SK1C, SK1D, SK2A, SK2C, SK4
1	□ 16 pin DIP socket	SK6
1	□ 20 pin DIP socket	SK8
2	□ 28 pin DIP sockets	SK3, SK9
1	□ 40 pin DIP socket	SK7

4 - Insert the zener diode making sure that the striped end (cathode) matches the stripe on the board. Bend, solder and clip the leads. Recheck the diode for proper orientation.

1	□ 2.5 Volt zener	1N5221
---	------------------	--------

5 - Locate the capacitors in the bag marked "Selected Capacitors". These capacitors are preselected for close tolerances and other capacitors should **NOT** be substituted. The tantalum capacitors have one lead marked "+" to indicate the positive side. Make sure that this lead goes into the hole marked "+". The remaining caps are not polarized and can go in either way. Note you will have to straighten the leads on the 5.6μ F capacitor.

8	□ 3.3μ F	Tantalum 5%	C1A, C1B, C1C, C1D C2A, C2B, C2C, C2D
4	□ 5.6μ F	Tantalum 5%	C4A, C4B, C4C, C4D
4	□ 10μ F	Tantalum 5%	C8A, C8B, C8C, C8D
12	□ .01μ F	Mylar 5%	C3A, C3B, C3C, C3D C7A, C7B, C7C, C7D C10A, C10B, C10C, C10D
8	□ .47μ F	Mylar 5%	C6A, C6B, C6C, C6D C11A, C11B, C11C, C11D
12	□ .1μ F	Monolithic 5%	C5A, C5B, C5C, C5D C9A, C9B, C9C, C9D C12A, C12B, C12C, C12D

6 - Locate the 47µF electrolytic capacitors and bend the leads for .75 inch spacing, making sure that the printed value and polarity arrow can be seen from the top. The arrow points toward the negative (-) end. This polarity must be followed when installing each capacitor on the board. The positive (+) end of the electrolytic cap is marked on the circuit board. Insert them into the board then bend, solder and clip the leads.

5 □ 47µF Electrolytic C19, C20, C21, C22, C29

Repeat this procedure for the 10µF electrolytic capacitors using .55 inch spacing.

2 □ 10µF Electrolytic C23, C24

7 - The rest of the capacitors have radial leads (both leads protrude from the same end of the cap) and can be inserted without forming the leads. These caps aren't polarized so they can be inserted in either direction. The spacing on the board is tight so use care when installing the remaining capacitors. It is suggested that the remaining selected capacitors be inserted first to insure proper placement. Insert the capacitors in the board a few at a time, bending the leads as you go. Solder and clip the leads on the circuit side of the board.

2 □ 27pF Monolithic C17, C18
 19 □ 0.1µF Monolithic C13A, C13B, C13C, C13D
 C14A, C14B, C14C, C14D
 C15A, C15C, C16A, C16C
 C25, C26, C27, C28, C30, C31, C32

8 - Insert the crystal into the board with the printed side up and the opposite side flat against the board. Bend, solder and clip the leads.

1 □ 11.059 MHz Crystal Y1

9 - Insert the LED making sure that the cathode (lead at the same side as the flat spot on the LED's perimeter) matches the stripe on the board. Insert the LED all the way into the surface of the board, solder and clip the leads. Recheck the LED for proper orientation.

1 □ LED Green LED1

10 - Locate transistor Q1 and voltage regulator V1. Bend the Base (center lead) of Q1 toward the flat side of the device to form a small tripod. Insert Q1 into the circuit board. Bend, solder and clip the leads. Bend the three legs of V1 backwards at the point where they become narrow. Insert V1 into the circuit board. Bend, solder and clip the leads.

1 □ JFET BS170 Q1
 1 □ Regulator 7805 V1

Next mount the slideswitch (SW1), the phone jack (J1), and the 1/8 inch stereo jack (J6) on the board. Solder and clip the leads before moving on.

***** Note that when a cable is inserted into the modular jack (J1), power is drawn from the 9V battery. To prevent premature failure of the battery, disconnect the cable from the board when not in use. *****

1 □ PC-mount slide switch DPDT SW1
 1 □ Modular phone jack J1
 1 □ Stereo mini phone jack J6

11 - Mount the nine RCA jacks on the board. It is important to mount the jacks so that are correctly aligned. Solder the pins and check for solder bridges before going on to the next step. Pay attention to the colors and compare to the list below.

- | | | |
|---|-------------------------|--------------------|
| 3 | □ RCA Phono Jacks RED | J1A, J1B, J1C, J1D |
| 3 | □ RCA Phono Jacks WHITE | J2A, J2B, J2C, J2D |
| 1 | □ RCA Phono Jack YELLOW | JS |

12 - Locate the two 1x4 square pin headers. You will find it easier to install these headers if do them one at a time and tack them in place. Finish by soldering all the pins to the board.

- | | | |
|---|-------------------------|-------|
| 2 | □ 1x4 square pin header | J2,J3 |
|---|-------------------------|-------|

NOTE --- Near U3 you will see two 2x8 sets of holes (J4 and J5). Nothing should be installed at these locations. These holes were used for design test points and have no effect on the operation of the board.

13 - As a last step, check each component for proper value, placement, polarity (if applicable), and proper solder joints. Clean the solder flux off the board with a proper solvent (i.e. TRI-CLOR), keeping the solvent away from the component side.

Now that the board is assembled, you may want to enclose it in a case. For information on mounting the HAL-4 in an enclosure, see the section entitled "Enclosing HAL".

Testing the HAL-4

Before trying to use your HAL-4, a few tests should be made to ensure it is operating properly. In order to test the board check the list below to see that you have all the items needed.

- 1 9V power source see pg. 43
- 1 ±6V power source see pg. 43
- 1 Electrode cable see pg. 40 (Parts included with kit)
- 1 HAL-4 to IBM serial cable see pg. 39 (Parts included with kit)

Once you have obtained all the items needed you can begin testing the board. The first step is to take the board with no ICs installed and connect the ±6V power supply. Check the polarity of the power supply before turning SW1 on. When SW1 is turned on, nothing should happen. If smoke or sparks appear or components on the board appear to overheat, immediately turn off power to the board. In addition, LED1 should not be on at this time. The LED is not a power on indicator, it is there to show when the board is transmitting information. Using a good quality test meter and the information supplied in the power table on page 34; test for power at all the points listed in the table EXCEPT:

V1 --- 7805
U6 --- MAX232

If your measurements are not reasonably close to those in the power table go back and recheck your work using the suggestions below.

1. Polarity of ±6V supply is reversed.
2. Shorts or solder bridges on the board.
3. Open traces on the board.
4. Incorrect placement or polarity of components.
5. Dead batteries.

If everything checks out so far, remove power from the board and install the ICs. The list below identifies where each of the ICs should be placed.

TL084	U1A, U1B, U1C, U1D, U2A, U2C
ADC0808	U3
74HC74	U4
TIL111	U5 (see note below)
MAX232	U6
80C31	U7
74HC373	U8
27C64	U9

NOTE ... U5 (TIL111) is a six pin IC, however, the socket in which it is placed (SK5) has eight pins. Pin 1 of U5 should be inserted in position 1 of SRS. Positions 4 and 5 should be left unused.

Once all the ICs are installed, reconnect the $\pm 6V$ supply and turn SW1 on. LED1 should now turn on and appear to flicker. This means that the board is running and trying to transmit data to the PC. If the LED does not come on or does not flicker go back and check your work using the suggestions below.

1. LED1 installed improperly.
2. Check crystal oscillator circuit for proper operation.
3. Check for shorts and/or opens on 80C31 address and data lines.
4. Improperly installed ICs.

If the board has passed these tests, connect the 9-volt battery (power is removed from RS-232 transmitter section until the modular phone type cable is attached). Connect the HAL-4 to a PC and run the software (BIO.EXE). With nothing connected to the boards inputs, you should see the display scanning through the chosen frequency range. The display should also show that no (or minimal - due to noise) energy levels are being seen. If your display is not similar to the one just described go back and recheck your work using the suggestions below.

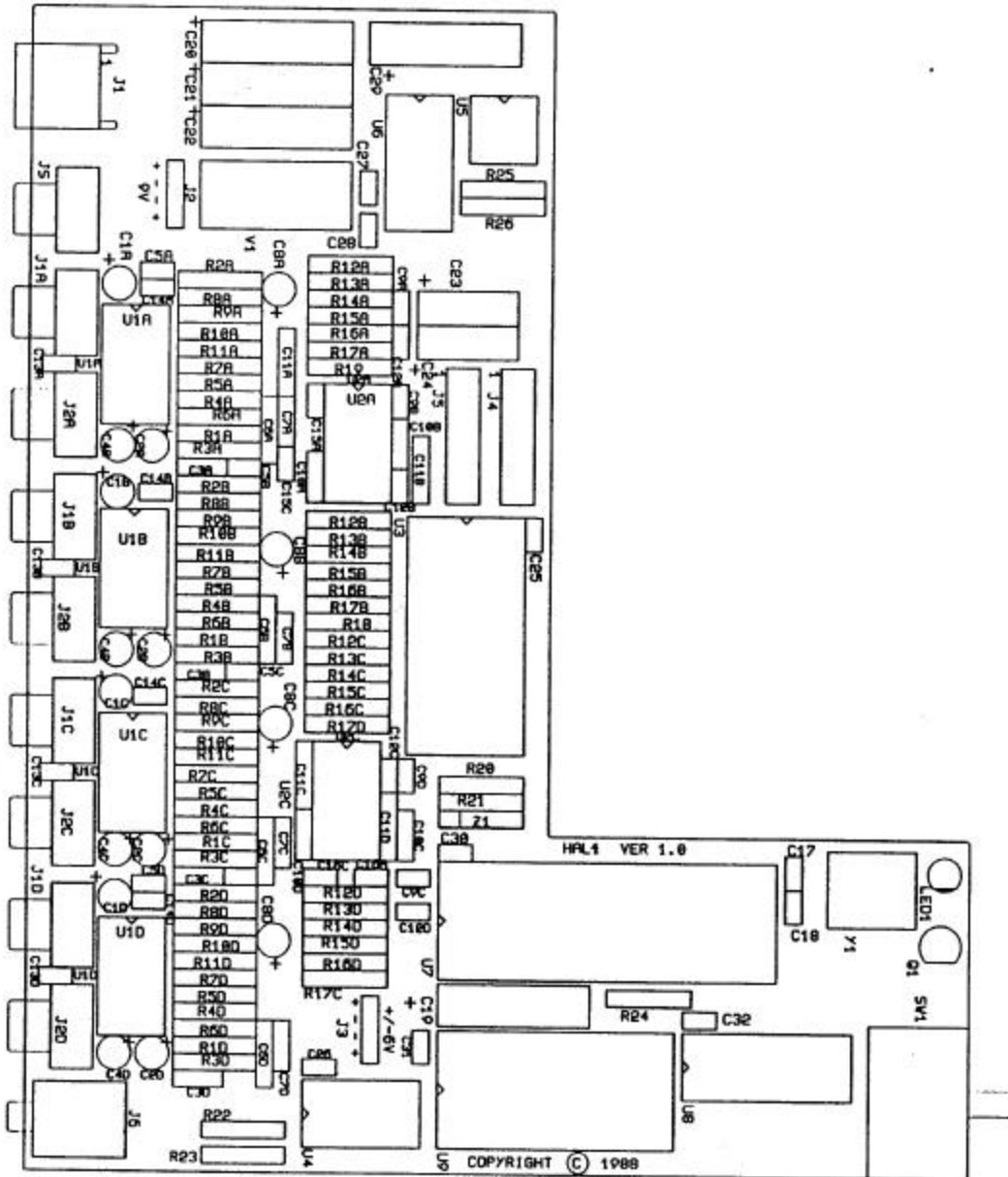
1. HAL-4 to IBM serial cable defective.
2. Problem in serial transmitter section. Check U5, U6, U7, V1.

If everything is working as described the last test is to connect an electrode cable to channel 1. An electrode need not be placed on the cable for this test. Now touch the end of the cable with your finger and the display should display random noise as varying energy levels at varying frequencies. If you do not get these results go back and check your work using the suggestions below.

1. Incorrect placement of parts in the analog section.
2. Shorts or opens in the analog section.
3. Defective electrode cable.

This concludes the testing of the board. If you would like to further test your HAL-4, please refer to the section entitled "Confidence in the system" on page 20.

HAL-4 Circuit Board Silkscreen



HAL-4 Kit Parts List

<u>QTY</u>	<u>ITEM</u>	<u>PART #</u>	<u>DESCRIPTION</u>
CIRCUIT BOARD			
1	PCB1		HAL-4 PRINTED CIRCUIT BOARD
INTEGRATED CIRCUITS			
6	U1A-U1D, U2A, U2C	TLO84	QUAD JFET OPERATIONAL AMPLIFIER
1	U3	ADC0808	8 INPUT 8 BIT A TO D CONVERTER
1	U4	74HC74	H-CMOS DUAL D FLIP-FLOP
1	U5	TIL111	OPTOCOUPLER
1	U6	MAX232	5V RS232 DUAL RCVR/TRNSMTR
1	U7	80C31	CMOS 8-BIT MICROCOMPUTER
1	U8	74HC373	H-CMOS OCTAL TRANSPARENT LATCH
1	U9	27C64	UV ERASABLE CMOS PROM 8KX8
RESISTORS			
1	R25	47 OHM	¼W, 5% (YEL-VIO-BLK)
2	R20, R21	240 OHM	¼W, 1% (RED-YEL-BLK-BLK)
1	R26	2.2K	¼W, 5% (RED-RED-RED)
4	R12A-R12D	4.7K	¼W, 1% (YEL-VIO-BLK-BRN)
8	R4A-R4D, R5A-R5D	5.1K	¼W, 1% (GRN-BRN-BRN-BRN)
1	R24	8.2K	¼W, 5% (GRY-RED-RED)
4	R8A-R8D	10K	¼W, 1% (BRN-BLK-BLK-RED)
4	R1A-R1D	16K	¼W, 1% (BRN-BLU-BLK-RED)
2	R18, R19	51K	¼W, 1% (GRN-BRN-BLK-RED)
2	R22, R23	100K	¼W, 5% (BRN-BLK-YEL)
24	R9A-R9D, R10A-R10D, R11A-R11D, R13A-R13D, R14A-R14D, R15A-R15D	100K	¼W, 5% (BRN-BLK-BLK-ORG)
12	R2A-R2D, R3A-R3D, R16A-R16D	470K	1/4W, 1% (YEL-VIO-BLK-ORG)
8	R6A-R6D, R7A-R7D	510K	1/4W, 1% (GRN-BRN-BRN-ORG)
8	R17A-R17D	1M	1/4W, 1% (BRN-BLK-BLK-YEL)
SEMICONDUCTORS			
1	V1	7805	VOLTAGE REGULATOR, +5VDC
1	LED1	N/A	GREEN LIGHT EMITTING DIODE
1	Q1	BS170	JFET
1	Z1	1N5221	2.5 VOLT ZENER DIODE

CAPACITORS SELECTED

12	C3A-C3D C7A-C7D, C10A-C10D	0.01 μ F	MYLAR 5%
12	C5A-C5D, C9A-C9D, C12A-C12D	0.1 μ F	MONOLITHIC 5%
8	C6A-C6D, C11A-C11D	0.47 μ F	MYLAR 5%
8	C1A-C1D, C2A-C2D	3.3 μ F	TANTALUM 5%
4	C4A-C4D	5.6 μ F	TANTALUM 5%
4	C8A-C8D	10 μ F	TANTALUM 5%

CAPACITORS

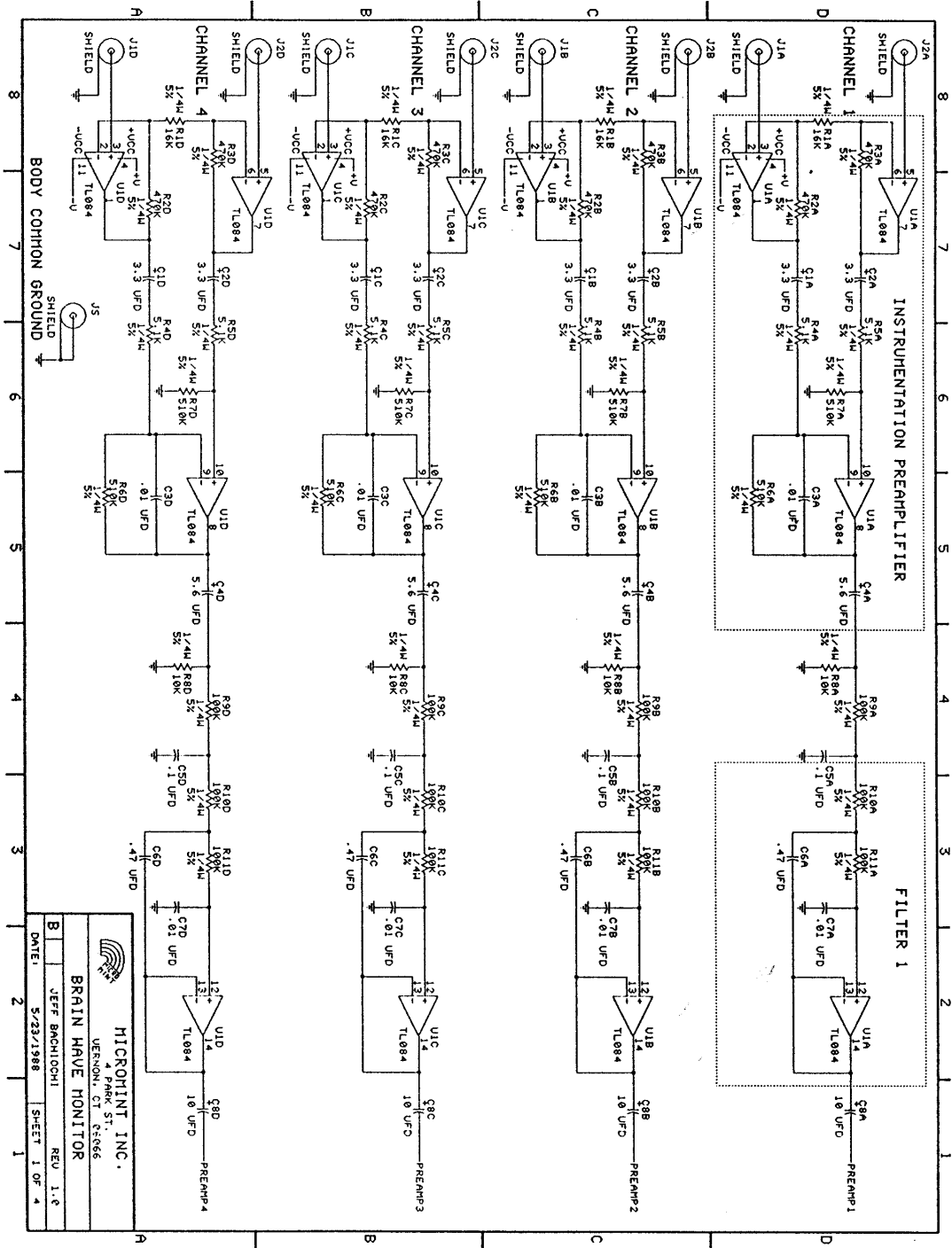
2	C17, C18	2pF	MONOLITHIC
19	C25-C28, C30-C32, C13A-C13D, C14A-C14D, C15A, C15C, C16A, C16C	0.1 μ F	MONOLITHIC
2	C23, C24	10 μ F	ELECTROLYTIC
5	C19-C22, C29	47 μ F	ELECTROLYTIC


IC SOCKETS

1	SK5	8 PIN	IC SOCKET
7	SK4, SK1A-SK1D, SK2A, SK2C	14 PIN	IC SOCKET
1	SK6	16 PIN	IC SOCKET
1	SK8	20 PIN	IC SOCKET
2	SK3, SK9	28 PIN	IC SOCKET
1	SK7	40 PIN	IC SOCKET

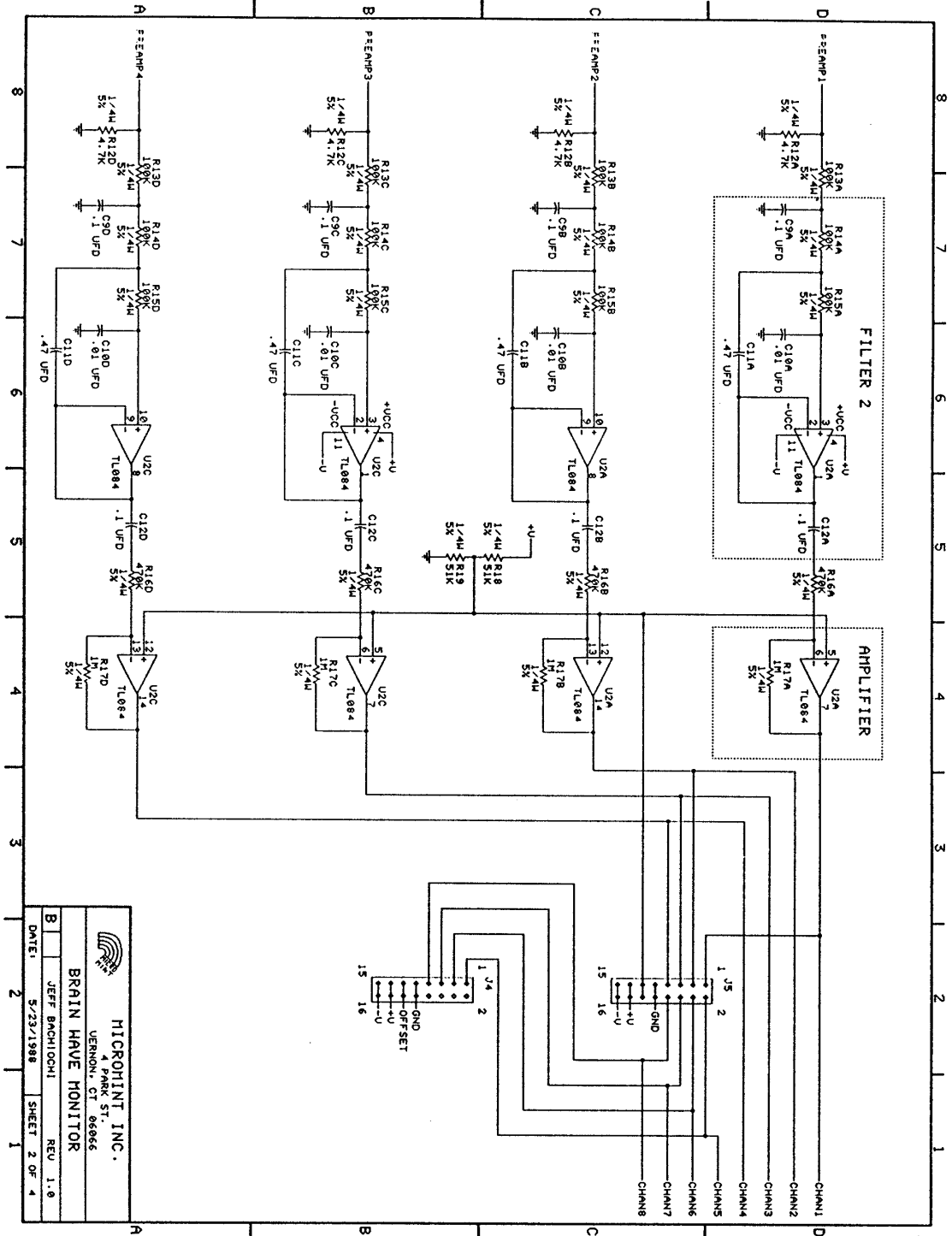
MISCELLANEOUS

1	H3		9V BATTERY CLIP
1	J1		MODULAR PHONE JACK
2	J2, J3	1x4	SQUARE PIN HEADER
1	JS	YELLOW	RCA PHONO JACK
4	J1A-J1D	RED	RCA PHONO JACK
4	J2A-J2D	WHITE	RCA PHONO JACK
1	J6		STEREO MINI JACK
1	SW1		SWITCH, DPDT
1	Y1	11.059 MHZ	CRYSTAL
2			C Battery Holders with Molex connector
9			6' RCA Cables with stripped end
1			6' Mini Jack Cable (Event Switch Cable)
1			7' Serial Cable w/RJ-11 connectors
1			RJ-11 to DB-25 Serial Adapter
4			Packs of pre gelled electrodes
9			Size #3 Snaps




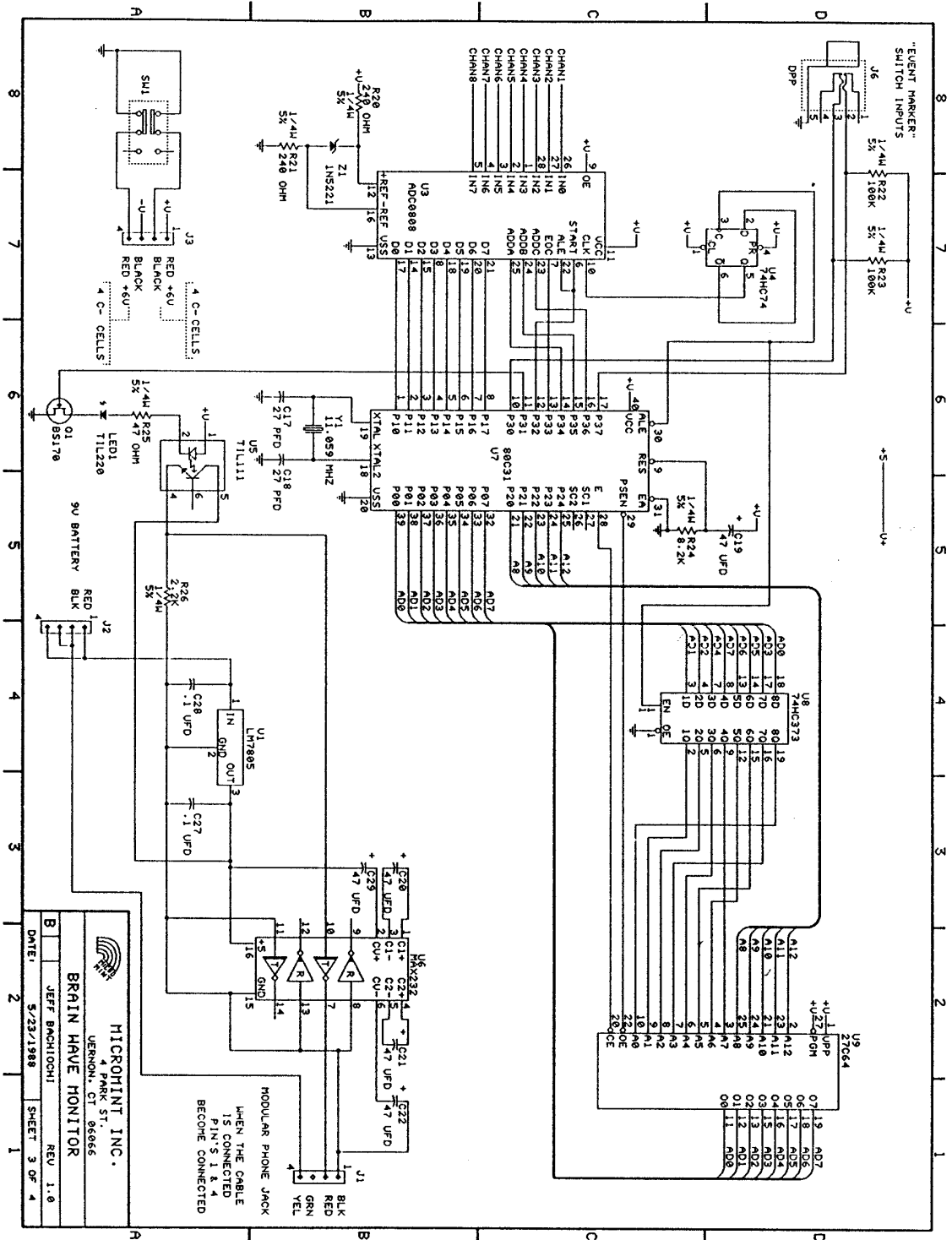

MICROINT INC.
 100 PARK ST. CT 06666
 WETHERFIELD, CT 06094
BRAIN WAVE MONITOR
 JEFF BACHIOCHI
 REV 1.6
 DATE: 5/23/1988
 SHEET 1 OF 4

HAL-4 Schematic 1 of 4

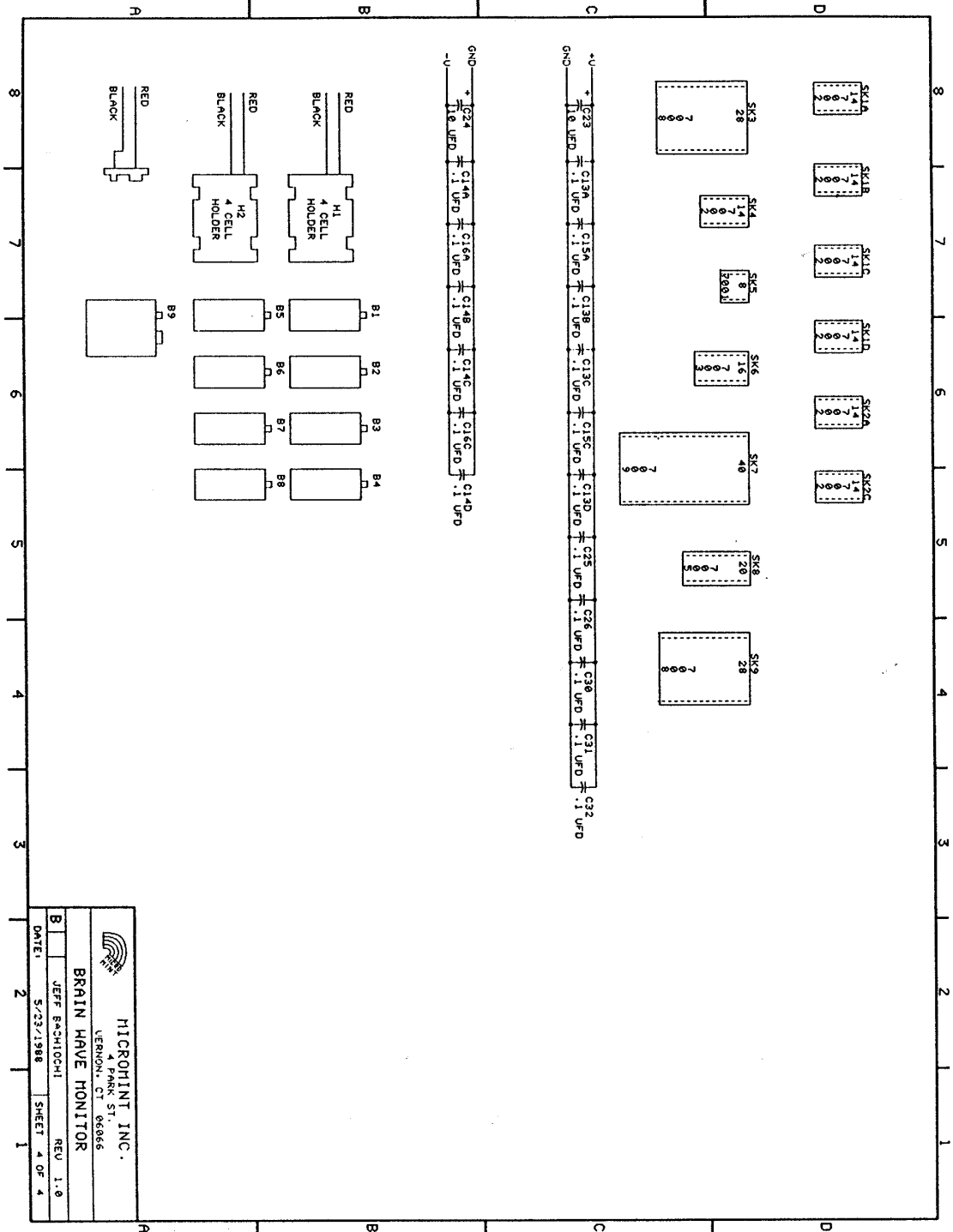


HAL-4 Schematic 2 of 4


MICROMINT INC.
 4 PARK ST.
 VERNON, CT 06066
JEFF BACHIOCHI
 DATE: 5/23/1988 SHEET 2 OF 4
BRAIN HAVE MONITOR
 REV 1.0



HAL-4 Schematic 3 of 4



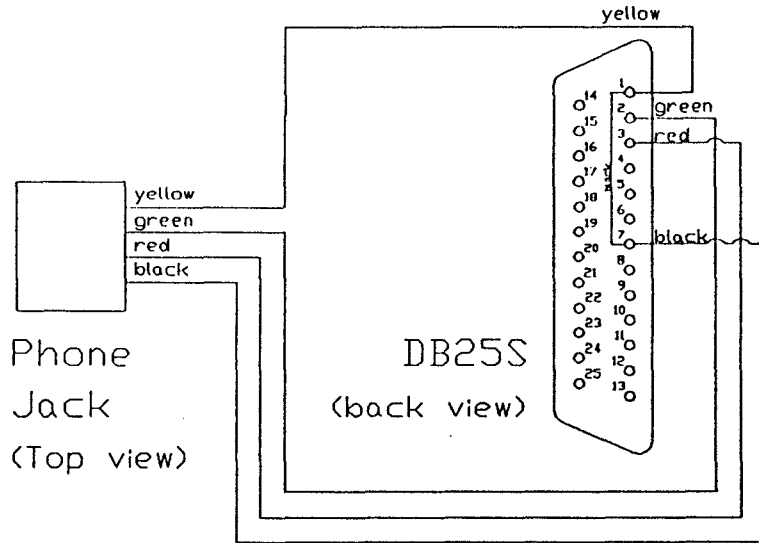
HAL-4 Schematic 4 of 4

HAL - 4 Power Table

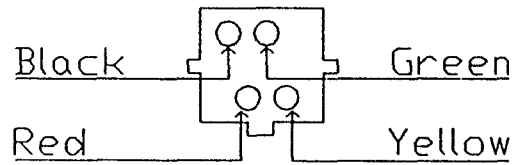
The table below outlines which IC pins are connected to a given power supply on the HAL-4 board. The HAL-4 board has multiple power supplies (+6, -6, +9) to drive various parts of the circuits. The digital logic is powered by +5V derived from the 7805 linear regulator which draws off the +9V battery.

IC#	Type	GND	+V +6	-V -6	+9	+5	+REF +3.25	-REF +1.75
U1A	TL084		4	11				
U1B	TL084		4	11				
U1C	TL084		4	11				
U1D	TL084		4	11				
U2A	TL084		4	11				
U2C	TL084		4	11				
U3	ADC0808	13	9,11				12	16
U4	74HC74	7	14					
U5	TIL111		1					
U6	MAX232C					16		
U7	P-80C31	20,31	40					
U8	74HC373	10	20					
U9	27C64	14	1,27,28					
V1	LM7805	2			1	3		

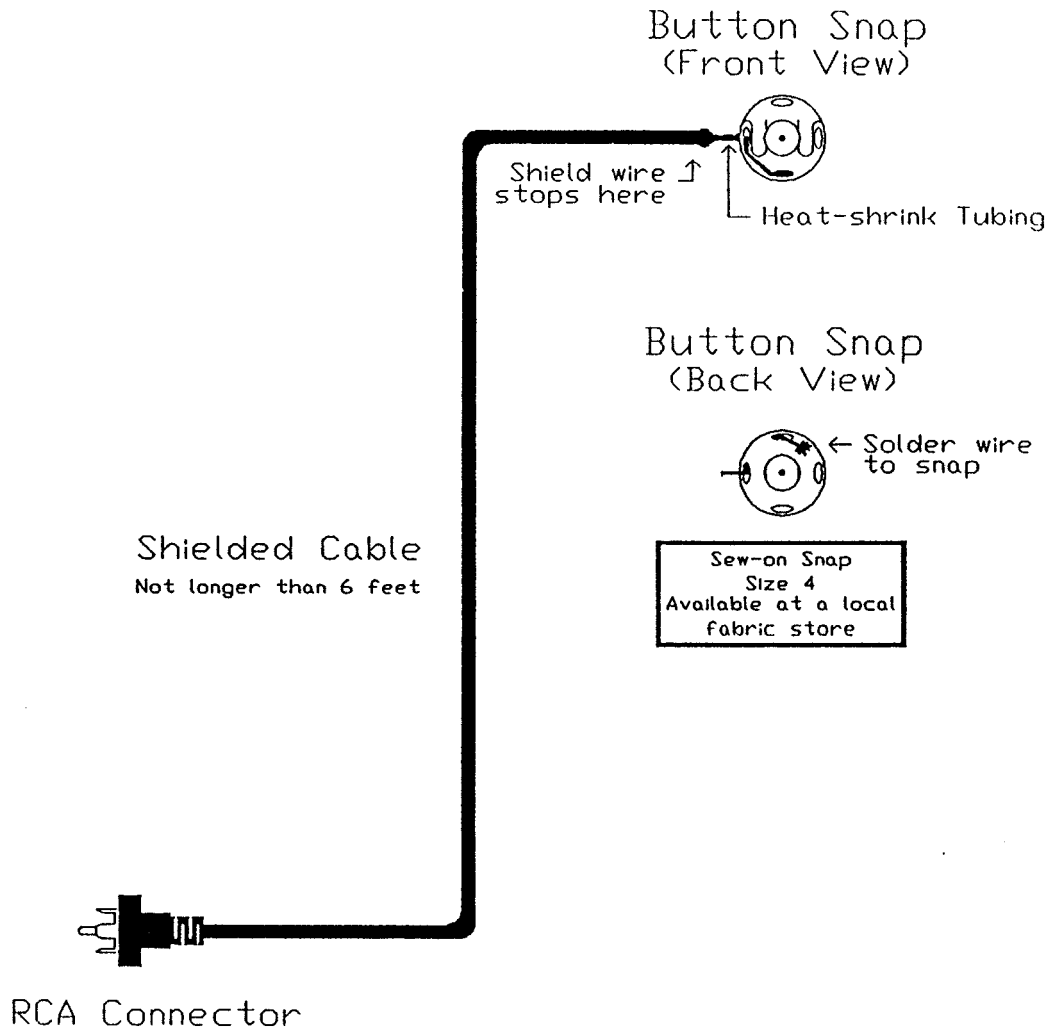
PC Cable Diagram



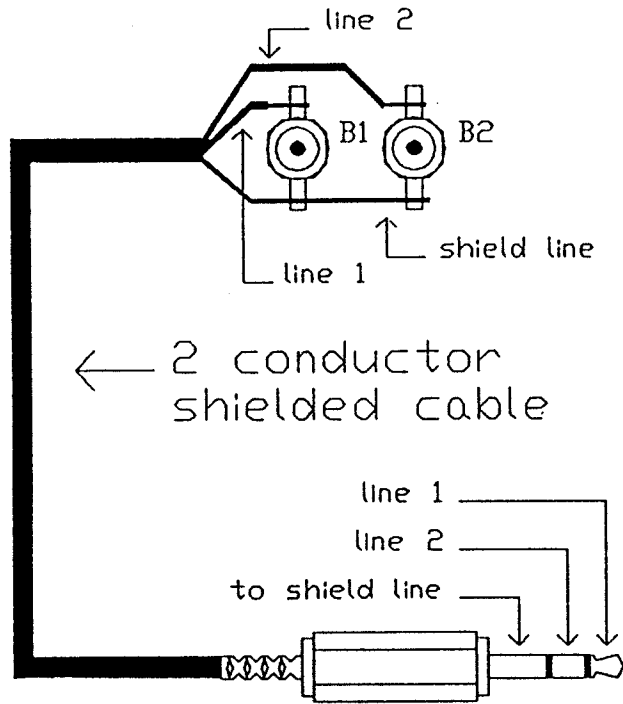
Phone Jack (back view)



Electrode Cable

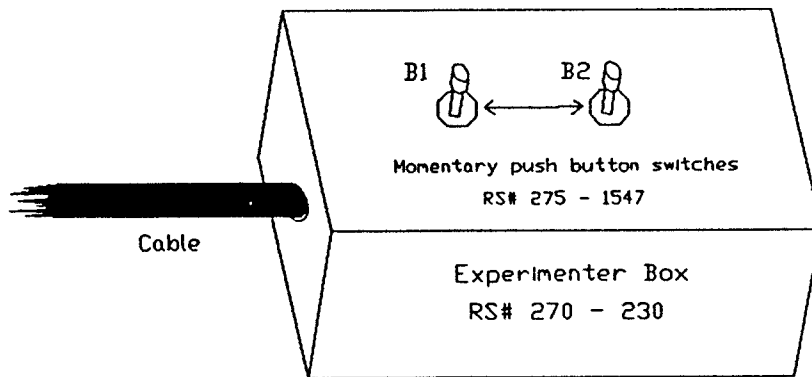


Event Marker Box Diagram



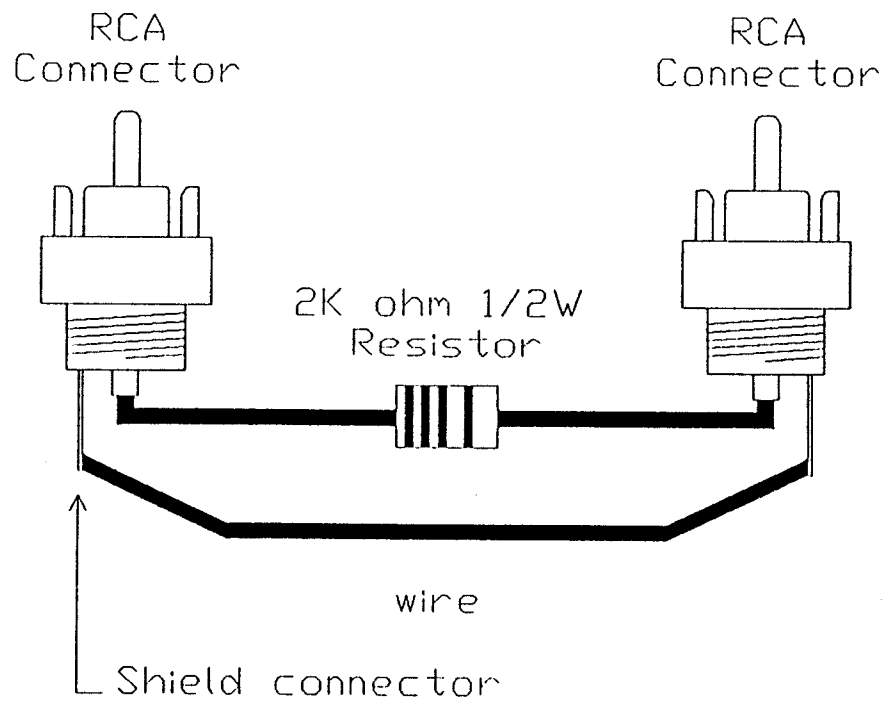
1/8" Stereo plug
RS# 274 - 284

Mounting the switches



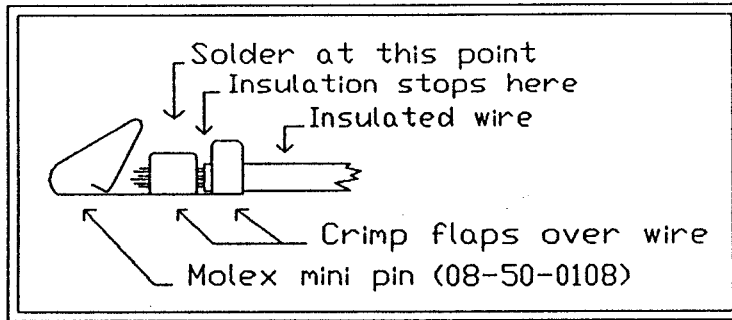
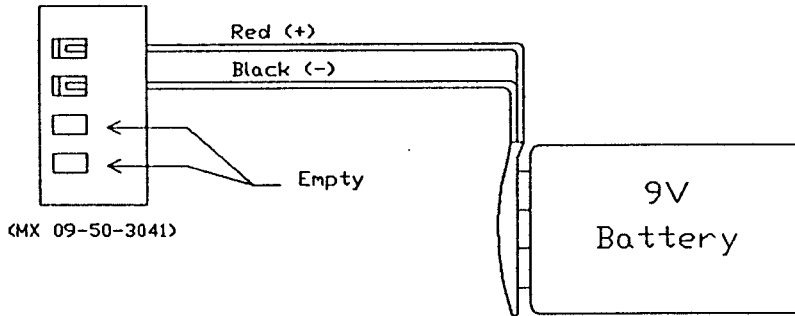
All "RS" parts available at Radio Shack

Unused Channel Shorting Cable

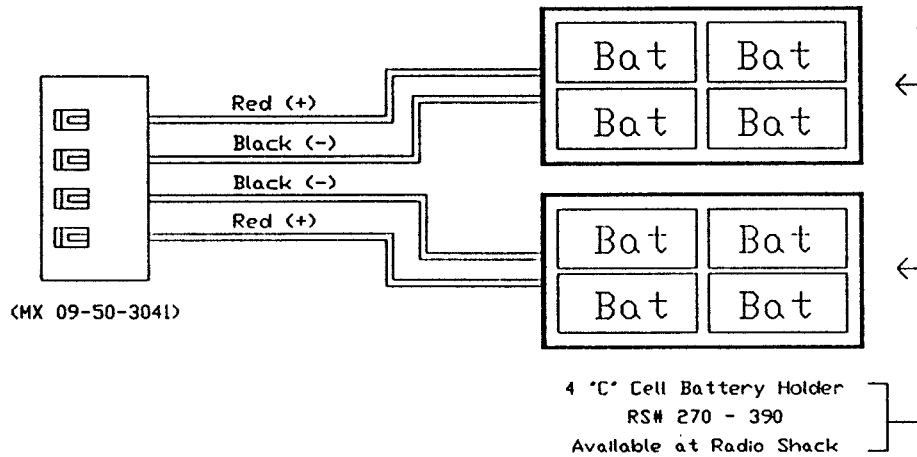


Power Supply/Battery Connections

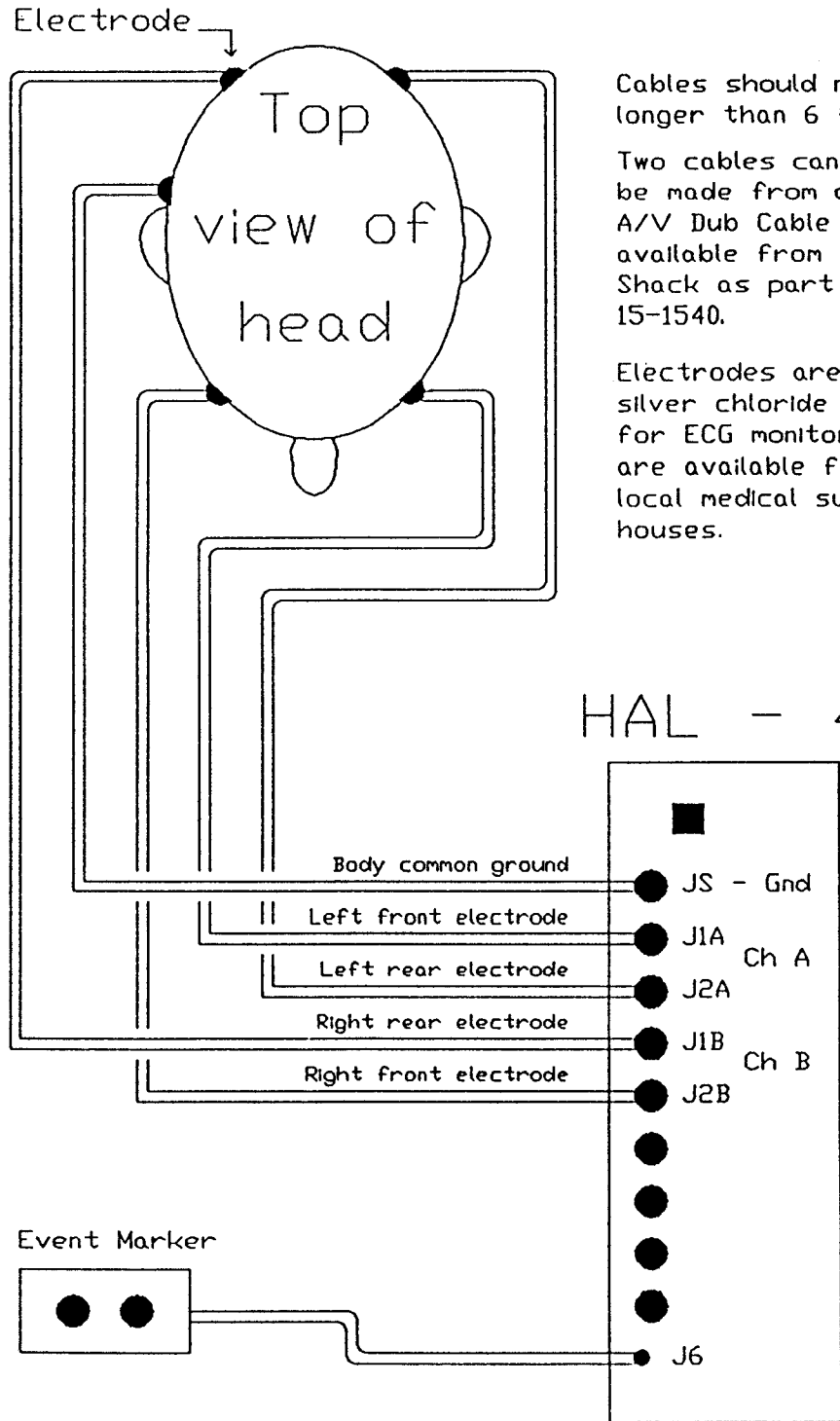
9V Source



+/- 6V Source



Electrode Placement Diagram



Cables should not be longer than 6 feet.

Two cables can be made from one A/V Dub Cable available from Radio Shack as part # 15-1540.

Electrodes are silver/silver chloride type used for ECG monitoring and are available from local medical supply houses.

Enclosing the HAL-4 in a Case

To make HAL a bit more presentable, you may wish to enclose the board in a case. One enclosure, which works with this project, is made by PACTEC (Part # CM86 - 225K). This enclosure is available from the following distributor for around \$20.00 + postage.

Midstate Electronics
71 S. Turnpike Rd.
Wallingford, CT 06492
(203) 265 - 9900

The enclosure comes with uncut end panels. To cut the panels to fit HAL refer to the figures on pages 46 & 47. The layout matches the parts supplied in the HAL - 4 kit.

See the diagrams on the following pages for dimensions and hole locations. Note the one hole in the back panel is for the LED so you may not want to install it during normal kit assembly. Once the case is ready, you can bend the LED leads and mount the LED so it is elevated and facing the hole.

Software

All PC software required for this device is available from the Creative Control Concepts website at <http://www.cc-concepts.com/>

BIO.EXE - Monitor software for the IBM PC:

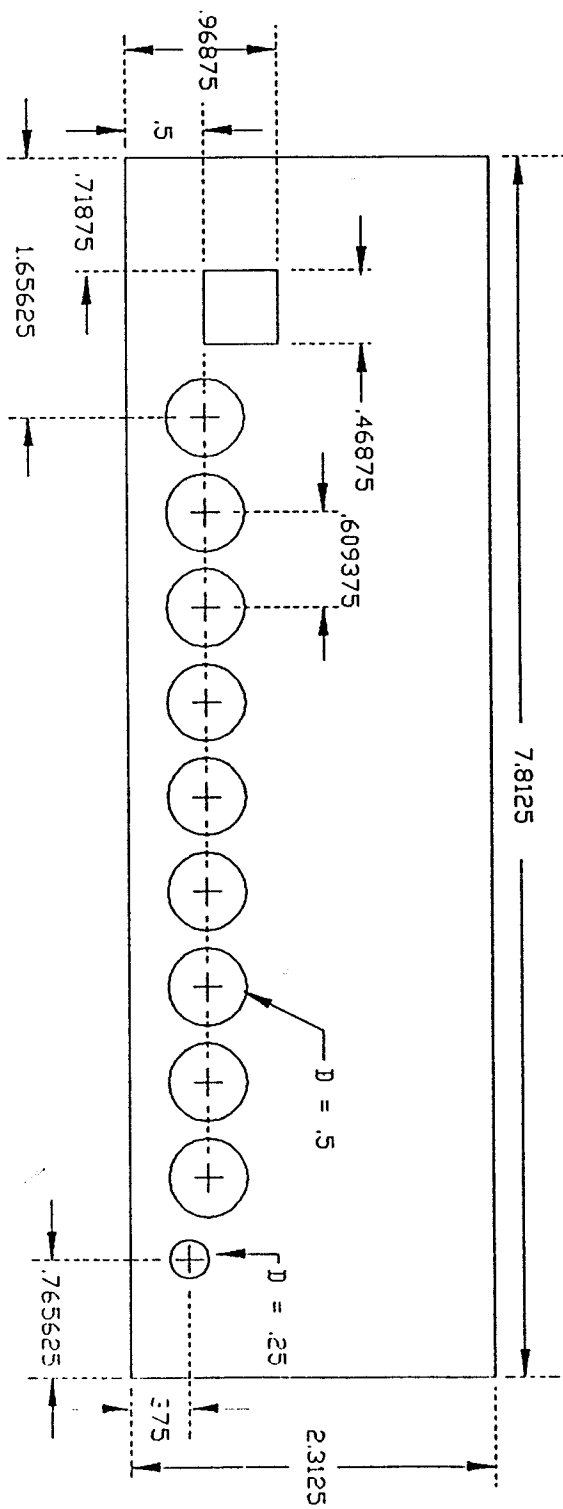
BIO.EXE	MS DOS based software
BIO.BAS	Quick BASIC required (main loop)
COMMO.ASM	Communications module
FFT.ASM	Fourier Transform algorithm
SINCOS.ASM	Sine and Cosine tables used by FFT
ROOTS.ASM	Integer square root table for FFT
LL.BAT	Linker command file

FFT.BAS - FFT graphic demonstration

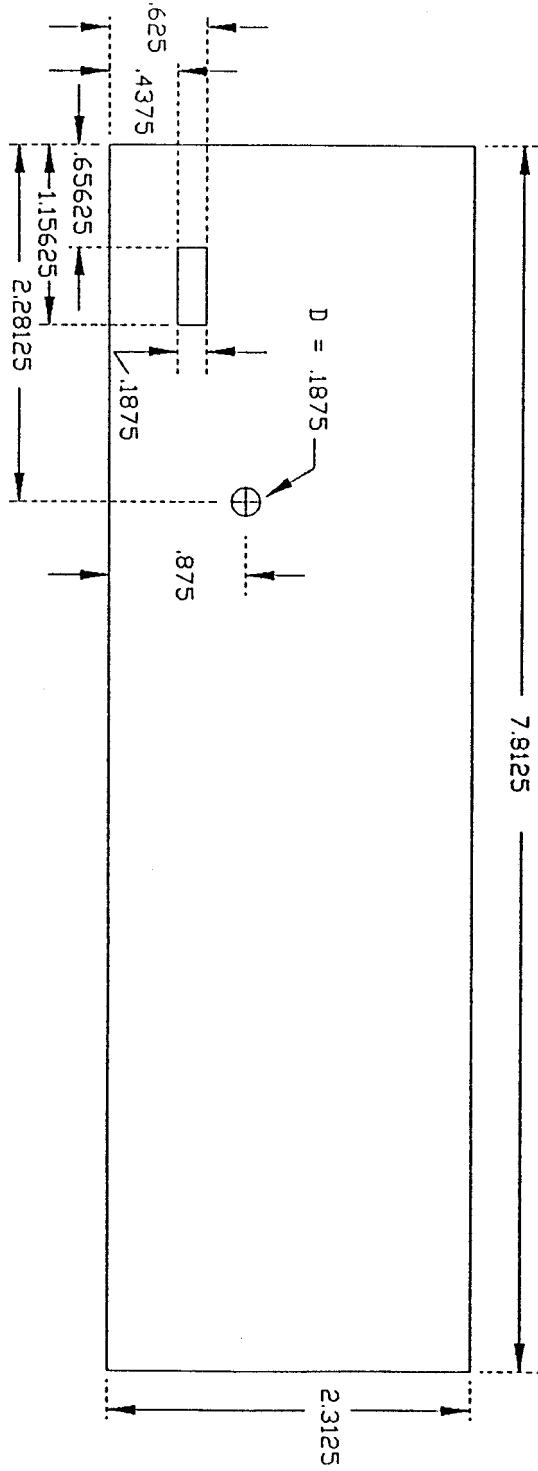
FFT.BAS ZBASIC interpiler required

NOTE – As you can see, a lot of the PC Host software is outdated. It works fine, but runs in DOS. We hope to have a Windows client available soon. Also, we are working on an Open Source initiative for our products so if you write your own client and want to share it with other HAL-4 users, let us know!

HAL-4 Front Panel



HAL-4 Rear Panel



Need Help?



If you get stuck trying to get your system to work, drop us a line at support@cc-concepts.com and we will do our best to help you get your HAL-4 working.

Check out our web site at <http://www.cc-concepts.com/> for updates, bug reports, etc.

Also, share your questions, comments, and experiences with other HAL-4 users on the HAL-4 newsgroup at <news://bbs.circuitcellar.com/local.cci.hal4>

If you can't access private news servers from your computer, point your web browser to <http://bbs.circuitcellar.com/cgi-bin/dnewsweb.exe>