AVW1 and AVW4 Vibrating Wire Interfaces

User Guide

Issued 23.7.97

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Section 1. Introduction

Campbell Scientific CR10/10X and CR500 dataloggers are capable of monitoring vibrating wire strain gauge sensors in addition to the piezoresistive type of strain gauge sensor.

Some vibrating wire sensors with short leads can be monitored without the AVW1 or AVW4. However, the AVW1 and AVW4 provide important signal conditioning that has the following functions:

1. *Complete the thermistor bridge for the measurement of the sensor's temperature.*
2. *Convert the swept frequency excitation from 2.5V (peak-to-peak) to 12V (peak-to-peak), thus 'plucking' the wire harder than the maximum 2.5V switched excitation. The result is a larger magnitude signal for a longer time.*
3. *Provide transformer isolation to strip off any DC noise on the signal. This improves the ability to detect cycles.*
4. *Provide additional transient protection for both the temperature and vibrating wire circuits.*

Both the AWV1 and the AVW4 interfaces can be used with the CR10/10X datalogger. However, only the AVW1 can be used with the CR500 datalogger, because there are less available single-ended channels.

When used with the CR10/10X datalogger and the AM416 Analogue Multiplexer, one AVW1 can monitor 16 strain gauges plus thermistors. Several multiplexers can be connected to one AVW1. (The AM416 multiplexer cannot be used with the CR500 datalogger.)

The AVW1 and AVW4 operate over the range -25°C to +50°C.

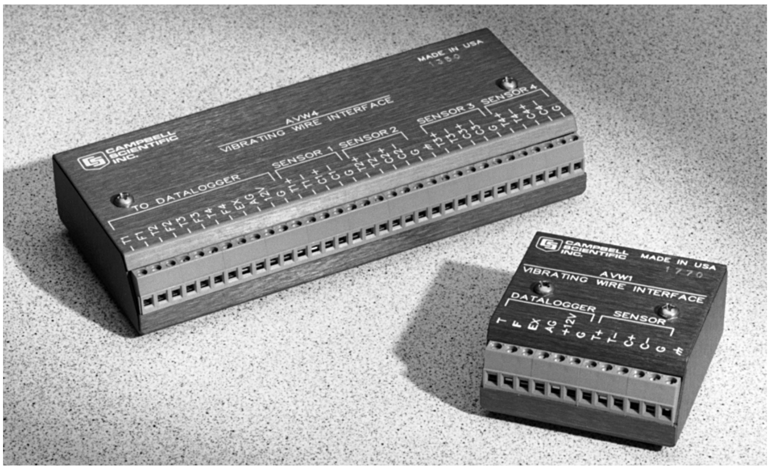


Figure 1-1 AVW1 and AVW4 Vibrating Wire Interfaces

1.1 Sensor Description

Strain gauge sensors of the vibrating wire type have a good reputation for long term stability. These sensors use a change in the frequency of a vibrating wire to sense strain. Two measurements are usually made; the first is the measurement of the frequency of the vibrating wire. The second is an optional measurement of the sensor temperature to allow temperature compensation in the frequency calculation.

The AVW1 and AVW4 contain circuitry needed to interface Geokon's Model 4500 vibrating wire strain gauge sensor to Campbell Scientific dataloggers. The CR10/10X can be used with both the AVW1 and the AVW4 but the CR500 datalogger can be used with the AVW1 only. The AVW1 interfaces one vibrating wire sensor (temperature and pressure) to two single-ended datalogger channels. The AVW4 interfaces four sensors to eight single-ended channels. (This is the reason that the AVW4 cannot be used with the CR500 datalogger, because there are not sufficient channels available.) The interfaces have no quiescent current drain. For the Geokon sensors, the current drain during the very short (2.4ms) temperature measurement is 0.4mA or less. The current drain during the vibrating wire measurement (170ms to 500ms) is 32mA.

The AVW1 and AVW4 have also been used very successfully with other strain gauge models made by Gauge Technique, Slope Indicator (VWP series) and Geokon, for use in structural testing.

This manual covers the use of the AVW1 or AVW4 with Geokon's Model 4500 vibrating wire sensor series. Sections 2 and 3 cover the temperature and vibrating wire measurements respectively. Sections 4 and 5 give detail concerning the use of the AVW1 and AVW4.

Geokon includes a calibration sheet and instruction manual with each sensor, and the sensor manual should be consulted for information on sensor selection and installation.

1.2 Sensor Selection

The vibrating wire sensors may be purchased as either vented or sealed sensors. The vented sensors have a small hollow 'vent tube' that connects the hollow chamber behind the diaphragm to the atmosphere. The vent tube allows the barometric pressure to act on both sides of the diaphragm equally, thus removing the barometric pressure from the reading. A pressure reading without a barometric pressure component is referred to as 'gauge' pressure. A pressure reading with a barometric pressure component is referred to as 'absolute' pressure. One disadvantage of the vented sensor is that the cable, which contains the vent tube, is more expensive than the cable for the unvented sensor. For this reason, it may be more economical to buy unvented sensors and use an extra one as a barometer to remove the barometric pressure. A second small disadvantage of the vented sensors is that they require the use of desiccant, which must be changed periodically, to dry the air entering the vent tube.

Figure 3-1 shows a typical vibrating wire sensor.

1.3 Sensor Care and Installation

1. Keep the moisture trap of the vented models closed until readings are to be taken. *Do not forget* to remove the screw that plugs the moisture trap when readings are to be taken.
2. The large diameter diaphragm used in the low pressure sensor requires special care when handling. Avoid bumping or jarring the sensor.
3. Orientation of the 4500 series sensors will affect the zero reading. Readings should be taken with the sensor in the same orientation at all times.

1.3.1 Determination of Zero Offset

The cavity between the sintered filter cap and the diaphragm should be filled with clean water without any air bubbles.

In most cases the sensor is made to output water height or pressure relative to a measured level. In this case the pressure sensor should be placed at the desired level and allowed to come to temperature equilibrium with its surroundings (five minutes or more). The multiplier determined in equation 3-2 should be entered and 0.0 should be entered for the offset. After the temperature and the reading has stabilised, determine the value that would have to be added to the reading to obtain the measured level. Enter this value as the offset.

In some cases there is no measured reference. In order to obtain the correct offset under these conditions, lower the sensor to a point just above the water level and wait five minutes. Use the multiplier, an offset of 0.0, and the temperature correction function determined in Section 3 to obtain a reading. Record the reading. Solve equation 3-3 for the new offset by substituting the 'reading' in place of the '[Gauge Factor * Zero Reading]' and the 'Barometric Pressure' from an accurate barometer or a reference sensor in the place of 'P_0' (unless it is a vented sensor, in which case use 0 in the place of 'P_0'). Enter the new offset.

Section 2. Temperature Measurement

Geokon vibrating wire sensors include a thermistor which is used to measure the temperature of the probe. Probe temperature is used to correct errors in the vibrating wire measurement caused by changes in the temperature of the probe.

The temperature correction is most important when the temperature of the medium the probe is measuring is changing (e.g. water temperature in a river or shallow lake). When concerned with the absolute reading, it is also important to make the temperature correction if the temperature of the medium differs from the calibration temperature. In a deep well where the water temperature does not change, the error due to temperature can be removed by allowing the sensor to come to thermal equilibrium and adjusting the sensor reading to read the correct depth by means of an offset.

2.1 Accuracy and Resolution

The accuracy of the temperature measurement is a function of the following factors listed in order of decreasing importance:

1. The thermistor's interchangeability
2. The resistance of the wire
3. The linearisation error
4. The precision of the bridge resistors
5. The accuracy of the datalogger's voltage measurement
6. The temperature coefficient of the bridge resistors.

1. The interchangeability of the thermistor is ±0.5ºC, although a thermistor with ±0.2ºC interchangeability is an option.
2. The error due to wire resistance is normally less than ±0.5ºC (see Figures 2-1 to 2-4).
3. The linearisation error is ±0.15ºC (see Figure 2-5) over the range from -5°C to +60ºC.
4. The precision of the bridge resistors (±0.1%) results in a tolerance of ±0.03ºC.
5. The accuracy of the datalogger's voltage measurement (±0.015%) results in a tolerance of ±0.01ºC.
6. The temperature coefficient of the bridge resistors (10ppm/ºC) results in a tolerance of ±0.0003ºC/ºC.

Errors 4, 5 and 6 mentioned above are all less than ±0.03ºC each and can probably be ignored. The wire resistance is primarily an offset error and its effect on the pressure measurement is removed by the initial calibration. Errors caused by the change in wire resistance due to temperature, thermistor interchangeability and the linearisation error are not removed by the initial calibration.

Ignoring the offset errors, the remaining temperature accuracy is expected to be about ±0.7ºC. The temperature correction for the vibrating wire measurement is typically less than 0.05psi/ºC. A ±0.7ºC temperature error would result in a 0.035psi (±1.0 inch H_2O) error on a 50psi full scale range.

The standard thermistor (Dale Electronics part number 1C3001-B3) has an interchangeability of ±0.5ºC. The optional thermistor (Dale Electronics part number 1C3001-C3) has an interchangeability of ±0.2ºC. Both of the above thermistors have the same resistance vs. temperature relationship as the YSI thermistor number 44005.

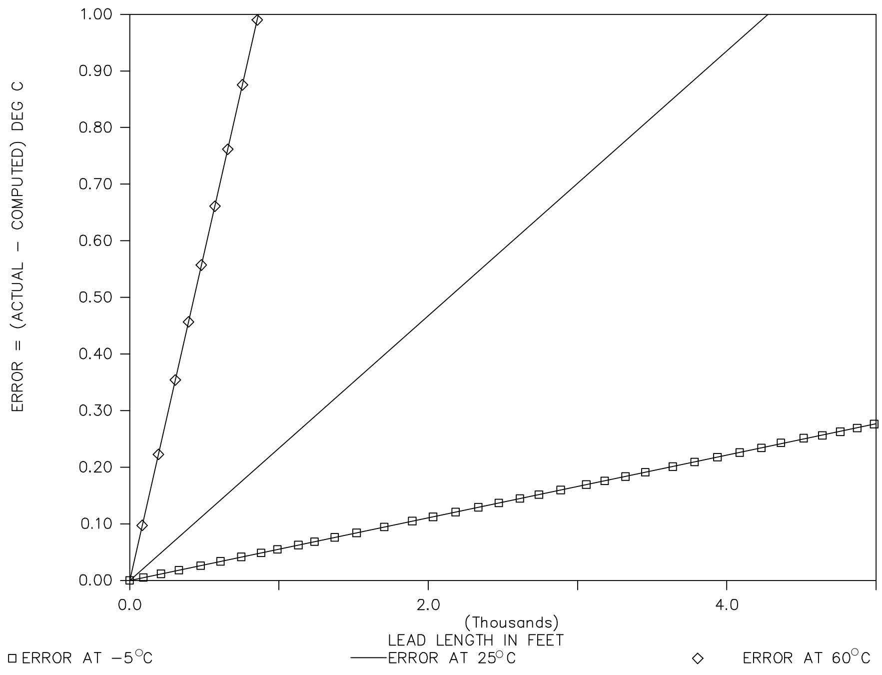
Table 2-1 shows the relationship between temperature and resistance, volts, CR10/10X output, and linearisation error.

Table 2-1 Temperature vs. Thermistor Resistance, V, ºC, and Linearisation Error

Temp (ºC)	Sensor Resistance (Ω)	Volts Out	CR10/10X Output, (ºC)	Error (ºC)
-5	12700	0.668449	-5.09136	-0.09136
-4	12050	0.692520	-4.02248	-0.02248
-3	11440	0.716743	-2.98315	0.016846
-2	10860	0.741399	-1.95557	0.044427
-1	10310	0.766400	-0.93843	0.061560
0	9796	0.791339	0.057084	0.057084
1	9310	0.816459	1.045822	0.045822
2	8851	0.841694	2.029469	0.029469
3	8417	0.867031	3.011520	0.011520
4	8006	0.892474	3.995450	-0.00454
5	7618	0.917902	4.979594	-0.02040
6	7252	0.943253	5.963992	-0.03600
7	6905	0.968616	6.954119	-0.04588
8	6576	0.993956	7.950259	-0.04974
9	6265	1.019160	8.949209	-0.05079
10	5971	1.044190	9.950388	-0.04961
11	5692	1.069107	10.95688	-0.04311
12	5427	1.093900	11.96879	-0.03120
13	5177	1.118368	12.97814	-0.02185
14	4939	1.142700	13.99297	-0.00702
15	4714	1.166697	15.00510	0.005100
16	4500	1.190476	16.01954	0.019545
17	4297	1.213945	17.03265	0.032652
18	4105	1.237011	18.04042	0.040421
19	3922	1.259826	19.04982	0.049822
20	3748	1.282314	20.05785	0.057855
21	3583	1.304393	21.06127	0.061275
22	3426	1.326119	22.06310	0.063105
23	3277	1.347418	23.06048	0.060484
24	3135	1.368363	24.05747	0.057474
25	3000	1.388888	25.05167	0.051679
26	2872	1.408926	26.04042	0.040428
27	2750	1.428571	27.02901	0.029014
28	2633	1.447932	28.02396	0.023968
29	2523	1.466619	29.00577	0.005777
30	2417	1.485089	29.99901	-0.00098
31	2317	1.502945	30.98300	-0.01699
32	2221	1.520496	31.97513	-0.02486
33	2130	1.537515	32.96311	-0.03688
34	2042	1.554339	33.96711	-0.03288
35	1959	1.570549	34.96239	-0.03760
36	1880	1.586294	35.95767	-0.04232
37	1805	1.601537	36.95011	-0.04988
38	1733	1.616448	37.95060	-0.04939

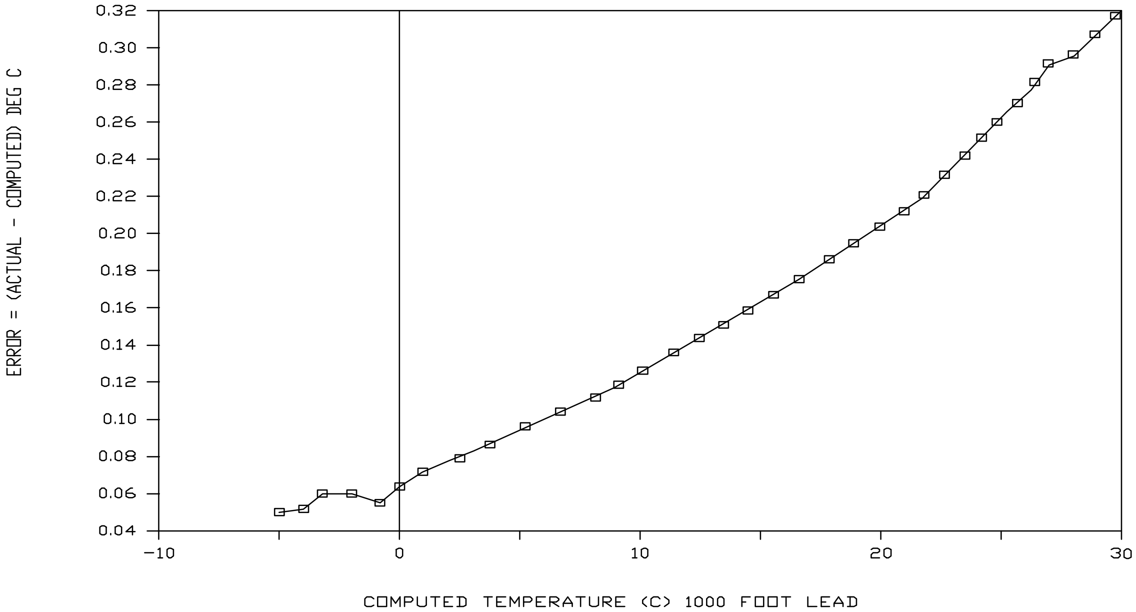
Table 2-1 (cont.)

39	1664	1.631002	38.95742	-0.04257
40	1598	1.645169	39.96844	-0.03155
41	1535	1.658925	40.98115	-0.01884
42	1475	1.672240	41.99263	-0.00736
43	1418	1.685090	42.99951	-0.00048
44	1363	1.697677	44.01695	0.016954
45	1310	1.709986	45.04335	0.043350
46	1260	1.721763	46.05610	0.056109
47	1212	1.733222	47.07191	0.071918
48	1167	1.744104	48.06568	0.065681
49	1123	1.754878	49.07873	0.078734
50	1081	1.765287	50.08636	0.086361
51	1040	1.775568	51.11067	0.110677
52	1002	1.785204	52.09809	0.098095
53	965	1.794687	53.09674	0.096746
54	929.6	1.803855	54.08849	0.088499
55	895.8	1.812697	55.07032	0.070322
56	863.3	1.821281	56.04819	0.048193
57	832.2	1.829571	57.01651	0.016519
58	802.3	1.837613	57.97896	-0.02103
59	773.7	1.845372	58.92977	-0.07022
60	746.3	1.852867	59.86962	-0.13037



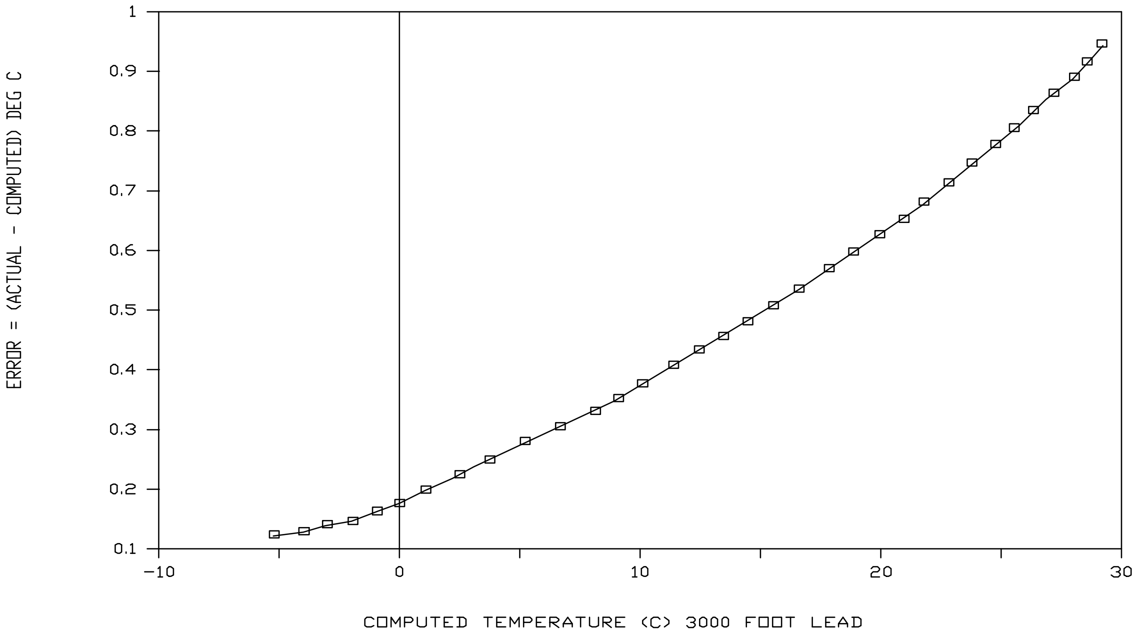
Wire is 0.64mm diameter (22AWG), resistance 5.2Ω per 100m (16Ω per 1000 feet).

Figure 2-1 Temperature Measurement Error at Three Temperatures as a Function of Lead Length



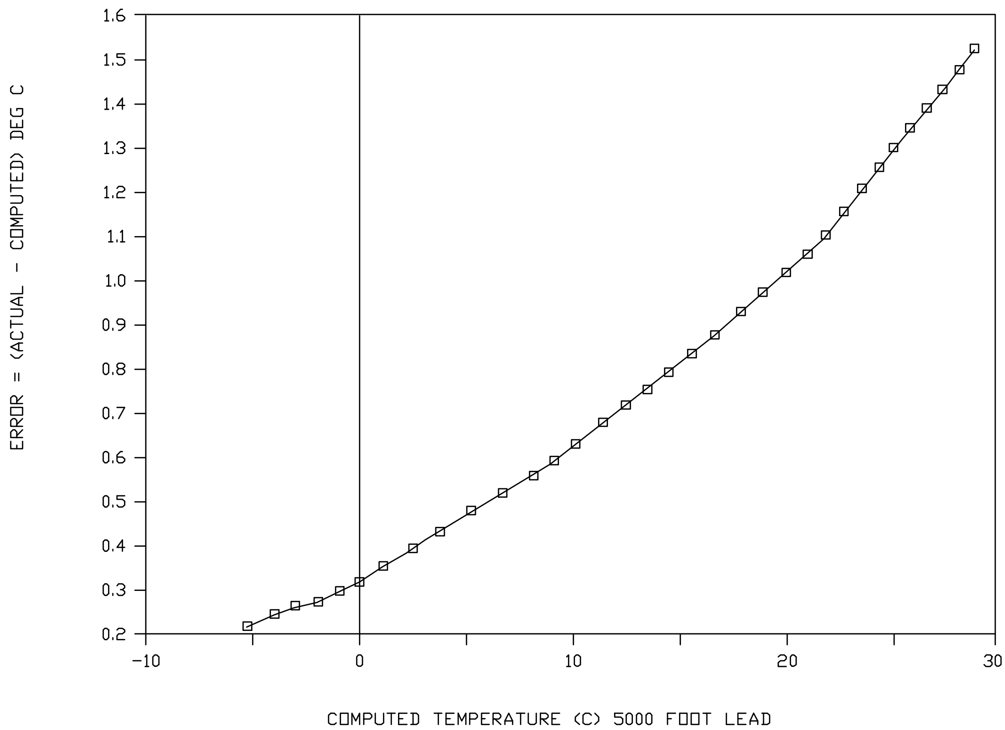
Wire is 0.64mm diameter (22AWG), resistance 5.2Ω per 100m (16Ω per 1000 feet).

Figure 2-2 Temperature Measurement Error on a 300m (1000 foot) Lead



Wire is 0.64mm diameter (22AWG), resistance 5.2Ω per 100m (16Ω per 1000 feet).

Figure 2-3 Temperature Measurement Error on a 900m (3000 foot) Lead



Wire is 0.64mm diameter (22AWG), resistance 5.2Ω per 100m (16Ω per 1000 feet).

Figure 2-4 Temperature Measurement Error on a 1500m (5000 foot) Lead

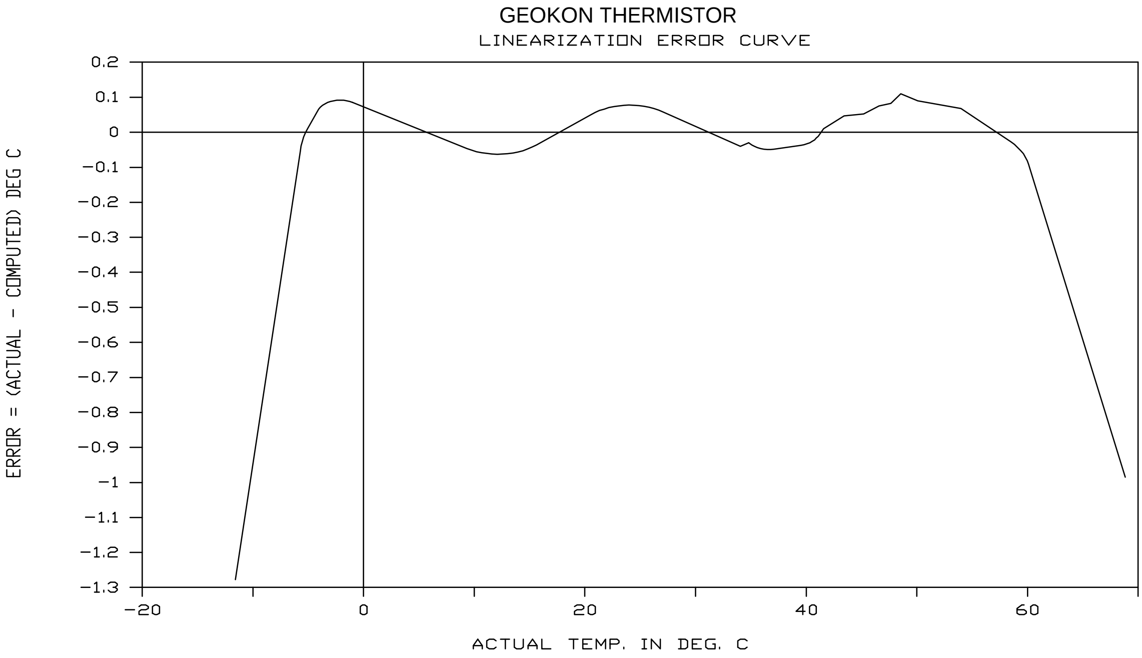


Figure 2-5 Thermistor Linearisation Error

2.2 Programming and Sensor Connection

Measure the thermistor temperature with Instruction 4 using a measurement range of 2500mV (fast), an excitation voltage of 2500mV, a delay of 1 and a multiplier of 0.001. The resulting value is linearised with Instruction 55 using the following coefficients:

C0 = -104.78
C1 = 378.11
C2 = -611.59
C3 = 544.27
C4 = -240.91
C5 = 43.089

The output is in degrees Celsius and covers the range -5ºC to +60ºC. Due to the small current requirement, up to 118 thermistors could theoretically be powered by one excitation channel.

When measuring the temperature of a Geokon sensor via the AVW1 or AVW4, see Sections 4 or 5 respectively for connection information.

When measuring the temperature of a Geokon sensor temperature directly with the CR10/10X, connect the leads and bridge completion resistors as shown in Figure 2-6.

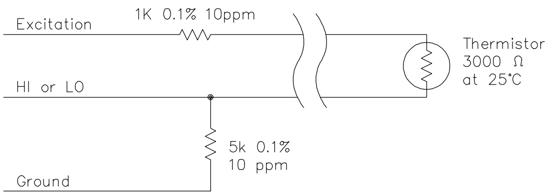


Figure 2-6 Direct Measurement of the Geokon Thermistor

Section 3. Vibrating Wire Measurement

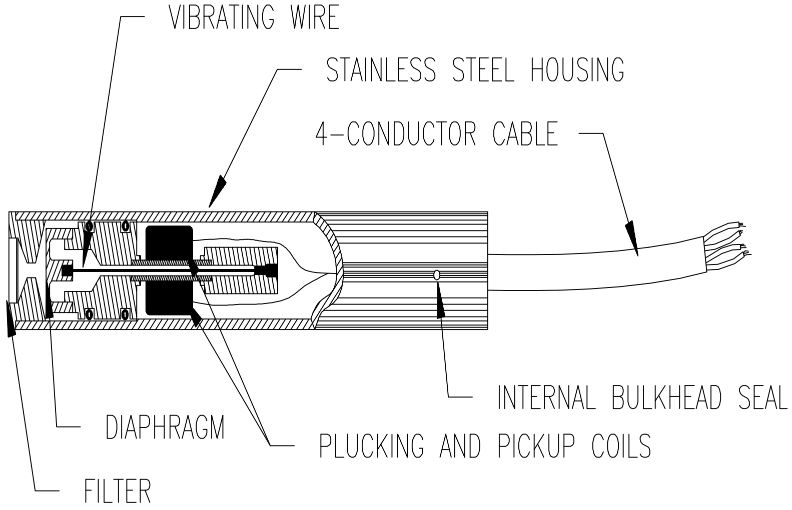


Figure 3-1 Vibrating Wire Sensor

3.1 Description of Measurement Process

Figure 3-1 illustrates how an increase in pressure on the diaphragm decreases the tension on the wire attached to the diaphragm. A decrease in the wire tension decreases the resonant frequency in the same way that loosening a string on a guitar decreases its frequency. Therefore, the resonant frequency of the vibrating wire sensor decreases with increasing pressure.

The Vibrating Wire Measurement instruction excites the ‘plucking’ and ‘pickup’ coils shown in the above figure with a ‘swept’ frequency. A ‘swept’ frequency is a group of different frequencies sent sequentially starting with the lowest frequency and ending with the highest. The lowest and highest frequencies are entered by the user in units of hundreds of Hz. The CR10/10X and CR500 dataloggers require 150ms to sweep through all of the frequencies. This swept frequency causes the wire to vibrate at each of the individual frequencies. Ideally, all of the frequencies except the one matching the resonant frequency of the wire die out in a very short time. The wire vibrates with the resonant frequency for a relatively long period of time and as it does so it cuts the lines of flux in the ‘plucking’ and ‘pickup’ coils inducing the same frequency on the leads to the datalogger. After waiting for the non resonant frequencies to die out (20ms) the datalogger accurately measures how much time it takes to receive a user-specified number of cycles. Knowing the length of time and the number of cycles, the datalogger then computes the square of the frequency expressed in units of kHz^2 (= $1/T^2$ where T is the period in milliseconds).

3.2 Multiplier and Offset

The 50psi vibrating wire pressure sensor used in this example is the Geokon Model 4500SV-50. It is vented to the atmosphere so is not affected by changes in barometric pressure. Each sensor is individually calibrated and has a unique set of calibration coefficients. A calibration sheet contains the model number, serial number, gauge factor (psi/digit), temperature coefficient (psi/°C), zero reading (digits), zero period (microseconds), calibration temperature (°C) and calibration barometric pressure (inches Hg). A Geokon ‘digit’ is defined as the square of the frequency in kHz multiplied by 1000(1 digit = 0.001kHz^2 = 1000Hz^2). The calibration coefficients for the sensor with serial number 3998 are given in Table 3-1.

Table 3-1 Calibration Data for Sensor 3998

Gauge Factor (psi/digit)	Temp. Coeff. (psi/^oC)	Zero Rdg. (digit)	Period (µs)	Temp. (^oC)	Baro. (in Hg)
0.0151	-0.0698	9431	325.6	24	29.51

The equation to change the datalogger's output into pressure (psi) exerted on the sensor is given below:

P = [M * X] + B [3-1]

where P is the pressure in psi and X is the result of Instruction 28 in kHz^2 (= $1/T^2$ where T is the period in milliseconds). The multiplier (M) and offset (B) are determined by equations [3-2] and [3-3].

M = -1000(digits/kHz^2) * Gauge Factor [3-2]

where M is the multiplier in psi/(kHz^2) and the Gauge Factor is found on the calibration sheet in psi/digit.

B = P_0 + [Gauge Factor * Zero Reading] [3-3]

where B is the offset in psi and P_0 is the pressure in psi at the time of calibration. For vibrating wire sensors not vented to the atmosphere, P_0 is the barometric pressure ['Baro.'(in Hg) * 0.49116 (psi/in Hg)] at the time of calibration. For the vented sensors, P_0 is 0psi. The Gauge Factor (psi/digit) and Zero Reading (digits) are found on the calibration sheet.

Example: Using sensor number 3998, the multiplier, offset, and equation for pressure would be:

M = (-1000 digits/kHz^2) * 0.0151psi/digit

M = -15.1psi/(kHz^2)

B = 0.0psi + (0.0151psi/digit * 9431 digits)

B = 142.4psi

P = [-15.1psi/(kHz^2) * X (kHz^2)] + 142.4psi

3.3 Swept Frequency: Start and End

The design of the interface coupling transformer in the AVW1 and AVW4 means that the optimum performance is achieved at frequencies of 1000Hz or more. However, sensors which operate at frequencies significantly below this can be used successfully with the AVW1 and AVW4. The actual performance of a given sensor will depend on the response of that sensor to the changing drive waveforms and also on the signal level it returns.

NOTE If you wish to use sensors which operate at frequencies below 1000Hz with the AVW1 and AVW4, please see Technical Note 23, available on request from Campbell Scientific, which gives further details about performance with this type of sensor.

In general, the starting frequency of the swept frequency for this sensor should be slightly lower than the frequency at the full scale pressure of the sensor. A rough rule of thumb would put the starting frequency at two thirds that of the ending frequency. Almost always the starting frequency should not be lower than half of the ending frequency.

Start Freq. ≤ ([Full Scale Pressure
- (Gauge Factor * Zero Reading)]/M)$^{0.5}$ * 1000Hz/kHz [3-4]

Therefore for this sensor:

Start Freq. ≤ ([50psi
- (0.0151psi/digit * 9431digits)]/[-15.1psi/kHz^2])$^{0.5}$ * 1000Hz/kHz

≤ 2474Hz (approx. 2.4kHz)

In general, the ending frequency of the swept frequency for this sensor should be slightly higher than the frequency at zero pressure.

End Freq. ≥ ([Zero Pressure
- (Gauge Factor * Zero Reading)]/M)$^{0.5}$* 1000Hz/kHz [3-5]

Therefore for this sensor:

End Freq. ≥ ([0.0psi
- (0.0151psi/digit * 9431digits)]/[-15.1psi/kHz^2])$^{0.5}$ * 1000Hz/kHz

≥ 3071Hz (approx. 3.1kHz)

Additional information concerning the swept frequency is given in Appendix C.

NOTE Sealed (or absolute) sensors calibrated near sea level give negative readings at higher elevations due to the decrease in barometric pressure with increasing elevation. In most cases the solution is to load the sensor with extra external pressure to cause it to operate in its calibrated range. For example, a sealed 0 to 5psi sensor used at 3000m (10,000 feet) elevation would have to be placed under 3.2m (10.6 feet) of water (4.6psi) in order to read 0psi. This is because the barometric pressure at 3000m is about 4psi lower than at sea level.

3.4 Resolution and Number of Cycles

We recommend that the number of cycles measured be between 200 and 500. Five hundred cycles would probably be the optimum for most applications, although this depends on the time constant of the sensor (see below). The measurement of more than 500 cycles is not recommended without testing. Some sensors, for example, will not vibrate a full 1000 cycles at all pressures in their pressure range.

For the sake of this discussion the resolution of the vibrating wire measurement is defined as plus or minus three standard deviations (±3 SD) of the vibrating wire measurement. The standard deviation of the measurement in psi is given by the following equation:

SD = (2*M*C)/(N*T^3) [3-6]

where M is the multiplier computed in equation [3-2]. ‘C’ is 0.00015ms, which is the typical standard deviation of a time interval measurement on the datalogger using a 4mV peak-to-peak signal with no external noise. ‘N’ is the number of cycles timed to determine the period (T) in ms of the signal being measured.

The standard deviation is greater when the period is shorter. The period is shortest at zero pressure so the 'Period' at zero pressure given in Table 3-1 is used for the example below, which assumes that 500 cycles are measured:

$SD = (2*-15.1psi/(kHz^2) * 0.00015ms)/(500 * (325.6us/1000us/ms)^3)$

$= 0.00026246$ psi

and therefore:

RESOLUTION = ±0.00078738psi

Resolution improves as the number of cycles measured increases but worsens as the signal level decreases and as the noise increases. The theoretical optimum resolution is obtained when the number of cycles measured covers one time constant (τ) of the decay of the signal, i.e. when:

Number of cycles measured = (τ/T)

where T is the period of the signal in milliseconds (obtained from the calibration sheet) and τ is the time in milliseconds required for the signal to decay from its initial peak-to-peak value to (0.368 * initial peak-to-peak value). An oscilloscope is required to measure the time constant. The time constants of Geokon sensors are typically between 0.33s and 1s.

The time required to make one repetition of the vibrating wire measurement is given below:

150ms to sweep the frequency

+ 20ms delay

+ (1.5 cycles + no. of cycles measured) * period of signal in ms

3.5 Temperature Correction

The equation used to remove errors caused by changes in the sensor's temperature is:

Pt = P + (TEMP. COEFF.)*(T - To) [3-7]

where Pt (psi) is the temperature corrected pressure. P (psi) is the uncorrected pressure from equation [3-1]. T (°C) is the current temperature of the sensor. 'To' (°C) is the 'Temp.' on the calibration sheet, which is the temperature of the sensor at the time of calibration. TEMP. COEFF. (psi/°C) is also found on the calibration sheet. It is important to note that the 'TEMP. COEFF.' can be either positive or negative.

Example: Using sensor number 3998 and assuming a sensor temperature of 15°C, the corrected pressure would be:

Pt = P + (-0.0698psi/°C)*(15°C - 24°C)

= P + 0.6282psi

3.6 Delay Between Measurements

The vibrating wire sensor should not be excited more often than once every five time constants if high resolution is important. If more than one repetition is specified the 'delay before excitation applied' parameter can be used to ensure the proper amount of delay between excitations. Excitation of the sensor while the wire is still vibrating can cause the signals to add or subtract (in phase or out of phase) causing the wire to vibrate excessively hard or almost not at all.

If two successive measurements (on two different sensors) are required they can be done in one of two ways:

With the AVW4 the repetitions parameter must be set to 2--. The '--' instructs the CR10/10X to excite both sensors, delay 20ms, measure the first sensor and then measure the second sensor. There is no delay or re-application of the excitation between the measurements. Successive measurements require that the sum of the number of cycles measured on each sensor does not exceed the time constant of the last sensor or the signal may have become too weak to be measured (e.g. two sensors measured separately, each having a time constant equal to 700 cycles would have to be measured back to back with a maximum of 350 cycles).

Successive measurements with two AVW1s and two excitation channels can be done simply by entering Instruction 28 twice, once for the first sensor and once for the second. In this case the second AVW1 measurement will begin 170 milli-seconds after the first one ended.

Section 4. The AVW1

The AVW1 contains circuitry needed to interface Geokon's 4500 series vibrating wire sensor to the CR10/10X and the CR500 dataloggers. The AVW1 is designed to interface one vibrating wire sensor (temperature and pressure) to two single-ended datalogger channels. The AVW1 has no quiescent current drain. For Geokon sensors, the current drain during the very short (2.4ms) temperature measurement is 0.4mA or lower. The current drain during the vibrating wire measurement (170ms to 500ms) is 32mA. The AVW1 can also be used with other compatible vibrating wire sensors – e.g. those made by Slope Indicator Inc. The dimensions of the AVW1 are 64 x 64 x 36mm.

4.1 Sensor Connections

CAUTION Some vibrating wire sensors may need a 5V excitation, rather than 12V. Such sensors should have the '+12V' terminal of the vibrating wire interface connected to the +5V supply terminal on the datalogger.

Using 12V with these sensors will cause measurement errors; if in doubt please consult the sensor manufacturer.

4.1.1 CR10/10X Datalogger

The connections for the CR10/10X datalogger are shown below in Figure 4-1.

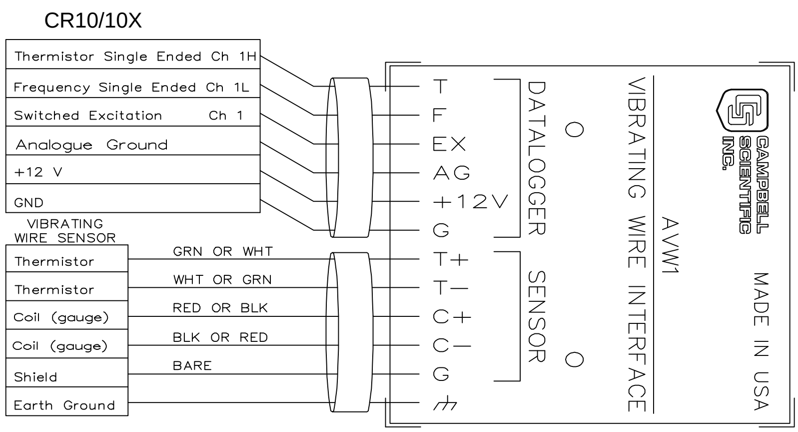


Figure 4-1 CR10/10X Connections to AVW1

Vibrating Wire Measurement Instruction 28 and 131

Instruction 28 is normally used with the CR10X datalogger for vibrating wire sensor measurements, and its use is demonstrated in the Well Monitoring Program Example that follows.

Instruction 131 has also been added to the CR10X instruction set. This Instruction has been specially written for use with Slope Indicator sensors, but may also have possible applications with other types of vibrating wire sensor. (See the CR10X manual for more details of this Instruction). Instruction 131 provides extra output data, and Slope Indicator have a special program which helps to analyse this data.

Please contact Slope Indicator Inc. for further advice on the use of this program with their sensors.

4.1.2 CR500 Datalogger

The CR500 is normally programmed using the Short Cut datalogger support software. Short Cut will produce a suitable wiring diagram indicating connections required. This wiring diagram should *always* be used with the CR500.

4.1.3 AM416 Multiplexer

The AM416 Analogue Multiplexer can be used with the CR10/10X datalogger, but cannot be used with the CR500. One AVW1 can monitor 16 strain gauges plus thermistors. Several multiplexers can be connected to one AVW1. The sensors are connected to the inputs of the multiplexer, and the common lines of the multiplexer to the ‘sensor’ inputs on the AVW1. The AVW1 measurement instructions are then added to an AM416 program (see AM416 manual for general program structure).

4.2 Well Monitoring Example

This section contains a programming example using a CR10/10X datalogger and an AVW1 to measure a vibrating wire sensor. (When using the AVW1 with the CR500 datalogger, programming will normally be done using the Short Cut program building software. Short Cut will also produce a suitable wiring diagram which should be used when connecting the interface to the datalogger.)

NOTE This example uses imperial units. Users working in metric units would use millibars and metres in place of psi and feet.

In this example the vibrating wire sensor is used to monitor the distance from the lip of the well to the water surface in a 150 foot well. The water level is expected to stay within 40 to 80 feet of the lip so the 50psi pressure sensor is placed approximately 100 feet below the lip of the well. The same sensor used in Section 3.2 for the calculation of multiplier and offset (serial number 3998) is used again in this example.

In the example program that follows the depth of water above the vibrating wire sensor is measured in psi and then converted into feet of water. The water depth above the sensor is referred to as the ‘Reading’ in the following equation. The Reading decreases with increasing ‘Distance’ from the lip of the well to the water surface so the Distance is computed by subtracting the Reading from the Offset as shown in figure 4-2.

The initial distance to the water surface is measured with a chalked line to be 47.23 feet below the lip. The initial reading is 54.832 feet (of head above the sensor). Solving for the offset gives:

Offset = Initial Distance + Initial Reading

= 47.23 feet + 54.832 feet

= 102.062 feet

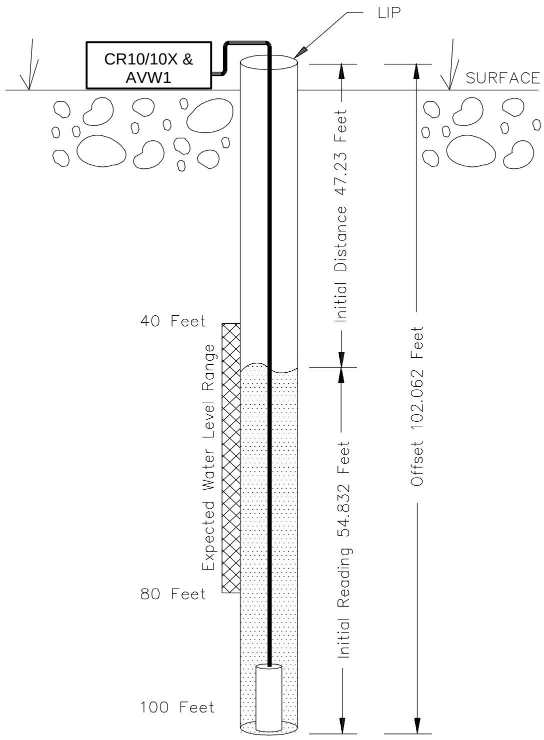


Figure 4-2 Well Monitoring Example

The following is a sample program that measures the temperature and frequency of the vibrating wire sensor and stores the temperature (ºC), pressure (psi), temperature corrected pressure (psi), correction factor (psi), temperature corrected pressure (feet of H_2O), and Distance from the lip to the water surface (feet) in input locations 1-6 respectively. This example assumes that the sensor has been connected as shown in Figure 4-1.

Program:

AVW1 & CR10/10X USED TO MEASURE ONE GEOKON VIBRATING WIRE SENSOR.

```
*        1     Table 1 Programs
  01:   10     Sec. Execution Interval
```

Measure and linearise thermistor output (see Section 2)

```
01:    P  4        Excite,Delay,Volt(SE)
  01:     1        Rep
  02:    15        2500mV fast Range
  03:     1        IN Chan
  04:     1        Excite all reps w/EXchan 1
  05:     1        Delay (units .01sec)
  06:  2500        mV Excitation
  07:     1        Loc [:TEMP  C]
  08:      .001    Mult
  09:     0.0000   Offset
```

```
02:    P 55         Polynomial
  01:     1         Rep
  02:     1         X Loc TEMP  C
  03:     1         F(X) Loc [:TEMP  C]
  04: -104.78       C0
  05:  378.11       C1
  06: -611.59       C2
  07:  544.27       C3
  08: -240.91       C4
  09:   43.089      C5

03:    P 28         Vibrating Wire (SE)
  01:     1         Rep
  02:     2         IN Chan
  03:     1         Excite all reps w/EXchan 1
  04:    24         Starting Freq. (units=100Hz)
  05:    31         End Freq. (units=100Hz)
  06:   500         No. of Cycles
  07:  0000         Rep delay (units=.01sec)
  08:     2         Loc [:PRESS psi]
  09:   -15.1       Mult
  10:   142.4       Offset
```

Temperature correction (see Section 3)

```
04:    P 34         Z=X+F
  01:     1         X Loc TEMP  C
  02:   -24         F calibration "Temp." in C
  03:     4         Z Loc [:(T-To)*C]

05:    P 37         Z=X*F
  01:     4         X Loc (T-To)*C
  02:     -.0698    F "Temp. Coeff."
  03:     4         Z Loc [:(T-To)*C]
06:    P 33         Z=X+Y
  01:     2         X Loc PRESS psi
  02:     4         Y Loc (T-To)*C]
  03:     3         Z Loc [:Pt  psi]

07:    P 37         Z=X*F
  01:     3         X Loc Pt  psi
  02:    -2.3067    F
  03:     5         Z Loc [:-Pt FEET H20]
```

Converts psi to negative ft $H_2 0$

```
08:    P 34     Z=X+F
  01:     5     X Loc -Pt FEET H20
  02:  102.06   F OFFSET
  03:     6     Z Loc [:DISTANCE FEET]
```

Adds the offset to the negative of the reading to obtain the distance from lip of the well to water surface.

```
09:    P        End Table 1
```

Input Location Labels:

```
1:TEMP    C
2:PRESS psi
3:Pt    psi
4:(T-To)*C
5:Pt Ft H20
6:DISTAN FT
```

Section 5. The AVW4

The AVW4 contains circuitry needed to interface Geokon's 4500 series vibrating wire sensor to the CR10/10X. It cannot be used with the CR500 basic datalogger because the CR500 does not have enough single-ended channels. The AVW4 is designed to interface four vibrating wire sensors (temperature and pressure) to eight single-ended CR10/10X channels. The AVW4 has no quiescent current drain. For Geokon sensors, the current drain during the very short (2.4ms) temperature measurement is .4mA per channel or lower. The current drain during each vibrating wire measurement (170ms to 500ms) is 32mA. The AVW4 can also be used with other compatible vibrating wire sensors – e.g. those made by Slope Indicator Inc. The dimensions of the AVW4 are 170 x 74 x 36mm.

5.1 Sensor Connections

CAUTION Some vibrating wire sensors may need a 5V excitation, not 12V. Such sensors should have the '+12V' terminal of the vibrating wire interface connected to the +5V supply terminal on the CR10/10X.

Using 12V with these sensors will cause measurement errors; if in doubt please consult the sensor manufacturer.

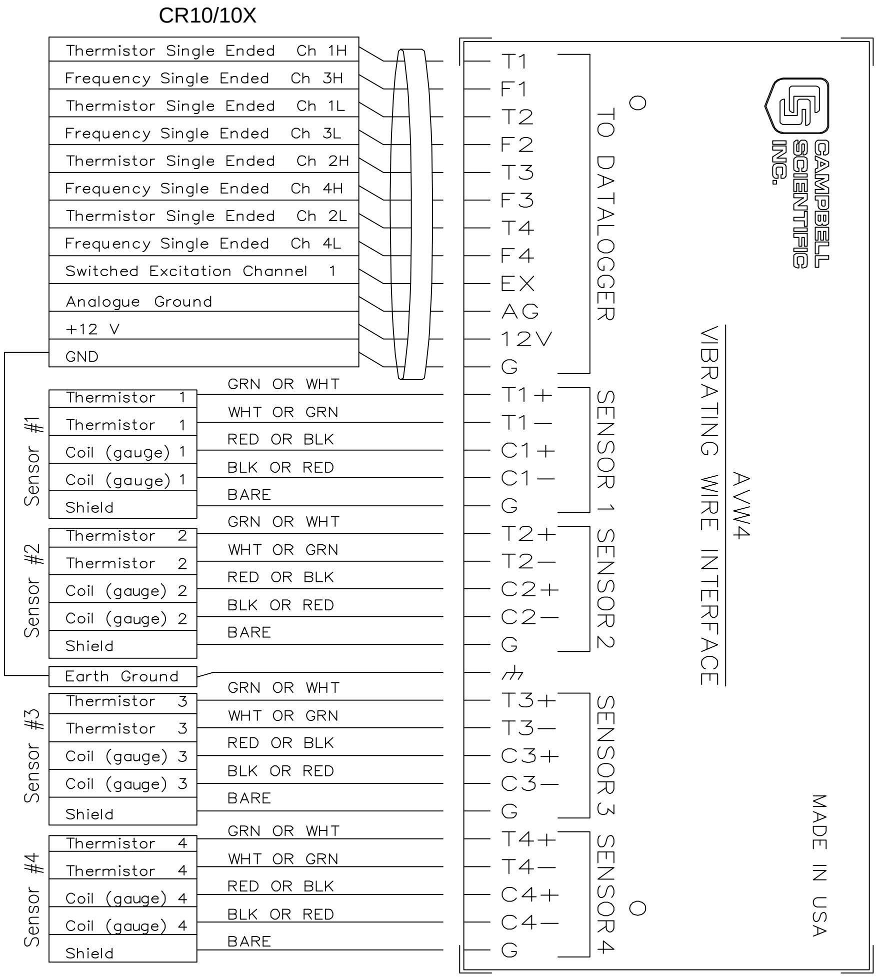


Figure 5-1 Connections for AVW4

5.1.1 Vibrating Wire Measurement Instruction 28 and 131

Instruction 28 is normally used with the CR10X datalogger for vibrating wire sensor measurements, and its use is demonstrated in the following programming example.

Instruction 131 has also been added to the CR10X instruction set. This Instruction has been specially written for use with Slope Indicator sensors, but may also have possible applications with other types of vibrating wire sensor. (See the CR10X manual for more details of this Instruction.) Instruction 131 provides extra output data, and Slope Indicator have a special program which helps to analyse this data. Please contact Slope Indicator Inc. for further advice on the use of this program with their sensors.

5.2 Datalogger Programming

The following is a sample program that measures four sealed Geokon sensors and stores the temperature, pressure, pressure corrected for temperature, and barometric corrected pressure in psi in Input Locations 1..4, 5..8, 9..12, and 10..12 respectively. The example uses the calibration data given previously from sensor number 3998. The first sensor measures barometric pressure only and is used to remove atmospheric pressure changes from the readings on the other three sensors. This example assumes that the sensors have been connected as shown in figure 5-1.

Program: AVW4 & CR10/10X used to measure four Geokon sensors. the first sensor serves as a barometer and its reading is subtracted from the other three to measure three water pressures in psi every five minutes.

```
*         1        Table 1 Programs
  01:   300        Sec. Execution Interval
```

Measure and linearise thermistor output (see section 2)

```
01:    P  4        Excite,Delay,Volt(SE)
  01:     4        Reps
  02:    15        2500mV fast Range
  03:     1        IN Chan
  04:     1        Excite all reps w/EXchan 1
  05:     1        Delay (units .01sec)
  06:  2500        mV Excitation
  07:     1        Loc [:TEMP C #1]
  08:      .001    Mult
  09:     0.0000   Offset

02:    P 55        Polynomial
  01:     4        Reps
  02:     1        X Loc TEMP C #1
  03:     1        F(X) Loc [:TEMP C #1]
  04:  -104.78     C0
  05:   378.11     C1
  06:  -611.59     C2
  07:   544.27     C3
  08:  -240.91     C4
  09:    43.089    C5
```

```
03:    P 28        Vibrating Wire (SE)
  01:     4        Reps
  02:     5        IN Chan
  03:     1        Excite all reps w/EXchan 1
  04:    24        Starting Freq. (units=100Hz)
  05:    31        End Freq. (units=100Hz)
  06:   500        No. of Cycles
  07:   500        Rep delay (units=.01sec)
  08:     5        Loc [:P psi #1]
  09:     1        Mult
  10:     0        Offset
```

5 sec delay between measurements

```
04:    P 53      Scaling Array (A*loc +B)
  01:     5      Start Loc [:P psi #1]
  02:   -15.1    A1
  03:   142.4    B1
  04:   -15.1    A2
  05:   142.4    B2
  06:   -15.1    A3
  07:   142.4    B3
  08:   -15.1    A4
  09:   142.4    B4
```

Apply mult & offset (see section 3)

```
05:    P 53      Scaling Array (A*loc +B)
  01:    13      Start Loc [:Cpsi/C #1]
  02:     0      A1
  03:     -.0698 B1
  04:     0      A2
  05:     -.0698 B2
  06:     0      A3
  07:     -.0698 B3
  08:     0      A4
  09:     -.0698 B4
```

Loads temp. coeff.

```
06:    P 87      Beginning of Loop
  01:    00      Delay
  02:     4      Loop Count
```

Temperature correction

```
07:    P 34      Z=X+F
  01:     1--    X Loc TEMP C #1
  02:   -24      F
  03:    17--    Z Loc [:T-To*C #1]
```

Assumes calibration temp. = 24^oC

```
08:    P 36      Z=X*Y
  01:    13--    X Loc Cpsi/C #1
  02:    17--    Y Loc T-To*C #1
  03:    17--    Z Loc [:T-To*C #1]

09:    P 33      Z=X+Y
  01:     5--    X Loc psi #1
  02:    17--    Y Loc T-To*C #1
  03:     9--    Z Loc [:Pt psi #1]

10:    P 95      End
```

Following three instructions subtract the barometric pressure from the three water pressures

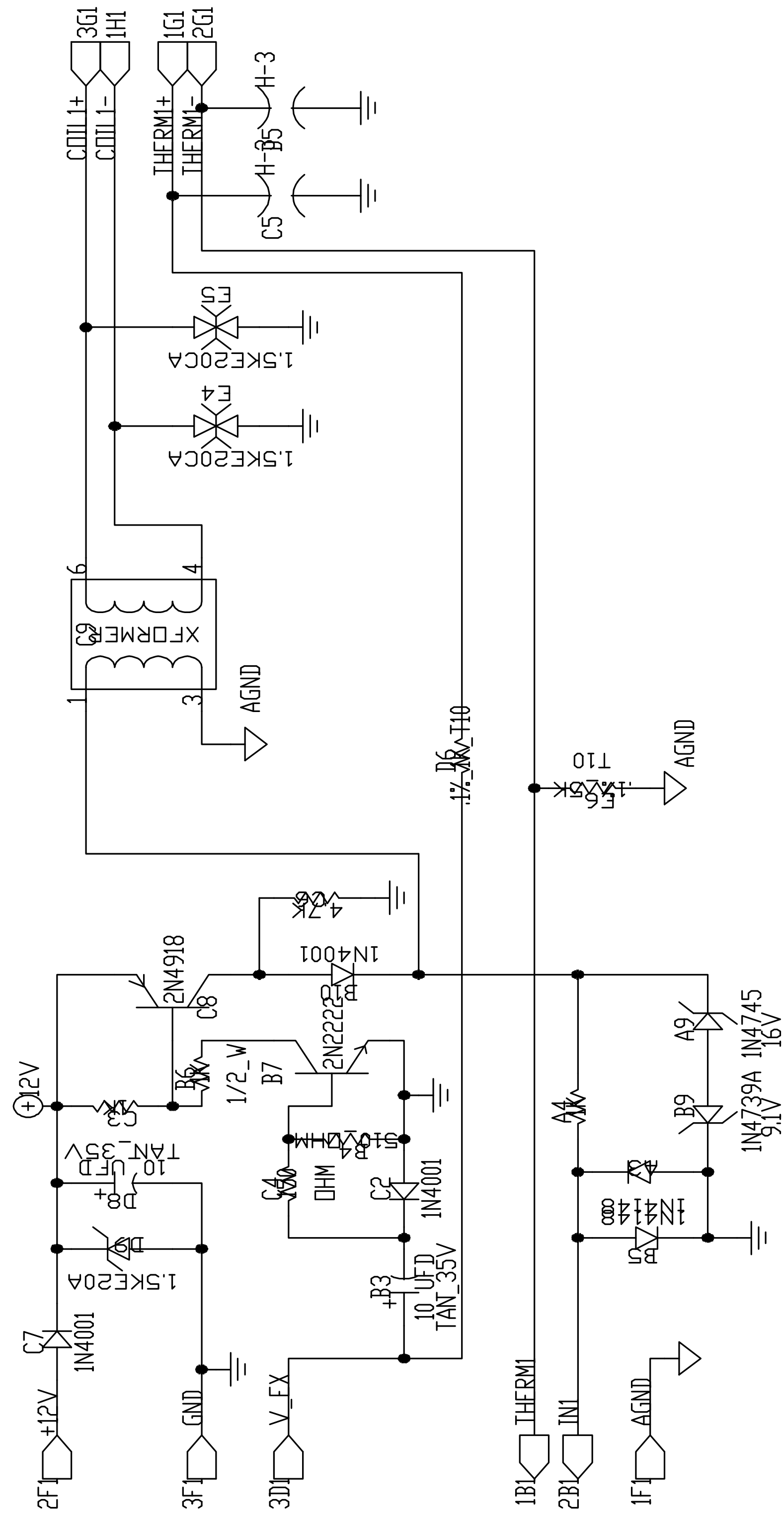
```
11:    P 35      Z=X-Y
  01:   10       X Loc Ptb psi #2
  02:    9       Y Loc Pt psi #1
  03:   10       Z Loc [:Ptb psi #2]

12:    P 35      Z=X-Y
  01:   11       X Loc Ptb psi #3
  02:    9       Y Loc Pt psi #1
  03:   11       Z Loc [:Ptb psi #3]

13:    P 35      Z=X-Y
  01:   12       X Loc Ptb psi #4
  02:    9       Y Loc Pt psi #1
  03:   12       Z Loc [:Ptb psi #4]

Input Location Labels:

1:TEMP C #1   11:Ptbpsi #3
2:TEMP C #2   12:Ptbpsi #4
3:TEMP C #3   13:Cpsi/C #1
4:TEMP C #4   14:Cpsi/C #2
5:P  psi #1   15:Cpsi/C #3
6:P  psi #2   16:Cpsi/C #4
7:P  psi #3   17:T-To*C #1
8:P  psi #4   18:T-To*C #2
9:Pt psi #1   19:T-To*C #3
10:Ptbpsi #2  20:T-To*C #42
```

Appendix A. Pressure Conversion Chart

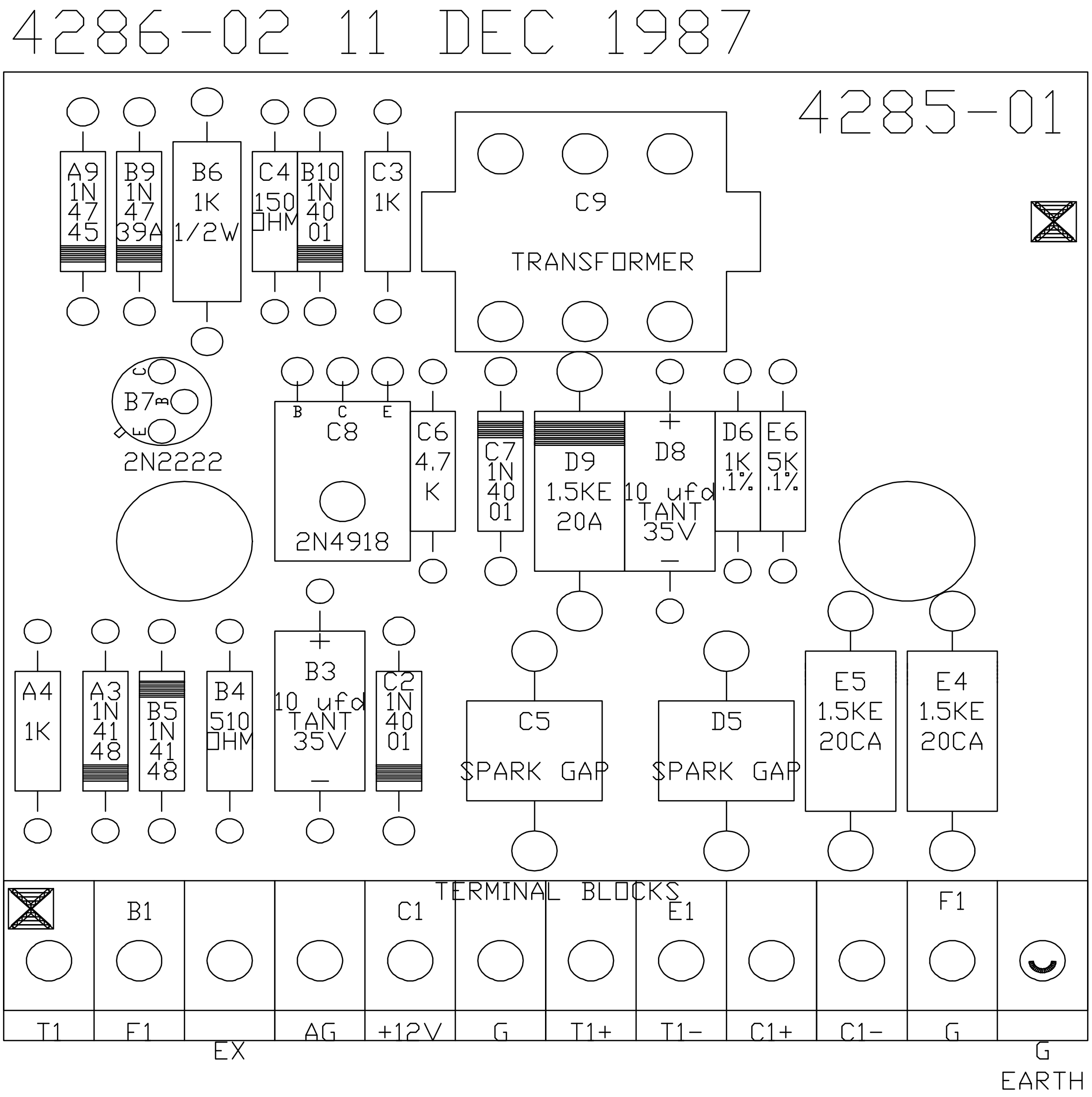
Multiplication Factors

FROM / TO	PSI (lb/in^2)	BAR	MILLIBAR	IN. HG. (at 0°c)	IN. H_2O (at 4°C)	MM. HG. (at 0°C)	MM. H_2O (at 4°C)	PASCAL (N/m^2)	ATM	TORR
PSI (lb/in^2)	1	14.5039	1.4504×10^{-2}	.491159	3.6127×10^{-2}	1.93368×10^{-2}	1.4223×10^{-3}	1.45038×10^{-4}	14.6960	1.9337×10^{-2}
BAR	6.8947×10^{-2}	1	1×10^{-3}	3.3865×10^{-2}	2.4908×10^{-3}	1.3332×10^{-3}	9.8068×10^{-5}	1×10^{-5}	1.0132	1.3332×10^{-3}
MILLIBAR	68.947	1×10^{3}	1	33.865	2.4908	1.3332	9.8068×10^{-2}	1×10^{-2}	1.0132×10^{3}	1.3332
IN. HG. (at 0°C)	2.0360	29.529	2.9529×10^{-2}	1	7.3552×10^{-2}	3.9368×10^{-2}	2.8959×10^{-3}	2.9529×10^{-4}	29.920	3.9368×10^{-2}
IN. H_2O (at 4°C)	27.680	401.47	.40147	13.596	1	.53525	3.9372×10^{-2}	4.0147×10^{-3}	406.78	.53525
MM. HG. (at 0°C)	51.7149	750.06	.75006	25.401	1.8683	1	7.3558×10^{-2}	7.5006×10^{-3}	760.00	1
MM. H_2O (at 4°C)	703.08	1.0197×10^{4}	10.197	345.32	25.399	13.595	1	.10197	1.0332×10^{4}	13.595
PASCAL (N/m^2)	6894.76	1×10^{5}	100	3.3865×10^{3}	249.08	133.32	9.8068	1	1.0332×10^{5}	133.32
ATM	6.8046×10^{-2}	.98692	9.8692×10^{-4}	3.3422×10^{-2}	2.4583×10^{-3}	1.3158×10^{-3}	9.6788×10^{-5}	9.8692×10^{-6}	1	1.3158×10^{-3}
TORR	51.7149	750.06	.75006	25.401	1.8683	1	7.3558×10^{-2}	7.5006×10^{-3}	760.00	1

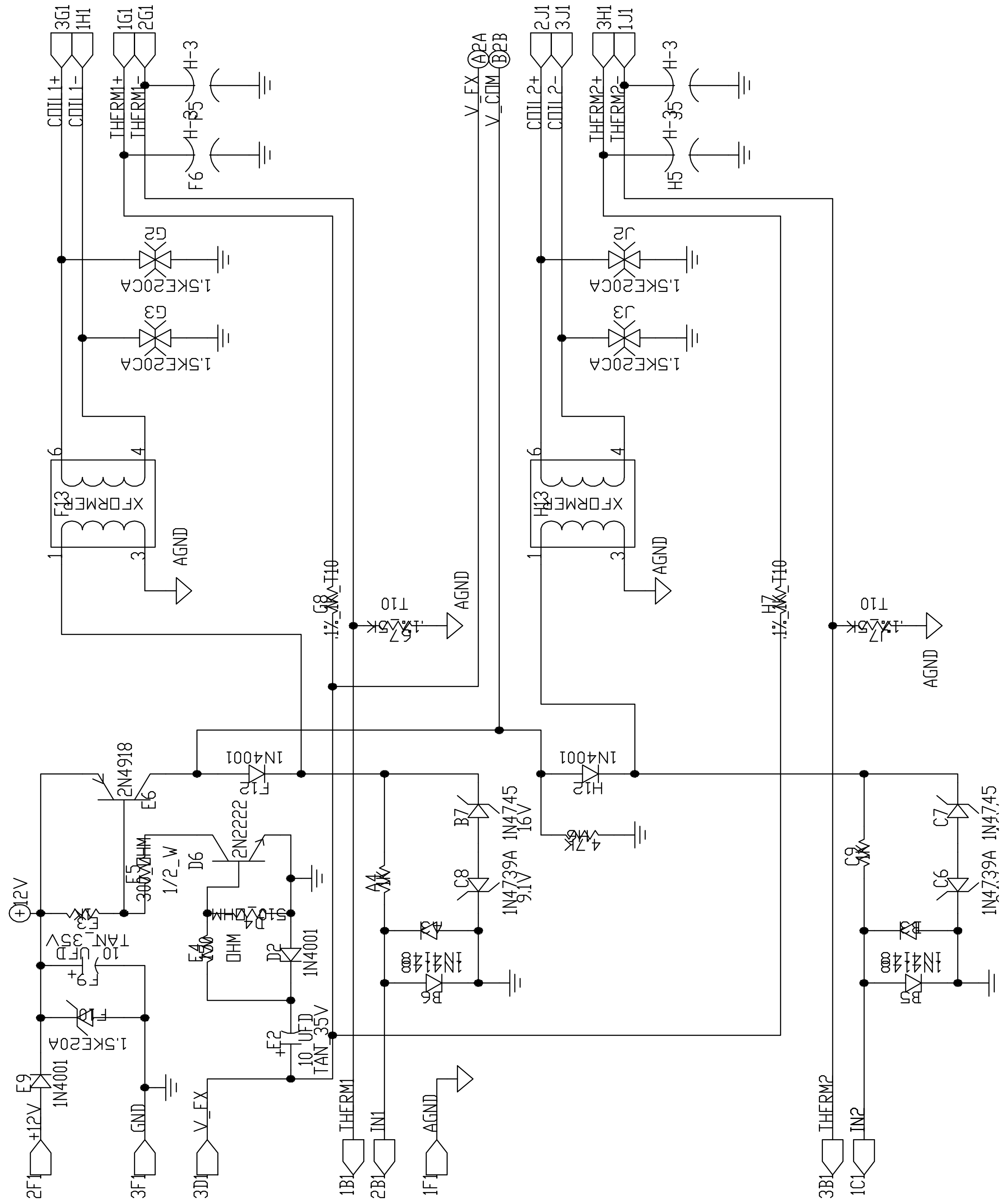
Appendix B. Schematics and PCB Layouts for AVW1 and AVW4



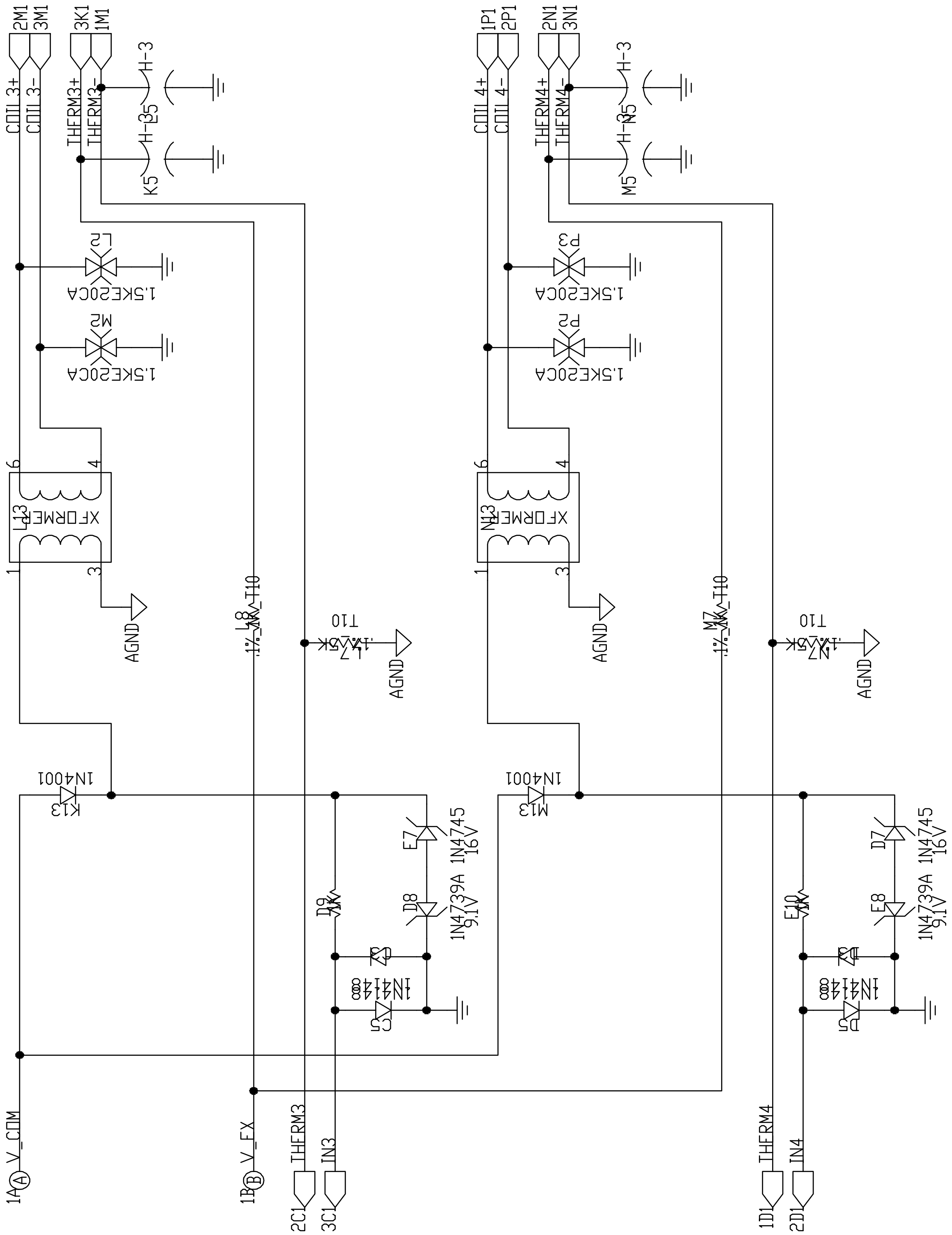
AVW1 Circuit Diagram



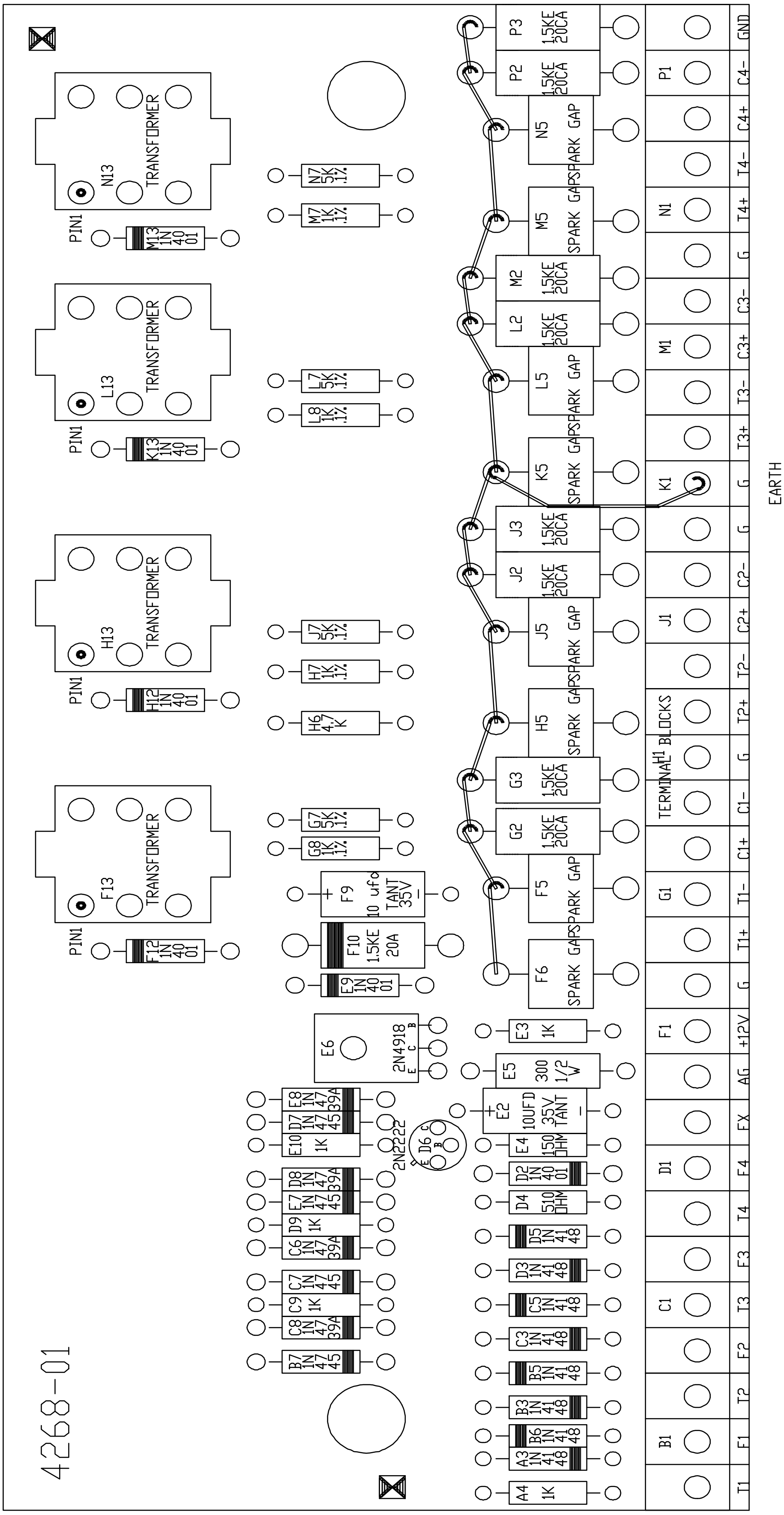
AVW1 PCB Layout



AVW4 Circuit Diagram



AVW4 Circuit Diagram (cont.)



AVW4 PCB Layout

Appendix C. Theory

C.1 Swept Frequency Theory

Example

f2 = 3100Hz
f1 = 2400Hz

X = (30*f1*f2)/(f2-f1)
= 3189

where f1 and f2 are the starting and ending frequencies in hundreds of Hz respectively. One clock cycle (CC) occurs every 813.8ns or at a rate of 1.2288MHz.

X must be between 256 and 65525. The 256 constraint is an 8-bit constraint. The 65535 constraint is a limit where the swept frequency can no longer be done in exactly 15ms.

The minimum increment in frequency is 1 clock cycle.

How many times does the half period have to be changed by 1 clock cycle to cover the frequency range?

1/(F1 * 2) = 1/(2400 * 2) = .208333ms = half period

1/(F2 * 2) = 1/(3100 * 2) = .161290ms = half period

Change in half period = .208333 - .161290 = .047043ms

Number of clock cycle increments to cover the .047043ms half period range is:

(.047043ms/.0008138ms) = 57.81

How much time is there between frequency increments to cover the frequency range in 15ms?

time = 15/58 = .2586ms/freq. incr.

C.2 Additional Theory on Multiplier and Offset

The result (X) of Instruction 28 is:

$X = 1/((t\ ms)^2) = 1{,}000{,}000/((t\ s)^2$

where t is the period in milliseconds. Since frequency (f) is the inverse of period, this can also be expressed as:

$X = (f\ kHz)^2 = [(f\ Hz)^2]/1{,}000{,}000$