Velocimeter

User Instruction Manual

6-Feb-2008

Draft revision 8


Fig.A. Velocimeter in Adalet housing.   Fig.B. in American Sensors' housing.

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1. Product description.

Velocimeter is millimeter microwave backscatter Doppler radar sensor designed for remote velocity measurement of metal strips in rolling mills, conveyor belts and other similar industrial applications.

Fig. 1. Velocimeter with 3 inch lens-horn, 4.5" cylindrical housing.

2. Specifications (preliminary, subject to changes).

Velocity ranges[1]:

1) 0.13 – 8.4 m/s (Low 3kHz)[2]
2) 0.16 – 16.7 m/s (6kHz)
3) 0.25 – 32.5 m/s (12kHz)
4) 0.46 – 78.6 m/s (29kHz)
5) 0.56– 150 m/s (High 53kHz)

Accuracy: calculated estimate ~ 0.02% of the full range in the best of conditions; experimental test shows, for example +/-5 mm/s error at v=4 m/s (at medium velocity range) using rotating steel disk (see chapter 8). Practical accuracy expected in the field conditions at rolling mills: 0.2-1%.

Response time: depends on the speed range and signal filtering setup. For example: 76ms on 150m/s range and 240ms on 8m/s range with no filtering, no averaging and no damping (low accuracy). With higher accuracy setting (more filtering and averaging) the

[1] At 45 deg antena inclination angle
[2] The names in brackets are range identifiers on the display menu selection.

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response time is correspondingly slower. For any given speed range, there is a compromise (inverse relation) between the achievable accuracy and the response time. Configuration for high accuracy results in slower response and vice versa. This is further discussed in chapter at the end (near page 27).

Mounting distance: the lens-to-target distance range measured along the antenna line-of-sight is 20 –120 cm, (optimum=30-60cm) for dry strips, and 50-200cm for wet strips (optimum 100cm).

Mounting position: antena pointing near-horizontally towards the edge of the strip, at an incidence angle of about 45 degree (+/-5deg) with respect to the edge of the strip. The antenna unit should be mounted slightly below the strip about 2.5-5cm (1-2") below the plane of the strip.

Polarity of the beam: microwave beam should be polarized (E-field) at approximately perpendicular angle to the edge of the strip. This should be experimentally adjusted for maximum signal strength (displayed as Syy on the screen number 1, see chapter 4), by rotating antena around its axis to a position where the SMA signal connector (FIG.3) is vertically up or down or at 45 degree angle to vertical.

Housing: cast aluminum cylindrical enclosure by Adalet, with a screwed-on lid with glass window; explosion-proof approval ratings. Weight: 3.5kg. External diameter 5 inch (12.5cm), height 6 inch (15cm). Two threaded conduit ports, ¾ inch NPT. One used for antena mount and one free, available for cable connection.

Antena: Aluminum horn with polypropylene (low temperature applications) or teflon lens (high temperature applications). Length 5.75 inch (14.5 cm), external diameter 3 inch (7.5cm),

Environmetal protection: similar to Nema-4. Operating temperature –10C to +45C.

Housing approvals: class I group B,C,D, class II group E,F,G, class III type 4X, class I zone 1 A Ex d IIC,
Exd IIC IEC 60529 IP66

Housing cable port: ¾" NPT conduit entry

Power Supply: 24V DC (19-29V) / 0.5A, fuse 2A

Transmitter Output: 10-50mW continous wave, fixed frequency in 76-78GHz range

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Process Variable Output: Analog output in form of a 4-20mA source from common 24V supply line (default) or opto-isolated bipolar sink (jumper-configurable). Voltage burden = 8V. Max load resistance 640 ohm. Current span is 3.5-25mA. Second output option requires an optional (additional) quadrature differential pulse output board and provides ground-isolated externally supplied frequency-modulated pulses (either 5V or 24V depending on the power supply used, 0-100kHz), where frequency is proportional to velocity or equivalently, each pulse has a direct relation to an incremental distance movement of the strip. The third method consists of using the serial data link interface to read the output process variable (or other internal sensor variables) digitally to a PC controller or PLC.

Diagnostic/setup data port: serial RS232-TTL 9.2-115kbaud, no handshaking. It is recommended to attach a USB or a RS485 interface (not included), for interfacing to a PLC or a PC. This port can be used for sensor diagnostics, for transfering sensor output variables, for setup and for calibration.

Configuration: Manual – direct parameter entry using a 2 lines by 8 characters LCD and two push-buttons (requires opening the enclosure). Remote – using serial data link and ‘snnvvvvvv’ command (see chapter 5). Remote configuration does not require enclosure opening.

Calibration: Calibration procedure consists of placing a calibration reference belt loop device of a known velocity in place of, or over the target strip, parallel with the strip direction; then by measuring the belt velocity by Velocimeter sensor mounted, aimed and installed in the required location; and then finally by calculating the new calibration constant CalFac and re-entering the new CalFac into the sensor using the “CalFac” screen or sending it by the ‘s33vvvvvv’ command through the serial data link (see chapter 5). Alternatively, calibration procedure can be exected automatically by activating the “Calibrate” button of the VelTerm.exe software (Version 4.00 or higher). Note that the sensor aim should not be adjusted after calibration!

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3. Installation.

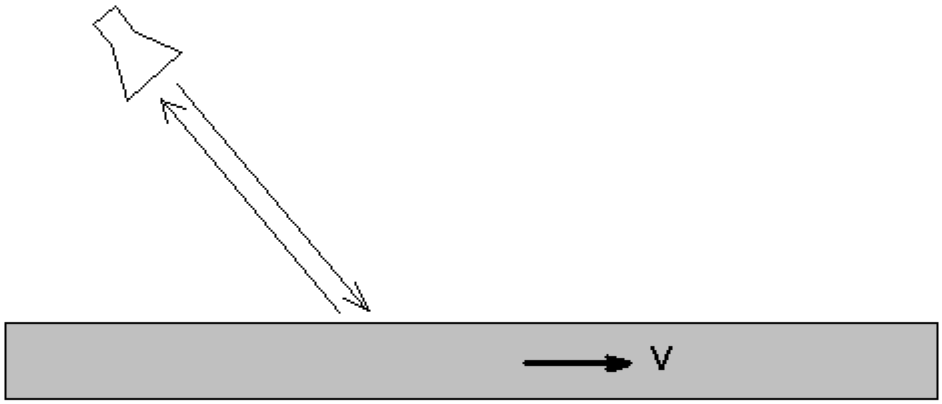

Fig.2. Position of Velocimeter antena with respect to a moving strip, as viewed from the top. Note: direction of the velocity vector is arbitrary, the sensor will work the same way from the same mounting position, if velocity direction reverses.

Position of Velocimeter antena with respect to the strip is depicted in a simplified form on Fig.2. The inclination angle between the line of sight (antena axis) and the edge of the strip should be between 10-80 degrees (best is 45+/-5deg). The distance along the line of sight (=antenna axis) between the antena and the strip edge should be between 20-120cm, the optimum is about 30-60cm (for dry strips). For wet strips – the optimum distance should be longer, about 1-1.5m. Inclination angle below 10 degrees would place the radar device too close to the strip, while angles above 80 deg would increase the minimal velocity limit and would also reduce the accuracy. Note: the inclination angle is one of the configuration parameter available from the menu (“Angle”) that has to be determined and entered into the system at installation. This parameter affects velocity conversion factor and calibration.

In order to maximise the strength of the Doppler signal, orientation of the antenna should be such that the polarisation (electric field) of the microwave beam is directed approximately perpendicular to the plane of the strip. Antenna is equipped with a detachable lens (or a lens extension) which should normally be on when the sensor is used in metal strip applications. The lens is designed for beam focus at about 40-150cm distance. Due to diffraction effects, a beam width is of the order of 2" even at the narowest (focal) point and may increase to about 4" at 120cm distance. If vertical deflections of the strip exceed 2-4" then the microwave lens should be re-positioned or even removed to widen the beam[3] such that its cross-section will always intersects the strip edge.

[3] Widening of the beam will reduce the signal strength. To compensate for that, antenna should be brought closer to the strip, for example 30-60cm maximum. If the horn antenna is installed with the lens removed, it's

Electrical connections.

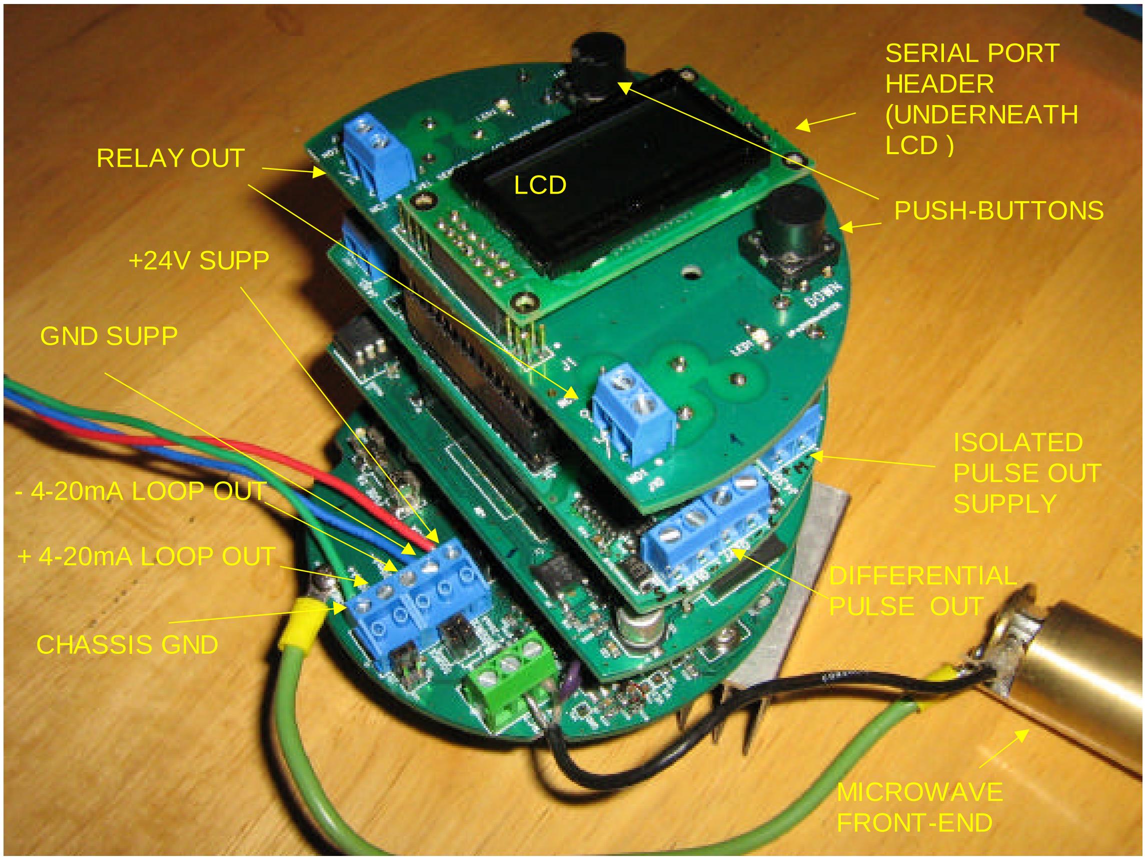

Fig.3. Inside the housing, board stack and connections. The boards are (bottom to top): Analog Driver and Power, CPU, Quadrature Pulse and LCD board.

Power and signal output cables (24V DC power and for example 4-20mA current loop or optional quadrature pulse output) are passed through the cable conduit port in the enclosure. +24Vdc power, ground and loop current connections are available on the 5 way detachable terminal block on the bottom board (see Fig.3). Pulse output terminals and relay terminals are mounted on different boards of the stack (refere to a separate manula for pulse output board and silnkscreen marking on the boards). Power the sensor up and set up the configuration parameters while the enclosure is open, using UP and DOWN push-buttons, and observe the LCD screen.

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opening should be watertight sealed with a low density polyethylene, polypropylene or teflon sheet and silicone sealant.

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4. Configuration screens and information screens.

The unit is equipped with a 2 lines by 8 characted LCD module. Two (UP and DOWN) push-buttons allow scrolling through a number of screens, and executing edit (ENTER) function by simultaneous pressing of UP and DOWN buttons. Some screens may require a 3-digit password number **(password number is 008)** to be entered before ENTER operation and parameter modification is executed.

The following list of screens is implemented as of the current version of the firmware (1.37)

Vel Syy
x.xxx uu - Displays velocity x.xxx in units indicated by characters uu = m , ft , in , cm or mm per second [4] and shows the signal to noise ratio in yy value (00..99). Note: this is the main screen displaying the primary sensor output variable.

Loop
x.xxx mA - Displays the loop current in milliampers. Note: the loop current is a linear function of velocity (see above) determined by two set points by screens "Set 4mA" and "Set 20mA" and can be fine-tuned and calibrated to a high accuracy by two other screens "Trim 4" and "Trim 20". Note: this screen shows the current value that is internally set, not the actual current in the output loop circuit.

Status
……….. - Displays system status messages. The messages are scrolling automatically once every 2 seconds, and are automatically cleared (unless underlying condition reoccurs) every 10 seconds. The following conditions may be shown:

Hi Noise - high noise level
Hi Sig - radar echo is too strong
Low Sig - radar echo is too weak
No Echo - loss of radar echo
[blank] - no messages, operating normally

Note: the above three screens will normally be displayed automatically after power up rotating every 2 seconds, for example "Vel Qyy" followed by "Loop" followed by "Status" (if there are messages to be displayed, otherwise skipped) and then again "Vel Qyy" and so on.

[4] Units are abbreviated with the per-second part removed, for example "mm" means "mm/s", "ft" means "ft/s" etc.

Diagnost
……….. - Displays diagnostic messages. The messages are scrolling automatically once every 2 seconds, and are accumulating ("sticky"). The messages persist and are not cleared automatically even if the underlying condition that caused them ceases to occur. The message list is the same as for "Status" screen above. Messages can be cleared manually by executing ENTER [5] twice.

Totalizr
xxxxxxxx - Displays time integral of velocity, in mm units. This quantity represent the total integrated strip length. Execution of ENTER (twice) resets this value back to zero.

Freq Hz
xxxx.xx - Displays the frequency in Hz of the highest spectral peak.

TotAmpPP
x.xxx V - Displays total peak-to-peak voltage over the entire spectrum integrated over all frequencies excuding DC. Equivalent to RMS voltage times 2.83 .

SigAmp
x.xxx V - Displays peak-to-peak amplitude of the single largest peak signal.

Noise
x.xxx V - Displays peak-to-peak baseline noise amplitude in the spectrum, calculated around the base of the largest peak.

RawFreq
xxx.xx - Displays the raw unscaled Doppler frequency in 0..512 units (test screen)

Vg
x.xxx V - Displays/sets voltage driving the microwave transceiver circuit. It can be changed within the range of 2-5V, for the purpose of controlling transmit power and frequency (factory-adjust only!)

Ig
xxx.x mA - Displays the microwave transceiver current (for diagnostics).

Temperat
xx C - Displays temperature inside the unit (Celsius)

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[5] ENTER function is triggered by pressing UP and DOWN buttons simultaneously. The top right character on the screen changes to "!" to indicate a pending ENTER condition. During a pending ENTER, a parameter value may be incremented or decremented or a list of selections may be scrolled (on some screens) using UP or DOWN keys. Subsequent execution of ENTER completes the sequence, and the exclamation character is cleared.

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SuppVolt

xx.xx V - Displays the supply voltage value. Should be 19-29V DC (for diagnostics).

Units

uuuu - Selects velocity units, from the list of: uuuu = mm/s , cm/s , in/s , ft/s and m/s.

Damping

xxx - Selects the strength of the damping filter for the output velocity variable. The selection is: 1,2,4,8,16,32,…4096. Setting of a very high value makes the sensor response very slow but less noisy. Setting it to a low value makes the response fast but may make the output variable (loop current) more noisy. Recommended value is 1.

Median

xx - Selects the length of the median filter acting upon the output variable (prior to the "Damping" filter), that filters out the "way-out" or intermittent odd noise-caused readings. The selection is: 1,3,6,12 and 24. Setting a high value makes the output signal more stable but slows down the sensor response time. Recommended value is 1.

SpectAvr

xx - Selects the length of power spectrum accumulation (Spectral Averaging): 1,2,4,8,16,32 and 64. Spectral Averaging acts as time filter upon every spectral frequency bin, prior to peak detection and prior to Median filtering stage. High value makes power spectrum more stable but slows down the response time against quick changes in velocity. Recommended value is 4.

FreqRng

xxxxxxxx - Selects velocity(frequency) range from the list of:

1) "Lo 3kHz" (typ Vmax=8.4 m/s at 45deg)
2) " 6kHz" (16.7 m/s) ✍ RECOMMENDED SETTING
3) " 12kHz" (32.5 m/s)
4) " 29kHz" (78.6 m/s)
5) "Hi 53kHz" (150 m/s)
6) "by SetAD" – special manual adjustment using "Set A/D" screen

Changing FreqRng is equivalent to changing the A/D sampling rate. Note: selecting 1-5 (but not 6) modifies also parameters settings on screens SpectAvr, Median, and Raw Fmin.

Set 4mA

x.xxx uu - Set velocity point for 4.00mA loop current. Note: this should almost always be set to velocity=0.000 . Since the (optional) pulse output board is set to output zero frequency at 4.000mA current, setting it to

0 will ensure that the zero pulse frequency always corresponds to zero velocity.

Set 20mA
x.xxx uu - Set velocity point for 20.00mA loop current.

Raw Fmin
xxx - Set lower window boundary for spectral frequencies in 0..512 units (spectral frequency bin). Note: permitted range is 1-510 (0=DC)

Raw Fmax
xxx - Set upper window boundary for spectral frequencies in 0..512 units (spectral frequency bin). Note: permitted range is 1-510 (512=Nyquist freq). The main purpose of Raw Fmin and Fmax setting is to eliminate spurious peaks due to noise, that may lie beyond the measured frequency range of the Doppler signal.

SysFault
xxx - Select exception-handling method in case of system faults or errors. The choice is:
"22mA" – set current loop output on 22.00mA
"3.6mA" – set current loop output on 3.6mA
"Hold" – hold a last good value on the current loop output

LOEFault
xxx - Select exception-handling method in case of the Loss-Of-Echo situation. The choice is:
"22mA" – set current loop output to 22.00mA
"3.6mA" – set current loop output to 3.6mA
"Hold" – hold a last good value on the current loop output

LoopTst
xx.x - Current loop test. Press ENTER (UP&DOWN) and set a current value. Press ENTER again to exit. This is diagnostic feature to help calibrating the current loop receiver, chart-recorder, testing wiring connections etc.

Data Log
xxx - Select data logging frequency. The choices are: 2s, 10s, 1m, 10m, 1h, 3h and "Never". Each data record contains velocity, time stamp and some internal variables and flags. History log can be downloaded through RS232 diagnostic port and displayed with VelTerm.exe (utility program provided by www.velsensor.com), Windows' Hyperterm or similar. Maximum number of data records is 1008, beyond which the history file will scroll out the oldest data.

BaudRate
xxxxxx - Select the baud rate for diagnostic RS232 port. The choices are:

"9.6k NoH" – 9600 bit/s, no handshaking
"19.2k NoH" – 19200 bit/s, no handshaking (default, recommended for slow PCs)
…
"115k NoH" – 115000 bit/s, no handshaking (recommended for fast PC and when using RS232/USB interfaces)

Cal Vel
xxxx mm - Calibration velocity in mm/s. Value of this parameter has to be equal to the actual speed of the calibration device, before the calibration procedure is entered (see below). This parameter is not relevant outside of the calibration procedure.

Calibrate
Escape/Proceed - Select calibration procedure (to Proceed). "Cal Vel" parameter is used as the actual known velocity to calibrate against. The result of the calibration is calculation and saving of a new CalFac parameter value. A moving calibration belt or a strip has to be placed at front of the sensor as in the working position, and the strip speed has to be stable and equal to "Cal Val" screen parameter. See also the chapter "Velocity Calibrator" around page 30 of this manual.

CalOffs
xx.x mm - Calibration offset in mm/s units[6]. Used in the linear formula mapping signal frequency into velocity. This should almost always be set to zero with the exception of one possible usage for fine-trimming the zero point of the pulse output.

CalFac
xxxx um - Calibration factor in um/s/Hz units[7]. This is a multiplicative factor used in the linear formula converting signal frequency into velocity. This value is typically of the order of ($c/2*F_0$), where c=speed of light (3e8m/s) and F_0=carrier frequency=77GHz. Note: running calibration procedure (see last chapter) modifies and re-assigns this value!

Angle
xxx.x dg - Beam incidence angle in degrees, between the antena direction and the strip edge. Allowed range is 0-89.9 degrees. This angle is used in the convertion of Doppler frequency f into velocity v formula: v = (CalFac*f)/cos(Angle) + CalOffs
Note: running calibration procedure with the Calibrator device (see last chapter) does not modify this value. However, it invalidates previous calibration if the "Angle" parameter gets subsequently changed.

[6] The units on this screen are always mm/s regardless of the "Units" screen selection.
[7] The units on this screen are always mm/s regardless of the "Units" screen selection.

Algorithm
xxxxxxx - Selection of spectrum processing algorithm. The choices are:
"NoSmooth" - no smoothing (default) - RECOMMENDED
"3pts" - 3-point formula for smoothing spectrum
"5pts" - 5-point formula
"9pts" - 9-point formula
"15pts" - 15 point formula
Note: it is recommended to use smoothing formulae (other than default) only for very unstable targets or when severe noise is present. It improves stability of the peaks at the expense of reducing the accuracy of peak position determination.

TestFlgs
0 - Binary flags alowing activation of self-test procedure (factory use only). Do change from the default value: under normal operation must be =0.

Tsmp us
xxx.xx - Displays the actual A/D sampling time in microseconds.

Set A/D
xxx - Alternative setup screen for setting the sampling rate clock divisor. Note: use this screen only for setting up a non-standard sampling rate, under normal circumstances use "FreqRange" screen for setting the velocity range and the A/D sampling time.

Trim 4
xxxxx - Setup of the current loop trimming parameter to calibrate the 4.00 mA point. Default value is 3400 (0-65534).

Trim 20
xxxxx - Setup of the current loop trimming parameter to calibrate the 20.00 mA point. Default value is 56350 (0-65534). Note: "Trim 4" and "Trim 20" screens are meant for fine-tunning the accuracy of the current loop output circuit using an ammeter connected through the loop, such that when the LCD screen shows a certain current value, the actual loop current flowing is that. This is not meant for setting of the 4 and 20mA set points versus velocity; or for trimming the zero pulse frequency. For that purpose use "Set 4mA" and "Set 20mA", or “CalOffs” screens, respectively.

Min Amp
x.xxx V - Set the minimum Doppler signal amplitude (peak-to-peak volts). Signals that are smaller are ignored.

Gain

x - Set receiver gain 0-10, such that the signal amplitude between 1 and 2 Vpp. Default gain = 5. Recommended range is 4-7

Set T

xxx.x C - Set temperature calibration value (factory calibration only). Must enter the actual (independently to Velocimeter) measured temperature (inside the enclosure) in order to calibrate Velocimeter built-in temperature sensor.

Set Vref

xxxx mV - Set internal voltage reference value (factory calibration only). Should be measured by a voltmeter on pin 1 of the 30-way header. Typically it should be about 3600mV .

LaserPtr

xxx - Manually switch relay 1 on or off. Relay 1 may be wired to an optional (external) laser pointer to facilitate aiming of the sensor onto the target strip). Note: when laser pointer aiming device is not used but VEL-PULSE-3 output interface board is plugged in and wired for 5V, this switch has to be set permanently on in order to enable the power to VEL-PULSE-3 output section.

Set Rly2

x.xxx uu - Set switching point for relay 2, in velocity units, for "Vel Swi" selection (below). Setting a positive value causes relay 2 to switch ON when velocity goes above the set value. If the set value is negative, relay stays on when velocity is lower, and switches OFF when velocity is higher than the absolute value set. When the value is exactly zero then the relay is disabled (always OFF). This is ignored when Rly2Mode is not "Vel Swi".

Rly2Mode

xxxxxxxx - Select relay 2 mode of operation from the list of:

1) "Vel Swi" - switching on velocity threshold as set by **SetRly2** screen
2) " LOE " – switch ON on Loss Of Echo condition
3) "No LOE" – switch OFF on Loss Of Echo condition
4) " Fault " – switch ON when a fault occurs that invalidates the measurements (including LOE).
5) "No Fault" – switch OFF on fault (including LOE)

T(days)

xxxx - Displays the total working time in days, from the first factory power up.

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Vel Rng

xxx.xx m - Displays the actual calculated maximal velocity range in m/s depending on the calibration coefficients, incidence angle and selected FreqRng (always in m/s regardless of the "Units" selection).

TcoPPM/K

xxxx - Temperature Correction factor in parts per million per Kelvin (PPM/K). This allows for the fine-tune correction of the temperature factor of the 4-20mA output and the associated quadrature pulse frequency output (if VEL-PULSE-3 board is plugged in). Note: this factor does not affect the digital read-out and LCD display. The allowed range is –5000 to +5000 ppm/K but the actually needed correction is typically very low, of the order of 100ppm/K. The output circuit is typically sufficiently stable to within +/-0.1% within the full operating temperature range even with this factor set at 0.

Velocmtr

Rel.1.37 - Displays the product name and the firmware revision number. Displays additional product information in the bottim line (scrollable) when ENTER is pressed.

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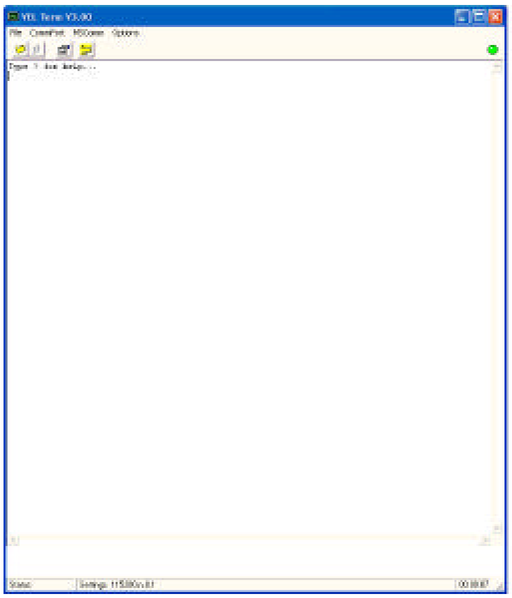
5. PC Host Application ‘VelTerm.Exe’

VelTerm is a PC host based application which interfaces to the velocimeter via a serial RS232 connection available through the 10-way 2.54mm DIL header (see also connection diagram at the end of this chapter).

The operation in principle is quite similar to commercially available terminal emulators such as Hyperterm however; VelTerm has some built in functionality for visualization and exporting of the velocimeter data. The main screen presented to the user is as follows.



The easiest way to get an overview of VelTerm operation is by pressing the question mark ‘?’ key. This will update the screen with a list of VelTerm commands as listed below.

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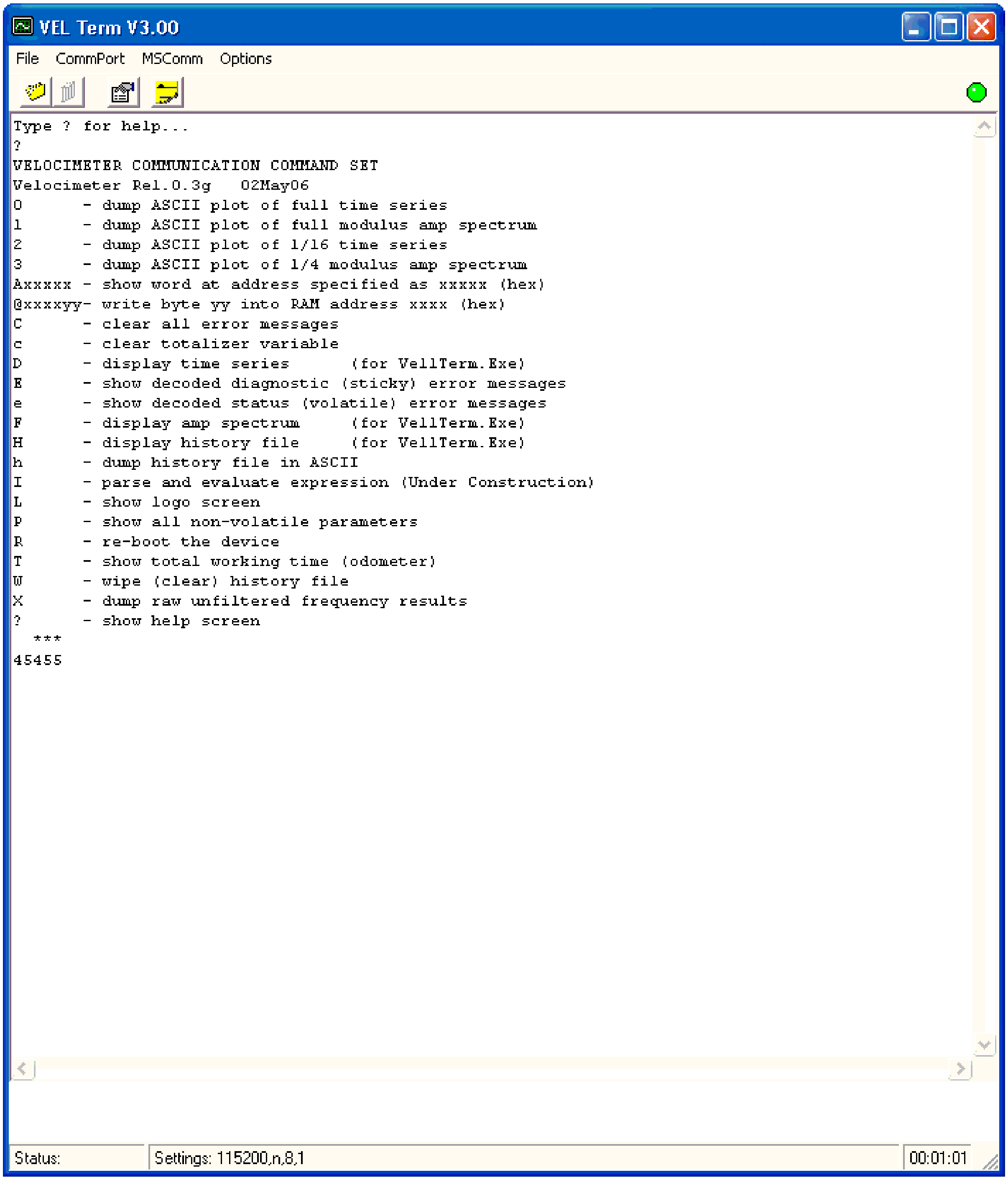
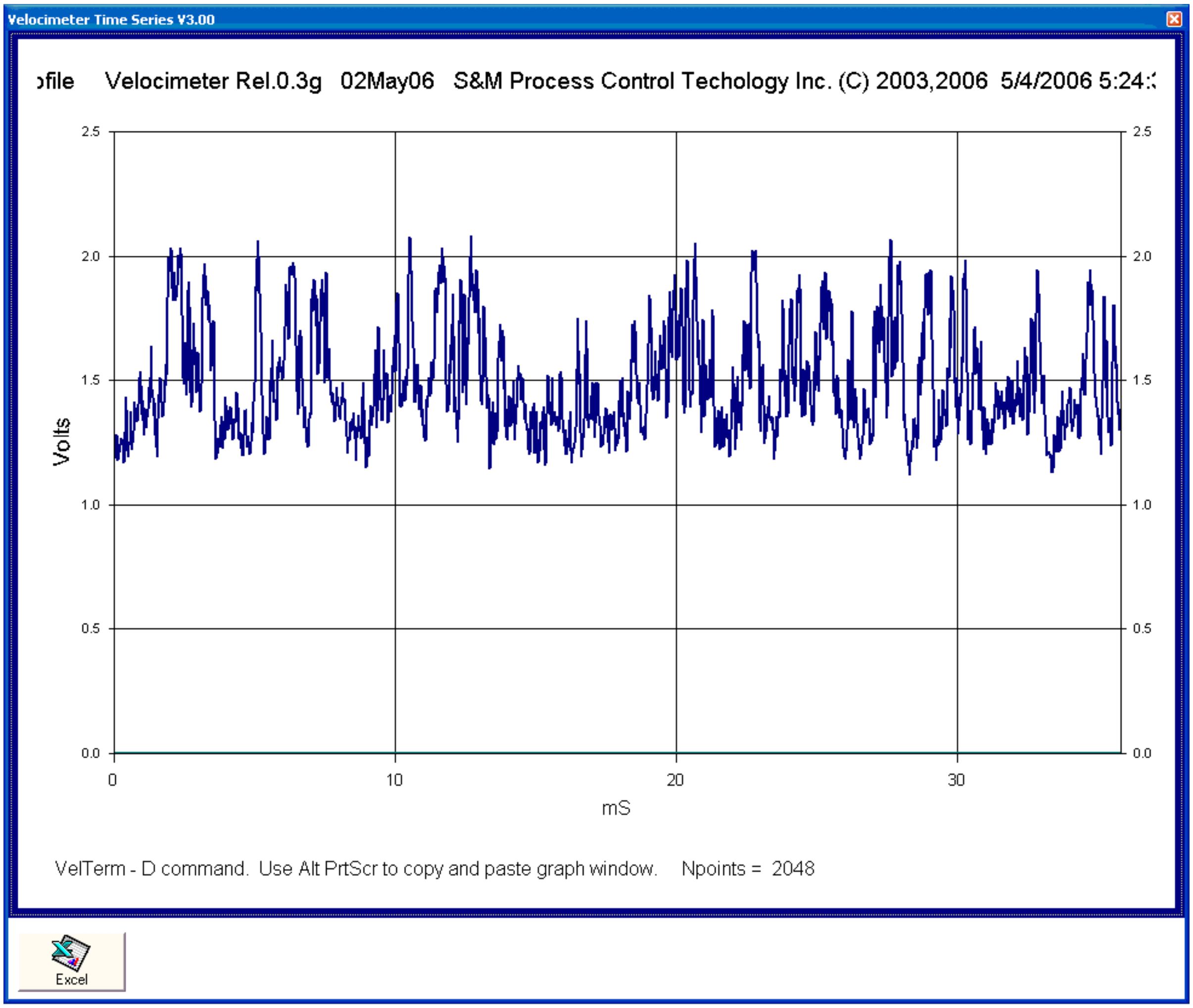


The main data visualization features which are useful for diagnostic and data analysis are ‘D’, ‘F’ and ‘H’.

‘D’ Command

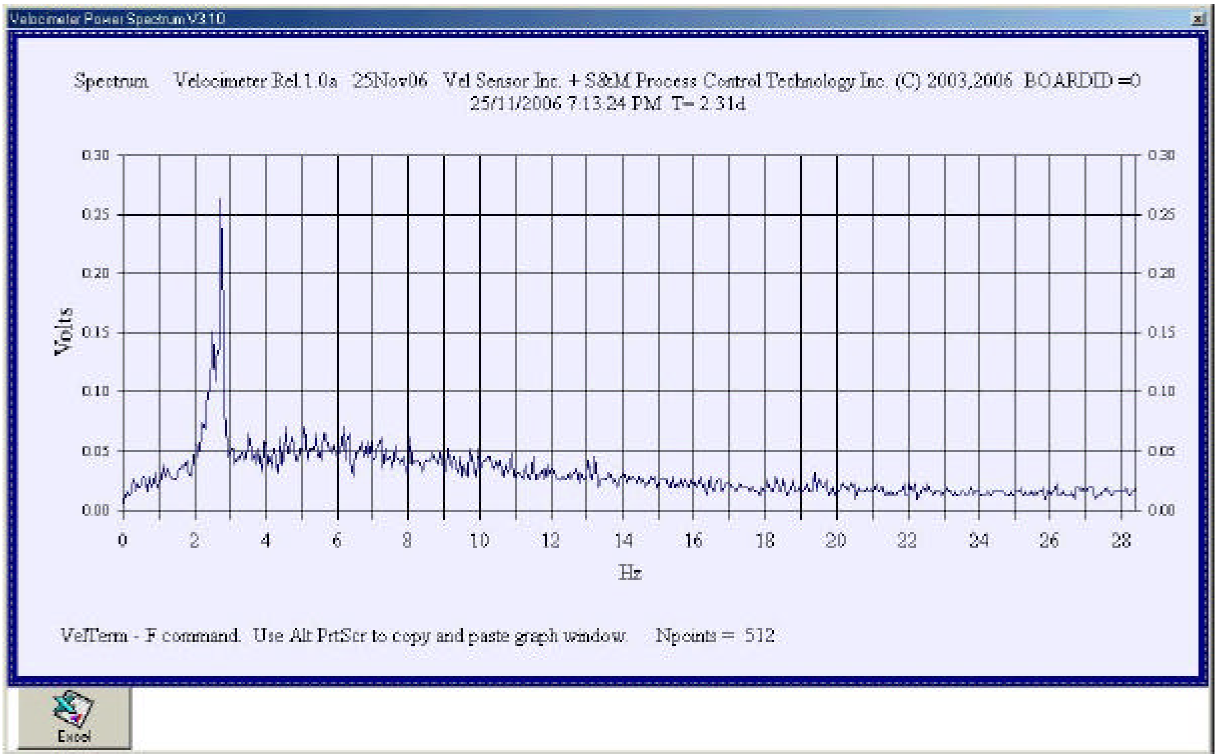
The ‘D’ command downloads a time series from the velocimeter unit and displays a chart of voltage vs. time. This feature is particularly useful for installation and adjustment of the unit and essentially emulates an oscilloscope. This can facilitate adjustment of the unit such as to maximize signal strength (voltage amplitude).



The ‘Excel’ button in the lower left hand corner of the screen launches Microsoft Excel, creates a new workbook and automatically populates two columns of data with time in mS as the independent variable and voltage as a function of time as the dependant variable. This feature allows the customer to use the features of Excel for further data analysis or visualization as per their own unique requirements.

‘F’ Command.

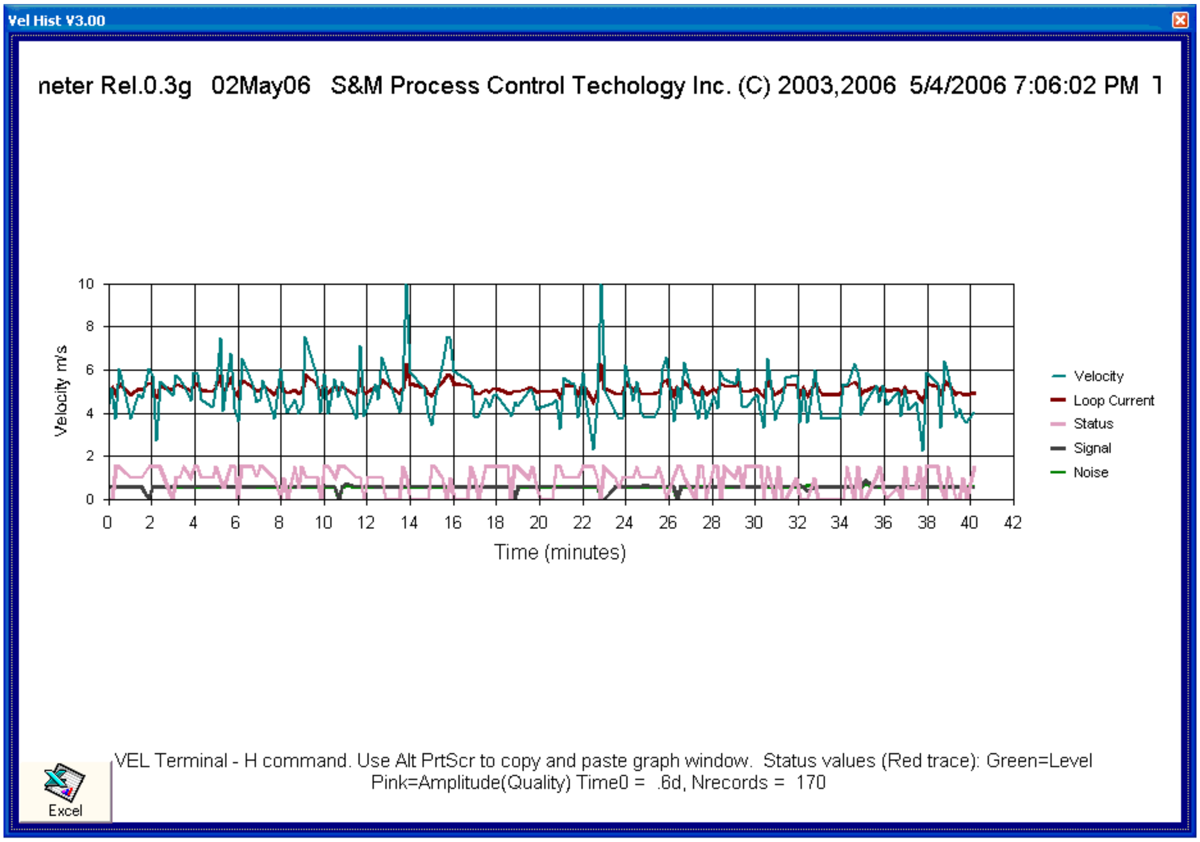
The ‘F’ command provides the frequency domain equivalent of the ‘D’ command in that it is also a visualization tool to assist installation and troubleshooting but in this instance it displays a Fourier spectrum of the data and displays signal power as a function of frequency. In this regard it is basically like an on board Spectrum Analyzer.



Again, the Spectral display screen contains a button to facilitate exporting the data to Excel. In this instance, two columns of data are populated on the spreadsheet, the independent variable is frequency in Hz and the dependant variable is in volts squared as a function of frequency i.e. V^2(Hz) which represents units of energy spectral density. The spectral peak in the plot above represents the Doppler frequency of a real moving target. These frequency peaks are subsequently calibrated internally in the Velocimeter unit and converted to report results in units of target velocity (m/s, ft/s etc.)

'H' Command.

The Velocimeter unit contains an internal EEPROM which facilitates data logging. At user defined intervals, the unit will take a snapshot of primary process variables. These, together with some system and environmental variables and error messages are time-stamped and logged in EEPROM. The 'H' command provides a means for the end user to read the contents of the EEPROM, display them in tabular and graphical format and also to export them to Microsoft Excel. After the data is read in from the system, VelTerm will launch the following graph. The graph contains various information relating to the primary process variables together with diagnostic information.



Again the graph has a button which exports the logging history to Excel. This appears as follows:

Microsoft Excel - Book1

File Edit View Insert Format Tools Data Window Help

A1 Status

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Status	Time	Vel(mm/s)	Totaliser(M)	I Loop mA	LOE	Temp C	Signal	Noise	Relay 1	Relay 2	Error Code	
2		0	634	21699.19141	5.011	0	20.3	0.551	0.559	0	0	0	
3		0.1689	749	21706.49609	5.194	0	20.3	0.559	0.559	0	0	0	
4		0.3364	539	21712.99219	4.859	1	20.3	0.559	0.559	0	0	2400	
5		0.5054	878	21720.76367	5.401	1	20.3	0.551	0.559	0	0	2400	
6		1.0442	539	21740.06641	4.859	0	20.3	0.551	0.551	0	0	400	
7		1.2131	627	21747.91992	4.999	0	20.3	0.582	0.566	0	0	400	
8		1.3806	704	21755.65234	5.122	0	20.3	0.551	0.559	0	0	400	
9		1.5481	679	21762.19531	5.083	0	20.3	0.59	0.559	0	0	400	
10		1.8831	872	21777.07031	5.391	1	20.3	0	0	0	0	2400	
11		2.0505	835	21784.77734	5.331	1	20.2	0.578	0.559	0	0	2400	
12		2.218	397	21793.15039	4.633	1	20.2	0.566	0.551	0	0	2400	
13		2.3855	791	21800.42383	5.261	1	20.3	0.551	0.551	0	0	2400	
14		2.971	692	21826.29102	5.103	0	20.2	0.578	0.551	0	0	0	
15		3.1384	831	21832.35938	5.326	0	20.3	0.582	0.551	0	0	400	
16		3.3059	802	21842.66406	5.279	0	20.2	0.578	0.551	0	0	400	
17		3.4734	768	21850.32422	5.224	1	20.3	0.582	0.559	0	0	2400	
18		3.8084	661	21864.14063	5.054	0	20.2	0.566	0.559	0	0	400	
19		3.9758	847	21870.53711	5.351	1	20.3	0.578	0.559	0	0	2400	
20		4.1433	842	21878.76367	5.342	1	20.2	0.578	0.539	0	0	2400	
21		4.3108	668	21885.27148	5.066	0	20.3	0.578	0.559	0	0	400	
22		4.8365	621	21905.26953	4.99	0	20.3	0.566	0.559	0	0	400	
23		5.0026	786	21912.91797	5.254	1	20.2	0.582	0.551	0	0	2400	
24		5.17	1078	21922.48047	5.719	0	20.3	0.578	0.551	0	0	400	
25		5.339	588	21930	4.938	1	20.2	0.551	0.551	0	0	2000	
26		5.6739	975	21944.75391	5.555	1	20.2	0.559	0.551	0	0	2400	
27		5.8429	606	21951.69531	4.965	1	20.2	0.551	0.559	0	0	2400	

The leftmost column 'Status' is color coded and represents a status flag for the current data sample, the legend is Red = Fatal Error, Orange = Warning, Yellow = System Information. The next column is the timestamp which is in units of the Velocimeter system timer which is currently approximately equal to 87 mS. The next column is velocity reported in mm/s followed by the totalizer value which represents integrated strip length in metres. The I Loop mA column contains the output current on the 4-20mA current loop. The LOE column contains a flag variable which indicates 'Loss of Echo' condition associated with the current data sample. Temp C is the Velocimeter internal temperature as measured by the on board temperature sensor. Signal and noise represent the instantaneous Doppler signal amplitude and spectral background noise and are expressed as dimensionless values between 0 and 1. Relay1 and Relay2 are flags representing the status of the on board relays which are user programmable to trip under predefined conditions. Finally the Error code column is a hexadecimal value where each bit is mapped to a specific error, warning or information condition.

Other useful commands:

e - displays decoded system status and error codes in plain English

V – displays results in ASCII format in 3 lines of textx. First line containing velocity Vel, signal to noise S, 8 digit status code (hex) and peak frequency in Hz. The format is position-fixed, as in the following example:
Vel = 1000.0mm/s S=40 stat=00000000 f = 1000.00Hz
Line 2 contains the end marker string " ***" and the third line contains the 5 decimal digit of 16-bit inverted check sum (by bytes) to allow channel error detection.

{ - begins continous (auto-repeat) display of "V" command output every 2 seconds

} - ends the above command ('R' command or power reset would also terminate it)

[- begins continous (auto-refresh) graphic display of power spectrum, similar to "F" command, refreshing automatically every 2s.

] - ends the above comand ('R' command or power reset would also terminate it)

P - show list of all internal configuration parameters and values

S - list all configurable parameter numbers that can be accessed through "s" (lowercase s) command. Displays the command formats and value ranges.

s - assign a new value vvvvvv to a parameter number nn. The command format is: snnvvvvvv where nn is the parameter number nn=14..50 (use "S" command to disply the list), vvvvvv is 6 digit decimal parameter value to be assigned. All 6 digits must be passed, the leading zeros must be inserted explicitly. The 'snnvvvvvv' command allows configuring the sensor through the digital remote serial link rather than using push-buttons and LCD interface. For example s19000004 command causes the Damping filter to be assigned a value of 4 (which produces a 16 cycle long averaging16=2^4). Another example useful for installation testing is the loop test command such as: s29000201 – it forces the loop output to 20.1mA current (and also forces the optional quadrature pulse output) until sending s29000000 restores the normal operation (it would time out after 5 minutes, also 'R' command or power reset cancel s29). Note: the allowed range for loop current is 3.6..25.0mA (with accuracy degraded beyond 21mA).

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6. RS232 Data Link Port

UART port for diagnostics, data transfer and configuration is available through the 10-way 2.54mm DIL header going through the entire board stack. It can be accessed from the top board. A photo below shows the 10 way header on the top above the LCD panel.

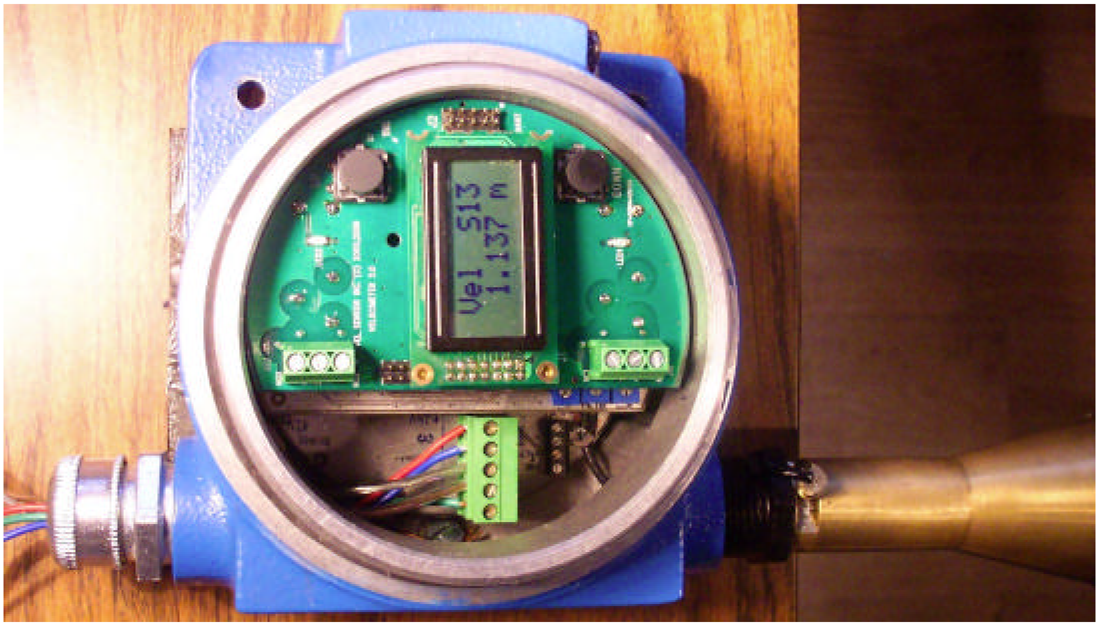
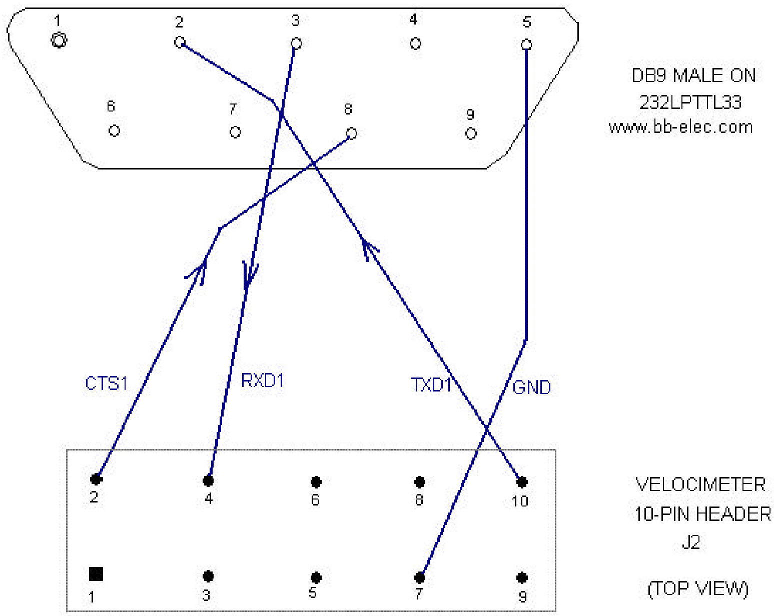


Fig. Sensor top board view (example: reading 1.137m/s, signal strength 13 on a 0-99 scale)

+3.3V	1	2	CTS1/RTS1
CLK1	3	4	**RXD1**
CE	5	6	EPM
GND	7	8	-RST
CNVss	9	10	**TXD1**

Table 1. Pin-out of 10-way serial port header.

The serial port conforms to 0-3.3V signal levels (serial asynch. TTL). If RS232 connection is required then a commercial TTL-to-RS232 signal level converter needs to be used. For example type “232LPT33” by www.bb-elec.com



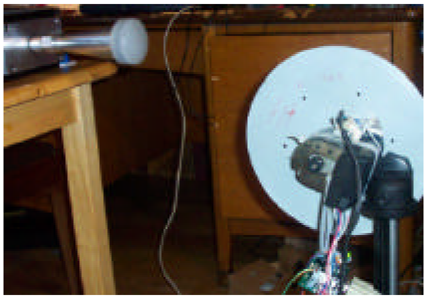
Note: only RXD1, TXD1 and GND are required for RS232 data link, other pins are used for in-circuit programming. RS232 data format is 1 start bit, 8-bits, no parity, 1 stop bit and no handshaking, allways ASCII (32-127), byte values >127 are not used. Baud rate is software selectable from 9600, 19200 (default, for slow ports), 57kbaud (recommended) to 230kbaud (only on fast PC's when using USB/RS232 interfaces).

Note 2: when data link cable has to be substantially longer than 10m, it is recommended to connect the 232LPT33 (TTL-to-RS232) interface on the cable within a few meters from the sensor and then connect another cable-inteface RS232-to-USB within a few meters from it. Alternatively a RS-485 interface may also be used.

7. Experimental lab test resuls using rotating steel disk.

Accuracy tests. Test setup:

Target: steel disk radius 124.1mm, thickness 0.7mm mounted on a shaft of a stepper motor 3.6V/1.16A, 1.8 degree per step, operated in the full step mode. The setup was installed indoors in an office room.



Rotation speed of the disk was monitored by a tachometer consisting of a magnet attached to the disk and a pickup coil connected to a HP5315A counter. Stepper motor was controlled by a micropocessor based driver board, clocked by a quartz crystal 8.000MHz. The speed and acceleration was programmed through RS232 serial link. The highest rotation speed attainable by the stepper controller was 3.255 rev/s, the lowest speed was 0.03242 rev/s. That corresponds to the linear speed at the disk perimeter from 2538mm/s down to 25.28mm/s.

Stability of the rotation period as measured by the tachometer counter was of the order of 0.0003% (3e-6) over a time scale of about 10s. Results were read off the Velocimeter sensor through its serial data link. Typically, rotating disk was placed at about 30 cm distance from the end of the horn antenna, the system was aligned for the maximum signal strength (using the “S=xx” indicator on the LCD) and the system was left unattended for a period of time collecting data in the “History” memory every 10s or every 1m, or alternatively collecting data on the PC side every 2 seconds using command ‘[‘ feature on Velterm.exe. Standard deviations and average velocity values were calculated either by dumping history data to a PC and Excel spreadsheet using ‘H’ command on VelTerm, or directly displayed using ‘[‘ command.

Measured velocity scatter results.

The following (relevant to accuracy) settings were applied on Velocimeter:

FreqRng = 3Khz" (note: max speed on this range is 8750mm/s).
Algorithm=NoSmooth
Damping=4
Median=4
SpectAvr=4

Note: Three last of the above filtering parameters are written using a notation of (D,M,S), for example in this case (4,4,4)

Scatter results for various speeds are presented in the following table (1) below. The first column contains the measured disk linear speed, in mm/s, the second column is the results "scatter", i.e. the relative error in % (standard dev) calculated

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over N consecuting measurements two seconds apart. The step motor controller allowed only certain discrete speed values. Number of measurement for each entry was N=30-100 (1-3minutes of data collection by VelTerm.exe, '[' command).

Disk speed mm/s	Scatter %
2518.7	0.023%
2504.1	0.075%
2464.4	0.023%
2424.7	0.088%
2345.4	0.012%
2311.3	0.008%
2275.9	0.027%
1883.1	0.072%
1603.2	0.223%
1211.0	0.053%
818.7	0.131%
423.4	0.087%
222.7[8]	0.9%

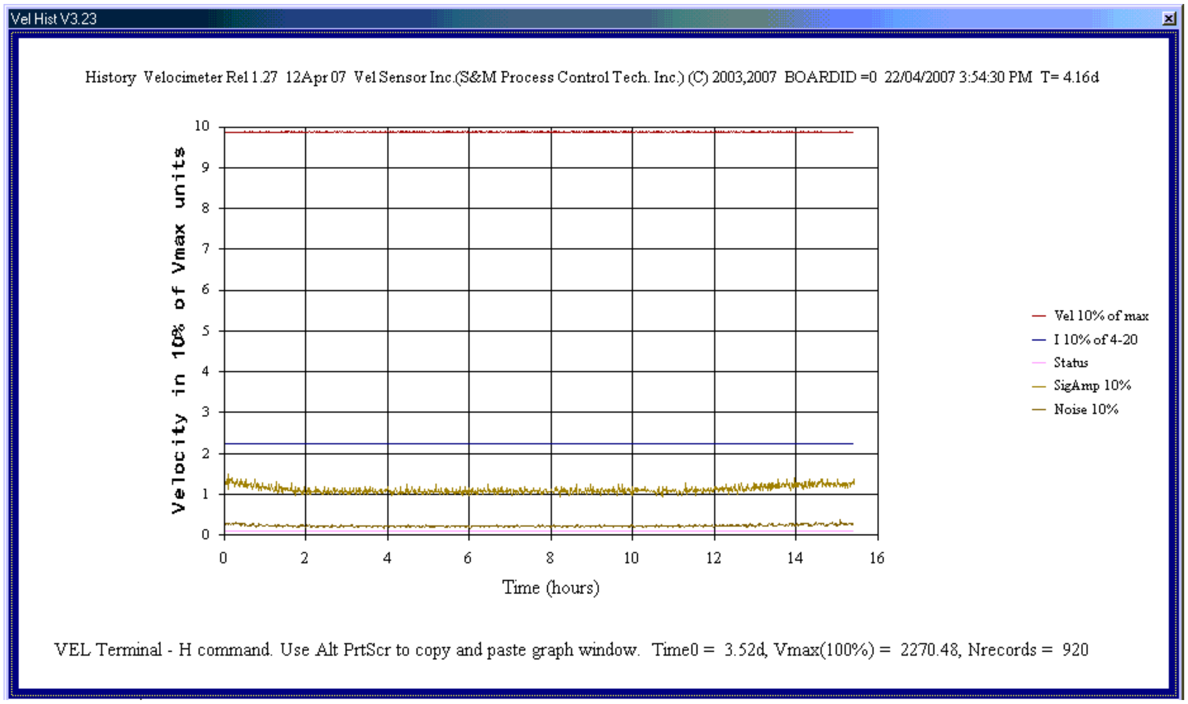
Table 2. Results relative scatter (standard dev. %) for various disk perimeter speeds

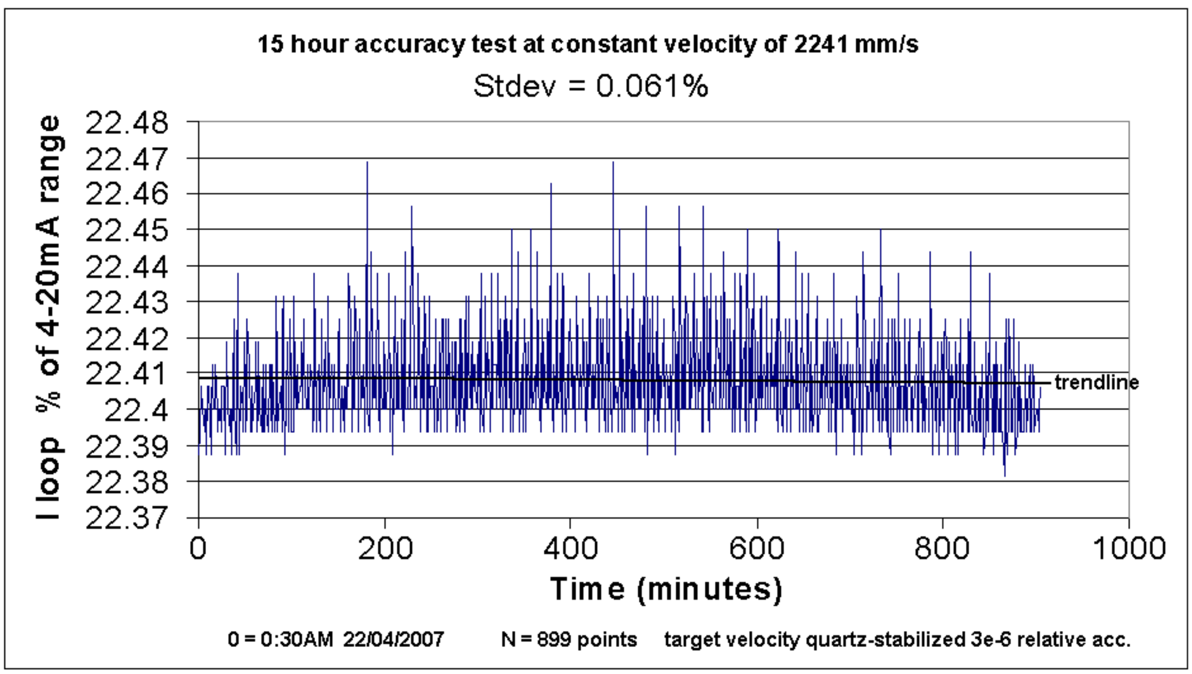
Long term stability results.

While the same Velocimeter settings were used as above, the system was left logging data into the sensor's internal "history" file white the target disk was spiining at constant rotation rate. The results of the stability testing in two cases are presented below on the following graphs:

[8] Below 200mm/s sensitivity of the system rolls off requiring gain change and filtering. Measurement at 3kHz FreqRng may be conducted down to a practical limit of about 150mm/s.

Case 1 – 15 hour stability test (logging rate = 1 result per 1m)





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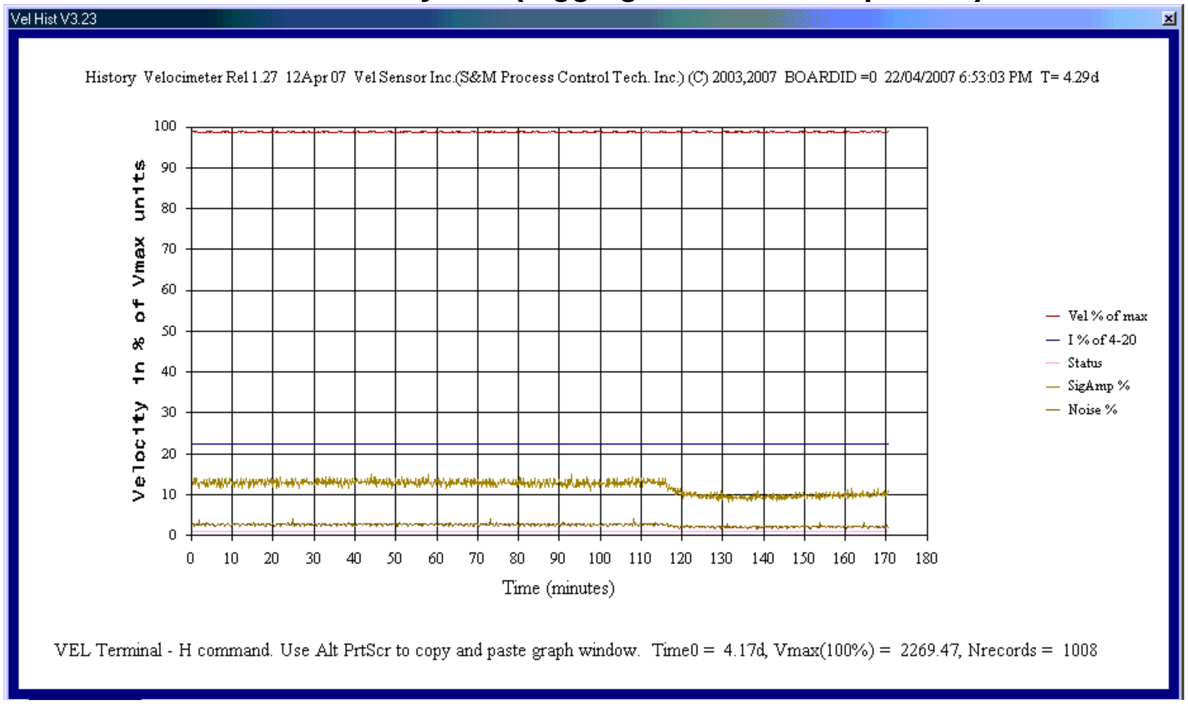
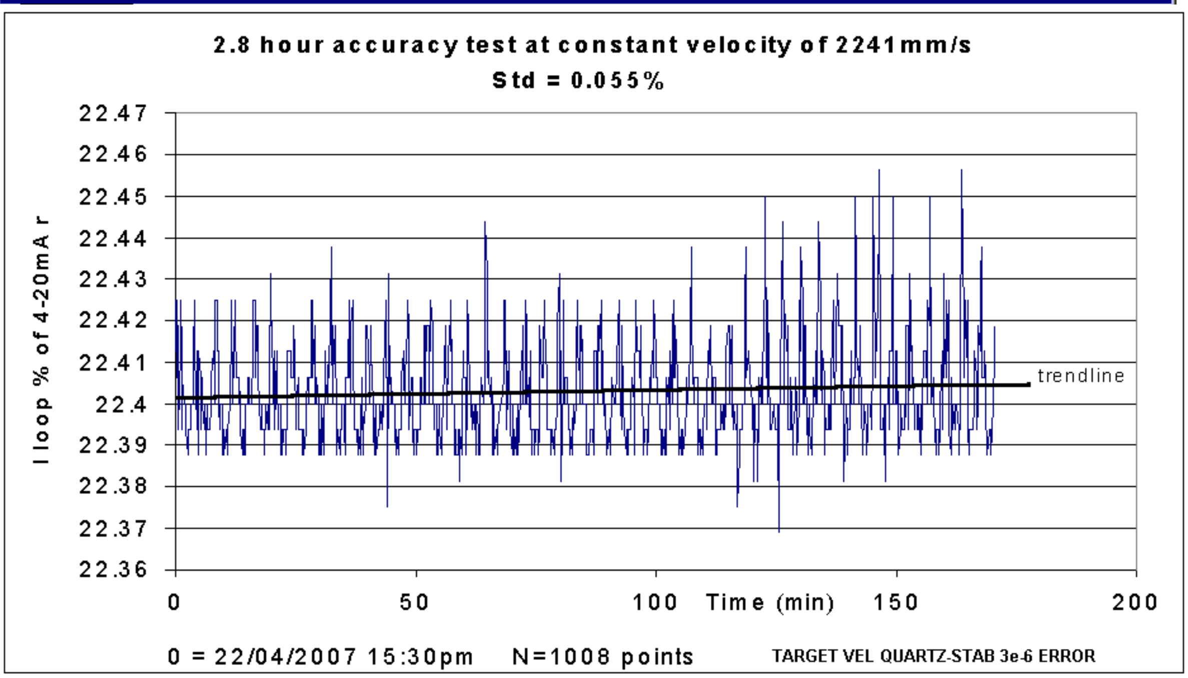
Case 2 – 170 minute stability test (logging rate = 1 result per 10s)





Conclusions:

Accuracy of the order of 0.06% is attainable under laboratory conditions in the 3kHz range and filtering parameters of (4,4,4), for velocities of 1-2.5m/s and probably for higher velocities as well. The sensor holds this accuracy over a period of minutes and hours. Note that this does not guarantee that the same accuracy may always be achievable under adverse condition in all applications and when using different (lower) filtering settings than (4,4,4).

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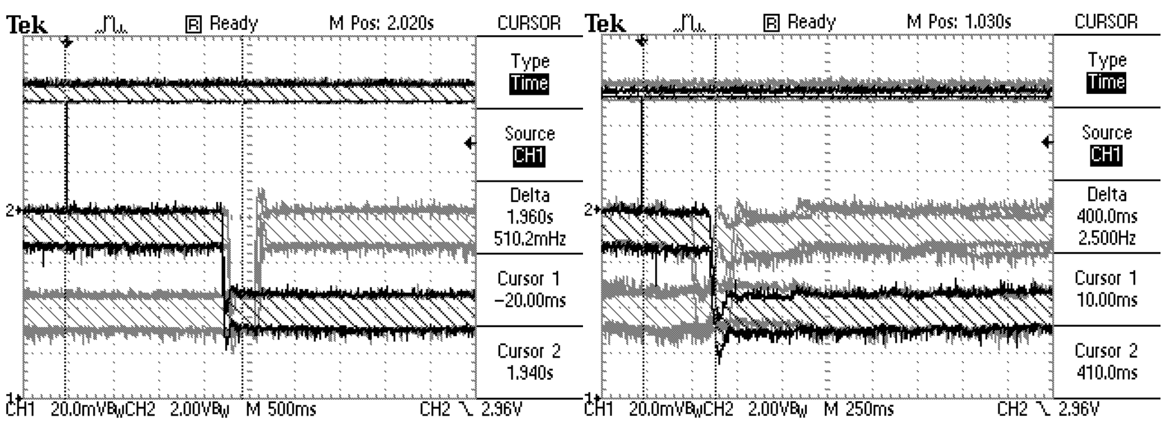
Sensor response speed versus accuracy.

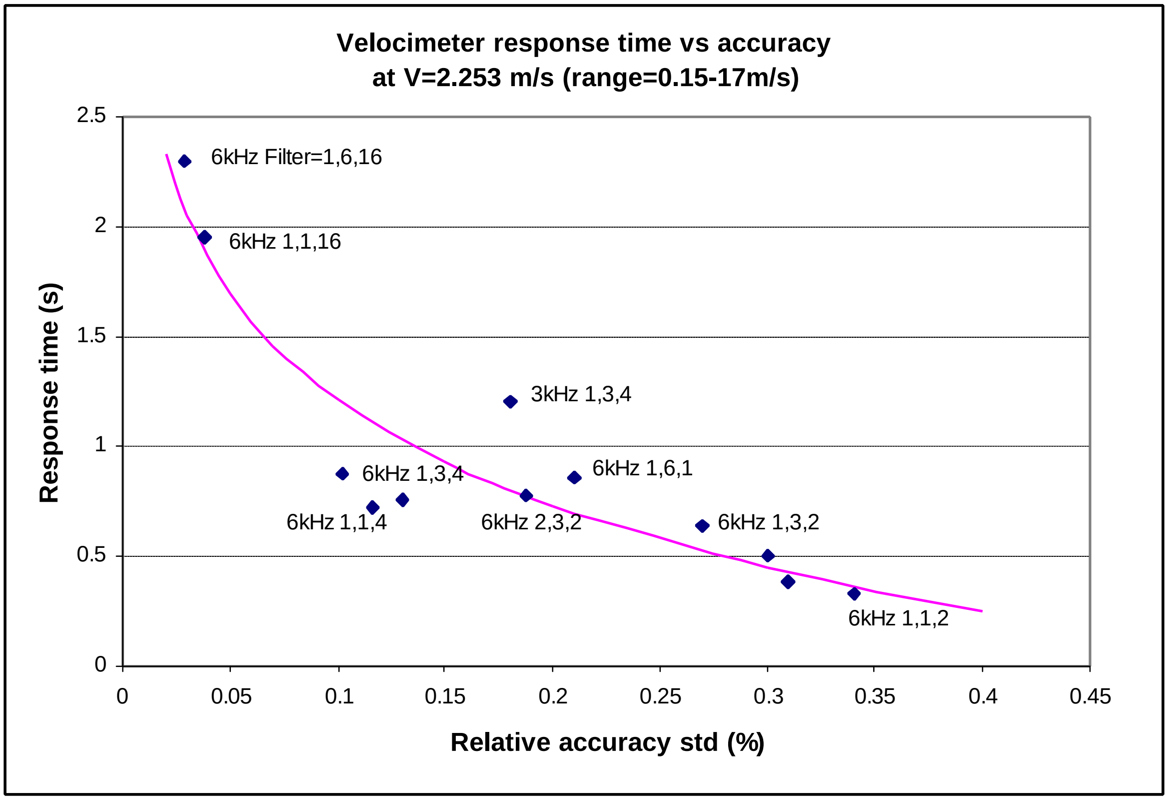
Depending on the various settings of the FreqRng, Damping, Median and SpectAvr settings the system can be configured to either exhibit the fastest possible response speed at low accuracy, or for the slow response speed but very high accuracy, or some intermediate combination. The system was tested at a constant linear speed 2.253m/s using a stepper motor driven steel disk (r=124.1mm,0.7mm thickness). Stability of the disk rotation was verified independently with a magnetic tachometer to be better than +/-0.007% over the time scale of minutes to days. The disk rotation speed was changed rapidly using the stepper motor controller by –10% down to 2.028m/s and then after a few seconds, was set back up to 2.253m/s again. The time for the the disk speed to settle was estimated to be less than 100ms.

Response speed was measured using storage oscilloscpe monitoring the 4-20mA output. The scope was triggered on the serial link activity (command send) to the step motor controller. A sample scope screen dump below shows a typical response curves.



Scope screens: response curve to 10% speed change (2.253-2.028m/s)
FreqRng=6kHz, Damp=1,Median=1,SpectAvr=16(left) and 2(right).
Top trace: RS232 activity by the step motor command (trigger)
Bottom traces (black and grey) overlaid 4-20mA sensor output
response curves (voltage drop across 100ohm load resistor)

It turns out that for the choosen disk speed, the best overall accuracy and response speed was obtained using the FreqRng=6kHz. This range was used for the results presented below. The filter settings notation is abbreviated to (d,m,s) indicating Damping=d, Median=m and SpectAvr=s.



Response time versus accuracy graph, firmware Rel. 1.30

Comments:

1) The sensor exhibits a certain constraint with respect to the accuracy and response time. The product of the relative accuracy and the response speed seems to be approximately constant (0.1%*s) within a wide range of filtering settings. In other words it is possible to set filtering for high response speed at the cost of lower accuracy, or for high accuracy at slow response but it is not possible to set it for both high response speed and high accuracy at the same time. Some of this constraint is related to the present version of the software and it is expected that the next software releases from 1.40+ will have a more optimized data sampling method utilizing DMA, allowing to speed up the above responses by a factor of about 2. Some of this is inherent in the properties of the microwave wavelegth and the doppler measurement technique.

2) The tests show that the absolute not relative accuracy seems to be roughly constant across target velocities, for a given filter setting. The relative accuracy (in %) should therefore be proportionally better than on the above graph for speeds greater than 2m/s and will be proportionally worse for lower speeds. For example, extrapolated accuracy for 0.3s response speed at 4m/s should be 0.2% and at 8m/s should be 0.1%.

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Thermal drift test

Thermal drift test was performed on a system with pulse output board installed, within temperature range of 6C to 40C. Results

Loop Test current mA	Tempco (6C-26C) PPM/K	Tempco (26C-40C) PPM/K
4.0	-3	-27
4.5	0	-24
5	0	-22
6	2	-21
8	2	-16
12	1	-12
20	-2	-12

Table 1. Temperature coefficient (ppm/K) of the 4-20mA output under constant Loop Test set current (first column). In 6C to 26C temperature range (second column) and in the 26C to 40C range (third column)

Loop Test current mA	Pulse freq kHz	Tempco (6C-26C) PPM/K	Tempco (26C-40C) PPM/K
4.0	0	-	-
4.5	2.5	195	-21
5	5	83	-4
6	10	31	-7
8	20	2	-16
12	40	-12	-19
20	80	-23	-23

Table 2. Temperature coefficient (ppm/K) of the frequency of pulse output under constant Loop Test set current (first column). In 6C to 26C temperature range (third column) and in the 26C to 40C range (fourth column). Note: frequency for 4.0mA setting is too close to zero to give reliable measurements of the relative drift. Since the pulse output is derived from the 4-20mA output, the thermal coefficient is a combination of both current output drift and the intrinsic current to pulse conversion drift.

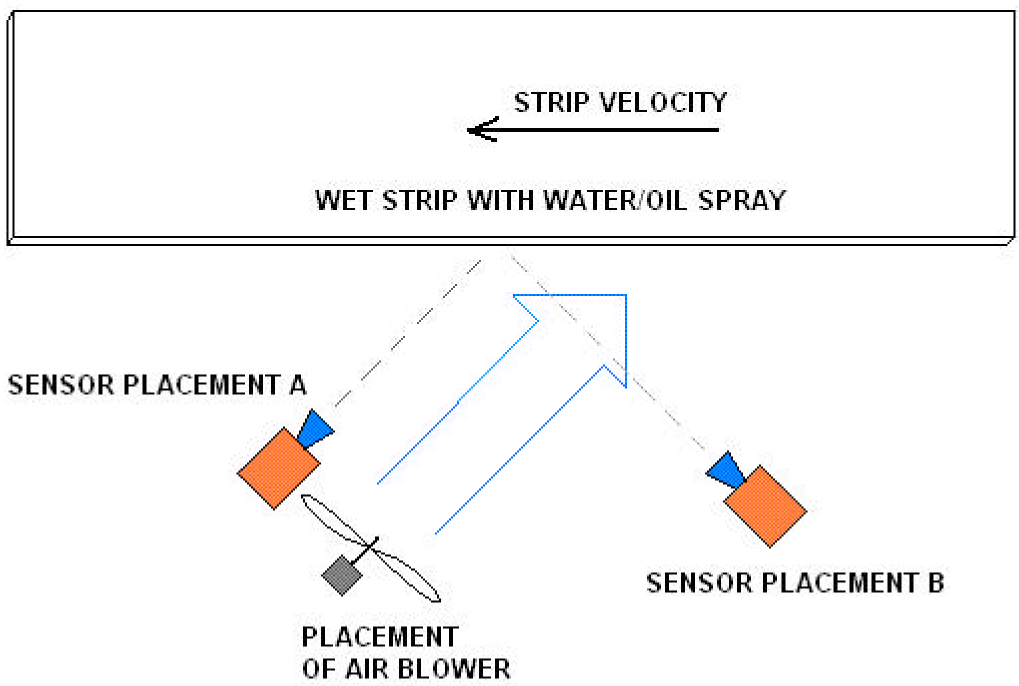
Conclusion:

Thermal drift of the analog outputs is generally less than 30ppm/K (0.06% over 20C span), with the exception of pulse output at low temperatures 6-26C and below 5kHz where it may reach 200ppm/K (0.4% over 20C span)

8. Application notes.

Wet strips.

A strip edge covered by moisture is a much better back-scatter microwave reflector than a dry metal strip edge, by a large factor (about 10 times). When the sensor is used on strips that are heavily sprayed with water/oil, then the gain should be adjusted down or mounting distance increased beyond 1m, to make sure that the signal as seen by 'D' command is not clipped (overrange). Use also 'e' command to verify that the "Signal too strong" message is not present. Reduce gain if that is the case. If liquid spray is present around the strip edge or if large flux of droplets is ejected from the strip edge towards the antena, then this has to be removed from the line of sight of the sensor by an air blower blowing air from the side onto the strip and against the strip velocity. The air blower should be directed at or ahead of the place where the sensor beam intersects the strip edge. Fan blades should not be intersecting antenna beam, nor be visible from the antenna. The best place for mounting the air blower is behind, beside or above the sensor. For example, see the following diagram:



Shock absorbing mount.

The sensor is sensitive to very strong acoustic vibrations. If strong vibrations are present in the application site then the sensor ought to be mounted through shock

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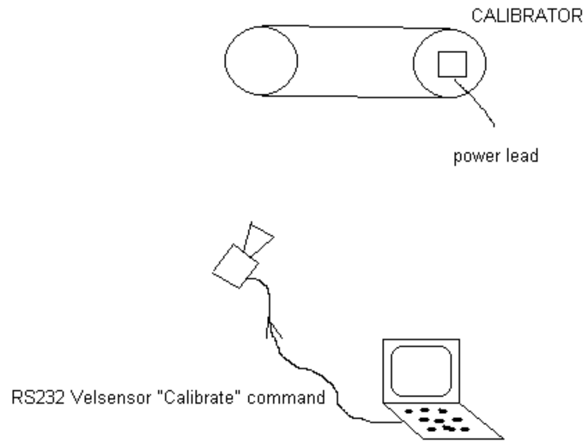
absorbing rubber blocks or pads. Oil-proof rubber substitute should be used rather than standard rubber.

Velocity Calibrator.



Calibrator view (without a case enclosure)

Calibrator connection

“Calibrator” is a recommended calibration accessory for Velocimeter sensor. One Calibrator should be available for a single or multiple sensors, or one per factory. Sensor has to be recalibrated every time the mounting changes may result in a different beam inclination angle. For example, when the sensor is removed from the mounting position and re-installed.

Since factory calibration is dependent on knowing the beam incidence angle at the installation site, it is recommended to use the “Calibrator” – the special calibration device for on-site calibration, immediately after installation. Calibrator consists of a steel belt loop driven by precisely speed-controlled motor. Calibrator is placed during calibration process on an unmoving strip table (before the strip is inserted and while mill is not run!). The calibrator has to be positioned such that the lower belt edge is aligned to within +/-0.25 degree (+/-3mm misalignment at each end)[9] with the normal position of the rolled strip edge and then it should be powered on to start spinning (automatically). Wait 10s for the calibrator to spin up and reach the nominal speed as marked on a label (typically 2386 mm/s). Make sure that the same speed value is also entered in the sensor parameter “CalVel”. Re-assign the correct value if necessary using push button interface or through the serial port, by issuing “s36xxxxxx” command, for example “s36002386” (in mm/s units). Positional accuracy in height and distance may be within +/- 1 inch (most important is to be parallel to the strip, the distance or height is less important). “Run “VelTerm.exe

[9] This will result in the absolute calibration accuracy of +/-0.4%. If better absolute accuracy is required then a more accurate parallel alignment may be necessary.

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008” [10] utility application from a PC (Windows 98/XP) to click “Calibrate” button or send command “c008” to initiate the calibration procedure, once the calibrator device has been positioned accurately at the normal strip location and aligned in the strip direction, and is spinning. The calibration procedure causes the sensor to accurately measure the calibrator belt speed (in internal arbitrary units) using high average settings and high noise rejection filtering, then it calculates the correct calibration factor and automatically uploads and saves the calibration factor in the sensor’s non-volatile memory. The whole process takes about 30 seconds and is fully confined in the sensor CPU (not using nor needing PC).

[10] Code 008 is velterm.exe command-line code that activates calibration button in VelTerm program but it is not strictly necessary since c008 command can always be used to accomplish the same

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9. Internal wiring diagram (with American Sensors Corp. housing).

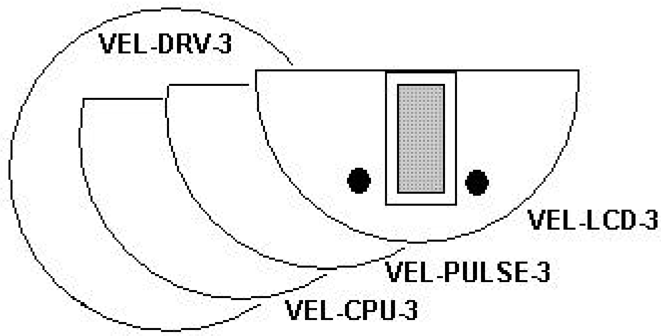

Fig.1 Board stack assembly (VEL-LCD-3 board is optional).

Velocimeter board set consists of 4 boards:

VEL-DRV-3 - contains power supply and analog signal processing electronics,

VEL-CPU-3 - consisting of a microprocessor with peripheral circuitry (port buffers and current loop interface)

VEL-PULSE-3 – 4-20mA current-loop to quadrature tacho pulse (5 to 24V, 1A) output converter board.

VEL-LCD-3 – carrier board for high current high voltage switching relays, two push buttons for manual configuration and a 2 line by 8 characters backlit LCD for displaying configuration data and sensor output variables.

All four boards can be stacked (mounted) on top of each other in any order using two headers: J1 and J2 (30 pin and 10 pin, DIL) and appropriate coupling sockets.

Only two boards are mandatory for the sensor to work: VEL-DRV-3 and VEL-CPU-3. Other boards are optional and need only be installed to fulfill some specific requirements.

Board VEL-PULSE-3 is a self-contained 4-20mA to tacho pulse converter that can be used independently, since it has separate power supply terminals and input/output terminals and does not rely on the headers J1 and J2 [11]. Tacho pulse outputs are optoisolated from the input section and can be supplied independently from a separate power and ground sources, 5-24V, in order to achieve very high

[11] Header J1 and J2 grounds are isolated, however it is recommended that the VEL-PULSE-3 grounds and VEL-DRV-3 input ground be wired together through an external lead.

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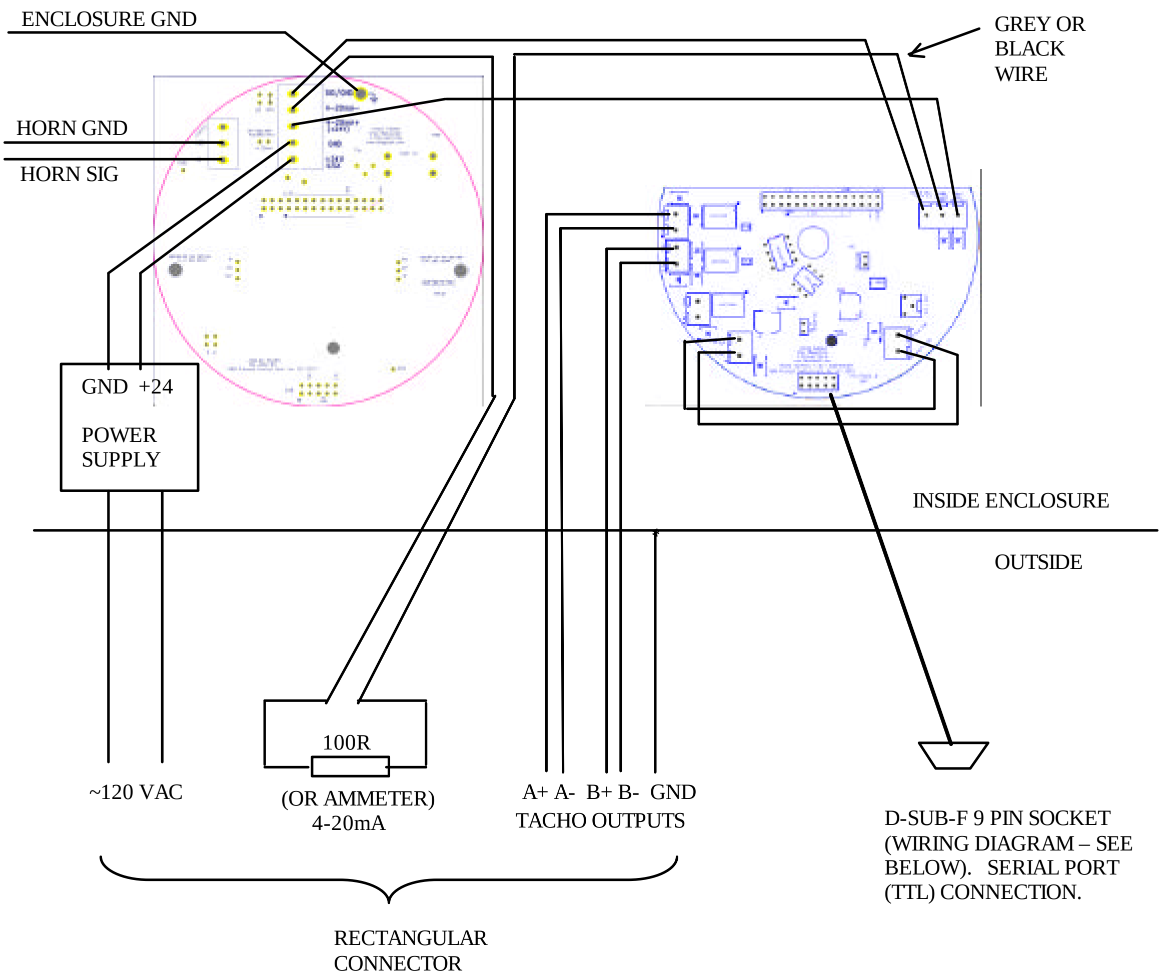
noise immunity[12]. However, in the present (and suggested) wiring this capability is not used, instead, for the sake of convenience, the tacho power +5V for J440 terminal [13] is drawn from the "LASER POINTER" +5V power output terminal J500 on the same board (downregulated from +24V). Tacho pulse is zeroed by potentiometer P400 ("NULL ADJ") such that pulse frequency becomes zero[14] at 4.000mA current.

Board VEL-LCD-3 is not normally needed when the sensor is mounted inside an enclosure that has no viewing window and if power relay outputs are not needed[15]. All capability available through the push-button and LCD interface is also available through the remote access by RS232 connection. However, manual configuration may be useful during a factory setup phase and during troubleshooting.



[12] The highest noise immunity is achieved when J440 is supplied with +24V (LN440 must be off) from the remote site with a separate return ground, not connected to the sensor ground. Note that in such a case, the remote pulse receiver must be able to accommodate 24V pulse amplitudes!

[13] J440 supply voltage range is 4.5 to 30V (voltage span of the tacho output is the same) but if the voltage is less than 6V then LN440 must be jumpered ON in order to bypass a regulator.

[14] Zero means less than 30Hz. Note that the maximum frequency is about 82-87kHz at 20mA.

[15] Power relays are necessary in some tank level applications (for pump switching) and if the sensor is used as an ON/OFF interrupter switch.

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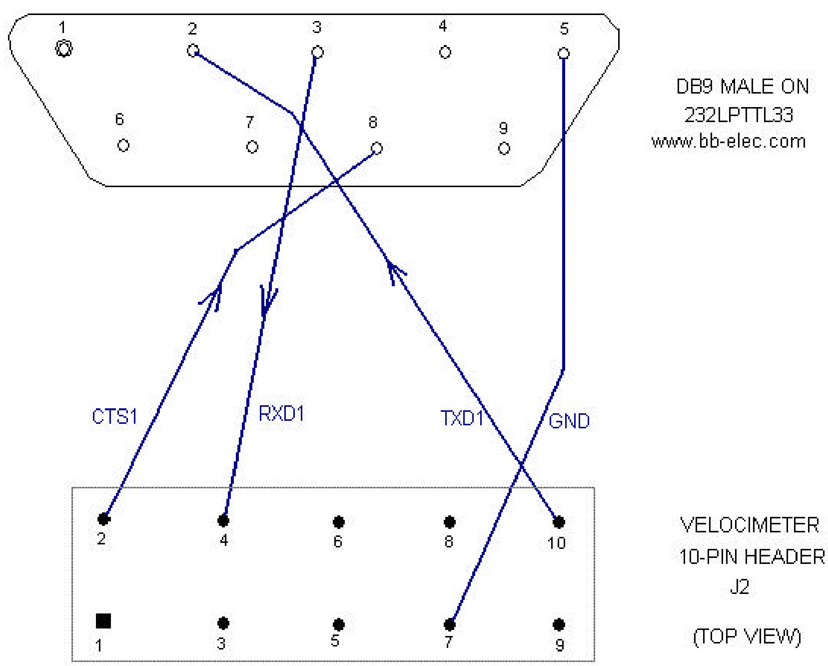
With the above wiring, it is important that on VEL-DRV-3 the links LK1 and LK3 are ON, LK5 is OFF, and on VEL-PULSE-3, link LN440 is ON. The 100 ohm loop load load resistor or ammeter should be floating (none of the leads could be grounded). When using a data acquisition system to read voltage across the load resistor, use differential +/- analog input pair compliant to 0-10V (relative to sensor enclosure ground), rather than a single-ended analog input. The load resistor should be less than 500 ohm (or shorted, if not used). It is recommended to use 100 ohm value 0.1% tolerance.

Since the tacho pulse output circuit is powered from the on-board "Laser Pointer" output port, this port must be always set ON (in the system configuration) if pulse output is used, otherwise pulse output will be disabled.

Wiring diagram for the serial port connection.

Serial port as is provided by the sensor has 0 to 3V digital signal levels. Use TTL-to-RS232 converter to translate the digital levels to RS-232 standard, for example "232LPTTL33" product from http://www.bb-elec.com .



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