Applied Technologies, Inc.

OPERATORS MANUAL

FOR A

SONIC ANEMOMETER/THERMOMETER

MODEL # _________________

SERIAL # _________________

Prepared By:

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OPERATOR'S MANUAL

FOR A

THREE AXIS SONIC

ANEMOMETER/THERMOMETER

Revision K2

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PREFACE

This new Sonic Anemometer/Thermometer incorporates many of the features from earlier models, using state-of-the-art microprocessor and surface mount technologies. Software that computes the wind velocities has been enhanced and optimized to provide a rapid response sonic anemometer/thermometer.

The electronics that operate the Sonic Anemometer/Thermometer are located in the probe array. Typically, the Sonic Anemometer/Thermometer is DC powered, however other power options are available by either external adapters or by contacting the factory. The Sonic Anemometer/Thermometer is usually connected to a computer running a terminal emulation program, or can be connected directly to a dumb terminal. The Applied Technologies, Inc. Sonic Anemometer/Thermometer is a stable, low powered anemometer, capable of running unattended for extended periods of time.

The system may include: single, double, or triple axis probe arrays, along with several other novel probe array designs. These designs reduce errors from both flow asymmetry and interference from structural members.

The system detects wind velocity components along mutually orthogonal acoustic paths, computes the wind velocity and provides an output directly in engineering units. The probe array designs of the Applied Technologies, Inc. Sonic Anemometer/Thermometer provide a true vertical velocity measurement. The "W" component is not inferred or calculated from some other measurement, but is a direct measurement that has an alignment accuracy of better than ±0.1°.

The system also provides calculations necessary to compute the sonic temperature, (in the "W" path), corrected for velocity contamination. It provides these data with excellent frequency response and makes it ideal for many aspects of basic atmospheric research.

INTRODUCTION

- **Section 1.0** is the general description of the Sonic Anemometer/Thermometer, including a summary of features and a listing of the specifications.
- **Section 2.0** is organized to familiarize the user with the theory of operation of the ultrasonic sensor technology, and how it applies to this Sonic Anemometer/Thermometer.
- **Section 3.0** describes the functional operation of the system with brief descriptions of each of the subsystems, including the sonic transducers within the probe array, and a brief description of the electronics involved.
- **Section 4.0** describes the Sonic Anemometer/Thermometer from the user's standpoint with instructions for setting up the hardware and software.
- **Section 5.0** describes the software commands, includes a description of each and a Table of Commands.
- **Section 6.0** describes the maintenance and setup procedures that may be required in the operation of the Sonic Anemometer/Thermometer.
- **Section 7.0** is a basic "Troubleshooting Guide" to aid in analyzing instrument operation and for tracking and isolating any problems that may occur.

1. DESCRIPTION

1.1 GENERAL

The Sonic Anemometer/Thermometer is a solid-state ultrasonic instrument capable of measuring wind velocities in three orthogonal axes (U, V, and W) and provides sonic temperature. The Sonic Anemometer/Thermometer is comprised of a probe array (containing all electronics necessary for operation), and a mounting bar. The probe array's sonic transducers are separated by 10 or 15 cm depending on the probe style.

Sonic pulses are generated at the transducers and are received by opposing transducers. Mathematics derived for these sonic pulses provide a wind velocity measurement in each of the corresponding axes and calculates a sonic temperature, which is generated from the speed of sound measurements in the "W" axis. These temperature measurements are also corrected for cross-wind contamination.

The Sonic Anemometer/Thermometer uses a microprocessor-based digital electronic measurement system to control the sample rate, and compute the wind speeds and temperature. The standard data output of the Sonic Anemometer/Thermometer is 10Hz, where each output represents the average of 20 discrete measurements. The sample rate and output rate are user programmable. The wind speed from each of the axes and the temperature are presented on the computer monitor, and the user can configure the Sonic Anemometer/Thermometer output to display many other parameters as well.

Calibration of the Sonic Anemometer/Thermometer can be performed by the operator. It only requires the installation of the "Zero-Air Chamber" over the axis being calibrated. A measurement of the ambient air temperature to an accuracy of ±1°C is necessary for calibration. A calibration command is issued from the computer, and the microprocessor automatically calibrates the Sonic Anemometer/Thermometer, compensating for any electronic drift. Enter the temperature and relative humidity at the computer terminal when prompted. A re-useable "Zero-Air Chamber" is supplied with the instrument, in the case of the "V" probe array only, the "Zero-Air Chamber" covers all three axes simultaneously.

The software provides the capability of automatic restart in the event of power failure. It detects and displays an error in the data due to blockage of the sonic path, and includes some self-diagnostics and reset capability in the event of a microprocessor failure due to outside interference.

1.2 SUMMARY OF FEATURES

The Applied Technologies, Inc.'s Sonic Anemometer/Thermometer has the following features:

- Single component wind velocity
- Fast response temperature
- Extreme accuracy
- Microprocessor-based
- Solid-state digital operation
- No moving parts
- Unattended operation
- Ease of mounting and operation
- Rugged construction
- Low power
- DC powered
- Ability to output Speed of Sound as well as Temperature
- Ability to change operational parameters using commands
- Ability to provide extra output words in the data string
- Ability to convert the horizontal velocities to wind speed and wind direction while retaining the vertical and temperature data
- Ability to synchronize multiple instruments so all take measurements during the same time period
- Ability to output a trigger pulse, to synchronize other instruments
- Median filter instead of the average data
- User adjustments to flow distortion
- User programmable sample rate
- Variable data output rates, from one output per 60 minutes to 200 Hz

1.3 SPECIFICATIONS

The Applied Technologies, Inc. Sonic Anemometer/Thermometer has the following specifications:

Measurement Range:	
Wind Velocity (V)	±15 m/sec.
Wind Velocity (Vx)	±20 m/sec
Wind Velocity (Sx, K)	±30 m/sec.
Wind Velocity (A)	±65 m/sec
Temperature	-50° to +70° C
Wind Direction	0 – 359 degrees
Path Length:	
"V" Circular Probe	10 cm
"A", "Sx", "K", and "Vx" Probes	15 cm
Accuracy:	
Wind Speed	±0.01 m/sec
Orthogonality (direction)	±0.1 degrees
Temperature (Absolute)	±1.2° C
Sonic Temperature	±0.1° C or ±0.05°C
Resolution:	
Wind Speed	0.01 m/sec. (normal) 0.001 m/sec. (optional)
Wind Direction	0.1 degrees
Temperature	0.01° C
Output:	
Data Rate	<1 Hz to 200 Hz - Variable
Digital	Serial RS-232C compatible RS-422 optional
BAUD Rate	4800 to 460,800
Speed of Sound	Operator Optional
Operating:	
Temperature Range	-50° C to +70° C Been used up to +250°C – with no damage
Relative Humidity	0 to 100%
Power Requirements	+12 VDC, @ <100 mA) (9 – 32 Vdc)
Probe Array:	
"A" – Non-Orthogonal	12.6cm x 22.6cm x 19.6cm
"Sx" – single axis	2.54cm x 15.9cm x 17.8cm
"Sx" – two axis	25.4cm x 25.4cm x 17.8cm
"Sx" – three axis	25.4cm x 35.6cm x 35.6cm
"K" – three axis only	25.4cm x 33.0cm x 40.6cm
"Vx" – three axis only	25.4cm x 25.4cm x 25.4cm
"V" – three axis only	17.8cm x 17.8cm x 17.8cm
Weight	<1.0 kg
Probe Mounting (all probe styles)	3.175 cm Square Tube

2. THEORY OF OPERATION

2.1 SPEED OF SOUND IN AIR

The speed of sound in still air can be measured accurately between two points a few centimeters apart by two ultrasonic transducers. The resulting speed of sound is a known function of the air temperature and composition.

The speed of sound in an ideal gas may be written

$$C = [\frac{\gamma RT}{M}]^{\frac{1}{2}}$$

where R is the universal gas constant (8314.34 mJ/mol K), T is the temperature in Kelvin, M is the molecular weight (grams/mol) of the gas, and γ is the ratio of heat capacities C_p and C_v; C_p and C_v are the specific heats at constant pressure and constant volume of the gas, respectively.

2.2 SPEED OF SOUND PRINCIPLE

The transit time of a sound signal traveling from one end of a sound path to the other, separated by distance d, can be written as follows (Schotland, 1955):

$$t = [\frac{(C^2 - V_n^{\ 2})^{\frac{1}{2}} \pm V_d}{(C^2 + V^2)}]d$$

where V is the total velocity, V_d and V_n are velocity components in the directions parallel and normal to the sound path, and C is the velocity of sound in still air.

If two transit times, t_1 and t_2 in opposite directions on the same sound path are detected, V_d can be obtained independent from V and V_n as follows:

$$V_d = \frac{d}{2}[\frac{1}{t_1} - \frac{1}{t_2}]$$

It is this principle that is used to compute the velocity of the air in the path between two opposing transducers.

2.3 CALCULATION OF THE WIND VELOCITY

In still air, t_1 and t_2 are equal. For a distance of 15 cm at 20°C, the transit time is approximately 450 μs.

If a 20 m/s wind is in the direction of the sonic pulse, the transit time t_1 will be approximately 427 μs. If the wind is opposing the sonic pulse, the transit time will be approximately 482 μs. If these two values are used in equation (3), the resultant velocity from equation (3) will be 20 m/s.

2.4 CALCULATION OF TEMPERATURE

The sonic anemometer/thermometer computes the sonic temperature of the air by first computing the speed of sound of the air:

$$C^2 = \frac{d^2}{4}[\frac{1}{t_1} + \frac{1}{t_2}]^2 + V^2$$

where V^2 is the crosswind component and t_1 and t_2 come from the "W" axis.

The calculated speed of sound of the air is substituted into the following equation for an ideal gas and solved for T_v.

$$T_v = \frac{C^2 M}{\gamma R}$$

The sonic temperature, T_v (in Kelvin), may differ from the absolute temperature by an amount equal to the water vapor content in the air measured. This difference amounts to ±1°C at 20°C and decreases as the temperature decreases.

3. FUNCTIONAL DESCRIPTION

3.1 ULTRASONIC TRANSDUCERS

The ultrasonic transducers used in the Sonic Anemometer/Thermometer are comprised of piezoelectric crystals enclosed in stainless steel housings. The transducers are 3/8 inches in diameter, 7/8 inches long, and are attached to the probe array arms.

The transducers are acoustically isolated from the housing, and then sealed to prevent exposure to the outside environment. This type of assembly provides transducers that are equipped for rugged outdoor use, and can operate in most environments.

The transducer assembly is part of the probe array and should never need to be changed. If it is required, the entire probe array must be returned to the factory.

3.2 SONIC ARRAY

The probe array is a self-contained system, housing the transducers, and operating electronics. An input/output connector enables connection to a DataLogger or computer.

The sonic probe array is machined to the specific dimensions required. The tolerance in any dimension is very tight, preserving the orthogonality to 0.1 degree in any direction. The array is a rugged sensor assembly capable of tower mounting and normal handling.

A flat surface on top of the array horizontal bar is provided as a leveling surface during installation. This surface is aligned to the probe array axes to less than 0.1 degrees.

All electronics necessary for the operation of the Sonic Anemometer/Thermometer are housed in the probe array arm. Surface mount technology has made it possible to put the electronics on a circuit card, small enough to be located in the mounting arm of the probe array. All connections to the transducers are made inside the probe array, and therefore are completely weatherproof. The electronics require DC power which is provided to the array through the cable connector.

3.3 MOUNTING BAR

A 1-1/4" square x 30" long mounting bar is provided to assist in mounting the Sonic Anemometer/Thermometer on a tower. The bar is designed to fit the connector end of the sonic array, allowing the cable to pass through the inside of the bar. Two captive thumbscrews are located in the end of the mounting bar, which secure the probe array to the bar.

3.4 RS-232C OUTPUT

The Sonic Anemometer/Thermometer default output is formatted in RS-232 and scaled such that it can be read directly on a terminal. There is a choice of output modes, which can be set by way of the OPTION MENUS. Refer to section 5.2 for the commands. The default output mode is "VERBOSE". The alternative output mode is "TERSE". Examples of both are shown below. The output of the Sonic Anemometer/Thermometer can also be used by most any DataLogger or computer that has a serial port.

The default conditions for the serial port are: Full Duplex, 9600 baud, 7 bit ASCII, even parity and 1 stop bit. The normal output is in meters per second for velocity and degrees centigrade for temperature.

With a CRT terminal in scroll condition the data should appear as follows:

EXAMPLE: {VERBOSE} (no wind & room temperature conditions)

```
U 00.02   V 00.03   W 00.01   T 20.02
U 00.02   V 00.03   W 00.01   T 20.02
U 00.02   V 00.03   W 00.01   T 20.02
   "         "         "         "
   "         "         "         "
```

The data format has all the spaces, periods, <CR>'s and <LF>'s required to printout on a CRT terminal as shown. Therefore, there is a <CR> & <LF> at the end of each record of data, where a record is one line of the display.

It will display one record of data every 100 milliseconds, when operating at the 10 Hz data rate. The data being displayed are 1/10 of a second behind the actual measurements. This means, the first processed measurements taken during the first 1/10 second time period, will be displayed while the second measurements are being taken. The second measurements will be displayed while the third measurements are being taken, and so on… There are 20 measurements evenly spaced over a given 10 Hz time period, and these are averaged together to provide the one output.

In the "TERSE' mode, the identifying letters, decimal points and some of the spaces are removed. The <CR> & <LF> are still at the end of each record for record synchronization. The above example then becomes:

EXAMPLE: {TERSE} (no wind & room temperature conditions)

```
0002 0003 0001 2002
0002 0003 0001 2002
0002 0003 0001 2002
  "    "    "    "
  "    "    "    "
```

NOTE: Refer to section 5.2 Command Tables – Output Options Menu – C & D for information on the above outputs.

3.5 BINARY OUTPUT

This format was developed to decrease the space and time required for data logging. The BINARY format is 8 bits, and NO parity. Two's compliment is used to express bipolar data as an integer. The most significant bit of the 16-Bit word is a sign bit. When this bit is 0, the number is positive, and when this bit is 1, the number is negative.

Example:

Hex Word	Decimal Value
00 00	0
00 01	1
FF FF	-1
7F FF	32767
80 01	-32767
09 C4	2500

NOTE:

The parity of the Binary Data is not affected by the parity setting of the Sonic Anemometer, however, the Power-up Diagnostic Messages, the command mode prompts, and the offset messages will be affected if the system parity is changed. These messages are always "text", regardless of the ASCII/Binary output setting.

The format of the Binary Output data will look like the following example:

80005500005600005700005409C48000…

8000 = Header (separates the data)
55 = "U" Tag
0000 = 16 Bit, 2's compliment data
56 = "V" Tag
0000 = 16 Bit, 2's compliment data
57 = "W" Tag
0000 = 16 Bit, 2's compliment data
54 = "T" Tag
09C4 = 16 Bit, 2's compliment data

The Tag characters can be removed from the data string, by selecting TERSE Binary Output.

NOTE: Refer to section 5.2 Command Tables – Output Options Menu – E for information on the above outputs.

3.6 EXTERNAL TRIGGER INPUT

External triggering is provided for customers who wish to synchronize the Sonic Anemometer/Thermometer or to provide a unique sampling rate. The customer must furnish a low going pulse, a (MARK) RS-232C pulse is best, but any pulse at least 5 V or larger will work as long as it goes from +5 to -5 in the transition. The pulse must be at least 10 μsec wide. The frequency of this pulse can be something less than 1.0 Hz or to a maximum of 200.0 Hz. This pulse ties into each system through the connector Pin 5, referenced to ground Pin 6 or 7. See Section 3.8 for pin-out of the sonic connector.

In order to use the External Trigger function, it must be turned ON by way of commands issued from the terminal or computer. Refer to Section 5.2.3 Command Tables, Trigger Options Menu, A – External Triggering. This command is toggled ON or OFF, and by default is set to OFF. Once the External Trigger is set to ON, and the command is sent to EXIT the Menus, there will be no more continuous output, but it will begin waiting for the external trigger pulses.

When External Trigger is used, the sonic will start the measurement process each time the trigger pulse is received. The instrument will than takes the number of samples, defined by the command as ‘A’ - Average Size in the Factory Menu, see Section 5.2.4. When the period ends for taking the required samples, the processor starts the processing. The digital output of this data will start appearing on the output lines approximately a couple of milliseconds after the completion of the data taking period.

When using the External Trigger, make sure the number used for the Average Size matches the timing of the trigger pulses, or is at least faster. If not, there will be problems.

3.7 EXTERNAL TRIGGER OUTPUT

An External Trigger Output is provided by the Sonic Anemometer/Thermometer on Pin 3 of the output connector. The output is an RS-232C signal (+12 to –12, High to Low). It is always present and does not require any commands to enable. It is provided to allow synchronization of several instruments, whether they are Sonics or other instruments. This output runs at the frequency determined by the Sonic acting as the "Master". If an External Trigger input pulse is connected to the "Master" sonic, via Pin 5, the sonic will operate at the required frequency, and the same rate will be output on Pin 3 allowing all instruments connected, to operate at the same rate.

3.8 CONNECTOR PIN-IN/OUT

The following table describes the pin-out of the Sonic Anemometer/Thermometer connector.

Pin Number	Function	Description
Pin 1	*Chassis Ground*	*Chassis Ground*
Pin 2	*Spare*	*N/C*
Pin 3	*Trigger Output*	*RS-232 Signal – (+12 to –12 V High to Low)*
Pin 4	*Spare*	*N/C*
Pin 5	*Trigger Input*	*RS-232 Signal – (+12 to –12 V High to Low)*
Pin 6	*Ground*	*GROUND*
Pin 7	*Ground*	*GROUND – (RS-232 Common)*
Pin 8	*Receive Signal*	*RS-232 Signal – Connects to Transmit Out of computer*
Pin 9	*Transmit Signal*	*RS-232 Signal – Connects to Receive In of computer*
Pin 10	*External Reset*	*Floats high and requires Grounding to perform Reset*
Pin 11	*Known State*	*Floats High, requires Grounding AND the External reset or powered-up.*
Pin 12	*Vcc Input*	*+9 to +18 VDC @ 1.2 Watts*
Pin 13	*Ground*	*GROUND – (Vcc Return)*

4. OPERATION

The operation of the Sonic Anemometer/Thermometer is essentially automatic, such that no specific setup procedure is necessary for normal operation. There are, however, commands that may be entered by the operator that will set and/or change certain operating parameters. Refer to the software Section 5.0, of the manual, for the commands. The built-in microprocessor power-up sequence sets the system in operation when power is applied.

4.1 HARDWARE INSTALLATION

For accurate measurements, the mount for this instrument should be firm with no slop, backlash, or movement. Use the flat surface of the horizontal bar as a leveling surface to make sure the instrument is mounted level. The probe, when mounting it to any structure, should always be mounted with the label on the bottom, and should be pointed into the prevailing wind to minimize shadowing of the wind by the structure. The probe should also be mounted to a boom laterally, from the structure, away from the structure at least 10 diameters or more for best results.

Secure the probe mounting bar on the structure, feed the output cable through the mounting bar, and connect the end to the probe array. Slide the connector end of the probe array into the mounting bar, lining up the holes in the probe array (they should be on the bottom side when the probe is oriented correctly) with the thumbscrews in the mounting bar. Secure the array, to the mounting bar, using the thumbscrews.

Orientation of the probe and the positive direction of the three axes are shown in a drawing in Appendix B.

Connect the other end of the output cable to the serial port of a computer or datalogger and a +12Vdc power source. Approximately 1.0W is all that is required for normal operation.

4.2 SOFTWARE

The Sonic Anemometer/Thermometer software is accessed by using a computer with a terminal emulation program, such as; HyperTerminal from Windows, or any other terminal emulation program. There are a variety available, at no cost, on the internet. Set the terminal to use the following settings"

Baud Rate – 9600 bps (10 Hz) or 19,200 bps (20Hz)

Parity – EVEN

Number of Data Bits – 7

Number of Stop Bits – 1

Flow Control – NONE

Operation – Full Duplex

The Sonic Anemometer/Thermometer is usually shipped in internal, free-running, mode. As such, once the anemometer is plugged into power, it will start sending out continuous data.

Once the terminal program is connected to the serial port to be used, the Sonic Anemometer/Thermometer output data will be visible on the monitor.

5. SOFTWARE COMMANDS

This section describes the commands available from the Sonic Anemometer/Thermometer's Main Menu and all the sub-menus. While the instrument is in operation, hit the {ESC} key on the terminal at any time, to access the Sonic Anemometer/Thermometer Main Menu. The Sonic Anemometer/Thermometer will stop sending out data and switch to Command Mode.

5.1 MAIN MENU

The main menu is the first menu to become visible on the monitor. When it appears on the screen, it will have a heading of:

Applied Technologies, Inc.
Sonic Anemometer/Thermometer
S/N xxxxxx
Version x.x.x

Then followed by eight choices listed as follows:

A – OUTPUT OPTIONS

This menu contains a minimum of eleven possible commands that will provide various outputs for the Sonic. Should your instrument have any options, there may be more commands available. Most of these options can be toggled “ON” or “OFF”, and the others require a specific key or number. Refer to the Command Table in Section 5.2.1 of this manual.

B – SAMPLING OPTIONS

This menu contains five possible commands that will provide configurable sampling options for the Sonic. These options are toggled “ON” or “OFF”, and will allow the user to change certain sampling parameters of the sonic operation. Refer to the Command Table in Section 5.2.2 of this manual for the specifics of each of these options.

C – TRIGGER OPTIONS

This menu contains four possible commands that will provide the configurable triggering options for the Sonic. Most of these options are toggled “ON or “OFF”, and can be changed by the operator as needed. Refer to the Command Table in Section 5.2.3 of this manual.

D – CALIBRATION

This command does not have a sub-menu, but is used to perform the calibration of the Sonic. Choose this command when a calibration is required, or just to be safe, or just for curiosity. The instrument will provide instructions, on the screen, for performing the calibration. Refer to Calibrating the Sonic Anemometer/Thermometer in Section 5.3 of this manual.

E – CURRENT SETTINGS

This command does not have a sub-menu, but is used to display the current settings of the Sonic. This command is provided so the user can see exactly how the Sonic is currently configured. Refer to Current Settings in Section 5.4 of this manual for more details.

F – RESET to FACTORY DEFAULTS

This command allows the operator to restore the original Factory settings as defaults. The sonic anemometer will be reset to these parameters when the Exit command is entered and the instrument is returned to normal operation. More details can be found in Section 5.5 of this manual.

Z – FACTORY SETTINGS

This menu contains a minimum of fourteen possible commands that are not normally required by the operator. Should your instrument have any options, there may be more commands available. These commands can be changed by the operator, but make sure you understand the consequences of your actions before the changes are made. Changing any of the values in this menu to a wrong value, could result in inaccurate data, or could make the system inoperable. These settings should NOT be changed unless the operator knows what to do or is instructed to do so by Applied Technologies, Inc.'s technical support.

Ø (zero)– EXIT

This command will end the command selection operation and return the system back to the data taking operation. If the sonic is in the Internal Timing mode, this command will cause the sonic to start sending out data. If the sonic was put into the External Trigger mode, the sonic may put out some characters that do not necessarily mean anything, but will then wait for an external trigger pulse to tell it when to start a measurement cycle.

5.2 COMMAND TABLES

Some of these commands will perform the required operations and some will bring up sub-menus to provide a selection of more commands to pick from. In all cases, with both the original menu and the sub-menus, a result of the command will be displayed along side the command. When the command is sent and executed, the results should return back up on the monitor to show the change that has been issued. A few of the sub-menus also have sub-menus that operate the same. They should all show the results of the command, before returning to the previous menu.

5.2.1 Output Options Menu

A – BAUD Rate	**(xxxxxx)**	This menu choice allows the user to enter a new baud rate for the data being sent as an output. The menu will provide a list of the possible standard baud rates from 4800 to 115.2K. Enter the "letter" associated with the baud rate required. CAUTION should be used when changing the baud rate, it is interrelated with the output data rate. As the data rate is increased, the output baud rate may also be required to increase. Also, when changing this baud rate make sure you change the serial port on the computer to match.
B – Parity (ON/OFF)	**(even/none)**	This menu choice allows the user to enter a different parity if desired. This command provides another sub-menu. Enter the "letter" associated with the parity required The default mode is "even parity", which means 7 data bits. If the parity is turned to "none parity", the output will be 8 data bits. CAUTION make sure you copy the change on the serial port of the computer.

C – ASCII Output	**(ON/OFF)**	This command sets the output of the Sonic to the Standard ASCII output. This is the best format for outputting the data to a display. See Section 3.4 for an example of the data output, in this mode. This command works in tandem with command E-Binary Output. This command turns on the ASCII output, but does not turn this output off. The Binary command turns the Binary Output on and automatically turns the ASCII command off at the same time. Likewise, the opposite is true.
D – Terse Output	**(ON/OFF)**	The default output format is VERBOSE. This command turns off the default and sets the output of the Sonic to a TERSE ASCII output. The TERSE output strips the beginning letters and decimal points from the data, to reduce the number of bits and therefore the space required to store the data. See Section 3.4 for an example of the data output, in this mode. TERSE also applies to both ASCII and BINARY output modes.
E – Binary Output	**(ON/OFF)**	The default output format is ASCII. This command sets the output of the Sonic to BINARY mode. This was developed to decrease the space and time required for data logging. See Section 3.5 for an example of the data output, in this mode. See command C-ASCII Output above for more info.
G – Output Temperature	**(ON/OFF)**	This command is used to toggle the display of the Temperature data "ON" and "OFF". When this command is turned on, a 'T' data word will be created in the output.
H – Output C_s	**(ON/OFF)**	This command is used to toggle the Speed of Sound data "ON" and "OFF". When this command is turned on, a 'C' data word will be created in the output. This data are in meters/second.
I – Output WS / WD	**(ON/OFF)**	This command is used to output actual horizontal wind speed and direction data, along with vertical wind plus temperature (if turned on). The format will then be "S", "D", "W" and "T". When this command is used, you will also get a choice of two settings for the WD. One is 0-359, the other is -180 to +180.
J – Output Sample Status	**(ON/OFF)**	This command displays the number of samples used by the processor, to get the averaged data output. Turning this command on will create a '#' word in the output that will contain the sample quantities. If 20 samples are taken for a 3D sonic, there should be three sets of 20 in the output word. If one of the axis has 3 samples thrown out, the display will show 17 for the reading of that axis.

O – Output Raw Temp All Axis (ON/OFF)	This command displays the raw temperature from each of the three axes, before the data is converted to the final processed temperature. The format of these words will by identified with Tu, Tv, & Tw.
Ø– Return to Main Menu	This command will return the system to the previous menu.

5.2.2 Sampling Options Menu

A – Median Filter (ON/OFF)	The default operation is for the data measurements to be Averaged. This command is used to toggle the Median Filter "ON" and "OFF". When turned on, the Averaging mode is turned off. The median filter is used to return a "median" value for whatever number of measurements that is set in the 'Factory Menu'.
B – Spike Detection Algorithm (ON/OFF)	This command is used to toggle the Spike Detection Algorithm "ON" and "OFF". This data quality is used to remove spikes caused by various external sources, such as radio frequency and acoustical interference. Default is OFF. If this operation is required, consult the factory first before using.
C - Shadow Correction (ON/OFF)	This command toggles the Shadow Correction "ON" and "OFF". The shadow correction is used to correct the flow distortion caused by the wind blowing directly along the axis of the upwind transducer. Default is ON. CAUTION should be used, if this correction is turned off, the accuracy of the output data will be questionable.
D – Remove RH from Temp Calculation (ON/OFF)	This command is used to toggle the Relative Humidity calculation "ON" and "OFF". When the RH calculation is on, the RH value shown in the Factory Menu command E, is used in the equation to calculate the temperature. When toggled "OFF" this factor is removed from the calculation of the Temperature. Default is ON. This command has the same effect as setting the RH Value (in the Factory Menu) equal to Zero, for generating a dry air measurement.

H—Heat Flux Correction	**(ON/OFF)**	This command will only show up for the 'A' probes. For the 'A' probe users that only require statistical summaries, we have a simple percentage correction. For the user who wants eddy correlation calculations of fluxes, we have an inclination angle correction which provides a better adjustment. The (OFF) command provides the percentage correction. The (ON) command provides the angle correction.
Ø– Main Menu		This command will return the system to the previous menu.

5.2.3 Trigger Options Menu

A – External Triggering	**(ON/OFF)**	The default operation is internal timing, which will cause the sonic to send out data continuously. This command toggles External Triggering ON and OFF. External Trigger turned on, turns the internal timing off, This trigger is provided for customers who wish to synchronize the Sonic to other instruments. See Section 3.6 for more details on this operation. CAUTION should be used when changing the triggering, it is interrelated with the number of samples per measurement. The Average Size samples, in the Factory Menu, must be set to the correct size to meet the requirements of the triggering rate.
B – Character Triggering	**(ON/OFF)**	This command toggles External Character Triggering ON and OFF. This is provided for customers who wish to synchronize the Sonic to other instruments, but have no external trigger pulse available. The Sonic will trigger on the character in the data stream chosen in the next command.
C – Trigger Character		This command allows the user to enter the character to be used to trigger the sonic. The default character is an Asterisk (*), however any character can be used except (!); {ESC} and ^C.
Ø– Main Menu		This command will return the system to the previous menu.

5.2.4 Factory Menu

(Do not use these commands unless their effect is know)

A – Average Size	**(xxx)**	This value is set to 20 for default. This parameter is the number of high-speed measurements averaged (or median size) to create the desired output.

B – Internal Sample Rate	**(xxx)**	This value is pre-set by the factory to 200 as default. This can be changed from 15 to 200, but if you need to change this number, consult with the factory.
C – Gamma for Zero RH	**(xxx.xxxxxx)**	This is set to a default value, and is displayed on the command and in Current Settings. This parameter is used to adjust the gamma of the air with zero humidity. C^2=Gamma/Temperature. Also see Gamma Slope.
D – Gamma Slope	**(x.xxxxxx)**	This is set to a default value, and is displayed on the command and in Current Settings. This command is used to change *gamma* (γ) in our equation if required. $T = \frac{C^2}{\gamma}$ if the *gamma* is not correct, adjust the *gamma slope* to correct. $gamma = (gamma\ slope)RH + gamma\ zero$ The RH and gamma zero can also be changed if required: RH, and gamma for zero RH are both in this Factory Menu.
E – RH Value	**(xxx)**	This default value is set to 50. This parameter is used to set up a known general relative humidity. For example, if the system is going to be used in the tropics, the user might enter a 90 (90% Humidity). This value is required in order to calculate the virtual (Sonic) temperature. Also, if the RH value is known for any given test, this value can be changed to that value of RH, and improve the accuracy of the temperature calculation. This command can be used as a work-around for the Remove RH from Temp. Calculation, by setting this value to zero (Ø).
F - FD Maximum Correction	**(0.84)**	This parameter is used to set the flow distortion maximum correction. Refer to the following equation for setting this parameter: $NewValue = \frac{Measured}{MaximumCorrection + \left(\frac{\theta}{CorrectionAngle}\right)}$
G - FD Correction Adjustment	**(0.16)**	This parameter is associated with the previous parameter. Use the previous equation in setting this parameter.

H – FD Correction Angle	**(70)**	This parameter is associated with the previous parameters. Use the previous equation in setting this parameter.
J – Spike Removal Parameter	**(200)**	Spike Removal works by comparing the current high-speed sample with an average, and then looking at this parameter to determine if the current sample has deviated too far from the average. If the deviation is larger than this value, the sample is discarded. If this operation is required, consult the factory first before using.
K – Spike Removal Reset Samples	**(100)**	This command is used to set the number of samples before the Spike Removal Algorithm is reset. This is necessary when poor data quality occurs for an extended period of time because the values could drift too far from the average they are compared to. This value is the number of output samples that occur before a reset of the Data Quality Algorithm happens.
L – Number of Axis	**(3)**	This parameter is used to tell the system how many axes the probe array has, 1; 2; or 3. A probe array may be built with any of these different axes.
M – Probe Size	**(15)**	This command allows the sonic software to be adjusted so it can also be used on a different size probe path.
N – Clear User Parameters		If user parameters are entered into the system, this command allows the operator to clear these parameters, which will allow the actual factory parameters to be used.
– Main Menu		This command will return the system to the previous menu.

5.3 CALIBRATING THE SONIC ANEMOMETER/THERMOMETER

The calibration of the Sonic Anemometer/Thermometer is established by its design parameters and therefore, can actually be used as an absolute instrument. The critical factor in the design is the mechanical distance between the transducers. The calibration command, in the sonic software, can be activated by the operator. See Section 5.1. This command causes the processor to perform a measurement of the mechanical distance to a high accuracy. It then stores this measurement and uses it in all future measurement calculations. Once the instrument has been calibrated, if this mechanical distance does not change, the accuracy of the instrument does not change.

The Sonic Anemometer/Thermometer is calibrated at the factory before shipping; however the sonic may be calibrated, at any time by the operator, should there be a need. The best approach for performing the calibration would be to move the sonic to a workbench for the ease of operation. Then follow the steps in the next paragraph to perform this calibration.

Install the Zero-Air Chamber over the axis to be calibrated, (the Zero-Air Chamber covers all axes on the "V" and "A" style sonic arrays). Hit {ESC} from the terminal program to bring up the Main Menu. Choose the D command for a calibration. The first prompt that comes up will be a request to make sure this is what you really want to perform. Hit the 'y' for yes if you want to proceed. The second prompt is a request for the temperature. Measure the ambient temperature to within 1.0°C or better (preferably inside the chamber if possible), and enter the temperature in degrees C at the prompt. After entering the Temperature, you will be prompted to enter the Relative Humidity. Enter an integer between 0 and 100, representing the percent of relative humidity (also preferably inside thee chamber). Next you will be prompted to enter the letter of the axis to be calibrated, (U, V, or W).

When the axis character is entered, the software will start the calibration immediately. At this point, there should then be some dots progressing across the screen while the instrument is performing the calibration. The software is taking several seconds of samples to process. When it is finished, it will display the distance it measured and the offset for that axis. The distance should be some number close to 0.15m ± a few millimeters, and the offset should be something smaller then 0.100000. These are the numbers that will be saved in memory for later processing. If the numbers turn out to be something beyond what is mentioned here, call the factory for assistance. Sending the zero character will return you to the Main Menu to perform the next axis.

Repeat the procedure to calibrate all three axes, choosing the correct letter for the next axis. Be sure that the Zero-Air Chamber has been moved to the correct axis before beginning the next calibration. When finished, check the status of the instrument by returning to the Main Menu, sending an 'E' character to bring up the Current Status screen. See Section 5.4 for a copy of the status screen.

For the most accurate measurement of wind velocity, make sure you have an accurate measurement of the temperature and relative humidity inside the Zero-Air Chamber. The more accurate these two values, the more accurate the instrument output will be. Likewise, if it is an accurate temperature you want, this value is calculated from the W axis. When calibrating this axis, rotate and hold the probe head so the W axis is horizontal. We have found that the sonic probe is so sensitive, the weight of the calibration box is enough to change the mechanical distance when calibrating. Then when the box is removed, the arms go back together and the calibration for that axis is slightly in error. This error has the greater effect on the temperature output.

The value of the temperature output is also as accurate as the values used. Once the calibration is performed using an accurate temperature, ATI also uses the latest NIST values for the atmosphere, when doing the calibration. The instrument than has a command (see Section 5.2.4 command E) that allows the operator to enter the RH value at the time of operation. When the appropriate numbers are used for calibration and during the field project, the ATI sonic can give an output temperature accurate to ±0.05°C.

5.4 CURRENT SETTINGS

This command does not have a table of subcommands, but is a single command that will display a screen. This screen will be a listing of information which will tell the operator what system settings have been already set. The following is an example of a settings screen.

Current Settings

Distance = [0] 0.14xxxx [1] 0.14xxxx [2] 0.14xxxx
WS_Offset = [0] 0.0xxxxx [1] -0.0xxxxx [2] 0.0xxxxx

Average Size = 20 Samples Sample Rate = 200 Hz Output Rage = 10.00Hz

Gamma at ZeroRH = 401.877800 Gamma Slope = 0.024200
Calculated Gamma = 403.087799 RH Value = 50

NumAxis = 3
Max_Correct = 0.84 Correct_Adjust = 0.16 Correction_Angle = 70

If options have been added to the sonic, there may be other lines of data associated to that option. See Appendix A for further information.

5.5 RESET FACTORY DEFAULTS

This command is a single command operation. It is provided so the operator has the ability to return the sonic system to a known group of settings. If there is any doubt about how the configuration has been set, this command can be used to reset back to a known starting point (9600 baud, 7 data bits, 1 stop bit, & even parity), and things can then be re-entered to make changes. If there are any questions about this command or the settings used, consult the factory.

6. MAINTENANCE

The Sonic Anemometer/Thermometer is designed to run unattended, with very little maintenance required. Since there are no moving parts to contend with, maintaining the Sonic Anemometer/Thermometer is very simple. Try to keep the transducers free from dirt and ice. Check the output cable occasionally for damage or degradation.

If there is a problem with the output data, check the Current Settings first, to make sure the settings are what is expected. Make sure the values are correct.

Check to see if the calibration data are correct.

Check out Section 7. for troubleshooting ideas.

All other required maintenance must be performed by the factory.

7. TROUBLESHOOTING

The Sonic Anemometer/Thermometer is quite reliable on its own and does not require much maintenance. Should you encounter a problem, a few basic steps can be taken to help troubleshoot the problem. The first step should be to cycle the power by turning the power off or by disconnecting the connector and reconnecting it. This process will reset the software program and it should reboot.

Make sure that all of the cables are connected and in good condition. If the display shows -99.99, the first indication should be that there is something blocking the transducer path reporting the -99.99. The four orthogonal probes will report a -99.99 for whichever axis is being blocked. If an axis on the non-orthogonal probe, all the data will report a -99.99 in the output.

If a check of the axes reveals no blockage, the second indication would be that a transducer may have failed. If a further check indicates the possibility of a bad transducer, the sonic must be returned to the factory for repair. The transducers in this latest instrument are NOT field replaceable.

If there is a problem with any one of the three axes, and the output of that axis is -99.99, the temperature output will also be -99.99, since all three axes are needed to process the correct temperature.

If the display shows a +99.99, the first indication is that the data quality algorithm has been turned on. The processor has observed some data, but discarded the complete sample when it considered the data incorrect. If this is the case, and it is a temporary problem, the instrument will continue to transmit reliable data once the situation corrects itself. The main reason for this type of condition is usually the velocity of the measurement has reached the upper limit of the instrument. In this case, the +99.99 will come-and-go as the wind speed fluctuates above or below the limit. External interference will also cause this type of symptom.

Should the +99.99 be displayed continuously, there may be several possible reasons for this error, but the first indication is that something has caused a partial blockage of a transducer. One cause of this may be a rain drop or light snow on a transducer, or something else such as bird droppings. If the cause has been removed and the problem does not cease, the instrument may have experienced a failure. Return it to the factory for checkup and repair.

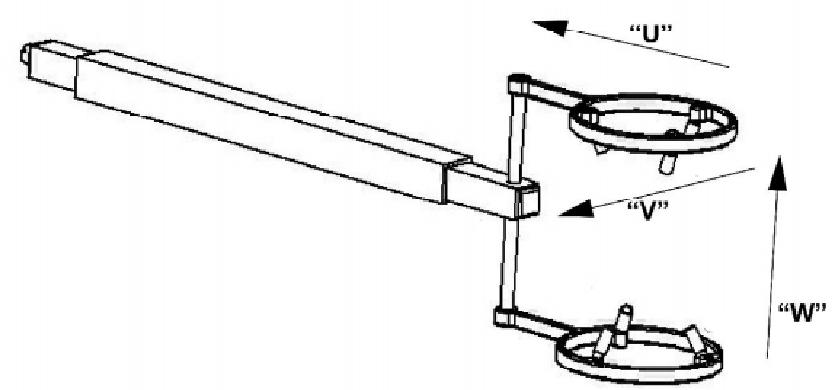
APPENDIX A

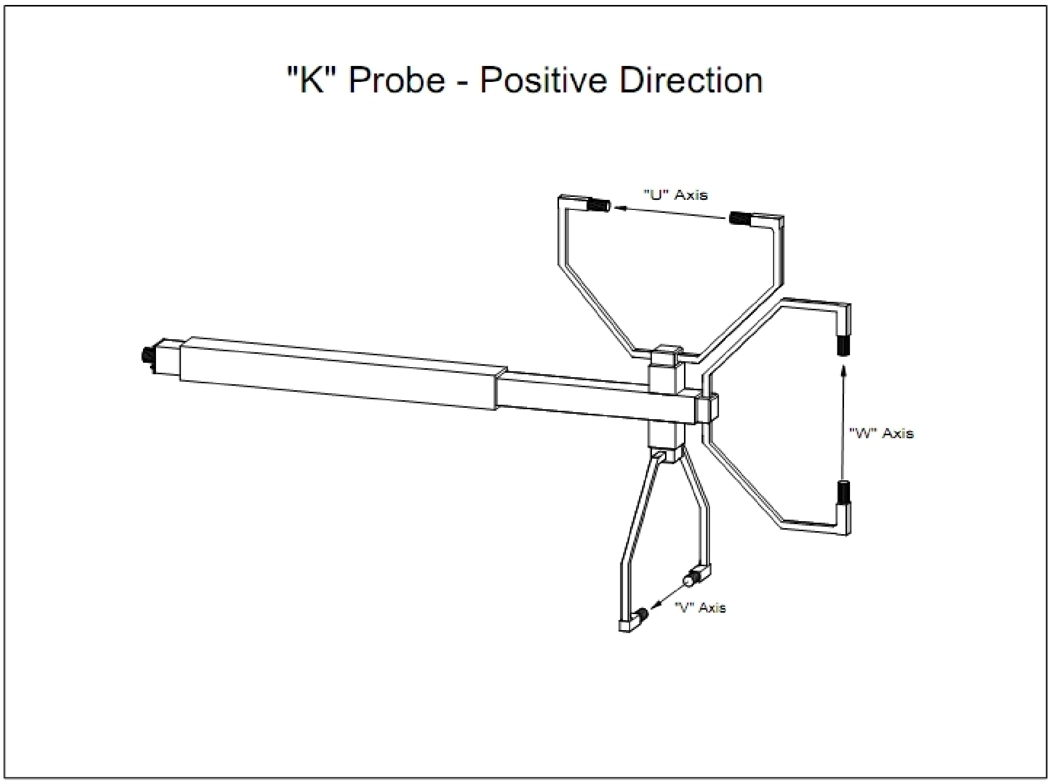
Options

<u>APPENDIX B</u>

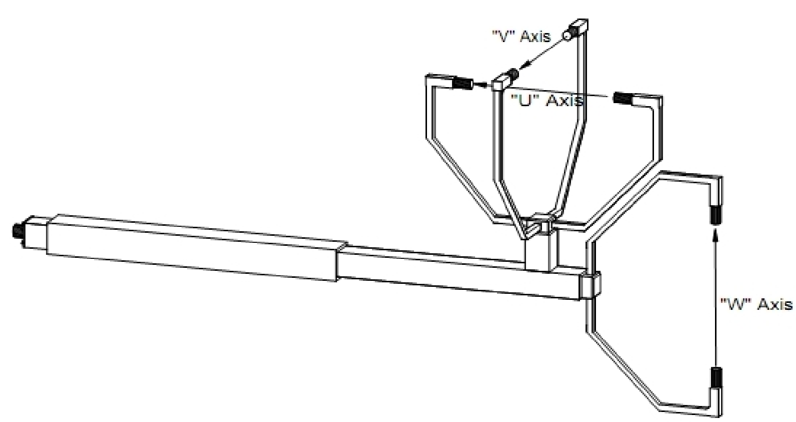
Drawings

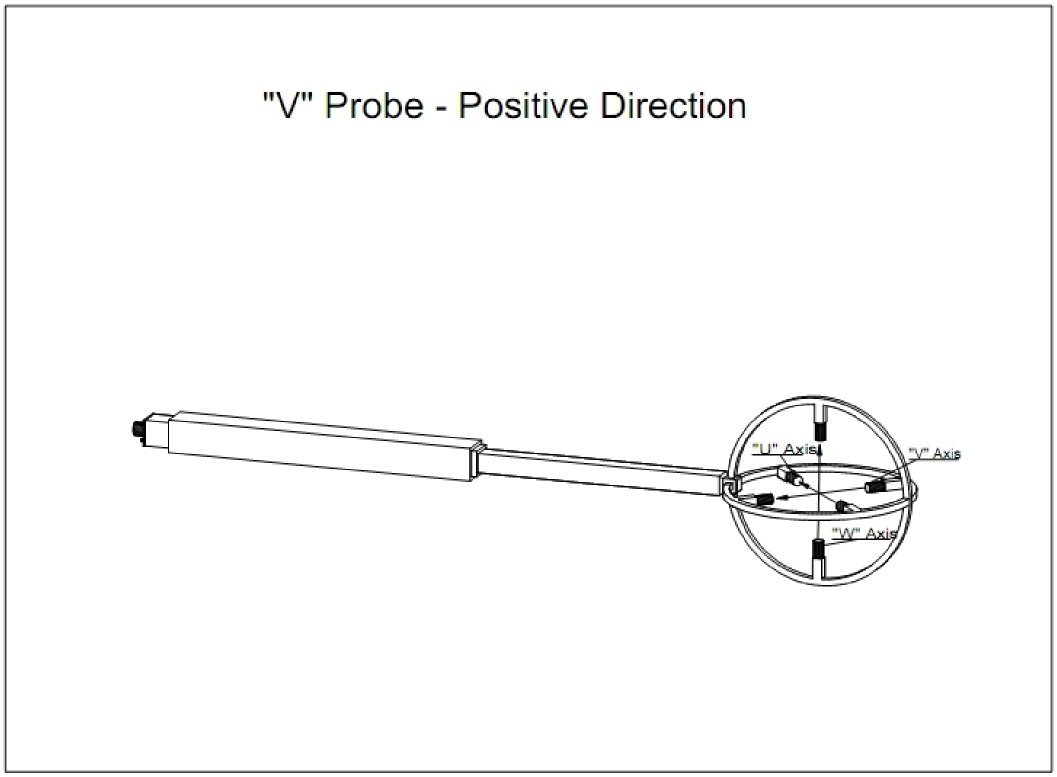
“A” Probe - Positive Direction

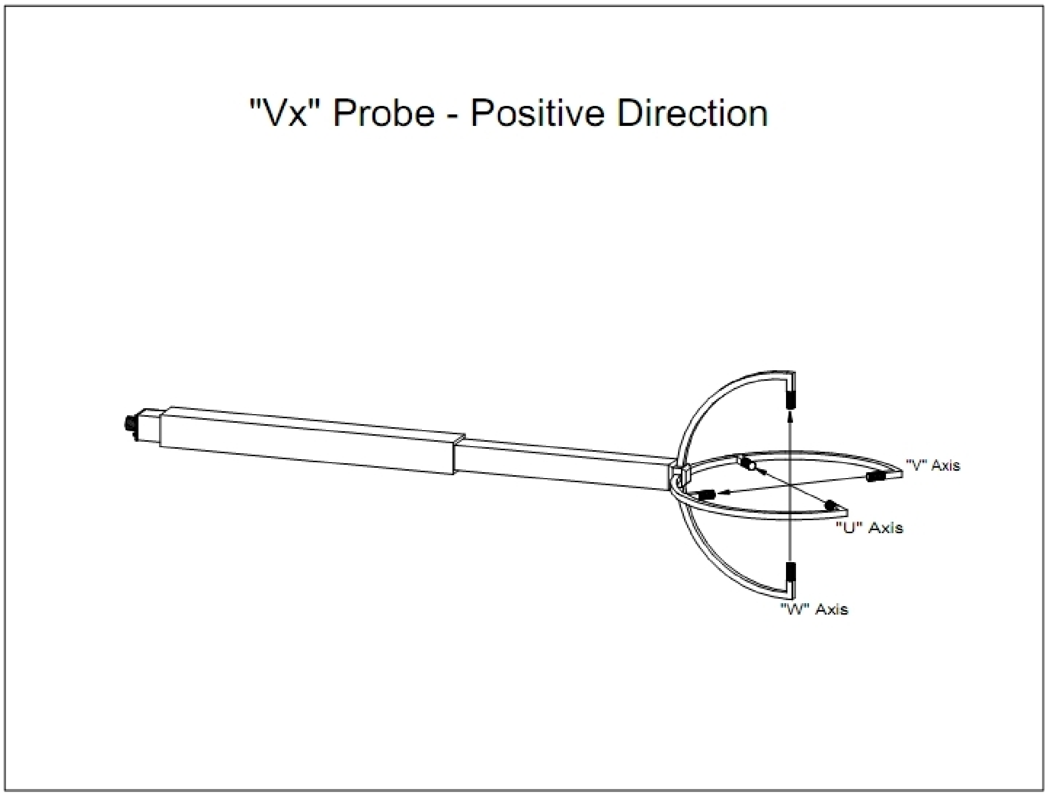



"K" Probe - Positive Direction
"U" Axis
"W" Axis
"V" Axis

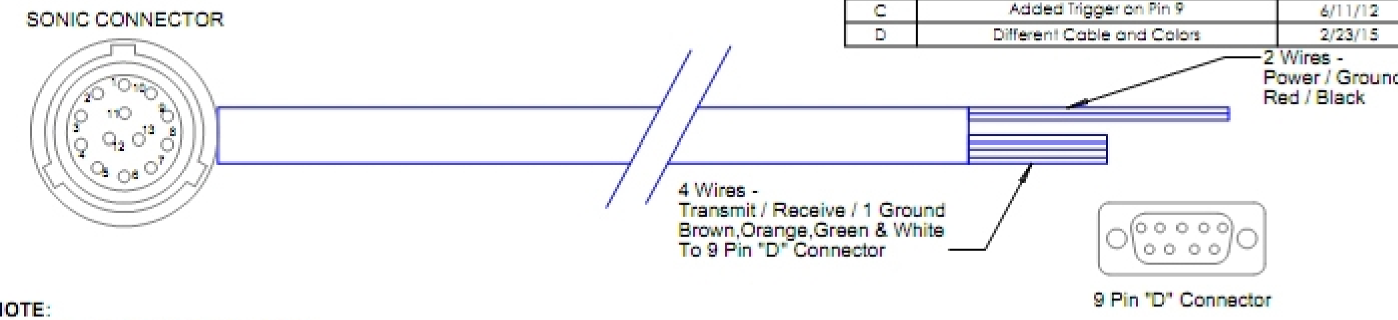
"Sx" Probe - Positive Direction




"V" Probe - Positive Direction
"U" Axis
"V" Axis
"W" Axis


"Vx" Probe - Positive Direction
"V" Axis
"U" Axis
"W" Axis

REVISIONS		
REV.	DESCRIPTION	DATE
A	Added RS-422 column	10/15/10
B	Added Pin #'s to RS-232 and RS-422	1/12/11
C	Added Trigger on Pin 9	6/11/12
D	Different Cable and Colors	2/23/15



NOTE:
Use Yellow and Purple in pins 4 & 2 of Sonic Connector for RS-422

PIN	VALUE	WIRE COLOR	RS-232	RS-422	OPEN ENDED
13	Ground	Blue			Blue/Ground
12	V In	Red			Red/Power
11	Known State	Yellow			
10	Ext. Reset	Purple			
9	Transmit	Brown	Pin 2 - Trans	Pin 3 - Trans (+)	
8	Receive	Orange	Pin 3 - Rec	Pin 7 - Rec (+)	
7	Ground	Green	Pin 5 - Gnd	Pin 4 - Gnd	
6					
5	Trigger In	White	Pin 9 - Trig	Pin 9 Trig	
4	Analog In 2			Pin 8 - Trans (-)	
3	Trigger Out	Gray			
2	Analog In 3			Pin 2 - Rec (-)	
1	Chassis Ground	Drain			

NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±0.025
ANGULAR: MACH ±0.1 BEND ±0.1
TWO PLACE DECIMAL ±0.015
THREE PLACE DECIMAL ±0.0005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Brett	6/11/12
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

APPLIED TECHNOLOGIES, INC.

TITLE:
SATI Standard Probe Cable Wiring

SIZE A | DWG. NO. 150-079 | REV D

SCALE: 1:1 | SHEET 1 OF 1

5 4 3 2 1

APPENDIX C

Application Notes

EFFECTS OF SPATIAL FILTERING, PREFILTERING, AND ALIASING IN MEASUREMENTS FROM APPLIED TECHNOLOGIES' SONIC K-PROBE

J.C. Kaimal

The Applied Technologies' Inc. (ATI) K-probe measures wind components along three mutually orthogonal axes separated spatially from each other to minimize flow distortion errors. The sonic anemometer samples the wind at a 100-Hz rate but constructs 0.1-s (10-point) non-overlapping block averages to provide. a 10-Hz data train for internal processing. This digital prefiltering is designed to minimize the effects of aliasing high-frequency spectral energy back into the region below the Nyquist frequency (5 Hz). The internal processing consists mainly of corrections for transducer shadowing error in the two horizontal wind measurements and correcting the sonic temperature, measured along the vertical velocity path, for cross-wind contamination. No shadow corrections are applied to the vertical velocity (w) component because of the low wind inclination angles typically encountered near the surface.

In this note all factors affecting the sonic anemometer spectral response are examined to arrive at a final form for the measured w spectrum (the only one spared the transducer Shadow correction). The processes are easy to demonstrate graphically on log-log paper where the multiplication process translates to simple addition of distances on the graph

We start in Figure 1 with an idealized -5/3 spectrum (I) extending from 1 to 100 Hz. The original 100-Hz sampling aliases the energy above 50 Hz primarily into the region from 10 to 50 Hz. The energy near the Nyquist frequency is raised by a factor slightly above 2, if one includes the second and third folds. But this spectral distortion is too far removed from the 5-Hz Nyquist frequency in the 10-point block-averaged output to affect the final spectrum.

Spatial averaging for the 15-cm path has only a very small effect at frequency $f < 5$ Hz. The transfer function in Figure 2 corresponds to the curve for w for a wind speed of 5 ms-^{1}. The half-power point falls approximately at a wavelength of 15 cm (the path length), or a frequency of 33.3 Hz. The spatially averaged spectrum (II) in Figure 1 represents the form for the 100-Hz data train.

The 10-point block averaging can be broken down, for the purpose of illustration, into two separate steps: (1) passing a 0.1-s moving average across the spatially averaged spectrum, and (2) picking points from it 0.1 s apart. The first process is represented by a $\sin^2 \pi f \Delta t/(\pi f \Delta t)^2$ function, Δt being 0.1 Hz, in our case (Figure 2), and the second by aliasing in the 1-5 Hz range. Their effects on the spectrum are represented in Figure 1 by curves III and IV. The departure from the original spectrum is the hatched area in Figure 1. Also shown, for comparison, is the spectrum (V) one can expect in the absence of any prefiltering, i.e., from 0.1-s grab samples of the vertical velocity field (Figures 1 and 2).

The advantages of prefiltering are twofold:

(1) It greatly reduces the energy aliased into the 1-5 Hz spectral range, making it easier to identify the onset of the -5/3 power law. (The spectrum can be corrected, if needed, for the droop in that region.)

(2) It attenuates potential noise contributions above 50 Hz that might fold back into the 1-50 Hz band. (It will have no effect on those that appear below 1 Hz.)

For the longitudinal (u) and lateral (v) spectra, one can safely assume that the spatial averaging effect, at least at $f < 5$ Hz, will not significantly differ from that for w. However, the combined effects of transducer shadow correction and coordinate rotation will add some spurious energy above 1 Hz, essentially eliminating the droop apparent in the w spectrum. No corrections are recommended for the u and v spectra.

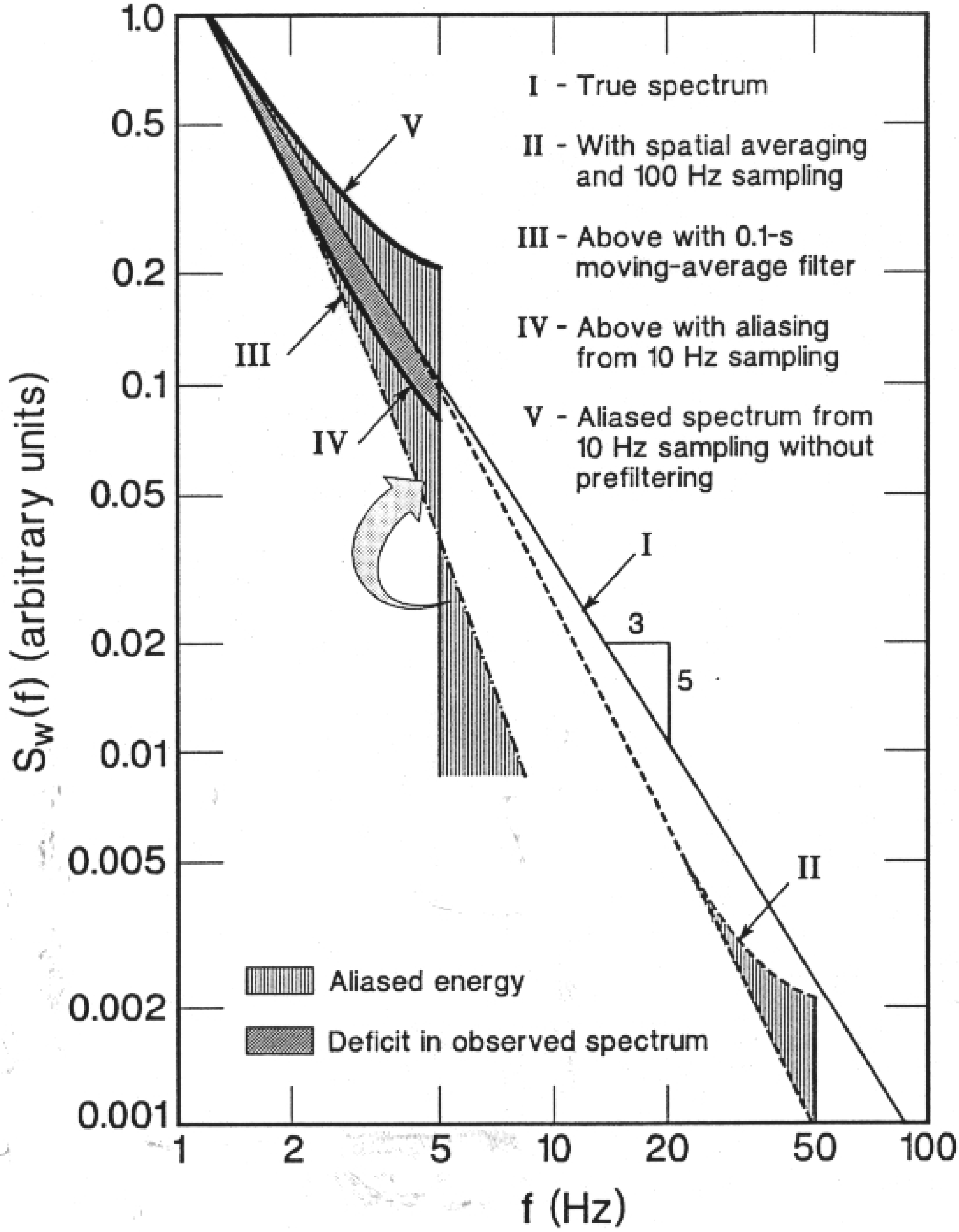


Figure 1. Effects of spatial averaging, digital prefiltering and aliasing on velocity spectral measurements with the ATI sonic K-probe.

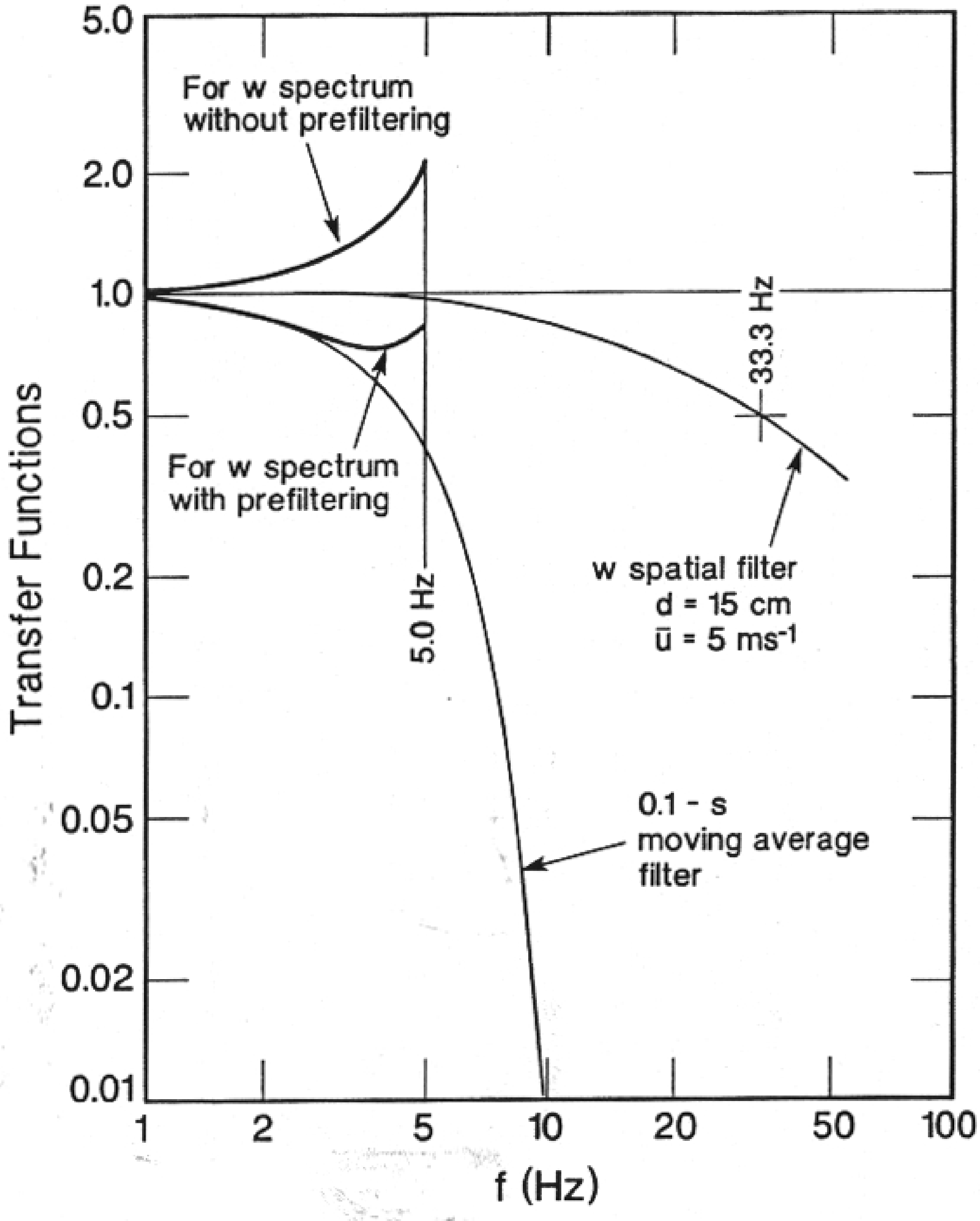


Figure 2. Transfer functions representing the effects of spatial averaging in *w*, digital prefiltering and aliasing.

<u>NOTE UPDATE</u>

Later instrument designs have also taken into account the shadow correction of the vertical velocity (w) component, even though it is considered minimal.

WPL Application Note No. 2 **December 1990**

TRANSDUCER SHADOW CORRECTION FOR APPLIED TECHNOLOGIES' SONIC K-PROBE

J.C. Kaimal

In the K-probe, as in many sonic probes available today, the transducers at the ends of its acoustic paths cast a "shadow" on the paths, causing the measured wind velocity component along the path to be underestimated. The degree of attenuation is a function of the angle between the wind direction and the acoustic path which increases with decreasing angle, reaching a minimum at 0°. At angles close to 90°, there is virtually no attenuation.

The exact functional form for the attenuation varies with probe design. For the K-probe, the form is approximated by two straight line fits based on wind tunnel tests conducted by C.B. Baker (personal communication, 1989):

$$(V_d)_m = \begin{cases} V_d\left(0.84 + 0.16\,\theta/70\right) & ; \quad 0° \le \theta \le 70° \\ V_d & ; \quad 70° \le \theta \le 90° \end{cases} \tag{1}$$

where $(\mathbf{V_d})_\mathbf{m}$ and $\mathbf{V_d}$ are the measured and true wind components along the path, and θ is the angle between the instantaneous wind direction and the path. The form would be symmetrical in either direction as shown in Figure 1. The two horizontal wind components are corrected for this attenuation immediately following the calculation of wind velocity from the reciprocals of the transit times by the sonic anemometer's microprocessor.

$$V_d = (d/2)(1/t_1 - 1/t_2) \tag{2}$$

where **d** is the path length and $\mathbf{t_1}$ and $\mathbf{t_2}$ are the travel times for sound pulses moving downwind and upwind, respectively. No correction is applied to the vertical velocity because wind elevation angles seldom exceed ±20° in the first 30 m or so above the ground.

A fixed 18.3-μs delay is subtracted from $\mathbf{t_1}$ and $\mathbf{t_2}$ to compensate for delays introduced in the transducers. This procedure, while important for the temperature calculation, (see WPL Application Note No. 3), has only a negligible effect on the velocity calculation.

In many wind tunnel studies, the response to flow distortion in a sonic anemometer probe is presented in the form of total wind speed measured by the probe divided by the wind tunnel speed. For comparison with such data, the uncorrected speed measured by the K-probe at 0° elevation as a function of azimuth angle is shown alongside the individual axes response in Figure 1. The curve rises to a maximum of 0.94 at ±45° and dips to a minimum of 0.84 at 0° and ±90°. Uncorrected wind speeds can therefore be expected to be 10% lower, on the average, than the true wind speeds.

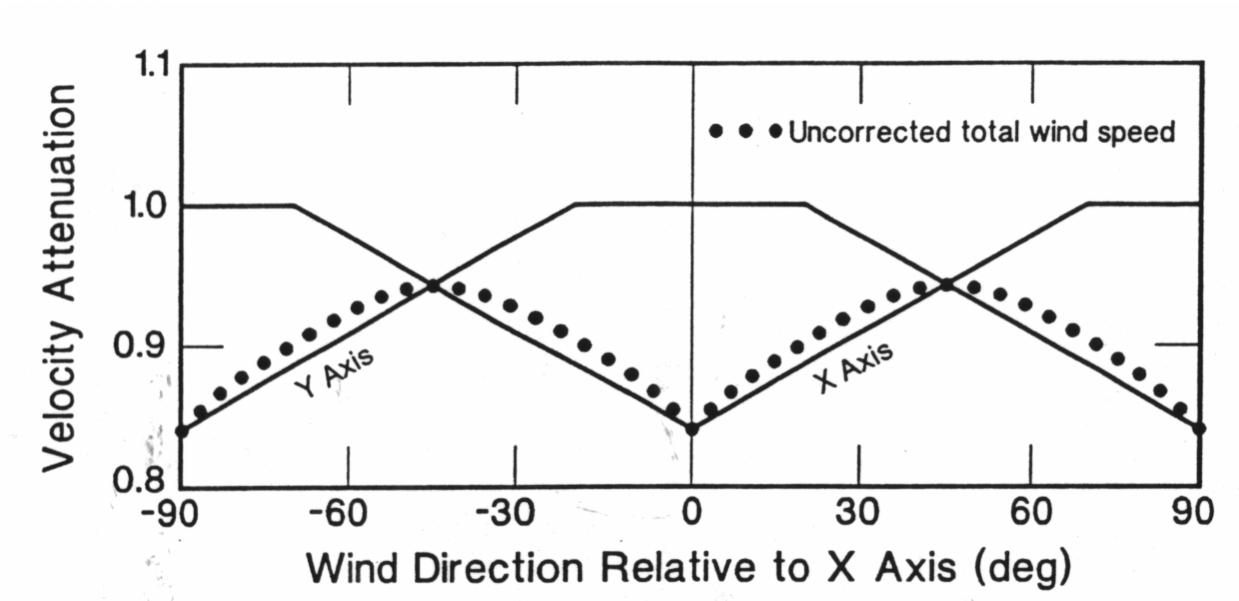


Figure 1. Velocity attenuation in the ATI K-probe from transducer shadowing is shown as a function of azimuth angle relative to the X axis (parallel to the support boom). Also shown is attenuation in the total wind speed from the combined attenuations along the X and Y axes.

NOTE UPDATE

Later instrument designs have also taken into account the shadow correction of the vertical velocity (w) component, even though it is considered minimal.

CONSEQUENCES OF OVERSAMPLING

J.C. Kaimal and LE. Gaynor

Oversampling is generally perceived as an inefficient practice because of the redundancy it creates in the data, but rarely is it considered detrimental. The resulting increase in bandwidth seldom if ever, provides new information, as the signal is often badly attenuated and not very useful above a certain frequency. The decision to oversample is often based on the assumption that no undue harm will result from sampling more frequently.

The problem arises when oversampling is performed on the output of a digital-to-analog (D/A) converter, where the signal is maintained at a constant voltage level (equal to the last reading) between successive samples of the original signal. This is tantamount to repeating each reading *n* times in the interval between samples (see Figure 1), where *n* (an integer) is the factor by which the sampling rate is increased. Clearly, the variance of the time series is unaffected by this oversampling. In a spectral plot it means the area under the curve remains the same but is redistributed to cover the added bandwidth, a process that is almost the reverse of aliasing.

A case in point is the Applied Technologies' (ATI) sonic anemometer output, which is updated every 0.1 s. in addition to providing serial digital readings representing wind measurements every 0.1 s, the manufacturer offers D/A outputs of the same readings, designed primarily for monitoring purposes. Many investigators not only treat the latter as their primary signal source, but sample them at rates which are multiples of 10 Hz, sometimes even at rates arbitrarily chosen to suit the requirements of other sensors in the field. In some cases, the investigators have noted a sharper than expected drop in spectral response at the high-frequency end, without knowing what caused it.

To test the effect of oversampling on atmospheric spectra, we selected an 819.2-s time series of vertical velocity (w) from an ATI sonic anemometer, mounted at 22 m, and sampled at their standard 10-Hz rate. We then simulated 20-Hz and 40-Hz oversampling by repeating each data point two and four times, respectively. The spectra computed for the three time series are shown superimposed in Figure 2. No corrections were made for distortions introduced by the spatial and digital smoothing of the signals, nor for aliasing due to discrete sampling. It should be noted, however, that the departure from the -2/3 slope observed in the 10-Hz spectrum follows the form predicted for the cumulative effect of all the distortions encountered. (See the graphical analysis of those errors presented in Application Note No. 1.)

The only significant difference is in the spectral shape at frequencies above 1 Hz. The spectrum drops more and more sharply with increased oversampling. As a result, the spectrum takes on an f^{-1} slope in the 1-5 Hz range. Looking from an entirely different perspective, one can see that the normal_and two-times-oversampled spectra are really aliased versions of the four-times-oversampled spectrum.

Our recommendation to ATI sonic anemometer users who sample the analog signals instead of the digital outputs is to keep the sampling rate strictly at 10 Hz or multiples of 10 Hz. In the latter case, it is possible to retrieve the 10-Hz time series by simply picking every nth data point. This would preserve the integrity of measurements and provide spectra that can be properly corrected for the filtering and the aliasing inherent in measurements from this sonic anemometer.

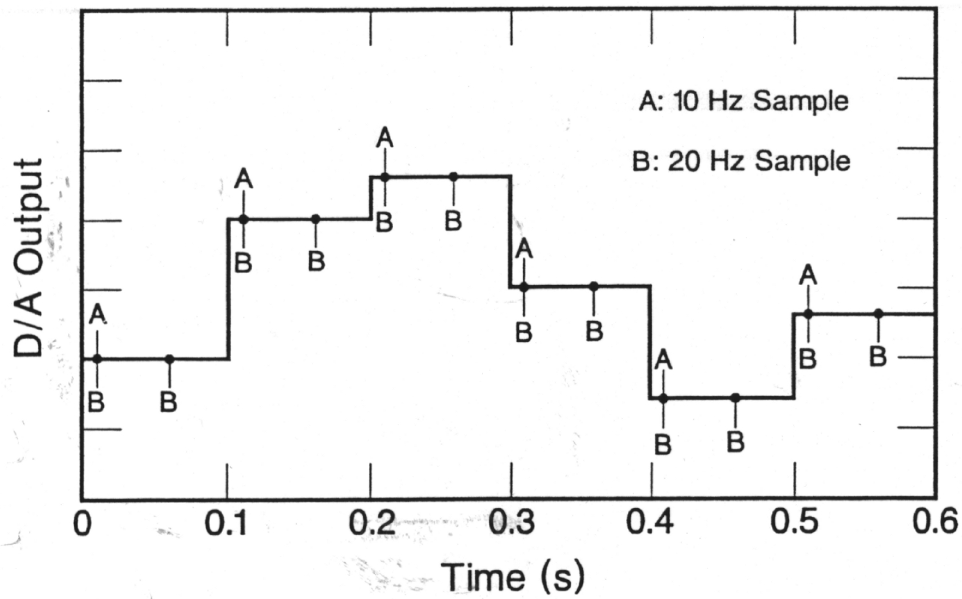


Figure 1. Effects of sampling ATI's digital-to-analog output more frequently than the prescribed 10 Hz rate.

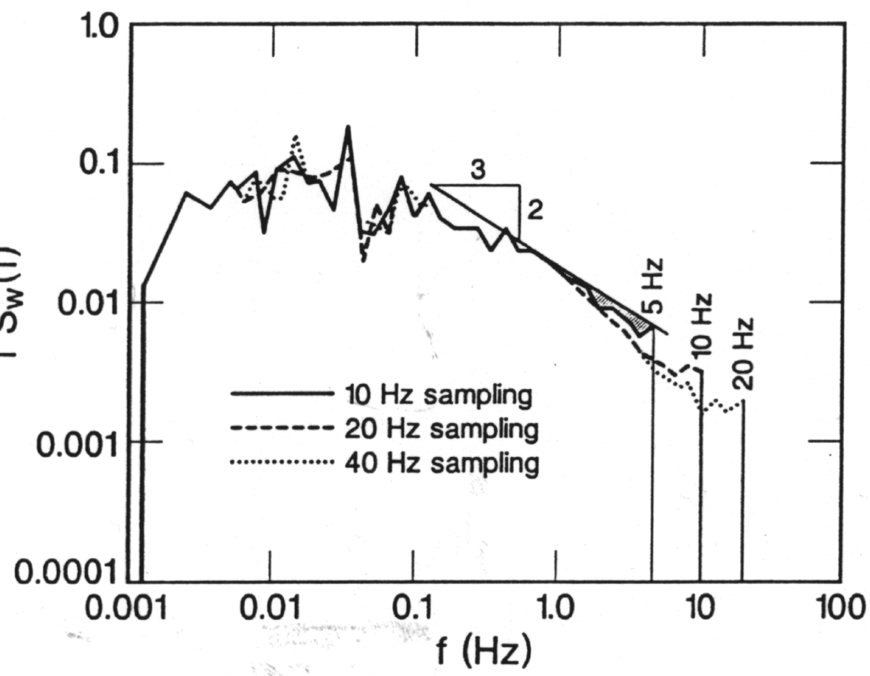


Figure 2. Consequences of two and four times oversampling of ATI's digital-to-analog output on the measured *w* spectrum.

SONIC TEMPERATURE SIGNIFICANCE AND LIMITATIONS

J.C. Kaimal

The ATI sonic thermometer measures temperature from transit times t_1 and t_2 measured along the vertical path of the anemometer's probe. They are the times taken by sound pulses to traverse the 15-cm acoustic path in opposite directions; (these same transit times are used also for computing the vertical wind component).

The instrument exploits the strong dependence that exists between the speed of sound in air and temperature, expressed usually in the form

$$c^2 = 403T(1 + 0.32e/p) \quad \textbf{(1)}$$

where c is the velocity of sound (m s^{-1}) in air, T is the temperature (K), and e and p are respectively the vapor pressure of water in air and absolute pressure. The humidity effect on the measured sonic temperature,
T_s [= $T(1 + 0.32\ e/p)$], resembles very closely the virtual temperature T_v defined by meteorologists as the temperature at which dry air has the same density as moist air at the same pressure:

$$T_v = T(1 + 0.38e/p) \quad \textbf{(2)}$$

Thus,

$$T_s = T_v(1 - 0.06e/p) \approx T_v - 0.06\left(\frac{T}{p}\right)e \quad \textbf{(3)}$$

Clearly, T_s more closely approximates T_v than it does T, the error being on the order of ±0.01°C in assuming
$T_s' = T_v'$, compared to ±0.05°C for $T_s' = T'$ (assuming a typical ($\sigma_e \approx 0.5$ mb at 10 m height).

In many boundary-layer calculations, T_v' rather than T' is needed to include the buoyancy contribution from moisture (e.g., Monin-Obukhov stability parameter, z/L, and buoyant production term in the TKE budget). Since the error in assuming $T_s' = T_v'$ is well within the bounds of experimental uncertainty, that distinction can now be dropped. The sonic temperature equation takes the form

$$1/t_1 + 1/t_2 = (2/d)\left(c^2 - V_n^2\right)^{1/2} \quad \textbf{(4)}$$

where v_n^2 is the magnitude of the wind vector normal to the acoustic path, and d is the path length.

Assuming c^2 - 403 T_v, we now have

$$T_v = \left(d^2/1612\right)\left[(1/t_1) + (1/t_2)\right]^2 + V_n^2/403 \quad \textbf{(5)}$$

The velocity contamination is usually ignored, but it grows in significance as the wind speed exceeds 5 m s^{-1}. (The vertical heat flux is particularly sensitive to this error when the stability is near neutral.) In the ATI sonic anemometer-thermometer v_n^2 is computed in real time from the horizontal wind components V_X and V_Y $\left(V_n^2 = V_X^2 + V_Y^2\right)$, already corrected for transducer shadow error T_v. The digital output from the instrument is scaled to read directly in degrees centigrade (or Kelvin as in earlier versions of the instrument).

A word of caution is in order for those planning_to use the mean T_v readings for vertical gradient measurements. The absolute value of the reading cannot be trusted partly because T_s is not exactly T_v, but more importantly, because t_1 and t_2 include additional delays introduced by the transducers. These delays cause the absolute temperature readings to be underestimated. In the ATI instrument, a time delay of 18.3 μs is subtracted from all measured transit times to compensate for this error. Uncorrected, these delays would cause T_v to be underestimated by 25°C. Corrected, the uncertainty is reduced to about ±1°C. Sample-to-sample variations in the transducers, therefore, impose a limit on the accuracy of mean temperature readings from the sonic thermometer, unless, of course, the bias has been carefully measured for the particular transducer pair, and removed from the readings. Another point to remember is that "spikes" in the data from mistriggering in the received pulses would be larger in the temperature signal than in the vertical velocity signal. Squaring of $\left[\left(1/t_1\right)+\left(1/t_2\right)\right]$ exaggerates the temperature spikes and causes the frequency-weighted temperature spectrum, $f\,S_T(f)$, to turn up at mid-to-high frequencies, when the vertical velocity spectrum shows only a small upturn at the very high end. An f^{+1} slope near the high end invariably spells trouble in the data, a fact easily confirmed by an examination of time series plots. If detected during the course of an experiment, readjustment of the triggering levels is often all that is needed to rectify the problem.

BASIC TESTS FOR CHECKING VALIDITY OF FIELD DATA

J.C. Kaimal

The following guidelines are suggested for verifying micrometeorological data gathered in field experiments. It is assumed, for simplicity, that the observations being tested are made over open, relatively flat and uniform terrain, with small roughness elements. It is also assumed that the sensors and the data acquisition and recording hardware are basically sound and that the purpose of the tests is to determine how good the measurements are. For this we divide the data into two categories: a) profile data from slow-response sensors like cup anemometers, glass-encapsulated platinum wire thermometers, and dew-point hygrometers, and b) turbulence data from sonic anemometers, sonic thermometers, infrared (or Lyman alpha) hygrometers. The former has response times of the order of seconds, or even minutes, while the latter typically has a usable frequency range extending to at least 5 Hz.

(a) *Profile data*

1) Make spot checks of collected time series by plotting concurrent 1-5 min segments from different heights. Look for spikes, signal dropouts, or any other unusual behavior.

2) Construct successive 15- (or 20-) minute averages of the time series for all heights over randomly selected periods and plot them as vertical profiles on the same graph. Look for consistent kinks in the profiles, indicative of faulty sensors or drifting calibration at one or more heights (see Figure 1).

3) Compute u_* from wind speed difference measured between winds at the lowest two heights (z_1 and z_2).

$$u_* \cong k\left[\frac{(u_2-u_1)}{ln(z_2/z_1)}\right] \quad \textbf{(1)}$$

Check for reasonableness of values obtained: $u_* \cong \sigma_w/1.3$ near the ground, or $u_* \lesssim 0.1\ \bar{u}_{1m}$

4) Plot mean wind profiles on log-linear paper and look for a straight fine fit for data points at the lowest levels (1-2 m). Extrapolate profile linearly to zero wind to estimate z_0 (the intercept when profile is passing through neutral stability). Z_0 should typically be a few centimeters high (or less) in open areas (see Figure 1).

5) Compute heat flux from the lowest (z < 2 m) $\bar{u}$ and $\bar{\theta}$ measurements

$$H\Big/\rho c_p = -\left[\frac{k}{ln(z_2/z_1)}\right]^2 \left(\overline{u_2}-\overline{u_1}\right)\left(\overline{\theta_2}-\overline{\theta_1}\right) \quad \textbf{(2)}$$

With winds expressed in m s^{-1} and temperatures in °C, $H/\rho C_p$ $\left(=\overline{w\theta'}\right)$ on moderately unstable days should stay around 0.25 m °C s^{-1}.

6) Compute Richardson numbers from the vertical gradients of $\bar{u}$ and $\bar{\theta}$. On a moderately unstable day, one should find Ri ≈ -z/L, if turbulence data are available.

(b) *Turbulence data*

1) Make spot checks for spikes and signal dropouts by plotting the time series of the three wind components and temperature one below the other. Look for spikes (common in sonic anemometer channels) and for noise.

2) Construct statistical summaries: $\bar{u}, \bar{v}, \bar{w}, \sigma_u, \sigma_v, \sigma_w, \overline{u'w'}, \overline{w'\theta'}$ over 15- (or 20-) min periods. (Rotate coordinates for computing u and v). Check for the following:

(i) $\bar{u}$ reads close to the mean wind profile value at that height.

(ii) $\bar{w}$ reads close to zero.

(iii) $\sigma_w / u_* \cong 1.3$ near the ground; $\sigma_w / \left(\overline{u'w'}\right)^{1/2} \approx 1.3$ at any height.

(iv) Compute z/L. It should read close to 1 for moderate instability and very nearly equal to Ri.

(v) Test if $\left.\begin{matrix} r_{uw} \approx -0.3 \\ r_{w\theta} \approx +0.5 \end{matrix}\right\}$ for moderate instability.

3) Compute 1-h spectra of u, v, w, and θ and plot them on log-log paper (Figure 1).

(i) Check for -5/3 power law at frequency $f > 2\bar{u}/z$ (i.e., wavelength < z/2).

(ii) Check for 4/3 ratio between transverse and streamwise spectra in that region.

$$\frac{S_w(f)}{S_u(f)} = \frac{S_v(f)}{S_u(f)} = \frac{4}{3}$$

(iii) Compute dissipation rate ε where

$$\varepsilon \approx \left[4.6/\left(\bar{u}\right)^{2/3}\right] \; \left[fS_w(f)\right]_{f=1Hz}$$

(iv) See if $k\,z\,\varepsilon/u^3_* \approx 1$ in near-neutral air.

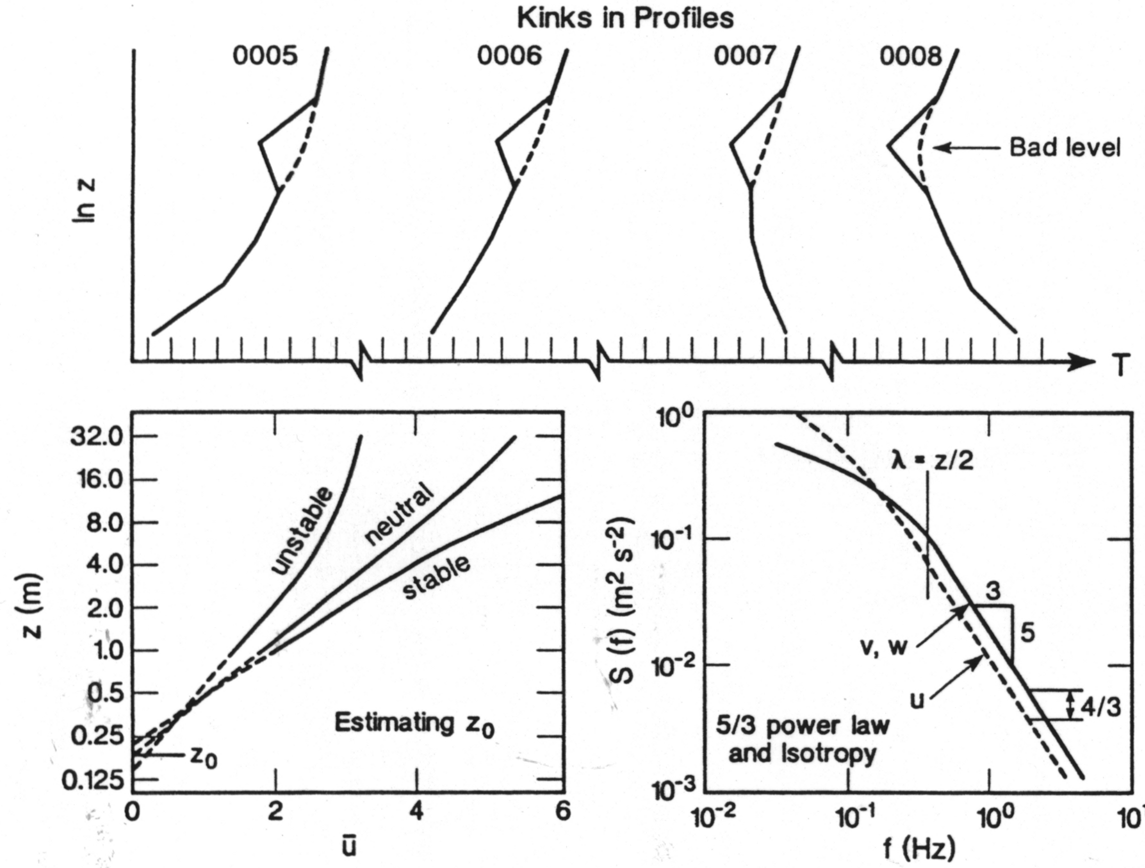


Figure 1. Illustrations of some basic checks for validation of field data.

A SIMPLE NOTCH FILTER FOR REMOVING HIGH FREQUENCY NOISE IN ATMOSPHERIC MEASUREMENTS

J.C. Kaimal and R.J. Lataitis

The experimenter occasionally encounters high-frequency (> 1 Hz) contamination in sonic anemometer data that adversely affects higher-order moment calculations. One has the option of applying a low-pass filter (either a simple, equally weighted moving average filter or any one of the sharper cut-off versions available today) to eliminate_not only the unwanted frequency, but all frequencies above it as well. A band rejection or notch filter would be a better choice because of its selectivity, but is seldom used because of computational complexity. In many instances the contamination is quasi-sinusoidal, often caused by vibration of the supporting boom at a frequency typically between 1 and 2 Hz. A simple procedure exists for removing such noise without seriously degrading the signal. It is a notch filter, realized by averaging data points spaced $\tau/2$ apart in time, where τ is the period of the noise signal.

$$y_i = \left(x_i + x_{i+\tau/2\Delta t}\right)/2 \quad ; \quad i = 1,2,3,\ldots,N \tag{1}$$

x_i represents the contaminated time series and y_i the new filtered time series; Δt is the interval between the successive samples and we assume for convenience that $\tau/2\Delta t$ is an integer.

To derive the transfer function for this process we will regard the signal as being continuous in time; x(t) and y(t) will replace time series x_i and y_i and their Fourier transforms in the frequency domain become $X(f)$ and $Y(f)$.

$$Y(f) = \int_{-\infty}^{\infty} e^{i2\pi ft}\, y(t)\, dt \tag{2}$$

$$\begin{aligned} &= 1/2\left[X(f) + e^{-i\pi f\tau} \cdot X(f)\right] \\ &= X(f)\cdot 1/2\left(1 + e^{-i\pi f\tau}\right) \end{aligned} \tag{3}$$

The power spectrum $S_y(f)\left[= \left|Y(f)\right|^2\right]$ becomes

$$\begin{aligned} S_y(f) &= S_x(f)\cdot 1/2\left(1 + \cos \pi f\tau\right) \\ &= S_x(f)\cos^2\left(\pi f\tau/2\right) \end{aligned} \tag{4}$$

The transfer function $K(f)$ for the process will be

$$K(f) = S_y(f)/S(f) = \cos^2 \pi f\tau/2 \tag{5}$$

This function, shown in Figure 1, has zeroes at $f = n/\tau$, where n is an odd number. For comparison, the transfer function $\sin^2 \pi f\tau/(\pi f\tau)^2$ for an equally weighted moving average filter of width τ is also shown on the same plot. This function drops to zero at $f = 1/\tau$, but slightly more rapidly than the cosine-squared function, and its lobes diminish in amplitude with increasing frequency, while those of the latter do not. By averaging data points spaced τ/2 apart in the time series we are, in fact, averaging pairs of points that are 180° out of phase. With the 10 Hz sampling rate in the ATI sonic anemometer, one can place the first notch at 5, 2.5, 1.67, 1.25, or 1 Hz (by averaging points separated by 1, 2, 3, or 5 sampling intervals apart, respectively, depending on which of the frequencies falls closest to the unwanted frequency in the signal.

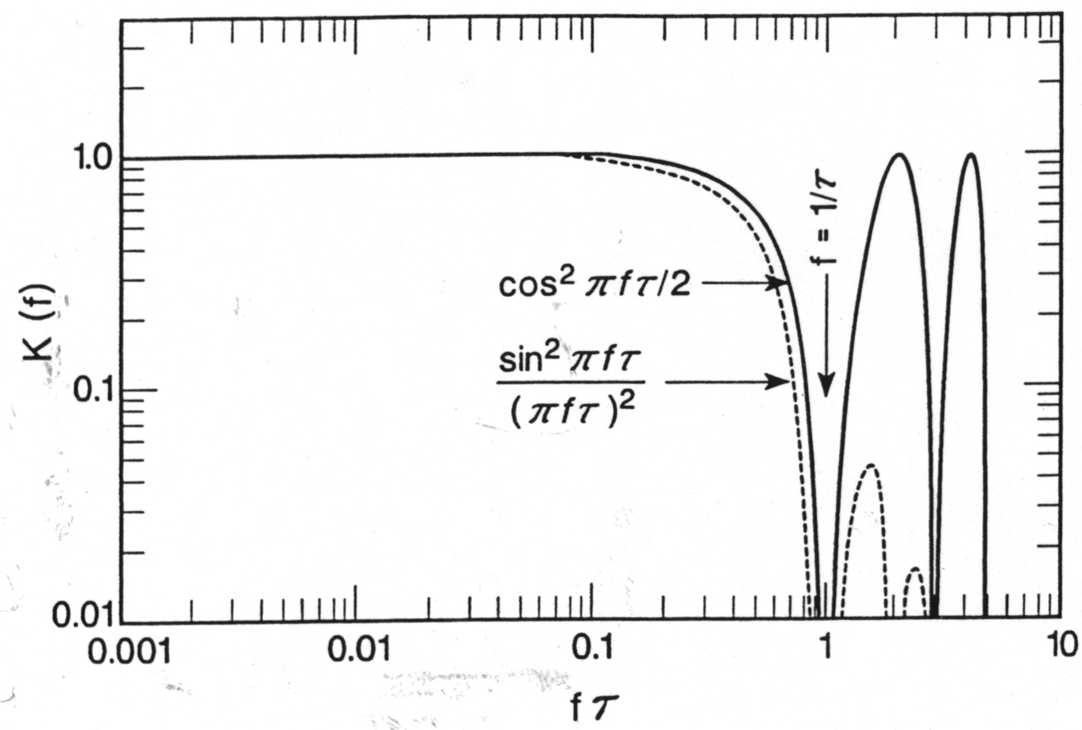


Figure 1. Transfer function for the cosine squared notch filter compared to that for a moving average rectangular filter.