CSAT3 THREE DIMENSIONAL SONIC ANEMOMETER INSTRUCTION MANUAL

REVISION: 3/98

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CSAT3 THREE DIMENSIONAL SONIC ANEMOMETER

1. GENERAL

The CSAT3 is a three dimensional sonic anemometer. It measures wind speed and the speed of sound on three nonorthogonal axes. From these measurements, orthogonal wind speed and sonic temperature is computed.

The CSAT3 can be used to measure average horizontal wind speed and direction or the turbulent fluctuations of horizontal and vertical wind. From the turbulent wind fluctuations, momentum flux is calculated. By finding the covariance between the vertical wind speed fluctuations, and temperature and humidity fluctuations (measured by fast response sensors) the sensible and latent heat flux can also be measured.

The sonic transducers are sealed and will not be damaged should they become wet. The wind measurements, however, will not be valid because the water droplets, on the face of the transducer, will scatter the sonic signal. As soon as all the transducer faces dry, the CSAT3 will lock on to the wind signal and begin making measurements.

The CSAT3 can be measured using SDM (Synchronous Device for Measurements) communications and a CSI datalogger. The CR23X and CR10X can be used to measure the CSAT3 using SDM without any special operating system. A 21X requires CSAT3 PROMs (P/N 10006). The CSAT PROMs includes the SDM-CSAT3 (P107), SDM Group Trigger (P110), and Set SDM Clock (P108) instructions. Initiate Telecommunications (P97) has been removed from the PROMs. The CR10 requires library special PROMs with the following instructions: SDM-CSAT3 (P107), SDM Group Trigger (P110), Set SDM Clock (P115), and Covariance/Correlation (P62).

The fine wire thermocouple used with the CSAT3 is the FW05. It is a 0.0005" diameter thermocouple mounted on a stainless steel bayonet. A FWC-L35 is required with the FW05. Four feet of the FWC-L35 is bundled up inside the enclosure to minimize conduction of heat into the terminal strips. The remaining 31 feet permits mounting the FW05 to the side of the CSAT3 head. Finally, the thermocouple

cover (P/N 10080) is placed over the connectors. This cover is used to mount the connectors to the side of the CSAT3 head and minimized temperature gradient across the omega brand connectors.

2. SPECIFICATIONS

MEASUREMENTS

The CSAT3 measures wind speed and the speed of sound along the three nonorthogonal sonic axes. The wind speeds are then transformed into the orthogonal wind components u_x, u_y, and u_z and are referenced to the anemometer head; the speed of sound, c, or sonic virtual temperature, T_s, is the average between the three nonorthogonal sonic axes. The errors caused by wind blowing normal to the sonic path is corrected on-line, before the wind speed is transformed into orthogonal coordinates. The CSAT3 can be configured to make a single measurement per trigger or multiple measurements that are centered around the trigger (oversampled).

MEASUREMENT RATE: programmable from 1 to 60 Hz.

NOISE EQUIVALENT WIND: u_x and u_y is 1 mm s^{-1}; u_z is 0.5 mm s^{-1}; c is 1 mm s^{-1} (0.002°C). Values are the standard deviations of instantaneous measurements made of a constant signal. The noise is unaffected by the sample rate.

WIND MEASUREMENT OFFSET: less than ±4 cm s^{-1} over -30° to 50°C operating range.

OUTPUT SIGNALS

The CSAT3 can output data to a data retrieval system using any of the following communications: SDM (Synchronous Device for Measurement), RS-232, or analog output. All the output signals have a two scan delay.

DIGITAL SDM: A CSI serial interface for datalogger/sensor communication
    Baud rate: 33.3 K (maximum)
    Data type: 2-byte integer

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DIGITAL RS-232:
    Baud rate: 9600
    Data type: 2-byte integer

SDM AND RS-232 DIGITAL
RANGE AND RESOLUTION:
    Full scale wind: ± 65.535 m s^{-1} autoranging
      between four ranges; least significant bit
      is 0.25 to 2 mm s^{-1}.
    Speed of sound: 300 to 366 m s^{-1} ($-50°$ to
      $+60°C$); least significant bit is 1 mm s^{-1}
      ($0.002°C$).

ANALOG:
    Number of outputs: 4
    Voltage range: ± 5 V
    Resolution: 2.4 mV

ANALOG RANGE AND RESOLUTION:
    Full scale wind: User selectable for u_x and
      u_y; ± 32.768 m s^{-1} (low range), least
      significant bit is 15 mm s^{-1} or ± 65.536 m
      s^{-1} (high range), least significant bit is
      30 mm s^{-1}; u_z is ± 8.192 m s^{-1}, least
      significant bit is 4 mm s^{-1}.
    Speed of sound: 300 to 366 m s^{-1} ($-50°$ to
      $+60°C$); least significant bit is 16 mm s^{-1}
      ($0.026°C$).

PHYSICAL DESCRIPTION

MEASUREMENT PATH LENGTH: 10.0 cm
vertical; 5.8 cm horizontal

TRANSDUCER PATH ANGLE FROM
HORIZONTAL: 60 degrees

TRANSDUCER: 0.64 cm (0.25 in) diameter

TRANSDUCER MOUNTING ARMS: 0.84 cm
(.33 in) diameter

SUPPORT ARMS: 1.59 cm (0.63 in) diameter

DIMENSIONS:
    Anemometer Head:
      47.3 cm (l) x 42.4 cm (h)
      (18.6 in x 16.7 in)
    Electronics Box: 26 cm x 16 cm x 9 cm
      (10.2 in x 6.3 in x 3.5 in)
    Carrying Case:
      71.1 cm x 58.4 cm x 33 cm
      (28 in x 23 in 13 in)

WEIGHT:
    Anemometer Head: 1.7 kg (3.7 lb)
    Electronics Box: 2.8 kg (6.1 lb)
    Shipping: 16.8 kg (37 lb)

OPERATING TEMPERATURE RANGE

$-30°$ to $+50°C$

POWER REQUIREMENTS

VOLTAGE SUPPLY: 10 to 16 VDC

CURRENT:
    200 mA @ 60 Hz measurement rate
    100 mA @ 20 Hz measurement rate

3. INITIAL SETUP

3.1 FACTORY SETTINGS

- Analog Outputs - Off
- Execution Parameter - 10 Hz (see Section 8 and B.1)
- Trigger Source - Internal Clock (see Section 8, 9, and B.1)
- SDM Address - 3 (see Section 3.2, 6.1, and 10.1)
- Unprompted Output - Off

The above settings can be changed with a PC, running the Windows CSAT3 monitor software, and the RS-232 cable.

3.2 SDM ADDRESS

Each CSAT3 on the SDM bus must have a unique address. A hex thumb switch within the electronics box is used to change the SDM address. Remove the lid and orient the electronics box with the connectors pointing down. The hex thumb switch is now located in the lower right hand side of the electronics box (see Table 3-1 for SDM addresses).

> **CAUTION:** SDM address F (hex) is a special address used during a Group Trigger. Do not set the hex thumb switch to SDM address F on the CSAT3's CPU board.

TABLE 3-1. SDM Addressing Scheme

Datalogger Address (base 4)	CSAT3 Thumb Switch (HEX)	Address (base 10)
00	0	0
01	1	1
02	2	2
03	3	3
10	4	4
11	5	5
12	6	6
13	7	7
20	8	8
21	9	9
22	A	10
23	B	11
30	C	12
31	D	13
32	E	14

4. INSTALLATION

4.1 ORIENTATION

The three components of wind are defined by a right handed orthogonal coordinate system. The CSAT3 points into the negative x direction (see Figure 4-1). If the anemometer is pointing into the wind, it will report a positive u_x.

In general, point the anemometer into the prevailing wind to minimize the amount of data that is contaminated by the anemometer's arms and other supporting structures.

4.2 MOUNTING

See Section 3 of the Tripod Weather Station Installation manual for details and recommendations on installing the tripod.

NOTE: Do not interchange electronics boxes and transducer heads from different CSAT3s. The electronics contain calibration information that is specific to its transducer head.

The sonic anemometer is mounted to the top of the CM6/CM10 tripod (or any vertical 3/4" diameter US bore pipe) with a 3/4" by 3/4" Nu-Rail (P/N 1017), the Nu-Rail is included with the CSAT3. The Nu-Rail will accommodate up to a 1" outside diameter pipe.

Attach the Nu-Rail to the vertical pipe and lightly tighten the vertical set screws. Insert the horizontal mounting arm into the Nu-Rail and lightly tighten the horizontal set screws. Point the horizontal arm into the prevailing wind. Tighten all the Nu-Rail set screws. Mount the anemometer head to the horizontal arm. Lightly tighten the bolt underneath the anemometer block (see Figure 4-1).

CAUTION: Do not carry the CSAT3 by the arms or the strut between the arms. Always hold the CSAT3 by the block, where the upper and lower arms connect.

Attach the electronics box to the body of the tripod. Use a 1/2" wrench to tighten the nuts. Connect the cable from the anemometer head to the connector on the electronics box labeled Transducer Head.

CAUTION: Over-tightening bolts will damage or deform the mounting hardware.

A krypton hygrometer can be mounted next to the CSAT3 on the same vertical pipe (see Figure 4-2).

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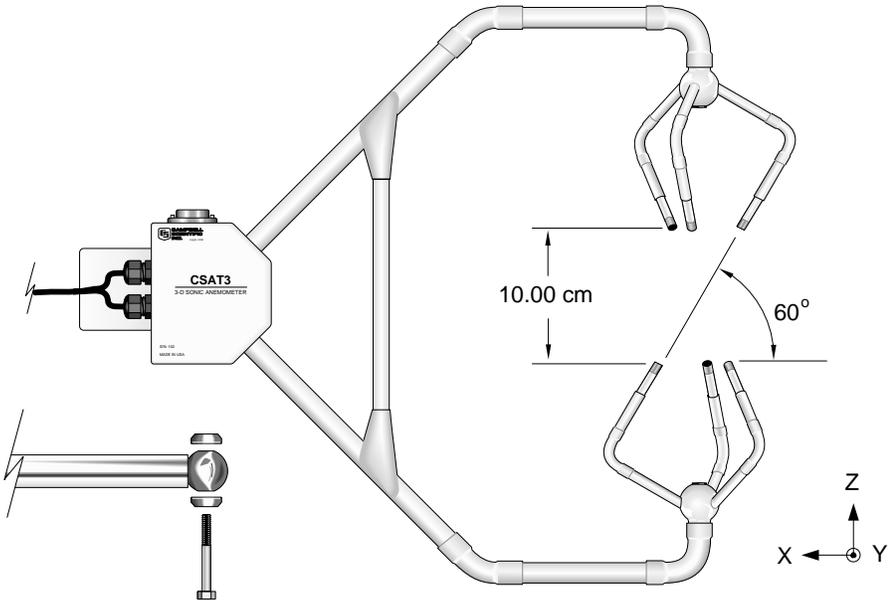
FIGURE 4-1. CSAT3 Coordinate System and Mounting Hardware
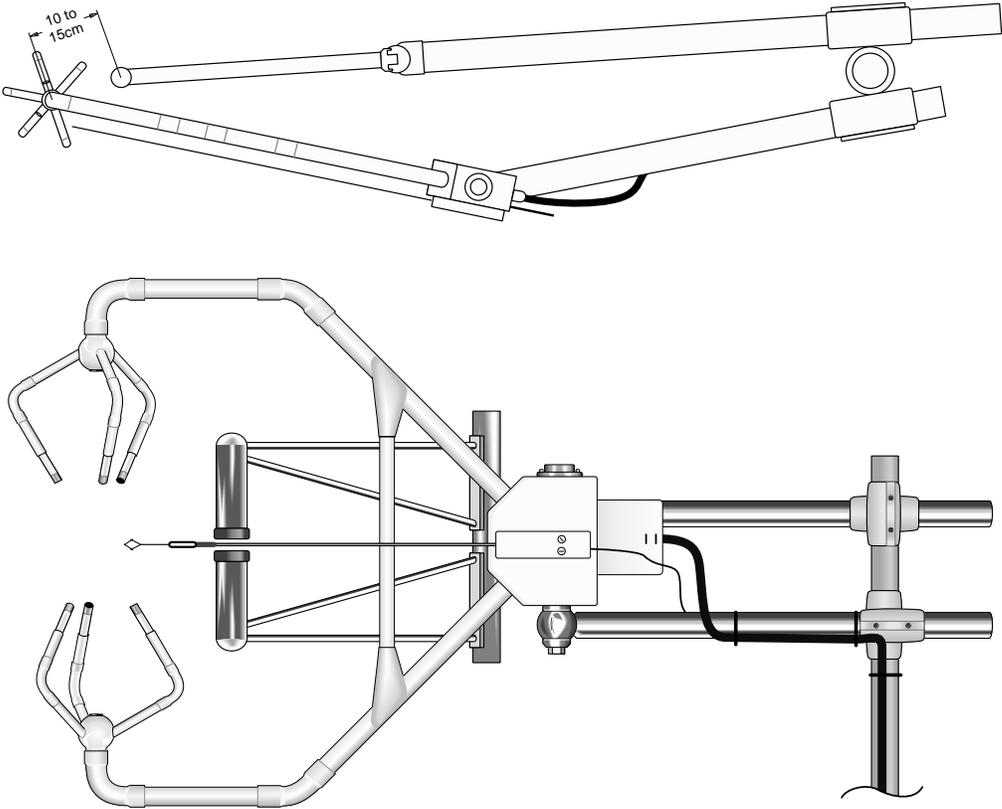
**FIGURE 4-2. CSAT3 Sonic Anemometer, KH20 Krypton Hygrometer,
and FW05 Fine Wire Thermocouple.**

4.3 LEVELING

Over flat level terrain, adjust the anemometer head so that the bubble within the level is in the bullseye. Over sloping terrain, adjust the anemometer head so that the horizontal surface that the bubble level is mounted on, is parallel to the terrain.

Firmly grasp the sonic anemometer block, loosen the bolt underneath the block, and adjust the head accordingly. Finally, tighten the bolt with a 9/16" wrench.

4.4 FINE WIRE THERMOCOUPLE

A fine wire thermocouple (model FW05 and FWC-L35) can be mounted to the side of the anemometer block to measure the temperature fluctuations. Attach the female connector from the FWC-L35, with the short screw (#2-56 0.437", P/N 3514) that was provided with the thermocouple cover, to the side of the anemometer. Insert the male connector of the FW05 into the female connector of the FWC-L35. Finally, attach the thermocouple cover to the anemometer block, using the two larger screws (#4-40 0.75", P/N 61), so that both the FW05 and FWC-L35 connectors are covered. All three screws are UNC threads.

5. WIRING

There are four military style connectors on the CSAT3 electronics box. They are labeled as +12V SDM, RS-232, Transducer Head, and Analog Output. Connect the cable from the anemometer head to the electronics box labeled Transducer Head. The anemometer head cable is 2.13 m (7 ft) in length. Each of the signal cables is 7.62 m (25 ft) in length. Connect the appropriate signal cable to the electronics box. See the Tables 5-1 through 5-7 for details on the wire color scheme.

> **NOTE:** Before extending the SDM signal cable, read Appendix D.

> **NOTE:** Short haul modems may be used to lengthen the RS-232 communications cable. Short haul modems do not include an RTS signal. The CSAT3's RS-232 drivers can be asserted by a software setting in the CSAT3. This setting will always power the RS-232 drivers, independent of the RTS line. Spark gaps (model 6536 and 6361) may be required to protect against transients when using short haul modems.

TABLE 5-1. CSAT3 Power

Battery Terminal	Description	Color
Positive	12 VDC	Red
Negative	Ground	Black

TABLE 5-2. CSAT3 SDM Output to a CR23X and CR10(X) Datalogger

Channel	Description	Color
C1	SDM Data	Green
C2	SDM Clock	White
C3	SDM Enable	Brown
G	Digital Gnd	Black
G	shield	Clear

TABLE 5-3. CSAT3 SDM Output to a 21X Datalogger

Channel	Description	Color
1H	SDM Data	Green
C1	10 K resistor to 1H	
C2	SDM Clock	White
C3	SDM Enable	Brown
$\perp$	Digital Gnd	Black
$\perp$	shield	Clear

TABLE 5-4. CSAT3 SDM Output to a CR9000 Datalogger

CR9000 9080 DB9 Pin	Datalogger Description	Color
8	SDM Data	Green
7	SDM Clock	White
6	SDM Enable	Brown
2	Digital Gnd	Black/Clear

TABLE 5-5. CSAT3 RS-232 Output Pin Out

CSAT3 DB9 Pin		PC DB9 Pin	Description
2	→	2	Receive Data
3	←	3	Transmit Data
5		5	ground
7	←	7	Request to Send
8	→	8	Clear to Send

TABLE 5-6. CSAT3 Analog Output Wiring

Description	Color
u_x sig high	Brown
u_x sig low	Black
u_y sig high	Red
u_y sig low	Black
u_z sig high	Green
u_z sig low	Black
c sig high	White
c sig low	Black
shield	Clear

TABLE 5-7. FW05/FWC-L35 Fine Wire Thermocouple

Description	Color
Signal High	Purple
Signal Low	Red

6. CSAT3 OUTPUTS

The CSAT3 has three signal outputs: SDM, RS-232, and analog. Campbell Scientific recommends that the SDM output be used when ever possible, followed by RS-232, and finally analog. Table 6-1 summarize the difference between the three output options. In general SDM communications has the following advantages: lowest CSAT3 current drain, best control and diagnostics, and highest data resolution.

TABLE 6-1. CSAT3 Outputs.

	SDM	RS-232	Analog
Typical Current Drain @ 10 Hz	51 mA	89 mA	99 mA
External Trigger Source	yes	yes	no
Output Dynamic Range	19 bit	19 bit	12 bit
Diagnostics Available	yes	yes	no

6.1 SDM

6.1.1 CR23X, 21X, CR10(X)

SDM is a Campbell Scientific communication protocol used between a Campbell Scientific datalogger and a smart sensor. This protocol uses control ports 1, 2, and 3 to communicate with the CSAT3. With a 21X, single ended analog input channel 1 (labeled 1H) and a 10 K resistor is used in conjunction with control port 1. SDM protocol allows synchronized measurement and rapid communication between a datalogger and the CSAT3. The datalogger instruction, SDM-CSAT3 (P107), is used to communicate with the CSAT3 over the SDM bus.

6.1.2 CR9000

SDM communications between the CR9000 and CSAT3 is achieved via the 9 pin CSI serial I/O port on the 9080 peripheral and memory card. The CR9000 instruction CSAT3() is used to communicate with the CR9000 over the SDM bus.

6.2 RS-232 OUTPUT

The Windows CSAT3 monitor software can be used to graph the CSAT3 data in real time or collect time series via the RS-232 serial port. Appendix B contains detailed information on the CSAT3 RS-232 commands.

6.3 ANALOG OUTPUT

The anemometer can be programmed to output four analog signals that correspond to u_x, u_y, u_z, and c. These signals range ±5000 mV. The analog output is enabled using the Windows CSAT3 monitor software using the PC's and CSAT3's RS-232 serial port. The u_x and u_y components of wind have two output ranges, low range (±32.768 m s^{-1}) and high range (±65.536 m s^{-1}). These ranges are changed using the Windows CSAT3 monitor software. Low range is adequate to measure wind speeds ±32.768 m s^{-1}. Table 6-2 gives the multipliers and offset for all the anemometer outputs in m s^{-1}.

TABLE 6-2. Calibration for Analog Outputs

	Slope Low Range $(m\ s^{-1}\ V^{-1})$	Slope High Range $(m\ s^{-1}\ V^{-1})$	Offset $(m\ s^{-1})$
u_x	6.5536	13.1072	0
u_y	6.5536	13.1072	0
u_z	1.6384	1.6384	0
c	6.5536	6.5536	340

When the analog outputs are used, the anemometer uses its internal timer to trigger the wind measurements. Thus, the wind measurements can be skewed in time $\pm 1/2$ the data acquisition system's scan interval from other analog measurements, e.g. temperature or humidity. Recall that the CSAT3 analog outputs also have a two measurement pipeline delay.

7. OPERATIONAL PRINCIPLES

The CSAT3 measures wind speeds and the speed of sound by determining the time of flight of sound between pairs of transducers, as described in Appendix C. However, unlike many other commercial anemometers it does not use simple threshold detection to determine the ultrasonic times of flight. Instead, it uses advanced, digital signal processing techniques which, in comparison to other systems, results in more accurate, lower noise measurements. These techniques also allow the system to quickly detect and indicate a degradation of signal quality and system performance.

The CSAT3 signal processing techniques result in slight differences in operation when compared to simpler sonic anemometers. These differences include a start-up delay before the system is fully functional plus a requirement for the correct triggering of the sensor to ensure a constant flow of synchronized data. The general principles of operation are described in the following section.

After the CSAT3 transmits an ultrasonic signal from one of its transducers, it then records the received signal from the opposing transducer. To optimize system performance, the CSAT3 only looks for the received signal during a limited window in time. The exact start and end time of the window are determined not only by the spacing between transducers but also by the current wind speed and speed of sound conditions.

After power-up or loss of signal, the CSAT3 enters a mode where it tests the forward and return paths for each of the pairs of ultrasonic transducers. This is called the "acquire" mode and takes about 10 seconds before normal output is available from the anemometer. This delay is caused in part because the anemometer has no recent knowledge of the responses of the transducer pairs, and in particular no past history of the of wind speed and speed of sound. During this acquire mode it has to search across quite wide windows in time to find the true arrival time of each received signal.

Once it has acquired the signal it then uses an tracking algorithm to adjust the start and end times of its search window based both on the Execution Parameter (see Section 8) and the last measured ultrasonic time of flight. The basis of this adjustment is that the dynamics of air movement prevent the time of flight changing by more than a certain amount in a given time. The result of using this algorithm is that the width of this window in time can be kept to a minimum and measurements can be made at a higher frequency for an overall lower consumption of power when compared to using wider fixed windows.

The main operational consequence of this tracking algorithm is that the Execution Parameter must be set to match the frequency at which the anemometer is triggered, because the Execution Parameter is used as an important input to the tracking algorithm. The setting of this parameter and matching it to the trigger frequency are discussed in the following section.

8. CSAT3 TRIGGER

The CSAT3 takes a measurement of wind speed and the speed of sound when triggered from one of three different sources. The trigger sources are the internal CSAT3 timer, SDM communications, or RS-232 communications.

In the case of the CSAT3 internal timer the Execution Parameter exactly defines the trigger rate. The Execution Parameter is set either via an SDM or RS232 command, or using the Windows based support software. Once set, this value is stored in non-volatile memory and is used thereafter. If the CSAT3 is set to use its

internal trigger then it will take measurements at this rate until it is changed.

Note that the power consumption of the anemometer is dependent on the Execution Parameter and the trigger rate (see Figure 8-1).

Where an external trigger source is used it is important to make sure the trigger rate is greater than or equal to the Execution Parameter. This is because, as discussed above, the Execution Parameter is used to define how much the wind speed could have changed from the previous reading. If the anemometer is triggered too slowly it is possible that under gusty conditions the wind speed could change to the extent that the CSAT3 sets its search window to a point in time which misses the ultrasonic pulse. This will cause it to give erroneous readings.

Conversely if the trigger rate is much higher than the Execution Parameter the CSAT3 will consume more current than necessary and at higher rates the CSAT3 will simply not be able to take measurements at the speed required, because it is analyzing wider time windows than necessary and it will run out of time. The latter will cause the CSAT3 to output 61503 as the diagnostic word, indicating an overrun (see Section 10.2 and B.4).

If the SDM or PC fails to provide a trigger to the CSAT3, it will enter a lost trigger state after three seconds. The data acquisition system will then have to reissue the acquire signal command (see Section 10.1 and B.1).

8.1 SAMPLING MODES

The CSAT3 can be configured to make measurements in either a single-measurement mode or a oversampled mode. In the single-measurement mode the CSAT3 makes one measurement synchronously with the trigger provided by the CSAT3 internal trigger, SDM communications, or RS-232 communications. In the oversampled mode, the CSAT3s internal trigger, SDM communications, or RS-232 communication trigger several measurements. The average of these measurements is output at the trigger rate.

8.1.1 Single-Measurement Mode

In the single-measurement mode, the anemometer makes one measurement per trigger. With this approach, the anemometer's high frequency response is limited only by the geometry of the anemometer head, thus minimizing the possibility of under-estimating high-frequency signal variations and covariations. However, this approach also aliases high-frequency information to lower frequencies. This aliasing is apparent in spectra from an upwards tail, when compared to the -5/3 power relationship, at frequencies approaching the Nyquist frequency (one-half the sample rate). This aliasing does not compromise the variances and covariances (and therefore, fluxes) computed from aliased data. The variance and covariance calculations are not frequency dependent, they simply measure a signal's total variation and two signal's total covariation, respectively.

8.1.2 Oversample Mode

In the oversample mode, the CSAT3 makes wind measurements at 60 Hz and then block averages those measurements to 10 or 20 Hz output. The output is synchronized to any one of the three triggers. The oversampling modes minimize aliasing by limiting the anemometer's high-frequency response. The 60 Hz data is filtered with a sin x/x function.

The oversampled modes maintain synchronization to the master trigger. In the six-times oversampled mode, the CSAT3 interpolates six minor triggers that are centered on the 10 Hz master trigger. In the three-times oversample mode, the CSAT3 interpolates three minor triggers that are centered on the 20 Hz master trigger. For compatibility with the existing single-sampled modes, the block-averaged output data have a fixed delay of two periods of the master trigger. However, as an option for the oversampled modes, experimenters can select block averaged output data that have a fixed delay of a one master trigger. Contact Campbell Scientific for details on changing this parameter.
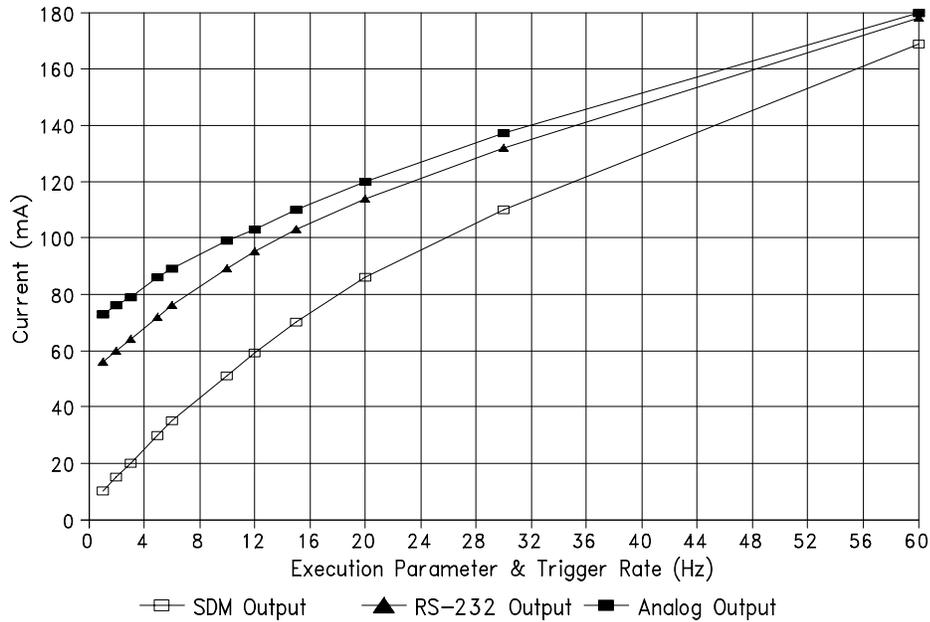
FIGURE 8-1. Typical Average CSAT3 Power Requirements at +12 VDC
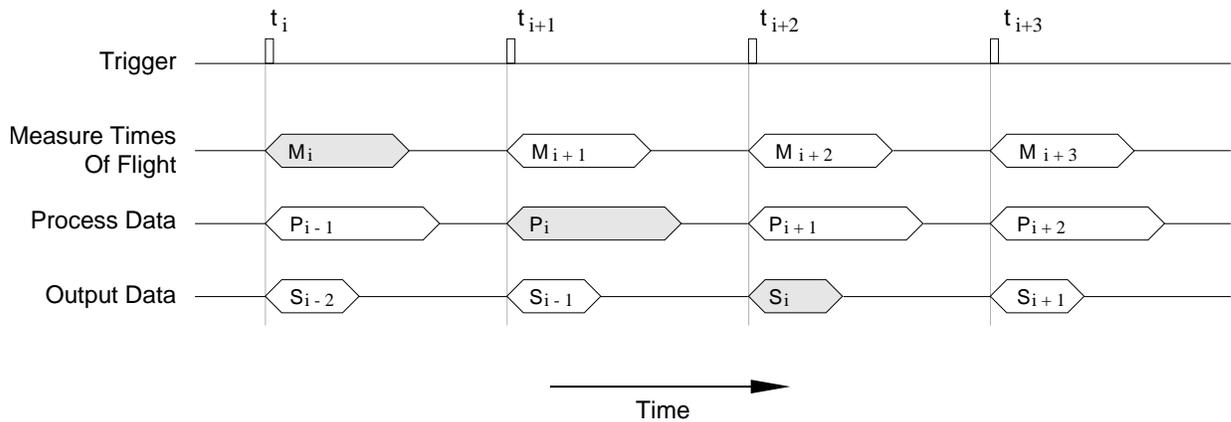
FIGURE 9-1. CSAT3 Pipeline Delay

9. DATA PIPELINE DELAY

When the CSAT3 is triggered to take a measurement, it determines the times of flight for all three transducer pairs. This process takes between 12 to 18 mSec, depending on the Execution Parameter. After determining the times of flight, the CSAT3 corrects these times of flight for transducer delays, and then calculates the u_x, u_y, and u_z components of the wind speed. In addition, it corrects each of the three sonic path speed of sound for the effects of wind normal to the sonic path. The three corrected speed of sound values are then averaged.

All the CSAT3 output signals (SDM, RS-232, and analog) have the two measurement pipeline delay. The wind speeds and speed of sound that are sent to the data acquisition system were measured by the anemometer two triggers ago (see Figure 9-1). To optimize system performance, the CSAT3 uses parallel processing techniques. These techniques cause a two measurement delay between the trigger and data output. This delay applies at all trigger frequencies.

When the covariance is found between the turbulence data from the CSAT3 and temperature from a fine wire thermocouple or a fast response

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hygrometer, the thermocouple and hygrometer data must be shifted back in time two triggers. This can be done on-line with a datalogger.

10. DATALOGGER PROGRAMMING USING SDM

10.1 SDM-CSAT3 (P107) USED WITH CR23X, 21X, OR CR10(X)

SDM-CSAT3 (P107) is an Input/Output instruction that controls and retrieves data from the CSAT3 (see Table 10-1). This instruction is available on the CR23X, 21X (with CSAT3 PROMs, P/N 10006), the CR10X, and the CR10 (with library special PROMs).

TABLE 10-1. SDM-CSAT3 (P107) Instruction Parameters

PARAMETER NUMBER	DATA TYPE	DEFAULT DESCRIPTION
01:	2	Reps
02:	2	SDM Address
03:	2	Option
04:	4	Ux Input Location

Reps: The number of CSAT3s on the SDM bus that will be sequentially addressed with the SDM-CSAT3 (P107) instruction.

SDM Address: The unique SDM Address of the CSAT3 that the datalogger will communicate with. The CSAT3 address is entered as a base four number in parameter 2 (see Table 3-1). The SDM Address is sequentially incremented if the Reps option is greater than 1.

The wind data and the speed of sound (sonic virtual temperature) is scaled by Instruction 107 into m s^{-1} or degrees Celsius.

> **CAUTION:** SDM address 33 (base 4) is a special address used during a Group Trigger. Do not program the datalogger to address SDM address 33.

Option 1, 2, 3, 5, 6, 10, 12, 15, 20, 30, and 60: "Set Execution Parameter" tells the CSAT3 which measurement parameters to use and what frequency to expect the measurement trigger from the datalogger. The datalogger Execution Interval and the appropriate CSAT3 Execution Parameter is summarized in Table 10-2 and 10-3.

Option 61 and 62: "Set Execution Parameter" tells the CSAT3 to oversample (Section 8.1.2) the wind measurements at a rate of 60 Hz and expect a trigger at a rate of 10 Hz (option 61) or 20 Hz (option 62) from a CR23X or 21X datalogger.

Option 51 and 52: "Set Execution Parameter" tells the CSAT3 to oversample (Section 8.1.2) the wind measurements at a rate of 48 Hz and expect a trigger at a rate of 8 Hz (option 51) or 16 Hz (option 52) from a CR10(X) datalogger.

Option 0, 90: "Trigger and Get Wind & c Data" sends a measurement trigger to the CSAT3 whose SDM address is specified in parameter 2. The CSAT3 also sends data to the datalogger.

Option 91: "Trigger and Get Wind & T$_s$ Data" sends a measurement trigger to the CSAT3 whose SDM address is specified in parameter 2. The CSAT3 also sends wind speed and the sonic virtual temperature (defined in Equation (9) in Appendix C) via the SDM bus to the datalogger.

Option 92: "Trigger and Get Wind & c-340 Data" sends a measurement trigger to the CSAT3 whose SDM address is specified in parameter 2. The CSAT3 also sends wind speed and the speed of sound minus 340 m s^{-1} via the SDM bus to the datalogger.

Option 97: "Get Wind and c-340 Data After a Group Trigger". The CSAT3, specified in parameter 3, sends wind speed and the speed of sound minus 340 m s^{-1} to the datalogger. A new measurement is not triggered. The SDM-CSAT3 (P107) Instruction must be preceded by the Group Trigger (P110) Instruction to use this option.

Option 98: "Get Wind and Ts Data After a Group Trigger". The CSAT3, specified in parameter 3, sends the wind speed and sonic virtual temperature (defined in Equation (9) in Appendix C) to the datalogger. A new measurement is not triggered. The SDM-CSAT3 (P107) Instruction must be preceded by the Group Trigger (P110) Instruction to use this option.

Option 99: "Get Wind and c Data After a Group Trigger". The CSAT3, specified in parameter 3, sends the wind speed and speed of sound to the datalogger. A new measurement is not triggered. The SDM-CSAT3 (P107) Instruction must be preceded by the Group Trigger (P110) Instruction.

TABLE 10-2. CR23X and 21X Execution Interval and CSAT3 Execution Parameter

CR23X/21X Execution Interval (seconds)	CR23X/21X Execution Frequency (Hz)	CSAT3 Execution Parameter
0.05	20	20
0.0625	16	15
0.075	13.333	12
0.0875 to 0.1	11.429 to 10	10
0.1125 to 0.1625	8.889 to 6.154	6
0.175 to 0.2	5.714 to 5	5
0.2125 to 0.325	4.706 to 3.077	3
0.3375 to 0.5	2.963 to 2	2
0.5125 to 1	1.951 to 1	1

TABLE 10-3. CR10(X) Execution Interval and CSAT3 Execution Parameter

CR10(X) Execution Interval (seconds)	CR10(X) Execution Frequency (Hz)	CSAT3 Execution Parameter
0.0625	16	15
0.078125	12.8	12
0.09375	10.667	10
0.109375 to 0.15625	9.143 to 6.4	6
0.171875 to 0.1875	5.818 to 5.333	5
0.203125 to 0.328125	4.923 to 3.047	3
0.34375 to 0.5	2.909 to 2	2
0.515625 to 1	1.939 to 1	1

Ux Input Location: The Input Location to store the first of five data values. The CSAT3 returns the following data after receiving the "Trigger and Get Data" or "Get Data after a Group Trigger" command in parameter 3. These data are: u_x, u_y, u_z, c or T_s, and a diagnostic word, where u_x, u_y, and u_z are the wind speeds along the x, y, and z axes defined by the anemometer head (see Figure 4-1), c is the speed of sound, and T_s is the sonic virtual temperature. The wind speed and the speed of sound are in units of m s^{-1}, and T_s is in degrees Celsius. If the Reps option in parameter 1 is greater than 1, the number of sequential Input Locations used is Reps ∗ 5.

10.2 DIAGNOSTIC WORD

The fifth output from the CSAT3 is the diagnostic word. The diagnostic word describes the status of the anemometer and is useful in filtering data. For example, when the anemometer is locking in on the ultrasonic signals after receiving the Acquire signals command, the -99999's it sends to the datalogger, for the science data, can be filtered out of the statistics based on the diagnostic word, see the example flux program in Section A.

The SDM-CSAT3 instruction (P107), decodes diagnostic word and represents it in base 10. The bits in the diagnostic word are grouped together into three categories. Bits 15 through 12 are four diagnostic flags (see Table 10-4 and 10-5), bits 11 through 6 represent the range the measurements are reported in (used by Instruction 107), and bits 5 through 0 are a counter. A detailed description of decoding the diagnostic word is given in Appendix B.

TABLE 10-4. Diagnostic Word

Diagnostic Word				
b15 - b12	b11 b10	b09 b08	b07 b06	b05 - b00
diagnostic flags	u_x range	u_y range	u_z range	counter

The following are four specific Diagnostic Words (Base 10) and the situation that produces them.

-99999, Anemometer does not Respond.
This is the special case when the datalogger attempts to address an anemometer and the anemometer does not answer. This occurs if the anemometer is not connected to the SDM bus, the anemometer is not connected to a 12 VDC power supply, or none of the anemometers on the SDM bus are set to the SDM address in the SDM-CSAT3 (P107) instruction.

61440, Lost Trigger. The anemometer has lost the trigger source, in this case all the diagnostic bits are set high, the range bits are set low, and the counter bits are low. This occurs if the anemometer is disconnected from the SDM bus; e.g. a loose SDM clock line. To bring the anemometer back on-line, connect the CSAT3 to the SDM bus and execute the SDM-CSAT3 (P107) instruction with the "Set Execution Parameter" option in parameter 3.

61503, No Data Available. The anemometer has no new data. In this case all the diagnostic bits are set high, the range bits are low, and all the counter bits are high. This occurs immediately after the anemometer receives the acquire signal command from the datalogger, i.e. an SDM-CSAT3 (P107) instruction with the "Set Execution Parameter" option in parameter 3. The no new data condition also occurs when the datalogger's execution frequency (inverse of the execution interval) is much greater than the execution parameter the anemometer was told to use.

61441, SDM Communications Error. The datalogger and CSAT3 are unable to communicate correctly. Extending the SDM cable beyond the standard 7.62 m (25 ft.) and not slowing down the SDM clock with Instruction 115 (CR23X or CR10(X)) or 108 (21X) is the most common cause of this error. See Appendix D for details on identifying the appropriate SDM clock rate for a given cable length.

10.3 SDM-GROUP TRIGGER (P110)

An SDM Input/Output Instruction that controls SDM devices that support the group trigger protocol, including the CSAT3. Up to 15 group trigger devices can be connected to the SDM bus. With the SDM Group Trigger (P110), all group trigger devices are triggered to make simultaneous measurements. The data from each device is then retrieved with the appropriate device specific instruction. For the CSAT3, the SDM-CSAT3 (P107) Instruction with the "Get data after Group Trigger" options (Option 97, 98, or 99) in parameter 3 is used to retrieve the data.

10.4 EXAMPLE DATALOGGER PROGRAM

In the following example, a CR23X is used to configure and then collect data from the CSAT3 using SDM communications. The CR23X will trigger each wind measurement over the SDM bus and retrieve wind speed data. An example flux program is given in Appendix A.

TABLE 10-5. CSAT3 Diagnostic Flags

Bit Set High	Description	Comment
b15	Difference in the speed of sound between the three non orthogonal axes is greater than 2.360 m s^{-1} (~ 4°C @ 25°C)	The anemometer path length may have been altered or the anemometer head is broken.
b14	Poor signal lock	There may be an obstruction in the anemometer path or on the transducer face.
b13	Sonic signal amplitude too high	An obstruction, in the anemometer path or on the transducer face, was removed.
b12	Sonic signal amplitude too low	There may be an obstruction in the anemometer path or on the transducer face.

EXAMPLE 1. Measuring the CSAT3 Using the SDM Output and a CR23X Datalogger

```
;{CR23X}
;

;Flag 1 - Set low to configure the CSAT3.

*Table 1 Program
  01:              .1      Execution Interval (seconds)

;Get the data from the CSAT3.
;
01: SDM-CSAT3 (P107)
    1:      1    Reps
    2:      3    SDM Address
    3:     91    Trigger and Get wind & Ts data
    4:      1    Ux Input Location [ Ux_in    ]

;Check the diagnostic word for lost trigger
;condition.  Set Flag 1 low to reconfigure the
;CSAT3 if it is in a lost trigger state.
;
02: If (X<=>F) (P89)
    1:      5    X Loc [ diag     ]
    2:      1    =
    3:  61440    F
    4:     21    Set Flag 1 Low

;Configure the CSAT3.  This is done the first
;time through Table 1 or if the CSAT3 loses
;the trigger.
;
03: If Flag/Port (P91)
    1:     21    Do if Flag 1 is Low
    2:     30    Then Do

;Look for a diag that is not -99999,
;meaning that the CSAT3 is connected
;to the CR23X and the two devices are
;communicating correctly.
;
04: If (X<=>F) (P89)
    1:      5    X Loc [ diag     ]
    2:      3    >=
    3:      0    F
    4:     30    Then Do
```

```
;Send the configuration command to the
;CSAT3 only if it is not acquiring the
;signal or making measurements, e.g.
;diag <> 61503.
;
05: If (X<=>F) (P89)
    1:      5    X Loc [ diag     ]
    2:      2    <>
    3:  61503    F
    4:     30    Then Do

06: Do (P86)
    1:     11    Set Flag 1 High

;Configure CSAT3 with 10 Hz parameters.
;
07: SDM-CSAT3 (P107)
    1:      1    Reps
    2:      3    SDM Address
    3:     10    Set Execution Parameter
    4:      1    Ux Input Location [ Ux_in    ]

08: End (P95)

09: End (P95)

10: End (P95)
```

Input Locations

```
1 Ux_in
2 Uy_in
3 Uz_in
4 Ts_in
5 diag
```

11. MAINTENANCE

The CSAT3, like other ultrasonic anemometers, is unable to measure wind when water droplets are present on the face of the transducers. The CSAT3 will be ready to measure wind as soon as the water droplets evaporate or are removed by the station operator. Remove the water droplets by dabbing a cotton swab or tissue on the face of the transducer. Execute the SDM-CSAT3 instruction with the "Set Execution Parameters" in option 3 to acquire the signal or send the "An" command over the RS-232 link.

> **CAUTION:** Lightly dab the face of the transducers to remove water droplets. Applying excessive force on the face of the transducer may separate the matching layer from the brass housing.

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There are no user serviceable components on the CSAT3. The only time the electronics box must be opened is to change the SDM address. Should the CSAT3 need to be serviced, call (435) 752-3268, to obtain an RMA number.

12. CALIBRATION

The CSAT3 is calibrated over the temperature range of -30° to +50°C. The CSAT3 will not operate outside that temperature range. Contact Campbell Scientific if the CSAT3 will be operated in an environment where temperature is outside the range of -30° to +50°C. The wind offset over that temperature range is ±4 cm s^{-1}. The CSAT3 does not require any field calibration.

APPENDIX A. EXAMPLE FLUX PROGRAM

A copy of the example CR23X program is available on the Campbell Scientific ftp site at ftp://ftp.campbellsci.com/pub/outgoing/files/ec_csat3.exe. The file ec_csat3.exe is a self extracting DOS file. At a DOS prompt type in ec_csat3.exe and press the <Enter> key.

The example flux program measures the CSAT3, a FW05 fine wire thermocouple, and a KH20 as well as a net radiation soil heat flux and soil moisture. Connect the KH20 to differential channel 3 and the FW05 to differential channel 4. The CR23X calculates the virtual sensible heat flux, sensible heat flux, latent heat flux, the momentum flux, and friction velocity, all other cross products required to apply a post processing coordinate rotation on the turbulent fluxes, and the average and variance of u_x, u_y, u_z, T_s, FW, and the average and standard deviation of V_h (krypton hygrometer). The fine wire thermocouple data (FW) and the krypton hygrometer data are shifted to match the CSAT3 pipeline delay.

The CR23X will miss one sample every 30 minutes, because of the additional overhead of computing the 30 minute statistics and fluxes. Background meteorological measurements of temperature and humidity are required to apply the oxygen correction to the latent heat flux measured by the KH20. The energy balance measurements are made in Table 2 to examine energy balance closure.

Connect all the sensors to the CR23X and power to the CSAT3 and the KH20. Download the program to the CR23X. Verify that all the sensors are reading correctly by checking the data in Input Locations 1 through 20. After the system is up and running, reenter the execution interval in Table 1 and compile the program (☀0). This clears all the Intermediate and Input locations and starts the program from scratch.

TABLE A-1. CR23X Sensor Connections

Channel	Sensor	Color
1H	HMP45C (temperature)	Yellow
1L	HMP45C (temperature)	Purple
⏚		
2H	HMP45C (RH)	Blue
2L	HMP45C (RH)	Jumper to 1L
⏚	HMP45C	Clear
3H	KH20	White
3L	KH20	Black
⏚	KH20	Clear
4H	FW05	Purple
4L	FW05	Red
⏚	FW05	Clear
6L	CS615	Green
⏚	CS615	Black
⏚	CS615	Clear
7H	Q7.1	Red
7L	Q7.1	Black
⏚	Q7.1	Clear
8H	HFT3#1	Black
8L	HFT3#1	White
⏚	HFT3#1	Clear
9H	HFT3#2	Black
9L	HFT3#2	White
⏚	HFT3#2	Clear
10H	TCAV	Purple
10L	TCAV	Red
⏚	TCAV	Clear
C1	CSAT3	Green
C2	CSAT3	White
C3	CSAT3	Brown
C4	HMP45C	Orange
C5	CS615	Orange
+12 V	CSAT3	Red
G	CSAT3	Black/Clear
+12 V	HMP45C	Red
+12 V	CS615	Red
G	HMP45C	Black

APPENDIX B. SERIAL COMMUNICATIONS WITH THE CSAT3

B.1 CSAT3 RS-232 COMMANDS

The CSAT3 powers up its RS-232 drivers when it detects that the RTS (request to send) line has been asserted by the PC. All RS-232 communications begin with the PC asserting the RTS line. The CSAT3 responds by asserting the CTS (clear to send) line. The PC must keep the RTS line asserted as long as it is communicating with the CSAT3.

RS-422 communications and short-haul modems do not include an RTS signal. The CSAT3s RS-232 drivers can be asserted by a software setting in the CSAT3. This setting will always power the RS-232 drivers, independent of the RTS line. Contact Campbell Scientific for details.

The unprompted output mode (Table B-1) complicates anemometer data processing software, because the original output format contains no fixed pattern to delimit the CSAT3's 10 byte output record. To configure the CSAT3 to output 12-byte records, with the last two bytes being a fixed pattern of AA55 hex, send an "rs n", where n = 0 (default) means no synchronization code and n = 1 means send the synchronization code, to the CSAT3. As is customary in the DOS environment, 55 hex is transmitted first followed by AA hex. This configuration will be lost if the CSAT3 power is cycled. To save this configuration into non-volatile memory contact Campbell Scientific.

The CSAT3 supports 9600 and 19200 baud RS-232 communications rate. The baud rate is changed by sending a "br n", where n = 0 (default) is 9600 baud and n = 1 is 19200 baud. This configuration will be lost if the CSAT3 power is cycled. To save this configuration into nonvolatile memory contact Campbell Scientific.

There are nine commands that may been sent to the CSAT3 over the RS-232 interface. These commands are described below. Before continuing on, read the section that describes the CSAT3 Trigger (Section 8).

TABLE B-1. RS-232 Command Codes

Command	Trigger before Command	Description	Trigger after Command
&	PC or CSAT3 timer	Unprompted data output mode. Send data and make measurements at the rate specified by the An command.	CSAT3 timer
P[1]	CSAT3 timer or PC	Send the RS-232 status (Table B-9) and trigger the next measurement now.	PC[2]
U[1]	CSAT3 timer or PC	Send the wind data and trigger the next measurement now.	PC[2]
S	PC or CSAT3 timer	Send the RS-232 status (Table B-9). The next measurement will be made in sync with the CSAT3 timer.	CSAT3 timer
W	PC or CSAT3 timer	Send the wind data. The next measurement will be made in sync the CSAT3 timer.	CSAT3 timer
A(1..e)[1,3,4]	PC or CSAT3 timer	Begin acquiring the signals in sync with this command.	No change
O	SDM, PC, or CSAT3 timer	Turn the analog outputs off in sync with the next trigger.	No change
L	SDM, PC, or CSAT3 timer	Turn the analog outputs on with ±32 m s^{-1} full-scale range in sync with the next trigger	No change
H	SDM, PC, or CSAT3 timer	Turn the analog outputs on with ±64 m s^{-1} full-scale range in sync with the next trigger	No change

APPENDIX B. SERIAL COMMUNICATIONS WITH THE CSAT3

1   The CSAT3 will ignore this command if a datalogger (SDM) is triggering the anemometer.

2   After the PC takes over as the trigger source it must continue to trigger the CSAT3 at the rate specified in the Execution Parameter (An). If the CSAT3 does not receive a trigger for three seconds it will enter the Lost Trigger state. The acquire signal (An) command will have to be issued in order for the anemometer to exit the Lost Trigger state.

3   Acquire signal commands.

An	Execution Parameter	An	Execution Parameter
A1	Not Used	A9	10 Hz
A2	1 Hz	Aa	12 Hz
A3	Not Used	Ab	15 Hz
A4	Not Used	Ac	20 Hz
A5	2 Hz	Ad	30 Hz
A6	3 Hz	Ae	60 Hz
A7	5 Hz	Ag	60 Hz $\rightarrow$ 10 Hz
A8	6 Hz	Ah	60 Hz $\rightarrow$ 20 Hz

4   The PC must send the second byte of this command (2..e) within two seconds of the first byte or the anemometer will reset itself. It will then acquire the signal using the Execution Parameter in static memory.

Generic flow charts are given in Figures B-1 and B-2 for collecting data using a PC and the RS-232 port. In Figure B-1 the PC is the Trigger Source and the data acquisition system. In Figure B-2 the anemometer is triggered by its internal timer and a PC is the data acquisition system. Use the logic in Figure B-1 when the CSAT3 is measured along with other analog/digital signals.

set RTS line high
read CTS line
until CTS line is high
send the An command to acquire signals
set timer to zero
sent the U or P command
make other PC based analog/digital measurements
read wind data (U) or long status (P) from serial port
process data
wait until timer = 1/(Execution Parameter)
repeat until finished collecting data
set RTS line low
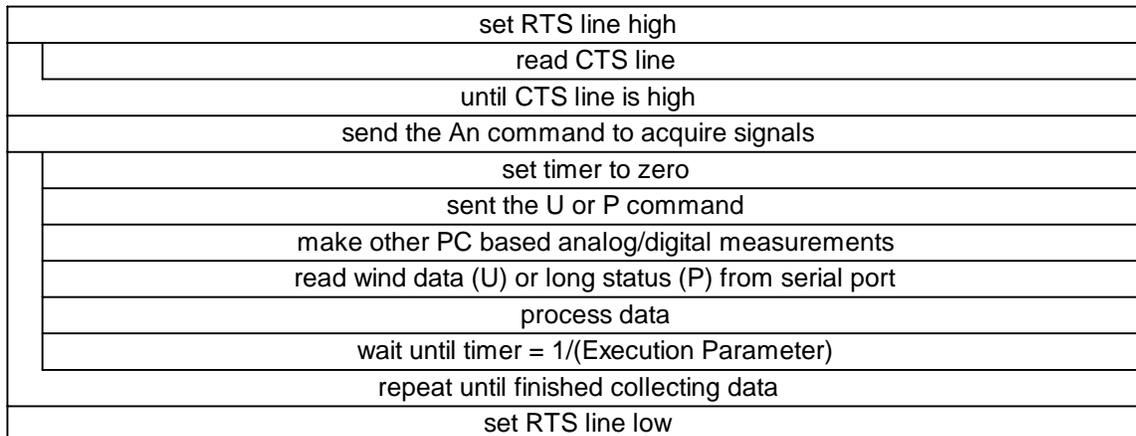
FIGURE B-1. PC as the Trigger Source.

set RTS line high
read CTS line
until CTS line is high
send the An command to acquire signals
send W or S command
check for data serial port
keep checking until there is data on the serial port
read wind data (W) or long status (S) from serial port
send W or S command
process data
repeat until finished collecting data
set RTS line low
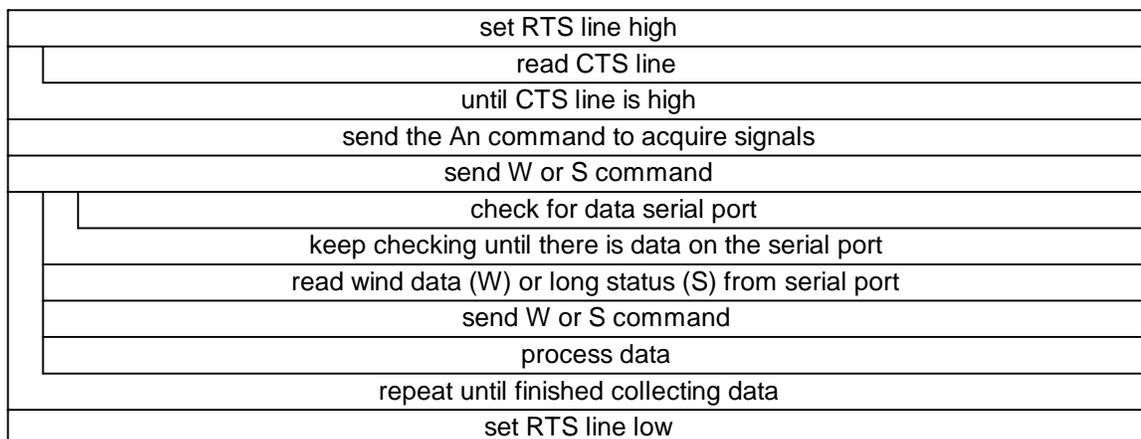
FIGURE B-2. CSAT3 as the Trigger Source.

B.2 CSAT3 BINARY DATA OUTPUT FORMAT

Five words are sent by the CSAT3's RS232 output. Words 0 through 3 are 16 bit signed integers and word 4 is 16 bit unsigned integer. The five words are sent starting with word 0 and ending with word 4. A description of each word is given in Table B-2.

TABLE B-2. RS-232 Output

Word 0	Word 1	Word 2	Word 3	Word 4				
b15 - b0	b15 - b0	b15 - b0	b15 - b0	b15 b14 b13 b12	b11 b10	b09 b08	b07 b06	b05 - b00
u_x wind	u_y wind	u_z wind	c	diagnostic flags	u_x range	u_y range	u_z range	counter

B.3 WORDS 0 THROUGH 3

The u_x, u_y, and u_z wind speed is reported on one of four different ranges. This range is given by bits b11 through b06 in word 4. In order to decode the wind speed, first look at the wind speed range code, then decode the data with the appropriate equations given in Tables B-3 through B-6. The data in words 0 through 3 must first be converted into a base 10 representation before applying the equations in Table B-3 through B-6.

TABLE B-3. Converting u_x Wind from Word 0

Range	Word 4 Range Code		Conversion	Output Resolution
	b11	b10		(mm s^{-1})
0	1	1	u_x wind (m s^{-1}) = word 0 $*$ 0.001 $*$ 0.25	0.25
1	1	0	u_x wind (m s^{-1}) = word 0 $*$ 0.001 $*$ 0.50	0.50
2	0	1	u_x wind (m s^{-1}) = word 0 $*$ 0.001 $*$ 1.00	1.00
3	0	0	u_x wind (m s^{-1}) = word 0 $*$ 0.001 $*$ 2.00	2.00

TABLE B-4. Converting u_y Wind from Word 1

Range	Word 4 Range Code		Conversion	Output Resolution
	b09	b08		(mm s^{-1})
0	1	1	u_y wind (m s^{-1}) = word 1 $*$ 0.001 $*$ 0.25	0.25
1	1	0	u_y wind (m s^{-1}) = word 1 $*$ 0.001 $*$ 0.50	0.50
2	0	1	u_y wind (m s^{-1}) = word 1 $*$ 0.001 $*$ 1.00	1.00
3	0	0	u_y wind (m s^{-1}) = word 1 $*$ 0.001 $*$ 2.00	2.00

TABLE B-5. Converting u_z Wind from Word 2

Range	Word 4 Range Code		Conversion	Output Resolution (mm s^{-1})
	b07	b06		
0	1	1	u_z wind (m s^{-1}) = word 2 $*$ 0.001 $*$ 0.25	0.25
1	1	0	u_z wind (m s^{-1}) = word 2 $*$ 0.001 $*$ 0.50	0.50
2	0	1	u_z wind (m s^{-1}) = word 2 $*$ 0.001 $*$ 1.00	1.00
3	0	0	u_z wind (m s^{-1}) = word 2 $*$ 0.001 $*$ 2.00	2.00

The speed of sound reported by the CSAT3 is the average between the three sonic paths. The relationship to find the speed of sound is given in Table B-6. Word 3 must be converted to a base 10 representation before applying the equation.

TABLE B-6. Converting Speed of Sound from Word 3

Conversion	Output Resolution	
	(mm s^{-1})	(°C @ 25°C)
speed of sound (m s^{-1}) = word 3 $*$ 0.001 + 340.0	1	0.0017

B.4 WORD 4

Word 4 contains diagnostic information and the reporting range of u_x, u_y, and u_z wind speed. The diagnostic flags, bits b15 through b12, describe the status of the anemometer. A flag is on if the bit is set high. All the flags are on while the anemometer is acquiring signals or is in a lost trigger state.

TABLE B-7. Decoding the Diagnostic Flags from Word 4

Bit Set High	Description	Comment
b15	Difference in the speed of sound between the three non orthogonal axes is greater than 2.360 m s^{-1} (~ 4°C @ 25°C)	The anemometer path length may have been altered or the anemometer head is broken.
b14	Poor signal lock	There may be an obstruction in the anemometer path or on the transducer face.
b13	Sonic signal amplitude too high	An obstruction, in the anemometer path or on the transducer face, was removed.
b12	Sonic signal amplitude too low	There may be an obstruction in the anemometer path or on the transducer face.

Bits b11 through b06 are used in determining the range of the wind speed reported in words 0 through 2.

Bits b05 through b00 are a diagnostic counter. This counter increments once per measurement. The minimum value is 0 and the maximum is 63. The counter wraps from 63 to 0 when the maximum value is incremented by one.

TABLE B-8. Special Case – Not a Number

Not a Number	Word 0		Word 1		Word 2		Word 3		Word 4	
Conditions	hex	base 10	hex	base 10	hex	base 10	hex	base 10	hex	base 10
Not Available	8000	-32768	8000	-32768	8000	-32768	8000	-32768	F03F	61503
Lost Trigger	8000	-32768	8000	-32768	8000	-32768	8000	-32768	F000	61440

B.5 CSAT3 RS-232 STATUS FORMAT

The CSAT3 returns a 10 ASCII byte status in response to an S or P command. This status provides information on the CSAT3's Trigger Source and the Execution Parameter. It also indicates if the analog outputs are on/off, if the CSAT3 is reporting good data, and serial number of the CSAT3. This software serial number matches those on the anemometer head and electronics box.

TABLE B-9. RS-232 Status, Response to the S or P command.

Byte	Description	Value		
0	Trigger Source	0 = CSAT3 Timer	1 = PC	2 = SDM
1	Execution Parameter	see Table B-1		
2	Analog Range	0 = Off	1 = ±32 m s^{-1}	2 = ±64 m s^{-1}
3	Data Status	0 = Good Data	1 = Acquiring Signals	2 = Lost Trigger
4	Terminal Mode	D = Normal Mode	T = CSI Mode	
5-8	CSAT3 Serial Number			
9	P or U	P = Prompted	U = Unprompted	

APPENDIX C. CSAT3 MEASUREMENT THEORY

C.1 THEORY OF OPERATION

C.1.1 WIND SPEED

Each axis of the CSAT3 pulses two ultrasonic signals in opposite directions. The time of flight of the first signal (out) is given by:

$$t_o = \frac{d}{c + u_a} \tag{1}$$

and the time of flight of the second signal (back) is given by:

$$t_b = \frac{d}{c - u_a} \tag{2}$$

where t_o is the time of flight out along the transducer axis, t_b is the time of flight back, in the opposite direction, u_a is the windspeed along the transducer axis, d is the distance between the transducers, and c is the speed of sound.

The windspeed, u_a, along any axis can be found by inverting the above relationships, then subtracting Eq. (2) from (1) and solving for u_a.

$$u_a = \frac{d}{2}\left[\frac{1}{t_o} - \frac{1}{t_b}\right] \tag{3}$$

The windspeed is measured on all three non-orthogonal axis to give u_a, u_b, and u_c, where the subscripts a, b, and c refer to the non-orthogonal sonic axis.

The non-orthogonal windspeed components are then transformed into orthogonal windspeed components, u_x, u_y, and u_z, with the following:

$$\begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix} = A \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{4}$$

where A is a 3 x 3 coordinate transformation matrix, that is unique for each CSAT3 and is stored in ROM memory.

C.1.2 TEMPERATURE

The sonically determined speed of sound can be found from the sum of the inverses of Eq. (1) and (2).

$$c = \frac{d}{2}\left[\frac{1}{t_o} + \frac{1}{t_b}\right] \tag{5}$$

The speed of sound in moist air is a function of temperature and humidity and is given by:

$$c^2 = \gamma P/\rho = \gamma R_d T_v = \gamma R_d T(1 + 0.61q) \tag{6}$$

where γ is the ratio of specific heat of moist air at constant pressure to that at constant volume, P is pressure, ρ is air density, R_d is the gas constant for dry air, T_v is virtual temperature, T is the air temperature, and q is the specific humidity defined as the ratio of the mass of water vapor to the total mass of air (Kaimal and Gaynor, 1991; Wallace and Hobbs, 1977).

Note that γ is a function of specific humidity. It would be convenient if the effects of humidity could be consolidated into one term.

The specific heats for moist air at constant pressure and volume are given by:

$$C_p = qC_{pw} + (1-q)C_{pd}$$

$$= C_{pd}(1 + 0.84q) \tag{7a}$$

$$C_v = qC_{vw} + (1-q)C_{vd}$$

$$= C_{vd}(1 + 0.93q) \tag{7b}$$

where C_p and C_v are the specific heats of moist air at constant volume and pressure, C_{pw} and C_{vw} is the specific heat of water vapor, and C_{pd} and C_{vd} is the specific heat of dry air, respectively (Fleagle and Businger, 1980).

Substitute Eq. (7a) and (7b) into (6) and ignore the higher order terms. This yields

$$c^2 = \gamma_d R_d T_s = \gamma_d R_d T(1 + 0.51q) \tag{8}$$

where T_s is sonic virtual temperature and γ_d is the ratio of specific heat of dry air at constant pressure to that at constant volume (Fleagle and Businger, 1980; Kaimal and Gaynor, 1991; Kaimal and Businger, 1963; Schotanus et al., 1983). With Eq. (8), the effect of humidity, on the speed of sound, is included in the sonic virtual temperature.

The sonic virtual temperature, in degrees Celsius, is given by Eq. (9), where $\gamma_d = 1.4$ and $R_d = 287.04 \, \text{JK}^{-1} \, \text{kg}^{-1}$.

$$T_s = \frac{c^2}{\gamma_d R_d} - 273.15 \qquad (9)$$

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APPENDIX D. SDM COMMUNICATIONS AND LONG SIGNAL CABLES

D.1 BRIEF DESCRIPTION OF SDM CLOCK RATES

The fastest rate that a datalogger and SDM sensors can communicate via the SDM bus is determined by the number of SDM sensors connected to the SDM bus and properties of the cable used to connect the sensors. This rate, called the SDM clock rate, has been optimized for the standard 7.62 m (25 ft.) SDM signal and power cable supplied with the CSAT3. Instruction SDM-CSAT3 (P107) and SDM Group Trigger (P110) on the CR23X, 21X, and CR10(X), and CSAT3() and SDMTrigger() on the CR9000 use this optimum SDM clock rate by default. For cases when longer lead lengths are required, the SDM clock rate may be slowed down using Instruction Set SDM Clock (P108 for a 21X and P115 for a CR23X and CR10(X)) or SDMSpeed() (CR9000). The SDM Clock rate is changed by entering a parameter between 1 and 255, where 1 is the fastest SDM clock rate and 255 is the slowest.

The appropriate SDM clock rate for a given system configuration, can be found with the example datalogger programs listed at the end of this section. The example programs start with the default SDM clock rate, clock parameter equal to 1, and systematically slow the rate down until there are no SDM communication errors. They then begin to speed up the rate until SDM communications fails. The processes of slowing down and speeding up the SDM clock rate around the fail threshold continues for approximately three minutes. The datalogger outputs three arrays. The first (array ID = 150) is the SDM parameter, the second (array ID = 151) is the number of failures at an SDM parameter as a percent of attempts at that SDM parameter, and the third (array ID = 152) is the number of attempts at an SDM parameter. The fastest SDM clock rate, that can be used with a particular system setup, can be found from the failure array by selecting the first clock parameter with zero failures. To provide a safety margin select the next slowest clock parameter. Test the new SDM clock rate in the datalogger program that will be used in the experiment.

D.2 CR23X EXAMPLE

Copies of the SDM search programs for the CR23X, 21X, CR10(X), and CR9000 are available on the Campbell Scientific ftp site at ftp://ftp/campbellsci.com/pub/outgoig/files/ sdm_srch.exe. The file sdm_srch.exe is a self extracting DOS file.

Connect all the CSAT3s to the datalogger with the cable in question. Download the example CR23X SDM search program to the datalogger, after the program compiles, set Flag 3 high to begin the experiment. When Flag 2 is set low the experiment is complete. Collect the data from the datalogger and run the example SPLIT parameters files, SDM_TRAN.PAR and SDM.PAR, to sort the data. Identify the correct SDM clock parameter to use for your system configuration from the report generated by the SPLIT parameter file SDM.PAR.

Take the following case, a 575 foot SDM signal and power cable is used to connect a CR23X datalogger and a single CSAT3 anemometer. Communication between the CR23X and CSAT3 fails at the default SDM clock rate. Thus, a slower SDM clock rate must be used. The example CR3X SDM clock rate search program generated the data in Table D1.

TABLE D-1. Data from Example CR23X SDM Clock Rate Search Program

150,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16, ... ,253,254,255
151,100,99999,99999,100,99999,99999,100,99 999,100,96,0,0,0,99999,99999,99999, ... ,99999,99999,99999
152,1,0,0,1,0,0,1,0,17,450,449,449,432,0,0,0, ... ,0,0,0

Run the SPLIT parameter file SDM_TRAN.PAR on the above data set to transpose the data into columns.

Now run the SPLIT parameter file SDM.PAR, to filter out the SDM clock parameters that were not tested, 99999 in array 151. This parameter file also creates a report of the SDM clock

parameters that were tested and their failure rate as a percent of attempts.

The following report was created from the above SPLIT parameter file, SDM.PAR.

TABLE D-2. SDM Clock Rate Report

SDM Clock Rate Report

SDM Param	Failures % Attmpt	Attempts
1	100	1
4	100	1
7	100	1
9	100	17
10	96	450
11	0	449
12	0	449
13	0	432

From the above results, the fastest rate that the SDM bus could run, without encountering communication errors, would be using a value of 11 for the SDM clock parameter in Instruction Set SDM Clock (P115). However, to have a safety margin, a value of 12 is used for the SDM parameter. The test showed that using a value of 12 or the SDM parameter in Instruction Set SDM Clock did not cause the CR23X to overrun the Tables each scan, thus the SDM clock rate is left at parameter 12.

With the CR9000, collect the datatable "report". This datatable contains an SDM Clock Rate Report similar in form to the one generated by SPLIT (Table D-2).

Instruction Set SDM Clock (P115) with a value of 12 for the SDM parameter is added to the flux program and tested.