RESPIRONICS®

Capnostat® 5

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Communication Interface to the Capnostat® 5

File Approval

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Table of Contents

1.0 Overview

The purpose of this document is to describe the protocol for the serial interface between the Capnostat 5 and the host system. This protocol allows for the transmission of waveform data and the setting and reading of various system parameters.

2.0 General Description

The Respironics Novametrix Capnostat 5 sensor is designed to measure CO_2 and O_2 at 100 Hz. The Capnostat 5 sensor is available as a mainstream CO_2 only sensor, a LoFlo sidestream CO_2 only sensor, and a CO_2/O_2mainstream combination sensor. This document provides a description of the serial communications for all three of these varieties of the Capnostat 5. References to O_2 apply to the CO_2/O_2 mainstream combination sensor only. References to the LoFlo sidestream system and the LoFlo sidestream sampling pump apply to the CO_2 sidestream Capnostat 5 only.

3.0 Abbreviations and Terminology

CKSUM	Checksum - each data packet has a checksum for error-detection
CMD	Command byte identifier - each interface command has a unique identifier
exp	Expired
$ETCO_2$	End tidal carbon dioxide
NBF	Number of bytes to follow - number of bytes remaining in a data packet

4.0 General Terminology

4.1 Gas Compensations

The measurement of CO_2 is affected by temperature, pressure, and gas compensations. The barometric pressure as well as the presence of O_2, N_2O, helium, and anesthetic agents in the gas mixture needs to be compensated for by the Capnostat in order to achieve its stated accuracy. The Capnostat provides instrument settings to allow the host to communicate these operating conditions. The instrument settings for these parameters should be set when initially connecting to the Capnostat and whenever there is a change in the conditions at the patient airway.

In the Capnostat 5, the temperature of the gas in the airway also effects the CO_2 measurement. The mainstream Capnostat assumes the gas is at a temperature of $35^{O}C$. Therefore under normal patient use, it is not necessary to adjust this setting. When performing bench tests with bottled gas at a room temperature or when using the LoFlo sidestream Capnostat 5, it is necessary to adjust the instrument setting for the gas temperature to achieve the maximum accuracy for the Capnostat.

The following table shows the affect of various concentrations of expired gas on the reported CO_2 values if the default compensations are not adjusted to match the mixture. The table assumes a CO_2 value of 38 mmHg, a default O_2 setting of 16%, all other compensations are 0%. The airway gas is 5% CO_2, 16% O_2, the temperature is 35 °C, and the barometric pressure is 760 mmHg.

Table 1: Gas Compensation Effects on CO_2

Expired Gas Mixture				
% O_2	**Balance Gas**	**Baro Pressure mmHg**	**Gas Temp °C**	**Reported CO_2 mmHg**
16	N_2	760	35	38
60	N_2	760	35	36.6
60	N_2O	760	35	39.9
40	N_2O	760	35	40.3
16	N_2	**700**	35	33.9(1)
16	N_2	760	**25**	39.1

Notes:
(1) At 700mmHg of pressure, the correct CO_2 value is 35.0 mmHg.

4.2 Capnostat Zeroing

The Capnostat is compatible with a variety of different airway adapters as described in the Capnostat product specification. The Capnostat Zero allows for the Capnostat to accommodate the optical characteristics of each of the different adapter types. A Capnostat zero should be performed whenever the type of adapter being used with the Capnostat is changed. For optimal accuracy, a Capnostat zero should also be performed whenever the Capnostat is connected to the host system.

Before performing a Capnostat zero, the Capnostat should be removed from the patient circuit and the airway adapter type to be used in the circuit should be inserted into the Capnostat. Care should be taken ensure that the airway adapter is clear of any residual CO_2 gas. The maximum elapsed time for a Capnostat zero is 30 seconds. The typical time for a zero is 15 – 20 seconds.

Several Capnostat conditions may also request that a zero be performed. These requests stem from changes in the airway adapter that may indicate that the sensor is not in optimal measuring condition. When this occurs, the airway adapter should be checked to ensure optical occlusions such as mucus have not obscured the adapter window. If occlusions are found, the airway adapter should be cleaned or replaced.

4.3 No Breaths Detected

The “No Breaths Detected” timeout is the maximum time allowed from the detection of one breath to the next breath. Therefore, if the time between breaths exceeds the time out period, the status condition “No Breaths Detected” will be set (see Appendix A). Upon reaching the time-out period, the No Breaths Detected bit will be set in the status byte and the $ETCO_2$ value, respiration rate and inspired CO_2 value will be set to zero.

At start-up or following a zero, three breaths need to be detected before this timer is activated. To clear the “No Breaths Detected” time-out condition three breaths are needed, a zero must occur, or the Reset No Breaths Detected command must be issued.

It is important to note that the Capnostat is not an apnea monitor. The software cannot discriminate between the patient no longer breathing and a sensor that is disconnected from the patient circuit.

5.0 Communication Setup

Serial transmission is performed using the RxD, TxD and GND lines of a standard RS-232 interface. Data is transmitted at a rate of 19200 baud, with a byte size of 8 data bits, 1 stop bit, and no parity checking. No hardware or software flow control (handshaking) is used.

5.1 Transmission Format

Data is transmitted and received as data packets in the following format:

CMD - NBF - [$data\_byte_0$ ... $data\_byte_n$] - CKS

where:

CMD - command byte, range 80h - FFh
NBF- number of bytes to follow this byte, including the checksum
$data\_byte_0$ ... $data\_byte_n$ - data bytes 0 thru n
CKS - checksum

Commands are expected to be transmitted in a timely fashion. No more than 500 msec may pass between the time the first byte is received and the time the last byte of a command is received. If more than 500 msec passes between the first and last bytes of a command, a time-out will occur and the module will record a NACK error (No ACKnowledgement error).

The command structure is formatted in such a way to allow easy synchronizing of command bytes. All command bytes have the most significant bit set to 1. Therefore, the range of all available command bytes is 80h to FFh. All other bytes in the data packet, including the checksum are not allowed to have their MSB bit set, and therefore fall in the range of 0h - 7Fh.

Command Byte:	1xxxxxxxb
NBF byte:	0xxxxxxxb
1 byte data:	0xxxxxxxb
2 byte data:	0xxxxxxxb 0xxxxxxxb
3 byte data:	0xxxxxxxb 0xxxxxxxb 0xxxxxxxb
4 byte data:	0xxxxxxxb 0xxxxxxxb 0xxxxxxxb 0xxxxxxxb
5 byte data[1]:	0000xxxxb 0xxxxxxxb 0xxxxxxxb 0xxxxxxxb 0xxxxxxxb
checksum byte:	0xxxxxxxb

where x signifies either a 0 or 1.

Multiple byte data is encoded as follows:

2 Byte data	xxxxABCD	EFGHIJKL	
transmitted as	0xxABCDE	0FGHIJKL	
3 Byte data	xxxxABCD	EFGHIJKL	MNOPQRST
transmitted as	0xABCDEF	0GHIJKLM	0NOPQRST

The ranges of the data types are as follows:

[1] The range for 5-byte data values is truncated to 32 bits as shown by the ranges specified in Table 2.

Table 2: Data Types and Ranges

Data Type	Unsigned Range	Signed Range
Command Byte	80 - FFh	NA
5 Byte Data[1]	0 – 4,294,967,295	-2,147,483,648, +2,147,483,647
4 Byte Data	0 - 268,435,455	-134,217,728, +134,217,727
3 Byte Data	0 - 2,097,151	-1,048,576, +1,048,575
2 Byte Data	0 - 16383	-8192, +8191
1 Byte Data	0 - 127	-64, +63
Checksum Byte	0 - 7Fh	NA
NBF Byte	0 - 7Fh	NA

The formula for extracting multiple byte data (both signed and unsigned) from a command string is defined as needed in the command definitions.

5.1.1 Packet Checksums

The checksum is computed by the formula:

$$CKSUM = (\text{not } (CMD + NBF + [\text{data byte}_0] + ... [\text{data byte}_n]) + 1) \& 7Fh$$

thus forming the checksum byte, so when added,

$$((CMD + NBF + [\text{data byte}_1] + ... [\text{data byte}_n]) \& 7Fh) + CKSUM) \& 7Fh = 0$$

It is strongly recommended that the checksum byte of each packet be computed to verify a valid packet.

Example:

The Get Revision Command is CAh 02h 00h CHKSUM (refer to section 8.7 for description)

CHKSUM = not (CAh + 02h+ 00h)
= not (CCh)
= 34h

Therefore, the full command is CAh 02h 00h 34h

The following C language source code can be used to compute the checksum for outgoing packets:

```
enum Boolean {FALSE, TRUE};

void AddChecksum(short num, char buf[])
{
      char checksum;
      short i;

      checksum = 0;
      for (i = 0; i < num; i++)
            checksum = (char) (checksum + buf[i]);
      checksum = (char) ((-checksum) & 0x7F);
      buf[num] = checksum;
}
```

The following C language source code can be used to verify the checksum for incoming packets:

```
Boolean IsChecksumValid(char *lpBuf, short num)
{
      char checksum;
```

```
        checksum = *lpBuf;
        lpBuf++;
        num--;

        for (; num > 0; num--) {
              if (*lpBuf >= 0x80)
                    return FALSE;  // invalid data byte
              checksum = (char) (checksum + *lpBuf);
              lpBuf++;
        }

        checksum &= 0x7F;
        if (checksum == 0)
              return TRUE;
        else return FALSE;  // invalid checksum
}
```

5.1.2 About the Packet's Number of Bytes to Follow

All command packets contain a NBF (number of bytes to follow this byte in the command packet) byte. This byte allows ease of decoding a command and future command enhancement. If enhancements to any commands are needed, the present command structure does not need to be changed. Enhancements will be incorporated by increasing the NBF for the command and adding additional bytes to the end of the present command to incorporate the change. This method allows for backward compatibility and future flexibility.

The example below illustrates decoding a packet. The host recognizes an existing command that has two parameters, $data\_byte_1$ and $data\_byte_2$. Instead of hard-coding the location of the checksum byte as the fifth byte in the packet, the host should use the NBF byte. In the existing command, the NBF byte = 3; so after reading the first two bytes (CMD and NBF), the host should read the next three bytes and the checksum byte is the last byte read. Where this really comes into play is when the host encounters the enhanced version of the command. In the enhanced version, an additional byte is added to the data bytes, $data\_byte_3$. The host is not expecting this byte to be there (it is only familiar with the existing command with two data bytes). If the host uses the NBF byte as a guide to the checksum, it can still interpret the packet and validate its integrity. The host will only use $data\_byte_1$ and $data\_byte_2$ and will ignore the unknown $data\_byte_3$, but it can correctly calculate the checksum for the packet.

Example:

Existing Command:

Assume there is an existing command with the following format:

CMD - NBF - $data\_byte_1$ - $data\_byte_2$ - CKSUM

where NBF = 3.

Enhanced Command:

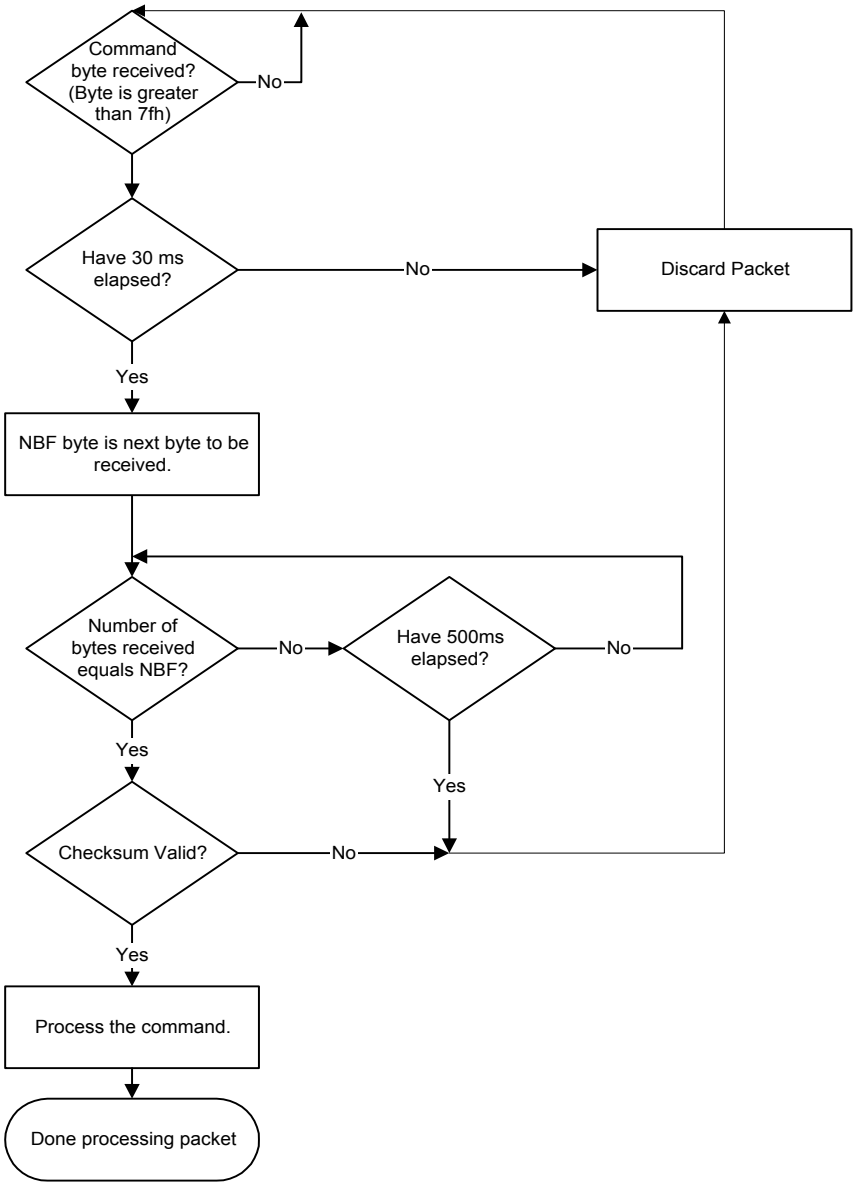
In the enhanced command, an additional byte is needed in the data packet.

CMD - NBF - $data\_byte_1$ - $data\_byte_2$ - $\mathit{data\_byte_3}$ - CKSUM

where NBF = 4, with the additional $\mathit{data\ byte_3}$.

5.1.3 Processing a command packet

The following flow chart describes the proper sequence for receiving and decoding a data packet sent from the Capnostat 5.



The host should wait to receive a command byte. If the byte greater than 7Fh it is a command byte, otherwise the host should discard this byte. Once the command byte is received, the next byte will be the Number of Bytes (NBF) to follow byte. The host should receive the NBF byte within 30 ms of receiving the command byte; if it does not then the host should discard the packet. The host should wait up to 500ms to receive the remaining bytes in the packet based on the NBF count. Once all the bytes in the packet have been received, the checksum byte should be used to ensure the integrity of the packet. If the packet is valid it can now be decoded based on the Command Byte.

6.0 Communicating with the Capnostat 5 via the Serial Interface

6.1 Startup

The Capnostat requires approximately five seconds from power up for internal initialization. The *Stop Continuous Mode* command (command C9, refer to section 8.6) should be sent until a valid response (non-NACK) is received. Once this response is received, the Capnostat startup has completed and the Capnostat is ready to respond to all commands via the serial interface.

6.2 Initialization of the Capnostat

For optimal CO_2 accuracy, the host must initialize several settings on startup or whenever the Capnostat is initially connected to the host.

The Get/Set Instrument Settings Command (Command 84h, described in section 8.3) should be used to input the following environmental conditions:

1) Barometric Pressure (Setting Byte Identified ISB #1)
2) Gas Compensations (O_2, N_2O, He, anesthetic agents) (Setting Byte Identified ISB #11)

These settings should also be updated whenever there is a change in these operating conditions. When the Capnostat is first connected or powered on, the “compensation not yet set” is set in the instrument status bytes (see Appendix A). This status message is cleared whenever the Capnostat receives both a barometric pressure and gas compensation setting via the Get/Set Instrument Settings command.

6.3 Enabling Sensor Capabilities

On startup, the mainstream Capnostat operates with CO_2 only enabled by default. The LoFlo sidestream Capnostat starts up with all capabilities disabled by default. This allows the Capnostat to start up with lower power requirements and also facilitates its use with a variety of different host systems which may or may not support these additional capabilities. If the host system can support other capabilities, such as O_2 or sidestream CO_2, the host must send the *Sensor Capabilities* command (Command CBh, described in section 8.8) and the Capnostat will enable their functionality. This command may also be used to disable these additional capabilities. On the Capnostat mainstream CO_2 sensor, the CO_2 mainstream functionality is always available and cannot be disabled.

6.4 Receiving Real-time Waveforms and Data Parameters

The serial interface commands CO_2 *Waveform /Data Mode* (Command 80h, described in section 8.1), and CO_2/O_2 Waveform Mode (Command 90h, described in section 8.4) are used to start waveform/data transmission. These waveform mode packets will continue to be transmitted from the Capnostat until the waveform/data mode is stopped using the *Stop Continuous Mode* command (Command C9h, described in section 8.6).

The data rate for the continuous waveform modes is 100 Hz, therefore a host can expect a new waveform packet approximately every 10 msec. Every waveform response packet will contain waveform data. The waveform modes may also transmit one of a list of available data parameters in the waveform packet (refer to the DPI tables in the waveform command definitions). Several of these additional data parameters are transmitted at a fixed data rate of once per second. Some are transmitted whenever an event occurs (such as the breath detected DPI). The majority of waveform mode packets will not contain a DPI nor its associated data parameter. No more than one data parameter is transmitted per waveform data packet.

The format of a CO_2 *Waveform/Data Mode* packet is as follows:

```
80h - NBF - WFB1 - WFB2 - [ DPI - DB1 .. DBn ] - CKS
```

where `80h` is the command identifier, `NBF` is the number in the packet, `WFB1` and `WFB2` are the real-time waveform samples, `DPI` is the data parameter identifier, and `DB1` thru `DBn` are the data parameter values. The braces ([ ]) around the data parameter bytes indicate that the transmission of these bytes are optional; some packets may have these bytes and some may not. The `NBF` byte can be used to determine if the waveform packet contains a data parameter.

6.4.1 Transmission of Data Parameters

Data parameters are transmitted after an event has occurred. The breath detected data parameter is transmitted whenever the Capnostat detects a breath. The Extended CO_2 Status/Error data parameter is transmitted every second (100 packets). The calculated parameters are transmitted once a second.

Only one data parameter is transmitted per *CO_2 Waveform/Data Mode* packet. Each data parameter has an associated unique data parameter identifier (DPI). The host uses the DPI value to determine which parameter is being transmitted. In the waveform packet, the data parameter bytes follow the waveform sample bytes. The number of bytes used to encode the data parameter value varies depending on the parameter; refer to the waveform mode commands for details on the size of each data parameter. For example, a waveform packet that has samples for CO_2 waveforms and has data parameter number #3 (Respiration Rate), will consist of the following bytes:

```
80h - 7 - SYNC - WFB1 - WFB2 - 3 - DB1 - DB2 - CKS
```

The decoding of the DPI parameter is dependent on the parameter; again, refer to the *CO_2 Waveform/Data Mode* for details on the decoding the parameter bytes. Many parameters, however, consist of two bytes (high-byte and low-byte). In the example above, to decode the value of Respiration Rate Flow, the following formula should be used:

Respiration Rate = (`DB1 * 128`) + `DB2`

When designing the host interface to the Capnostat 5, the host communications routine should be robust enough to interpret any future changes which may be added to commands. For backward compatibility, additional DPI numbers may be added to an existing command. Since the existing host software will not know how to interpret any future DPIs, it should ignore the DPI and its associated data while still decoding the data contained in the remainder of the command packet.

6.4.2 Validity of Data Parameters

Capnostat errors can cause the CO_2 waveform and selected patient parameters to be set to default values. The table below lists the Capnostat errors and the effect they have on the given parameters. Refer to tables A2 & A3 in Appendix A for suggested responses to each of the given error conditions.

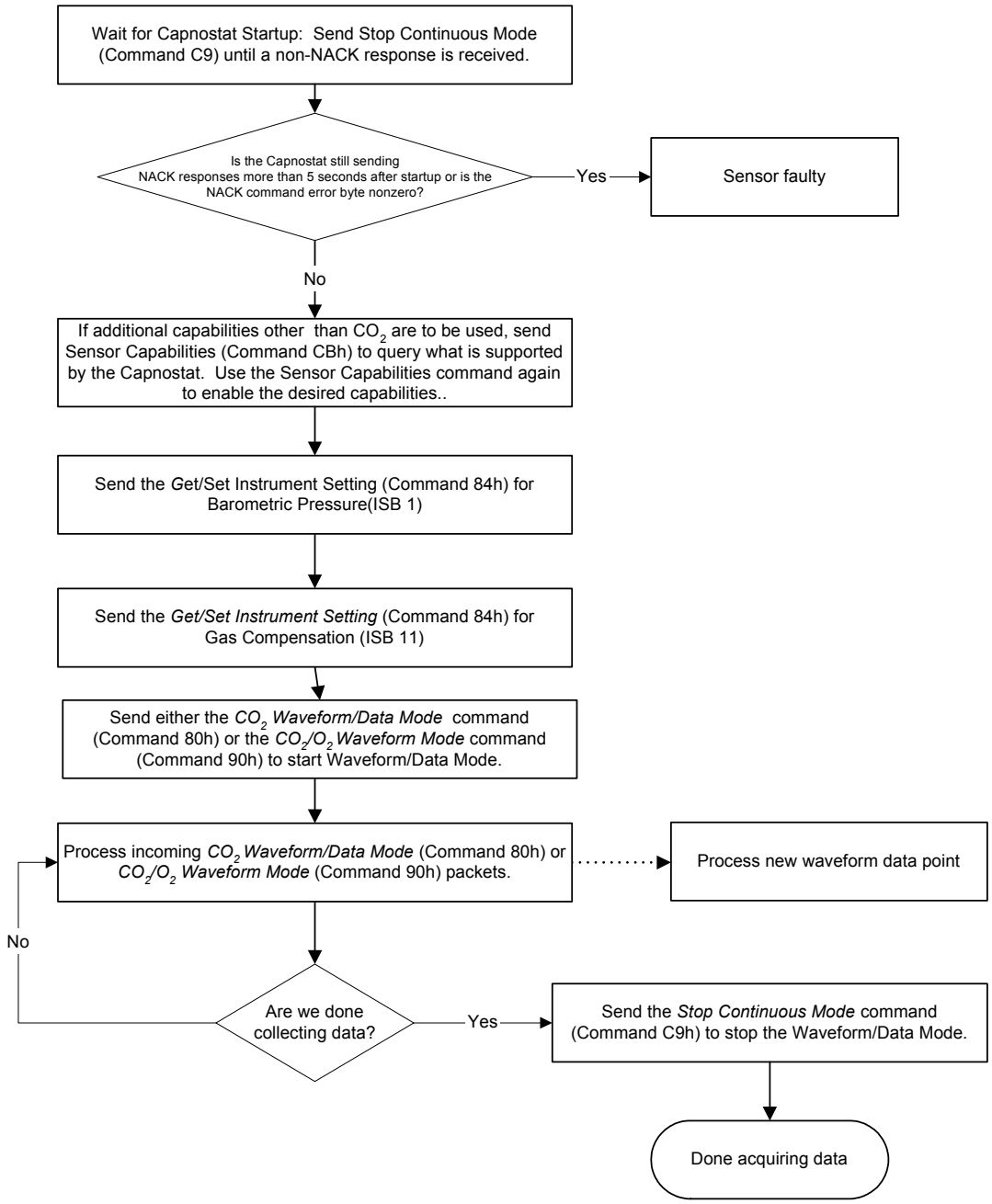
Affected Parameters	Values Sent for Affected Parameters	Error Condition (Cause)
$ETCO_2$ Inspired CO_2 Respiratory Rate	0	Compensations Not Set
		Zero in Progress
		Zero Error
		Zero Required
		EEPROM Not Formatted
		Source Current Drift
CO_2 Waveform	-10.00	Check Airway Adapter
		Source Current Drift
		Source Current Limit Error
		Zero in Progress
		Zero Error

6.5 Stopping Waveform/Data Mode

The *Stop Continuous Mode* command (Command C9h) is used to end the continuous stream of *Waveform/Data Mode* packets.

7.0 General Usage Overview

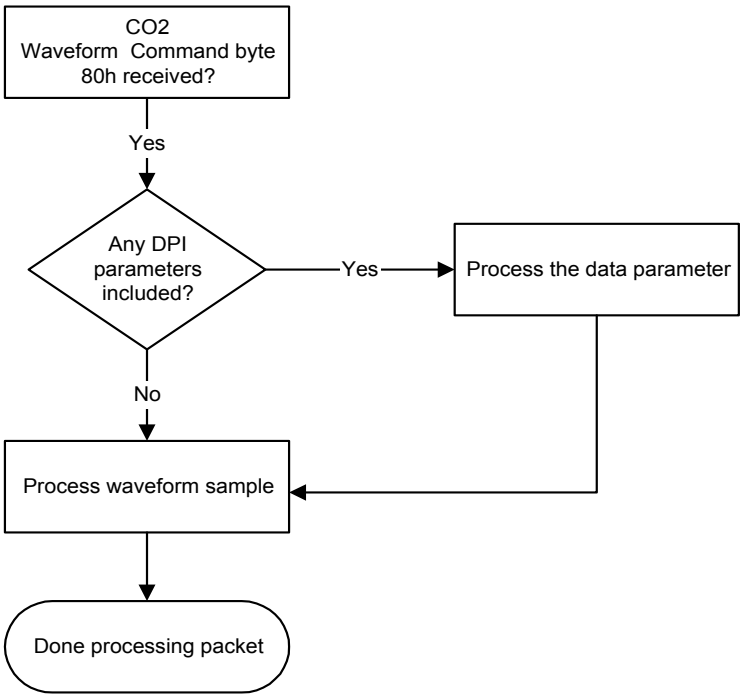
The flow-chart below illustrates the command sequence that should be used to communicate with the Capnostat using the Waveform/Data Mode.



The first step in starting the data acquisition is setting the Barometric Pressure and gas compensations using the *Get/Set Instrument Settings* command. The *Start Waveform/Data Mode* command is used to start the transmission of waveform and parameter data; the Waveform Mode byte is saved from the response packet. Then the host enters a data acquisition loop where incoming CO_2 Waveform/Data Mode packets are received and processed. When data acquisition is complete, the host sends the Stop Continuous Mode command to stop the transmission of data. To

ensure the most accurate measurements of the Capnostat, the Get/Set Instrument Settings should be used whenever the conditions change.

The flow-chart below illustrates the steps that should be taken to properly interpret *CO_2 Waveform/Data Mode* packets.



When the host receives a CO_2 Waveform/Data Mode packet, it should first check the validity of the packet. Any included data parameters can then be decoded. The host should then process the waveform sample that is transmitted. When the packet processing is complete, the host should prepare to process the next packet.

8.0 Command Reference

There are two basic types of commands: continuous response commands and single response commands. Continuous response commands return a continuous stream of data, whereas single response commands return a single response.

To stop a continuous response command from transmitting, use the command *Stop Continuous Mode* (Command C9h; see section 8.6).

While the continuous command is transmitting data, all single response commands are still valid. Due to the high throughput required by the continuous mode commands, single response command transmissions sent while a continuous response command is transmitting should be kept to a minimum. A continuous response command is given transmission preference over single response commands in certain situations. When the module's 256-byte serial transmit buffer is 75% full, only the continuous command will be transmitted to prevent buffer overrun. The response to the single response command is not transmitted. Under normal circumstances, this should not happen; if this is happening, limit the number of commands transmitted or transmit the commands over a longer time period.

The following pages describe the current available commands.

8.1 CO_2 Waveform/Data Mode (Command 80h)

Command:
80h - NBF - 0 - CKS

Command Type:
Continuous Response Command

Response:
80h - NBF – SYNC - CO2WB1 - CO2WB2 - [DPI – DPB1 - DPBn] - CKSUM

Definitions:

80h	command byte
NBF	number of bytes to follow
SYNC	Synchronization counter which increments with each packet sent. Counter starts at 0 and rolls over to zero when it reaches 127. This byte can be used to detect missed packets.
CO2WB1, CO2WB2	CO_2 Waveform x100[1].
DPI	Data Parameter Index (Valid DPI's are defined below) The DPI is sent only when necessary.
DPB1, DPBn	These bytes are sent only as necessary. These bytes contain the DPI data and the number of bytes can vary from zero to five bytes.
CKSUM	Checksum byte

Description:

The CO_2 Waveform Mode command is sent at a rate of 100 Hz. This command is used to transmit CO_2 waveforms and data. Whenever the CO_2 waveform cannot be computed, the minimum CO_2 value (-10.00) is sent as a waveform "penlift" (See section 6.4.2). This corresponds to CO2WB1 & CO2WB2 both being zero. Additionally, the value for 0 in all units (mmHg, kPa, and %) is the same absolute byte value for CO2WB1 & CO2WB2.

The CO_2 waveform can be decoded as follows:

Units	Range	Resolution	Conversion
mmHg	-9.99 to 150.00 mmHg	0.01 mmHg	((128 * CO2WB1) + CO2WB2) – 1000
kPa	-9.99 to 20.00 kPa	0.01 kPa	((128 * CO2WB1) + CO2WB2) – 1000
Percent	-9.99 to 19.70 %	0.01 %	((128 * CO2WB1) + CO2WB2) – 1000

The DPI byte contains patient parameter data. The types of DPI are summarized in the table below and described in detail in Appendix B.

[1] CO_2 values are transmitted in the current CO_2 units which can be set and retrieved using the Get/Set Instrument Setting (ISB # 7). Units cannot be changed while this command is active.

Command 80h DPI Parameter Table

DPI	Number Bytes	Description	Calculation
1	5	CO_2 Status/Errors	See Appendix A
2	2	$ETCO_2$ x10[1]	$ETCO_2 = (DB1 * 2^7) + DB2$
3	2	Respiration Rate	$RespRate = (DB1 * 2^7) + DB2$
4	2	Inspired CO_2 x10[1]	$Insp\ CO_2 = (DB1 * 2^7) + DB2$
5	0	Breath Detected Flag	Breath has been detected when this DPI is sent.
7	2	Hardware Status	Only sent when nonzero. See Appendix A

Refer to the DPI Reference in Appendix B for a detailed description of the DPIs.

8.2 Capnostat Zero Command (Command 82h)

Command:
82h -NBF - CKS

Command Type:
Single Response Command

Response:
82h - NBF - ZSB - CKS

Definitions:
82h - command byte
NBF - number of bytes to follow
ZSB - Zero status byte (see table below)
CKS - checksum

Description:
This command is used to initiate a Capnostat zero. A zero is used to correct for differences in airway adapter types. The Capnostat zero must be performed free of any CO_2. Refer to section 4.2, *Capnostat Zeroing* for a detailed description.

ZSB	Description
0	Capnostat Zero started.
1	Capnostat not ready. See the errors in Appendix A and remedy the Capnostat error before attempting another zero. This is caused by one of the following errors: • In sleep mode • Capnostat temperature not stable • Capnostat sensor faulty
2	Capnostat Zero in already progress (started).
3	Capnostat Zero attempted and breaths have been detected in the last 20 seconds. Remove Sensor and Airway Adapter from presence of CO_2 and wait for Breath Detected Status bit, in Appendix A, to clear before attempting another Zero.

Capnostat Zero Status Byte

8.3 Get/Set Sensor Settings (Command 84h)

Command:

84h - NBF - ISB - [DB_1 - … - DB_N] - CKS

Command Type:

Single Response Command

Response:

84h - NBF - ISB - DB_1 - … - DB_N - CKS

Definitions:

84h - command byte
NBF - number of bytes to follow
ISB - Sensor Setting Byte Identifier (see table below)
DB_1 … DB_N - Data bytes used to set and return the value of a particular sensor setting
CKS - checksum

Description:

This command is used to get and set the various sensor settings in the Capnostat module. When the command is transmitted to the Capnostat without the optional DB_1 … DB_N data bytes, the current value of the specified sensor setting is transmitted in the command's response string. This corresponds to "getting" the current value of the sensor setting. If the DB_1 … DB_N data bytes are transmitted from the host, the sensor setting is set to that value. This corresponds to "setting" the specified sensor setting, and this new value is transmitted in the command's response string.

A host must request a valid setting byte identifier - ISB. If an invalid ISB is requested, the command's response string will return with the ISB = 0 and no returned data bytes.

Examples:

- This example command string gets the current $ETCO_2$ Time Period:

  84h - 02h - 05h – 75h

  The Capnostat's response would be:

  84h - 03h – 05h - 01h – 73h (current $ETCO_2$ Time Period is 1 breath)

- This example command string sets the current $ETCO_2$ Time to 10 seconds:

  84h - 03h - 05h - 0Ah – 6Ah

  The Capnostat's response would be:

  84h - 03h - 05h - 0Ah – 6Ah (current $ETCO_2$ Time Period is 10 seconds)

The table below lists the ISB byte identifiers and the corresponding sensor settings.

ISB	Number of Bytes	Sensor Setting Description
0	0	*Invalid Instrument or Parameter Setting* Number of Data Bytes = 0
1	2	*Barometric Pressure* Default: 760 mmHg. Resolution: 1 mmHg (400-850 mmHg) Conversion: Barometric Pressure = (128 * DB_1) + DB_2 DB_1 = (Barometric Pressure / 128) & 7Fh DB_2 = (Barometric Pressure) & 7Fh Notes: This setting is used to set current Barometric Pressure.
4	2	*Gas Temperature* Default: 35.0 ^{o}C. Resolution: 0.1 ^{o}C (0.0 – 50.0 ^{o}C) Conversion: Gas Temperature ^{o}C = (128 * DB_1 + DB_2) / 10 Notes: This setting is used to set temperature of the gas mixture. This setting is useful when bench testing using static gasses where the temperature is often room temperature or below.
5	1	*Current $ETCO_2$ Time Period* Default: 10 Seconds. Conversion: $ETCO_2$ time period = DB_1 = 1 1 breath = 10 10 seconds = 20 20 seconds Notes: This setting is used to set the calculation period of the $ETCO_2$ value. The end-tidal CO_2 value is the highest peak CO_2 value of all end of expirations (end of breaths) over the selected time period. If less than two breaths exist in the selected time period, the value will be the maximum $ETCO_2$ value for the last two breaths.
6	1	*No Breaths Detected Timeout* Default: 20 seconds. Resolution: 1 second (10 to 60 seconds) Conversion: No Respiration Timeout = DB_1 Notes: This setting is used to set the no breaths detected time-out. This time-out is the time period in seconds following the last detected breath at which the Capnostat will signal no breaths detected.
7	1	*Current CO_2 Units* Default: mmHg Conversion: CO_2 units = DB_1 = 0 CO_2 units are mmHg = 1 CO_2 units are KPa = 2 CO_2 units are percent (%) Note: Continuous waveform mode commands (the CO_2 Waveform Mode command [command 80h] and the CO_2/O_2 Waveform Mode command [command 90h]) MUST NOT be active when this command is used otherwise this command will be ignored and the setting will remain unchanged. If any continuous waveform mode command is active, the following must occur: 1) The continuous waveform mode command must first be stopped with the Stop Continuous Mode Command (command C9h). 2) The CO_2 Units Setting can be changed with this command. 3) Then the continuous waveform command may be restarted.

ISB	Number of Bytes	Sensor Setting Description
8	1	*Sleep Mode* Default: Normal Operating Mode Conversion: Sleep mode setting = DB_1 = 0 Normal Operating Mode = 1 Mode 1 – Turn Off Source (Maintain Heaters) = 2 Mode 2 - Maximum Power Savings Notes: Sleep mode is used to save power when the host monitor is in standby mode. There are two sleep modes available for the Capnostat. Using Sleep Mode 1 maintains the heaters so the Capnostat is able to run immediately after exiting the sleep mode. Mode 2 will require the Capnostat to go through its warm up sequence when exiting this mode and a delay will be introduced until the system has stabilized.
9	1	*Zero Gas Type* Default: zero on room air Conversion: zero gas = DB_1 = 0 zero on N_2 = 1 zero on room air Notes: When performing a zero on room air, this setting should be set to room air (the default). Only change to nitrogen (N_2) when performing a zero on 100% N_2 gas; this is provided for use in a laboratory environment.
11	4	*Get/Set Gas Compensations* DB_1 = O_2 Compensation Default: 16 % Conversion: O_2 compensation = DB_1 Resolution: 1 % (0 – 100 %) DB_2 = Balance gas Default: 0 (room air) Conversion: balance gas = DB_2 = 0, room air = 1, N_2O = 2, Helium DB_3, DB_4 = Anesthetic agent x10 Default: 0.0 % Conversion: Anesthetic agent = [(DB_3 * 2^7) + DB_4] / 10 Resolution: 0.1 % (0.0 – 20.0 %) Notes: Use this setting to correct for the compensation of the gas mixture administered to the patient. Anesthetic agent is ignored when the balance gas is set to helium. Example: An oxygen value of 40%, balance N_2O with 3.5 % anesthetic agent would correspond to the following data byte values: DB_1 = 40, DB_2 = 1, DB_3 = 0, and DB_4 = 35

ISB	Number of Bytes	Sensor Setting Description
18	10	*Get Sensor Part Number (Get Only)* Conversion: DB_1 - DB_{10} are ASCII characters *Notes: The sensor part number is a string of 10 ASCII characters that is **not** NULL terminated.*
19	1	*Get OEM ID (Get Only)* Conversion: ID = DB_1 Notes: The ID is a 7-bit identifier which is set at the factory to a unique value for each OEM.
20	5	*Get Sensor Serial Number* (Get Only) Conversion: Serial Number = $(DB_1 * 2^{28}) + (DB_2 * 2^{21}) + (DB_3 * 2^{14}) + (DB_4 * 2^7) + DB_5$ Notes: This is a 32-bit number that is unique for each Capnostat.
21	3	*Get Hardware Revision Number* (Get Only) Conversion: DB_1 – DB_3 are ASCII characters. Note: This command returns the current hardware revision level. The revision level is a string of 3 ASCII characters that is **not** NULL terminated.
23	5	*Get Total Use Time* (Get Only) Resolution: 1 minute Update frequency: every 5 minutes Conversion: minutes of use = $(DB_1 * 2^{28}) + (DB_2 * 2^{21}) + (DB_3 * 2^{14}) + (DB_4 * 2^7) + DB_5$ Notes: This is the total time the sensor has been in service. The usage time is sent in 1-minute units, however the usage time is updated once every 5 minutes so the usage time will not return contiguous values, as numbers between the five minute updates will be skipped.
24	5	*Get Last Zero Time* (Get Only) Resolution: 1 minute Update frequency: every 5 minutes Conversion: minutes of use = $(DB_1 * 2^{28}) + (DB_2 * 2^{21}) + (DB_3 * 2^{14}) + (DB_4 * 2^7) + DB_5$ Notes: This is the total time that has elapsed with the sensor in service since the last Capnostat Zero. The time is sent in 1-minute units, however the value is updated once every 5 minutes so values between the five minute updates will be skipped.
25	5	*Get Pump Total Use Time **(Capnostat 5 with LoFlo only)*** (Get Only) Resolution: 1 minute Update frequency: every 5 minutes Conversion: minutes of use = $(DB_1 * 2^{28}) + (DB_2 * 2^{21}) + (DB_3 * 2^{14}) + (DB_4 * 2^7) + DB_5$ Notes: This is the total time the pump has been on. The usage time is sent in 1-minute units, however the usage time is updated once every 5 minutes so the usage time will not return contiguous values, as numbers between the five minute updates will be skipped.
26	5	*Get Pump Max Use Time **(Capnostat 5 with LoFlo only)*** (Get Only) Resolution: 1 minute Conversion: maximum minutes of use = $(DB_1 * 2^{28}) + (DB_2 * 2^{21}) + (DB_3 * 2^{14}) + (DB_4 * 2^7) + DB_5$ Notes: This value indicates the maximum rated lifetime of the sampling pump.

ISB	Number of Bytes	Sensor Setting Description
27	1	*Disable Sampling Pump* Default: Normal Operating Mode Conversion: Pump Disabled Setting = DB_1 = 0 Normal Operating Mode = 1 Pump Disabled Notes: This setting allows the pump to be forced off. In Normal Operating Mode, the pump will be turned on when the sampling cell is connected and no pneumatic system errors are detected. In Pump Disabled Mode, the pump will remain off in all circumstances.

8.4 CO_2 / O_2 Waveform Mode (Command 90h)

Command:

90h - NBF - 0 - CKS

Command Type:

Continuous Response Command

Response:

90h - NBF – SYNC - CO2WB1 - CO2WB2 - O2WB1 - O2WB2 – [DPI – DPB1 - DPBn] - CKSUM

Definitions:

90h	command byte 90h
NBF	number of bytes to follow
SYNC	Synchronization counter which increments with each packet sent. Counter starts at 0 and rolls over to zero when it reaches 127. This byte can be used to detect missed packets.
CO2WB1, CO2WB2	CO_2 Waveform x100[1]
O2WB1, O2WB2	O_2 Waveform x100[1]
DPI	Data Parameter Index (Sent only when necessary. Valid DPI's are defined in the below table)
DPB1, DPBn	These bytes are sent only as necessary. These bytes contain the DPI data and the number of bytes can vary from zero to five bytes. Refer to the below table.
CKSUM	Checksum byte

Description:

The CO_2 / O_2 Waveform Mode command is sent at a rate of 100 Hz. Whenever the CO_2 or O_2 waveforms cannot be computed, the minimum CO_2 or O_2 value (-10.00) is sent as a waveform "penlift" (See section 6.4.2). This corresponds to CO2WB1 & CO2WB2 (or OWB1 & OWB2) both being zero. Additionally, the value for 0 in all units (mmHg, kPa, and %) is the same absolute byte value for both waveform data bytes.

The CO_2 and O_2 waveforms (O_2 in percent only) can be decoded as follows:

Units	Range	Resolution	Conversion
mmHg	-9.99 to 150.00 mmHg	0.01 mmHg	((128 * CO2WB1) + CO2WB2) – 1000
kPa	-9.99 to 20.00 kPa	0.01 kPa	((128 * CO2WB1) + CO2WB2) – 1000
Percent	-9.99 to 19.70 % (for CO_2) -9.99 to 100.00 % (for O_2)	0.01 %	((128 * CO2WB1) + CO2WB2) – 1000 and ((128 * O2WB1) + O2WB2) – 1000

[1] CO_2 values are transmitted in the current CO_2 units which can be set and retrieved using the Get/Set Instrument Setting (ISB # 7). Units cannot be changed while this command is active.

Command 90h DPI Parameter Table

DPI	Number Bytes	Description	Calculation
1	5	CO_2 Status	See Appendix A
2	2	$ETCO_2$ x10[1]	$ETCO_2 = (DPB1 * 2^7) + DPB2$
3	2	Resp Rate	RespRate = $(DPB1 * 2^7) + DPB2$
4	2	Insp CO_2[1]	Insp $CO_2 = (DPB1 * 2^7) + DPB2$
5	0	Breath Detected Flag	Breath has been detected when this DPI is sent.
6	2	O_2 Status	See Appendix A
7	2	Hardware Status	Only sent when nonzero. See Appendix A
10	2	FiO_2	Fractional Inspired $O_2 = (DPB1 * 2^7) + DPB2$
11	2	FeO_2	Fractional Expired $O_2 = (DPB1 * 2^7) + DPB2$

Refer to the DPI Reference in Appendix B for a detailed description of DPIs.

[1] CO_2 values are transmitted in the current CO_2 units which can be set and retrieved using the Get/Set Instrument Setting (ISB # 7). Units cannot be changed while this command is active.

8.5 NACK Error (Command C8h)

Response:

C8h - NBF - CEB - CKS

Definitions:

C8h - command identifier
NBF - number of bytes to follow
CEB - command error byte (see Table below)
CKS - checksum byte

Description:

The communications protocol has built-in command error checking. The following command errors are detected:

CEB	NACK Error	Description
0	Bootcode	Waiting for bootloader – Startup only
1	Invalid Command	This occurs whenever a command other than the defined commands is received. It can also occur when a command byte (byte > 80h) is expected and the byte is < 80h.
2	Checksum Error	This occurs whenever an improper checksum is received.
3	Time-out Error	This occurs whenever more than 500 msec elapses between the first and last bytes of a command.
4	Invalid Byte count	This occurs whenever the byte count is less than the number of bytes expected for a particular command.
5	Invalid Data Byte	This occurs whenever a non-command byte is expected and a command byte (byte with MSB=1) is encountered.
6	System Faulty	This occurs when the system is in a non-functional state due to a system fault. All commands will be ignored. Contact Service.
7		
8		
9		
10		
11 - 19	Not used	Reserved for future use.
20	System Faulty	This occurs when the system is in a non-functional state due to a system fault. All commands will be ignored. Contact Service.
21		
22		
23		
24		

NACK Errors

During normal operation, command errors should not occur. In cases where one of these errors is encountered, the CO_2 module will respond by sending the appropriate NACK response.

If system faulty errors are encountered, the Capnostat is in a non-functional state and all commands will be rejected. Check that the sensor is properly plugged in. Reinsert or reset the sensor if necessary. If the error persists, return the sensor to the factory for servicing

8.6 Stop Continuous Mode (Command C9h)

Command:

C9h - NBF - CKS

Command Type:

Single Response Command

Response:

C9h - NBF - CKS

Definitions:

C9h - command
NBF - number of bytes to follow
CKS - checksum

Description:

This command is used to stop the data transmission of a continuous response command. The response is sent as soon as the current process is halted. Any data packet currently being sent will be sent in its entirety before the current continuous response is halted. If the waveform mode command is not active, the Stop Continuous Mode command will send the appropriate response but the command has no effect.

8.7 Get Software Revision (Command CAh)

Command:
CAh - NBF - RF - CKS

Command Type:
Single Response Command

Response:
CAh - NBF - RF - SRB0 - SRB1 - .... - SRBn - CKSUM

Definitions:
CAh - command byte
NBF - number of bytes to follow
RF - revision format: (valid range: 0 – 3, see *Revision Strings* table below)
SRB0 - SRBn - Maximum of 35 bytes containing ASCII characters.
CKSUM - checksum

Description:
This command returns the current software revision level. The revision level is a string of a maximum of 35 ASCII characters that is not NULL terminated; its length is NBF - 2.

The byte RF describes which revision string is requested. The table below describes the available revision string requests.

Revision Strings

RF Byte	Revision String
0	Full Software Revision This string describes the current main software revision level and the date of the revision. This is the default string that is transmitted if the RF byte is not one of the valid selections. Example: Released Software - code-instr-09 4/26/95 15:19:53 Unreleased Software - code-instr-xxp 5/13/95 9:25:23 where: code - code identifier (main code, boot code), language identifier, or OEM identifier instr - Sensor type (e.g., “capno5“) 09 – revision number xxp – unreleased software
2	Bootcode revision This string describes the current bootcode software revision level and the data of the revision. Example: Released bootcode – boot-capno5-02 4/26/02 15:15:40 Unreleased bootcode – boot-capno5-xxp 5/25/02 14:10:02 The revision information follows the same nomenclature as outlined in the description for RF Byte 0.

8.8 Sensor Capabilities (Command CBh)

Command:

CBh – NBF – SCI – [SCB] – CKS

Command Type:

Single Response Command

Response:

CBh – NBF – SCI – SCB – CKSUM

Definitions:

CBh - command byte
NBF - number of bytes to follow
SCI - sensor capabilities index
SCB - sensor capabilities byte (optional: see description below)
CKSUM - checksum

Description:

This command returns the sensor capabilities (including whether it supports O_2 or LoFlo) and also allows for these capabilities to be enabled or disabled. When the mainstream Capnostat is powered on, only the mainstream CO_2 is enabled. All other sensor capabilities are off by default at startup. If the Capnostat and the host system both support the additional O_2 or LoFlo capabilities, then they may be enabled using this command. This command should first be used by the host system (with SCI = 0) to determine if the Capnostat supports these additional capabilities.

To retrieve the sensor capabilities available in the sensor, send this command with SCI = 0. To query the Capnostat to determine which capabilities are currently enabled, send this command with SCI = 1. Sending this command with the SCI set to 2 will enable and disable the associated capabilities sent in the SCB byte. The only two instrument capabilities that can be enabled at the same time are the CO_2 Mainstream and O_2 Mainstream options.

NOTE: The SCB is only sent to the Capnostat when enabling sensor capabilities. It is always returned in the response from the Capnostat to indicate either the available capabilities (for SCI = 0) or the current state of the enabled capabilities (SCI = 1 or SCI = 2).

Sensor Capabilities Index (SCI) Table:

SCI	Definition	Description
0	Get available capabilities	Return all sensor capabilities available (regardless of whether or not they are enabled).
1	Get current capabilities	Return the currently enabled sensor capabilities.
2	Set current capabilities	Set the enabled sensor capabilities. Returns the currently enabled sensor capabilities.

Sensor Capabilities Byte (SCB) Table:

Bit	Definition	Description
0	CO_2 Mainstream	When available, this bit is always enabled. This can be combined with O_2 Mainstream.
1	CO_2 Sidestream	LoFlo CO_2 Sidestream
2	O_2 Mainstream	O_2 Mainstream. This can be combined with CO_2 Mainstream.

8.9 Reset No Breaths Detected Flag (Command CCh)

Command:
CCh - NBF- CKSUM

Command Type:
Single Response Command

Response:
CCh - NBF- CKSUM

Definitions:
CCh - command byte
NBF - number of bytes to follow
CKSUM - checksum

Description:
This command is used to force the system to clear the No Breaths Detected flag. When this command is issued, the status bit for No Breaths Detected is cleared and the system enters a state similar to initial startup. Note that all DPI parameters are also reset. This command can be sent even if the status flag for No Breaths Detected is not set.

8.10 Reset Capnostat (Command F8h)

Command:
F8h - NBF- CKSUM

Command Type:
Single Response Command

Response:
None

Definitions:
F8h - command byte
NBF - number of bytes to follow
CKSUM - checksum

Description:
This command is used to cause a system watchdog reset in the sensor. When this command is issued, the system enters an infinite loop and a watchdog timer resets the system one second later.

Appendix A: Status/Error Bytes

A.1 CO_2 Status/Error

The status of the system is encoded in DPI #1 of the CO_2 Waveform Data Mode packet (command 80h) and the CO_2/O_2 Waveform Mode packet (command 90h).

The status of the system can be determined though two methods: the Extended Status Bytes and the Prioritized Status byte.

The *Extended Status Bytes* contain the full status information for the Capnostat at the time of transmission. This allows for multiple messages to be displayed by the host simultaneously. For each status condition, a value of '1' signifies the given condition exists. This allows for multiple messages to be displayed by the host simultaneously.

The *Prioritized Status Error Byte* can be used to simplify the messaging for the host. With this status, only the highest priority message will be transmitted. The host can then use the suggested Message/ Response to indicate to the user how to proceed. There is no correlation between the value byte of the status and its priority in the list.

- The *No Respiration Timeout* and *Breaths Detected* flags are only available through the Extended Status Byte and should be monitored.
- For the LoFlo sidestream Capnostat, the *Pump Off*, *Pump Life Exceeded*, and *Sidestream Adapter Not Detected* flags are only available through the Extended Status Byte and should be monitored.
- Values for the Prioritized Status Error Byte not specified in Table A.4 are reserved for future use by Respironics. Host software should ignore any undefined Prioritized Status Error Bytes not specified in the table.

There are several levels of status message:

1) *Hardware Error* – These are severe latched errors that usually require contacting Service for correction.

2) *Correctable Error* – These messages are used to indicate that a condition exists that may impair the sensor from correctly calculating CO_2 values. These messages often require user interaction, such as a Capnostat Zero, to remove the error.

3) *Informative* – These messages relay to the host the current state of the Capnostat. The can be used by the host to decide if any action is required or to give further detail to an error message.

The tables below describe the CO_2 status bytes.

A.2 O_2 Status/Error

The status of the system is encoded in DPI #6 of the CO_2/O_2 Waveform Data Mode packet (command 90h).

The extended status byte information for O_2 follows the same format as that for CO_2 described in section A.1 above.

A.3 Hardware Status/Error

The status of the hardware is encoded in DPI #7 of the CO_2 Waveform Data Mode packet (command 80h) and the CO_2/O_2 Waveform Data Mode packet (command 90h). It is only sent by the Capnostat 5 when it is nonzero.

A.4 Prioritized CO_2 Status/Error Byte

Priority	Value	Suggested Message/Response	Status Type	Description
1 Highest	01h	*"Sensor Over Temp"* Make sure sensor is not exposed to extreme heat (heat lamp, etc.). If error persists, return sensor to factory for servicing.	Hardware Error	The sensor temperature is greater than 40 °C.
2	02h	*"Sensor Faulty"* Check that the sensor is properly plugged in. Reinsert or reset the sensor if necessary. If error persists, return sensor to factory for servicing	Hardware Error	One of the following conditions exist: Capnostat Source Current Failure EEPROM Checksum Faulty Hardware Error
3	03h	*No message* The host must set the Barometric Pressure and compensations to clear this error; no user intervention should be required.	Correctable Error	Barometric Pressure and/or gas compensations (N_2O, O_2, helium, and anesthetic agent) have not been set since power on. For CO_2 to be calculated with the stated accuracy, these values should be set whenever the Capnostat is plugged in.
4	04h	*"Capnostat in Sleep Mode"*	Informative	This bit is set when sensor has been placed in sleep mode.
5	05h	*"Zero In Progress* "	Informative	A Capnostat Zero is currently in progress.
6	06h	*"Sensor Warm Up "* This error condition is normal at startup. This error should clear when the warm up is complete.	Informative	One of the following conditions exist: Sensor under temperature Temperature not stable Source Current unstable
7	0Ah	"Check Sampling Line" Check that the sampling line is not occluded or kinked.	Correctable Error	This error occurs whenever the pneumatic pressure is outside the expected range.
8	07h	*"Zero Required"* To clear, check airway adapter and clean if necessary. If this does not correct the error, perform an adapter zero. If you must adapter zero more than once, a possible hardware error may exist.	Correctable Error	One of the following conditions exist: Zero Required Zero Required: Zero Error
9	08h	*"CO_2 Out of Range"* If error persists, perform a zero.	Correctable Error	The value being calculated is greater than the upper CO_2 limit (150 mmHg, 20.0 kPa, or 19.7 %). The maximum value output is the upper CO_2 limit.

10 Lowest	09h	*"Check* Airway *Adapter"* To clear, clean airway adapter if mucus or moisture is seen. If the adapter is clean, perform a Capnostat zero.	Correctable Error	Usually caused when the airway adapter is removed from the Capnostat or when there is an optical blockage on the windows of the airway adapter. May also be caused by failure to perform Capnostat zero to when adapter type is changed.

NOTE: Prioritized Status values beyond 0Ah (0Bh – 7Fh) are reserved for future use by Respironics. Any undefined prioritized status values should be ignored.

CO_2 Status/Error Byte

Byte 1: Bit	Status/Error	Status Type	Description	Suggested Message/Response
7	Sync	NA	Always zero.	NA
6	No Breaths Detected	Informative	This message results whenever the "no breaths detected" timeout condition occurs.	*"CO_2 No Breaths Detected"*
5	In Sleep Mode	Informative	This bit is set when the Capnostat has been placed in sleep mode.	"*Capnostat* in Sleep Mode"
4	CO_2 Sensor NOT Ready to Zero	Informative	This bit is set if the CO_2 sensor is not ready for a Capnostat Zero. If the Zero Required (Byte 2, Bit 1) is set, and this bit is set, one or more of the following conditions may exist: • Breaths detected (Byte 2, Bit 2) • Temperature is not stable (Byte 2, Bits 1,0) • Source Current unstable (Byte 2, Bits 5) • In sleep mode. (Byte 2, Bits 5)	No Message
3	CO_2 Out of Range	Correctable Error	The value being calculated is greater than the upper CO_2 limit (150 mmHg, 20.0 kPa, or 19.7 %). The maximum value output is the upper CO_2 limit.	*"CO_2 Out of Range"* If error persists, perform a zero.
2	Breaths Detected	Informative	Breaths have been detected by the Capnostat within the last 20 seconds while a Capnostat zero was attempted.	No message. Disconnect airway adapter from patient circuit and wait for status to clear before attempting a Capnostat Zero.
1	Check Adapter	Informative	Usually caused when the airway adapter is removed from the Capnostat or when there is an optical blockage on the windows of the airway adapter. May also be caused by failure to perform a Capnostat zero when the adapter type is changed.	*"Check Adapter"* To clear, clean airway adapter if mucus or moisture is seen. If the adapter is clean, perform a Capnostat zero.
0	Negative CO_2 Error	Informative	This error occurs when the calculated CO_2 is less than zero for a period of time. This can be caused by a Capnostat that was zeroed with CO_2 in the airway or by an optical blockage of the airway adapter.	*"Check Adapter"* To clear, check airway adapter and clean if necessary. If this does not correct the error, perform an adapter zero.

Byte 2: Bit	Status/Error	Status Type	Description	Suggested Message/Response
7	Sync	NA	Always zero.	NA
6,5	Capnostat Source Current	Informative	00 – source current normal	No message
		Informative	01 – Waiting for source current stabilization. The Capnostat source current is required to stabilize before a zero can be performed. This error clears in approximately 20 seconds.	No message If calibration is required while this error is set, the message "*Wait for Sensor"* can be shown.
		Hardware error	10 – source current drift. The current through the source has drifted from the value read at factory calibration. The sensor can no longer be zeroed to factory specification.	*"Sensor Faulty"* Check that the sensor is properly plugged in. Reinsert or reseat the sensor if necessary. If error persists, return sensor to factory for servicing.
		Hardware error	11 – source current limit error. The current through the source is outside of operational specification.	*"Sensor Faulty"* Check that the sensor is properly plugged in. Reinsert or reseat the sensor if necessary. If error persists, return sensor to factory for servicing.
4	Compensation Not Yet Set	Correctable error	Barometric Pressure or gas compensations have not been set since power on. For CO_2 to be calculated with the highest accuracy, these values should be set whenever the Capnostat is plugged in or the gas compensations change. When this error bit is active, the Capnostat will send end tidal CO_2 ($ETCO_2$), Inspired CO_2, and respiratory rate as zeroes.	*"Capnostat not initialized"* Set the Barometric Pressure and gas compensations to clear this error.

Byte 2: Bit	Status/Error	Status Type	Description	Suggested Message/Response
3,2	Capnostat Calibration Status	Informative	00 – No Zeroing in Progress	No message
			01 – Zeroing in Progress - A Capnostat Zero is currently in progress.	*"Zero In Progress* "
			10 – Zero Required - A Capnostat Zero is required for the Capnostat, for one of the following reasons: • Check Adapter (Byte 1, Bit 1) • Negative CO_2 error (Byte 1, Bits 1, 0)	*"Zero Required"* See cause of status bit to see if additional messages should be displayed.
			11 – Zero Required: Zero Error - An error was found during Capnostat zero. This could occur if the airway adapter is occluded or CO_2 gas is present in the adapter. For LoFlo, this could indicate attempting to zero when the sample cell is not inserted.	*"Zero Required* " Perform adapter zero to correct. If you must adapter zero more than once, a possible hardware error may exist.
1, 0	Capnostat Temperature Status	Informative	00 – Stable at Operating Temperature – The sensor temperature is stable and ready for operation.	No message
			01 – Below Operating Temperature - The sensor has not reached operating temperature. This condition is typical at power on or after inserting a sensor into the host system.	"*Sensor Warm Up* " If calibration is required while this error is set, the message "*Wait for Sensor"* can be shown.
			10 - Above Operating Temperature - The internal temperature of the sensor is above the operating temperature.	*"Sensor Over Temp"* Make sure sensor is not exposed to extreme heat (heat lamp, etc.). If error persists, return sensor to factory for servicing.
			11 – Temperature Unstable	*"Sensor Warm Up "* If calibration is required while this error is set, the message "*Wait for Sensor"* can be shown.

Byte 3: Bit	Status/Error	Status Type	Description	Suggested Message/Response
7	Sync	NA	Always zero.	
6	EEPROM Checksum Faulty	Hardware error	The calibration values in the Capnostat EEPROM failed the checksum test.	*"Sensor Faulty"* Check that the sensor is properly plugged in. Reinsert or reset the sensor if necessary. If error persists, return sensor to factory for servicing.
5	Hardware Error	Hardware error	The Capnostat has detected a hardware error.	"Sensor Faulty" Check that the sensor is properly plugged in. Reinsert or reset the sensor if necessary, try to plug the sensor into a different host power supply as this error may result from a faulty sensor or a faulty host supply. If error persists, return sensor to factory for servicing.
4 - 0	Not used	NA	Reserved for future use [(1)]	NA

NOTE: The following byte is for sensors with LoFlo only. This byte will be zero for all Capnostats not equipped with LoFlo technology.

Byte 4: Bit	Status/Error	Status Type	Description	Suggested Message/Response
7	Sync	NA	Always zero.	
6 – 4	Not used	NA	Reserved for future use [(1)]	NA
3	Pump Off	Informative	This bit is set when the sampling pump is off.	No message
2	Pneumatic System Error	Correctable error	This error occurs whenever the pneumatic pressure is outside the expected range.	"Check Sampling Line" Check that the sampling line is not occluded or kinked.
1	Pump Life exceeded	Informative	This bit is set when the manufacturer stated pump life has been exceeded. Service may be required if Pneumatic System Error is present and can no longer be cleared.	No message.
0	Sidestream adapter not detected	Informative	There is no sidestream sampling set connected to the LoFlo Capnostat.	"Sample Line Disconnected" Connect a sampling adapter to clear.

NOTE [(1)]: Do not assume the state of this bit is a particular value. It may be used by Respironics Novametrix for internal use.

A.5 O_2 Status/ErrorByte

Byte 1: Bit	Status/Error	Status Type	Description	Suggested Message/Response
7	Sync	NA	Always zero.	NA
6	O_2 Sensor NOT Ready to Zero	Informative	This bit is set if the O_2 sensor is not ready for a Capnostat O_2 Zero.	No Message
5, 4	O_2 Signal Strength	Informative	00 – Signal normal	No message
			01 – Low signal	"O_2 Signal Low"
			10 – Signal Failure	"Check O_2 Adapter"
			11 – No adapter present	"Check O_2 Adapter"
3, 2	O_2 Adapter Zero status	Informative	00 – No O_2 zero in progress.	No message
			01 – O_2 zero in progress.	"O_2 Adapter Zero in Progress"
			10 – O_2 zero required.	"O_2 Adapter Zero Required"
			11 – O_2 zero error.	"O_2 Adapter Zero Required"
1, 0	O_2 System Zero Status		00 – No O_2 system zero in progress.	No message
			01 – O_2 system zero in progress.	"O_2 System Zero in Progress"
			10 – O_2 system zero required.	"O_2 System Zero Required"
			11 – O_2 system zero error.	"O_2 System Zero Required"

Byte 2: Bit	Status/Error	Status Type	Description	Suggested Message/Response
7	Sync	NA	Always zero.	
6, 5	O_2 Temperature Status	Informative	00 – Stable at Operating Temperature – The sensor temperature is stable and ready for operation.	No message
			01 – Below Operating Temperature - The sensor has not reached operating temperature. This condition is typical at power on or after inserting a sensor into the host system.	"*Sensor Warm Up* " If calibration is required while this error is set, the message "*Wait for Sensor"* can be shown.
			10 - Above Operating Temperature - The internal temperature of the sensor is above the operating temperature.	*"Sensor Over Temp"* Make sure sensor is not exposed to extreme heat (heat lamp, etc.). If error persists, return sensor to factory for servicing.
			11 – Temperature Unstable	*"Sensor Warm Up "* If calibration is required while this error is set, the message "*Wait for Sensor"* can be shown.
4 - 0	Not used	NA	Reserved for future use (1)	NA

NOTE (1): Do not assume the state of this bit is a particular value. It may be used by Respironics Novametrix for internal use.

A.6 Hardware Status Bytes

Byte 1: Bit	Status/Error	Status Type	Description	Suggested Message/Response
7	Sync	NA	Always zero.	NA
6	Pulse Width Watchdog Error	Hardware Error	A problem has been detected in the pulse width watchdog.	*"Sensor Faulty"* **Check that the sensor is properly plugged in. Reinsert o**r reseat the sensor**. If error persists, return sensor to factory for servicing.**
5	Pulse Width Range Error	Hardware Error	The calculated width of the pulse is out of range.	
4	Source Voltage Range Error	Hardware Error	The calculated source voltage is out of range.	
3	Bias Voltage Range Error	Hardware Error	The calculated bias voltage is out of range.	
2	5 Volt Voltage Range Error	Hardware Error	The calculated 5 volt voltage is out of range.	
1	Heater Thermistor Error	Hardware Error	Error detected in the heater thermistors.	
0	Software Fault	Hardware Error	A software error or fault has been detected.	

Byte 2: Bit	Status/Error	Status Type	Description	Suggested Message/Response
7	Sync	NA	Always zero.	NA
6	Program RAM checksum error	Hardware Error	The checksum of the program segment stored in RAM does not match the value calculated after loading.	*"Sensor Faulty"* Check that the sensor is properly plugged in. Reinsert or reseat the sensor. If error persists, return sensor to factory for servicing.
5	Main Flash checksum error	Hardware Error	The main flash checksum is corrupt. The checksum value stored in the flash does not match the calculated checksum.	
4	CO_2 Warm-up Period Exceeded	Hardware Error	The Capnostat CO_2 warm-up period has been exceeded.	
3	O_2 Warm-up Period Exceeded	Hardware Error	The Capnostat O_2 warm-up period has been exceeded.	
2 - 0	Not used	NA	Reserved for future use [(1)]	NA

NOTE [(1)]: Do not assume the state of this bit is a particular value. It may be used by Respironics Novametrix for internal use.

Appendix B: DPI Reference

B.1 Data Parameter Index (DPI)

DPI = 1 *CO_2 Status/Errors*

Description: This parameter returns a comprehensive bitwise summary of the current CO_2 status. For more information on the CO_2 status, see Appendix A.
Updated: once a second
Length = 5 bytes
Conversion: Extended Status Byte 1 = DB1
Extended Status Byte 2 = DB2
Extended Status Byte 3 = DB3
Extended Status Byte 4 = DB4
Prioritized Status Byte = DB5

DPI = 2 *End-Tidal CO_2 ($ETCO_2$)*

Description: The end-tidal CO_2 value is the highest peak CO_2 value of all end of expirations (end of breaths) over the selected time period$ETCO_2$. If less than two breaths exist in the selected time period, the value will be the maximum $ETCO_2$ value for the last two breaths. The method is determined by the $ETCO_2$ time period setting in the instrument settings (refer to the Get/Set Sensor Settings Command in section 8.3)
Resolution: 0.1 (0 – 150.0 mmHg, 0 – 20.0 kPa, or 0 – 19.7 %)
Updated: once a second
Length = 2 bytes
Conversion = (128 * DB1) + DB2

DPI = 3 *Respiratory Rate, Total (Freq t)*

Description: This parameter returns the average respiratory rate for the last eight breaths.
Resolution: 1 br/min (0 - 150 br/min)
Updated: once a second
Length = 2 bytes
Conversion = (128 * DB1) + DB2

DPI = 4 *Inspired CO_2*

Description: The inspired CO_2 is the minimum average value of CO_2 over the inspiratory period. An inspired CO_2 is reported if the level of CO_2 greater than or equal to 3 mmHg is detected. The inspired CO_2 value reported is a 20 second average.
Resolution: 0.1 (3 – 50.0 mmHg, 0.4 – 6.6 kPa, or 0.4 – 6.6 %)
Updated: once a second
Length = 2 bytes
Conversion = (128 * DB1) + DB2

DPI = 5 *Breath Detected*

Description: This parameter is sent to indicate that the Capnostat has detected a breath. This parameter is sent at the end of expiration of each breath and has no data bytes. It is sent only once per breath.
Updated: Each breath
Length = 0 bytes

DPI = 6 *O_2 Status/Errors*

Description: This DPI returns a bitwise summary of the current O_2 status. For more information on the O_2 status, see Appendix A.
Updated: once a second
Length = 2 bytes
Conversion: O_2 Extended Status Byte 1 = DB1
O_2 Extended Status Byte 2 = DB2

DPI = 7 *Hardware Status*

Description: This DPI returns a bitwise summary of the current hardware status and is intended to be a more comprehensive description of hardware errors of the sensor. This DPI is only sent when a hardware error is detected. Whenever this DPI is sent, byte 3, bit 5 of the CO_2 Status/Error bytes in DPI 1 will also be set.. For more information on the hardware status, see Appendix AB.
Updated: once a second
Length = 2 bytes
Conversion: Hardware Status Byte 1 = DB1
Hardware Status Byte 2 = DB2

DPI = 10 *FiO_2*

This DPI is only used by CO_2/O_2 Waveform Mode (Command 90h).
Description: The fractional inspired O_2 is the minimum average value of O_2 over the inspiratory period.
Resolution: 0.1 (0 – 100.0 %)
Updated: once a second
Length = 2 bytes
Conversion = (128 * DB1) + DB2

DPI = 11 *FeO_2*

This DPI is only used by CO_2/O_2 Waveform Mode (Command 90h).
Description: The fractional expired O_2 is the maximum average value of O_2 over the expiratory period.
Resolution: 0.1 (0 – 100.0 %)
Updated: once a second
Length = 2 bytes
Conversion = (128 * DB1) + DB2