INSTRUMENTS

INSTRUCTIONAL DOCUMENT

APOGEE BLUETOOTH API

Revision 2.0

Rev: 26-July-2024

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REVISION HISTORY

Table 1: Revision History

Revision	Date	Description
1.0	2021-05-10	Initial Release.
2.0	2024-07-26	Added new Bluetooth product: Guardian CEA Multi-Sensor Monitor. Added new sensors for the Guardian: Sensor ID 29: SM-500 Guardian with PAR Sensor Sensor ID 30: SM-600 Guardian with ePAR Sensor Added new sensors for the µCache: Sensor ID 37: SU-300 UV Sensor ID 38: SF-110 Radiation Frost Added new Bluetooth characteristics for the Guardian: LED Control Characteristic Fan Control Characteristic Modbus Settings Characteristic The Data Log Timing Characteristic was extended to include Stop Time. The Data Log Transfer Characteristic was updated for faster transfer.

CERTIFICATE OF COMPLIANCE

EU Declaration of Conformity

This declaration of conformity is issued under the sole responsibility of the manufacturer:

Apogee Instruments, Inc.
721 W 1800 N
Logan, Utah 84321
USA

for the products mentioned in this document.

The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

2014/30/EU	Electromagnetic Compatibility (EMC) Directive
2011/65/EU	Restriction of Hazardous Substances (RoHS 2) Directive
2015/863/EU	Amending Annex II to Directive 2011/65/EU (RoHS 3)

Standards referenced during compliance assessment:

EN 61326-1:2013	Electrical equipment for measurement, control, and laboratory use – EMC requirements
EN 63000:2018	Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances

Please be advised that based on the information available to us from our raw material suppliers, the products manufactured by us do not contain, as intentional additives, any of the restricted materials including lead (see note below), mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), polybrominated diphenyls (PBDE), bis (2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP), and diisobutyl phthalate (DIBP). However, please note that articles containing greater than 0.1 % lead concentration are RoHS 3 compliant using exemption 6c.

Further note that Apogee Instruments does not specifically run any analysis on our raw materials or end products for the presence of these substances, but we rely on the information provided to us by our material suppliers.

Signed for and on behalf of:
Apogee Instruments, July 2024

Bruce Bugbee
President
Apogee Instruments, Inc.

CE

CERTIFICATE OF COMPLIANCE

UK Declaration of Conformity

This declaration of conformity is issued under the sole responsibility of the manufacturer:

Apogee Instruments, Inc.
721 W 1800 N
Logan, Utah 84321
USA

for the products mentioned in this document.

The object of the declaration described above is in conformity with the relevant UK Statutory Instruments and their amendments:

2016 No. 1091	The Electromagnetic Compatibility Regulations 2016
2012 No. 3032	The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012

Standards referenced during compliance assessment:

BS EN 61326-1:2013	Electrical equipment for measurement, control, and laboratory use – EMC requirements
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APOGEE BLUETOOTH® PRODUCTS

Apogee Bluetooth products make precision environmental measurements. The measurements are managed in two ways: live data and data logging.

Live measurements are made when connected via Bluetooth to a central device such as a mobile app. The Apogee Connect mobile app displays live data and allows the user to record samples in the app and export them.

Data logging makes and stores measurements with no Bluetooth connection required. Data logging is set up in sampling and averaging intervals. A Bluetooth connection with a central device is required to configure and collect the data. It has a large memory capacity of over 400,000 entries or over 9 months of one-minute data. The Apogee Connect mobile app interfaces with the Apogee Bluetooth products to configure, collect, display, and export logged data.

µCache

The µCache AT-100 makes precision environmental measurements using Apogee's analog sensors.

The µCache has an M8 connector which is used to connect to an analog sensor.

The µCache is powered by a 2/3 AA battery. Battery life is highly dependent on the average daily time connected over Bluetooth and the sampling interval.

The µCache housing has a button and LED to manage Bluetooth connectivity and provide visual status feedback.

Button and LED Interface

The µCache has one button and one RGB LED. The button reads short, long, and extra-long presses, and the LED provides visual feedback.

A short button press (< 1 second) will be followed by one or more LED blinks indicating the current status.

- White indicates that it is not connected over Bluetooth, data logging is disabled, and the battery is in good condition.
- Blue indicates that it is connected over Bluetooth.
- Green indicates that data logging is enabled.
- One red blink indicates that the battery is “low.”
- Three red blinks indicate that the battery is “critically low,” too low to make measurements.

If there is a solid red indication (without blinking) for 30 seconds, the µCache is in Bootloader Mode.

A long button press (> 1 second) will toggle Bluetooth connectivity of the µCache.

- If it is not connected, a long button press will start Bluetooth advertising.
- If it is advertising, a long button press will stop Bluetooth advertising.
- If it is connected, a long button press will cause the µCache to disconnect from the central device.

An extra-long button press (10 seconds) will toggle the data logging status of the µCache. Once data logging has been toggled it will give the same LED indication as a short button press.

- If it is not data logging, data logging will start. LED indication will include a green LED blink.
- If it is data logging, data logging will stop. LED indication will not include a green LED blink.

When the µCache is advertising, the LED blinks blue every two seconds. Advertising will time out after 30 seconds if no connection is made.

Guardian CEA Multi-Sensor Monitor

The Guardian is a self-contained unit that measures PAR or ePAR, Temperature, Relative Humidity, CO2, and Pressure. The SM-500 measures PAR, and the SM-600 measures ePAR.

The Guardian has an M8 connector which is used to power the unit and has a Modbus communication interface.

The Guardian housing has LEDs that provide visual status feedback.

LED Interface

The Guardian has three RGB LEDs. When data logging, they blink green to indicate that a measurement is taking place. When a Bluetooth connection is made, they blink blue three times.

GENERIC ACCESS PROFILE (GAP)

Company Identifier

The Company Identifier for Apogee Instruments assigned by the Bluetooth SIG is 0x0644.

https://www.bluetooth.com/specifications/assigned-numbers/company-identifiers

Advertising

µCache Advertising

Advertising is started 1) when the Bluetooth device is first powered up, and 2) with a long button press. Advertising takes place until connected to a central device or until it times out after 30 seconds.

Advertising can also be set up to take place periodically, synchronized with data logging using the Data Log Collection Rate Characteristic in the Apogee Service. See Data Log Collection Rate Characteristic section for more information.

Guardian Advertising

The Guardian advertises continuously when powered on and not already connected to a central device.

Advertising Data

NOTE: The advertising data was changed in Guardian firmware version 2 and µCache firmware version 9. See information for both versions below.

Guardian (Firmware version ≤ 1) and µCache (Firmware version ≤ 8):

Advertising Data only contains the Company Identifier in Manufacturer Specific Data to minimize packet size.

Table 2: Example Manufacturer Specific Data in Scan Response Packet

Characteristic Packet	Value(s)	Description
44-06	0644	44-06 = Company Identifier

Guardian (Firmware version ≥ 2) and µCache (Firmware version ≥ 9):

Advertising Data contains the Company Identifier, Serial Number, Hardware Version Number, Firmware Version Number, Model Number, and Sensor ID.

Model Number Enumeration:

- 0 µCache
- 1 SM-500
- 2 SM-600

For sensor ID enumeration, see Sensor ID Characteristic section below.

Table 3: Example Manufacturer Specific Data in Scan Response Packet

Characteristic Packet	Value(s)	Description
44-06-E8-03-00-01-02-1E	0x0644, 1000, 0, 1, 2, 30	44-06 = Company Identifier E8-03 = Serial Number 00 = Hardware Version 01 = Firmware Version 02 = Model Number 1E = Sensor ID

Scan Response Data

Scan Response Data contains the Company Identifier and the Alias in Manufacturer Specific Data. Alias is one of the characteristics of the Apogee Service (See Alias Characteristic section below). This allows the central device to read and display the Alias of the peripheral device when searching for sensors.

Table 4: Example Manufacturer Specific Data in Scan Response Packet

44 06 47 72 65 65 6E 68 6F 75 73 65	
Field	**Description**
44-06	Company Identifier: 0x0644
47-72-65-65-6E-68-6F-75-73-65	Alias: “Greenhouse”

GENERIC ATTRIBUTE PROFILE (GATT)

The Apogee Profile consists of the Device Information Service (DIS), the Battery Service (BAS), the Secure DFU service, and the custom Apogee Service. **Table 5**, **Table 6**, and **Table 7** summarize important information about some of these services.

Device Information Service (DIS)

Table 5: Device Information Service

Service/Characteristic	UUID	Properties	Value Contents
Device Information Service	0x180A		
Manufacturer Name	0x2A29	Read	UTF8S
Model Number	0x2A24	Read	UTF8S
Serial Number	0x2A25	Read	UTF8S
Firmware Revision	0x2A26	Read	UTF8S
Hardware Revision	0x2A27	Read	UTF8S
Software Revision	0x2A28	Read	UTF8S

The Device Information Service contains basic information about the Apogee Bluetooth device in several characteristics. These characteristics include the Manufacturer Name, Model Number, Serial Number, Firmware Revision, Hardware Revision, Software Revision. Firmware Revision and Hardware Revision are significant to the Bootloader. The Software Revision will be a single whitespace character for a production-ready version and will contain descriptive text for any pre-release version.

Battery Service

The Battery Service is only used by the Apogee Bluetooth products containing a battery, currently including only the µCache.

Table 6: Battery Service

Service/Characteristic	UUID	Properties	Value Contents
Battery Service	0x180F		
Battery Level	0x2A19	Read/Notify	UINT8

The Battery Level Characteristic in the Battery Service contains the battery level as a percentage. A battery level between 1 and 100% indicates the approximate battery level. A battery level of 0% indicates that the battery level is too low to make a measurement.

The battery in the µCache is a primary lithium-thionyl chloride (Li-SOCl2), which is difficult chemistry to monitor. The discharge curve is fairly flat through most of the battery life with a fast drop-off at the end. An algorithm has been optimized to determine the remaining battery life, but the accuracy may vary according to temperature and other conditions.

Secure DFU Service

The Secure Device Firmware Update (DFU) Service provides a way to enter a bootloader mode to update the firmware. See the Bootloader section for more information.

Apogee Service

The Apogee Service is a custom service that serves two primary purposes: transmit real-time sensor measurements (live data) and data logging sensor measurements. Data logging will take place continually even when the Apogee Bluetooth device is not connected to a central device. The data log can then be transferred over Bluetooth when it is connected.

The following sections give a detailed description of each characteristic in the Apogee service.

Table 7: Apogee Service

Service/Characteristic	UUID[1]	Properties	Value Contents
Apogee Service	0x0001		
Live Data Characteristic	0x0002	Notify	(1-5) INT32s
Sensor ID Characteristic	0x0003	Read/Write	UINT8
Alias Characteristic	0x0004	Read/Write	UTF8S up to 20 bytes
Live Data Control Characteristic	0x0005	Read/Write	UINT8
LED Control Characteristic[2]	0x0006	Read/Write	UINT8
Fan Control Characteristic[2]	0x0007	Read/Write	2 UINT8s + UINT16
Current Time Characteristic	0x000A	Read/Write	UINT32
Data Log Full Time Characteristic	0x000C	Read	UINT32
Data Log Entries Available Characteristic	0x000D	Read	3 UINT32s
Data Log Latest Timestamp Transferred Characteristic	0x000E	Read/Write	UINT32
Data Log Control Characteristic	0x0010	Read/Write	UINT8
Data Log Timing Characteristic	0x0012	Read/Write	2, 3, or 4 UINT32s
Data Log Transfer Characteristic	0x0013	Read/Notify or Indicate	UINT32 + UINT16 + 2 UINT8s + (1-59) INT32s
Data Log Collection Rate Characteristic	0x0014	Read/Write/Notify	UINT8
Calibration Characteristic	0x00FF	Read/Write/Notify	UINT8
Coefficients1 Characteristic	0x0100	Read/Write	3 FLOAT32s
Coefficients2 Characteristic	0x0101	Read/Write	3 FLOAT32s
Modbus Settings Characteristic[2]	0x0200	Read/Write	4 UINT8s
Base UUID for Apogee Service and Characteristics:	0xB3E0_ _ _ _259442A1A5FE4E660FF2868F		

[1] The 32-bit UUIDs listed must be inserted into the base UUID for the Apogee Services and Characteristics to make a 128-bit UUID.
[2] This characteristic is only used by the Guardian.

Chronological Overview

The typical use of the Apogee Service proceeds as follows:

1. Bluetooth advertising is started via button press or other means.
2. A central device scans for Apogee Bluetooth devices by searching for the Apogee Company Identifier 0x0644 in the Manufacturer Specific Data portion of the Advertising packet.
3. The Alias of the Apogee Bluetooth device can be read in the Scan Response Data. The central device could display the Alias in a list of available Apogee Bluetooth devices.
4. The central device connects to an Apogee Bluetooth device.
5. Once connected, the Current Time Characteristic should be checked (read) and updated (written) if not accurate.
6. The Alias Characteristic can be used to give the device a name for reference. This name will show up in advertising packets when the central device is scanning for Apogee Bluetooth devices.
7. The Sensor ID Characteristic can be read to find out which sensor to expect data from. It can also be changed to another sensor as needed.
8. Coefficients need to be programmed for some sensors using Coefficients1 and Coefficients2 Characteristics.
9. Calibration can be done for some sensors using the Calibration Characteristic.
10. The Live Data Control Characteristic can be used to set averaging time for live data.
11. Live data can be received by enabling notifications of the Live Data Control Characteristic.
12. Data Logging can be set up at desired intervals using the Data Log Timing Characteristic. It includes a sampling interval, an averaging interval, an optional start time, and an optional stop time.
13. Data logging can be enabled or disabled using the Data Log Control Characteristic.
14. When data logging is enabled, the Data Log Full Time Characteristic can be read to know when the data log will be full and start overwriting entries that have not been transferred.
15. The Data Log Latest Timestamp Transferred Characteristic can be read to find out the latest timestamp that has been transferred. This characteristic can also be written to move the starting point of the transfer forward, skipping a portion of the data log, or back to transfer data that has already been transferred before. It can also be used to ensure the data log transfer picks up where it left off from the previous transfer. Following is an example:
    a. A central device has the following data log stored from previous connections shown in **Table 8**.

Table 8: Example Data Log

Timestamp	Timestamp Converted to Date and Time	Measurement
1562884620	2019-07-11 22:37:00	888.5174
1562884680	2019-07-11 22:38:00	890.2397
1562884740	2019-07-11 22:39:00	891.3032
1562884800	2019-07-11 22:40:00	891.2341

b. The central device reads the Data Log Latest Timestamp Transferred Characteristic.
c. The central device compares the characteristic value to the most recent timestamp from the collected data log. In this example, it is 1562884800.
d. If these values do not match, 1562884800 is written to Data Log Latest Timestamp Transferred Characteristic.
e. The central device proceeds with the data log transfer.

16. The Data Log Entries Available Characteristic can be read to find out how many data log entries are available to be transferred, the timestamp of the oldest entry in the data log, and the total number of entries in the data log.
17. A data log transfer is done using reads, notifications, or indications of the Data Log Transfer Characteristic.
18. The Data Log Collection Rate Characteristic can be written to advertise only with a button press or to advertise synchronized with data logging to collect data as it becomes available.
19. Additional settings can be made for the Guardian using the LED Control Characteristic, Fan Control Characteristic, and the Modbus Settings Characteristic.
20. The central device disconnects from the Apogee Bluetooth device.

Live Data Characteristic

Table 9: Live Data Characteristic

Product	UUID (within base)	Properties	Value Contents
µCache	0x0002	Notify	(1-4) INT32s
Guardian	0x0002	Notify	5 INT32s

The Live Data Characteristic sends notifications of the sensor output. For the µCache, it is an array of 1 to 4 32-bit signed fixed-point values with a decimal exponent of -4. For the Guardian, it is an array of 5 32-bit signed fixed-point values with a decimal exponent of -4.

The number of outputs and units for each sensor is listed in **Table 12** in the Sensor ID Characteristic section.

Each value in the array is a unique measured value from the sensor. For example, the IR sensor will have a packet with two values. The first is the target temperature and the second is the sensor temperature.

Live data is unconditionally sent every 0.5 seconds when notifications are enabled. The entire array of values is sent each time.

For the µCache, the characteristic data length is always a multiple of 4 bytes, up to 16 bytes. For the Guardian, the characteristic data length is always 24 bytes.

Table 10: Live Data Characteristic Examples

Live Data Characteristic	Value(s)	Description
25-E7-83-00	864.4389	Live data is one value of 864.4389
89-EF-FF-FF-CD-26-02-00	-0.4215, 14.1005	Live data is two values of -0.4215 and 14.1005

Sensor ID Characteristic

Table 11: Sensor ID Characteristic

UUID (within base)	Properties	Value Contents
0x0003	Read/Write	UINT8

The Sensor ID Characteristic is an enumeration of the sensor connected to the Apogee Bluetooth Device. This must be chosen by the user and set by the central device. **Table 12** (next page) lists each enumeration, sensor name, description, number of outputs, and units.

When the sensor ID is changed, the Calibration, Coefficients1, and Coefficients2 characteristics must be carefully managed. See the Calibration Characteristic section and the Coefficients1 and Coefficients2 Characteristics section for more information.

Data length is one byte.

Table 12: Sensor ID Enumeration

Sensor ID	Sensor Name	Sensor Description	Number of Outputs	Units
0	No sensor chosen			
1	SP-110	Pyranometer	1	W m^{-2}
2	SP-510	Thermopile Pyranometer	1	W m^{-2}
3	SP-610	Thermopile Pyranometer (Downward)	1	W m^{-2}
4	SQ-110	Quantum (Electric)	1	µmol m^{-2} s^{-1}
5	SQ-120	Quantum (Solar)	1	µmol m^{-2} s^{-1}
6	SQ-500	Quantum (Full Spectrum)	1	µmol m^{-2} s^{-1}
7	SL-510	Pyrgeometer	1	W m^{-2}, °C
8	SL-610	Pyrgeometer (Downward)	1	W m^{-2}, °C
9	SI-100	IR Sensor	2	°C, °C
10	SU-200	UV Sensor	1	W m^{-2}
11	SE-100	Photometric	1	lm m^{-2}
12	S2-111	NDVI	2	W m^{-2}, W m^{-2}
13	S2-112	NDVI (Downward)	2	W m^{-2}, W m^{-2}
14	S2-121	PRI	2	W m^{-2}, W m^{-2}
15	S2-122	PRI (Downward)	2	W m^{-2}, W m^{-2}
16	S2-131	Red/FarRed	2	µmol m^{-2} s^{-1}, µmol m^{-2} s^{-1}
17	S2-141	PAR/FAR	2	µmol m^{-2} s^{-1}, µmol m^{-2} s^{-1}
18	SQ-610	ePAR	1	µmol m^{-2} s^{-1}
19	ST-1X0	Thermistor	1	°C
20	SP-700	Albedometer	2	W m^{-2}, W m^{-2}

Table 12 Continued: Sensor ID Enumeration

Sensor ID	Sensor Name	Sensor Description	Number of Outputs	Units
21	SQ-620	Extended Range LED Quantum	1	µmol m^{-2} s^{-1}
22	SQ-640	Low Light Extended Range LED Quantum	1	µmol m^{-2} s^{-1}
23	NDVI Pair	NDVI and NDVI (Downward)	4	W m^{-2}, W m^{-2}, W m^{-2}, W m^{-2}
24	PRI Pair	PRI and NDVI (Downward)	4	W m^{-2}, W m^{-2}, W m^{-2}, W m^{-2}
25	4 Single Ended	4 Single-Ended Measurements	4	mV, mV, mV, mV
26	2 Differential	2 Differential Measurements	2	mV, mV
27	SQ-100X	Quantum	1	µmol m^{-2} s^{-1}
28	SQ-31X	Line Quantum	1	µmol m^{-2} s^{-1}
29	SM-500	Guardian with PAR Sensor, PAR, Temperature, Relative Humidity, CO2, and Pressure	5	µmol m^{-2} s^{-1}, °C, % RH, ppm, kPa
30	SM-600	Guardian with ePAR Sensor, ePAR, Temperature, Relative Humidity, CO2, and Pressure	5	µmol m^{-2} s^{-1}, °C, % RH, ppm, kPa
31-34		Reserved for Future Use		
35	SO-100	Oxygen Sensor Soil Response	3	% O_2, °C, mV
36	SO-200	Oxygen Sensor Fast Response	3	% O_2, °C, mV
37	SU-300	UV	1	W m^{-2}
38	SF-110	Radiation Frost	1	°C

Alias Characteristic

Table 13: Alias Characteristic

UUID (within base)	Properties	Value Contents
0x0004	Read/Write	UTF8S up to 16 bytes

The Alias Characteristic is used to give a name to an Apogee Bluetooth device unit for reference. It is displayed in advertising data in the Scan Response packet.

Data length is up to 16 bytes.

Table 14: Alias Characteristic Example

Characteristic Packet	Description
41-71-75-61-72-69-75-6D-20-32	The Alias of this Apogee Bluetooth device is "Aquarium 2"

Live Data Control Characteristic

Table 15: Live Data Control Characteristic

UUID (within base)	Properties	Value Contents
0x0005	Read/Write	UINT8

The Live Data Control Characteristic controls averaging time of the Live Data Characteristic. Valid values are 0-127 in units of 0.25 seconds. A value of 0 is interpreted as no averaging with data calculated from a single ADC sample. It is okay to write this value while live data is running. Longer averaging time buffers the data more, although it is less responsive.

When live data is first turned on and the averaging buffer is not yet full, live data is calculated only from measured values.

Data length is one byte.

Table 16: Data Log Control Characteristic Bitfield

Bit	Name	Description
7	RESERVED	Reserved for future use.
6:0	AVERAGING_TIME	0: Live data is calculated from one sample. 1-127: Time in units of 0.25 seconds. Live data is calculated from an averaging buffer of .25 to 31.75 seconds.

Table 17: Live Data Control Characteristic Examples

Characteristic Packet	Value	Description
00	0	Live Data is calculated from 1 measurement sample.
01	1	The averaging time for Live Data is 0.25 seconds.
28	40	The averaging time for Live Data is 10 seconds.
7F	127	The averaging time for Live Data is 31.75 seconds.

LED Control Characteristic

Table 18: LED Control Characteristic

UUID (within base)	Properties	Value Contents
0x0006	Read/Write	UINT8s

The LED control Characteristic is used to control the LED status lights on the Guardian to turn them on or off. This characteristic is only used by the Guardian.

Table 19: Fan Control Characteristic Speed Bitfield

Bit	Name	Description
7:1	RESERVED	Reserved for future use.
0	LED_INDICATION_STATE	0 = LED indication off 1 = LED indication on

Table 20: LED Control Characteristic Example

Characteristic Packet	Value	Description
00	LED_INDICATION_STATE = 0	LED indication is off
01	LED_INDICATION_STATE = 1	LED indication is on

Fan Control Characteristic

Table 21: Fan Control Characteristic Reads

UUID (within base)	Properties	Value Contents
0x0007	Read	UINT8 + UINT 16 + UINT 8 + UINT16

The Fan Control Characteristic provides fan speed control and a fan pause timer intended for turning off the fan for a time when fogging. This characteristic is only used by the Guardian.

The Fan Control Characteristic has a different interface for reads and writes. See details for writes below.

A read of the Fan Control Characteristic will provide Duty Cycle, Darkness Threshold, Fan Pause Time, and the measured Fan RPM.

Table 22: Fan Control Characteristic Read Fields

Duty Cycle	Darkness Threshold	Fan Pause Time	Fan RPM
1 byte	2 bytes	1 byte	2 bytes

Duty Cycle controls the fan speed as a percent of full speed. Duty Cycle values are 0 and 40 – 100. A value of 0% indicates that the fan is off. A duty cycle of 40% is the minimum running speed of the fan.

The Darkness Threshold is used to save power. It sets the fan's duty cycle to 40% when the detected light is below the Darkness Threshold value. The value is an integer representing a fixed-point value with a decimal exponent of -1. Valid values are 0 – 65535, representing 0 – 6553.5 µmol m^{-2} s^{-1}. A value of 0 disables power saving, and the fan will run at the given duty cycle in all light levels.

The Fan Pause Time refers to the number of minutes the fan will remain off before turning back on. Valid values are 0 – 255. A value of 0 indicates that there is no timer running to turn the fan back on after pausing.

The fan rpm ranges between 0 and about 4000. The fan RPM is controlled by the Duty Cycle field. It is a measured value and cannot be written.

Table 23: Fan Control Characteristic Read Example

Characteristic Packet	Value	Description
28-05-00-00-37-05	DUTY_CYCLE = 40 DARKNESS_THRESHOLD = 0.5 FAN_PAUSE_TIME_REMAINING = 0 FAN_RPM = 1335	The fan is on with a duty cycle of 40% and a darkness threshold of 0.5. The fan is not paused and has an RPM of 1335
64-00-00-00-2A-0F	DUTY_CYCLE = 100 DARKNESS_THRESHOLD = 0 FAN_PAUSE_TIME_REMAINING = 0 FAN_RPM = 0x0537 = 3882	The fan is on with a duty cycle of 100% and no darkness threshold is set. The fan is not paused and has an RPM of 3882
00-00-00-0C-00-00	DUTY_CYCLE = 0 DARKNESS_THRESHOLD = 0 FAN_PAUSE_TIME_REMAINING = 12 FAN_RPM = 0	The fan is paused for 12 more minutes. No darkness threshold is set.

Table 24: Fan Control Characteristic Writes

UUID (within base)	Properties	Value Contents
0x0007	Write	UINT8 Header + Optional UINT8 + Optional UINT16 + Optional UINT8

The Fan Control Characteristic provides a 1-byte header to inform which values are included in the characteristic packet.

Table 25: Fan Control Characteristic Write Fields

Header – 1 Byte (8 bits)				1 Byte	2 Bytes	1 Byte
Bits 7:3	**Bit 2**	**Bit 1**	**Bit 0**			
Reserved for future use	Pause Time Remaining field present	Darkness Threshold field present	Duty Cycle field present	Optional Duty Cycle	Optional Darkness Threshold	Optional Pause Time

When writing the Fan Control Characteristic, 1, 2, or all 3 values of the characteristic may be included. The 1-byte header indicates which fields are present in the rest of the characteristic packet. This design allows updating any number of values of the characteristic without including all of them.

For example, if Pause Time Remaining is the only value included in the write, the header will have bit 2 set to 1 and bits 0 and 1 set to 0, resulting in a binary value of '00000100.' See examples below.

Table 26: Fan Control Header Examples

Binary Representation	Byte Representation	Description
00000001	0x01	Duty cycle is present
00000010	0x02	Darkness threshold is present
00000100	0x04	Pause time remaining is present
00000011	0x03	Darkness threshold is present Duty cycle is present
00000101	0x05	Pause time remaining is present Duty cycle is present
00000110	0x06	Pause time remaining is present Darkness threshold is present
00000111	0x07	All three values are present

Table 27: Fan Control Characteristic Packet Example

Characteristic Packet	Description
01-32	Duty cycle is present, and the duty cycle will be set to 50%.
02-05-00	Darkness threshold is present and the darkness threshold will be set to 0.5 µmol m^{-2} s^{-1}.
05-0A-28	Pause time and duty cycle are present. The Fan will pause for 10 minutes and duty cycle (once fan is no longer paused) will be set to 40%.
07-64-F4-01-1E	All values are present. Fan will be paused for 30 min. Once fan resumes, the duty cycle will be set to 100% and the darkness threshold will be set to 50.0 µmol m^{-2} s^{-1}.

Current Time Characteristic

Table 28: Current Time Characteristic

UUID (within base)	Properties	Value Contents
0x000A	Read/Write	UINT32

The Current Time Characteristic is formatted in Epoch/Unix Time. It is a 32-bit unsigned integer. It is used to track time for data logging.

The Current Time is recommended to be Greenwich Mean Time (GMT). The central device would then convert GMT and display local time. This simplifies Daylight Savings Time changes.

The Real-Time Clock (RTC) on the Apogee Bluetooth device is temperature-corrected, although it will get ahead and behind a little throughout the temperature swings of the day.

The Current Time Characteristic should only be written responsively. A few seconds of tolerance should be allowed before writing the characteristic to correct it. Each time the characteristic is written, sample data is reset, and a data log entry may be skipped. Therefore, the characteristic should not be written arbitrarily. Instead, the Current Time Characteristic should be read, checked whether it is out of tolerance, and written only if it is out of tolerance.

The Apogee Bluetooth device uses an internal RTC. It has a supercapacitor as a backup power source that will last for a limited amount of time when the battery is not installed. When the RTC is first powered on and hasn't been running on backup power, the default time is January 1, 2000, 12:00 AM. When a battery is changed or power temporarily lost, a central device should connect to the Apogee Bluetooth device to verify that the time is correct, and the logging status is as desired.

Data length is 4 bytes.

Table 29: Current Time Characteristic Example

Characteristic Packet	Value	Description
20-60-AB-5B	1537957920	Current time is 2018-09-26 10:32:00 GMT.

Data Log Full Time Characteristic

Table 30: Data Log Full Time Characteristic

UUID (within base)	Properties	Value Contents
0x000C	Read	UINT32

The Data Log Full Time Characteristic is the time that the last data log entry will be recorded before the data log entries that have not been transferred will be overwritten. The Data Log Latest Timestamp Transferred Characteristic is the reference from which this time is calculated.

It is formatted in Epoch/Unix Time. It is relative to Current Time Characteristic which should be in GMT.

If data logging is disabled, Data Log Full Time will be 0. Note that this should not be interpreted as 1970-01-01 00:00:00.

Data length is 4 bytes.

Table 31: Data Log Full Time Example

Characteristic Packet	Value	Description
B0-39-23-5C	1545812400	The data log memory will be full 2018-12-26 08:20:00 and the next entry will overwrite data that has not been transferred.

Data Log Entries Available Characteristic

Table 32: Data Log Entries Available Characteristic

UUID (within base)	Properties	Value Contents
0x000D	Read	3 UINT32s

Data Log Entries Available gives information about the data log. It contains three fields: Number of Data Logs Available, Oldest Timestamp in Data Log, and Total Entries Available.

Table 33: Data Log Entries Available Characteristic Fields

Number of Entries Available	Oldest Timestamp in Data Log	Total Entries Available in Data Log
4 Bytes	4 Bytes	4 Bytes

Number of Data Logs Available indicates how many data logs are available for transfer continuing from where the previous transfer left off.

Oldest Timestamp in Data Log is the timestamp of the oldest entry in the data log. It is formatted in Epoch/Unix Time.

Total Entries Available is the total number of entries in data log memory.

If the data log is empty, the Oldest Timestamp in the Data Log field will be 0. Note that this should not be interpreted as 1970-01-01 00:00:00.

Data length is 12 bytes.

Table 34: Data Log Full Time Characteristic Example Packet

7D-00-00-00-7E-29-A2-5B-FE-22-00-00		
Field	**Value**	**Description**
7D-00-00-00	125	125 data log entries have not been transferred.
7E-29-A2-5B	1537354110	The oldest timestamp in the data log is 2018-09-19 10:48:30
FE-22-00-00	8958	There is a total of 8958 data log entries in the data log.

Data Log Latest Timestamp Transferred Characteristic

Table 35: Data Log Latest Timestamp Transferred Characteristic

UUID (within base)	Properties	Value Contents
0x000E	Read/Write	UINT32

The Data Log Latest Timestamp Transferred Characteristic is the last timestamp that was transferred during the previous data log transfer. It is formatted in Epoch/Unix Time.

The most common use of the Data Log Latest Timestamp Transferred Characteristic is to ensure the data log transfer picks up where it left off from the previous transfer. Ideally, the characteristic and the last timestamp in the collected log will always match.

This characteristic can also be used to change the starting point of the next data log transfer. A later time can be written to set the next transfer forward in time to skip a portion of the data log. An earlier time can be written to transfer data that may have already been transferred before.

If 0 is written to this characteristic, the oldest timestamp will be found. The next data log transfer will begin at the earliest entry.

If the current time or a time in the future is written, the next transfer

The Data Log Latest Timestamp Transferred Characteristic should not be written during a data log transfer.

If the data log is empty, this characteristic will be 0. Note that this should not be interpreted as 1970-01-01 00:00:00. If the first transfer has never taken place the characteristic value will be one averaging interval before the first entry.

Data length is 4 bytes.

Table 36: Data Log Latest Timestamp Transferred Characteristic Examples

Field	Value	Description
6A-BB-1A-5B	1528478570	The latest timestamp transferred is 2018-06-08 17:22:50. The next transfer will start at the next entry.
00-00-00-00	0	Data log is empty

Data Log Control Characteristic

Table 37: Data Log Control Characteristic

UUID (within base)	Properties	Value Contents
0x0010	Read/Write	UINT8

The Data Log Control Characteristic uses one flag to enable and disable data logging.

Table 38: Data Log Control Characteristic Bitfield

Bit	Name	Description
7:1	RESERVED	Reserved for future use.
0	DATA_LOGGING_ACTIVE	Flag to indicate that data logging is active (on, enabled).

Before data logging is turned on, the Current Time Characteristic should be checked for accuracy and updated if not accurate.

When the battery is too low to make accurate measurements, data logging will be turned off internally. This will happen when the battery is determined “critically low”.

Data length is 1 byte.

Table 39: Data Log Control Characteristic Examples

Characteristic Packet	Value	Description
00	0	Data logging is disabled.
01	1	Data logging is enabled.

Data Log Timing Characteristic

NOTE: The Data Log Timing Characteristic was extended in Guardian firmware version 3 and µCache firmware version 8. An optional field was added to the characteristic. See information for both versions below.

All Guardian and µCache firmware versions:

Table 40: Data Log Timing Characteristic

UUID (within base)	Properties	Value Contents
0x0012	Read/Write	2 or 3 UINT32s

Data Log Timing sets up intervals for data logging. It contains three fields: Sampling Interval, Averaging Interval, and Start Time. Start time is optional when writing to the characteristic.

Table 41: Data Log Timing Characteristic Fields

Sampling Interval	Averaging Interval	Start Time
4 Bytes	4 Bytes	4 Bytes

Sampling Interval is the time between sensor measurement samples in seconds. When the sampling interval is reached, a sensor measurement will be made.

Averaging Interval is the time between averages in seconds. When the averaging interval is reached, the samples will be averaged and placed in the data log for transfer later.

Note that “Logging Interval” and “Averaging Interval” terms are used interchangeably. It was originally named “Averaging Interval” in the documentation. The mobile app used the term “Logging Interval.” They are synonymous because every time an “averaging” interval occurs, a new data “log” is made.

Table 42 gives an example of timing for a 10-Second Sampling Interval and 60-Second Averaging Interval. The Apogee Bluetooth device measures or “samples” the sensor every 10 seconds and “averages” or “logs” the values every 60 seconds. The last row of the table is the data log entry that will be saved in memory and transferred by the Data Log Transfer Characteristic.

Table 42: Example Measurement Times for 10-Second Sampling Interval and 60-Second Averaging Interval

	Timestamp	Measurement
Sampling Events	2019-07-11 08:05:10	1152.24
	2019-07-11 08:05:20	1160.45
	2019-07-11 08:05:30	1155.32
	2019-07-11 08:05:40	1150.15
	2019-07-11 08:05:50	1149.80
	2019-07-11 08:06:00	1152.47
Averaging Event (Data Log Entry)	2019-07-11 08:06:00	1153.41

Start Time is the time that data logging started. It is formatted in Epoch/Unix Time. It is optional on a write operation and always present on a read operation. When written it can be used to start data logging in the future at a given time.

If Start Time is not included when the Characteristic is written, then data logging will be started automatically. The sampling and averaging times will be calculated to a time that aligns with minutes. For example, a ten-second sampling interval will take place at 0, 10, 20, 30 40, and 60 seconds of the minute and a one-minute averaging interval will start at the next minute.

If data logging is disabled, Start Time will be 0. Note that this should not be interpreted as 1970-01-01 00:00:00.

When a new Data Log Timing value is written it is validated as follows:

- Averaging Interval ≠ 0
- Sampling Interval ≠ 0
- Averaging Interval ≥ Sampling Interval
- Averaging Interval % Sampling Interval = 0

If these conditions are met, then the write will be successful. Otherwise, it will not be successful, and the previous value will persist.

Data length is 8 or 12 bytes when written and 12 bytes when read.

Table 43: Data Log Timing Characteristic Examples

Characteristic Packet	Values	Description
0A-00-00-00-3C-00-00-00 (write)	10, 60	Averaging Interval of 10 seconds, Sampling Interval of 60 Seconds, Start Time will be calculated and started to align with the nearest minute.
10-00-00-00-3C-00-00-00 (write)	16, 60	Averaging Interval of 16 seconds, Sampling Interval of 60 Seconds. This write will fail because Averaging Interval % Sampling Interval ≠ 0.
3C-00-00-00-2C-01-00-00-00-47-8A-5B	60, 300, 1535788800	Averaging Interval of 60 seconds, Sampling Interval of 300 Seconds, Start Time 2018-09-01 08:00:00

Guardian (Firmware version ≥ 3) and µCache (Firmware version ≥ 9):

An optional Stop Time field was added to the Data Log Timing Characteristic to allow ending data logging at a given time. All information and use described in the previous section still applies.

Table 44: Data Log Timing Characteristic Fields

Sampling Interval	Averaging Interval	Start Time (optional or required if Stop Time is present)	Stop Time (optional)
4 Bytes	4 Bytes	4 Bytes	4 Bytes

When a Stop Time is desired, the Start Time is required. If data logging should start immediately, writing 0 to the Start Time is the best practice.

When the characteristic value for a write contains only the Sampling Interval and Averaging Interval, and data logging is on, data logging will start immediately. The Start Time will be added for the next read. If data logging is off, reading the characteristic will only contain the Sampling Interval and Averaging Interval.

When the characteristic value for a read or write contains Sampling Interval, Averaging Interval, and Start Time, data logging started or will start at the Start Time. It will not stop data logging.

When the characteristic value contains Sampling Interval, Averaging Interval, Start Time, and Stop Time, data logging started or will start at the Start Time. Data logging will stop at the Stop Time.

To add or change a Stop Time and start logging immediately or continue logging, write 0 for the Start Time and include the Stop Time.

If data logging is turned back on after a stop time, data logging will start, a new start time will be added, and the stop time will be removed.

When data logging is turned off, the Start Time and Stop Time fields will not be present when the characteristic is read.

Data Log Transfer Characteristic

NOTE: The Data Log Transfer Characteristic was changed in Guardian firmware version 3 and µCache firmware version 9. See information for both versions below.

Guardian (Firmware version ≤ 2) and µCache (Firmware version ≤ 8):

Table 45: Data Log Transfer Characteristic

Product	UUID (within base)	Properties	Value Contents
µCache	0x0013	Notify or Indicate	UINT32 + (0-4) INT32s
Guardian	0x0013	Notify or Indicate	UINT32 + 5 INT32s

The Data Log Transfer Characteristic transfers the data log from memory on the Apogee Bluetooth device to the central device via notification or indication. Notifications are much faster. Indications have a smaller chance of packet loss.

Each data log entry is transferred individually into one notification or indication packet. It contains one timestamp formatted in Epoch/Unix Time followed by an array of 1 to 5 32-bit signed fixed-point values with a decimal exponent of -4. This is like the Live Data Characteristic with the addition of a timestamp.

The number of outputs for each sensor is listed in a chart in the Sensor ID Characteristic section.

The timestamp is relative to Current Time Characteristic which should be in GMT. The central device should convert this to local time.

The end of the data log transfer is indicated with a packet of value FF-FF-FF-FF. When the end of the data log transfer is reached, notifications or indications must be turned off and on again to receive more entries when they are available.

For the µCache, the data length is always a multiple of 4 bytes between 8 and 20 bytes. For the Guardian, data length is 24 bytes and requires Data Length Extension (DLE).

Table 46: Data Log Transfer Characteristic Examples

Characteristic Packet	Value(s)	Description
A0-6F-A3-5B-3E-2C-19-01	1537437600, 1842.6942	Data log entry with timestamp of 2018-09-20 10:00:00 and sensor value of 1842.6942
22-FA-A5-5B-57-75-04-00-9A-CF-FF-FF	1537604130, 29.2183, -1.2390	Data log entry with timestamp of 2018-09-22 08:15:30 and sensor values of 29.2183 and -1.2390
B2-50-A6-5B-FA-81-03-00-2B-AB-08-00 -BB-74-C4-00-86-19-03-00	1537626290, 22.9882, 56.8107, 1287.4939, 20.3142	Data log entry with timestamp of 2018-09-22 14:24:50 and sensor values of 22.9882, 56.8107, 1287.4939 and 20.3142
FF-FF-FF-FF	EoT	End of Transfer. (Do not place this value in the data log.)

Guardian (Firmware version ≥ 3) and µCache (Firmware version ≥ 9):

Table 47: Data Log Transfer Characteristic

UUID (within base)	Properties	Value Contents
0x0013	Read or Notify	UINT32 + UINT16 + 2 UINT8s + (1-59) INT32s

The Data Log Transfer Characteristic transfers the data log from memory on the Apogee Bluetooth device to the central device via notification or reads. A read will provide a single packet starting after the last timestamp transferred from the Latest Timestamp Transferred Characteristic.

Each data log transfer packet contains a maximum of 244 bytes. The first 8 bytes of each packet contain header information that includes Timestamp formatted in Epoch/Unix Time, Logging Interval in seconds, the number of Measurements Per Logging Interval, and Packet Number.

Table 48: Data Log Transfer Header

Timestamp	Logging Interval	Measurement(s) Per Logging Interval	Packet Number
4 bytes	2 bytes	1 byte	1 byte

The rest of the packet is filled with data measurements that are 32-bit signed fixed-point values with a decimal exponent of -4. There is only a single timestamp which is contained in the header of each data packet. The timestamp for each set of measurements can be calculated from the Logging Interval and associated with the number of Measurements Per Logging Interval.

The number of outputs for each sensor is listed in a chart in the Sensor ID Characteristic section and will match the number of measurements per logging interval.

The timestamp is relative to the Current Time Characteristic which should be in GMT. The central device should convert this to local time.

Packet lengths can vary depending on a change in Logging Interval or a change in Measurement(s) Per Logging Interval. For example, if data logging is turned off for a time and then turned back on, there will likely be a smaller packet of measurements before the next set of measurements.

The Packet Number can be used to detect a missed or dropped packet so that the missing data can be reconciled. The Packet Number is a number between 0 and 255 and will wrap over to 0 if there are more than 255 packets. When a missed or dropped packet is detected, missing data can be reconciled using the Latest Timestamp Transferred Characteristic. The Latest Timestamp Transferred Characteristic is used to recollect missing data by writing the value of the timestamp before the missing data, followed by a read of the Data Log Transfer Characteristic. One or more reads may be required to fill in missing data. This should be done after the notification transfer has been completed to avoid interrupting the notifications. After recollecting missed data, the Latest Timestamp Transferred Characteristic should then be set to the timestamp of the last data measurement to avoid transferring duplicate data.

The end of the data log transfer is indicated with a packet of value FF-FF-FF-FF. When the end of the data log transfer is reached, notifications or indications must be turned off and on again to receive more entries when they are available.

Table 49: Data Log Transfer Characteristic Examples

Characteristic Packet	Value(s)	Description
88-A1-9C-66-58-02-05-9F-8D-4C-91-00-86-94-03-00-45-6B-05-00-40-16-40-00-C0-41-0D-00-83-42-90-00-D4-93-03-00-38-6E-05-00-A0-00-41-00-C0-41-0D-00	1721541000, 10, 5, 159, (952.2317, 23.4630, 35.5141, 42.0000, 86.800), (945.4211, 23.4452, 35.5896, 42.6000, 86.8800)	A timestamp of 2024-07-21 05:50:00, a logging interval of 10 min, 5 measurements per logging interval, and a packet number of 159. The 5 measurements of the first timestamp are: 952.2317, 23.4630, 35.5141, 42.0000, 86.800. The 5 measurements at an interval of 10 min after the previous timestamp are: 945.4211, 23.4452, 35.5896, 42.6000, 86.8800.
A8-4E-A2-66-2C-01-01-49-25-E7-83-00 -18-D6-85-00-22-E3-84-00-1A-C2-83-00-B3-C6-83-00	1721913000, 5, 1, 73, 864.4389, 877.1096, 870.8898, 863.4906, 863.6083	A timestamp of 2024-07-25 13:10:00, a logging interval of 5 min, 1 measurement per logging interval, and a packet number of 73. The measurement of the first timestamp is 864.4389. The measurement at an interval of 5 min after the previous timestamp is 877.1096. The measurement at the next interval is 870.8898. The measurement at the next interval is 863.4906. The measurement at the next interval is 863.6083.
FF-FF-FF-FF	EoT	End of Transfer. (Do not place this value in the data log.)

Data Log Collection Rate Characteristic

Table 50: Data Log Collection Rate Characteristic

UUID (within base)	Properties	Value Contents
0x0014	Read/Write	UINT8

The Data Log Collection Rate Characteristic provides the functionality for the Apogee Bluetooth device to advertise periodically, synchronized with data logging. This allows a central device to collect data log entries as they become available.

The value in the Data Log Collection Rate Characteristic determines how often the Apogee Bluetooth device will advertise as new entries are added to the data log. It advertises once every n data log entries. For example, if the value is 0, the Apogee Bluetooth device will only advertise with a button press. If the value is 1, the Apogee Bluetooth device will advertise every time a new entry is added to the data log. If the value is 5, it will advertise every 5 entries that are added to the data log. However, if there is not a successful connection, the Apogee Bluetooth device will advertise for 10 seconds each time a new entry is added to the data log (as if the Data Log Collection Rate Characteristic is 1). After a successful connection, the Apogee Bluetooth device reverts to the Data Log Collection Rate Characteristic value; the Apogee Bluetooth device will accumulate the number of data logs in the Data Log Collection Rate Characteristic and then advertise for 10 seconds again.

When advertising is initiated by the Data Log Collection Rate Characteristic, the Apogee Bluetooth device will advertise for up to 10 seconds or until connected. Upon disconnection, the Apogee Bluetooth device does not advertise.

The Data Log Collection Rate Characteristic value will have a major impact on battery life because advertising is far more power-intensive than sleeping. This characteristic is intended for use in a gateway or IoT environment, in which the central device is always in range of the Apogee Bluetooth device. To minimize the impact on battery life, the central device should connect, collect data, read and/or write any other characteristics necessary, and then disconnect as quickly as possible.

Data length is 1 byte.

Table 51: Data Log Collection Rate Characteristic Examples

Characteristic Packet	Value	Description
00	0	The Apogee Bluetooth device will not advertise periodically. It will only advertise with a button press.
01	1	The Apogee Bluetooth device will advertise every time a new entry is added to the data log.
03	3	The Apogee Bluetooth device will advertise every three entries that are added to the data log.

Calibration Characteristic

Table 52: Calibration Characteristic

UUID (within base)	Properties	Value Contents
0x00FF	Read/Write/Notify	UINT8

The Calibration Characteristic is used for dark offset calibration and oxygen sensor calibration. The dark offset is used to increase the accuracy of low light measurements. This Characteristic can initiate a dark offset calibration routine, initiate an oxygen calibration routine, and control the use of the results.

The Calibration Characteristic uses two flags and an enumeration as described in **Table 53**.

Table 53: Calibration Characteristic Bitfield

Bit	Name	Description
7:5	RESERVED	Reserved for future use.
4:2	0XYGEN_CALIBRATION	000 No Ongoing Oxygen Calibration 001 Oxygen Calibration for Zero Offset 010 *Oxygen Calibration for Relative Oxygen for Multiplier at Ambient Oxygen 011 *Oxygen Calibration for Relative Oxygen for Multiplier at 100% Oxygen 100 Oxygen Calibration for Absolute Oxygen at Ambient Oxygen Coefficient4 will be used for the pressure in the calculation, so it should be written before this command is called. Sensors other than oxygen ignore these bits.
1	CALIBRATION_BEGIN	Flag to indicate that calibration is in progress. Writing 1 to this bit will initiate the calibration routine. Writing 0 does not stop the routine. When the calibration is finished, the Apogee Bluetooth device will internally change this bit to 0 and send a notification if notifications are enabled.
0	OFFSETS_ACTIVE	Flag to indicate that the offset calibration is used in the sensor output calculation. For the oxygen sensor, this bit is ignored.
*After Calibration for Relative Oxygen for Multiplier, Pressure coefficient at Coefficient4 is set to 0.0.		

If notifications are enabled for this characteristic, a notification will be sent with CALIBRATION_BEGIN = 0 and OFFSETS_ACTIVE = 1 when the calibration process is complete.

When a new Sensor ID Characteristic is written, the Calibration Characteristic will automatically be reset to 0 internally, and a new dark offset calibration will need to be completed if desired. A new dark offset calibration should also be completed or turned off if a new sensor of the same type is plugged into the Apogee Bluetooth device.

This characteristic only is only applicable to some sensors. See **Table 54** for a list of supported sensors.

Data length is 1 byte.

Table 54: Dark Offset Calibration Sensor Support

Sensor ID	Sensor Name	Support Dark Offset Calibration?
0	No sensor chosen	No
1	SP-110	Yes
2	SP-510	Yes
3	SP-610	Yes
4	SQ-110	Yes
5	SQ-120	Yes
6	SQ-500	Yes
7	SL-510	No
8	SL-610	No
9	SI-100	No
10	SU-200	Yes
11	SE-100	Yes
12	S2-111	Yes
13	S2-112	Yes
14	S2-121	Yes
15	S2-122	Yes
16	S2-131	Yes
17	S2-141	Yes
18	SQ-610	Yes
19	ST-1X0	No
20	SP-700	Yes
21	SQ-620	Yes
22	SQ-640	Yes
23	NDVI Pair	Yes
24	PRI Pair	Yes

Table 54 Continued: Dark Offset Calibration Sensor Support

Sensor ID	Sensor Name	Support Dark Offset Calibration?
25	4 Single Ended	Yes
26	2 Differential	Yes
27	SQ-100X	Yes
28	SQ-31X	No
29	SM-500	Yes
30	SM-600	Yes
35	SO-100	No
36	SO-200	No
37	SU-300	Yes
38	SF-110	No

Table 55: Calibration Characteristic Examples

Characteristic Packet	Value	Description
00	OFFSET_CALIBRATION_BEGIN = 0 OFFSETS_ACTIVE = 0	Offset calibration is not in progress and it is not used in the sensor output calculation.
01	OFFSET_CALIBRATION_BEGIN = 0 OFFSETS_ACTIVE = 1	The offset calibration result is used in the sensor output calculation. If notifications are enabled, this will be the notification when calibration is complete.
03	OFFSET_CALIBRATION_BEGIN = 1 OFFSETS_ACTIVE = 1	Offset calibration is in progress and will be used in the sensor output calculation.
0A	0XYGEN_CALIBRATION = 0b010 OFFSET_CALIBRATION_BEGIN = 1	Oxygen Calibration is in progress for Relative Oxygen for Multiplier at Ambient Oxygen

Coefficients1 and Coefficients2 Characteristics

Table 56: Coefficients1 Characteristic

UUID (within base)	Properties	Value Contents
0x0100	Read/Write	3 FLOAT32s

Table 57: Coefficients2 Characteristic

UUID (within base)	Properties	Value Contents
0x0101	Read/Write	3 FLOAT32s

Coefficients1 and Coefficients2 Characteristics are used to write custom coefficients for the calculation of sensor output. Each of these characteristics contains three 32-bit floating-point numbers.

Table 58: Coefficients1 Characteristic Fields

Coefficient 1	Coefficient 2	Coefficient 3
4 Bytes	4 Bytes	4 Bytes

Table 59: Coefficients2 Characteristic Fields

Coefficient 4	Coefficient 5	Coefficient 6
4 Bytes	4 Bytes	4 Bytes

Not all sensors use coefficients, and the sensors that use coefficients may use any number of them between one and six.

Some sensors have default coefficients that are recommended and are stored internally. To signal the Apogee Bluetooth device to use a default coefficient, a value of 0.0 needs to be written to a field in the Coefficients1 or Coefficients2 Characteristic. A custom coefficient may be used for any sensor with a default coefficient. See **Table 62** for a complete list of coefficient usage for each sensor.

Coefficients1 and Coefficients2 Characteristics are not reset or changed when the Sensor ID Characteristic is changed. Therefore, when a different sensor is connected to an Apogee Bluetooth device, the Coefficients1 and Coefficients2 Characteristics will need to be changed accordingly by the central device. If they are not changed, an unintended coefficient may be applied to the calculation of the output of the new sensor.

Data length is 12 bytes.

Table 60: Coefficients1 Characteristic Example

Characteristic Packet	Value(s)	Description
BD-C9-B4-4E-9A-BD-09-4B-9A-82-9E-47	1516560000.00, 9026970.00, 81157.20	Coefficient 1: 1516560000.00 Coefficient 2: 9026970.00 Coefficient 3: 81157.20
00-00-00-00-00-00-00-00-00-00-00-00	0, 0, 0	Use default coefficients in calculations.
9A-99-CC-42-00-00-00-00-00-00-00-00	102.3, 0, 0	Coefficient 1: 102.3

Table 61: Coefficients2 Characteristic Example

Characteristic Packet	Value(s)	Description
34-E5-51-CB-9A-90-9D-47-48-15-5F-45	-13755700.00, 80673.20, 3569.33	Coefficient 4: -13755700.00 Coefficient 5: 80673.20 Coefficient 6: 3569.33

Table 62: Coefficient Usage for Each Sensor

Sensor ID	Sensor Name	Default Coefficients	Custom Coefficients	Default Recommended?
0	No sensor chosen	Not Applicable	Not Applicable	Not Applicable
1	SP-110	Multiplier of 5 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
2	SP-510	Multiplier of 17.5 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	No
3	SP-610	Multiplier of 6.7 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	No
4	SQ-110	Multiplier of 5 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
5	SQ-120			
6	SQ-500	Multiplier of 100 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes

C1: Coefficient 1 **C2**: Coefficient 2 **C3**: Coefficient 3
C4: Coefficient 4 **C5**: Coefficient 5 **C2**: Coefficient 6

Table 62 Continued: Coefficient Usage for Each Sensor

Sensor ID	Sensor Name	Default Coefficients	Custom Coefficients	Default Recommended?
7	SL-510	Multiplier of 8.5 if **C1** = 0 (C2 is required)	Multiplier of **C1** if **C1** ≠ 0 **C2** is required	No
8	SL-610			
9	SI-100	Default Not Available	**C1**, **C2**, **C3**, **C4**, **C5**, and **C6** are all required	Default Not Available
10	SU-200	Multiplier of 10 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
11	SE-100	Multiplier of 1000 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
12	S2-111	Shorter Wavelength: Millivolt signal if **C1** = 0 Longer Wavelength: Millivolt signal if **C2** = 0	Shorter Wavelength: Multiplier of **C1** if **C1** ≠ 0 Longer Wavelength: Multiplier of **C2** if **C2** ≠ 0	No
13	S2-112			
14	S2-121			
15	S2-122			
16	S2-131			
17	S2-141			
18	SQ-610	Multiplier of 100.0 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
19	ST_1X0	No coefficients used	No coefficients used	Not Applicable
20	SP-700	Upward Facing Sensor: Multiplier of 17.5 if **C1** = 0 Downward Facing Sensor: Multiplier of 6.7 if **C2** = 0	Upward Facing Sensor: Multiplier of **C1** if **C1** ≠ 0 Downward Facing Sensor: Multiplier of **C2** if **C2** ≠ 0	No
21	SQ-620	Multiplier of 20.0 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
22	SQ-640	Multiplier of 1.0 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes

C1: Coefficient 1 **C2**: Coefficient 2 **C3**: Coefficient 3
C4: Coefficient 4 **C5**: Coefficient 5 **C2**: Coefficient 6

Table 62 Continued: Coefficient Usage for Each Sensor

Sensor ID	Sensor Name	Default Coefficients	Custom Coefficients	Default Recommended?
23	NDVI Pair	Upward Shorter Wavelength: Millivolt signal if **C1** = 0 Upward Longer Wavelength: Millivolt signal if **C2** = 0 Downward Shorter Wavelength: Millivolt signal if **C3** = 0 Downward Longer Wavelength: Millivolt signal if **C4** = 0	Upward Shorter Wavelength: Multiplier of **C1** if **C1** ≠ 0 Upward Longer Wavelength: Multiplier of **C2** if **C2** ≠ 0 Downward Shorter Wavelength: Multiplier of **C3** if **C3** ≠ 0 Downward Longer Wavelength: Multiplier of **C4** if **C4** ≠ 0	No
24	PRI Pair			
25	4 Single Ended	Millivolt signal if **C1** = 0 Millivolt signal if **C2** = 0 Millivolt signal if **C3** = 0 Millivolt signal if **C4** = 0	Multiplier of **C1** if **C1** ≠ 0 Multiplier of **C2** if **C2** ≠ 0 Multiplier of **C3** if **C3** ≠ 0 Multiplier of **C4** if **C4** ≠ 0	Not Applicable
26	2 Differential	Output1 = ((Yellow-Blue in mV) - **C2**) * **C1** Output2 = ((White-Black in mV) - **C4**) * **C3** If a multiplier coefficient (**C1** or **C3**) is 0, then 1.0 is used as default.		Not Applicable
27	SQ-100X	10 if **C1** = 0	**C1** if **C1** ≠ 0	Yes
28	SQ-31X	5 if **C1** = 0	**C1** if **C1** ≠ 0	Yes

C1: Coefficient 1 **C2**: Coefficient 2 **C3**: Coefficient 3
C4: Coefficient 4 **C5**: Coefficient 5 **C2**: Coefficient 6

Table 62 Continued: Coefficient Usage for Each Sensor

Sensor ID	Sensor Name	Default Coefficients	Custom Coefficients	Default Recommended?
29	SM-500	Factory Calibration	C1 (To return to factory calibration, write 0.)	Yes
		C4: temperature offset **C5:** humidity offset **C6:** CO_2 Offset		Yes
30	SM-600	Factory Calibration	C1 (To return to factory calibration, write 0.)	Yes
		C4: temperature offset **C5:** humidity offset **C6:** CO_2 Offset		Yes
35	SO-100	When the Sensor ID Characteristic is written to an Oxygen Sensor (35 or 36), the following default coefficients are written to the Coefficient Characteristics. Multiplier **C1**: 0.4 Offset **C2**: 3.0 Temperature at Calibration **C3**: 20.0 Pressure at Absolute Calibration **C4**: 0.0 These may then be over-written manually using the Coefficients1 and Coefficients2 Characteristics or by running internal calibration routines using the Calibration Characteristic.		Use default as a starting point, then calibrate using the Calibration Characteristic.
36	SO-200			
37	SU-300	Multiplier of 100.0 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
38	SF-110	No coefficients used	No coefficients used	

C1: Coefficient 1 **C2**: Coefficient 2 **C3**: Coefficient 3
C4: Coefficient 4 **C5**: Coefficient 5 **C6**: Coefficient 6

Modbus Settings Characteristic

Table 63: Modbus Settings Characteristic

UUID (within base)	Properties	Value Contents
0x0200	Read/Write	4 UINT8s

The Modbus Settings Characteristic provides a way to adjust Modbus communication settings via Bluetooth. Any invalid values are changed to default. An address change will take effect immediately, but the other settings require a power cycle to change. This characteristic is only used by the Guardian.

Table 64: Valid Modbus Values and Defaults

	Address	Baud Rate	Parity	Stop Bits
Valid Values	1 – 247	0: 115200 1: 57600 2: 38400 3: 19200 4: 9600	0: No Parity 2: Even Parity	1: 1 Stop Bit 2: 2 Stop Bits
Default	1	3: 19200	2: Even Parity	1: 1 Stop Bit

APPLICATION RECOMMENDATIONS

Mobile App Interfacing

Mobile app interfacing with the Apogee Bluetooth device should proceed as described in the Chronological Overview section with additional consideration for the Data Log Collection Rate Characteristic.

Mobile app users who have easy access to the button on the Apogee Bluetooth device will optimize battery life by setting the Data Log Collection Rate Characteristic to 0 and only using a button press to initiate advertising.

Mobile app users can optionally set the Data Log Collection Rate Characteristic to a value greater than 0 to create the opportunity to automatically connect when the central device is in range, but it will decrease battery life.

Network Interfacing

The Apogee Bluetooth device may be used in a network environment where the central device is always in range such as a gateway. The benefit of such an environment is that data could be collected as it becomes available. Interfacing with the Apogee Bluetooth device should proceed as described in the Chronological Overview section, except some characteristics are not intended to be used in a network environment.

The characteristics that are not intended (although not restricted) to be used by the gateway are Live Data, Live Data Control, Data Log Full Time, and Calibration Characteristics.

The Data Log Collection Rate Characteristic should be set to a number greater than 0 so that the Apogee Bluetooth device advertises periodically. When the Apogee Bluetooth device advertises, the central device should connect, collect data and carry out any other Bluetooth interfacing, then disconnect as quickly as possible to maximize battery life. The Apogee Bluetooth device will advertise again when there is more data to collect. The central device should not stay connected to the Apogee Bluetooth device.

Figure 1 shows a routine network connection to collect data from an Apogee Bluetooth device.

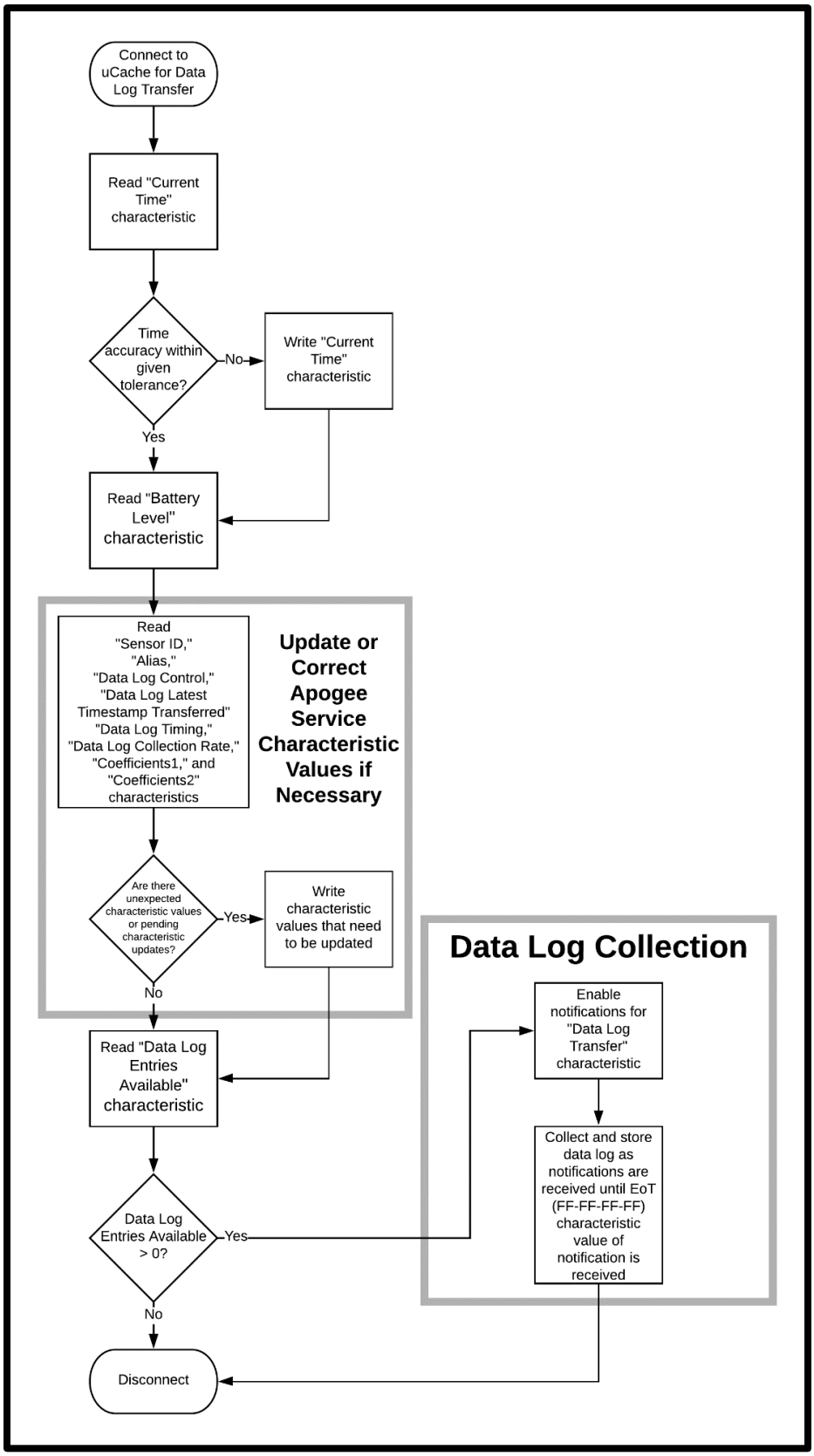

Figure 1 Routine Network Connection

SUPPLEMENTAL EQUATIONS

The mobile app provides additional measurements for some sensors which are calculated from the raw data after Bluetooth transfer to maximize the efficiency of Bluetooth communication. The supplemental equations below can be used to calculate additional data for the following sensors.

Guardian SM-500 and SM-600

Temperature and relative humidity (RH) are given.

VPD

$$esa = 0.61121 * e^{(18.678 - Temp/234.5)Temp/257.14 + (2.57 + Temp)}$$

$$ea = esa * RH/100$$

$$vpd = esa - ea$$

Dew Point

$$dew\ point = \frac{257.14 * \ln\left(\frac{ea}{0.61121}\right)}{18.678 - \ln\left(\frac{ea}{0.61121}\right)}$$

UV-A Sensor

EFD is given.

$$PFD = EFD * 3.0$$

UV-B Sensor

UVI is given.

$$EFD = -0.0037 * UVI^2 + 0.21 * UVI + 0.0$$

$$PFD = UVI * 2.6$$

BOOTLOADER

Apogee Bluetooth devices have a bootloader to support Over-The-Air Device Firmware Updates (OTA-DFU). This allows a central device to update the firmware via Bluetooth.

Note that “revision” and “version” are used interchangeably when discussing the bootloader.

Button and LED Interface in Bootloader Mode

The button and LED are generally not needed during the OTA-DFU process; however, they do have functionality.

The LED will be solid red (not blinking) when the Apogee Bluetooth device is advertising in bootloader mode. Advertising times out after 30 seconds, and then the Apogee Bluetooth device goes to sleep. When the OTA-DFU goes correctly, the LED will be red for a few seconds and the central device will connect to the Apogee Bluetooth device and proceed with the update.

The button will wake up the Apogee Bluetooth device from sleeping and it will start advertising. When the OTA-DFU goes correctly, the Apogee Bluetooth device will not go to sleep or require a button press.

If an Apogee Bluetooth device is ever found to have a solid red LED for 30 seconds after a short button press, this indicates that there is no valid application. Something may have gone wrong in a previous OTA-DFU attempt. A central device needs to connect and update the Apogee Bluetooth device with valid firmware.

Secure DFU Service

To get to bootloader mode, use the Secure DFU Service. The OTA-DFU bootloader is based on a bootloader written by Nordic Semiconductor. Resources can be found on their website to help implement it on a central device to update the firmware on Apogee Bluetooth devices.

Advertising

When the Apogee Bluetooth device advertises in bootloader mode, the following are in the advertising data:

- Apogee Company Identifier 0x0644, and
- Device name ApogeeDFU.

OTA-DFU Firmware Package

The OTA-DFU firmware image and resources are provided in a zip file. Following is an example file name:

ucache_app_update_hw6_fw7_s140_nrf52_7.0.1.zip

The package used to update the Apogee Bluetooth device needs to have the correct hardware version, firmware revision, and Nordic SoftDevice version. These three version numbers can be found in the file name.

The Hardware Version and Firmware Version can be read in the **Device Information Service (DIS)** of the Apogee Bluetooth device to help choose the correct OTA DFU package.

The hardware version of the OTA-DFU package must match the hardware version of the target Apogee Bluetooth device.

The firmware version of the OTA-DFU package must be equal to or greater than the current firmware version on the target Apogee Bluetooth device. The Bootloader allows the same version number to be loaded but blocks lower versions. For example, if the current firmware version is 2, it will allow an OTA-DFU of firmware version of 2, 3, 4... to be loaded, but not firmware version 1.

The Nordic SoftDevice version of the OTA-DFU package must match the Nordic SoftDevice version of the target Apogee Bluetooth device. It can be updated but will likely remain the same. If firmware version 8 had a Nordic SoftDevice update, then upgrading from firmware version 7 to 9 will require a special package that includes the new SoftDevice or require updating from 7 to 8, and then 8 to 9.